Environmental Assessment of Multiklient Invest's Newfoundland Offshore Seismic and Environmental Data Collection Program, 2026–2030

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Prepared for

Multiklient Invest AS

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Acronyms and Abbreviations

2D	Two-dimensional
3D	Three-dimensional
4D	Four-dimensional
ADCP	Acoustic Doppler Current Profiler
AGC	Atlantic Groundfish Council
AIS	Automatic Identification System
ALTRT	Atlantic Leatherback Turtle Recovery Team)
AOI	Area of Interest
AZMP	Atlantic Zone Monitoring Program
CAPP	Canadian Association of Petroleum Producers
CBC	Canadian Broadcasting Corporation
CBD	Convention on Biological Diversity
CCG	Canadian Coast Guard
CCS	Carbon Capture and Storage
CEA	Cumulative Effects Assessment
CH_4	Methane
C-NLOER	Canada-Newfoundland and Labrador Offshore Energy Regulator
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CO_2	Carbon Dioxide
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPCAD	Canadian Protected and Conserved Areas Database
CPUE	Catch Per Unit Effort
CTD	Conductivity, Temperature, Depth
CTF	Commander, Task Force
CWS	Canadian Wildlife Service
DFO	Fisheries and Oceans Canada
DGNSR	Director General Naval Strategic Readiness
Div.	Division [NAFO]
DND	Department of National Defence
DU	Designatable Unit
EA	Environmental Assessment
EBSA	Ecologically and Biologically Significant Area
ECAREG	Eastern Canada Vessel Traffic Services Zone
ECCC	Environment and Climate Change Canada
ECSAS	Eastern Canadian Seabirds at Sea
eDNA	Environmental DNA
EEZ	Exclusive Economic Zone
Equinor	Equinor Canada Ltd.
ESA	*Endangered Species Act*
ESRF	Environmental Studies Research Fund

ESS	Eastern Scotian Shelf
FLO	Fisheries Liaison Officer
FLS	Floating Lidar Systems
FPSO	Floating Production, Storage, and Offloading
FSC	Food, Social, and Ceremonial
GEAC	Groundfish Enterprise Allocation Council
GHG	Greenhouse Gas Emissions
GNL	Government of Newfoundland and Labrador
HF	High Frequency marine radio
HFC	Hydrofluorocarbon
HPC	High Priority Candidate
Husky	Husky Oil Operations Limited
IAAC	Impact Assessment Agency of Canada
ICCAT	International Commission for the Conservation of Atlantic Tunas
IMO	International Maritime Organization
IPP	International Ice Patrol
LiDAR	Light Detecting and Ranging
LPC	Low Priority Candidate
MAMKA	Mi'kmaq Alsumk Mowimsikik Kogoey Association
MARFIS	Maritime Fishery Information System
MARPOL	*International Convention for the Prevention of Pollution from Ships*
MFN	Miawpukek First Nation
MKI	Multiklient Invest AS
MMO	Marine Mammal Observer
MMR	Marine Mammal Regulations
MMSI	Maritime Mobile Service Identity
MPA	Marine Protected Area
MPC	Mid Priority Candidate
N_2O	Nitrous Oxide
NACES	North Atlantic Current and Evlanov Sea
NAFO	Northwest Atlantic Fisheries Organization
NAISS	Northwest Atlantic International Sightings Surveys
NAO	North Atlantic Oscillation
NAVWARN	Navigational Warning
NCC	NunatuKavut Community Council
NE	Northeast
NG	Nunatsiavut Government
NL	Newfoundland and Labrador
NLCI	Newfoundland and Labrador Climate Index
NMCA	National Marine Conservation Area
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NOTSHIP	Notice to Shipping
NS	Nova Scotia
NW	Northwest

OBIS	Ocean Biodiversity Information System
OBN	Ocean Bottom Node
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PAM	Passive Acoustic Monitoring
PGS	Petroleum Geo-Services ASA
PIROP	Programme Intégré de Recherches sur les Oiseaux Pélagiques
QFN	Qalipu [Mi'kmaq] First Nation
RMA	Representative Marine Area
ROV	Remotely Operated Vehicle
RV	Research Vessel
SAR	Species at Risk
SARA	*Species at Risk Act*
SBA	Significant Benthic Area
SD	Standard Deviation
SE	Southeast
SEA	Strategic Environmental Assessment
SFA	Shrimp Fishing Area
SOPEP	Shipboard Oil Pollution Emergency Plan
SPL	Sound Pressure Level
SPOC	Single Point of Contact
SST	Sea Surface Temperature
SSTA	Sea Surface Temperature Anomaly
SW	Southwest
SWOT	State of the Sea turtle Worlds' Sea Turtles
TAC	Total Allowable Catch
UAV	Unmanned Aerial Vehicle
US	United States of America
UXO	Unexploded Explosive Ordnance
VC	Valued Component
VHF	Very High Frequency marine radio
VME	Vulnerable Marine Ecosystem
VMS	Vessel Monitoring System
WWII	World War II

1.0 Introduction

Multiklient Invest AS (MKI) is proposing to conduct two-dimensional (2D), three-dimensional (3D), and/or four-dimensional (4D) seismic surveys offshore Newfoundland. In addition, MKI is proposing to collect environmental data (meteorological, oceanographic) via moored instrumentation. MKI is proposing to conduct seismic surveys, sometimes two or more operations, and collect environmental data during one or more years within the 2026–2030 timeframe within the Project Area (Figure 1.1). This document is the Environmental Assessment (EA) of the Project.

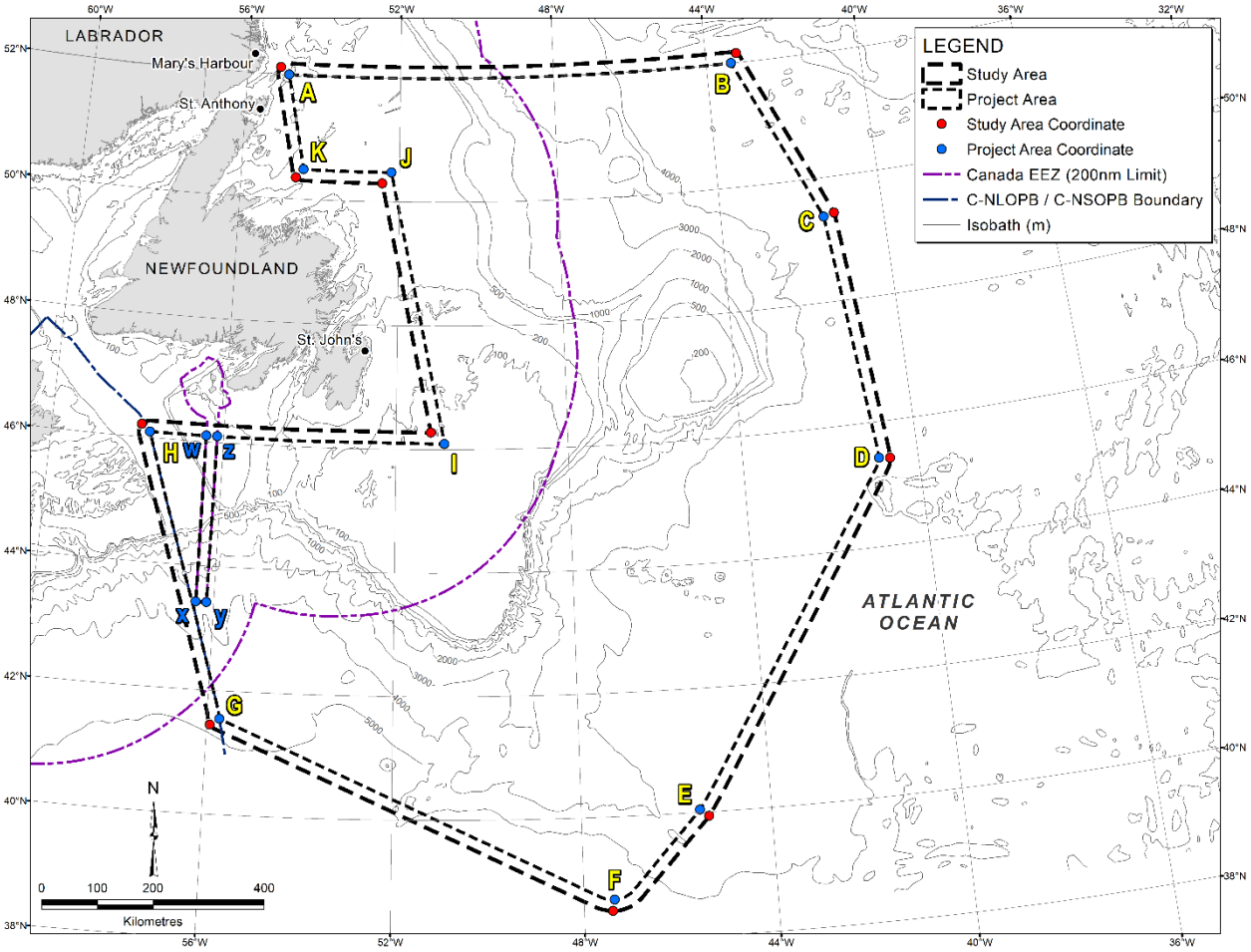


Figure 1.1. Locations of Project Area and Study Area for MKI's proposed offshore Newfoundland seismic and environmental data collection program, 2026–2030.

The EA is intended to enable the Canada-Newfoundland and Labrador Offshore Energy Regulator (C-NLOER)[1] to fulfill its responsibilities under Section 138 (1)(b) of the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Act* and Section 134(1)(b) of the *Canada-Newfoundland and*

[1] On 2 June 2025, the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) changed its name to the Canada-Newfoundland and Labrador Offshore Energy Regulator (C-NLOER).

Labrador Atlantic Accord Implementation Newfoundland and Labrador Act (Accord Acts). This EA has been guided by the C-NLOER's Final Scoping Document (C-NLOPB 2024) dated 1 November 2024, as well as by advice and information received and issues identified through various communications and consultations with other agencies, interest groups, stakeholders and beneficiaries. An EA Update document will be submitted to the C-NLOER each year that MKI plans to conduct seismic surveying.

1.1 Relevant Legislation and Regulatory Approvals

An *Authorization to Conduct a Geophysical Program* will be required from the C-NLOER. The C-NLOER is mandated by the Accord Acts. Pursuant to the Accord Acts, the C-NLOER is responsible for seeking to identify the federal departments or agencies that may have expertise required in the completion of the assessment. Because seismic survey activities have the potential to affect fish and fish habitat, fisheries, marine mammals, sea turtles, and marine-associated birds, Fisheries and Oceans Canada (DFO) and Environment and Climate Change Canada (ECCC) are the government agencies most involved in the EA process. Legislation that is relevant to the environmental aspects of the Project includes:

- *Canada-Newfoundland and Labrador Atlantic Accord Implementation Act;*
- *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act;*
- *Oceans Act;*
- *Fisheries Act;*
- *Navigation Protection Act;*
- *Canada Shipping Act;*
- *Migratory Birds Convention Act;*
- *Species at Risk Act (*SARA*); and*
- *Canadian Environmental Protection Act.*

1.2 The Operator

The Operator, MKI, is a wholly owned subsidiary of TGS. TGS and Petroleum Geo-Services ASA (PGS) officially merged on 1 July 2024, and the combined company has retained the TGS name.

1.3 Canada-Newfoundland and Labrador Benefits

In full appreciation of the requirements of the Accord Acts, MKI is committed to providing maximum benefits associated with East Coast operations to Canadians, and in particular, to individuals and companies from Newfoundland and Labrador (NL) that are commercially competitive in accordance with MKI's requirements.

MKI will manage the seismic operations from St. John's, NL. MKI agrees that first consideration will be given to personnel, support, and other services that can be provided from within NL, and to goods manufactured in NL, if the goods and services can be delivered at a high standard of Health, Safety, and Environmental competency, are of high quality, and are competitive in terms of fair market price.

All contractors and subcontractors working for MKI in NL must also apply these principles in their operations.

1.4 Contacts

Contact information for MKI personnel overseeing the Project is provided below (Table 1.1).

Table 1.1. MKI contact information.

Name	Position	Address	Company	Phone	Email
Executive Contact					
Mr. Jason Norman	Project Manager	10451 Clay Road Houston, Texas 77041	TGS	1-709-749-6046	Jason.Norman@tgs.com
Mr. Steve Whidden	Project Development Manager, Offshore North America Arctic	2100, 250-5th Street S.W. Calgary, Alberta T2P 0R4	TGS	1-403-852-6115	Steve.Whidden@tgs.com
Environment Contact					
Mr. Chris Wilkes	Senior Director, HSE	10451 Clay Road Houston, Texas 77041	TGS	1-832-217-8875	Chris.Wilkes@tgs.com

2.0 Project Description

The official name of the Project is Multiklient Invest Newfoundland Offshore Seismic and Environmental Data Collection Program, 2026–2030. MKI is proposing to conduct 2D, 3D and/or 4D seismic surveys within its proposed Project Area (see Figure 1.1) between 2026 and 2030. The EA will consider a maximum of four simultaneous seismic surveys within a given year: three 3D/4D surveys and one 2D survey. However, in most survey years, there would typically be no more than two simultaneous seismic surveys. The timing of the seismic surveys is subject to MKI priorities and circumstances, weather conditions, contractor availability, and regulatory approvals.

MKI is proposing to deploy one or more Floating Lidar Systems (FLS) buoys to acquire meteorological and oceanographic data. The FLS have instrumentation on the ocean surface and are moored to the seafloor. A FLS would typically be deployed for one to three years and require maintenance typically every 3–6 months.

2.1 Spatial and Temporal Boundaries

The Study Area includes the Project Area plus a 20-km buffer around the Project Area to account for the propagation of seismic survey sound that could potentially affect marine biota (see Figure 1.1; Table 2.1). The proposed Project Area includes space to account for ship turning and streamer deployment. The areal extents of the Project Area and the Study Area are 1,244,143 km^2

and 1,354,951 km², respectively. Larger proportions of the Project Area and Study Area lie outside of Canada's Exclusive Economic Zone (EEZ; ~68%) than inside the EEZ (~32%; see Figure 1.1). Water depths within the Project Area range from approximately 100 m to 4000 m.

Table 2.1. Geographic coordinates (decimal degrees, WGS84 Datum) delineating the Project and Study areas.

Coordinate Point [a]	Project Area		Study Area	
	Latitude	Longitude	Latitude	Longitude
A	52	-54.913	52.114	-55.138
B	52	-43.348	52.151	-43.189
C	49.374	-41.468	49.415	-41.201
D	45.417	-40.887	45.395	-40.636
E	40.042	-45.501	39.934	-45.315
F	38.658	-47.365	38.478	-47.41
G	41.546	-55.727	41.445	-55.925
H	46.093	-57.716	46.205	-57.917
w	46.099	-56.404	-----	-----
x	43.418	-56.398	-----	-----
y	43.416	-56.157	-----	-----
z	46.1	-56.151	-----	-----
I	46.091	-50.869	46.274	-51.184
J	50.473	-52.199	50.294	-52.427
K	50.481	-54.424	50.345	-54.608

[a] See Figure 1.1 for location of coordinate points.

The temporal boundaries of the Project are 1 May–30 November during 2026–2030.[2] The duration of individual seismic surveys will vary from year to year but will typically occur within a May–November timeframe. The approximate durations of proposed 3D/4D and 2D seismic surveying in any given year are 90–150 days and 150 days, respectively. The FLS would be deployed year-round with maintenance occurring approximately every 3–6 months.

2.2 Project Overview

The proposed Project includes a ship-borne geophysical program and the collection of environmental data via the use of moored FLS buoys.

The ship-borne geophysical program may include as much as 20,000 km² of 3D seismic survey and 20,000 km of 2D seismic survey lines in a given year. Specific data acquisition plans for 2D, 3D and/or 4D surveys during 2026–2030 are not yet determined. The specific seismic survey vessel(s) and supporting vessels to be used during 2D/3D/4D surveys are currently unknown but will be approved for operation in Canadian waters and will be typical of the worldwide fleet. Information on representative seismic and support vessels are provided in Sections 2.2.5 and 2.2.9.1, respectively. It is possible that MKI will use Ocean Bottom Nodes (OBNs; see Section 2.2.7) and as an option may utilize the Gemini sound source (see Section 2.2.6). MKI will adhere to established mitigation measures and monitoring for marine mammals, sea turtles, and seabirds required for seismic surveys

[2] Note that the Project Description for this EA indicated that the temporal scope was 2025–2029. As a result of updated project planning, the temporal boundaries have been revised to 2026–2030.

(see Section 2.3 for further details). A Fisheries Liaison Officer (FLO) will be on board the seismic vessel(s) to ensure implementation of communication procedures intended to minimize conflict with the commercial fishery.

MKI will typically deploy 1–3 FLSs (up to a maximum of ten) in a given year. Information on the FLS is provided in Section 2.2.8.

DFO's *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment* (CNSOPB and C-NLOPB 2024) will be used as the basis for the marine mammal (and sea turtle) monitoring and mitigation program for the seismic surveys. A FLO will be on board the seismic vessel to ensure implementation of communication procedures intended to minimize conflict with the commercial fishery. MKI will also follow all ECCC-Canadian Wildlife Service (CWS) requirements for conducting seabird surveys and monitoring/implementing mitigation measures for stranded birds onboard Project vessels. Mitigation measures and monitoring requirements for the Project are detailed in Section 5.5.

2.2.1 Objectives and Rationale

The primary objective of a seismic survey is to determine the presence and likely locations of geological structures that might contain hydrocarbon deposits. Existing seismic data in the area do not provide sufficient detail or coverage to serve the needs of the energy companies in their exploration, development and production activities. Availability of such modern seismic data has triggered recent exploration interest, particularly in Orphan Basin and Flemish Pass. Furthermore, MKI's advanced OBN systems (detailed below) provide much deeper, and more precisely defined features, identifying source rocks, migration pathways, and play types. These data will enhance the understanding of Newfoundland's offshore hydrocarbon potential, and aid future exploration and development activities, delivering – for instance – better information for those deciding on future exploration drilling locations, reducing the need for additional drill sites. Employed near existing production operations, the data will allow better reservoir delineation, better decision-making for the placement of satellite or tie-back wells and other development decisions, as well as reservoir optimization and conservation.

The primary objective of collecting environmental data via FLS is to assess the wind resource in offshore Newfoundland. The FLS will collect high-quality wind speed and direction data from the ocean surface to various heights above sea level. Data on waves, currents, water salinity, water temperature, and weather (air temperature, relative humidity, air pressure, and rainfall) will also be collected. Acquisition of these data is anticipated to assist with the potential development of offshore wind turbines to electrify (power) oil and gas facilities.

2.2.2 Project Scheduling

As indicated in Section 2.1, the seismic surveys will be conducted between 1 May and 30 November of any given year from 2026–2030. In 2026, it is anticipated that seismic surveys would occur from mid-May through September.

The FLS may be deployed year-round of any given year from 2026–2030. As soon as 2026, it is anticipated that 1–3 FLS would be deployed with servicing occurring approximately every 3–6 months.

2.2.3 Site Plans

In any given year from 2026–2030, it is possible that there will be ~20,000 km^2 of 3D and 4D seismic survey lines and 20,000 km of 2D seismic survey lines. The specific location, orientation, length, and spacing of seismic survey lines will be determined prior to each survey year. For 3D and 4D seismic surveys, a racetrack survey design is used and for 2D seismic surveys, lines can be separated by approximately 5–50 km with variable lengths. In 2026, it is anticipated that MKI will acquire approximately 5000–10,000 km^2 of seismic data in the Orphan Basin.

In any given year from 2026–2030, it is possible that up to ten FLS will be deployed and operational; however, in most years, 1–3 FLS would be deployed. FLS will typically be deployed in areas where water depths are less than 2000 m and FLS will be separated by a minimum distance of 30 km. The specific locations of the FLS are not yet determined.

2.2.4 Personnel

A typical seismic vessel can accommodate ~55–75 personnel. Personnel on a seismic vessel include ship's officers and marine crew as well as technical and scientific personnel. The seismic vessel will also have Marine Mammal Observers (MMOs), Passive Acoustic Monitoring (PAM) Operators, and a FLO on board.

A typical vessel that will be used to deploy a FLS can accommodate 15–25 personnel that will include ship's officers, marine crew, and technical personnel.

All project personnel will have the required certifications (safety, medical) as specified by the relevant Canadian legislation and the C-NLOER.

2.2.5 Seismic Vessel

The MV *Ramform Atlas* or a similar vessel(s) will be used for the 3D and 4D seismic surveying, and the MV *Sanco Swift* or a similar vessel for 2D surveying. Seismic vessels will typically travel at a speed of ~8.2–9 km/h (4.4–4.9 knots) while conducting 3D, 4D, and 2D seismic surveying.

The MV *Ramform Atlas* was built in 2013 and is flagged in Norway (Figure 2.1). It is 104.2 m long, with a beam of 70 m and a draft of about 6.4 m. The *Ramform Atlas* has six diesel electric engines that have 20,400 kW of total power. The *Ramform Atlas* and its sister ships (*Ramform Titan, Ramform Tethys*) have previously been used by MKI for 3D seismic surveying in the Project Area.

Figure 2.1. A representative 3D/4D seismic vessel: MV *Ramform Atlas*.

For 2D seismic surveying or a source vessel for undershoots, the MV *Sanco Swift* or similar vessel will be used (Figure 2.2). The MV *Sanco Swift* was built in 2013 and is flagged in Gibraltar. It is 96.15 m long, with a beam of 23 m and a draft of about 7 m. The *Sanco Swift* has four 4000 kW diesel engines.

For seismic surveys during the 2026–2030 temporal scope, vessel specifics will be provided once the vessel(s) has been identified.

Figure 2.2. A representative 2D seismic vessel or source vessel for undershoots: MV *Sanco Swift*.

2.2.6 Seismic Energy Source Parameters

For surveying, the typical sound sources for the proposed 2D/3D/4D survey program will consist of one, two, or three airgun arrays. For any sound source that consists of either two or three airgun arrays, the arrays will be discharged alternately (i.e., multiple airgun arrays will not be discharged simultaneously). The total volume of an airgun array will range from 3000–6000 in^3. The airgun array(s) will be deployed at depths ranging from 6–15 m. The airguns will be operated with compressed air at pressures ranging from 2000–2500 psi and a source level of ~260–266 dB re 1 µPa ·m $_{pk-pk}$. A typical shotpoint interval will be one array pulse every 12.5 m, 18.75 m or 25 m. Detailed specifications of the airgun array for the anticipated 2026 seismic program will be provided once the Project design is completed and parameters are selected.

In one or more years, MKI may optionally use a two-airgun configuration called "Gemini". Two 4000 in^3 airguns are configured in a barbell-type arrangement (Figure 2.3) and deployed at similar depths to a multi-airgun array (i.e., 6–15 m). The two airguns activate simultaneously (8000 in^3 total), operate at 2000 psi and have an estimated source level of ~248.7 dB re 1µPa ·m $_{pk-pk}$ (Grooms et al. 2019). The Gemini configuration enhances the low frequency broadband portion of the sound spectrum (1–4 Hz), which produces higher-quality seismic images than other configurations. This is also expected to result in lower sound pressure levels relative to a conventional, multi-airgun array of the same total volume (Grooms et al. 2020). As with a conventional airgun array, a typical shotpoint interval will be one array pulse every 12.5 m, 18.75 m, or 25 m.

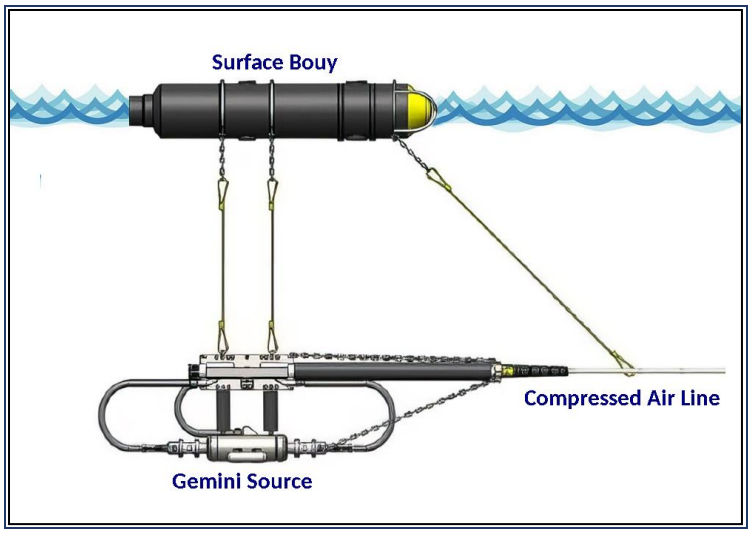


Figure 2.3. Schematic of Gemini sound source.

2.2.7 Seismic Streamers and Ocean Bottom Nodes

For 3D and 4D seismic surveys, vessels will tow as many as 16 solid streamers, ranging in length from 6–14 km at depths ranging from 9–25 m. The streamers are typically spaced 100 m apart. For 2D seismic surveys, vessels will tow one solid streamer that may range from 8–12 km in length.

MKI may use OBNs in conjunction with streamers to acquire seismic data. OBN acquisition produces very detailed imaging of complex subsurface structures and strata types. It is used mainly in locations where towed-streamer data are difficult to collect (e.g., close to existing marine structures) or where other methods cannot provide the data quality needed. These types of data can be used for many purposes, such as determining best drilling locations, or quantifying reservoir size and behaviour over time. In an OBN survey, the nodes are placed on the seafloor in an orderly grid enabling recording of cleaner, high-fidelity data without gaps in coverage. OBN surveys also improve repeatability in 4D seismic surveying. Each OBN will have a footprint of about 0.1 m^2 and will contain a hydrophone and geophones (Figures 2.4 and 2.5). The OBNs are deployed over an area by a node installation vessel and then recovered and re-deployed again in new area within the larger survey area. A Remotely Operated Vehicle (ROV) will be used for OBN deployment and recovery. The OBN spacing is typically 300–500 m on the ocean floor, and approximately 1000–3000 OBNs may be used in total depending on the size of the seismic survey. These units are completely autonomous to operate on the seabed until retrieved and can be left unattended for up to 100–150 days. OBNs can operate in water depths down to 3500 m.

Detailed specifications of the streamers (and potential OBNs) for the anticipated 2026 seismic program will be provided once the Project design is completed and parameters are selected.

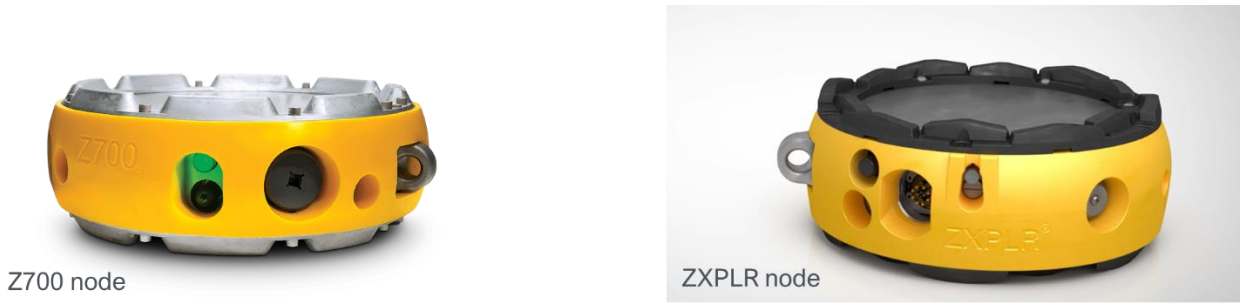


Figure 2.4. Typical Ocean Bottom Nodes (models Z700 and ZXPLR) used by MKI.

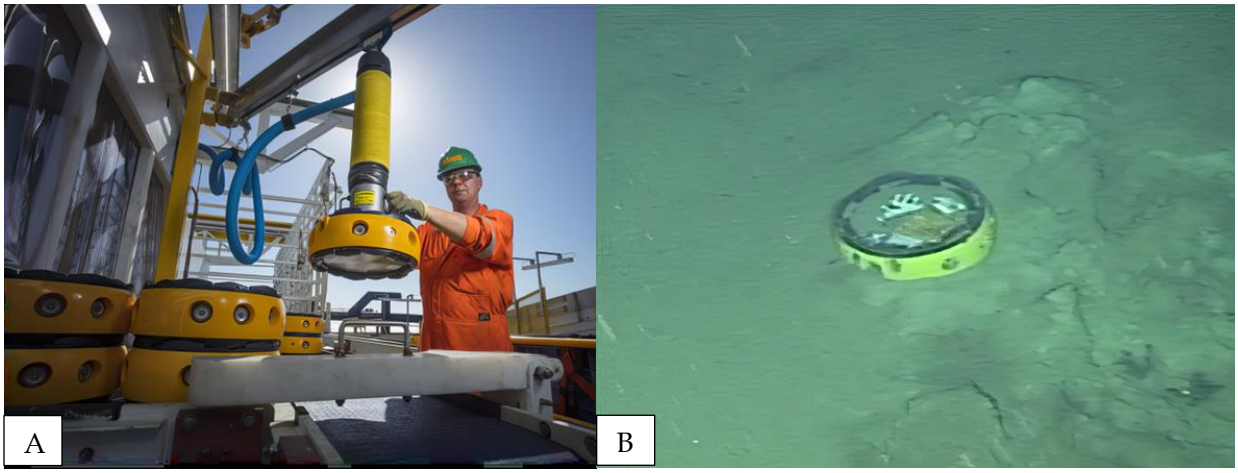


Figure 2.5. Node handling on a vessel (A) and node on the seafloor (B).

2.2.8 Floating Lidar Systems

MKI is proposing to deploy FLS in the Project Area. The FLS will collect meteorological and oceanographic data via a series of sensors affixed to the buoy and seabed mooring frame (Table 2.2). A representative FLS that may be deployed is the Eolos FLS200 model (Figure 2.6). This FLS weighs 4500 kg and is 4 m wide x 4 m long with a height of 4 m. The Eolos FLS200 is powered by renewable energy sources and batteries, which allow full autonomy. The buoy is typically deployed with a seabed frame that is ~ 1.3 m wide x 1.8 m long. Depending on the water depth, the mooring lines would be chain or rope. The FLS requires power to operate sensors, store data, and provide real-time data access via satellite. It is typically powered by a series of solar panels and small wind turbines. Some FLS models have a backup ethanol fuel cell and generator. The FLS is equipped with the following key safety features: bright colouring, radar reflector, marine lantern, drift alarm, and Maritime Mobile Service Identity (MMSI) number, which enables it to broadcast a signal for detection in the international Automatic Identification System (AIS) and electronic navigation charts.

Table 2.2. Summary of the meteorological and oceanographic data that may be collected by the FLS.

Meteorological Sensor/Data	Oceanographic Sensor/Data
LiDAR (Light Detecting and Ranging) – pulsed laser - wind speed / direction	Acoustic Doppler Current Profiler (ADCP) – current speed and direction
Anemometer (cup and ultrasonic) – wind speed / direction	Single point current meter
Barometer – atmospheric pressure	Wave Sensors and Wave Buoy – wave height, period, and direction
Temperature Sensor – air temperature	CTD – conductivity, temperature (sea water), and depth (pressure)
Humidity Sensor – relative humidity	Water Level Recorder (high precision tide gauge) – for tidal harmonic analysis / tidal predictions
Pyranometer – solar irradiance sensor	
Rainfall (derived from LiDAR data)	

Figure 2.6. Example of a Floating LiDAR System, the Eolos FLS200, which may be deployed by MKI.

2.2.9 Logistics/Support

2.2.9.1 Vessels

MKI's primary support and supply will be provided by either the TGS vessel MV *Thor Magni* or a similar vessel. The operational objective is to have one escort vessel available with each seismic vessel. When necessary, escort vessels will be used to scout ahead of the seismic vessels for fishing vessels and gear, as well as for hazards such as ice and floating debris. Resupply will be provided by *Thor Magni* or a similar vessel.

It is anticipated that a node installation vessel will be used to deploy and retrieve OBNs. Vessel specifics will be provided once the vessel has been identified.

It is anticipated that an anchor handling vessel or support vessel will be used to deploy, retrieve, and service the FLS. Vessel specifics will be provided once the vessel has been identified.

2.2.9.2 Crew Changes

Crew changes for the seismic vessels will be conducted by either ship-to-ship transfer or ship-to-shore transfer.

2.2.9.3 Shore Base, Support, and Staging

MKI will have a shore representative based in St. John's for the duration of the seismic and environmental data collection program. No new shore base facilities will be established as part of the Project.

2.2.10 Waste Management

Waste management will be consistent with industry best practices in offshore NL. MKI follows MARPOL 73/78 Annex IV: *Pollution by Sewage from Ships*, and Annex V: *Pollution by Garbage from Ships*.

2.2.11 Atmospheric Emissions

Atmospheric emissions will be those associated with standard operations for marine vessels, including the seismic vessel(s) and support vessel(s). Emissions from survey vessels result from diesel combustion and typically include carbon dioxide/monoxide, sulphur dioxides, nitrogen oxides, and particulate matter (Stantec 2022). Transport Canada's *Regulations for the Prevention of Pollution from Vessels and for Dangerous Chemicals* requires that all vessels in Canadian waters are banned from releasing ozone-depleting substances and vessels >400 t gross tonnage must keep an Air Pollution Prevention Certificate on board (TC 2019). The Regulations require that on-board incinerators receive approval and ban the incineration of specific substances (TC 2019). The Regulations also indicate that vessels must keep records as per the NOx Technical Code and specify permissible fuel quality (TC 2019). MKI follows Transport Canada's Regulations as well as MARPOL 73/78 Annex VI: *Regulations for the Prevention of Air Pollution from Ships*.

2.2.12 Accidental Events

In the unlikely event of the accidental release of hydrocarbons during the Project, the measures outlined in MKI's Oil Spill Response Plan will be implemented. The oil spill response plan will be filed with the C-NLOER. In addition, MKI will have an Emergency Response Procedure in place.

2.3 Mitigation and Monitoring for Marine Mammals, Sea Turtles, and Seabirds

Project mitigation measures will be detailed in the EA (see Section 5.5). MMOs will monitor for marine mammals and sea turtles and implement mitigation measures as appropriate. PAM Operators will also monitor for marine mammals. The airgun array will be ramped up (over a minimum of 30 minutes), and ramp ups will be delayed if a marine mammal or sea turtle is detected within the appropriate safety zone (minimum of 500 m as noted in the *Statement of Canadian Practice with respect*

to the Mitigation of Seismic Sound in the Marine Environment). The airgun array will be shut down any time an *Endangered* or *Threatened* (as listed on Schedule 1 of the *Species at Risk Act* [SARA]) marine mammal or sea turtle (as well as a beaked whale) is detected within the safety zone. These measures are designed to minimize the potential for effects (e.g., auditory, disturbance) on marine life, particularly marine mammals and species considered at risk under SARA.

In addition, the MMOs will conduct a monitoring and release program for seabirds which may strand on Project vessels. Seabird monitoring will include systematic counts based on protocols issued by the ECCC-CWS. Likewise, mitigation measures and monitoring for stranded birds will follow established ECCC-CWS procedures.

2.4 Environmental Monitoring

MMSOs will be on board the seismic vessel(s) to monitor for and implement mitigation measures specific to marine mammals and sea turtles, and to collect systematic data on marine mammal/sea turtle behaviour and distribution with and without airguns operating. MKI will also use PAM for cetaceans. Systematic seabird counts will also be conducted during the seismic surveys. As per the most up-to-date ECCC-CWS protocols (Gjerdrum et al. 2012), seabird surveys will be conducted two to three times daily, each survey period consisting of at least six, consecutive, 5-minute observation periods. ECCC-CWS now has a mobile version of the Eastern Canadian Seabirds at Sea (ECSAS) database (CWS 2019), which can be used by observers to facilitate data entry with little to no need for post-processing. The decision as to whether to use the mobile version will be made by MKI in conjunction with the observer provider; regardless, the ECCC-CWS ECSAS protocols will be followed, and the required data fields will be collected. The seabird observations will be conducted by an experienced MMSO, during which time, ideally, a second experienced MMSO is observing for marine mammals and sea turtles. Therefore, marine mammal and sea turtle observations are continuous throughout the daytime period.

Weekly reports from the seismic vessel to the C-NLOER during operations will also include information related to commercial fishing (e.g., FLO reports of gear and/or fishing vessels encountered during the seismic survey).

2.5 Project Site Information

The Project is in the offshore areas east, southeast, and south of Newfoundland. It includes the Northern and Southern Grand Banks, Flemish Cap, and shelf region off Northeast (NE) Newfoundland, as well as offshore slope and deep water regions associated with the shelf (e.g., Flemish Pass, Orphan Basin, parts of the Newfoundland basin; see Figure 1.1).

2.5.1 Environmental Features

The physical and biological environments of the general area have been described in the Eastern Newfoundland Strategic Environmental Assessment (SEA; C-NLOPB 2014)[3], Southern Newfoundland SEA (C-NLOPB 2010)[4], Impact Assessment Agency of Canada's (IAAC's) Regional Assessment of Offshore Oil and Gas Exploration Drilling East of Newfoundland and Labrador (IAAC 2020)[5], as well as in the following project-specific EA: Environmental Assessment of Multiklient Invest Newfoundland Offshore Seismic Program, 2018–2023 (LGL 2018). New information published since the release of the SEAs, IAAC's drilling EA, and project-specific EA are provided in Sections 3.0 and 4.0 of this EA, respectively.

Figure 2.7 shows the extent to which the proposed MKI Study Area overlaps the study areas associated with the SEAs, IAAC drilling EA, and project-specific EA. The proposed Study and Project Areas are the same as those of the LGL (2018) EA.

2.5.1.1 Physical Environment and Potential Effects on the Project

As indicated above, descriptions of the general physical environment of the Study Area are contained in the aforementioned SEAs (C-NLOPB 2010, 2014), IAAC drilling EA (IAAC 2020), and project-specific seismic EA (LGL 2018). The proposed seismic surveys could be conducted in areas with water depths ranging from approximately 100–4000 m. Extreme wind, wave, and ice conditions can slow or even halt survey operations, and accidents are more likely to occur during extreme conditions than during calm conditions. The scheduling of 2D, 3D, and/or 4D seismic surveys during a period (May 1–November 30) when Northwest (NW) Atlantic operating conditions are typically less severe compared to the late-fall/winter/early-spring period should decrease the risk of potential effects of the environment on the Project.

A summary of the potential effects of the physical environment on the Project, based on information in the SEAs (C-NLOPB 2010, 2014), IAAC drilling EA (IAAC 2020), and relevant project-specific seismic EA (LGL 2018), and any new available information, is provided in Section 5.6.

[3] Available at https://www.cnlopb.ca/sea/eastern/.
[4] Available at https://www.cnlopb.ca/sea/southern/.
[5] Available at https://iaac-aeic.gc.ca/050/evaluations/proj/80156.

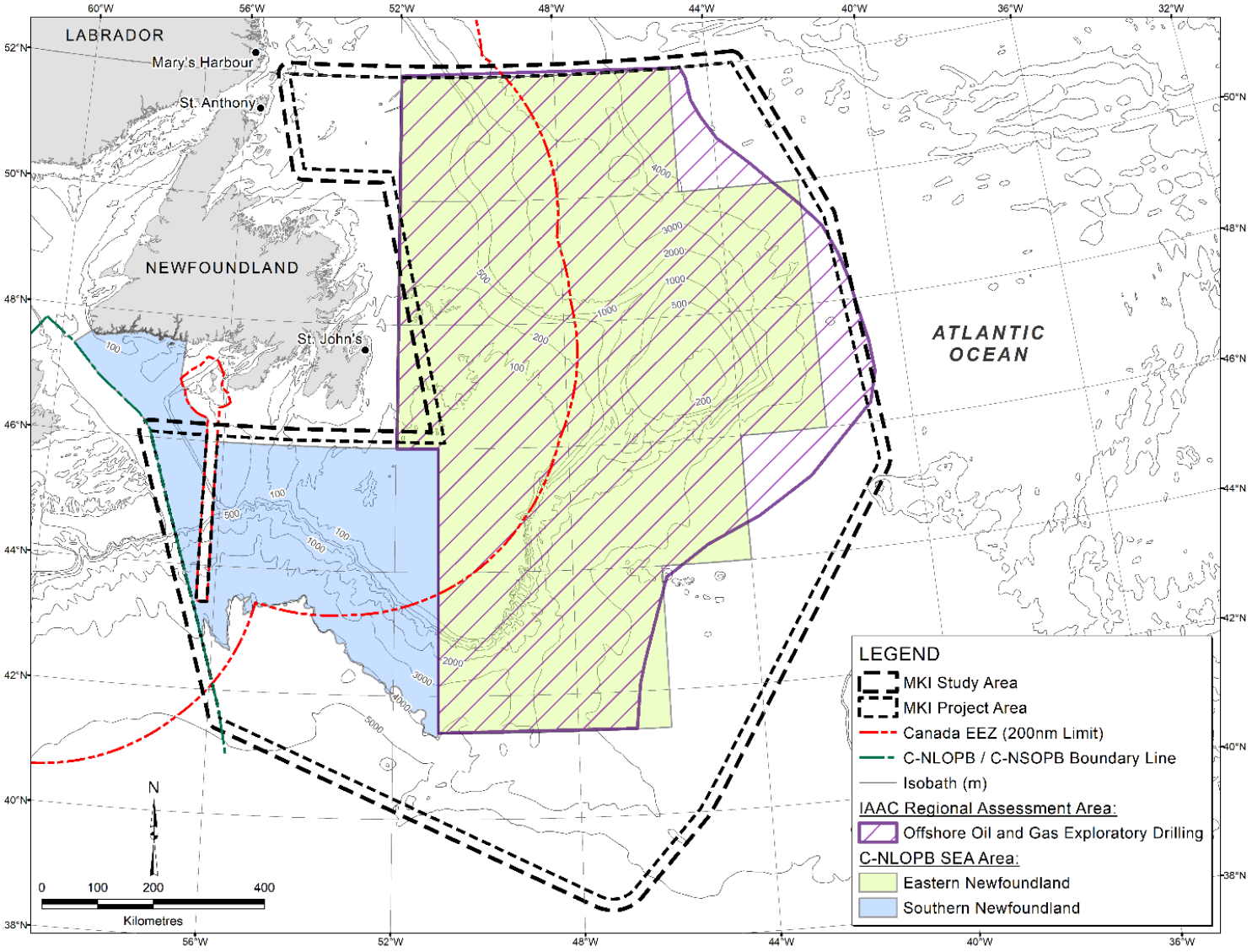


Figure 2.7. Location of MKI's Study Area relative to Study Areas associated with relevant SEAs, IAAC drilling EA, and project-specific EA.

2.5.1.2 Biological Environment

Considering the size of the Study Area for the proposed Project, the biological environment within it is varied and complex. The description of the biological environment is presented in Section 4.0 on the basis of the following seven Valued Components (VCs):

- Fish and fish habitat;
- Fisheries;
- Marine-associated birds;
- Marine mammals
- Sea turtles;
- Species at risk; and
- Sensitive areas.

The potential effects of routine Project activities and accidental events (e.g., unplanned hydrocarbon release) associated with Project activities are assessed in this EA. Cumulative effects on the VCs are also considered in this EA. Other marine users typically considered in the discussion on cumulative effects includes fishing, cargo, and passenger vessels, other oil industry-related vessels, transport and military vessels, or vessels conducting other commercial work.

2.6 Consultations

Consultations were undertaken with relevant government agencies, representatives of the fishing industry and other interest groups based in St. John's. The objectives of these consultations were to describe the proposed seismic program, identify any issues and concerns, and gather additional information relevant to the EA process.

Face-to-face consultations, organized and coordinated by MKI, were held in St. John's during November 2024. Federal and provincial government agencies and industry stakeholder groups, which met with MKI and a summary of their feedback are provided in Table 2.3. Feedback was provided after MKI provided a presentation on the Project overview and planned activities for 2025. Since consultations occurred, MKI has since learned that Project activities are unlikely in 2025 but may occur in 2026.

At the request of One Ocean, MKI attended the Canadian Association of Petroleum Producers (CAPP) Offshore Environmental Forum (27 November 2024) and gave a presentation on seismic operations in the NL offshore and an update on the EA to members of the NL fishing industry, members of the petroleum industry, researchers, and other stakeholders. Topics raised after the MKI presentation included questions on the size of OBN; 4D seismic surveys; seismic data availability (whether it was open source); mitigation measures used to avoid active fishing; and requirements on spatial and temporal avoidance requirements for post-season crab surveys. DFO gave a presentation later in the Forum, which addressed this last point.

Table 2.3. Consultation meetings held in-person* in St. John's, NL in 2024.

Organization	Date	Contact Person/Role	Comments
FFAW/Unifor	12 November	Katie Power, Industry Relations Representative	• The possible survey locations are outside of the fishing areas so no issue. • Annual Convention with fish harvesters scheduled for 18–19 November so MKI supplied a map of possible locations for FFAW to show their members.
One Ocean	12 November	Ashley Woodford, Managing Director	• Discussed giving a "Seismic 101" presentation to the CAPP Offshore Environmental Forum that includes various stakeholders.
DFO	12 November	Corey Morris, Research Scientist Kate Tobin, Biologist, Impact Assessment and Major Projects	• General concern about node surveys and node placement over coral/sponge areas. • Adequate mitigation measures are expected in such sensitive areas. • MMI discussed the questions that DFO brought up in their initial comments sent to the C-NLOER
ECCC	13 November	Sydney Roberts, Environmental Assessment Coordinator Michael Hingston, Head, Environmental Assessment, Environmental Protection Operations Directorate – Atlantic	• No comments beyond the presentation given at the meeting.
NL Department of Fisheries, Forestry, and Agriculture (FFA)	20 November	Taylor Sheppard, Policy, Planning and Research Analyst Samantha Coombs, Resource Policy Development Officer	• Questions on Ocean Bottom Node details. • Benthic Areas • Concerns about nodes being placed on Corals and Sponges • Clarified that their comments on EM do not pertain to this EA since MKI removed it from the previous EA. • FFA gave a list of contacts for EA consultations, most were already contacted, and the rest were not relevant for seismic work offshore.
Ocean Choice International (OCI)	21 November	Rick Ellis, Director, Fleet Operations	• No concerns from their end since they are not in any of the initial possible locations. • OCI mentioned a new marine refuge area.

Notes:
On 12 March 2024, a video conference call was held with Vanessa Byrne, the Director of Fisheries Management and Science of the Atlantic Groundfish Council (AGC). AGC requested to defer all comments/questions to OCI as they are the main contact for AGC.

2.7 Effects of the Project on the Environment

The proposed Project is within the scope of other seismic programs routinely conducted offshore NL. Potential environmental effects are examined with focus on the VCs listed above in Section 2.5.1.2 and the cumulative effects associated with other marine users. The assessment of the effects of the Project on the environment also relies on information presented in the Eastern Newfoundland SEA (C-NLOPB 2014), Southern Newfoundland SEA (C-NLOPB 2010), IAAC regional drilling EA (IAAC 2020; i.e., the Regional Assessment GIS Decision Support Tool noted in the Scoping Document), and relevant project-specific seismic EAs (LGL 2015, 2016, 2018).

3.0 Physical Environment

The Final Scoping Document (C-NLOPB 2024) requires that the EA include a review of the meteorological and oceanographic characteristics of the Study Area, including extreme conditions, to provide a basis for assessing the effects of the environment on the Project. The physical environment of the Study Area has been described in the Eastern Newfoundland SEA (Section 4.1 of C-NLOPB 2014), Southern Newfoundland SEA (Section 2.0 of C-NLOPB 2010), and the IAAC regional drilling assessment (Section 3 of IACC 2020) and Interactive Assessment Map (also known as the "GIS Decision Support Tool"; IAAC 2024). An overview of new physical environment information for the Study Area published since the SEAs (C-NLOPB 2010, 2014) and IAAC (2020, 2024) is provided below.

3.1 Bathymetry and Geology

The bathymetry and geology of the Study Area are visualized in IAAC's Interactive Assessment Map (IAAC 2024) and described in Sections 2.4 and 2.5 in C-NLOPB (2010) and Sections 4.1.1 and 4.1.2 in C-NLOPB (2014). Welford (2024) utilized constrained 3D gravity inversion modelling to generate a density model and crustal thickness structure for Atlantic Canada. The modelling allowed for analysis of the upper, middle, lower, and full crustal layers that agreed with and expanded upon previous data for the region. Welford (2024) produced an improved database of continental, oceanic crust, and continent-ocean transition zone characteristics that is freely available for use at https://zenodo.org/records/10114011. Recent research based on available seismic data has indicated the presence of several potential carbon capture and storage (CCS) reservoir rock units on the Whale and South Whale basins in the southern Grand Banks (i.e., within the southwestern portion of the Study Area). These units are porous and overlain by "an impermeable caprock unit", rendering them ideal for injection of carbon dioxide (CO_2) and of relevance for oil and gas producers in the Newfoundland offshore as an increasingly common method of climate change mitigation. Research is ongoing and the end goal will be a quantification of overall CO_2 storage potential for the area (Johnson et al. 2025a).

3.2 Climatology

All marine seismic surveys are influenced by weather conditions, from both routine operational and environmental safety perspectives. During routine activities, seismic data quality can be affected by weather, particularly by wind and wave conditions. Furthermore, the ability of a MMSO to detect

marine mammals and sea turtles relative to the safety zone is affected by environmental conditions. Climatology for the Study Area was described in Section 2.1 of C-NLOPB (2010) and Section 4.1.3 of C-NLOPB (2014). This section provides relevant updates more appropriate to recent climatology in the Study Area compared to the information described in the SEAs, as climate change has led to notable differences in the region in the past decade. Recent information pertaining to climate change is incorporated throughout the EA where applicable. The Proponent submitted a request for updated MSC50 wind and wave climate hindcast data from Environment Canada MSC Applied Climatology Services and received a response that government departments no longer maintain data beyond 2018. Therefore, this EA relies largely on updated climatology data made available through IAAC (2024). As up-to-date daily and/or monthly climatology data layers are continuously available through IAAC (2024), this section provides a basic summary of new, relevant information, and the reader is referred to IAAC (2024) for details.

3.2.1 Wind

Average wind speeds provided in C-NOPB (2010, 2014) were based on long-term, historic wind data (i.e., the 1950s to 2005 for C-NLOPB 2010 and to 2011 for C-NLOPB 2014). More recently, the Global Wind Atlas layer in IAAC (2024) indicates that wind speeds in the Study Area range from monthly average highs of ~31–34 m/s in January to lows of ~15–20 m/s in June (based on global wind data from 2008–2017 generated by the European Centre for Medium-Range Weather Forecasts). Although there is considerable uncertainty regarding wind projections for eastern Newfoundland (particularly in the offshore), available research indicates that, consistent with global climate change trends, there was a general decrease in maximum annual wind gust speeds in recent years ("global stilling"), which has since rebounded (Climate Signals n.d.; Fausto 2023). Between 2010–2020, the overall number of days with wind gusts >60 km/h and >100 km/h in St. John's, NL increased, although there has been interannual variability (see wind gust figures in Wilhelm et al. 2022). Precautionary future projections suggest average annual wind speeds for Eastern Canada will increase by ~4% for the 50-year return period, and the number of days with wind gusts ≥70 km/h are anticipated to increase by 30–50% by the 2050s to 2080s (Fausto 2023).

Typical monthly/seasonal/annual wind directions and relative intensities for the Study Area were provided in Section 2.1.2 in C-NLOPB (2010) and Section 4.1.3.1 in C-NLOPB (2014). The Environment Canada Wind Speed and Direction and Current Weather and Wind Station Data layers in IAAC (2024) provide daily wind direction and speed pictorial indicators and numerical data for NL and elsewhere. The Canadian Coast Guard (CCG) e-NAV online application also provides a visual of current wind direction and speed (in 5 knot increments) on a global scale (CCG 2025).

3.2.2 Waves

Wave climatology in the Study Area was described in Section 2.1.3 in C-NLOPB (2010), Section 4.1.4.1 in C-NLOPB (2014), and Section 3.2.2 in LGL (2018). Historical significant wave height statistics for the Study Area are available in Tables 4.18–4.21 in C-NLOPB (2014); Tables 2.4–2.5 in Oceans (2014); and Table 5.9 in Stantec (2023). A long-term trend of rising sea levels has been occurring since the 1940s for the coastal St. John's, NL area, with a relative sea level change of +1.9 mm/year

(Fausto 2023). Sea levels for the area are projected to continue rising (Fausto 2023) and by 2100, portions of the province are expected to experience a sea level increase of up to 100 cm (ECC 2024a).

3.2.3 Wind and Wave Extreme Value Analysis

The occurrence of severe wind and waves associated with extreme storm events is of particular importance for the planning and execution of marine seismic surveys. Extreme wind and wave events were described in Section 4.1.4.4 in C-NLOPB (2014) and Section 3.2.3 in LGL (2018). Estimates for extreme wind speed and extreme significant wave height for the Study Area for 1954–2010/2011 are available in Tables 4.38–4.41 in C-NLOPB (2014), Tables 3.2 and 3.5 in Oceans (2014), and for the Jeanne d'Arc Basin for 1962–2018 in Table 5.10 in Stantec (2023). The NL Atlas of Storm Surge and Wave Climates modelled potential climate change projections, and the resultant simulations predicted changes in storm surges between 0.01–0.10 m off Newfoundland by 2070–2100 compared to the baseline (1984–2014; see Figure 5.1 in DHI 2024). Predicted changes in significant wave height off Newfoundland were more variable depending on the model used, ranging from decreasing by ~0.5 m to increasing by up to 1.0 m (see Figure 5.2 in DHI 2024). Overall, by 2100, portions of NL are expected to experience storm surges >4 m and storm waves >10 m (ECC 2024a).

3.2.4 Weather Variables

Air and sea temperature and visibility for the Study Area were described in Sections 2.1.4–2.1.5 in C-NLOPB (2010), Sections 4.1.3.2, 4.1.3.4, and 4.1.4.3 in C-NLOPB (2014), and Section 3.2.4 in LGL (2018). This section provides relevant updates more appropriate to recent weather variables in the Study Area compared to the information described in the SEAs.

3.2.4.1 Temperature

Air and Sea Surface Temperatures

Mean monthly air temperatures within the Study Area (1950–2012/1980–2013, depending on measurement site) are provided in Tables 4.5–4.8 in C-NLOPB (2014) and Table 2.14 in Oceans (2014). Mean monthly sea surface temperatures (SSTs) within the Study Area during the same periods are provided in Tables 4.22–4.25 in C-NLOPB (2014) and Table 2.14 in Oceans (2014). Mean and maximum monthly air and SSTs for the Jeanne d'Arc Basin (1980–2019) are provided in Tables 5.2 and 5.3 in Stantec (2023). The CCG e-Nav online application provides a visual of current air temperature ranges (in 5°C increments) on a global scale (CCG 2025). There are also several data layers available through IAAC (2024) for air and SSTs, including:

- Air Temperature:
  - "Global Monthly Temperature Anomaly (Latest)" and "Global Monthly Temperature Anomaly (1850-present)" – Combined analysis of global monthly air and SSTs up to the present month compared to the baseline average (1971–2000; latest layer) or 20th century (1850-present layer);

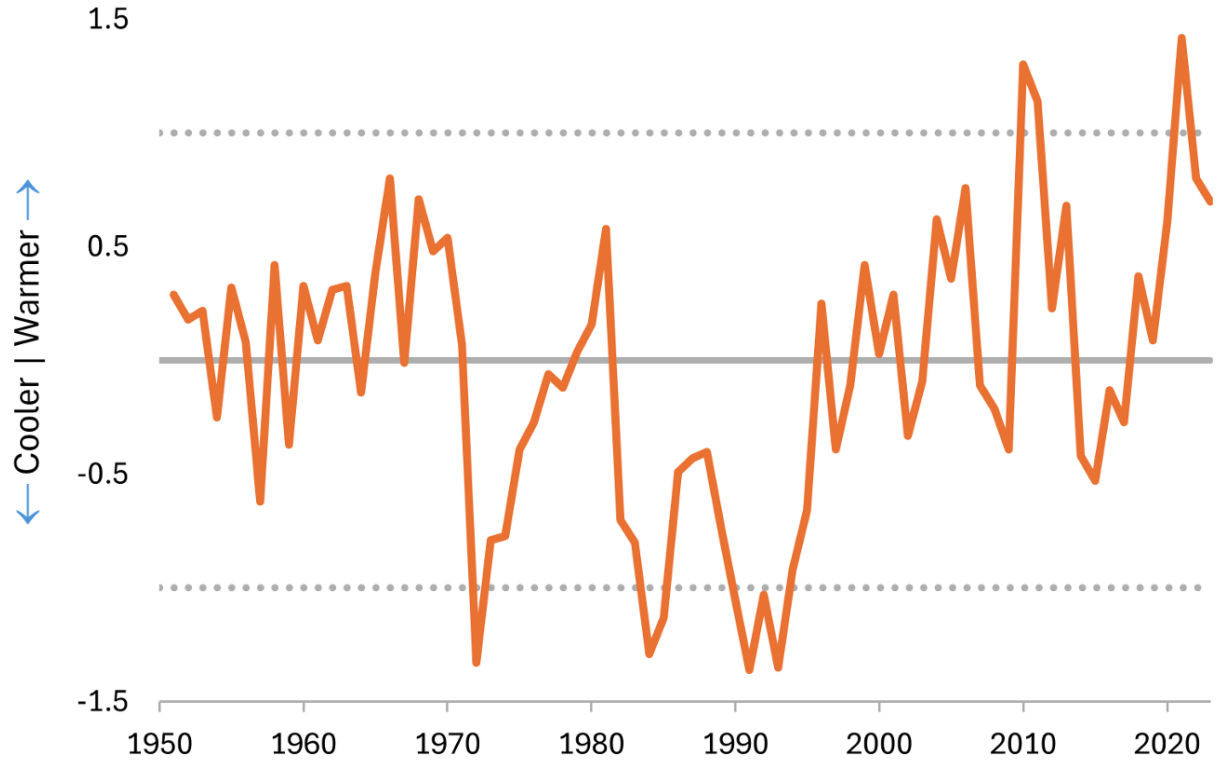
    - "Global Yearly Temperature Anomaly (1850-present)" – Combined analysis of global yearly air and SSTs up to the present year compared to the 20th century average;
    - "Surface Air Temperature (Average Annual)" – Global mean surface air temperature from 1981–2010;
- SST:
    - "Sea Surface Temperature (SST)" – Daily updates of nighttime SST measured by satellites at 5-km resolution (global), for 1985-present; and
    - "Sea Surface Temperature Anomaly (SSTA)" – Daily updates of the calculated difference between the long-term SST and a daily SST value at 5-km resolution (global), for 1985 to present (note: positive anomaly = warmer than average; negative anomaly = cooler than average);

During 2024, combined air and SST annual temperature anomaly analysis indicated that temperatures within the Study Area were ~1.5–1.9°C above the 20th century average (IAAC 2024). The North Atlantic experienced an extreme all-time high in SSTs in summer 2023, an event only considered possible due to climate change and, given the current warmer climate, anticipated to be a decadal-type event (Guinaldo et al. 2025). The 2023 highs surpassed the previous record highs experienced during 2022, including several records within the Study Area reported between May and November as part of the Atlantic Zone Monitoring Program (AZMP; DFO 2023a; Guinaldo et al. 2025). The Newfoundland and Labrador Climate Index (NLCI) for the NL shelf provides a combined summary of the winter North Atlantic Oscillation (NAO; see Section 3.3.1), air and SSTs, vertically averaged temperature and salinity, seasonal sea ice severity, iceberg counts, summer cold intermediate layer core temperature and area, and bottom temperature (Cyr and Galbraith 2021). During 1950–2023, the NLCI indicates that, apart from several record cold years between the early 1970s and 1990s, the NL climate has mainly undergone a warming trend, particularly in 2010 and the early 2020s (Figure 3.1). Since the 1940s, the coastal region of St. John's, NL has been experiencing warming SST of 0.13°C per decade and warming subsurface waters (0–175 m depth) of 0.02°C per decade, a trend which is anticipated to continue (Fausto 2023).

Greenhouse Gas Emissions

Greenhouse gas emissions (GHG) contribute to rising air and SSTs through the greenhouse effect, whereby GHG trap outgoing heat from the Earth, warming the air temperature and increasing SSTs as the trapped heat is absorbed by oceanic waters. GHG associated with offshore oil and gas drilling was considered in IAAC (2020), including data from 2016–2018, estimated projections into the early 2030s, and national GHG targets (see Sections 4.2.5 and 7.2.1–7.2.2 in IAAC 2020). GHG were also considered in Section 4.4.5 in C-NLOPB (2010) and Section 4.1.6 in C-NLOPB (2014). The Canadian Greenhouse Gas Emissions layer in IAAC (2024) includes mandatory annual data reported through Canada's Greenhouse Gas Reporting Program for facilities that emit ≥10 kt of GHG emissions per year (ECC 2025). Within the Study Area, reporting sites include the Hibernia platform, Sea Rose Floating Production, Storage, and Offloading (FPSO), Terra Nova FPSO, and Hebron Platform, with 2023 as the latest data year. During the 2023 year, all four sites were within the 100–499 kt of CO_2 equivalent range. As an update to Table 7.4 in IAAC (2020), annual GHG emissions from NL offshore oil production facilities during 2019–2023 are provided in Table 3.1. Note that in 2019, the *Henry Goodrich*

semi-submersible rig was operating at the West White Rose Oilfield for Husky Oil Operations Limited (Husky), and the *Transocean Barents* rig was operating at the Terra Nova Oilfield for Suncor Energy Inc. Both rigs were operated by Transocean Canada Drilling Services Ltd. Hebron's annual CO_2 and methane (CH_4) emission levels have been decreasing each year since 2019, for a total decrease of ~34% in CO_2 and ~90% in methane in 2023 compared to 2019. Methane emissions at Hibernia have similarly been decreasing, with the 2023 level 84% lower than that of 2019. Other emissions from NL offshore facilities have been variable in recent years. During 2023, the combined offshore oil and gas production facilities accounted for 40% of NL's GHG emissions (for industrial facilities required to submit annual reports), increased from the 2019 value of 33% (GC 2024). Overall, the oil and gas industry has been the third largest emitting sector in NL in recent years, representing ~15% of GHG emissions in the province in 2022 (Figure 3.2; CER 2024). The provincial GHG reduction targets are emissions 30% lower than 2005 levels by 2030 and net-zero emissions by 2050 (ICAP 2022).



Source: Figure 7.4.4 in CRAOWD NL (2025).

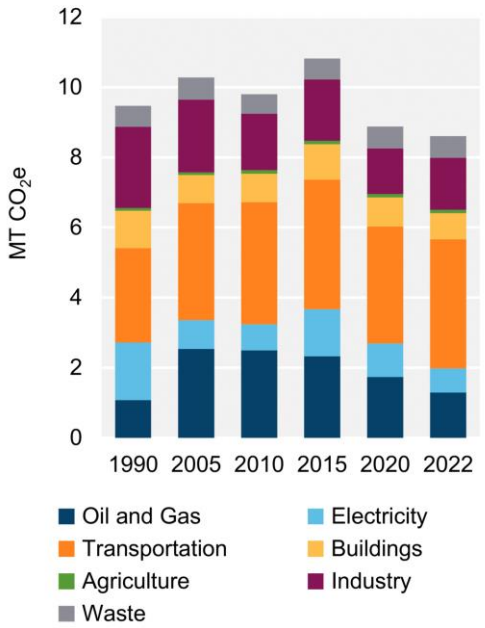
Figure 3.1. Newfoundland and Labrador Climate Index, 1950–2023.

Table 3.1. Annual GHG emissions from NL offshore oil production facilities (2019–2023).

Year	CO_2	CH_4	N_2O	HFCs	Total
Hibernia Platform (Hibernia Management and Development Company Limited)					
2019	457	50	3	0	**509**
2020	541	19	3	0	**563**
2021	510	18	3	0	**530**
2022	440	13	2	0	**456**
2023	486	8	2	0	**497**
Total	**2434**	**108**	**13**	**0**	**2555**

Year	CO_2	CH_4	N_2O	HFCs	Total
Sea Rose FPSO (Husky Oil Operations Limited 2019–2021; Cenovus Energy Inc. 2022–2023)					
2019	240	17	2	0	**260**
2020	343	19	2	0	**364**
2021	311	20	2	0	**333**
2022	297	19	2	0	**317**
2023	260	11	2	0	**273**
Total	**1451**	**86**	**10**	**0**	**1547**
Terra Nova FPSO (Partnership: Suncor Energy Inc., Cenovus Energy Inc., Murphy Oil)					
2019	491	24	6	0	**521**
2020	43	0	2	0	**45**
2021	-	-	-	-	**-**
2022	-	-	-	-	**-**
2023	135	13	1	0	**149**
Total	**669**	**37**	**9**	**0**	**716**
Hebron Platform (ExxonMobil Canada Properties)					
2019	520	89	3	0	**611**
2020	482	22	3	0	**507**
2021	469	15	3	0	**487**
2022	415	12	3	0	**430**
2023	342	9	2	0	**353**
Total	**2227**	**147**	**14**	**0**	**2388**
Henry Goodrich (Transocean Canada Drilling Services Ltd.)					
2019	21	0	1	0	**22**
Transocean Barents (Transocean Canada Drilling Services Ltd.)					
2019	38	0	2	0	**40**

Source: GC (2024).
Notes:
All units are in kt of CO_2 equivalent. CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; HFC = hydrofluorocarbon.



Source: Figure 6 in CER (2024).

Figure 3.2. NL GHG emissions by sector, 1990–2022.

As a GHG emissions reduction effort, the Government of Newfoundland and Labrador (GNL) implemented a carbon pricing system in 2019 specifying performance standards for large industrial facilities via the *Management of Greenhouse Gas Act* and associated regulations (ECC 2025). Annual reports are required from facilities emitting ≥15 kt of GHG emissions per year and reduction targets are established for those that emit ≥25 kt per year (or those that emit ≥15 kt and voluntarily opt to be regulated by the *Management of Greenhouse Gas Act*). Industrial facilities that do not fall under the above regulations are bound by the Federal Fuel Charge under Part 1 of the *Greenhouse Gas Pollution Pricing Act* (ECC 2025). Under the *Management of Greenhouse Gas Act*, industrial facility operators may purchase NL Greenhouse Gas Reduction Fund credits, which are used to meet emissions reduction obligations. Deposits into the Fund may also result from enforcement activities associated with the Act and regulations (ECC 2024b, 2025). During the 2023–2024 fiscal year, a total of $185,800 was deposited into the Fund, for a total balance of $428,962 as of 31 March 2024 (ECC 2024c). In addition, the Canadian Offshore Emissions Reduction Fund (now closed to applications) is a $75-million investment established under the Emissions Reduction Fund to assist the country in meeting environmental commitments, economical growth, and decreasing our carbon economy, particularly in terms of GHG emissions (NRC 2025). There are two offshore components, including the Offshore Deployment Program ($42 millions allotted to support projects to reduce GHG emissions or otherwise improve performance) and Offshore RD&D Program ($33 million research, development, and demonstration projects to "decarbonize NL's offshore industry"; collaborative effort with Energy Research & Innovation NL).

GHG emissions associated with the Project would be considerably lower than the above industry facilities and equivalent to those of standard commercial vessels that operate in or transit through the Study Area. Given this low value, calculations of emissions and offsetting are not required for the Project.

3.2.4.2 Visibility

Visibility is considered the greatest distance at which objects (e.g., marine mammals, fishing buoys) can be seen and identified. Visibility may be reduced by fog (i.e., in-air water droplets that reduce visibility to <1 km); mist (i.e., in-air water droplets/wet hygroscopic particles that reduce visibility to 1–5 km; relative humidity ≥95%); haze (i.e., reduced visibility in the absence of water droplets; relative humidity <95%); smoke; liquid precipitation (e.g., rain, drizzle); freezing precipitation (e.g., freezing rain); frozen precipitation (e.g., snow), and blowing snow (see Isaac et al. 2020). Reduced visibility can affect crew changes and work boat operations, increase the risk of interactions of a seismic vessel and its towed gear with obstructions in the water, and reduce the ability of MMSOs to effectively monitor the safety zone. Visibility and fog in the Study Area were described in Section 2.1.5 in C-NLOPB (2010), Section 4.1.3.4 in C-NLOPB (2014), and Section 3.2.4.2 in LGL (2018).

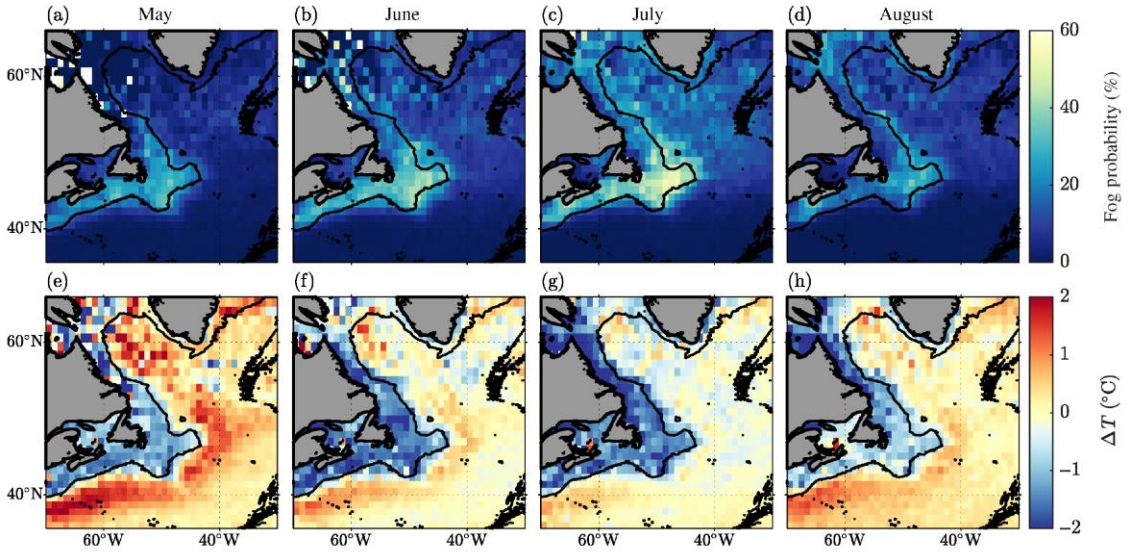
The monthly and annual frequency of occurrence of visibility states (i.e., very poor [<0.5 km] to good [>10 km]) for the Study Area for 1950–2012 are provided in Tables 4.13–4.16 in C-NLOPB (2014), for 1980–2013 in Figures 2.33 and 2.35 in Oceans (2014), and for 1980–2019 in Table 5.5 in Stantec (2023). The monthly probabilities for the occurrence of fog in the Jeanne d'Arc Basin for 1997–2017 are provided in Table 3.2. In the Study Area, fog is most prevalent during the summer (especially June and July), with peak fog occurrence on the continental shelf (Formby-Fernandez et al. 2025). The

occurrence of fog notably decreases along the shelf break (around the 2000-m depth contour), particularly for the southern Grand Banks, and minimal fog occurs south of the shelf (Formby-Fernandez et al. 2025). This clear delineation is mainly due to differences in air and SSTs, whereby a negative difference tends to occur on the shelf (especially in July, when southwest (SW) winds transport warm air over the considerably colder shelf waters) and positive values off the shelf (Figure 3.3; Formby-Fernandez et al. 2025). The Study Area's best visibility tends to occur in September and October (Isaac et al. 2020). At this time, it is uncertain how the region's warming climate will impact the occurrence and properties of fog, although the passage of cyclones has been recorded to result in rapid formations of large, deep fog and cloud layers, such as that observed off Nova Scotia (NS) in July 2019 (Figure 3.4; Koračin et al. 2024).

Table 3.2. Monthly fog probabilities at differing times of day for the Jeanne d'Arc Basin, 1997–2017.

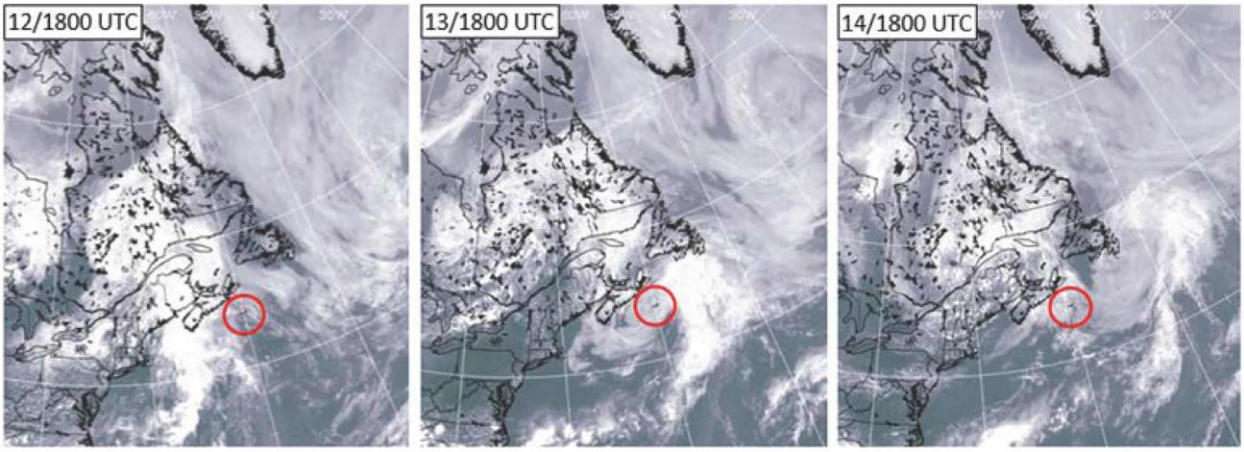
Month	Fog Probability (%) at Times of Day (UTC)							
	0000	0300	0600	0900	1200	1500	1800	2100
Jan	8.1	4.1	7.2	4.5	4.9	6.2	8.0	8.2
Feb	7.2	5.8	6.0	6.7	8.2	6.2	3.7	6.1
Mar	10.4	10.9	9.1	12.6	10.0	8.8	11.4	10.8
Apr	21.5	24.1	23.0	19.4	23.0	19.5	19.5	20.1
May	28.4	30.8	33.5	32.0	31.1	29.6	25.9	27.1
Jun	39.0	39.8	38.1	45.5	36.1	35.2	37.5	38.7
Jul	44.0	44.0	45.8	45.6	45.4	41.6	41.9	46.0
Aug	24.9	27.8	28.7	24.7	27.4	22.0	24.0	26.0
Sep	11.5	14.7	12.3	12.8	11.8	11.7	10.8	10.5
Oct	9.4	11.8	13.0	11.0	10.7	12.2	10.6	10.8
Nov	9.7	7.3	7.7	9.6	9.6	10.3	9.9	11.1
Dec	4.3	5.7	6.7	6.2	5.6	6.4	4.5	7.3

Source: Table 1 in Isaac et al. (2020).



Source: Figure 4 in Formby-Fernandez et al. (2025).
Notes:
Values represent averages calculated based on data collected between 1950–2020. Black line = 2000-m depth contour.

Figure 3.3. Probability of fog occurrence (%; panels a-d) and average air-sea temperature difference (ºC; panels e-h) for the Grand Banks region during May–August.



Source: Figure 7 in Koračin et al. (2024).
Notes:
Red circle is centered on Sable Island. Inset values are date (day)/time 24-h format).

Figure 3.4. Geostationary Operational Environmental Satellite East images of a rapid marine fog-cloud formation between 12–14 July 2019 because of a cyclone passage.

3.2.5 Weather Systems

Tropical storm systems in the Study Area were described in Section 2.1.8 in C-NLOPB (2010), 4.1.6.6 in C-NLOPB (2014), and Section 3.2.5 in LGL (2018). Major storms travelling west-to-east across Canada generally pass through the Gulf of St. Lawrence and move seaward over the Grand Banks and Labrador Sea (CCG 2022), whereas hurricanes and tropical storms travel northwards toward Newfoundland and the Grand Banks from the south. The Historical Hurricane Tracks layer in IAAC (2024) provides information regarding global hurricane and tropical storm pathways from 1842–2024, and data can be filtered by year and month. An examination of tracks during May–November since 2020 indicates that storm systems that have moved through the Study Area have ranged in strength from extratropical to tropical (including hurricane status; i.e., maximum sustained winds ≥74 mph [~119 km/h or ~64 knots]). For the May–November period since 2020, a range of ~1–3 storm systems per year have tracked through the Study Area. No tracks have been recorded in the Study Area during May or June since 2020 and most systems have moved through the Study Area during the month of September.

3.3 Physical Oceanography

A detailed review of the key physical oceanographic conditions and characteristics, including ocean currents, current velocities, and water mass properties (temperature, salinity, density), were provided in the Southern Newfoundland and Eastern Newfoundland SEAs (CNLOPB 2010, 2014). An indication of available data via IAAC (2024) and summary of recent data relevant to major currents in the Study Area are provided below.

3.3.1 Major Currents in the Study Area

Oceanic currents in the Study Area were described in Section 2.2.1 in C-NLOPB (2010), Section 4.1.4.2 in C-NLOPB (2014), and Section 3.3.1 in LGL (2018). Annual global ocean surface current magnitude (m/s) and direction (geographic degrees; WGS84) data (2005–2023+) are available via the Ocean Surface Currents – Annual Climatology layer in IAAC (2024). Additionally, annual mean global near-surface circulation based on data from satellite-tracked surface velocity program drifting buoys that form the Global Drifter Array of the Global Ocean Observing System is available via the Global Near-Surface Currents (Annual Mean) layer in IAAC (2024). Circulation within the Study Area is impacted by wind-stress forces along the shelf and coast and within shallower waters, and by open ocean gyres along the outer shelf (Yang and Chen 2021). A positive NAO index (affects winds, air temperature, precipitation, and hydrographic properties in eastern Canada through advection) is typically associated with strong northwest winds, cold air/sea temperatures, and heavy ice in the Labrador Sea (DFO 2023a). Following a historic low NAO index (-1.5) in 2010, the Labrador Sea NAO index has mostly been positive (see Figure 16 in DFO 2023a). Along the NL shelf break, mean transport of the Labrador Current is 13 Sv (1 Sv = 10^6 m^3 s^{-1}) ±1.4 Sv standard deviation (SD; Cyr et al. 2022). A weakening trend in annual mean transport occurred between 2019 and 2021 (Cyr et al. 2022). However, during 2022, the AZMP indicated that the Labrador Current transport was above normal for the NL shelf break (+1.2 SD), coincident with a positive NAO index (+1.0; DFO 2023a).

3.4 Ice Conditions

Ice conditions are an important component of the physical environment and can directly affect offshore activities, including seismic surveys, along the coast of NL. Ice conditions in the Study Area were described in Section 2.3 in C-NLOPB (2010), Section 4.1.5 in C-NLOPB (2014), and Section 3.4 in LGL (2018). The North America Glaciers and Sea Ice layer in IAAC (2024) provides visual extents of permanent ice on the North America landmass (including Greenland), areas of land within glaciers, and estimated extent of permanent ice in the Arctic (last updated in 2023); however, these areas do not extend into the Study Area and no other ice-related layers for the region could be found via IAAC (2024). A summary of updated information relative to the sources listed above and relevant to the Project is provided below.

3.4.1 Sea Ice

Sea ice and sea ice concentrations in the Study Area were described in Section 2.3.2 in C-NLOPB (2010), Section 4.1.5.1 in C-NLOPB (2014), and Section 3.4.1 in LGL (2018). Offshore eastern NL, ice typically occurs as freely moving pack or drift ice which, during years with harsh winters, may drift southward via the Labrador Current as far east and south as the Flemish Cap and 43°N, respectively (ECCC 2022). Following a rebound period during 2014–2017 (i.e., "heavy sea ice conditions"), recent ice conditions in the Study Area have been considered closer to normal (DFO 2023a). That said, ice coverage in the Study Area during the 2023/2024 season was below the 30-year median for all weeks (Figure 3.5). The maximum and total averaged ice coverage levels have been on a declining trend in recent years, with maximum ice coverage decreasing by ~66%, 75%, and 86% (percent change) for new, young, and first year ice, respectively, in 2024 compared to 2019 (Figures 3.6–3.7). Although there has been interannual variability in total averaged ice coverage for the Study Area in recent years, the overall total

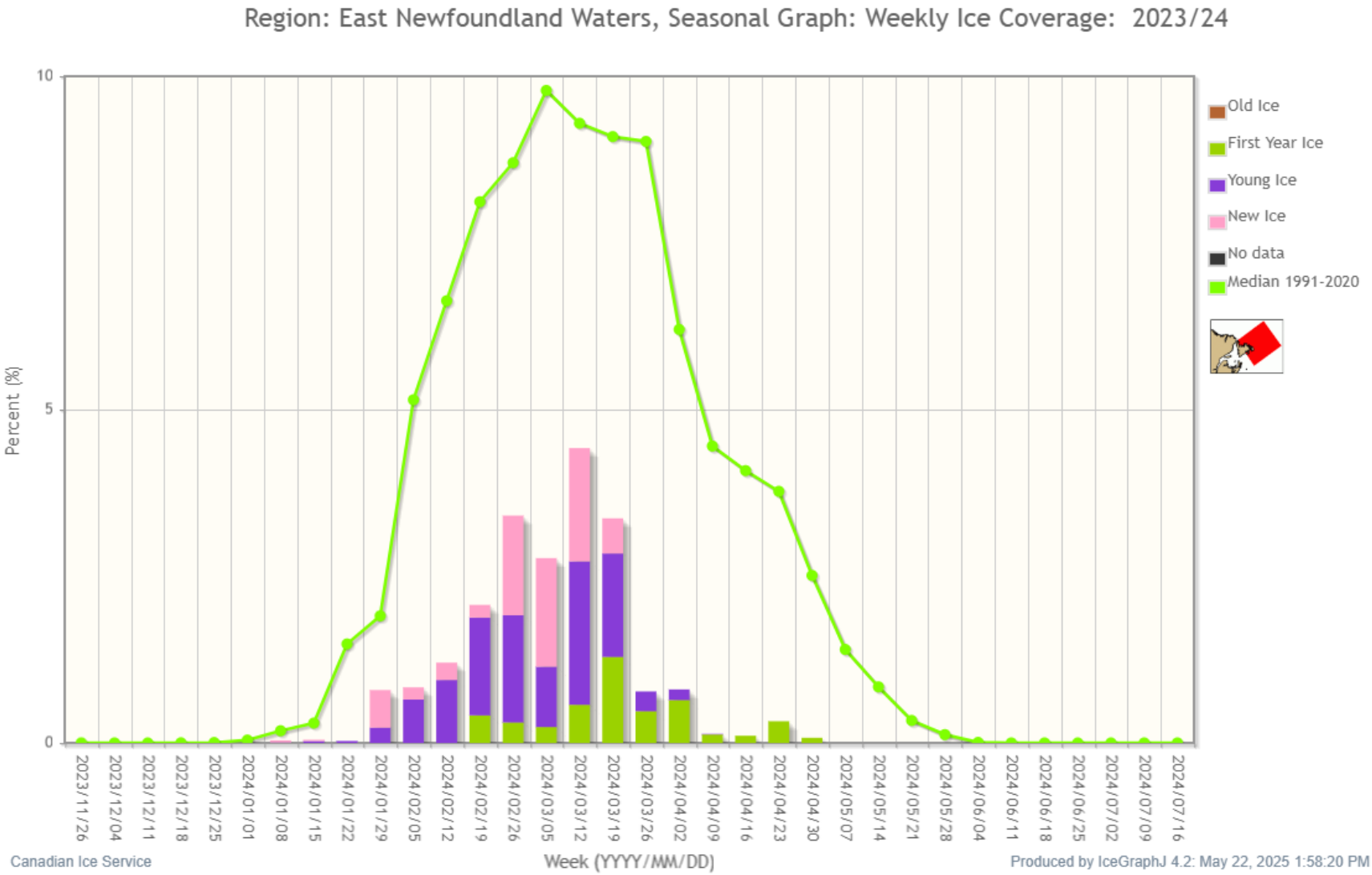
concentration in the 2023/2024 season was less than half that of 2019/2020 (Figure 3.7). Recent sea ice and iceberg modelling for the northern Grand Banks, Flemish Pass, and Orphan Basin relating to offshore floating wind turbines and associated subsea infrastructure (e.g., mooring lines, electrical cables) concluded that risk from potential contact is low for the region and risk levels are anticipated to decrease further in the future given the overall decline in sea ice (Ralph and King 2024).

3.4.2 Icebergs

Icebergs in the Study Area were described in Section 2.3.3 in C-NLOPB (2010), Section 4.1.5.2 in C-NLOPB (2014), and Section 3.4.2 in LGL (2018). No data layers relating to icebergs in the region could be found via IAAC (2024). Warmer temperatures within the Study Area mean that icebergs there generally have a higher rate of deterioration and instability relative to those found further north and may roll multiple times daily. As such, vessels should keep a wide berth in the presence of an iceberg as part of safety protocols (CCG 2022).

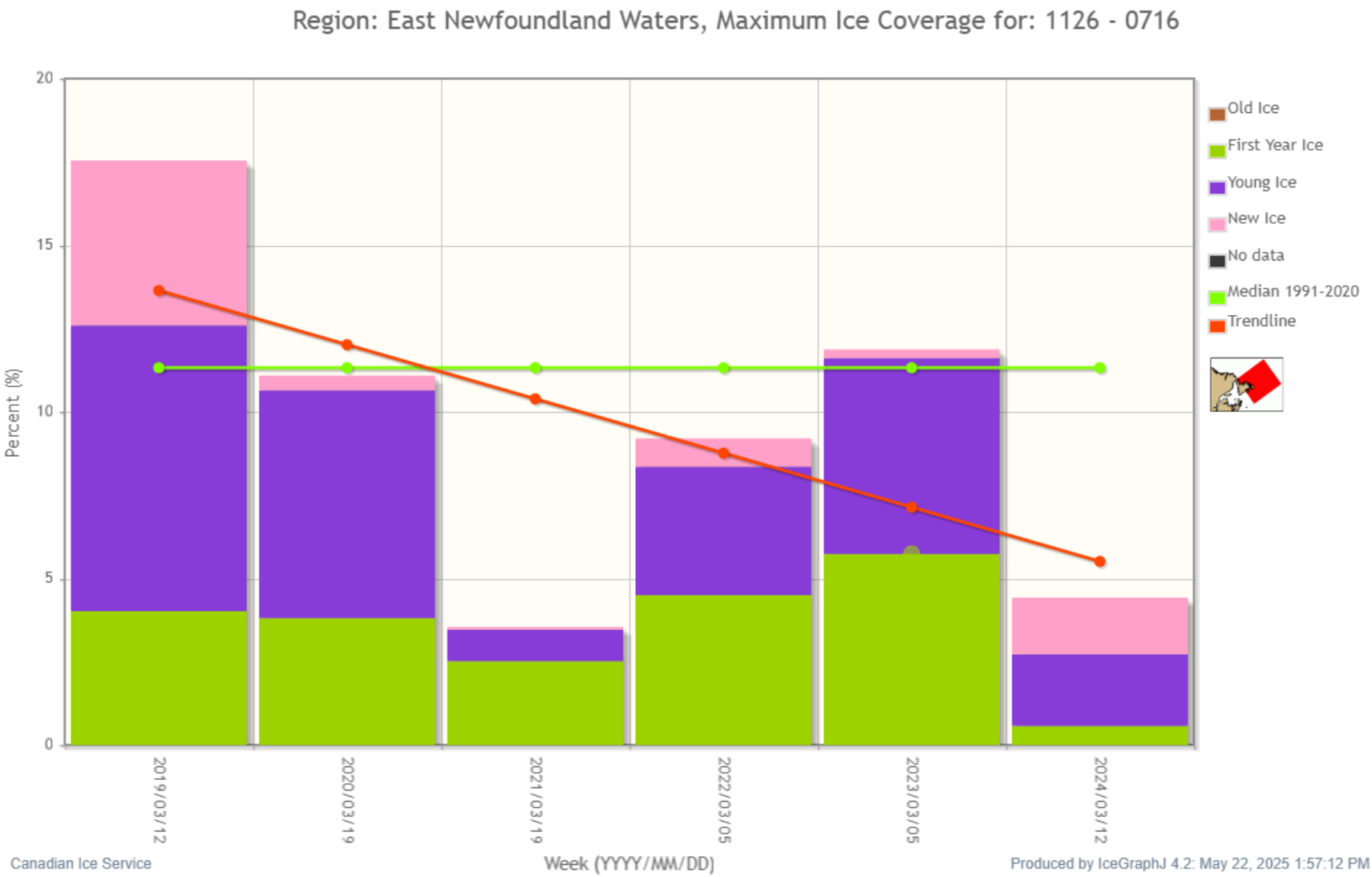
An estimated ~25,000–40,000 icebergs are created in Baffin Bay each year, mostly from west Greenland glaciers (CCG 2022). From there, while it is possible for an iceberg to travel the required ~2700–3700 km to the Grand Banks in a single year, a travel time of two to three years is more realistic (CCG 2022). Iceberg drift patterns are influenced by strong winds and currents but generally, icebergs calved on the west coast of Greenland typically drift north before heading west in northern Baffin Bay, travelling southward along eastern Baffin Island, and ultimately carried to nearshore Newfoundland and the Grand Banks via the Labrador Sea (Figure 3.8; CCG 2022).

Although numbers vary widely between years, a climatological (1991–2020) average of 771 icebergs per year drift south of 48°N, mostly between March and June with a peak in April (Figure 3.9; CCG 2022; Cyr et al. 2022). Low numbers of icebergs are typically correlated with years that have higher air and SSTs, and lighter sea ice conditions compared to normal for the NL shelf (Cyr et al. 2022). The International Ice Patrol (IPP) Iceberg Sightings Database (Version 1) indicates that an average of 3333 icebergs per year occurred in the Study Area during 2016–2021, with most (87%) icebergs present during March through May (Table 3.3). There has been considerable interannual variation in the number of icebergs that pass through the Study Area in the past ~20 years (see also Table 3.15 in LGL 2018). Although the number of icebergs recorded in the Study Area were considerably lower during 2020 and 2021 compared to 2016–2019, this may be at least in part a reflection of decreased offshore activities and associated observer/reporting opportunities during the COVID-19 pandemic lockdown periods that occurred during 2020–2021. Regardless, similar annual values to those observed in the Study Area during 2020–2021 occurred during six other years between 2005 and 2013, indicating that occasional low iceberg years are historically normal for the region. Location data from 2022 onwards have not yet been posted by the IIP, but trends will be further examined in later EA Updates once more recent data become available (NSIDC 2025). During 2016–2021, icebergs were reported in the northwestern portion of the Study Area, mostly in water depths <2000 m and west of the Flemish Cap, which is generally consistent with iceberg locations during the past ~20 years (Figure 3.10; see also Figure 3.7 in LGL 2018). Overall, fewer icebergs have been observed crossing south of 48°N in recent years (Table 3.3).



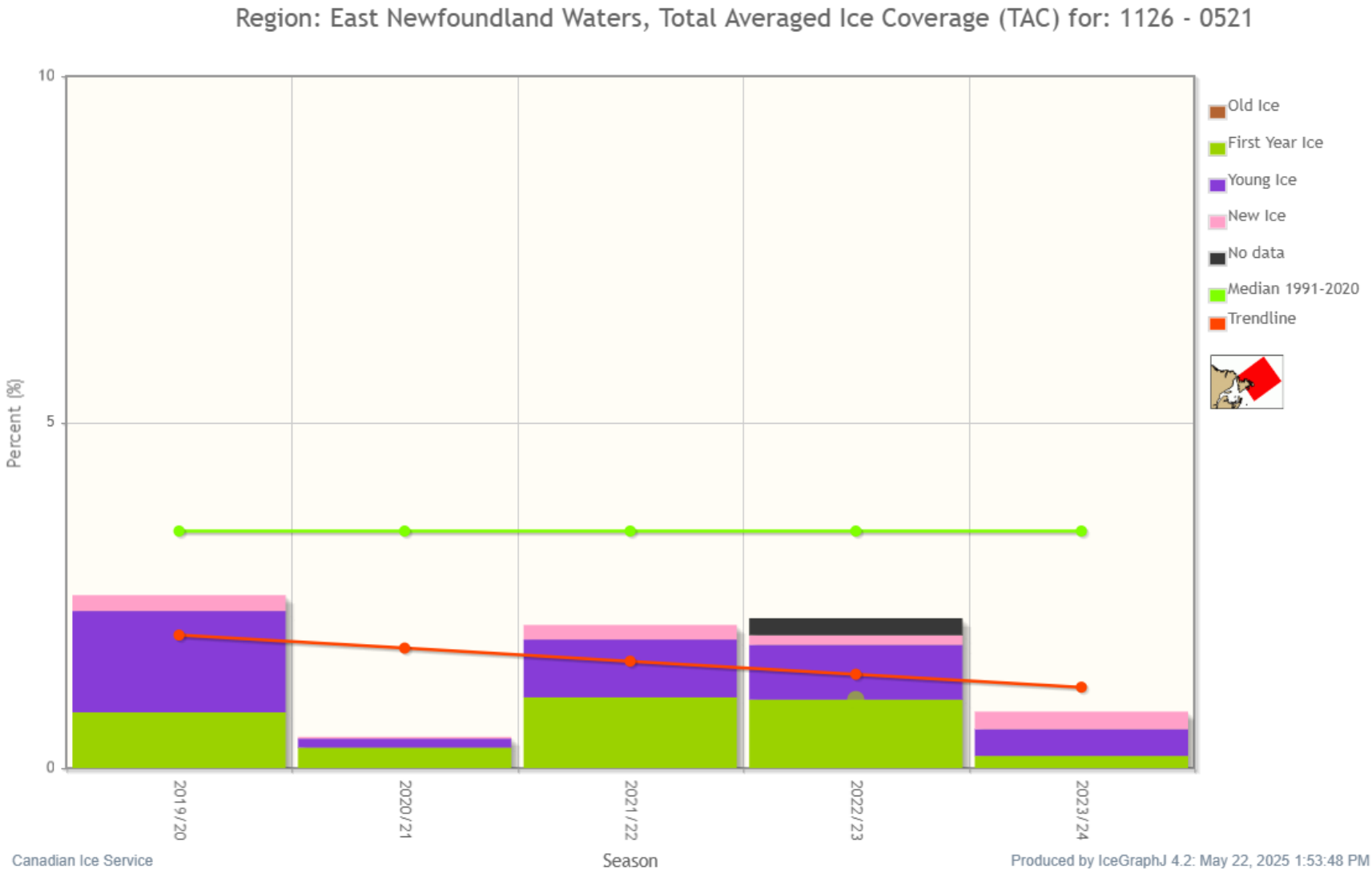
Source: Generated using Canadian Ice Service's IceGraphJ Tool (see CIS 2025).

Figure 3.5. Weekly ice coverage in east Newfoundland waters (see red rectangle in inset for regional extent) for the 2023/2024 season.



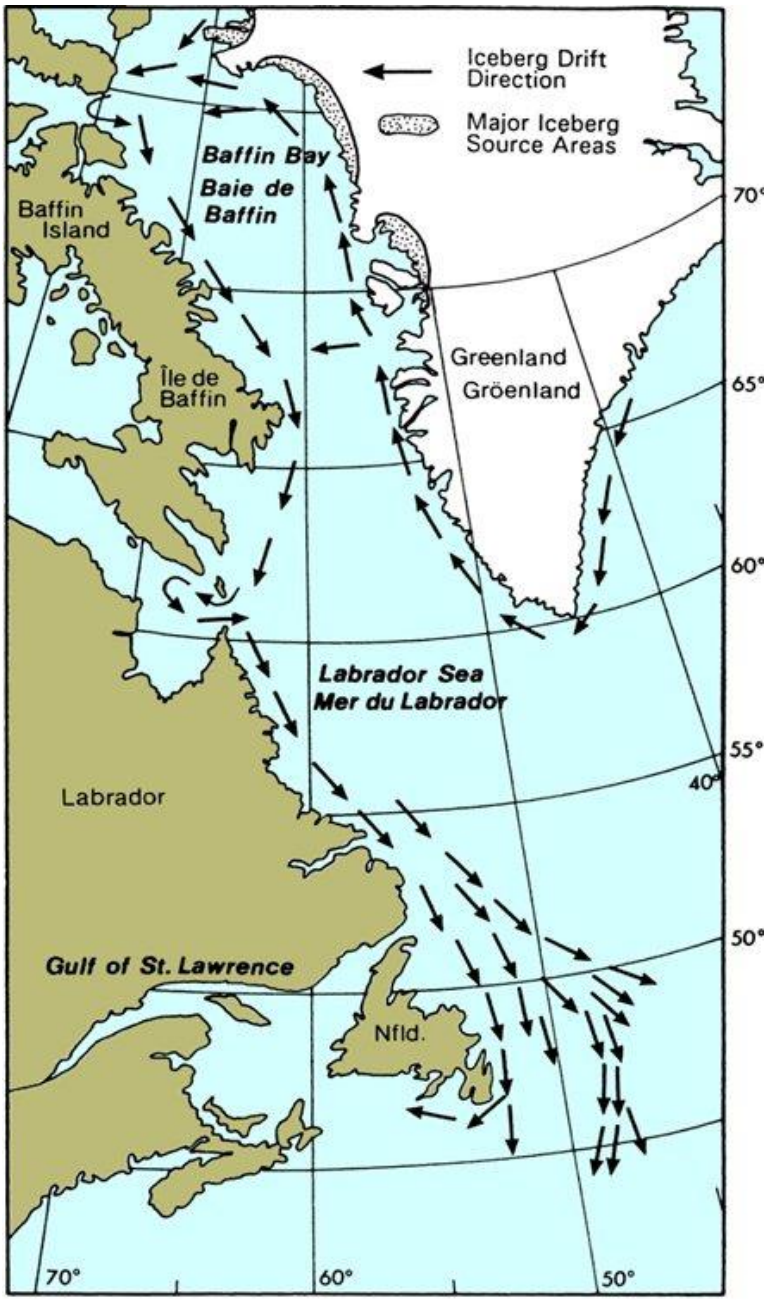
Source: Generated using Canadian Ice Service's IceGraphJ Tool (see CIS 2025).

Figure 3.6. Maximum ice coverage in east Newfoundland waters (see red rectangle in inset for regional extent), 2019–2024.



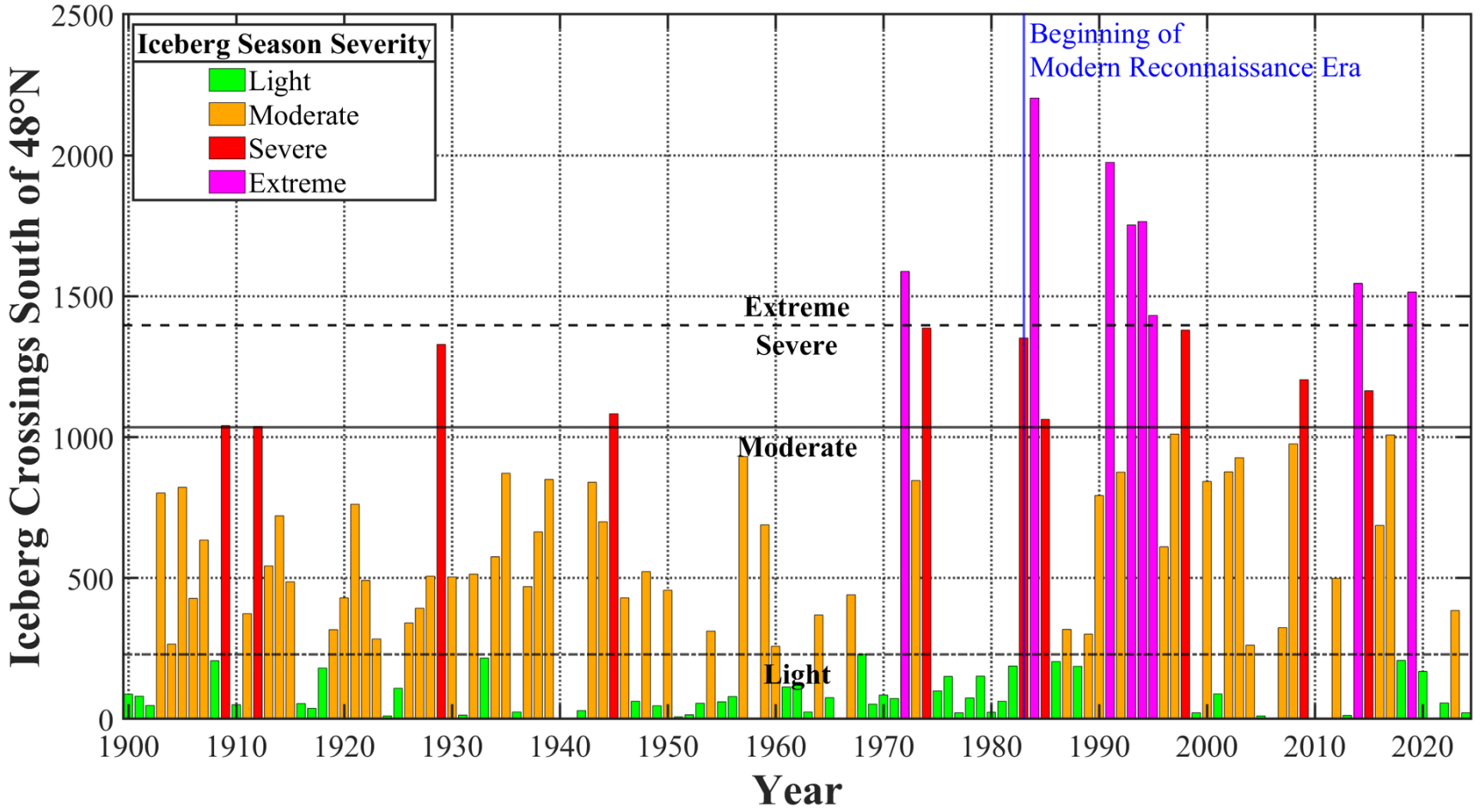
Source: Generated using Canadian Ice Service's IceGraphJ Tool (see CIS 2025).

Figure 3.7. Total averaged ice coverage in east Newfoundland waters (see red rectangle in inset for regional extent), 2019–2024.



Source: Figure 21 in CCG (2022).

Figure 3.8. Primary direction of travel for icebergs calved off west Greenland.



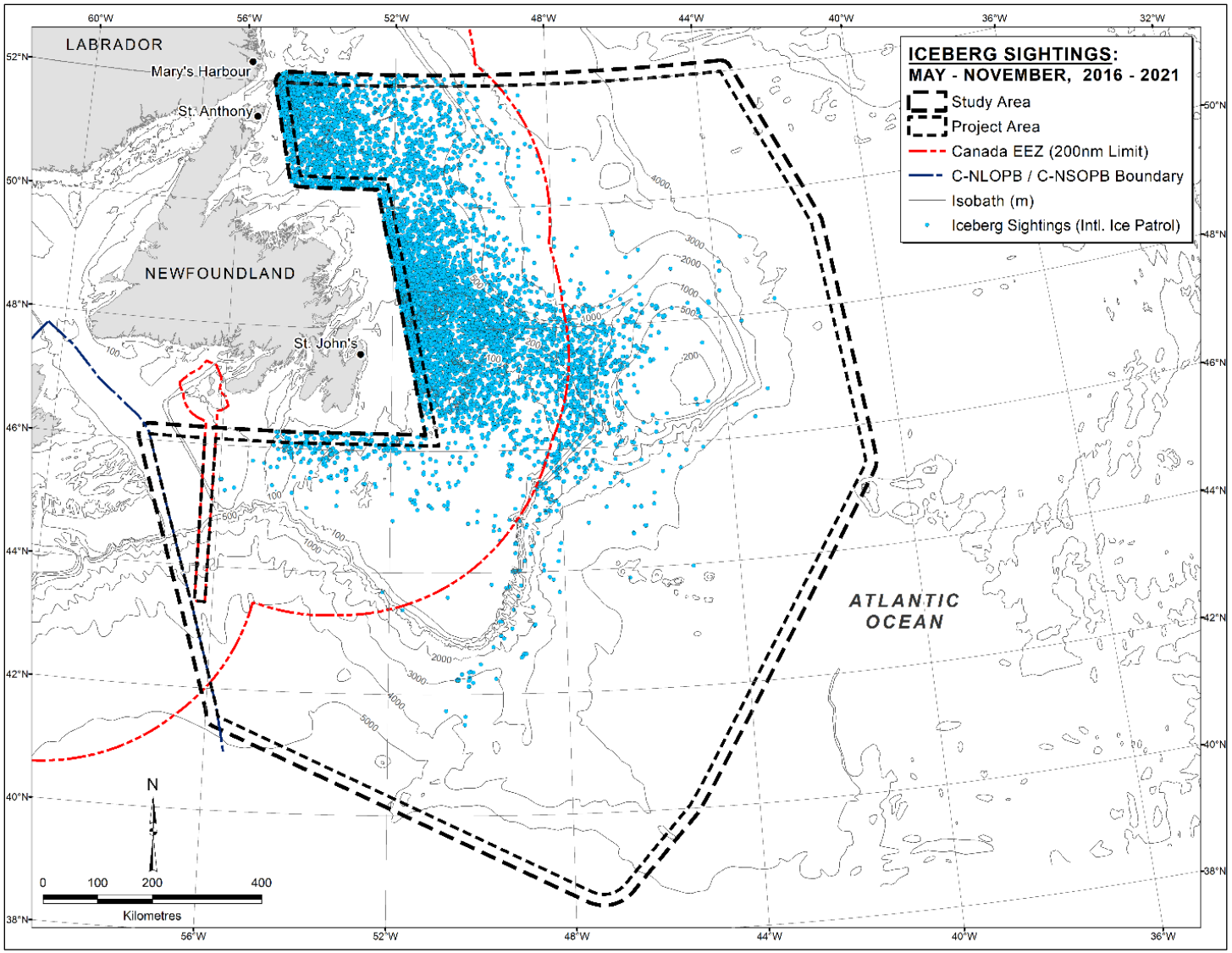
Source: Figure 2.3 in IIP (2024).

Figure 3.9. Annual count of icebergs that crossed south of 48°N around the Grand Banks, 1900–2024.

Table 3.3. Annual and monthly iceberg sightings within the Study Area, 2016–2021.

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
No. Icebergs within the Study Area													
2016		2	3	19	1527	2105	2891	1311	896	71	51	7	**8883**
2017			8	16	160	1060	857	550	110	127	23	16	**2927**
2018	1	7	1	1	104	97	379	674	496	238	61	9	**2068**
2019	1	2		2	433	3129	3620	2687	161	25	8		**10,068**
2020	2				41	428	629	301	75	20	2	6	**1504**
2021	2			3	1	19	69	1	1		1		**97**
Total	**6**	**11**	**12**	**41**	**2266**	**6841**	**8445**	**5524**	**1739**	**481**	**146**	**38**	**27,567**
% of Total	**0.02**	**0.04**	**0.04**	**0.1**	**8.2**	**24.8**	**30.6**	**20.0**	**6.3**	**1.7**	**0.5**	**0.1**	**-**
No. Icebergs that Crossed South of 48ºN (within and beyond Study Area)													
2016	0	0	0	4	26	182	159	199	91	25	1	0	**687**
2017	0	0	0	0	11	282	383	206	99	16	7	4	**1008**
2018	0	0	0	0	3	55	41	47	61	0	1	0	**208**
2019	0	0	0	0	15	390	274	792	44	0	0	0	**1515**
2020	0	0	0	0	1	41	33	76	17	1	0	0	**169**
2021	0	0	0	0	1	0	0	0	0	0	0	0	**1**
2022	0	0	0	0	0	13	36	6	2	0	1	0	**58**
2023	0	0	0	0	0	188	104	16	59	17	1	0	**385**
2024	0	0	0	0	1	1	18	2	0	0	0	0	**22**
Total	**0**	**0**	**0**	**4**	**58**	**1152**	**1048**	**1344**	**373**	**59**	**11**	**4**	**4053**
% of Total	**0.0%**	**0.0%**	**0.0%**	**0.1%**	**1.4%**	**28.4%**	**25.9%**	**33.2%**	**9.2%**	**1.5%**	**0.3%**	**0.1%**	**-**

Source: IPP Iceberg Sightings Database and Annual Reports (NSIDC 2025).



Source: IPP Iceberg Sightings Database (NSIDC 2025).

Figure 3.10. Iceberg sightings in the Study Area, 2016–2021.

4.0 Biological Environment

The biological environment in and near the Study Area has been described in the Southern Newfoundland SEA (C-NLOPB 2010), Eastern Newfoundland SEA (C-NLOPB 2014), IAAC regional drilling EA (IAAC 2020), and a project-specific seismic EA (LGL 2018). In addition to updated information, overviews of relevant new or updated information available since the above reports were published are presented in the following subsections for fish and fish habitat, fisheries, marine-associated birds, marine mammals, sea turtles, species at risk, and sensitive areas. Data gaps identified in the two SEAs (C-NLOPB 2010, 2014) and IAAC (2020) have also been examined for any change in status.

4.1 Ecosystem

An ecosystem is an inter-related complex of physical, chemical, geological, and biological components that can be defined at many different scales from a relatively small area that may only contain one primary habitat type (e.g., a shelf) to a relatively large regional area ecosystem which is topographically and oceanographically complex with shelves, slopes, valleys, and several major water masses and currents (e.g., the NW Atlantic). This EA focuses on components of the ecosystem such as selected species and stages of fish, marine-associated birds, and marine mammals and sea turtles that are important ecologically, economically, and/or socially, with potential to interact with the Project. This is the VC approach (see Section 2.5.1.2) to environmental assessment and this approach is described in Section 5.0. The VCs and/or their respective groups are discussed in the following subsections. The GIS Decision-support Tool has been transitioned from IAAC to C-NLOER and is now titled the IAAC Interactive Assessment Map (IAAC 2024). It has an updated configuration compared to its description in IAAC (2020) and, while there are various new layers available, numerous layers listed in Table 2.5 in IAAC (2020) are no longer available for selection and/or public access. Wherever possible, applicable layers in IAAC (2024) are referenced throughout Section 4.0.

4.2 Fish and Fish Habitat VC

This section provides a description of the new or updated fish/shellfish and fish habitat in the Study Area with emphasis on those species/species group most likely to be affected by Project activities.

4.2.1 Fish Habitat

In this EA, 'fish habitat' includes physical and biological aspects of the marine environment used by macro-invertebrate and fish species in the Study Area. The physical and chemical nature of the water column (i.e., water temperature, depth, salinity) and bottom substrate (i.e., surficial sediment) are critical factors affecting the characterization of associated marine biological communities. Subsection 3.1 of this EA discusses both the bathymetry and the geology of the Study Area. The biological component of fish habitat refers to phytoplankton, zooplankton, and benthos (i.e., infaunal and epibenthic invertebrates, such as polychaetes and echinoderms, not typically harvested during commercial fisheries in the Study Area).

4.2.1.1 Plankton

Plankton is composed of free-floating organisms that form the basis of the pelagic ecosystem. Plankton constituents include bacteria, fungi, phytoplankton, and zooplankton (mostly invertebrates, but may also include eggs and larvae of fishes, known as ichthyoplankton). Plankton in the Study Area was described in Section 3.1.3 in C-NLOPB (2010), Section 4.2.1.3 in C-NLOPB (2014), Section 3.2.1.1 in IAAC (2020), and Section 4.2.1.1 in LGL (2018).

In recent years, the NL Shelf has experienced a shift in its copepod community structure, from larger, more energy-rich species to smaller copepods (Solberg et al. 2025). This can have a rippling effect on higher trophic-level predators in the region that heavily rely on copepod for prey, such as capelin (*Mallotus villosus*), which in turn are keystone species for the marine ecosystem (Solberg et al. 2025). Continuous Plankton Recorder data (1966–2021) indicate that during the day, the Grand Banks portion of the Study Area is predominated by *Temora longicornis*, *Centropages hamatus*, and *Isias clavipes* copepods, while the remainder of the Study Area mainly includes *Calanus finmarchicus*, *Paraeuchaeta norvegica*, *Calanus hyperboreus*, *Calanus glacialis*, and *Metridia longa* copepod species (see Figure 3 in Vilain et al. 2025). At night, owing to diel migration, copepods mainly present on the Grand Banks include *Centropages typicus*, *T. longicornis*, *C. helgolandicus*, *C. hamatus*, and *Candacia armata*, and in the remainder of the Study Area include *C. finmarchicus*, *P. norvegica*, *M. longa*, *C. glacialis*, and *C. hyperboreus*.

A single-dimensional biophysical timing model for the NL Shelf's spring phytoplankton bloom is currently under development as part of the newly emerging biogeochemical modelling group at DFO (Lavoie et al. 2025). The model will incorporate environmental factors (e.g., freshwater transport, sea-ice melt, surface heating, wind-induced mixing) and be used to predict when water column stratification and nutrient distribution will result in annual onsets of the spring phytoplankton bloom, which can vary anywhere from February–April (Lavoie et al. 2025). In 2023, the spring phytoplankton bloom in the NL region started later than normal and the bloom intensities have been lower than normal since 2020 (Cyr and Bélanger 2024). Overall, in recent years (2018–2020), primary and secondary productivity for the Grand Banks and NL region has increased and is closer to that of the pre-early 1990s cod collapse period than it was during 2013–2015 (Wudrick et al. 2024).

The Atlantic Zone Monitoring Program (AZMP) was implemented by DFO in 1998 to better understand, describe, and forecast the state of the marine ecosystem. A critical element of the AZMP is an observation program designed to assess variability in nutrients, phytoplankton, and zooplankton (Galbraith et al. 2024). The most recent AZMP findings in relation to oceanographic conditions in the Study Area for 2023 are summarized below:

- SSTs were the second highest in the recorded series (i.e., since 1982);
- Overall zooplankton biomass declined in recent years, with lower abundances of *C. finmarchicus* and higher abundances of *Pseudocalanus* spp., although a record high of *C. finmarchicus* occurred in 2023;
- Subsurface nitrate inventories (i.e.., amount of nitrate in the mixed layer; 50–150-m depth for the NL Shelf) were higher than normal for the NL Shelf and Grand Bank, although lower than normal in other regions;

- The rates of pH decrease were generally higher for Atlantic Canada compared to elsewhere globally;
- Annual chlorophyll-*a* inventories were near or below normal; and
- Dissolved oxygen saturation was generally high.

Planktonic organisms are so ubiquitous and abundant, and typically have such rapid generation times, that there will be negligible effect on planktonic communities from the proposed seismic program. Therefore, no further assessment of the potential effects of the Project on phytoplankton and zooplankton will be discussed here. However, planktonic stages of commercial invertebrates (e.g., northern shrimp *Pandalus borealis*, snow crab *Chionoecetes opilio*, and fishes (e.g., Atlantic cod *Gadus morhua*) are described in the following subsections because of their VC status.

4.2.1.2 Benthic Invertebrates

Benthic invertebrate communities within the Study Area are described in Section 3.1.4 in C-NLOPB (2010), Section 4.2.1.5 in C-NLOPB (2014), Sections 3.2.1.2–3.2.1.3 in IAAC (2020), and Section 4.2.1.2 in LGL (2018).

An analysis of ecosystem dynamics of the NL Shelf (Northwest Atlantic Fisheries Organization [NAFO] Divisions [Div.] 2J and 3K) following the cod moratorium in the early 1990s indicates a clear transition from an invertebrate-dominated to a groundfish-dominated ecosystem between 1995–2019 (see Figure 2 in Solberg et al. 2025). The shifts were largely noticeable in the eastern offshore portion of the modelled extent starting in 2007 and then progressively more from the south as of 2011 (Solberg et al. 2025). Invertebrate biomass has continuously decreased in Div. 2J and 3K since 2002/2023 (see Figure 4 in Solberg et al. 2025), and overall marine biomass is predicted to decrease in the region due to ocean warming from climate change, as water column stratification increases and primary production is negatively impacted (Solberg et al. 2025).

Benthic invertebrates are bottom-dwelling organisms that can be classified into three categories: (1) infaunal organisms; (2) sessile organisms; and (3) epibenthic species (Barrie et al. 1980). Infaunal organisms live on or are buried in soft substrates and include bivalves, polychaetes, amphipods, sipunculids, ophiuroids, and some gastropods. Sessile organisms live attached to hard substrates and include barnacles, tunicates, bryozoans, holothurians, and some anemones. The epibenthic organisms are active swimmers that remain in close association to the seabed and include mysiids, amphipods, and decapods.

Benthic invertebrate communities can be spatially variable because of variability associated with physical habitat characteristics, such as water depth, substrate type, currents, and sedimentation. The primary factors affecting the structure and function of such communities in high latitude communities are water mass differences, sediment characteristics, and ice scour (Carey 1991). The wide range of these characteristics within the Study Area ensures a variety of benthic communities. The structure and metabolism of benthic communities can also be directly affected by the rate of sedimentation of organic detritus in shelf and deeper waters (Desrosiers et al. 2000). The seasonality of phytoplankton can influence production in benthic communities, adding temporal variability to a highly heterogeneous community.

Several recent studies have contributed to the characterization of benthic communities on the Grand Banks (e.g., Gullage 2022 – see Deep-water Corals and Sponges below). Using Hierarchical Modelling, Murillo (2020) indicated that the Flemish Cap's shallower portion (<500 m depth) has benthic invertebrate communities that are dominated by small- and medium-sized species with short lifespans. Deeper portions (500–1500 m) are characterized by communities with larger species and longer lifespans, many of which use broadcast spawning (Murillo et al. 2020). In marine ecosystems, sediment bioturbation is crucial for nutrient exchange and biogeochemical cycles. According to kernel density estimates, the Flemish Cap's northern, northwestern, and northeastern slopes contain the highest biomass of bioturbating benthic invertebrates (Kenchington et al. 2020).

DFO Research Vessel (RV) trawl survey catches are often dominated by relatively large taxa, such as sponges, anemones, shrimp, crab, and urchins. Other taxa typically include echinoids such as sand dollars, sea stars, brittle stars, and basket stars (see Section 4.3.7). During the 2023–2024 fall and spring DFO RV surveys in Div. 3LNO (mean depths 39–1401 m), ascidian tunicates (*Boltenia* sp.) were observed in ~6% of tows at mean depths of 50–223 m, and two high concentrations (≥0.35 kg/tow) of sea squirts occurred in similar areas (NAFO 2024). Bryozoans were recorded in ~25% of the analyzed tows (mean depth 39–670 m), including one relatively high catch (≥0.2 kg/tow; NAFO 2024). NAFO Working Group discussions have been underway since 2021 to determine methodology for improving data accessibility and discoverability, by ultimately uploading annual RV data to a central data access system, such an ArcGIS Online data repository (NAFO 2024).

It is important to note that beyond the Canadian 200 nm limit, excluding the Nose and Tail of the Grand Banks, the Flemish Pass, and the Flemish Cap, there is a substantial deficiency in data related to the benthos. The information presented in this subsection mainly pertains to studies completed on the continental shelf and slope of the Study Area.

Deep-water Corals and Sponges

Deep-water corals and sponges in the Study Area are described in Section 3.1.4 in C-NLOPB (2010), Section 4.2.1.45 in C-NLOPB (2014), Section 3.2.1.3 in IAAC (2020), and Section 4.2.1.2 in LGL (2018). The Coral Bleaching Alert Level layer in IAAC (2024) provides a visual of daily updates for potential risk levels of coral bleaching heat stress on a global scale. During May 2025, risk levels within the Study Area ranged from bleaching warning (alert level 2) to bleaching alert level 1–2 (alert levels 3–4).

A variety of coral groups occur in Newfoundland waters, with over 160 species of corals and sponges observed to date (Gullage et al. 2022). These include scleractinians (solitary stony corals), antipatharians (black wire corals), alcyonaceans (large and small gorgonians, soft corals), and pennatulaceans (sea pens; Wareham and Edinger 2007; Wareham 2009). Lirette et al. (2021) review of closure areas to protect Vulnerable Marine Ecosystems (VMEs) using RV survey data collected during 1995–2019 to provide biomass estimates for large-sized sponges, black corals, large and small gorgonian corals, sea pens, sea squirts (*Boltenia ovifera*), and erect bryozoans. The highest sponge and coral biomasses within the NAFO footprint (see Section 4.3.3) were predicted to occur around the Flemish Cap and edges of the southern Grand Banks. Murillo et al. (2024) updated distribution models for large-sized sponges, sea pens, and black corals within the NAFO Regulatory Area. The updated

predicted distribution agreed, with most of the predicted presence occurring around the Flemish Cap, Flemish Pass, and slope edge (see Figures 4–5, 8–10, 13–15, 18–20, 23–25, 28–30, 33–35, 38–40, 43–45, 48–50, and 53–55 in Murillo et al. 2024).

Gullage (2022) mapped the general distribution of coral (large and small gorgonians, sea pens, soft corals, cup corals, black corals) and sponge species using a compilation of data from multiple surveys (NSRF surveys [2005–2018]; DFO RV trawl surveys [NL, 1995–2019] and Central and Arctic regions [2006–2017]; historical DFO research surveys [1948–1994]; and EU-Spain Bottom Trawl Surveys [2002–2013]), which were carried out using various types of gear. Although it is acknowledged that these distribution generalizations are broad, this approach was considered necessary to acquire adequate data regarding species that have otherwise been underrepresented in the literature (Gullage et al. 2022). Generally, large gorgonians, small gorgonians, sea pens, cup corals, and black corals have a broad distribution, extending along the edges of the continental shelf, channels, and canyons (see Figures 2–4 and 6–7 in Gullage et al. 2022). Soft corals occupy a broader spatial distribution and are found across much of the continental shelf with a nearly continuous distribution along the shelf edge, likely due to their high tolerance for temperature ranges (Gullage et al. 2022). Black corals have been observed less frequently in DFO-NL trawl surveys compared to other groups (Gullage et al. 2022). The most observed species in the region has been *Stauropathes arctica*, but five additional black coral species were recorded during a 2010 ROV survey of the Flemish cap and Orphan Knoll in water depths >1,500 m (Gullage et al. 2022). On the Orphan knoll, ROV surveys indicate that cold-water corals mainly colonize the mounds (Meredyk et al. 2020). With some unique exceptions (e.g., the gorgonian coral *Corallium niobe* [found on the Southeast Orphan Knoll mounds] and the scleractinian *Caryophyllia ambrosia*), the coral fauna on the Orphan Knoll is generally like species assemblages elsewhere offshore Newfoundland (Meredyk et al. 2020).

Sponges, large gorgonians, small gorgonians (including *Radiceipes* sp. and *Acanella arbuscula*), sea pens (including *Anthoptilum* sp.), and black corals were observed during tows conducted in Div. 3L (Flemish Pass)/3M (Flemish Cap)/3NO (Grand Banks) for the EU-Spain and Portugal EU-Spain 2024 Groundfish Surveys (NAFO 2024). In 2024, Equinor Canada released an Environmental Seabed Survey Program report for seabed surveys conducted in 2023 at their Sitka (~850-m depth) and Cappahayden (~900-m depth) sites (NAFO 2024). The substrate at both locations was fine and sea pens (highest abundance of observed corals and sponges), small gorgonians, soft corals, cup corals and sponges were observed, but not large gorgonians or black corals (NAFO 2024). A 2024 3O closure drop camera survey was conducted by DFO, in which sea pens and cup corals were frequently observed, along with brittle stars. Full analysis of the collected video is planned for 2025 (NAFO 2024).

Trawl data is known to have observation bias to locations in which trawling is possible; hence, there is limited knowledge about the distribution and biomass of species in areas of hard substrates, vertical rock walls, shallower waters, and waters deeper than 1,500 m (Gullage et al. 2022). Specimens are often damaged (e.g., fragmented) upon collection, resulting in difficulty obtaining reliable abundance and biomass records for some taxa (e.g., gorgonians; Gullage et al. 2022). Stable isotope carbon and nitrogen analyses from a submarine canyon wall off NS (~450-m depth) revealed the occurrence of resource partitioning between deep-water corals, sponges, ascidians, and anemones, with gorgonian and soft corals distributed along the cliff wall with the lowest relative measured carbon and nitrogen

isotope concentrations, sponges distributed where concentrations were highest, and anemones and ascidians somewhere in between (see Figure 3 in Greenman et al. 2025).

Areas of high coral species richness have been positively correlated with areas of high fish species richness (Gullage et al. 2022). Diverse species (e.g., fish, crustaceans, mollusks, echinoderms, cnidarians, polychaetes) associate with corals and sponges in the Newfoundland region for feeding, resting, predator avoidance, or as nurseries for juvenile fish and invertebrates (Gullage et al. 2022). Sponges also provide significant deep-sea habitat and enhance species richness and diversity, supporting increased biodiversity compared to structurally complex abiotic habitats or habitats that do not contain these organisms (Beazley et al. 2013). Siliceous hexactinelid sponges can form reefs as their glass spicules fuse together and when the sponge dies, the skeleton remains. Organisms commonly associated with sponges and sponge grounds include polychaetes and bryozoans, as well as fauna of higher trophic levels. A wide range of bacteria also find a home in the skeleton, tissue, and mucus of some sponge and coral species (Gullage et al. 2022). Long-term monitoring (30-min intervals, 2021–2023) at the Sambro Bank Conservation Area indicated sponge grounds there were serving as nursery, feeding, and shelter habitats for commercially important fish species, including redfish, hakes (De Clippelle et al. 2025). Diel and seasonal use patterns were observed, and environmental factors (e.g., food availability, sponge density, current speed) were found to influence the abundance and behaviour of fish using sponge habitats (De Clippelle et al. 2025).

Various sea pen species (e.g., *Pennatula aculeata*) have been observed completely withdrawing into the seafloor sediment, possibly in response to changing water currents (e.g., tides) or increased water turbidity, depending on location (NAFO 2024). Machine learning (RootPainter) and web annotation (BIIGLE) tools were recently used to analyze the presence of and withdrawal periods of sea pens from time series photos acquired in The Gully off NS. This novel methodology allowed for relatively rapid data analyses, which is a step forward towards closing presence/absence and in some cases, behavioural coral/sponge data gaps as a reasonably fast and budget-friendly data analysis option and will be published in a DFO report (NAFO 2024). The use of environmental DNA (eDNA) was recently explored as a possible option to conduct community-wide metabarcoding to evaluate faunal diversity on North Atlantic (Northeastern Atlantic, Davis Strait, Orphan Knoll) sponge grounds (Gallego et al. 2024). Preliminary evaluations yielded "unprecedented levels of taxonomic diversity per unit effort", including at least 406 marine multicellular (i.e., metazoan) species, indices of latitude- and depth-related spatial patterns, and detection of species currently identified as indicators for vulnerable marine habitats (Gallego et al. 2024).

Since 2008, the NAFO Scientific Council has been identifying various areas of significant coral and sponge concentrations within the NAFO Regulatory Area (NAFO 2024). Areas that have been closed to fishing with bottom gear are shown in Section 4.8 of this EA. DFO has not yet updated their 2015 *Coral and Sponge Conservation Strategy for Eastern Canada* (DFO 2015a). The Strategy includes discussion of the status of coral and sponge conservation in Eastern Canada, research on corals and sponges in Eastern Canada, and other aspects of corals and sponges in both Canadian and international contexts.

4.2.2 Fish

For the purposes of this EA, 'fish' includes macro-invertebrates (shellfish) that are targeted in the commercial fisheries and all fishes, either targeted in the commercial fisheries or otherwise. The focus is on key commercially- and ecologically-important fishes.

4.2.2.1 Principal Macro-invertebrates and Fishes Commercially Harvested

This section describes the principal macroinvertebrate and fish species that are typically harvested in the Study Area during commercial fisheries. These include both targeted species (e.g., snow crab, northern shrimp, and Greenland halibut *Reinhardtius hippoglossoides*) and other species caught incidentally (e.g., wolffishes *Anarhichas* spp.).

Snow crab, Atlantic halibut, Atlantic cod, northern shrimp, Greenland halibut, redfish, and yellowtail flounder have dominated directed commercial fishery landings for the Study Area in recent years. Some of the 'incidental catch' species and key ecologically important fishes are also discussed in this subsection.

Macroinvertebrates

Snow Crab

Aspects of snow crab life history, including information on distribution, are discussed in Section 3.2.1.1 in C-NLOPB (2010) and Section 4.2.1.5 in C-NLOPB (2014). Snow crab are also discussed in Sections 3.2.1.2, 3.3.1.1, and 5.1.1 in IAAC (2020).

Since reaching a 25-year low of 26,400 t in 2019, snow crab landings in NAFO Div. 2HJ + 3KLNOPs + 4R have been increasing, reaching nearly 50,000 t in 2022 (see Figure 2 in DFO 2023b). In terms of catch weight, most harvests occur off northeastern and southeastern Newfoundland, on the northern Grand Banks, and in the Flemish Pass (see Figure 3 in DFO 2023b). Following a ~20-year low in 2020, overall effort has increased, reaching ~3.4 million trap hauls in 2022 (DFO 2023b). Similarly, following a time-series low in 2018, catch per unit effort (CPUE) neared the time series high in 2022 (nearly 14 kg/trap; DFO 2023b). The overall exploitable biomass has recently returned to nearly the long-term average following historic lows in 2016–2018 and snow crab offshore NL were expected to be in the healthy zone for 2023, except 2HJ which was expected to be in the cautious zone (DFO 2023b).

During 2024, 56,133 mt of snow crab worth a total value of $ 436,271,366 were landed for the NL Region (DFO 2024a). The Total Allowable Catch (TAC) for the NL Region in 2025 is 62,883 t, an overall increase of 9% from 2024 (DFO 2025a).

There is one fishery closure area that occurs within the Project Area: Funk Island Deep (see Figure 4.40). This closure area was created in part to offer protection to important habitat for snow crab (DFO 2020a).

Northern Shrimp

Aspects of northern shrimp life history, including information on distribution, are discussed in Section 3.1.4.1 in C-NLOPB (2010) and Section 4.2.1.5 in C-NLOPB (2014). Northern shrimp are also briefly discussed in Sections 3.3.1.1 and 5.1.1 in IAAC (2020).

Recent stock structure modelling of northern shrimp from Baffin Island to the Grand Banks indicated peak densities along slope edges in water depths ~250–300 m, decreased presence of males with increasing depth, and maximum female body length in water depths >400 m and in the northern portion of the analysed range (Baker et al. 2025). Although currently considered a single biological unit, modelling suggests the existence of north and south clusters with the demarcation occurring off Labrador, in the central portion of Shrimp Fishing Area (SFA) 5 (see Figure 6 in Baker et al. 2025).

Northern shrimp biomass in SFA 6 is in the critical zone as of 2023, remaining at near time-series lows since 2016 (DFO 2024b). Approximately 40% of the 2023/2024 TAC was not caught and large-vessel CPUE was below the long-term mean, continuing a declining trend observed since 2020 (DFO 2024b).

During 2024, a total landing of 27,213 mt was reported for the NL Region, valued at $ 133,981,491 (DFO 2024a). The 2025/2026 TAC for SFA 6, which includes the northern portion of the Study Area, increased by 50% from 2024/2025, from 8909 t to 13,363 t (DFO 2025a). The defined shrimp closure areas in Div. 3LM remain in effect for 2025 (NAFO 2025a; see Section 4.8).

Cockles

Greenland cockle (*Serripes groenlandicus*) is a polar to temperate species that inhabits various substrate types (silt, sand, clay, mud, gravel, pebble) in depths up to 100–125 m within the Study Area (Rosenberg 2009; Caroll 2011; Gerasimova et al. 2019; FishBase 2023; OCAC 2023). As of 2019, the Grand Bank hosts an estimated stock size of 51,819 t (DFO 2022a). Greenland cockle generally exhibit relatively low densities, usually ≤30 ind. m^{-2} (Gerasimova et al. 2019). Surveys conducted during 2006, 2008, and 2009 indicated that the highest biomass was present along the Grand Bank's eastern edge (Roddick et al. 2011).

The maximum known age and size for Greenland cockle on the Grand Bank is 39 years and 93.3 mm (DFO 2022a). This hermaphroditic, sedentary cockle utilizes broadcast spawning for reproduction (DFO 2022a). Kilada et al. (2007) determined the minimum size and age at sexual maturity for Greenland cockles collected from the Grand Bank and Banquereau Bank were ~27.9 mm and 2.8 years for male tissues and ~37.2 mm and 3.7 years for female tissues. Their embryos develop into free-swimming, planktonic larvae before transitioning to their benthic life stage in the form of miniature adults (FishBase 2023), likely during late summer (Christian et al. 2010).

Greenland cockle is a suspension/filter-feeder (Denisenko et al. 2003; Amiraux et al. 2021). As it generally only burrows ≤7 cm into the surficial sediment, it employs escape behaviour to avoid predation by sea stars (particularly *Leptasterias polaris* and *Asterias rubens*), demersal fish (e.g., cod, haddock), and marine mammals (e.g., seals; Christian et al. 2010). Empty shells of deceased Greenland

cockle that remain submerged in the substrate have been found to provide structural habitat for epibiota (Yakovis and Artemieva 2017).

Greenland cockle have been variably landed in offshore commercial clam fisheries on the Grand Bank since 1994, but as the market is currently under development, historical fishing activity is not considered representative of potential future fishing efforts (DFO 2022a). During 1994–2020, Greenland cockle landings on the Grand Bank averaged ~748 t (range: 0.4 to ~3674 t), with zero landings during some years (DFO 2022a). Presently, there is an unlimited bycatch set for Greenland cockles in the region's offshore Stimpson's (i.e., Arctic) surf clam fishery (OCAC 2023).

Stimpson's Surf Clam

Life history aspects of the Stimpson's surf clam are provided in Section 3.1.4.1 in C-NLOPB (2010).

The fishery for Stimpson's surf clam was established in 1986 and takes place on sandy substrates on Banquereau Bank and the Grand Bank (i.e., NAFO Div. 3LNO), typically in water depths of 50–110 m using factory freezer fishing vessels equipped with hydraulic clam dredges (DFO 2024c). In 2023, there were three licences and three vessels that participated in this fishery (DFO 2024c). The stock, which does not have a high exploitation rate, is in in the healthy zone (DFO 2024c).

During 2023, Stimpson's surf clam landings in the Maritime Fishery Information System (MARFIS) and NL Catch and Effort databases were 14,796 t, representing 100% of the TAC for the Grand Bank (DFO 2024c). During 2025, the TAC for the Grand Bank remains unchanged from previous years, at 14,756 t (DFO 2025a).

Fishes

Greenland Halibut (Turbot)

Life history aspects of Greenland halibut, including distribution information, are presented in Section 3.2.1.2 in C-NLOPB (2010), Section 4.2.1.6 in C-NLOPB (2014). Greenland halibut are also briefly discussed in Sections 3.3.1.1 and 3.3.1.5 in IAAC (2020).

Fixed gear Greenland halibut fisheries for NAFO Div. 2GHJ3K and 3LMNO are restricted to inshore groundfish licence holders whose vessels are <27.4 m with homeports in NAFO Div. 2GHJ3KL, while groundfish licence holders in NAFO Div. 4R may participate but only within NAFO Subarea 2 (DFO 2025a). There are various gear placement restrictions and catch limitations for the fixed gear fishery for this species, including permit requirements and fish size and by-catch protocols (DFO 2025a). The opening dates of the fixed gear Greenland halibut fisheries are decided annually in consultation with Greenland Halibut Working Groups (DFO 2025a).

The mobile groundfish fishery in NAFO Subarea 2 and Div. 3KLMNO include provisions for Greenland halibut (DFO 2025a). This fishery is open to inshore groundfish licence holders with vessels <27.4 m in length and a homeport in NAFO Div. 2GHJ3KL. Catch quotas for Greenland halibut in the mobile fishery vary annually based on random draws for eligible fishers that hold the necessary

permit. Otherwise, like the fixed gear fishery, there are various gear and catch limitations and size and by-catch protocols. During 2025, the mobile Area 2 + Div. 3KLMNO Greenland halibut fishery season was designated to run from 15 May–31 December, providing ice conditions allow (DFO 2025a).

For all fleets and NAFO Div. in the NL Region combined, a total of 9922 t of Greenland halibut worth $ 56,660,425 were landed during the 2024 season (DFO 2024a). The 2025 TAC for Greenland halibut in NAFO Div. 3LMNO is 10,960 t (NAFO 2025a).

Atlantic Halibut

Life history aspects of Atlantic halibut (*Hippoglossus hippoglossus*), including distribution information, are presented in Section 3.2.1.2 in C-NLOPB (2010) and Section 4.2.1.2 and 4.2.1.5 in C-NLOPB (2014). Atlantic halibut is also mentioned in Section 3.3.1.3 in IAAC (2020).

In 1988, an initial TAC of 3,200 t was first established in response to an 8-year decline in landings and was subsequently reduced to a low of 850 t in 1995. The TAC since peaked at 5507 t in 2020, after which it decreased somewhat (DFO 2023c). The TAC for 2022 was set at 4807 t (DFO 2023c). During 2024, 1041 mt of halibut were landed in the NL Region, for an estimated total landed value of $10,393,656 (DFO 2024a).

Atlantic Cod

Life history aspects of Atlantic cod, including distribution information, are presented in Section 3.2.1.2 in C-NLOPB (2010), and Section 4.2.1.6 in C-NLOPB (2014). Atlantic cod are also discussed in Sections 3.2.1.4, 3.3.1.1, and 3.3.1.5 in IAAC (2020).

The relative spawning stock biomass for Atlantic cod in NAFO Div. 3Ps has consistently been in the critical zone since 2000 (see Figure 8 in DFO 2024d). Estimated recruitment for the stock has been below the median (1959–2022) since 1992–1993 and natural mortality has been notably impacted by poor fish condition (e.g., death due to starvation, higher susceptibility to predation/parasites, poor swimming performance, decreased competitive ability; see Figure 9 in DFO 2024d). Bottom-up effects due to climate change, including ocean warming, decreasing dissolved oxygen and pH, and decreased prey availability (e.g., capelin), are major factors influencing the high natural morality of cod in the region (DFO 2024d). Predation by seals is not considered a primary factor driving stock dynamics for cod off southern Newfoundland DFO 2024d). Mortality due to fishing is currently low, estimated at 0.02 for age 5–8 fish during 2022 (DFO 2024d). A rebuilding plan was implemented in 2023 with a goal of rebuilding the stock within 25 years (DFO 2024d).

During 2024, 16,147 mt of Atlantic cod worth a total $30,466,402 were landed in the NL Region (DFO 2024a). The fishing ban for Atlantic cod has remained in place for Div. 3NO (NAFO 2025a). The TAC for Atlantic cod in NAFO Div. 3Ps is 1251 t for 2025 (DFO 2025a).

American Plaice

Life history aspects of American plaice (*Hippoglossoides platessoides*), including distribution information, are presented in Section 3.7.1 in C-NLOPB (2010) and Section 4.2.1.6 in C-NLOPB (2014). American plaice are also mentioned in Section 3.3.1.1 in IAAC (2020).

The abundance and biomass of American plaice in NAFO Subarea 2 and Div. 3K declined drastically from the 1980s to 2000s, showed a minor increase in 2013, and has since declined again (DFO 2021a). Following a seven-year period of at or above average recruitment (2011–2018, except 2016), the recruitment index decreased to 74% of the long-term mean during 2019 (DFO 2021a). Spawning stock biomass significantly decreased during 1982–2005 and increased slightly thereafter, to 15% of the average from 1978–1982; no aging data have been available since 2012 (DFO 2021a). Bycatch of American plaice primarily occurs during the Greenland halibut trawl fishery (DFO 2021a). Overall, the stock status is considered in the critical zone (DFO 2021a) and the moratorium on directed catch of American plaice in NAFO Div. 3LMNO that was declared in 1994 remains in place (NAFO 2025a).

Yellowtail Flounder

Life history aspects of yellowtail flounder (*Pleuronectes ferruginea*), including distribution information, are presented in Section 3.2.1.2 in C-NLOPB (2010) and Section 4.2.1.6 in C-NLOPB (2014). Yellowtail flounder are also mentioned in Sections 3.2.1.4, 3.3.1.1, and 3.3.1.5 in IAAC (2020).

In 2024, the NL Region landed a total of 3,008 mt for all flounders combined, valued at $ 5,434,770 (DFO 2024a). The TAC for yellowtail flounder in NAFO Div. 3LNO has been decreasing in recent years, down to 15,810 t in 2025 (NAFO 2025a).

White Hake

Life history aspects of white hake (*Urophycis tenuis*) are presented in Section 3.2.1.2 in C-NLOPB (2010) and Section 4.2.1.6 in C-NLOPB (2014). White hake are also mentioned in Sections 3.2.1.4 and 3.3.2 in IAAC (2020).

Within the Study Area, white hake inhabits soft, muddy bottoms of the continental shelf and upper slope in depths up to ~180 m (DFO 2016a; FishBase 2023). Larger individuals typically occupy deeper waters than juveniles, which generally inhabit nearshore, shallow bank habitats (GC 2025). Population estimates for white hake in Div. 3Ps averaged 7.6 million in 1996–2016, during which time biomass estimates averaged 5737 t (DFO 2019a). During 2017, the abundance and biomass indices were 7.1 million and 4848 t, respectively (DFO 2019a). Abundance and biomass estimates in 2009–2013 for Div. 3Pn were 1.6 million and 720 t (DFO 2019a).

White hake can potentially produce millions of eggs per spawner, with spawning suspected to occur during spring or summer. Their eggs are buoyant and remain in the upper water layer where they undergo dispersion via ocean currents. Demersal juveniles are known to utilize estuaries and eelgrass as nursery habitats (DFO 2016a). There are indications of ongoing ecosystem structural changes for white hake habitat in Div. 3Ps, along with low productivity indices (DFO 2019a). There is uncertainty

regarding the specific impacts of such changes on the life stages of white hake (i.e., bottom-dwelling juveniles and adults, pelagic eggs, and larvae), but there may be implications for at least some aspects of white hake productivity (DFO 2019a).

During 2024, a total of 147 mt of white hake were landed in the NL Region, for a total value of $191,427 (DFO 2024a). The TAC for white hake in NAFO Div. 3NO was set at 1,000 t for 2025, unchanged in recent years (NAFO 2025a).

Redfish

Life history aspects of redfish, including distribution information, are presented in Section 3.2.1.2 in C-NLOPB (2010) and Section 4.2.1.6 in C-NLOPB (2014). Redfish are also discussed in Sections 3.2.1.4, 3.3.1.1, and 3.3.1.5 in IAAC (2020).

In 1995, a temporary moratorium was enacted for the redfish fishery due to diminished stock abundance and poor recruitment (DFO 2025b). Strong cohorts in 2011–2013 increased stock biomass, but there has not been a strong cohort observed since 2013 (DFO 2025b). In 2024, the spawning stock biomass for deepwater redfish (*Sebastes mentella*) was 1737 kt and was considered in the healthy zone using a precautionary approach (DFO 2025b). The spawning stock biomass of Acadian redfish (*S. fasciatus*) was estimated at 190 kt, also considered in the healthy zone (DFO 2025b). Although still among time series highs, biomass for Unit 1 deepwater redfish >22 cm in length has notably decreased in recent years, while that of Unit 2 seems to be within time series highs (DFO 2025b). The biomass of Unit 1 Acadian redfish has been relatively steady and somewhat above average in recent years, while those >22 cm in Unit 2 decreased from 2016–2018 and have remained around the 2018 levels which are below the time series average (DFO 2025b).

During 2024, a total of 4639 mt of redfish were landed in the NL Region, valued at $3,385,418 (DFO 2024a). For the 2025 season, the following TACs apply: Div. 3NL = 6000 t; 3M = 17,503 t; and 3O = 20,000 t (NAFO 2025a). For the 2024–2025 season, the TAC for redfish in Unit 1 is 3365.04 t for the NL fleet (DFO 2025a).

4.2.2.2 Other Fishes of Note

Capelin

Life history aspects of capelin, including distribution information, are presented in Section 3.2.2.3 in C-NLOPB (2010) and Section 4.2.1.6 in C-NLOPB (2014). Capelin are also discussed in Section 3.2.1.4 in IAAC (2020).

Oceana Canada, a non-profit organization dedicated to ocean conservation, recently conducted research that suggests capelin is currently critically depleted and overfished (Jubinville et al. 2022). Available data indicates that capelin abundance in NAFO Div. 2J3KL have continued to exhibit low biomass in the past several decades and there is a chance it may be in the critical zone for 2024 as it experiences "delayed spawning, early maturation, and age-truncated population structure" (DFO 2024e).

Recent modelling (2018–2021) for northeastern Newfoundland indicated that the densities of larval capelin increase in positive correlation to zooplankton prey biomass but are not affected by predator biomass or temperature (Tripp et al. 2024). Although capelin spawning habitat shifts between warm, intertidal waters in cooler years to cool, subtidal (15–40-m water depth) in warmer years, Tripp et al. (2024) suggest that such shifts likely have minimal impact on stock recovery in comparison to year-specific conditions that directly affect larval conditions (e.g., food availability).

In 2024, a total 16,126 mt of capelin valued at $8,077,408 were landed in the NL Region (DFO 2024a). The TAC for Div. 4RST in 2025 is set at 10,225 t (DFO 2025a) and for 2024 was 6146 mt for Div. 3KL in 2024 (DFO 2024a). A moratorium remains in effect for Div. 3NO (NAFO 2025a).

Wolffishes

Three species of wolffish (i.e., northern *Anarhichas denticulatus*, spotted *A. minor*, and Atlantic [striped] *A. lupus*) are listed on Schedule 1 of SARA. Northern and spotted wolffishes are listed/designated as *Threatened* under Schedule 1 of SARA and by COSEWIC. Atlantic wolffish has *Special Concern* status under Schedule 1 of SARA and COSEWIC (see Section 4.7).

Profiles for northern and spotted wolffishes are presented in Section 3.7.1.2 in C-NLOPB (2010), Section 4.2.1.6 in C-NLOPB (2014), and Section 4.6 of LGL (2018). Wolffish are also discussed in Section 3.2.1.5 in IAAC (2020). DFO RV data collected in the Study Area during May–November 2018–2023 indicated that northern and spotted wolffishes were mainly caught in water depths between 200–1000 m throughout the Study Area, and Atlantic wolffish were caught in the shelf and slope areas of the southern, central, and northwestern portions of the Study Area (see Section 4.3.7).

Swordfish

Life history aspects of swordfish (*Xiphias gladius*) are presented in Section 3.2.1.2 of the Southern Newfoundland SEA (C-NLOPB 2010). Swordfish are also discussed in Sections 3.1.2.4, 3.2.1.5, 3.3.1.1, 3.3.1.2, and 3.3.2 in IAAC (2020).

Since swordfish is such a highly migratory species that occurs in many different regions of the world, they are managed by an international body, the International Commission for the Conservation of Atlantic Tunas (ICCAT). ICCAT establishes quotas, although the fisheries are well-managed, there are issues regarding bycatch in the pelagic longline fishery. Since 2000, DFO has overseen international Canadian transfer processes with the objective of enhancing access to this fishery for Indigenous groups (ICCAT 2022). The revenue generated from this fishery can support small indigenous communities that may otherwise experience economic hardships (ICCAT 2022).

Canada's 2024 allocation of North Atlantic Swordfish was 1880 t (ICCAT 2024). During 2018–2023, the number of swordfish catches within the Study Area recorded in DFO's commercial fisheries database variably ranged between 59–205 per year (see Tables 4.3–4.8 below).

Anadromous Fishes

The predominant anadromous fish species that occurs within the Study Area is Atlantic salmon (*Salmo salar*). Section 3.2.2.8 in C-NLOPB (2010) provides details regarding Atlantic salmon populations that occur in the southern portion of the Study Area; see also Section 4.6 of LGL (2018). Atlantic salmon are also discussed in Section 3.2.1 in IAAC (2020).

As indicated in Section 3.2.2.8 in C-NLOPB (2010), "The two Atlantic salmon management areas (salmon fishing areas in the SEA Area) are salmon fishing areas 11 and 12. Twenty-seven scheduled salmon rivers and 82 salmon populations occur in these two SFAs with fourteen scheduled rivers occurring within the SFA Area". Within the total 15 salmon fishing areas in NL, there are ~407 rivers with reportedly unique Atlantic salmon populations in terms of life history traits (e.g., freshwater residence time, first spawning age, extent of ocean migrations; DFO 2025c). Atlantic salmon were not reported as bycatch in commercial fisheries within the Study Area during 2010–2015 (LGL 2018) or 2018–2023 (see Section 4.3 of this EA), a reflection of the 1992 moratorium. As such, this EA does not specifically identify the hundreds of salmon populations that may occur within or near the Study Area beyond those considered at risk (see Section 4.7).

There were no estimates for total salmon returns for rivers within salmon fishing area 12 for 2024 but returns ranged from 160 (Garnish River) to 659 (Conne River) for salmon fishing area 11 (DFO 2025d). No change could be calculated compared to previous recent years for Garnish River due to an incomplete dataset, but the total returns for Conne River were 52% lower in 2024 than the previous three generations and is considered in the critical zone (DFO 2025d). In terms of productivity, 2024 smolt production for Conne River was 57% lower in 2024 compared to the previous generation average and marine survival for smolt returning as adults was 223% higher than the previous generation average (although 2% lower than the previous three generation average; see Table 2 in DFO 2025d).

4.2.2.3 Macroinvertebrate and Fish Reproduction in the Study Area

Temporal and spatial details of macroinvertebrate and fish reproduction within the Study Area are provided in Table 4.1.

Table 4.1. Reproduction specifics of macroinvertebrate and fish species likely to spawn within or near the Study Area.

Species	Locations of Reproductive Events	Times of Reproductive Events	Duration of Planktonic Stages
Northern Shrimp	On banks and in channels over the extent of its distribution	Spawning in late-summer/fall. Fertilized eggs carried by female for 8–10 months and larvae hatch in the spring	12–16 weeks
Snow Crab	On banks and possibly along some upper slope regions over the extent of its distribution	Mating in early-spring. Fertilized eggs carried by female for 2 years and larvae hatch in late-spring/early-summer	12–15 weeks
Greenland Cockle	Eastern Grand Banks	Uncertain	Uncertain

Species	Locations of Reproductive Events	Times of Reproductive Events	Duration of Planktonic Stages
Stimpson's Surf Clam	Eastern Grand Banks	Fall	4–8 weeks
Greenland Halibut	Spawning grounds extend from Davis Strait (south of 67°N) to south of Flemish Pass between 800 m and 2,000 m depth	Spring/summer or winter months	Uncertain
Yellowtail Flounder	Shallower sandy areas – typically <100 m water depth – at bottom	May–September, typically peaking in June/July. Both eggs and larvae are planktonic.	Pelagic larvae are brief residents in the plankton
Witch Flounder	Throughout the Grand Banks, particularly along slopes >500 m	Late-spring to late-summer/early-fall	Uncertain
Thorny Skate	Throughout distribution range	Year-round. Eggs deposited in capsule (one egg per capsule), possibly on bottom	None
Roundnose Grenadier	Uncertain	Year-round. Eggs are free-floating	Uncertain
Roughhead Grenadier	Likely along southern and southeastern slopes of Grand Banks	Winter/early-spring	Uncertain
Capelin	Spawning generally on beaches or in deeper waters	Late-June to early-July	Several weeks
Atlantic Halibut	Uncertain	Likely spawns between January and May. Both eggs and larvae are planktonic	6–8 weeks
American Plaice	Spawning generally occurs throughout the range the population inhabits.	April–May	12–16 weeks
Redfish	Primarily along edge of shelf and banks, in slope waters, and in deep channels	Mating in late winter and release of young between April and July (peak in April)	No planktonic stage
Atlantic Cod	Spawn along outer slopes of the shelf in depths from tens to hundreds of metres	March–June	10–12 weeks
Atlantic Salmon	Spawn in freshwater	October–November	Several weeks in freshwater
Wolffishes	Along bottom in deeper water, typically along continental slope	Summer to early-winter (species-dependent)	Uncertain
Swordfish	NW Atlantic population believed to spawn in the Caribbean Sea, Gulf of Mexico, and off Florida	Year-round	Uncertain
Porbeagle Shark	Very little known about the location of the pupping grounds; likely southern Grand Banks	Mating in late-summer/fall and pupping between early-April and early-June	Uncertain
Cusk	Uncertain	May–August	Presumed to be 4–16 weeks
Sand Lance	On sand in shallow water of the Grand Banks	November–January	Several weeks

Source: Derived from Section 3.2.5 in C-NLOPB (2010) and Section 4.2.1.6 in C-NLOPB (2014).

4.2.3 Fish and Fish Habitat Data Gaps Identified in Relevant SEAs

The following data gaps associated with the Fish and Fish Habitat VC were identified in Section 3.4.1.1 in IAAC (2020):

- Although chlorophyll-*a* satellite imagery is a useful indicator for spatial and temporal distributions, it does not consider physical, chemical, or biological factors that may impact the distribution of plankton;
- There is uncertainty for the NL Region regarding seasonal effects on plankton in relation to the above factors;
- There are few directed studies for phytoplankton for the region, and these are effectively outdated and focus on site-specific inshore areas;
- Species distributions during months of the year beyond the DFO RV spring and fall surveys are not available in an RV database;
- The use of bottom trawls for the DFO RV surveys restrict the substrate types and depths at which the surveys may be performed, which introduces bias towards certain species/habitat types; this gear type also does not account for larval/pelagic life stages of various fish species (e.g., capelin, Atlantic salmon);
- The Spanish EU RV data are not available in its entirety but rather in a summarized format and for particular environmental components;
- The DFO RV and Spanish EU RV datasets are not directly comparable quantitatively and "do not necessarily provide comprehensive and comparable coverage in all areas of interest";
- Survey coverage in many portions of offshore NL are lacking for various benthic invertebrates, including corals and sponges, limiting regional-scale generalizations;
- Further sampling is required to confirm predicted coral and sponge distributions;
- Relatively little is known of the at-sea/overwintering portion(s) of the life history of Atlantic salmon; much of the available information is limited in resolution and outdated;
- Data beyond the eastern continental slope are lacking;
- Relatively little is known regarding habitat use of the offshore NL area by large pelagics; and
- Regime shifts and impacts from climate change are altering our current understanding of fish and fish habitat in the region.

The following data gap associated with the Fish and Fish Habitat VC was identified in the Eastern Newfoundland SEA (Section 6.1.6 of C-NLOPB 2014):

- Limited data regarding fish and fish habitat in deep water beyond the continental slope, particularly for species that are not commercially important at this time.

The following data gaps associated with the Fish and Fish Habitat VC were identified in the Southern Newfoundland SEA (Sections 3.1.6 and 3.2.6 of C-NLOPB 2010):

- Data regarding the spatial and temporal distributions of macroinvertebrate eggs and larvae, and ichthyoplankton are deficient. Some spawning areas have been identified but little work has been done on the passive movements of the eggs and larvae of macroinvertebrates and fishes. More knowledge of drift routes would also provide more perspective on nursery areas;
- Data regarding benthos are quite dated and are primarily related to specific coastal areas and/or restricted time periods;
- Data regarding benthic community composition are limited, most resulting from species-specific studies;
- Data regarding the life histories of many macroinvertebrates and fishes are deficient;
- Data regarding the population size and structure of several macroinvertebrate and fish species are deficient; and
- Data regarding many pelagic fishes are deficient.

All the data gaps indicated above still exist, although there has been progress in addressing at least some of them. Where available, updated information addressing life history, population size/status, and distribution from recent stock assessments for important fish/invertebrate species within the Study Area was provided in this EA, a recent EA for the Study Area (LGL 2018), and the regional drilling assessment (IAAC 2020). Updated information available in scientific literature regarding planktonic and benthic community composition, particularly for corals and sponges, was provided in Section 4.2.1 of this EA. The distribution of corals and sponges within the Study Area – based on the most recent available (2018–2028) DFO RV survey catch locations – along with the boundaries of Significant Benthic Areas (SBAs) identified by DFO for sea pens, small and large gorgonian corals, and sponges are also provided in this EA (see Sections 4.3.7 and 4.8).

The collection of temporal and spatial data with regards to species life history (e.g., spawning locations, abundance, distribution, areas of high productivity) for data-deficient and lesser-known non-commercial species would be valuable when considering environmental effects assessments and fisheries resource management. Similarly, addressing these data gaps would aid in assessing cumulative effects from multiple industrial activities, especially in terms of mitigating possible marine ecosystem impacts. Gaps in our knowledge of marine ecosystems are significant, and these deficiencies make it difficult to determine the extent to which humans have influenced and affected marine ecosystems, particularly with the expansion and intensification of anthropogenic activities in the past decade or so. The interaction between climate change and ecosystem/species specific impacts is a developing research area that will most likely help fill existing data gaps and provide new data. As stated in Section 6.2 in C-NLOPB (2014): "The C-NLOPB, in consultation with advisory agencies within governments and with relevant stakeholders, will promote the planning, prioritizing, and undertaking of research (e.g., through research organizations such as the Environmental Studies Research Funds). In addition, Operators may be required to collect data as part of their program operations, either opportunistically during program operations or prior to the start of program activities. The requirement and nature of the latter will be determined during project-specific assessment."

4.3 Fisheries VC

The Fisheries VC of the Study Area has been previously described in the Eastern Newfoundland SEA (Section 4.3.4 of C-NLOPB 2014), Southern Newfoundland SEA (Section 3.3 of C-NLOPB 2010), and IAAC EA (Section 3.3 of IAAC 2020). An overview of the fisheries of the Study Area, based on new information since these documents were published, is provided below. Where appropriate, relevant sections of the previous EA for the Study Area (LGL 2018) are referenced to avoid unnecessary repletion of previously published data. Relevant data gaps identified in the SEAs and IAAC (2020) are also discussed in terms of current status.

This section describes the commercial fishery in the Study Area during 2018–2023. The Study Area overlaps portions of NAFO Divisions 3KLMNOPs, 4VnVs and 6H (Figure 4.1).

This subsection also briefly describes updated historical, recreational, and Indigenous fisheries, aquaculture activity, and fisheries research surveys in the Study Area. New information regarding the biology and status of the principal macro-invertebrates and fishes discussed in this section was included in Section 4.2, Fish and Fish Habitat.

4.3.1 Information Sources

NAFO catch weight data are used to describe domestic and foreign fisheries conducted beyond the 200-nm Exclusive Economic Zone (EEZ). Much of the Study Area is located outside of the 200-nm limit (see Figure 4.1). The NAFO data were obtained from the STATLANT21A dataset for 2018–2024 (Table 4.2). The STATLANT21A reporting system of questionnaires database is a long-standing, standardized, publicly available statistical inquiry for the submission of national catch data to international fisheries agencies by national reporting offices. It includes annual catches at the NAFO Division level by species, country, year, and catch weight. The data analyses in this EA quantify harvesting in NAFO Divisions 3KLMNOPs, 4VnVs and 6H (Figure 4.1).

The primary fisheries data analyses use all DFO Atlantic Region's gridded cell landings for 2018–2023 (Table 4.2). The DFO dataset records domestic and foreign harvests landed in Canada. The landings data are provided by DFO as ranges of catch weights and values calculated by annual quartiles and are presented within 6 min x 6 min cells (latitude x longitude). The data primarily used to characterize the fisheries in this EA are harvest catch weight quartiles. Catch value quartiles are used to indicate that some species may have lower catch weight quartiles but have higher quartiles in terms of value. Catch value is important in the case of a gear damage incident and would be carefully evaluated at that time, based on current value(s), to calculate compensation. DFO catch data are displayed as coloured grid cells representing cells within which harvesting was reported in a given year. Other sources used for this assessment include DFO species management plans, DFO stock status reports, and other internal documents.

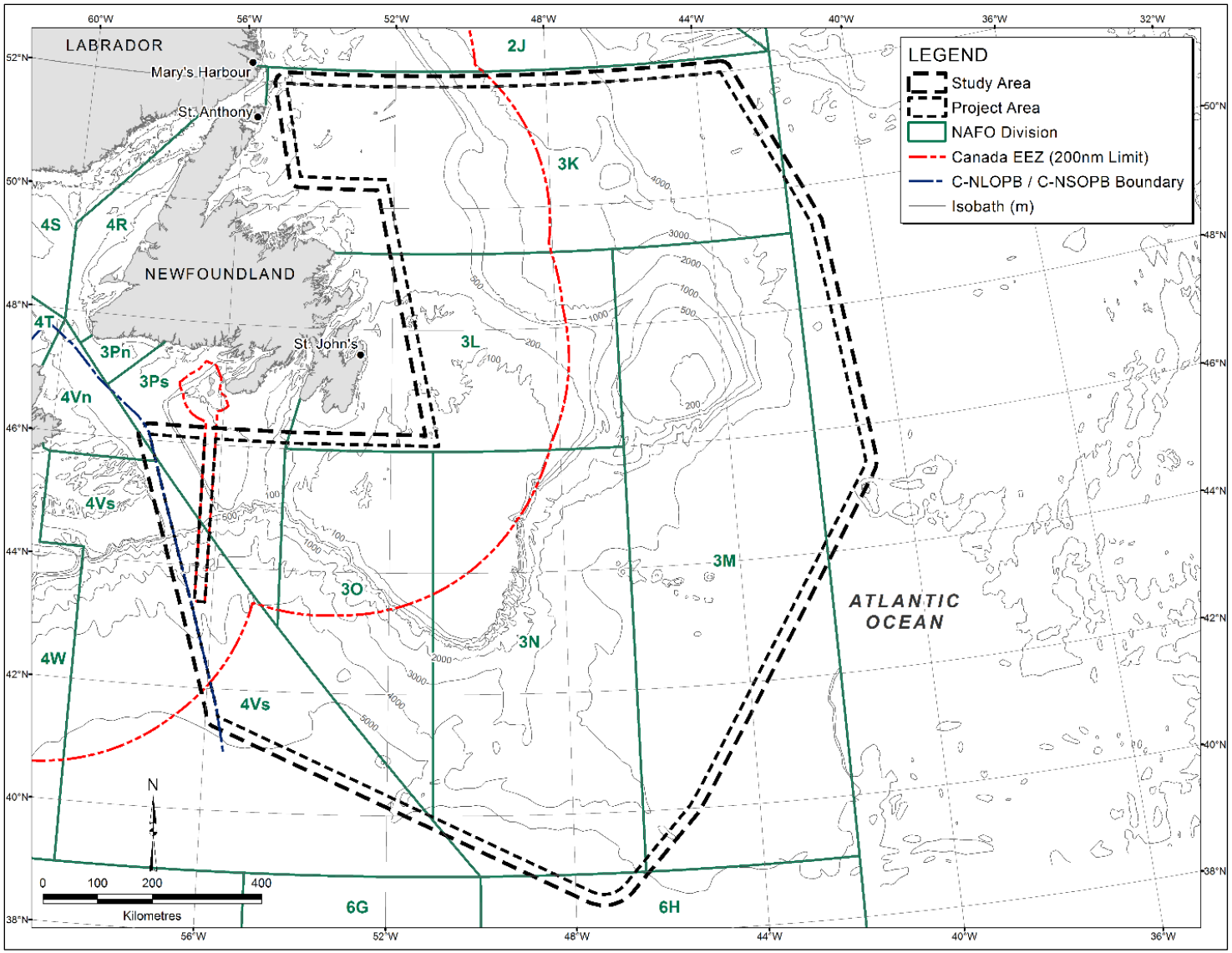


Figure 4.1. Study Area and Project Area in relation to Regional Fisheries Management Areas (NAFO Divisions).

Table 4.2. Summary of information sources for commercial fisheries data.

Data Source	Domestic/Foreign Fisheries	Temporal Period	Geographic Area	Spatial Resolution
DFO	Domestic	May–November 2018–2023	Within Study Area; mostly within Canadian EEZ but generally within 2,000 m depth	Gridded 6'x6' (latitude x longitude) cells
NAFO	Domestic/Foreign	2018–2024 (2004–2024 for historical overview, Section 4.3.3.1)	Within/beyond Study Area; beyond Canadian EEZ	NAFO Divisions

Source: NAFO (2025b).

4.3.2 Regional NAFO Fisheries

NAFO manages 20 stocks comprised of 12 species:

- Cod (stocks: 3L, 3M, 3NO);
- Redfish (3LN, 3M, 3O, 1F-2-3K [i.e., Subarea 2 and Divisions 1F+3K];
- American plaice (3LNO, 3M);
- Yellowtail flounder (3LNO);
- Witch flounder (*Glyptocephalus cynoglossus*; 3L, 3NO);
- White hake (3NO);
- Capelin (3NO);
- Skates (3LNO);
- Greenland halibut (3LMNO);
- Squid (*Illex* sp.; 3_4 [i.e., Subareas 3+4]);
- Shrimp (3L, 3NO); and
- Alfonsino (*Beryx* sp.; 6 [i.e., Subarea 6]).

During the 2018–2024 period, commercial harvesting within the Study Area beyond the 200-nm EEZ was dominated (in terms of catch weight) by snow crab (20% of total catch weight; primarily in NAFO Division 3L), Atlantic redfish (13%, mainly 3M), Atlantic cod (10%, mainly 3M), surf clam (10%, mainly 3N), capelin (7%, mainly 3L), Greenland halibut (6%, mainly 3L), yellowtail flounder (5%, mainly 3N), and northern shrimp (4%, mainly 3K). Proportional catch weights in the Study Area during the seven-year period, in descending order of magnitude, were 30% in NAFO Division 3L, 19% in 3N, 16% in 3K, 12% in 3Ps, 9% in 3M, 7% in 3O, 6% in 4Vs, 1% in 4Vn, and 0.3% in 6H.

Canadian vessels accounted for 75% of the commercial catch weight reported for this area during 2018–2024. While Canadian vessels accounted for most catches in NAFO Divisions 3KLNPs and 4VnVs, foreign vessels dominated catches in Divisions 3MO and 6H. Catches predominantly consisted of Atlantic cod and Atlantic redfish in Division 3M; Atlantic redfish and silver hake in 3O, and great blue shark and swordfish in 6H. Most fishing for relevant species in the NAFO Convention Regulatory Area is conducted using bottom trawlers (LGL 2015).

4.3.3 Domestic Fisheries

The following subsection provides an overview of the commercial fisheries within and/or adjacent to the Study Area. Historical fishing activity during the last 20 years with available data, including abundance information for historically principal species, are presented. Statistical summaries of the commercial catch data specific to the Study Area, based on the annual gridded cell (6′ x 6′) data for 2018–2023, are also provided in this subsection.

4.3.3.1 Historical Fisheries

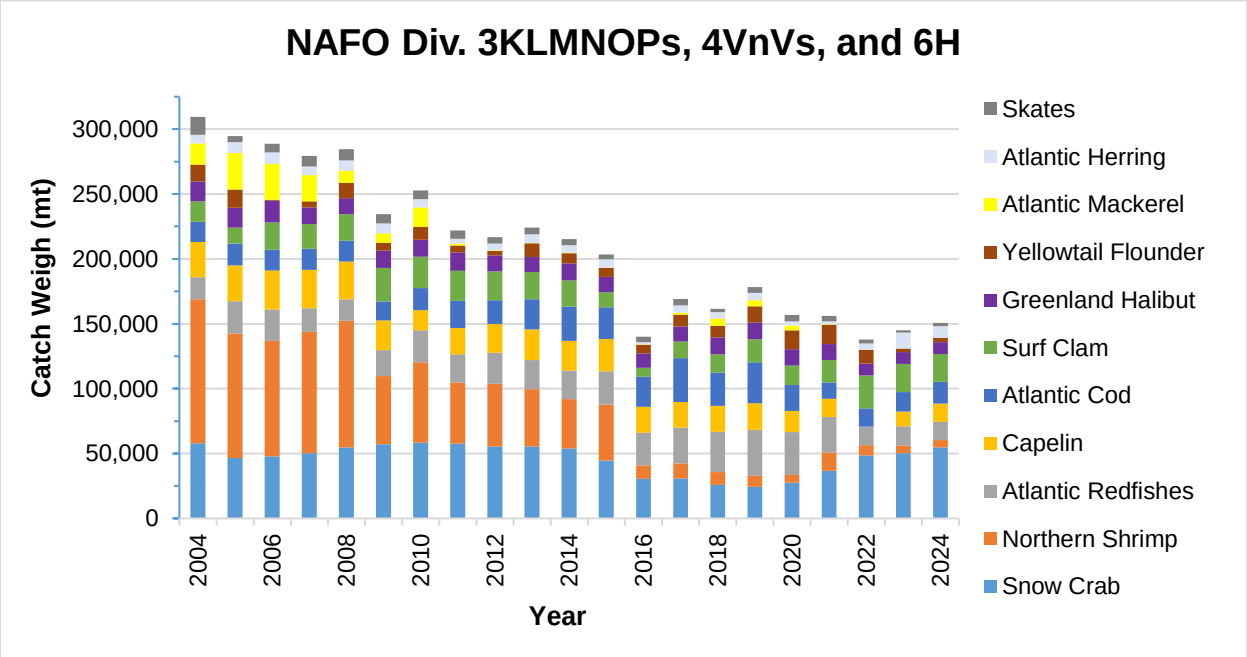
A historical overview of fisheries was given in Section 4.3.4.2 of C-NLOPB (2014) and Section 4.3.3.1 of LGL (2018). In the late 1980s, fishes such as Atlantic cod, capelin, Atlantic redfish, and American plaice were the primary species harvested in NAFO Divisions 3KLMNOPs, 4VnVs, and 6H. These fisheries were considerably reduced in the early 1990s during the moratorium, after which crustaceans, such as northern shrimp and snow crab, became the predominant target species (see Section 4.3.3.1 of LGL 2018 and Section 3.3.1.1 in IAAC 2020). While groundfish fisheries and harvesters declined in the province, the overall landed commercial fisheries value in NL remained relatively steady and/or increased in some cases, as higher-value species have been mainly targeted since the moratorium (IAAC 2020; see also Section 4.3.3.1 of LGL [2015] for a description of Integrated Fisheries Management Plans for priority groundfish species).

The exploitable biomass and recruitment of snow crab in the region declined to historic lows during the mid- to late-2010s but has increased in recent years following an increase in recruitment largely associated with cool bottom water temperatures during 2012–2017, a modest decline in predation in most areas offshore NL, and "substantially decreased fisheries exploitation rates" around the year 2020 associated with fisheries/market impacts of the COVID-19 pandemic (DFO 2023b). This trend was reflected in the commercial fishery by a decrease in snow crab catch weight within the Study Area after 2014 and increase since ~2021 (Figure 4.2; see Section 4.2.2.1; DFO 2023b). However, since 2018, oceanic conditions have trended towards a warmer and possibly less favourable environment for future snow crab productivity offshore NL; modelling of this factor, in combination with changes in the Arctic Oscillation and sea ice extent, suggests snow crab productivity may remain at its current level for most of the 2020s (DFO 2023b). Northern shrimp stocks offshore NL entered a state of decline during the late-2000s and 2010s (Figure 4.2; see also Figure 2 in DFO 2023d), resulting in a shrimp fishing moratorium in Shrimp Fishing Area (SFA) 7 since 2015 (NAFO 2025a). Commercial northern shrimp catch per unit effort (CPUE) in SFA 6 reached a multi-decadal low during 2017/2018, and fishable biomass and female spawning stock biomass indices have been in decline since 2020 and are currently amongst survey time series lows (Figure 4.2; DFO 2023d). Although CPUE has increased since 2019/2020, it remains below the long-term mean (DFO 2023d). Following these recent changes in predominant shellfish species, a regime shift is currently underway from a shellfish to a mixed shellfish/groundfish-dominated fishery. During 2024, the highest catch weights within Divisions 3KLMNOPs, 4VnVs, and 6H combined were for snow crab, surf clam, Atlantic cod, capelin, and redfish (Figure 4.2).

NAFO's bottom fishing footprint includes the most historically highly bottom-fished areas beyond Canada's EEZ (see Section 4.3.3.1 of LGL 2015 for further detail regarding the history and development of the footprint). The footprint lies entirely within the Project Area (Figure 4.3).

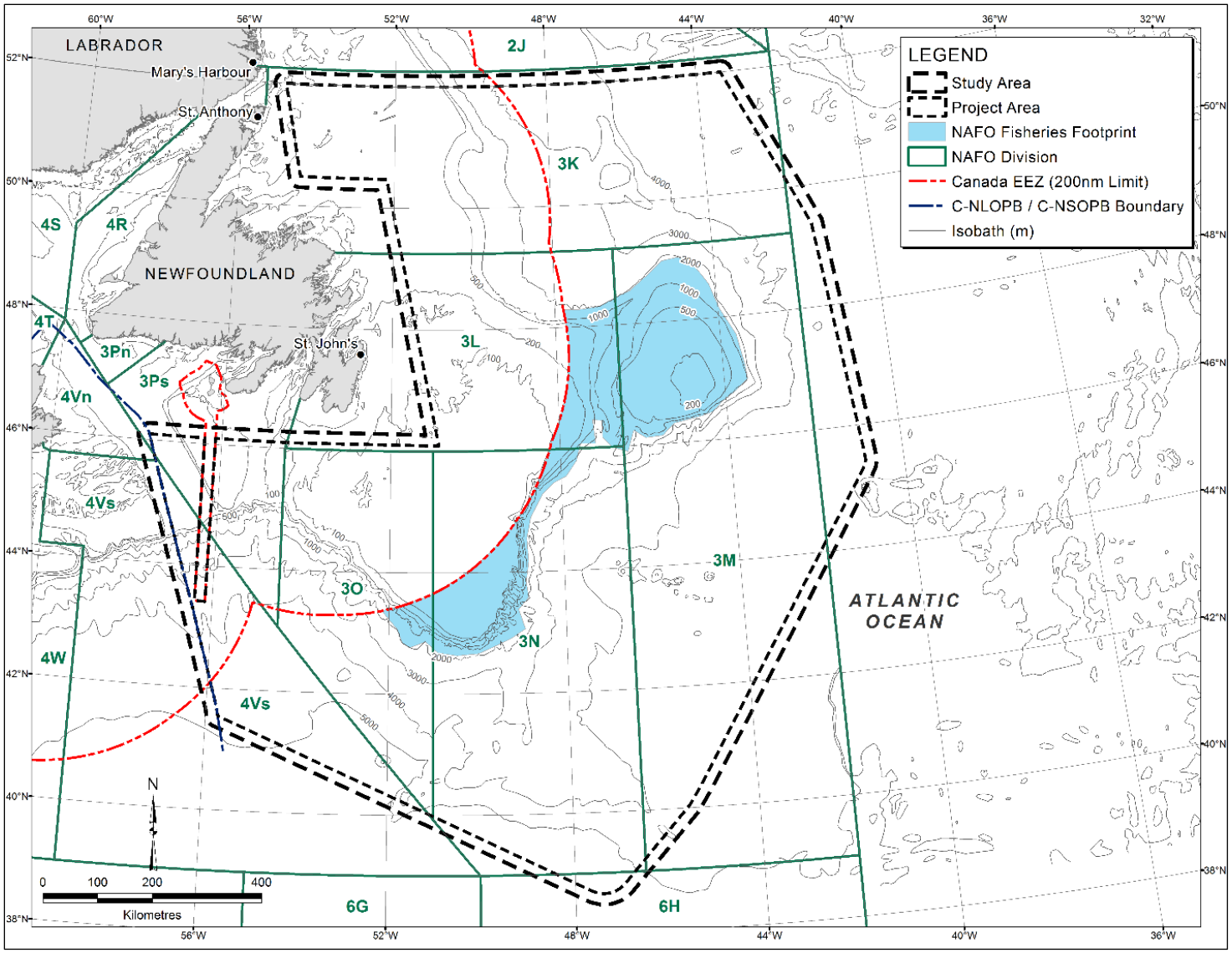
4.3.3.2 Study Area Catch Analysis, 2018–2023

Information on domestic harvests in the Study Area during May–November 2018–2023 are shown in Tables 4.3–4.8. The principal fisheries harvested included snow crab and Atlantic halibut. Other notable species harvested during the May–November 2018–2023 commercial fisheries in the Study Area included Atlantic cod, northern shrimp, Greenland halibut, redfish, and yellowtail flounder. During May–November 2018–2023, the sum of quartile catch ranges in the Study Area decreased by about 20% between 2018 and 2021 and then returned to near the 2018 value in 2022 and 2023 (see Figure 4.4). Commercial fisheries in the Study Area are mainly conducted using vessels with length classes of 45–64.9′ (46%) and ≥125′ (24%; Tables 4.3–4.8).



Source: NAFO (2025b).

Figure 4.2. Historical catch weights for predominant species in the commercial fisheries in NAFO Divisions 3KLMNOPs, 4VnVs and 6H, all Countries, 2004–2024.



Source: NAFO (2025c).

Figure 4.3. Location of the NAFO bottom fisheries footprint, 1987–2007.

Table 4.3. Commercial catch weights and values in the Study Area, May–November 2018 (values indicate the frequency of catch weight and value quartile codes [i.e., 1–4] attributed to each species).

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9’	35-44.9’	45-64.9’	65-99.9’	100-124.9’	≥125’	
Snow Crab	398	602	543	141	221	449	606	408	75	448	1022	126	13		**1684**
Atlantic Halibut	104	232	247	126	237	301	152	19		90	221	70		328	**709**
Greenland Halibut	79	168	190	68	140	181	159	25	1	73	274	15		142	**505**
Northern Shrimp	166	136	109	78	188	130	120	51		8	358	63		60	**489**
Atlantic Cod	57	135	161	97	154	183	103	10		67	129	29		225	**450**
Redfish	50	109	142	73	126	142	90	16		4	166	43		161	**374**
Yellowtail Flounder	17	102	116	65	100	128	66	6		3				297	**300**
White Hake	52	121	92	22	142	119	26			69	172	46			**287**
American Plaice	11	70	111	69	69	117	69	6		3	9	6		243	**261**
Witch Flounder	12	38	70	55	39	62	61	13			11			164	**175**
Pollock	14	52	65	19	78	55	17			23	97	30			**150**
Haddock	23	31	57	18	54	52	23			32	61	13		23	**129**
Swordfish	69	32	12	2	25	62	25	3		31	47	37			**115**
Cusk	15	38	39	16	25	64	19			35	47	26			**108**
Monkfish	6	37	44	9	48	41	7			11	80	4		1	**96**
Mako Shark	47	23	9	2	17	44	18	2		20	33	28			**81**
Stimpson's Surf Clam	3	5	19	36	5	15	13	30						63	**63**
Propellor Clam	1	4	18	32	3	13	12	27						55	**55**
Cockle		3	11	33	1	10	8	28						47	**47**
Sea Cucumber		2	12	25	2	12	11	14	3	26	10				**39**
Albacore Tuna	18	14	4		6	19	10	1		6	10	20			**36**
Whelk	14	15	2	3	20	9	5			20	14				**34**
Skate sp.	1	10	20	3	18	15	1			4	30				**34**
Dolphinfish	11	14	6			17	12	2		10	11	10			**31**
Sea Scallop	3	8	6	10	6	7	8	6		1	5	2	13	6	**27**
Bigeye Tuna	10	9	4	1	5	8	9	2		2	6	16			**24**
White Marlin	5	8	2		3	4	7	1		2	9	4			**15**
Bluefin Tuna	8	3	1	3	6	5	4		1	4	4	6			**15**
Silver Hake	12	3			15									15	**15**
Iceland Scallop	4	1	1		4	1	1		1	2	3				**6**
Toad Crab		4			2	2				4					**4**
Mackerel			3	1	2	2				1	3				**4**

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9'	35-44.9'	45-64.9'	65-99.9'	100-124.9'	≥125'	
Atlantic Wolffish	1	2			1	2					3				**3**
Roughead Grenadier		1	1	1		1	1	1		2	1				**3**
Capelin			3		3				1	1	1				**3**
Quahaug Clam		1	1			2								2	**2**
Total	**1211**	**2033**	**2121**	**1008**	**1765**	**2274**	**1663**	**671**	**82**	**1002**	**2837**	**594**	**26**	**1832**	**6373**

Source: DFO commercial landings database, All Atlantic Regions (2018).

[a] Quartile ranges provided by DFO (quartile ranges calculated annually by DFO based on total catch weights in a given year, all species combined). 2018 quartile ranges: 1 = 0-2045 kg; 2 = 2046-8549 kg; 3 = 8550-33,818 kg; 4 = ≥33,819 kg.

[b] Quartile ranges provided by DFO (Quartile ranges calculated annually by DFO based on total catch values in a given year, all species combined). 2018 quartile ranges: 1 = $0-$10,353; 2 = $10,354-$45,610; 3 = $45,611-$166,300; 4 = ≥$166,301.

[c] Includes the total quartile code count for ranges 1-4; total counts for catch weight and catch value are equal.

[d] Total counts of the number of catch records per species; the total quartile range counts for catch weight and catch value are equal.

Table 4.4. Commercial catch weights and values in the Study Area, May–November 2019 (values indicate the frequency of catch weight and value quartile codes [i.e., 1–4] attributed to each species).

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9'	35-44.9'	45-64.9'	65-99.9'	100-124.9'	≥125'	
Snow Crab	237	429	536	126	131	284	501	412	51	341	797	139			**1328**
Atlantic Halibut	106	223	197	155	242	244	163	32	1	101	253	77		249	**681**
Redfish	74	140	123	99	197	127	96	16		5	222	60		149	**436**
Northern Shrimp	126	114	109	86	156	113	100	66		7	334	54		40	**435**
Greenland Halibut	63	135	154	66	116	145	132	25	1	92	246	23		56	**418**
Atlantic Cod	65	94	87	113	112	119	108	20	2	64	144	47		102	**359**
White Hake	65	97	94	63	135	118	60	6		69	189	61			**319**
Yellowtail Flounder	13	63	76	64	56	88	53	19		1				215	**216**
American Plaice	10	53	78	71	48	87	58	19		10	20			182	**212**
Pollock	14	29	39	42	37	43	39	5		8	82	34			**124**
Monkfish	12	39	40	27	54	42	18	4		10	93	11		4	**118**
Cusk	12	31	40	32	29	46	38	2		46	38	31			**115**
Witch Flounder	7	19	25	37	23	26	23	16			11	4		73	**88**
Haddock	11	22	22	17	27	28	17			15	37	16		4	**72**
Swordfish	23	23	13	5	10	21	26	7		18	12	34			**64**

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9’	35-44.9’	45-64.9’	65-99.9’	100-124.9’	≥125’	
Stimpson's Surf Clam		4	15	44	1	16	15	31						63	**63**
Cockle		3	15	42		15	14	31						60	**60**
Propellor Clam		2	15	38		14	12	29						55	**55**
Mako Shark	15	12	10	4	6	14	16	5		8	10	23			**41**
Whelk	10	13	10	3	13	16	7			26	10				**36**
Silver Hake	23	8	2	2	22	10	3				9			26	**35**
Sea Cucumber	1	2	13	18	3	11	7	13		26	8				**34**
Sea Scallop	3	8	4	13	11	3	7	7			4	4	12	8	**28**
Albacore Tuna	5	11	9	2	1	7	16	3		4	6	17			**27**
Bluefin Tuna	9	9	3	5	10	9	6	1		1	16	9			**26**
Skate sp.	4	8	8	5	16	6	3			3	22				**25**
Bigeye Tuna	7	3	4	2	4	5	6	1		6	2	8			**16**
Roughead Grenadier		3	4	3	2	2	4	2		1	9				**10**
Dolphinfish	1	4	3	1	1		6	2		3	3	3			**9**
Blue Shark	3	3	1		1	3	3					7			**7**
Ocean Quahaug				4		2	1	1						4	**4**
Capelin		1		1	1	1			2						**2**
Mackerel	1		1		1	1				2					**2**
Roundnose Grenadier		1				1						1			**1**
Total	**920**	**1606**	**1750**	**1190**	**1466**	**1667**	**1558**	**775**	**57**	**867**	**2577**	**663**	**12**	**1290**	**5466**

Source: DFO commercial landings database, All Atlantic Regions (2019).

[a] Quartile ranges provided by DFO (quartile ranges calculated annually by DFO based on total catch weights in a given year, all species combined). 2019 quartile ranges: 1 = 0-1938 kg; 2 = 1939-8218 kg; 3 = 8219-33,113 kg; 4 = ≥33,114 kg.

[b] Quartile ranges provided by DFO (Quartile ranges calculated annually by DFO based on total catch values in a given year, all species combined). 2019 quartile ranges: 1 = $0-$11,209; 2 = $11,210-$46,951; 3 = $46,952-$176,461; 4 = ≥$176,462.

[c] Includes the total quartile code count for ranges 1-4; total counts for catch weight and catch value are equal.

[d] Total counts of the number of catch records per species; the total quartile range counts for catch weight and catch value are equal.

Table 4.5. Commercial catch weights and values in the Study Area, May–November 2020 (values indicate the frequency of catch weight and value quartile codes [i.e., 1–4] attributed to each species).

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9’	35-44.9’	45-64.9’	65-99.9’	100-124.9’	≥125’	
Snow Crab	210	493	701	225	132	359	633	505	52	378	1031	152	16		**1629**
Atlantic Halibut	172	266	206	131	226	323	186	40		125	223	129		298	**775**
Greenland Halibut	74	191	118	29	101	195	98	18	1	82	236	35		58	**412**
Redfish	57	128	108	60	117	128	90	18		1	135	98		119	**353**
Atlantic Cod	47	111	106	89	80	140	105	28		43	101	49		160	**353**
Northern Shrimp	86	100	85	43	116	110	57	31			235	53		26	**314**
Yellowtail Flounder	21	86	91	82	76	105	77	22						280	**280**
American Plaice	13	69	100	83	55	106	82	22		2	7			256	**265**
White Hake	31	88	62	39	62	88	60	10		42	114	64			**220**
Witch Flounder	1	23	35	48	12	34	46	15			28			79	**107**
Cusk	24	50	16	16	27	49	26	4		39	58	9			**106**
Monkfish	4	29	35	30	22	35	32	9		6	59	31		2	**98**
Pollock	2	29	30	22	15	31	33	4		9	45	29			**83**
Stimpson's Surf Clam	1	5	23	44	2	17	19	35						73	**73**
Cockle		5	18	38	1	14	13	33						61	**61**
Swordfish	20	18	20	1	33	21	5			23	1	35			**59**
Sea Cucumber		2	8	30	2	7	14	17		23	17				**40**
Propellor Clam		1	10	18		8	5	16						29	**29**
Haddock	5	7	11	4	7	13	7			13	9	5			**27**
Bigeye Tuna	4	8	13	1	8	14	4			10		16			**26**
Albacore Tuna	10	6	8		13	10	1			6		18			**24**
Bluefin Tuna	14	2	5	1	14	4	4			15		7			**22**
Whelk	6	6	7	1	8	8	4			14	6				**20**
Sea Scallop		4	1	13		4	1	13			3		10	5	**18**
Roughead Grenadier	2	11	3		3	10	3				7	9			**16**
Roundnose Grenadier	4	5	1		3	6	1				10				**10**
Dolphinfish	3	1	2		3	3				6					**6**
White Marlin	2	1			3					1		2			**3**
Silver Hake				3			2	1			3				**3**
Skate sp.			2		1		1			2					**2**

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9’	35-44.9’	45-64.9’	65-99.9’	100-124.9’	≥125’	
Capelin			1	1		2			1		1				**2**
Atlantic Herring				1		1					1				**1**
Total	**813**	**1745**	**1826**	**1053**	**1142**	**1845**	**1609**	**841**	**54**	**840**	**2330**	**741**	**26**	**1446**	**5437**

Source: DFO commercial landings database, All Atlantic Regions (2020).

[a] Quartile ranges provided by DFO (quartile ranges calculated annually by DFO based on total catch weights in a given year, all species combined). 2020 quartile ranges: 1 = 0-1989 kg; 2 = 1990-8428 kg; 3 = 8429-34,645 kg; 4 = ≥34,646 kg.

[b] Quartile ranges provided by DFO (Quartile ranges calculated annually by DFO based on total catch values in a given year, all species combined). 2020 quartile ranges: 1 = $0-$8664; 2 = $8665-$38,347; 3 = $38,348-$144,765; 4 = ≥$144,766.

[c] Includes the total quartile code count for ranges 1-4; total counts for catch weight and catch value are equal.

[d] Total counts of the number of catch records per species; the total quartile range counts for catch weight and catch value are equal.

Table 4.6. Commercial catch weights and values in the Study Area, May–November 2021 (values indicate the frequency of catch weight and value quartile codes [i.e., 1–4] attributed to each species).

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9’	35-44.9’	45-64.9’	65-99.9’	100-124.9’	≥125’	
Snow Crab	173	448	678	249	60	226	578	684	40	352	950	193	13		**1548**
Atlantic Halibut	211	241	180	102	232	318	154	30		203	207	116		208	**734**
Northern Shrimp	86	125	97	75	150	112	99	22			296	68		19	**383**
Atlantic Cod	75	95	83	77	92	135	79	24	2	49	75	60		144	**330**
Greenland Halibut	34	156	98	20	76	164	59	9		46	195	28		39	**308**
Redfish	33	100	98	38	106	112	46	5		1	105	69		94	**269**
Yellowtail Flounder	23	64	74	68	69	86	52	22			1			228	**229**
White Hake	59	83	62	20	88	98	36	2		52	100	72			**224**
American Plaice	19	51	66	68	55	76	50	23		3				201	**204**
Pollock	2	37	30	22	32	34	23	2		4	34	28		25	**91**
Swordfish	39	28	10		30	31	16			35	6	36			**77**
Monkfish	2	26	35	12	24	40	10	1		1	40	31		3	**75**
Cusk	19	26	17	9	23	34	14			7	36	28			**71**
Witch Flounder	3	13	26	28	8	21	27	14			6			64	**70**
Haddock	20	21	13	8	21	27	12	2		19	32	4		7	**62**
Stimpson's Surf Clam		2	19	40	2	20	10	29						61	**61**
Propellor Clam		1	16	40	1	17	10	29						57	**57**
Cockle			17	39		18	9	29						56	**56**

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9'	35-44.9'	45-64.9'	65-99.9'	100-124.9'	≥125'	
Sea Cucumber		3	14	28	1	16	11	17		29	16				**45**
Bigeye Tuna	7	12	6		5	10	10			8	4	13			**25**
Sea Scallop	3	3	2	15	3	3	4	13		1	4		11	7	**23**
Albacore Tuna	9	8	2		7	9	3			11	3	5			**19**
Roughead Grenadier	1	12	4		8	6	3			1	16				**17**
Atlantic Wolffish	4	5	2		2	8	1				11				**11**
Silver Hake	4	2		1	3	1	3			6				1	**7**
Atlantic Herring	3	1	3		6	1			3	3		1			**7**
Dolphinfish	6	1			4	2	1			4		3			**7**
Bluefin Tuna	5	1			5	1				3	3				**6**
Lobster		2	3			1	3	1		1	4				**5**
Capelin			3	1		4				2	2				**4**
Whelk	1	1	2		1	3				4					**4**
Yellowfin Tuna	2	2			2	2				4					**4**
Skate sp.			3			3					3				**3**
Mackerel	2	1			2	1						3			**3**
Squid sp.	2				2							2			**2**
Atlantic Rock Crab	2				2					2					**2**
Iceland Scallop		1				1					1				**1**
Jonah Crab			1				1				1				**1**
Pelagic sp.			1				1					1			**1**
Roundnose Grenadier		1				1					1				**1**
Total	**849**	**1573**	**1665**	**960**	**1122**	**1642**	**1325**	**958**	**45**	**851**	**2152**	**761**	**24**	**1214**	**5047**

Source: DFO commercial landings database, All Atlantic Regions (2021).

[a] Quartile ranges provided by DFO (quartile ranges calculated annually by DFO based on total catch weights in a given year, all species combined). 2021 quartile ranges: 1 = 0-2025 kg; 2 = 2026-8783 kg; 3 = 8784-35,210 kg; 4 = ≥35,211 kg.

[b] Quartile ranges provided by DFO (Quartile ranges calculated annually by DFO based on total catch values in a given year, all species combined). 2021 quartile ranges: 1 = $0-$11,497; 2 = $11,498-$53,379; 3 = $53,380-$227,707; 4 = ≥$227,708.

[c] Includes the total quartile code count for ranges 1-4; total counts for catch weight and catch value are equal.

[d] Total counts of the number of catch records per species; the total quartile range counts for catch weight and catch value are equal.

Table 4.7. Commercial catch weights and values in the Study Area, May–November 2022 (values indicate the frequency of catch weight and value quartile codes [i.e., 1–4] attributed to each species).

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9’	35-44.9’	45-64.9’	65-99.9’	100-124.9’	≥125’	
Snow Crab	161	451	766	342	55	260	616	789	41	333	1077	256	13		**1720**
Atlantic Halibut	266	288	201	105	254	356	225	25		85	417	134		224	**860**
Atlantic Cod	107	173	143	99	146	192	159	25		26	221	60		215	**522**
Greenland Halibut	55	166	146	12	106	187	83	3		62	240	72		5	**379**
Yellowtail Flounder	36	116	106	77	135	119	67	14		1				334	**335**
Northern Shrimp	42	81	77	89	96	80	76	37			235	46		8	**289**
American Plaice	23	81	86	77	95	93	64	15						267	**267**
White Hake	50	89	69	39	60	105	69	13		13	105	104		25	**247**
Redfish	33	72	87	36	69	78	69	12			81	106		41	**228**
Haddock	23	66	30	26	37	54	47	7		8	89	8		40	**145**
Cusk	29	48	30	18	25	57	36	7		7	71	47			**125**
Stimpson's Surf Clam	2	12	38	48	8	36	23	33						100	**100**
Propellor Clam	1	12	38	47	9	35	21	33						98	**98**
Swordfish	37	43	16	1	16	54	27			8	61	28			**97**
Cockle		13	33	47	8	32	20	33						93	**93**
Monkfish	13	33	30	16	33	32	24	3		3	17	58		14	**92**
Pollock	3	24	39	26	13	36	33	10		1	34	48		9	**92**
Witch Flounder	7	14	20	19	18	21	18	3			1	21		38	**60**
Sea Cucumber		1	8	23	2	4	14	12		21	11				**32**
Dolphinfish	9	12	4		4	15	6			2	20	3			**25**
Sea Scallop	5	4	4	10	7	4	2	10		2	5		9	7	**23**
Bigeye Tuna	5	9	7	1	3	9	10				9	13			**22**
Skate sp.	1	13	4	2	19	1					20				**20**
Albacore Tuna	7	9	3		4	8	7			1	10	8			**19**
Silver Hake	2	5	8	4	6	9	4							19	**19**
Whelk		8	7	2	6	9		2		5	12				**17**
Atlantic Wolffish	7	9		1	4	12	1				17				**17**
Yellowfin Tuna	5	4	4		3	6	4				8	5			**13**
Bluefin Tuna	6	1	2	1	5	2	2	1			9	1			**10**
White Marlin	3	3	4		2	2	6				10				**10**
Winter Flounder		2	4	3		4	3	2			9				**9**

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9’	35-44.9’	45-64.9’	65-99.9’	100-124.9’	≥125’	
Roughead Grenadier		3	4			5	2				7				**7**
Argentine			2	1			3					3			**3**
Roundnose Grenadier	3				3						3				**3**
Iceland Scallop	1				1						1				**1**
Atlantic Herring			1		1						1				**1**
Total	**942**	**1865**	**2021**	**1172**	**1253**	**1917**	**1741**	**1089**	**41**	**578**	**2801**	**1021**	**22**	**1537**	**6000**

Source: DFO commercial landings database, All Atlantic Regions (2022).

[a] Quartile ranges provided by DFO (quartile ranges calculated annually by DFO based on total catch weights in a given year, all species combined). 2022 quartile ranges: 1 = 0-2144 kg; 2 = 2145-8782 kg; 3 = 8783-35,473 kg; 4 = ≥35,474 kg.

[b] Quartile ranges provided by DFO (Quartile ranges calculated annually by DFO based on total catch values in a given year, all species combined). 2022 quartile ranges: 1 = $0-$13,904; 2 = $13,905-$60,222; 3 = $60,223-$237,098; 4 = ≥$237,099.

[c] Includes the total quartile code count for ranges 1-4; total counts for catch weight and catch value are equal.

[d] Total counts of the number of catch records per species; the total quartile range counts for catch weight and catch value are equal.

Table 4.8. Commercial catch weights and values in the Study Area, May–November 2023 (values indicate the frequency of catch weight and value quartile codes [i.e., 1–4] attributed to each species).

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9’	35-44.9’	45-64.9’	65-99.9’	100-124.9’	≥125’	
Snow Crab	245	588	965	510	260	555	859	634	10		29	363	1632	274	**2308**
Atlantic Halibut	231	256	136	49	191	262	173	46		118		71	376	107	**672**
Atlantic Cod	92	149	97	43	103	133	113	32		122	2	12	173	72	**381**
Northern Shrimp	70	88	100	44	106	86	93	17		14			257	31	**302**
Greenland Halibut	79	116	94	11	93	128	69	10		11	3	108	134	44	**300**
Yellowtail Flounder	52	81	55	23	112	60	30	9		211					**211**
Swordfish	61	111	30	3	24	99	60	22				26	110	69	**205**
Redfish	52	59	63	18	79	71	37	5		8		33	50	101	**192**
White Hake	26	47	53	19	46	57	36	6				12	51	82	**145**
American Plaice	21	54	43	21	58	45	28	8		138			1		**139**
Monkfish	12	24	32	14	30	29	20	3				1	18	63	**82**
Cusk	17	23	27	13	20	32	24	4				2	29	49	**80**
Witch Flounder	5	28	27	18	19	31	23	5		57			5	16	**78**
Haddock	21	31	21	3	15	31	27	3		8		3	51	14	**76**

Species	Catch Weight Quartile Code Counts [a]				Catch Value Quartile Code Counts [b]				Vessel Length Class Total Quartile Code Counts [c]						Total Counts [d]
	1	2	3	4	1	2	3	4	1-34.9’	35-44.9’	45-64.9’	65-99.9’	100-124.9’	≥125’	
Cockle	1	13	16	42	4	18	11	39		72					**72**
Stimpson's Surf Clam	1	12	15	43	3	17	12	39		71					**71**
Pollock	10	18	30	13	20	26	21	4				1	25	45	**71**
Propeller Clam		10	15	43	3	14	12	39		68					**68**
Whelk	1	17	21	22	6	26	13	16				30	31		**61**
Bigeye Tuna	17	36	5	1	5	35	14	5				6	18	35	**59**
Silver Hake	2	18	22	8	17	19	12	2					5	45	**50**
Mahi Mahi (Dolphinfish)	12	16	12	3	4	17	11	11				11	32		**43**
Albacore Tuna	3	22	7	1	1	14	12	6				3	17	13	**33**
Atlantic Wolffish	30	2			22	9	1					28	4		**32**
Bluefin Tuna	18	10	2	1	11	12	5	3				1	20	10	**31**
Sea Cucumber		1	6	24		3	12	16				20	11		**31**
Roundnose Grenadier	28	2			21	8	1					30			**30**
Sea Scallop	2	5	4	11	3	6	1	12	11	8	1		2		**22**
Yellowfin Tuna	6	10	4	1	3	8	5	5				4	7	10	**21**
White Marlin	2	2	6	2		4	3	5				2	10		**12**
Atlantic Herring	1	2		1	3	1					1	3			**4**
Skate sp.	2	1		1	3		1					2	2		**4**
Atlantic Rock Crab	3				3							3			**3**
Capelin			1	1		2					1	1			**2**
Roughhead Grenadier		1	1			1	1						2		**2**
Argentine			1				1						1		**1**
Groundfish sp.	1				1								1		**1**
Blue Marlin	1					1						1			**1**
Pelagic sp.		1				1								1	**1**
Shark sp.	1				1							1			**1**
Total	**1126**	**1854**	**1911**	**1007**	**1290**	**1861**	**1741**	**1006**	**21**	**906**	**37**	**778**	**3075**	**1081**	**5898**

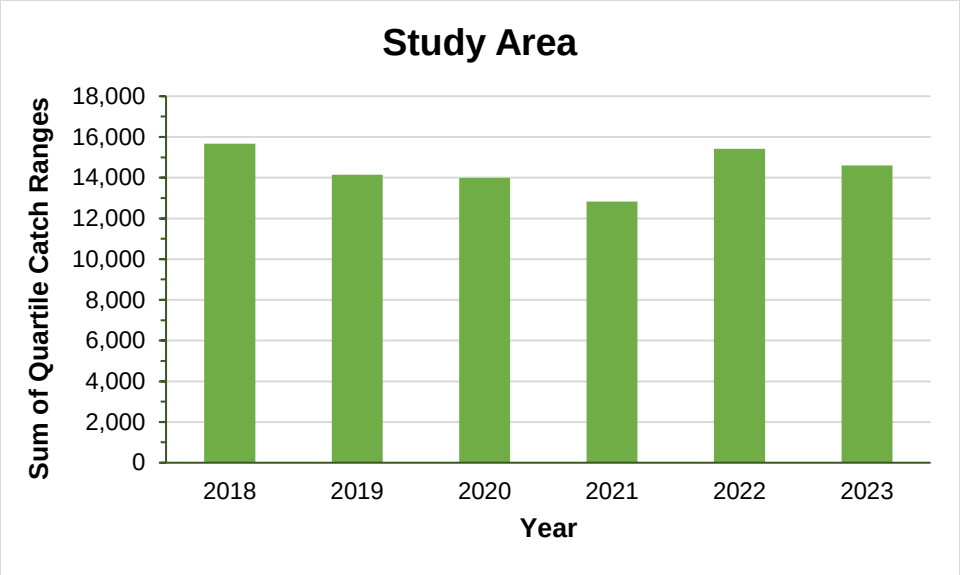
Source: DFO commercial landings database, All Atlantic Regions (2023).

[a] Quartile ranges provided by DFO (quartile ranges calculated annually by DFO based on total catch weights in a given year, all species combined). 2023 quartile ranges: 1 = 0-1859 kg; 2 = 1860-7992 kg; 3 = 7993-31,927 kg; 4 = ≥31,928 kg.

[b] Quartile ranges provided by DFO (Quartile ranges calculated annually by DFO based on total catch values in a given year, all species combined). 2023 quartile ranges: 1 = $0-$9662; 2 = $9663-$37,885; 3 = $37,886-$126,284; 4 = ≥$126,285.

[c] Includes the total quartile code count for ranges 1-4; total counts for catch weight and catch value are equal.

[d] Total counts of the number of catch records per species; the total quartile range counts for catch weight and catch value are equal.

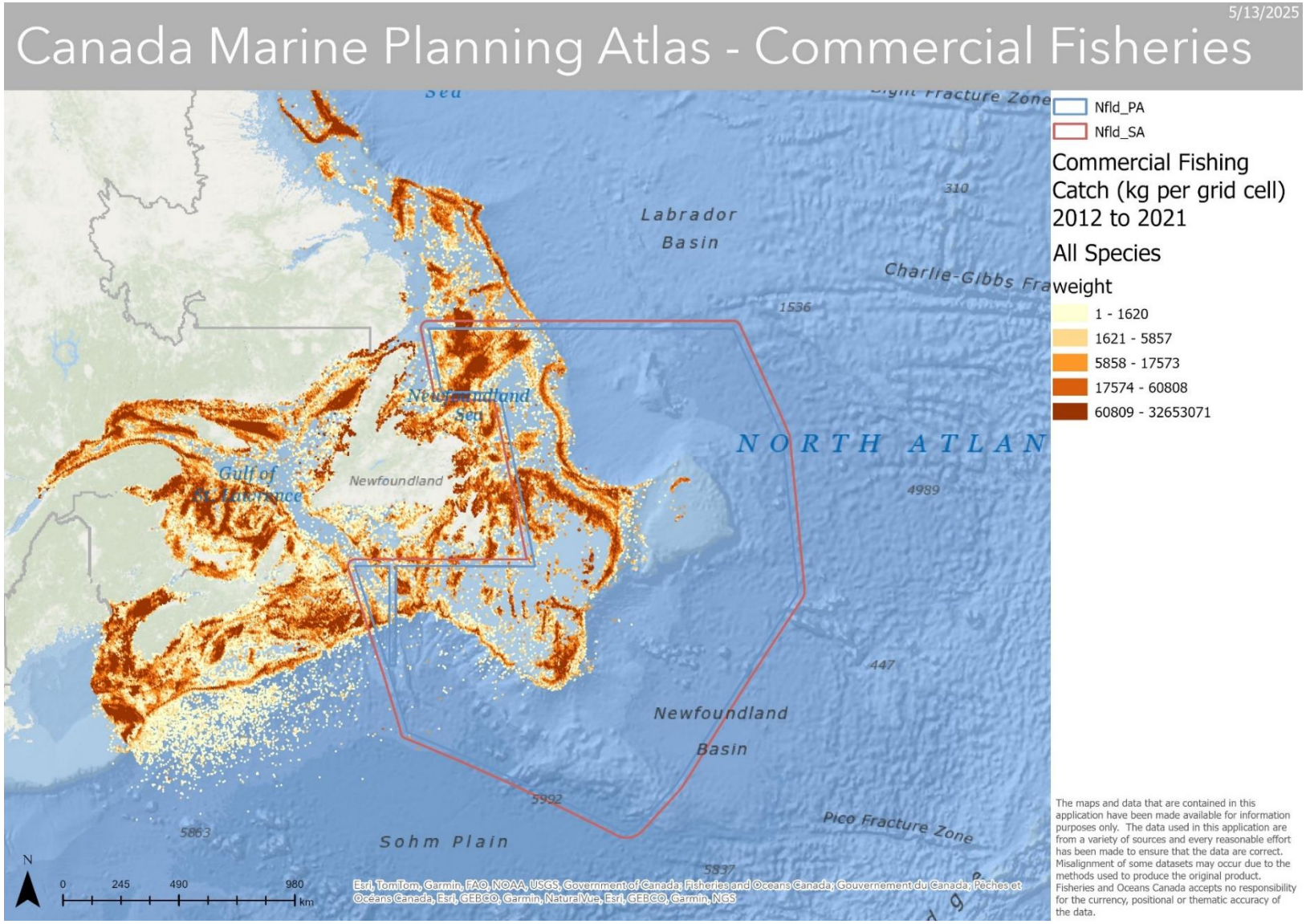


Source: DFO commercial landings database, All Atlantic Regions (2018–2023).
Notes:
Sum of quartile catch ranges is the summation of catch weight quartile ranges (i.e., 1–4) for all catch records for all species; the greater the sum of quartile range counts, the greater the catch weight for a given year.

Figure 4.4. Annual total catch weight quartile codes, May–November 2018–2023 (all species within the Study Area).

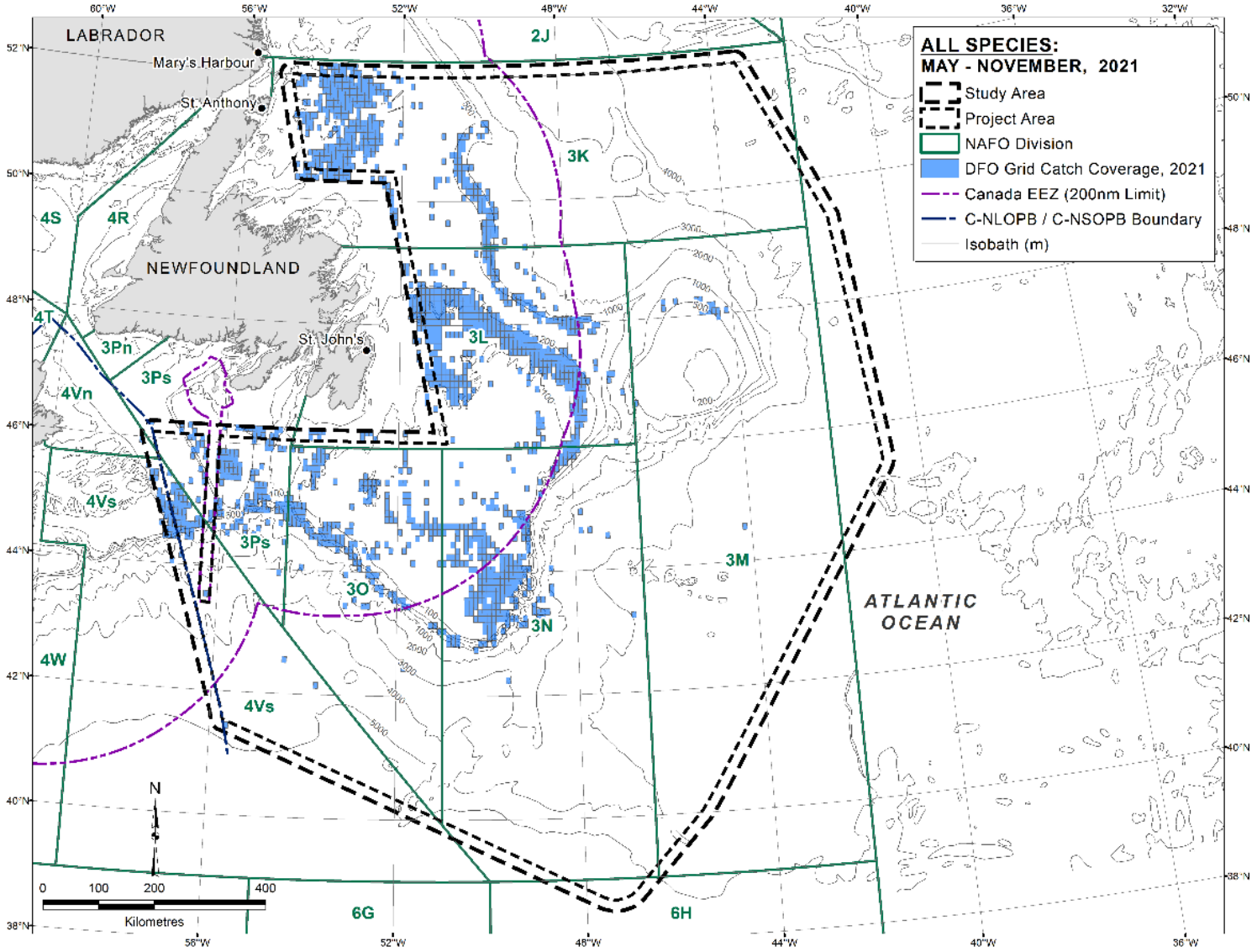
Commercial Harvest Locations in the Study Area

Year-round harvest locations for 2008–2012 are indicated in Figures 4.123–4.124 of C-NLOPB (2014) and for 2006 and 2007 in Figure 3.18 of C-NLOPB (2010). Grid cell harvest locations for May–November for the Study Area for 2015 are shown in Figure 4.5 of LGL (2018). Commercial harvest locations and relative catch weight for 2012–2021 in the Atlantic region are provided in Figure 4.5. Figure 4.6 shows grid cell harvest locations for all species within the Study Area, May–November 2021–2023. Minimal fish harvesting occurred in the eastern and southern portions of the Study Area. Most harvesting occurred on the shelf and slope of the Grand Banks out to the 1,000 m isobath. These locations are quite consistent from year to year, although some harvesting has extended further east than the historic norm in recent years, with catch locations in water depths ≥4000 m and near the northern Flemish Cap.



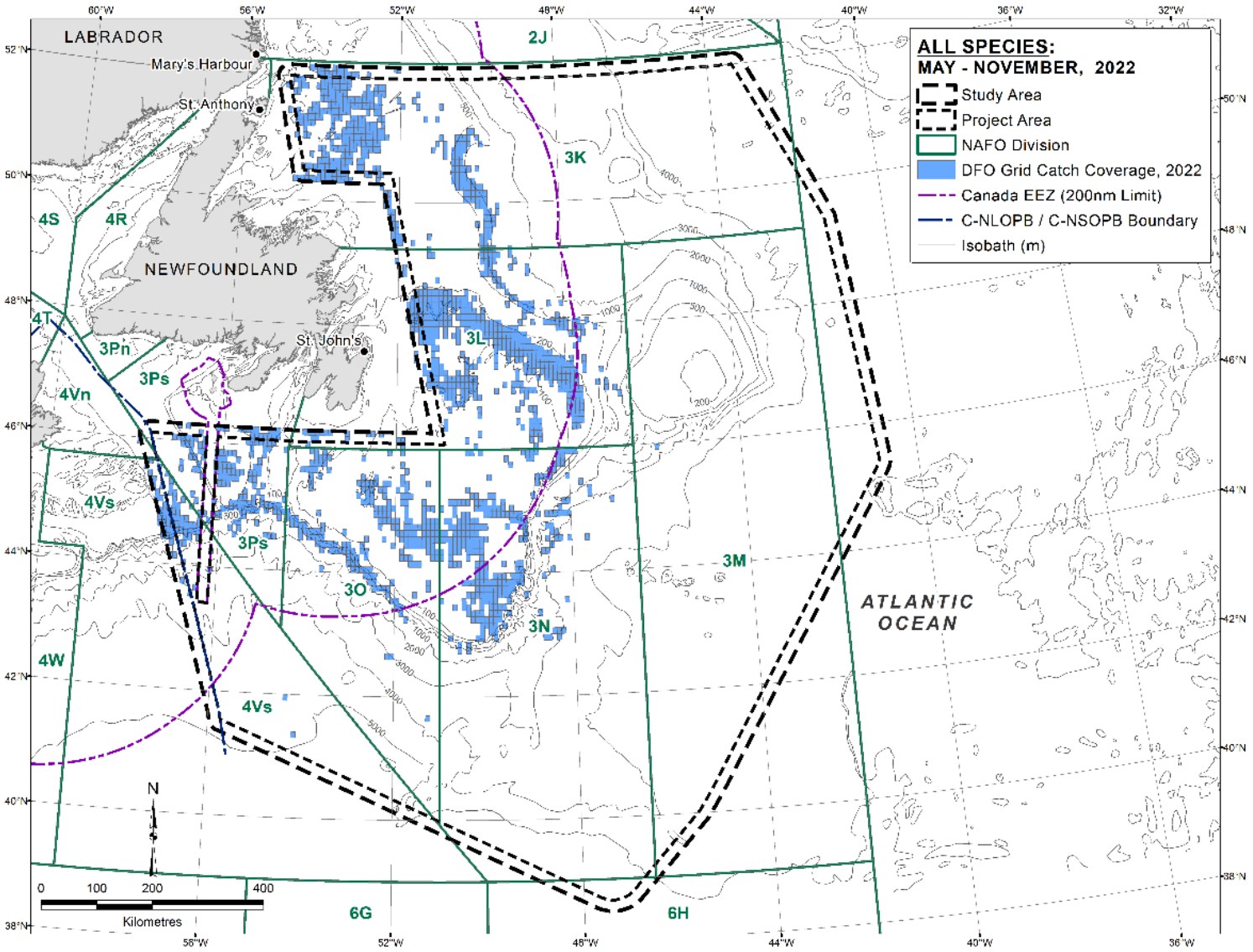
Source: DFO (2025f).

Figure 4.5. Distribution of commercial harvest locations and relative catch weight (kg), all species, 2012–2021.



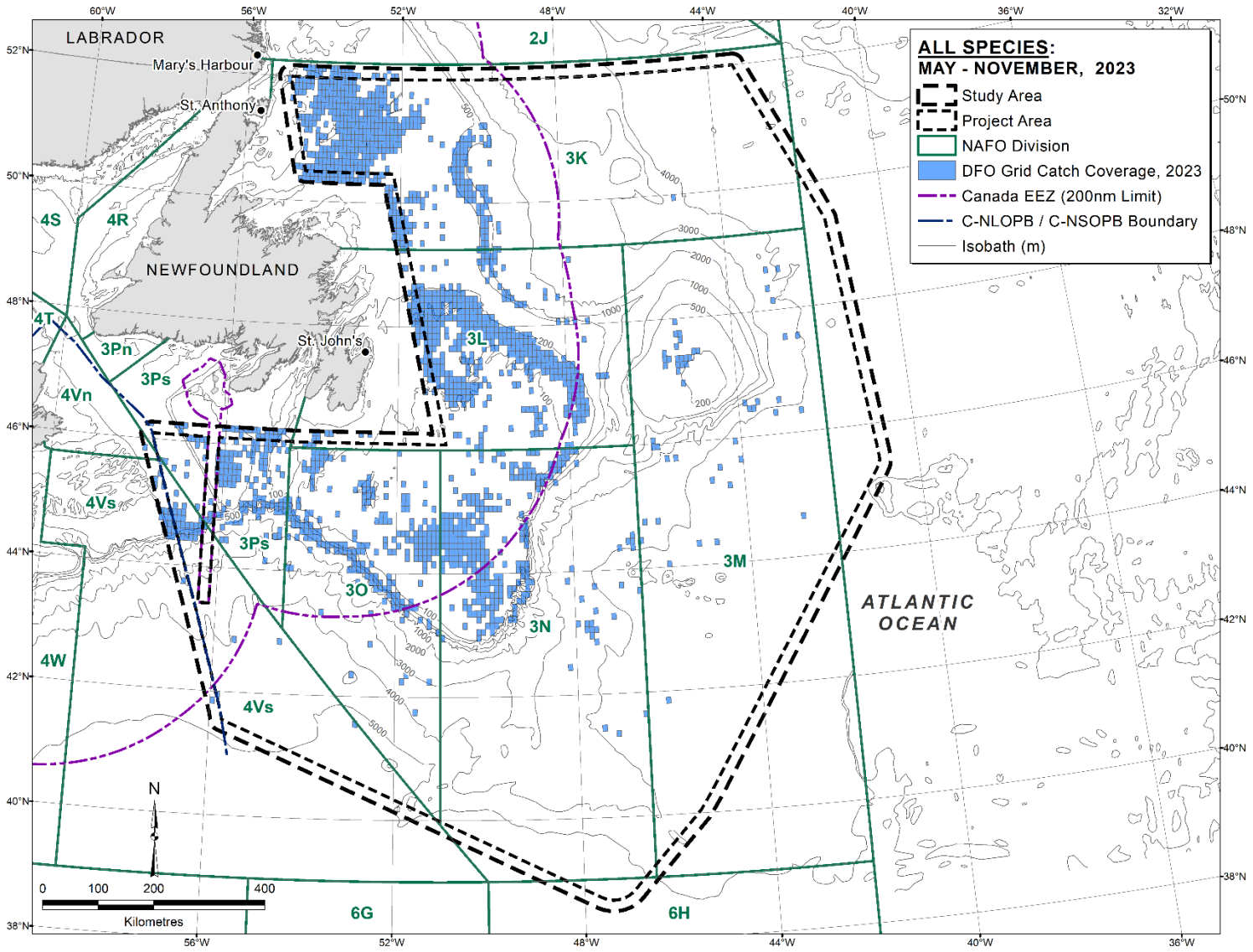
Source: DFO commercial landings database, 2021–2023.

Figure 4.6. Distribution of commercial harvest locations, all species, May–November 2021, 2022, 2023.



Source: DFO commercial landings database, 2021–2023.

Figure 4.6 (Continued). Distribution of commercial harvest locations, all species, May–November 2021, 2022, 2023.



Source: DFO commercial landings database, 2021–2023.

Figure 4.6 (Continued). Distribution of commercial harvest locations, all species, May–November 2021, 2022, 2023.

Fishing Gear Used in the Study Area

Fishing gears and harvest locations by gear type typically used in the Study Area are provided in Table 3.5 and Figures 2.19–3.20 in C-NLOPB (2010), Table 4.119 and Figure 4.137 of C-NLOPB (2014), and Table 4.10 and Figure 4.6 in LGL (2018). A variety of fishing gear types were used in the Study Area during May–November 2018–2024. Snow crab were targeted using pots (fixed gear), and Atlantic halibut were mainly caught using trawls (mobile) and longlines (fixed; Table 4.9). Atlantic cod were mainly harvested using trawls and, to a lesser extent, longlines (fixed). Northern shrimp were only caught, and redfish and yellowtail flounder were mainly caught using trawls. Greenland halibut were predominantly fished using gillnets (set of fixed) and trawls. Bivalve species were harvested using dredges (mobile) and large pelagics were mainly caught using free-floating longline gear.

Fishing with fixed gear (e.g., pot fishery for snow crab) poses the highest potential for conflict with Project activities, because they use submerged lines attached to buoys at the ocean surface which can be snagged by towed seismic gear, causing damage to both the fishing gear and seismic streamer(s). Fixed gear is often set in one location for several days at a time, can be difficult to detect, and may be deployed over long distances in the water. The risk for potential conflict is reduced through the use of OBNs, by eliminating the presence of towed streamers that could entangle with surface buoys and/or lines attached to fixed fishing gear.

Mobile and fixed gear harvest locations offshore eastern Newfoundland are shown in Figures 4.138–4.139 of C-NLOPB (2014). Fixed and mobile gear harvest locations in the Study Area during May–November 2015 are shown in Figure 4.6 of LGL (2018). Figures 4.7–4.9 show fixed, mobile, and free-floating gear catch locations in the Study Area during May–November 2021–2023.

Table 4.9. Summary of gear types used in the commercial fishery in the Study Area, by species, May–November 2018–2023.

Species	Mobile									Fixed						Free-Floating	Unknown
	T	S	D	EH	HL	H	RR	SCD	TL	Gd	Gf	JP	L	P	TN		
Snow Crab												■		■			
Atlantic Halibut	■	■	■								■		■				■
Greenland Halibut	■	■									■		■				■
Atlantic Cod	■	■			■						■		■	■			■
Northern Shrimp	■																
Redfish	■	■	■								■		■				■
Yellowtail Flounder	■										■		■				
White Hake	■	■									■		■				■
American Plaice	■										■		■				
Pollock	■	■									■		■				■
Cusk	■	■									■		■				
Witch Flounder	■																
Monkfish	■	■									■		■				
Haddock	■	■									■		■				■
Swordfish						■										■	
Stimpson's Surf Clam			■														
Cockle			■														
Propellor Clam			■														
Sea Cucumber			■					■									
Albacore Tuna																■	
Mako Shark											■					■	
Sea Scallop			■														
Bigeye Tuna																■	
Whelk														■			
Skate sp.	■										■		■	■			
Silver Hake	■												■				
Bluefin Tuna				■			■		■							■	
Dolphinfish																■	
Roughead Grenadier											■		■				
Atlantic Wolffish													■				
White Marlin																■	
Yellowfin Tuna																■	
Roundnose Grenadier													■				
Capelin		■													■		
Atlantic Herring		■								■	■		■				
Winter Flounder	■												■				
Mackerel		■			■						■		■				
Iceland Scallop			■														

Species	Mobile									Fixed						Free-Floating	Unknown
	T	S	D	EH	HL	H	RR	SCD	TL	Gd	Gf	JP	L	P	TN		
Blue Shark																■	
Lobster														■			
Toad Crab														■			
Ocean Quahaug			■														
Argentine	■																
Squid sp.													■				
Atlantic Rock Crab														■			
Quahaug Clam			■														
Pelagic sp.													■				
Shark sp.																■	
Blue Marlin																■	
Groundfish sp.													■				
Jonah Crab														■			

Source: DFO commercial landings database, 2018–2023.

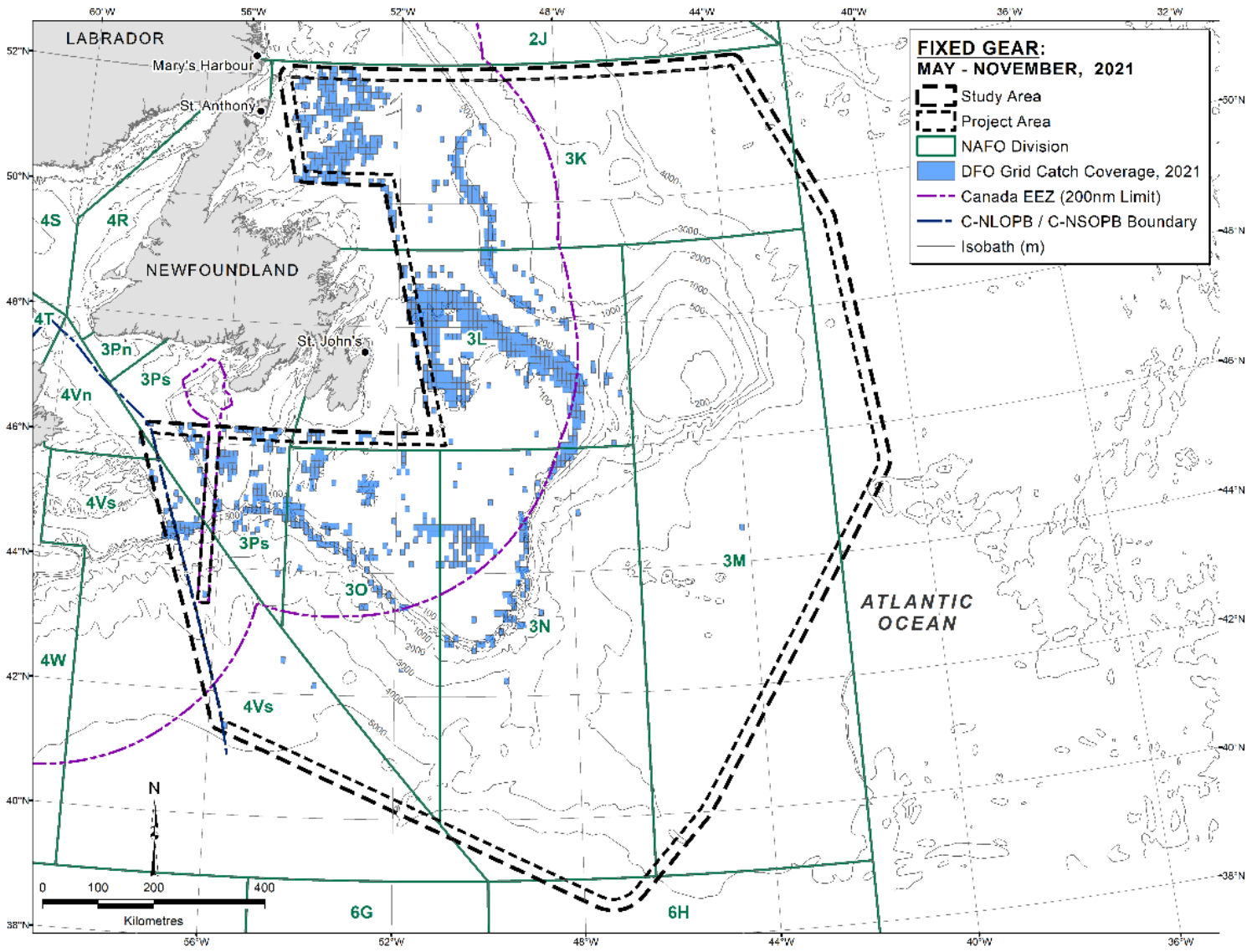
Notes:

Shaded cell indicates harvest occurred using a given gear type; depending on the species and gear type in question, harvest may have been directed or bycatch.

Mobile Gear: T = Trawl (Bottom Otter and/or Shrimp); S = Seine (Danish, Purse, Scottish, and/or Tuck); D = Dredge (boat); EH = Electric Harpoon; H = Harpoon; HL = Hand Line (baited); RR = Rod and Reel (trolling); SCD = Sea Cucumber Drag; T = Shrimp Trawl; TL = Troller Lines.

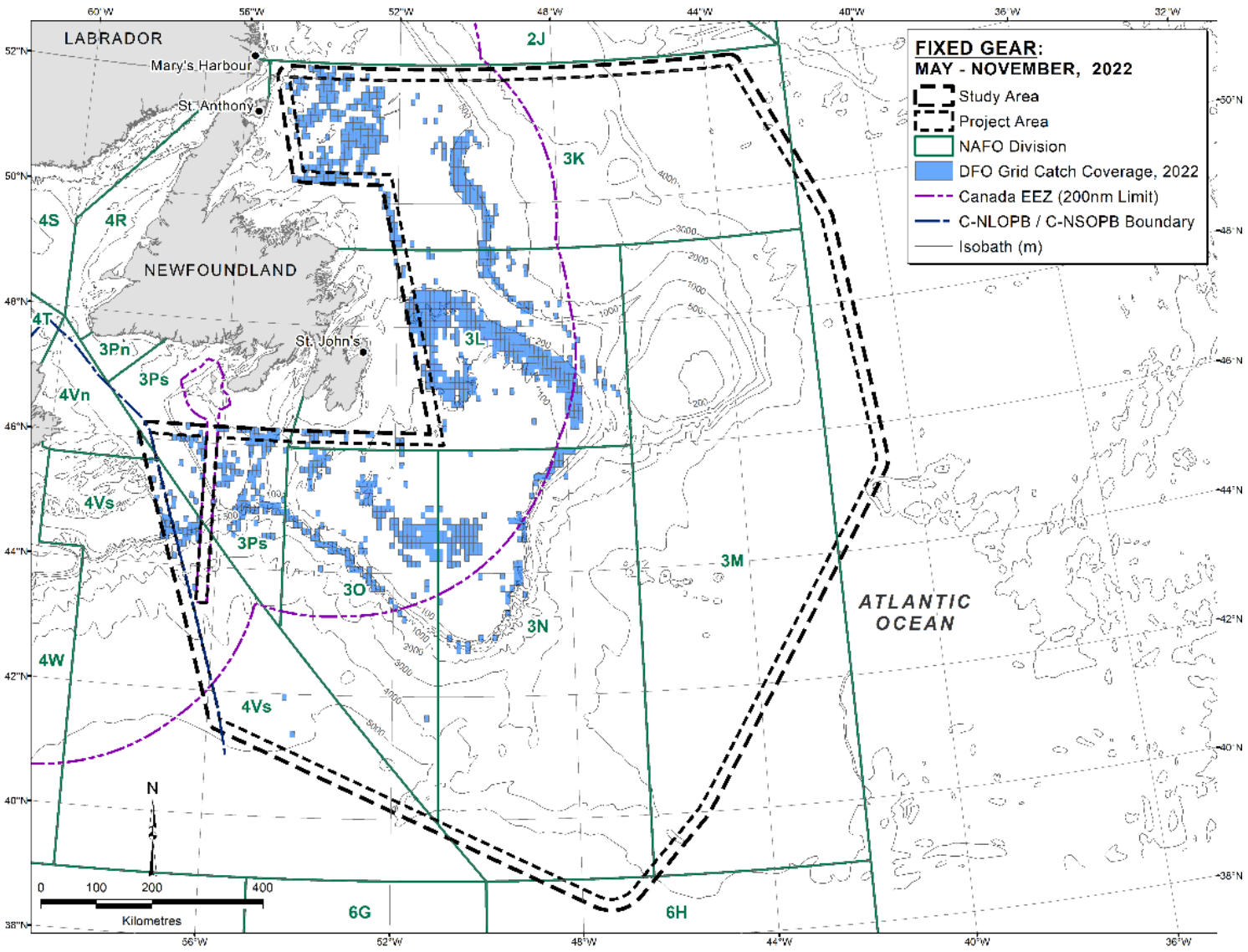
Fixed Gear: Gd = Gillnet (drift); Gf = Gillnet (set of fixed); JP = Japanese Trap; L = Longline; P = Pot; TN = Trap Net.

Free-Floating: Longline gear for large pelagics.



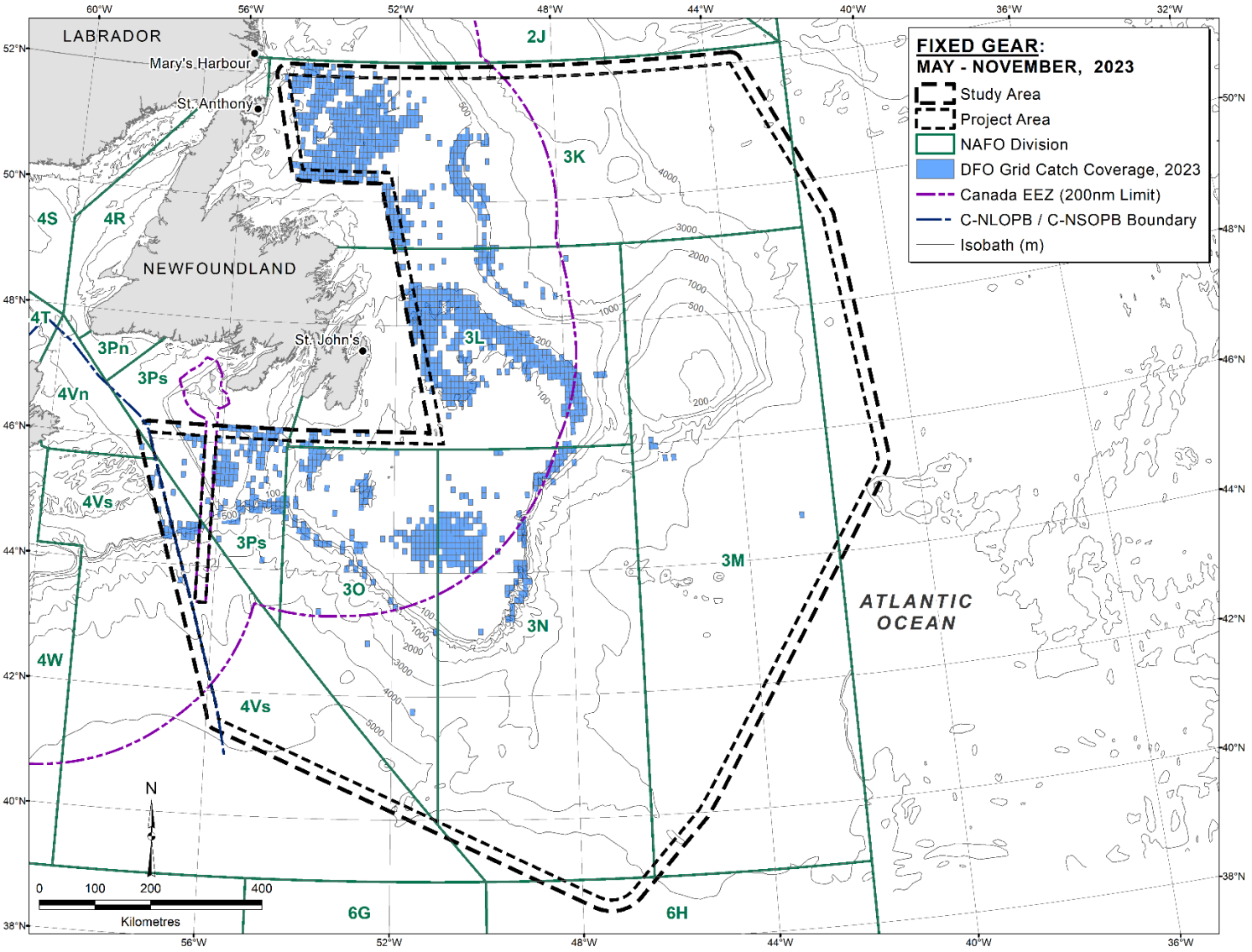
Source: DFO commercial landings database, 2021–2023.

Figure 4.7. Distribution of fixed gear commercial harvest locations, all species, May–November 2021, 2022, 2023.



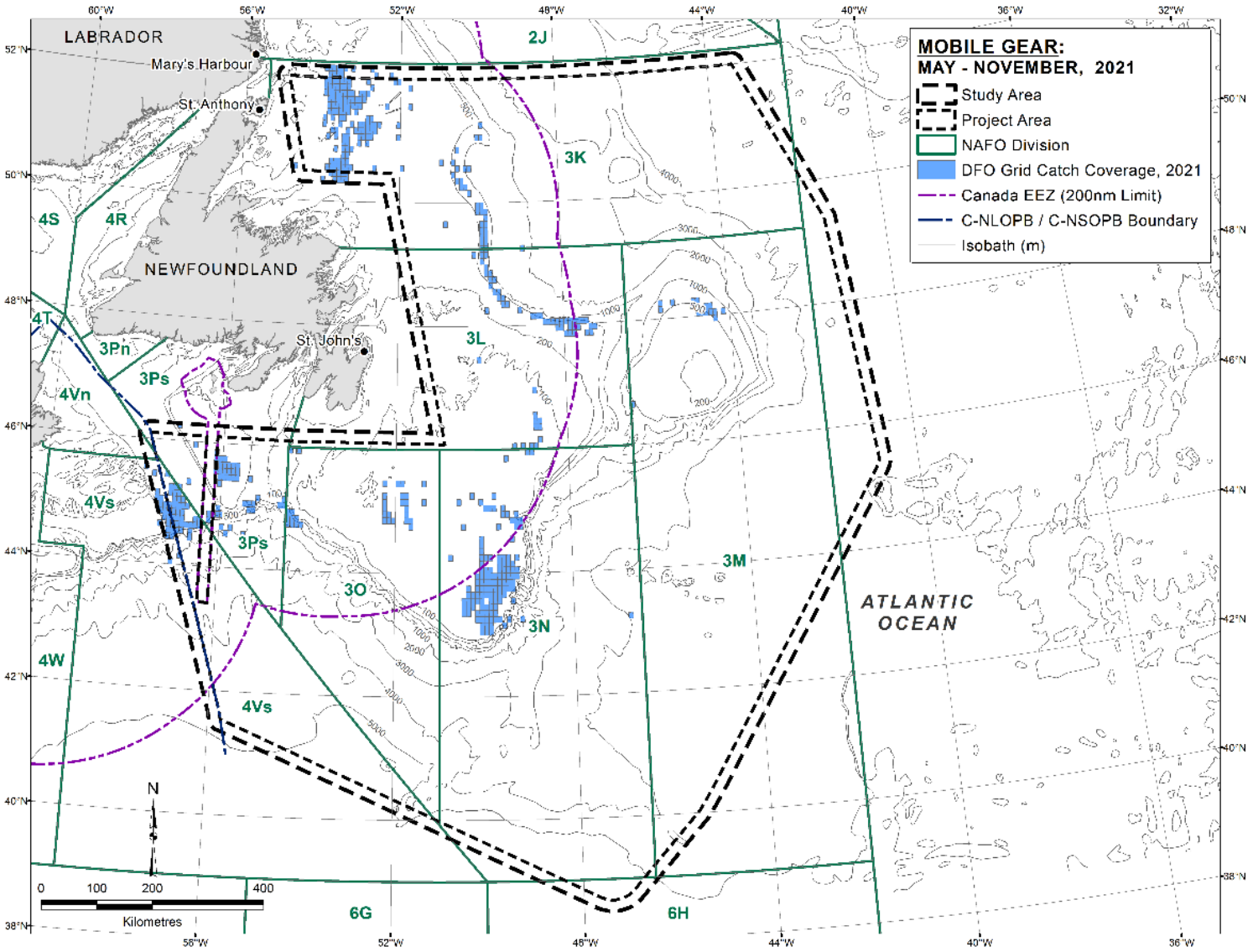
Source: DFO commercial landings database, 2021–2023.

Figure 4.7 (Continued). Distribution of fixed gear commercial harvest locations, all species, May–November 2021, 2022, 2023.



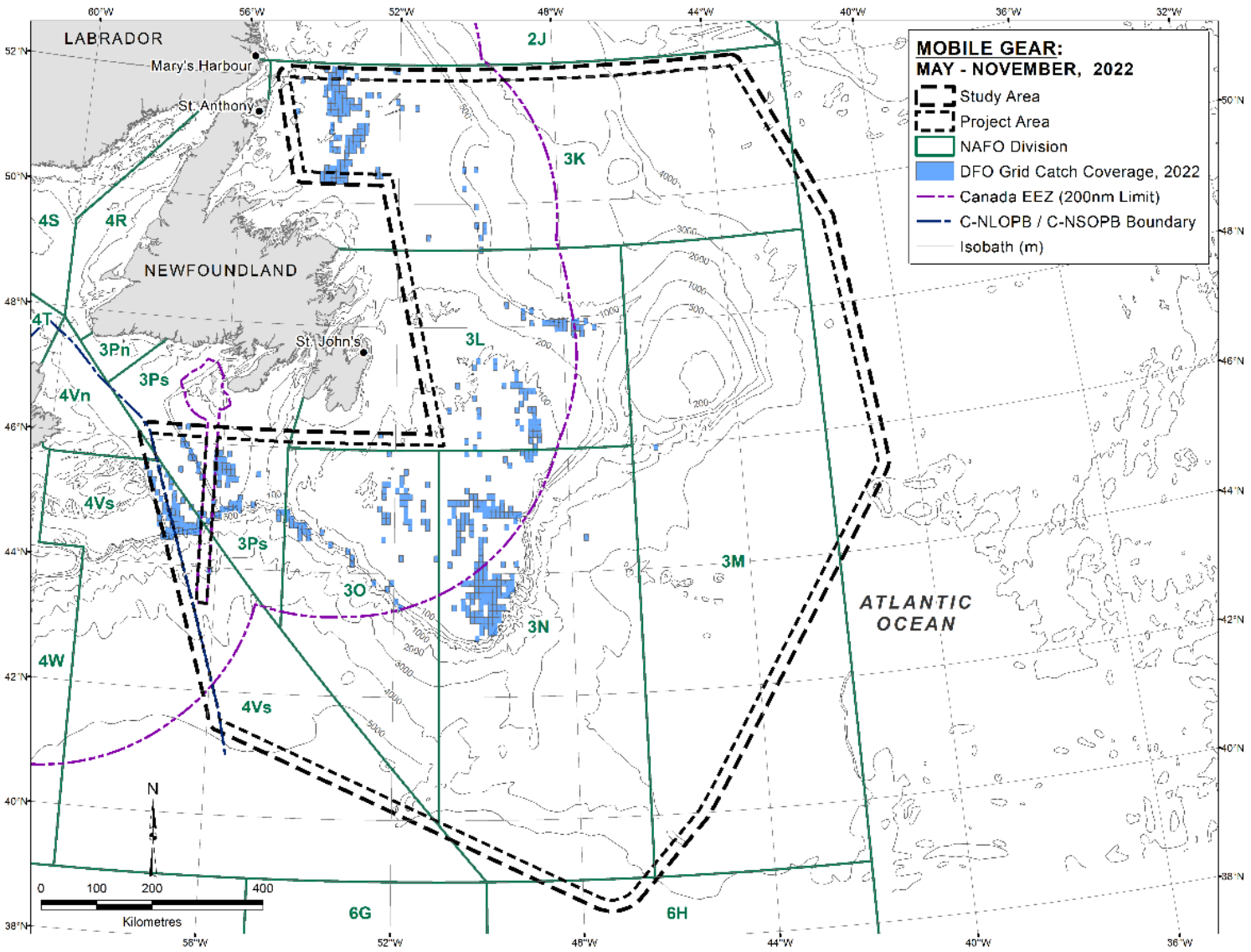
Source: DFO commercial landings database, 2021–2023.

Figure 4.7 (Continued). Distribution of fixed gear commercial harvest locations, all species, May–November 2021, 2022, 2023.



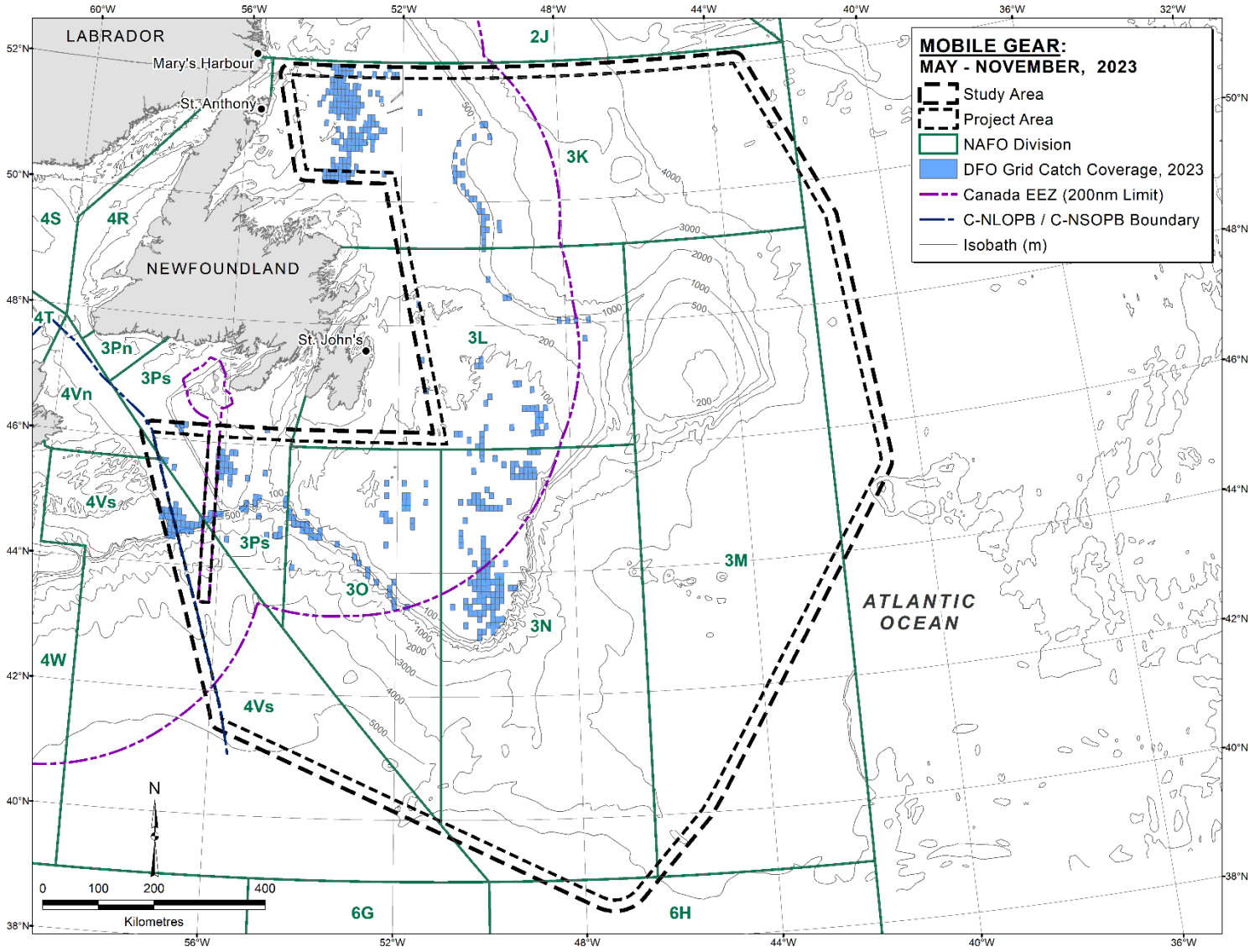
Source: DFO commercial landings database, 2021–2023.

Figure 4.8. Distribution of mobile gear commercial harvest locations, all species, May–November 2021, 2022, 2023.



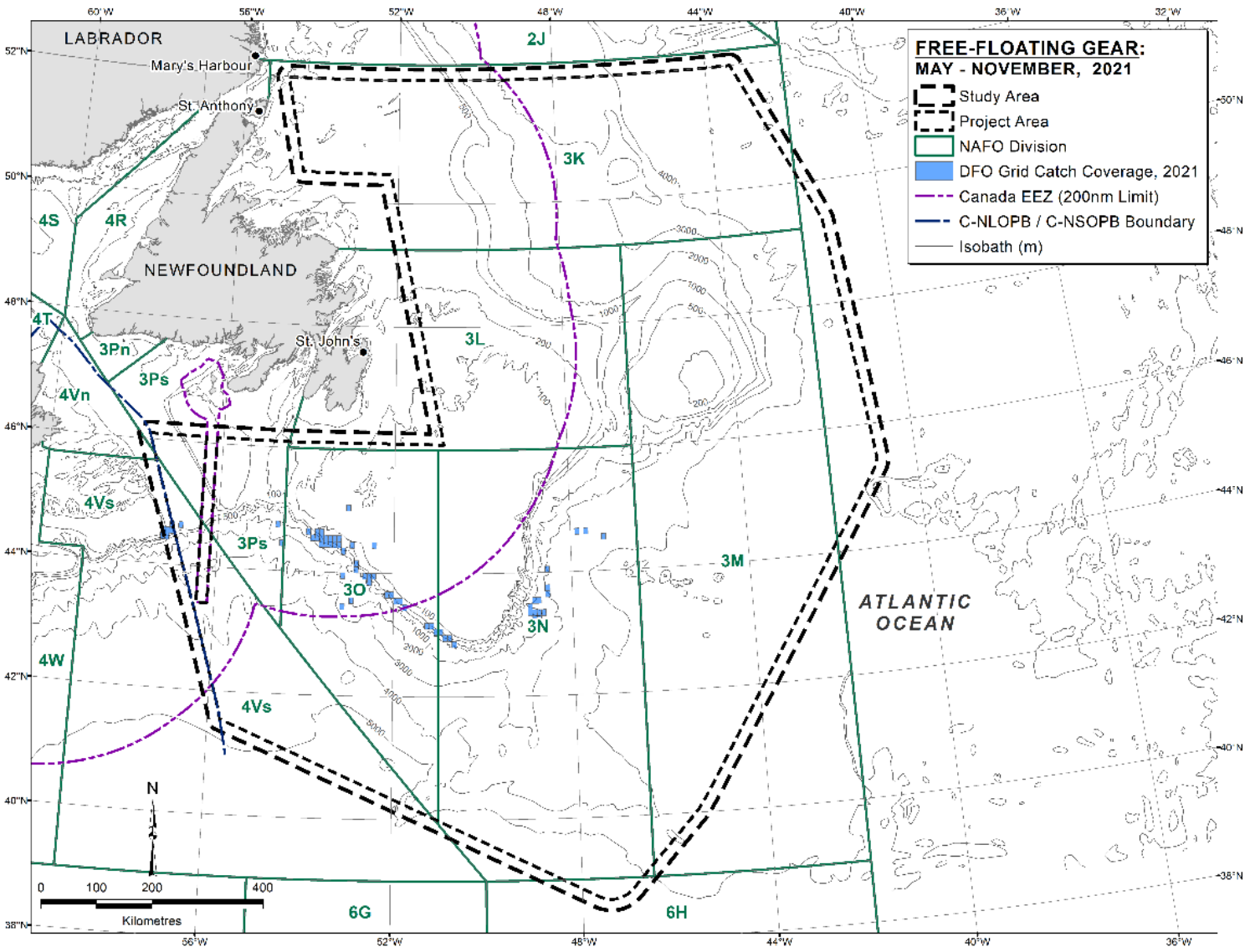
Source: DFO commercial landings database, 2021–2023.

Figure 4.8 (Continued). Distribution of mobile gear commercial harvest locations, all species, May–November 2021, 2022, 2023.



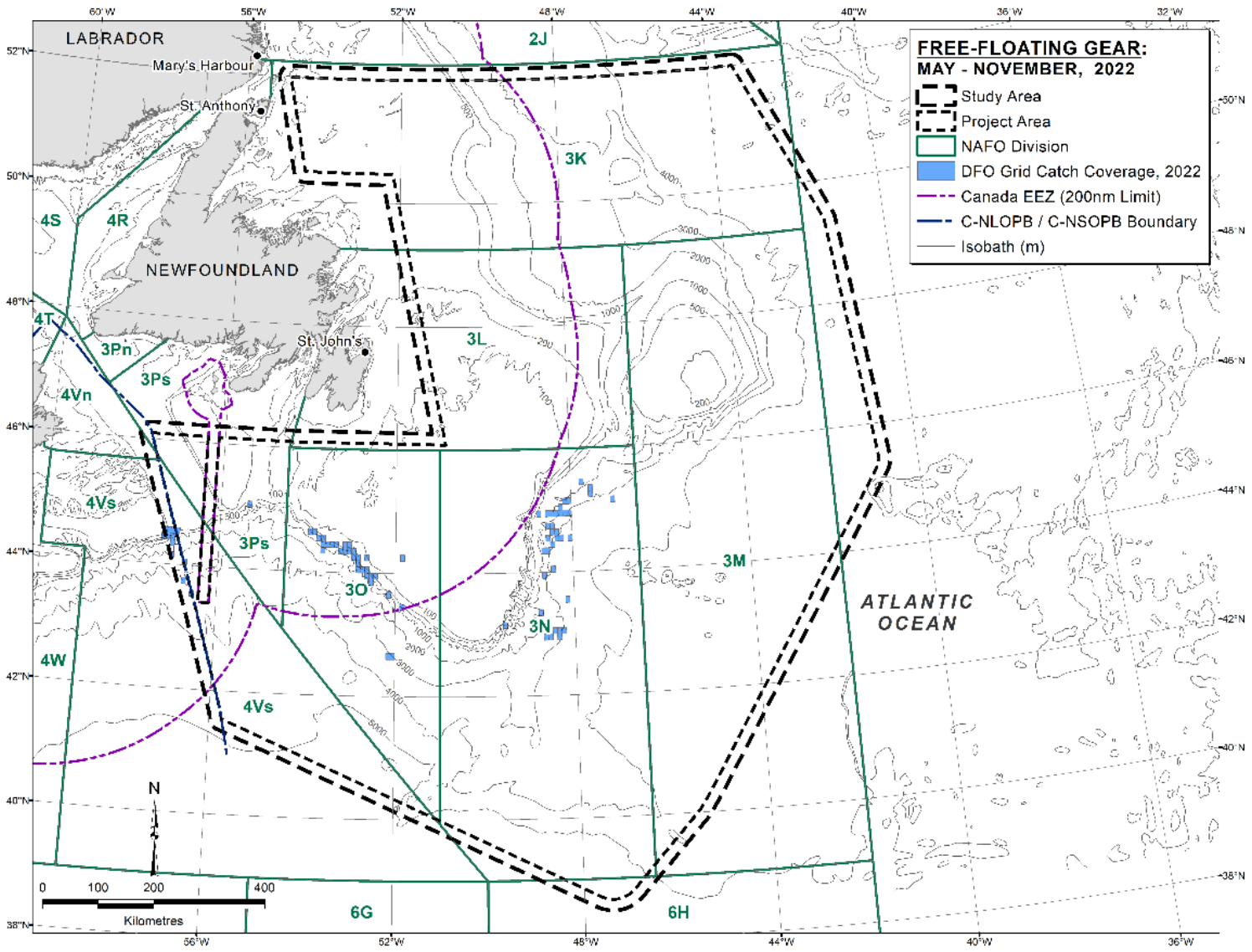
Source: DFO commercial landings database, 2021–2023.

Figure 4.8 (Continued). Distribution of mobile gear commercial harvest locations, all species, May–November 2021, 2022, 2023.



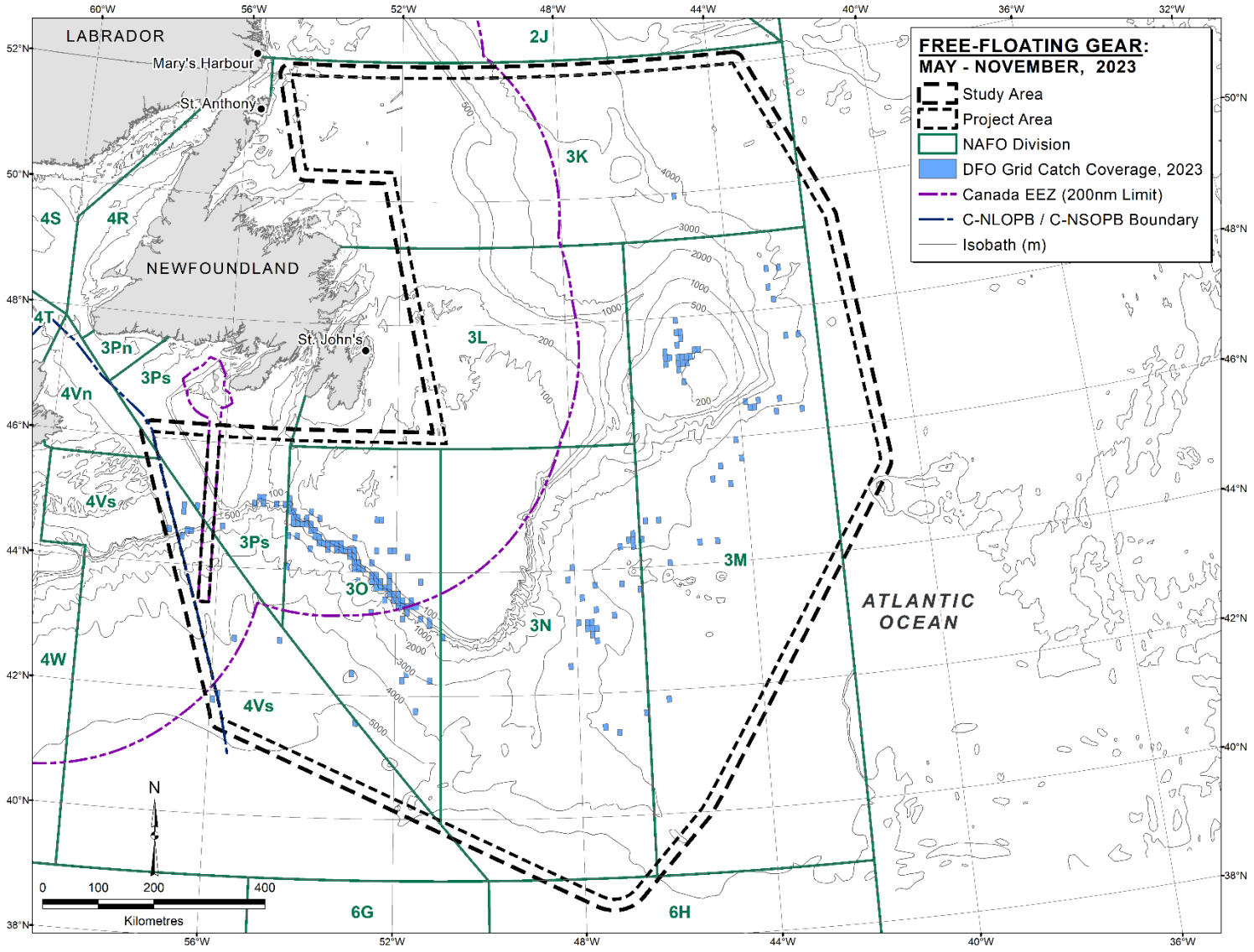
Source: DFO commercial landings database, 2021–2023.

Figure 4.9. Distribution of free-floating gear commercial harvest locations, all species, May–November 2021, 2022, 2023.



Source: DFO commercial landings database, 2021–2023.

Figure 4.9 (Continued). Distribution of free-floating gear commercial harvest locations, all species, May–November 2021, 2022, 2023.

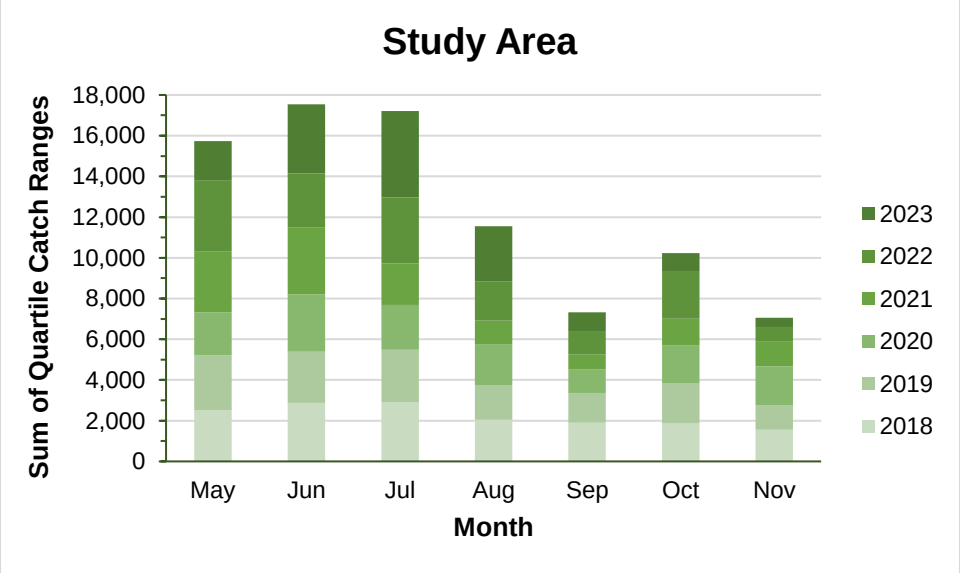


Source: DFO commercial landings database, 2021–2023.

Figure 4.9 (Continued). Distribution of free-floating gear commercial harvest locations, all species, May–November 2021, 2022, 2023.

Harvest Timing in the Study Area

The total sum of monthly catch weight quartile codes for all species combined for May–November 2018–2023 are indicated in Figure 4.10. Monthly catch weights were highest during the May–July period and lowest during the fall. Note that the timing of harvesting can vary from year to year depending on resource availability, fisheries management plans, and enterprise harvesting strategies. Within the Study Area, snow crab are harvested during May–August, while Atlantic halibut are caught throughout the May–November period (Table 4.10). Atlantic cod, Greenland halibut, redfish, and yellowtail flounder are also caught throughout the May–November period. Northern shrimp are harvested during the spring and summer months, and variably caught during early- to mid-fall. Various other species are typically caught throughout most or all the May–November period in the Study Area, such as white hake, American plaice, pollock, cusk, witch flounder, monkfish, haddock, Stimpson's surf clam, cockle, and propellor clam.



Source: DFO commercial landings database, 2018–2023.
Notes:
Sum of quartile catch ranges is the summation of catch weight quartile ranges (i.e., 1–4) for all catch records for all species; the greater the sum of quartile range counts, the greater the catch weight for a given month.

Figure 4.10. Total monthly sum of catch weight quartile codes, May–November 2018–2023 (all species within the Study Area).

Table 4.10. Summary of monthly timing of the commercial fishery in the Study Area, May–November 2018–2023.

Species	Harvest Month						
	May	Jun	Jul	Aug	Sep	Oct	Nov
Snow Crab	■	■	■	■			
Atlantic Halibut	■	■	■	■	■	■	■
Greenland Halibut	■	■	■	■	■	■	■
Atlantic Cod	■	■	■	■	■	■	■
Northern Shrimp	■	■	■	■	■	■	■
Redfish	■	■	■	■	■	■	■
Yellowtail Flounder	■	■	■	■	■	■	■
White Hake	■	■	■	■	■	■	■
American Plaice	■	■	■	■	■	■	■
Pollock	■	■	■	■	■	■	■
Cusk	■	■	■	■	■	■	■
Witch Flounder	■	■	■	■	■	■	■
Monkfish	■	■	■	■	■	■	■
Haddock	■	■	■	■	■	■	■
Swordfish		■	■	■	■	■	■
Stimpson's Surf Clam	■	■	■	■	■	■	■
Cockle	■	■	■	■	■	■	■
Propellor Clam	■	■	■	■	■	■	
Sea Cucumber		■	■	■	■	■	■
Albacore Tuna		■	■	■	■	■	■
Mako Shark			■	■	■	■	
Sea Scallop	■	■	■	■	■	■	■
Bigeye Tuna		■	■	■	■	■	■
Whelk	■	■	■	■	■	■	■
Skate sp.	■	■	■	■	■	■	
Silver Hake	■	■	■	■		■	■
Bluefin Tuna		■	■	■	■	■	■
Dolphinfish			■	■	■	■	
Roughead Grenadier				■			
Atlantic Wolffish	■	■	■	■			
White Marlin			■	■	■		
Yellowfin Tuna			■	■	■	■	
Roundnose Grenadier				■	■		■
Capelin			■	■	■		
Atlantic Herring	■			■	■	■	■
Winter Flounder		■				■	
Mackerel	■	■			■	■	
Iceland Scallop		■	■	■	■		■
Blue Shark				■			
Lobster				■	■	■	■
Toad Crab		■					
Ocean Quahaug	■		■				
Argentine		■	■				
Squid sp.	■						
Atlantic Rock Crab			■			■	■
Quahaug Clam	■						
Pelagic sp.		■		■			
Blue Marlin				■			
Groundfish sp.		■					
Shark sp.						■	
Jonah Crab					■		

Source: DFO commercial landings database, 2018–2023.

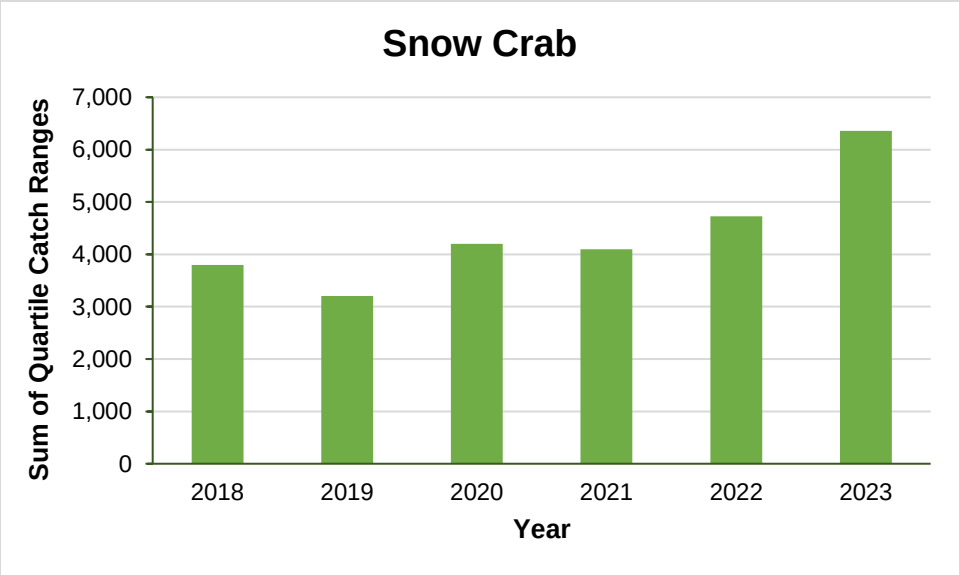
Notes:

Shaded cell indicates harvest occurred during a given month (either directed or bycatch).

Principal Species in the Study Area

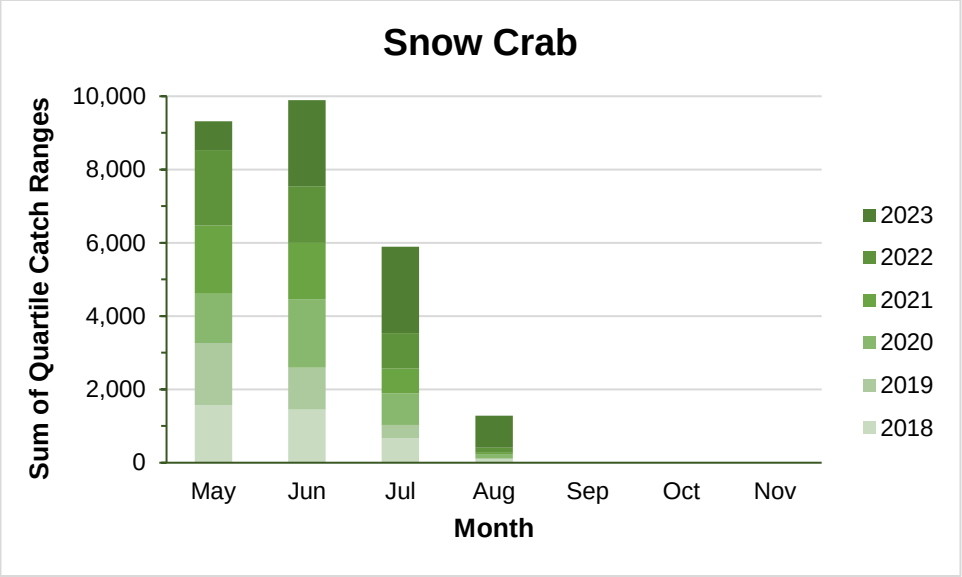
Snow Crab

In terms of both catch weight and value, snow crab was the most important commercial species in the Study Area during May–November 2018–2023. Although there were interannual variations, the total sum of annual quartile catch weights remained relatively steady (Figure 4.11). Snow crab were captured between May and August in the Study Area, with most of the catch taken during May and June (Figure 4.12). Snow crab harvest locations in the Study Area during 2015 are provided in LGL (2018). During May–November 2021–2023, most snow crab were caught in the western portion of the Study and Project Areas, in water depths <200 m (Figure 4.13).



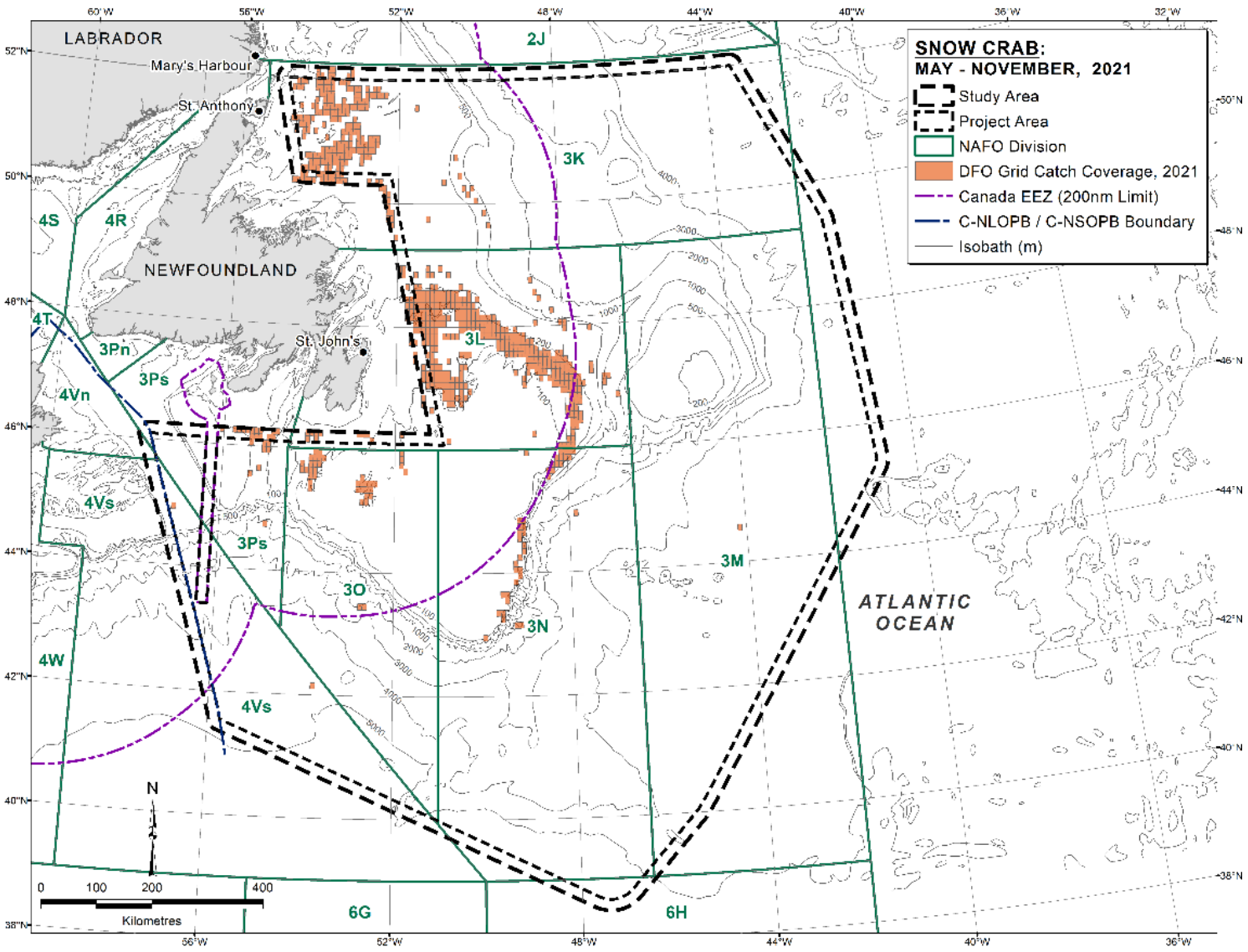
Source: DFO commercial landings database, 2018–2023.
Notes:
Sum of quartile catch ranges is the summation of catch weight quartile ranges (i.e., 1–4) for all catch records for all species; the greater the sum of quartile range counts, the greater the catch weight for a given year.

Figure 4.11. Total sum of annual catch weight quartile codes for snow crab in the Study Area, May–November 2018–2023.



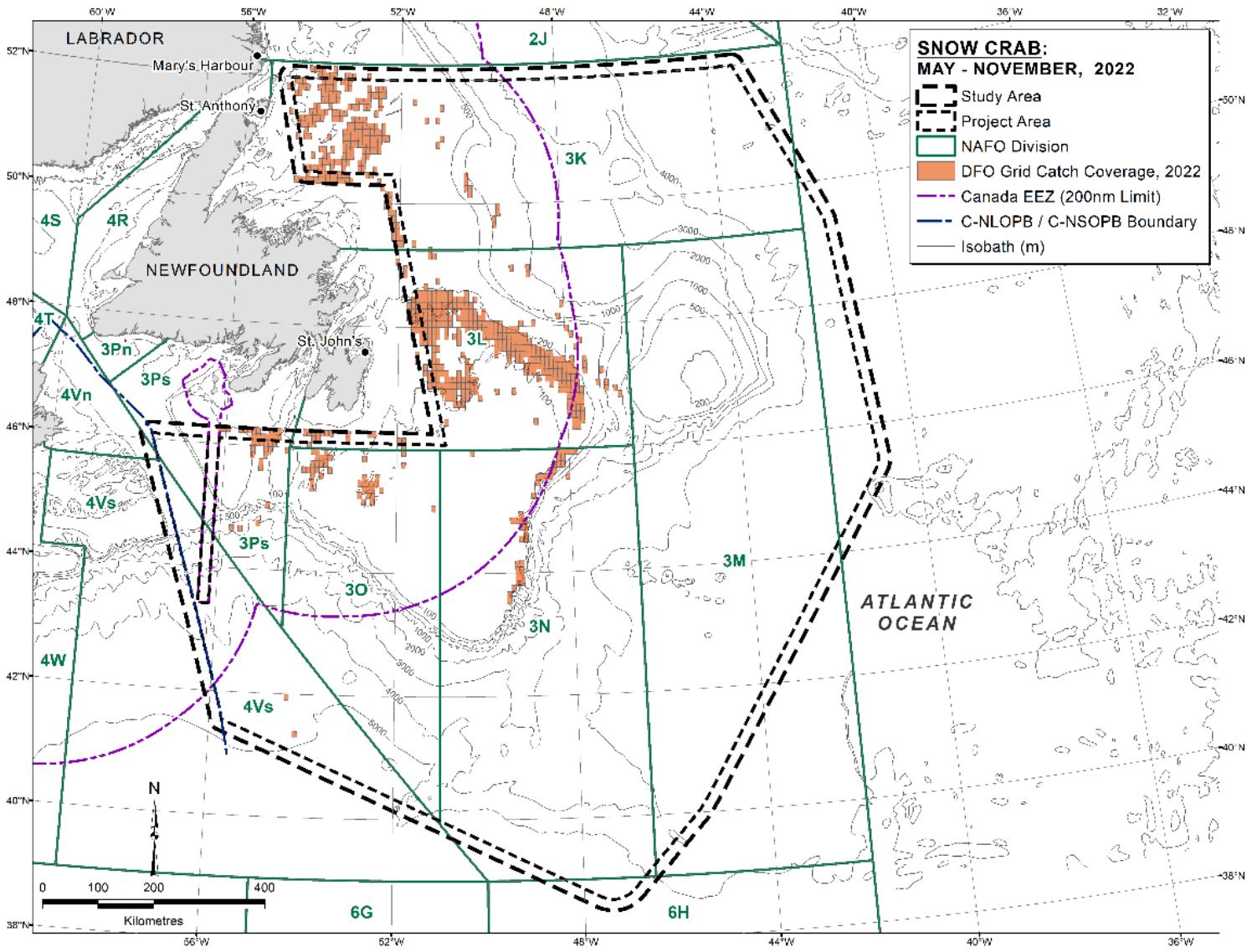
Source: DFO commercial landings database, 2018–2023.
Notes:
Sum of quartile catch ranges is the summation of catch weight quartile ranges (i.e., 1–4) for all catch records for all species; the greater the sum of quartile range counts, the greater the catch weight for a given month.

Figure 4.12. Total sum of monthly catch weight quartile codes for snow crab in the Study Area, May–November 2018–2023.



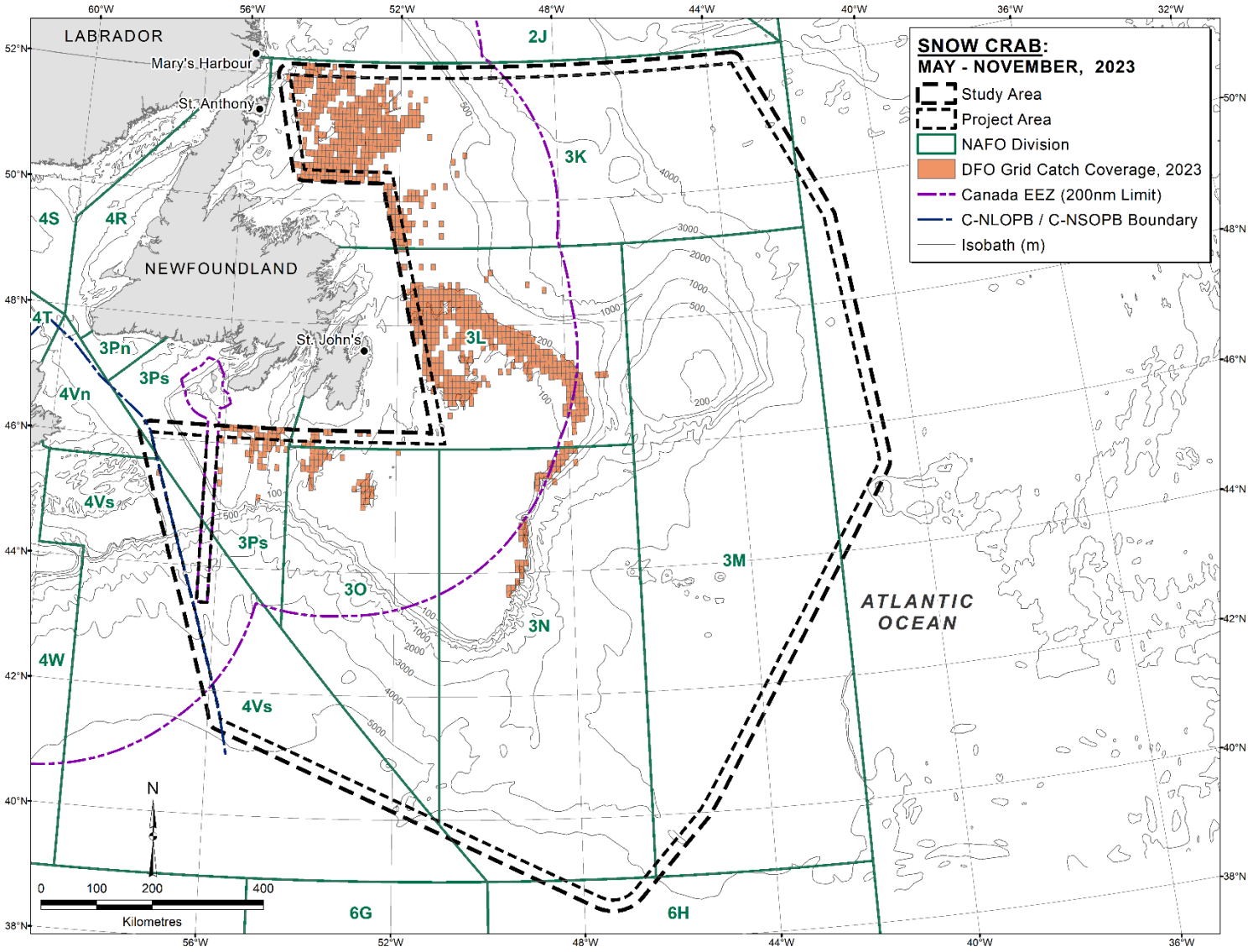
Source: DFO commercial landings database, 2021–2023.

Figure 4.13. Distribution of commercial harvest locations for snow crab in the Study Area, May–November 2021, 2022, 2023.



Source: DFO commercial landings database, 2021–2023.

Figure 4.13 (Continued). Distribution of commercial harvest locations for snow crab in the Study Area, May–November 2021, 2022, 2023.

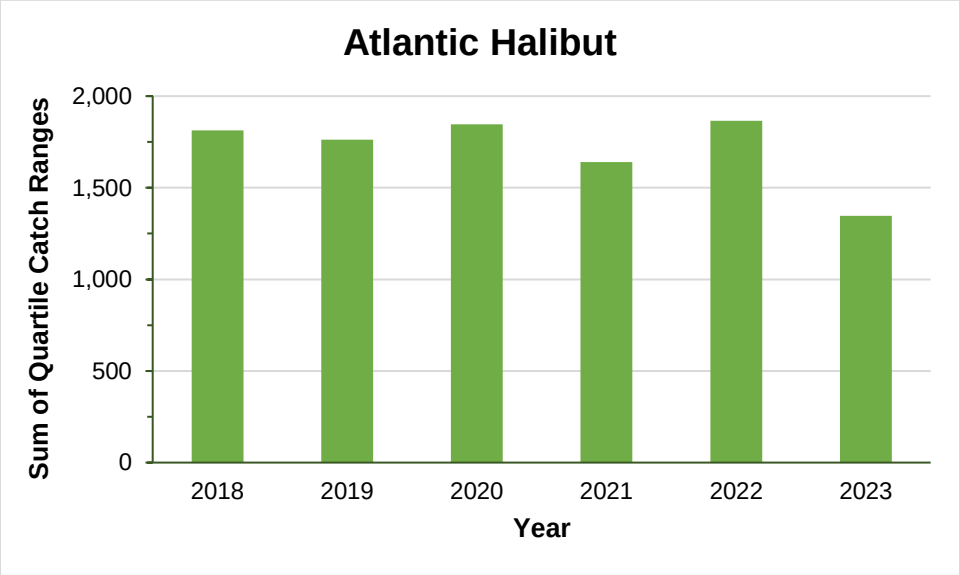


Source: DFO commercial landings database, 2021–2023.

Figure 4.13 (Continued). Distribution of commercial harvest locations for snow crab in the Study Area, May–November 2021, 2022, 2023.

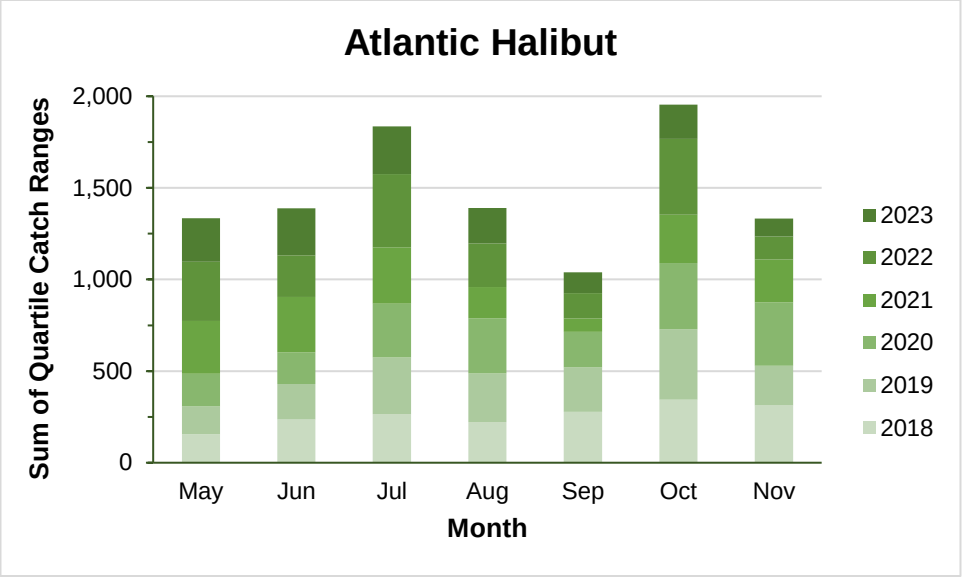
Atlantic Halibut

In terms of both catch weight and value, Atlantic halibut was the second most important commercial species in the Study Area during May–November 2018–2023. The total sum of annual quartile catches remained relatively steady for Atlantic halibut in the Study Area, although there were some increases during the latter portion of this period (Figure 4.14). Atlantic halibut were captured throughout May–November in the Study Area, with most catches occurring during July and October (Figure 4.15). Atlantic halibut harvest locations in the Study Area during 2015 are provided in LGL (2018). During May–November 2018–2023, most Atlantic halibut were caught in the western portion of the Study and Project Areas, in water depths <1000 m (Figure 4.16).



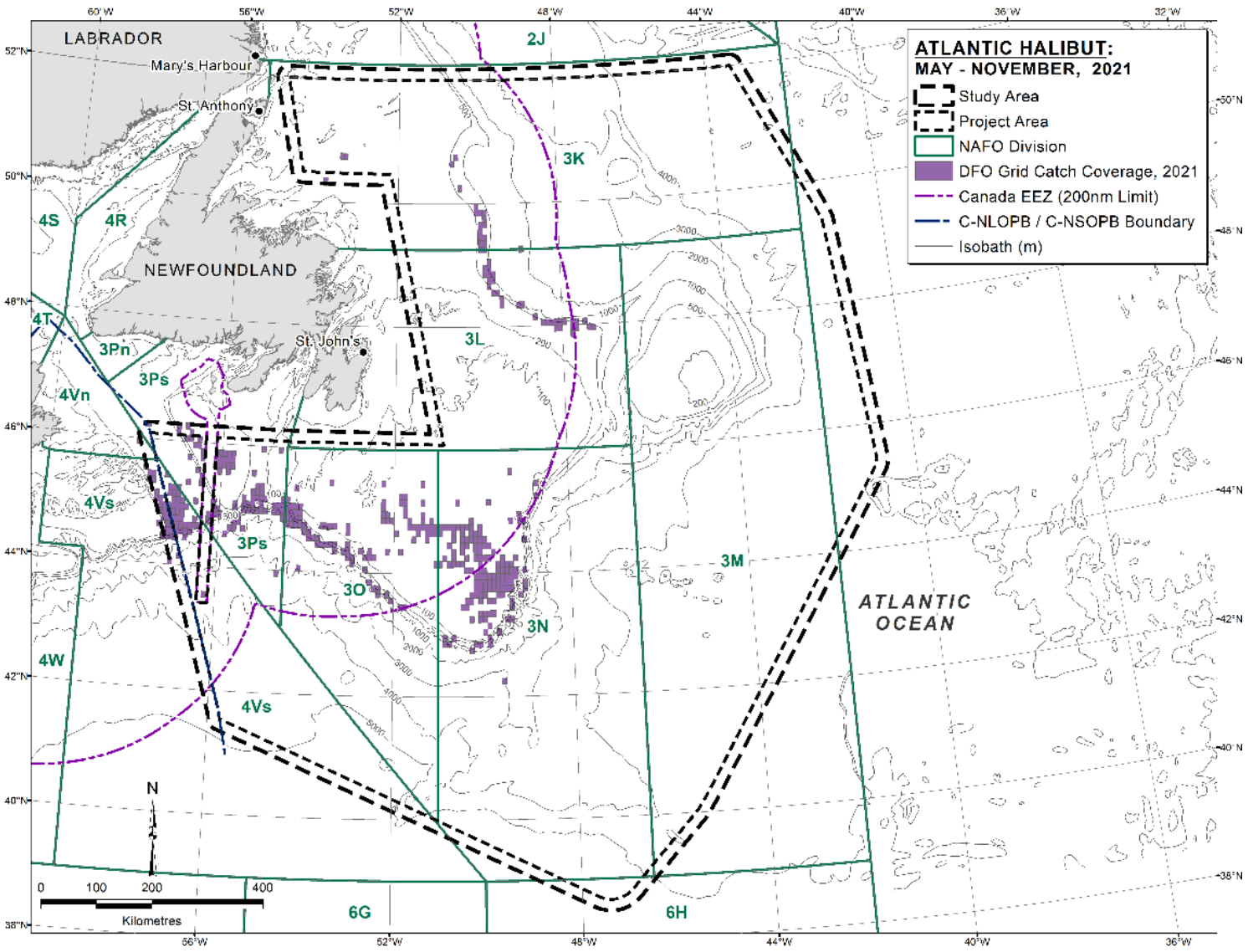
Source: DFO commercial landings database, 2018–2023.
Notes:
Sum of quartile catch ranges is the summation of catch weight quartile ranges (i.e., 1–4) for all catch records for all species; the greater the sum of quartile range counts, the greater the catch weight for a given year.

Figure 4.14. Total sum of annual catch weight quartile codes for Atlantic halibut in the Study Area, May–November 2018–2023.



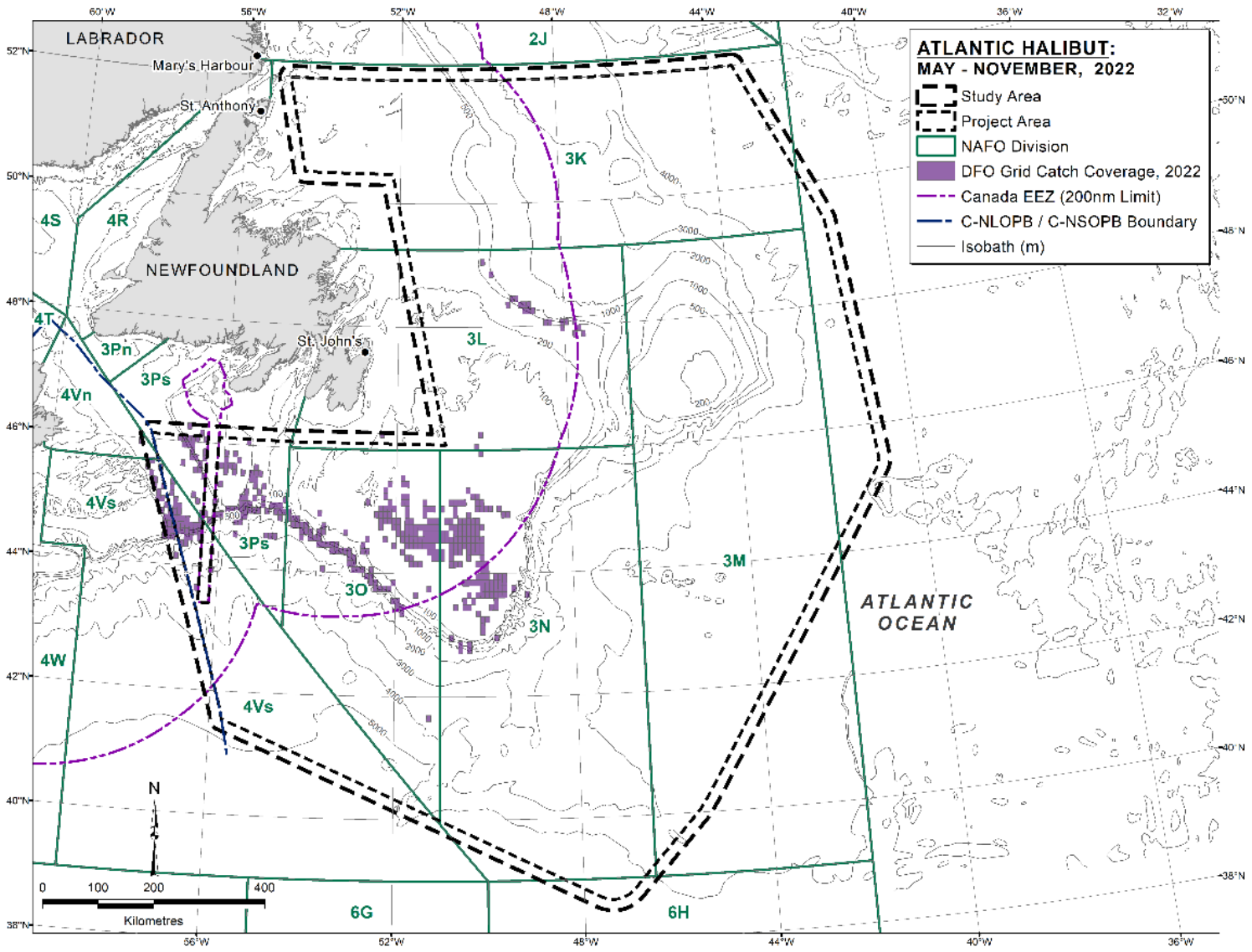
Source: DFO commercial landings database, 2018–2023.
Notes:
Sum of quartile catch ranges is the summation of catch weight quartile ranges (i.e., 1–4) for all catch records for all species; the greater the sum of quartile range counts, the greater the catch weight for a given month.

Figure 4.15. Total sum of monthly catch weight quartile codes for Atlantic halibut in the Study Area, May–November 2018–2023.



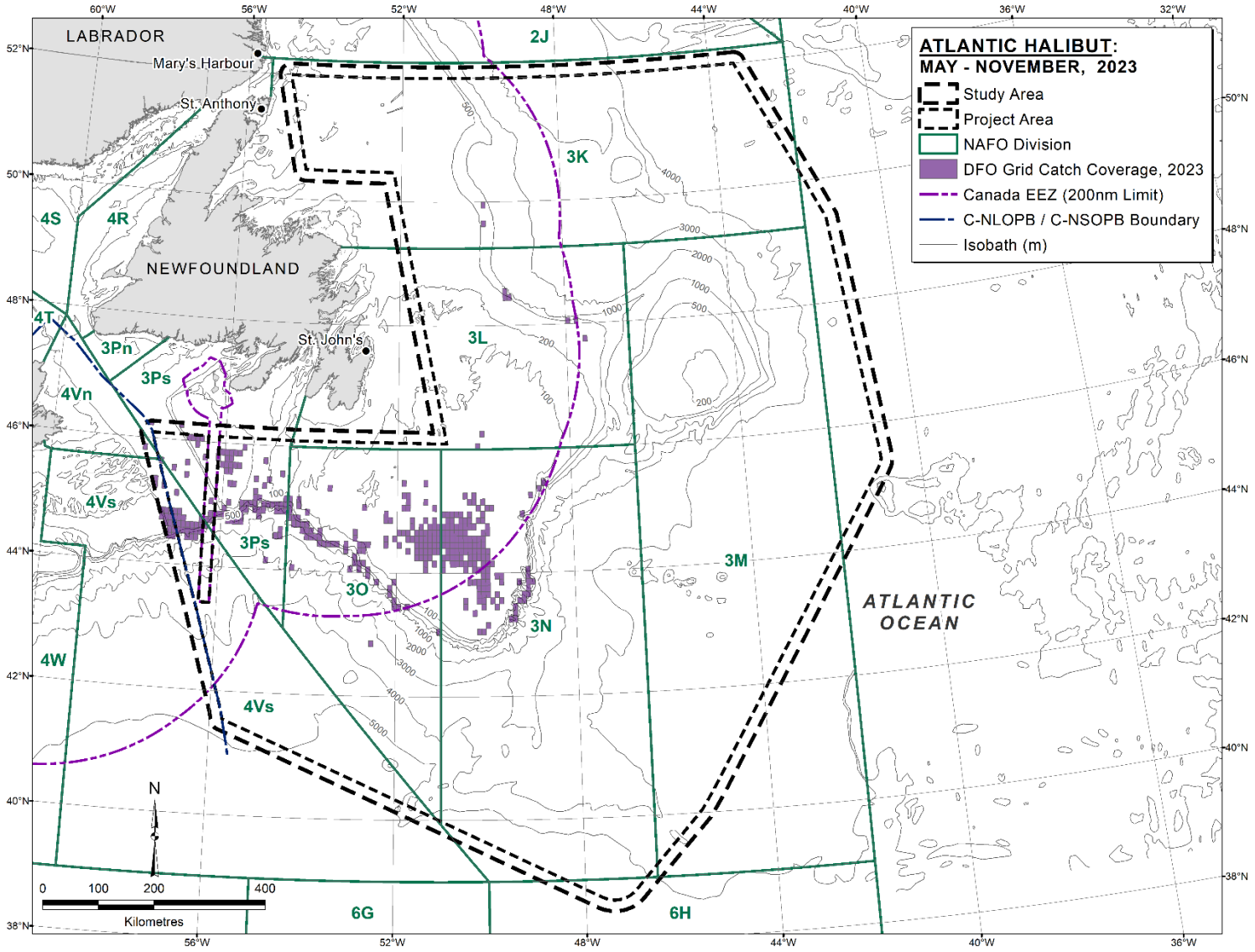
Source: DFO commercial landings database, 2021–2023.

Figure 4.16. Distribution of commercial harvest locations for Atlantic halibut in the Study Area, May–November 2021, 2022, 2023.



Source: DFO commercial landings database, 2021–2023.

Figure 4.16 (Continued). Distribution of commercial harvest locations for Atlantic halibut in the Study Area, May–November 2021, 2022, 2023.



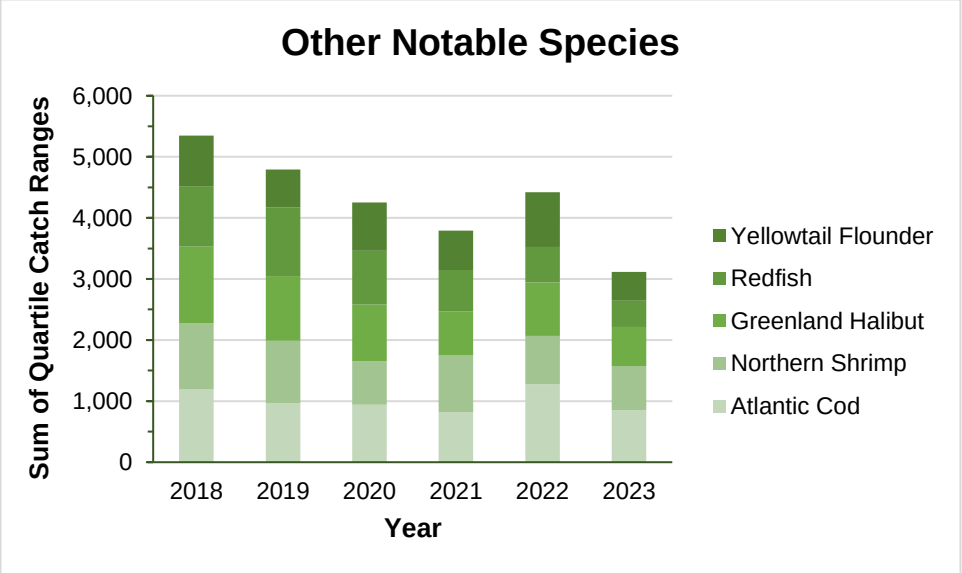
Source: DFO commercial landings database, 2021–2023.

Figure 4.16 (Continued). Distribution of commercial harvest locations for Atlantic halibut in the Study Area, May–November 2021, 2022, 2023.

Other Notable Species: Atlantic Cod, Northern Shrimp, Greenland Halibut, Redfish, and Yellowtail Flounder

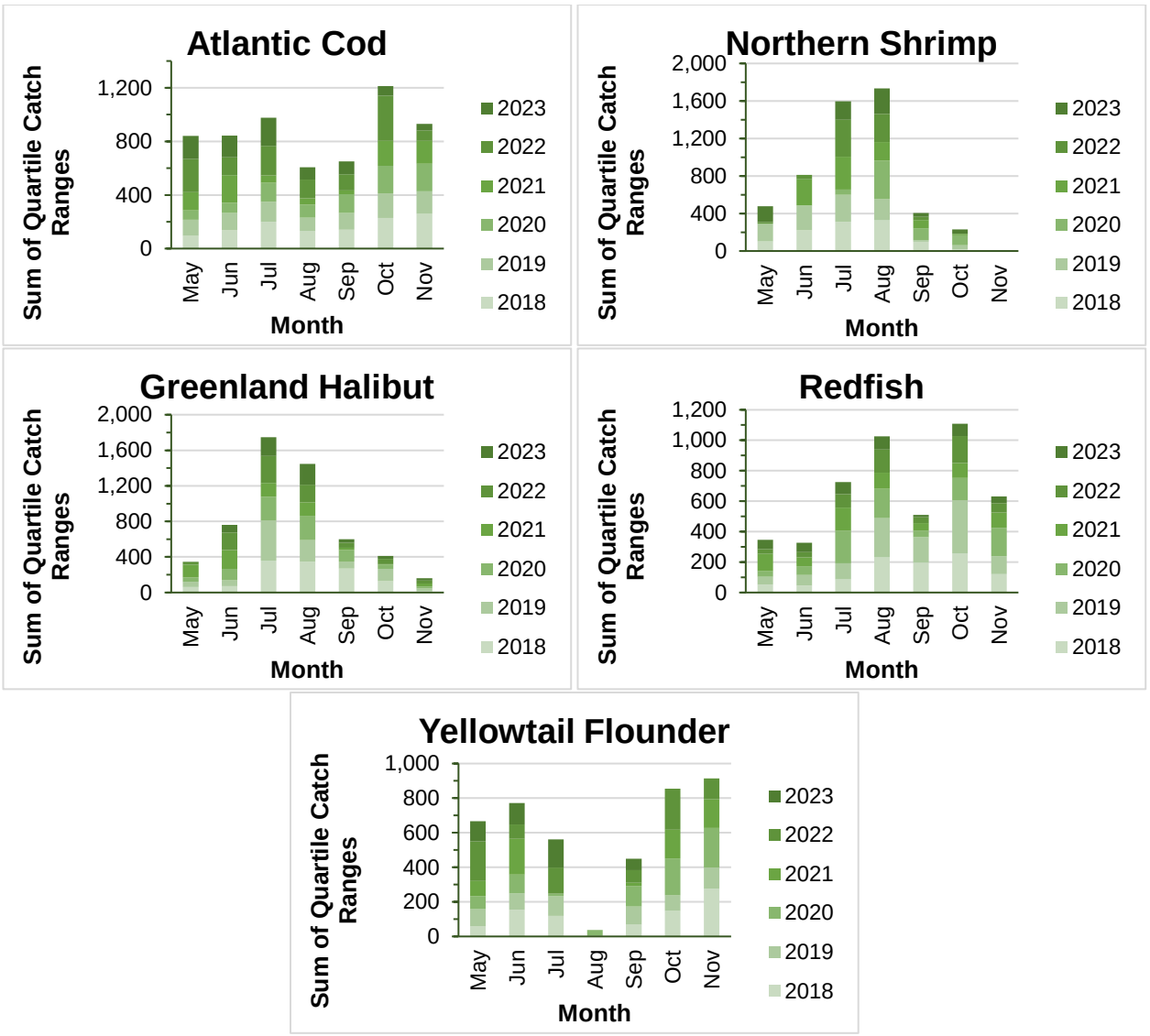
In addition to snow crab and Atlantic halibut, Atlantic cod, northern shrimp, Greenland halibut, redfish, and yellowtail flounder have also been identified as important commercial species in the Study Area during May–November 2018–2023 (see Section 4.3.3.2 and Tables 4.3–4.8). During 2018–2023, there has been an overall decreasing trend in catches of Atlantic cod, northern shrimp, Greenland halibut, and redfish in the Study Area (Figure 4.17). Inter-annual catches of yellowtail flounder have been variable but overall steady, apart from a series (2018–2023) low in 2023. Most Atlantic cod catches occurred during the spring and fall, while northern shrimp and Greenland halibut were mostly caught during the summer (Figure 4.18). Redfish and yellowtail flounder were mainly harvested during the spring/summer and fall.

The distribution of harvest locations for northern shrimp, Greenland halibut, Atlantic cod, and redfish within/near the Study Area for May–November 2015 are provided in Figures 4.9, 4.15, and 4.19–4.20 of LGL (2018). Harvest locations for yellowtail flounder during May–November 2015 are provided in Figure 4.18 of LGL (2016). During May–November 2021–2023, most of these species were harvested in the western and southwestern portions of the Study Area, in areas with water depths <1000 m, similar to previous years (Figures 4.19–4.23). Northern shrimp were mainly caught in the northwestern portion of the Study Area, with some harvest locations near the northern Flemish Cap.



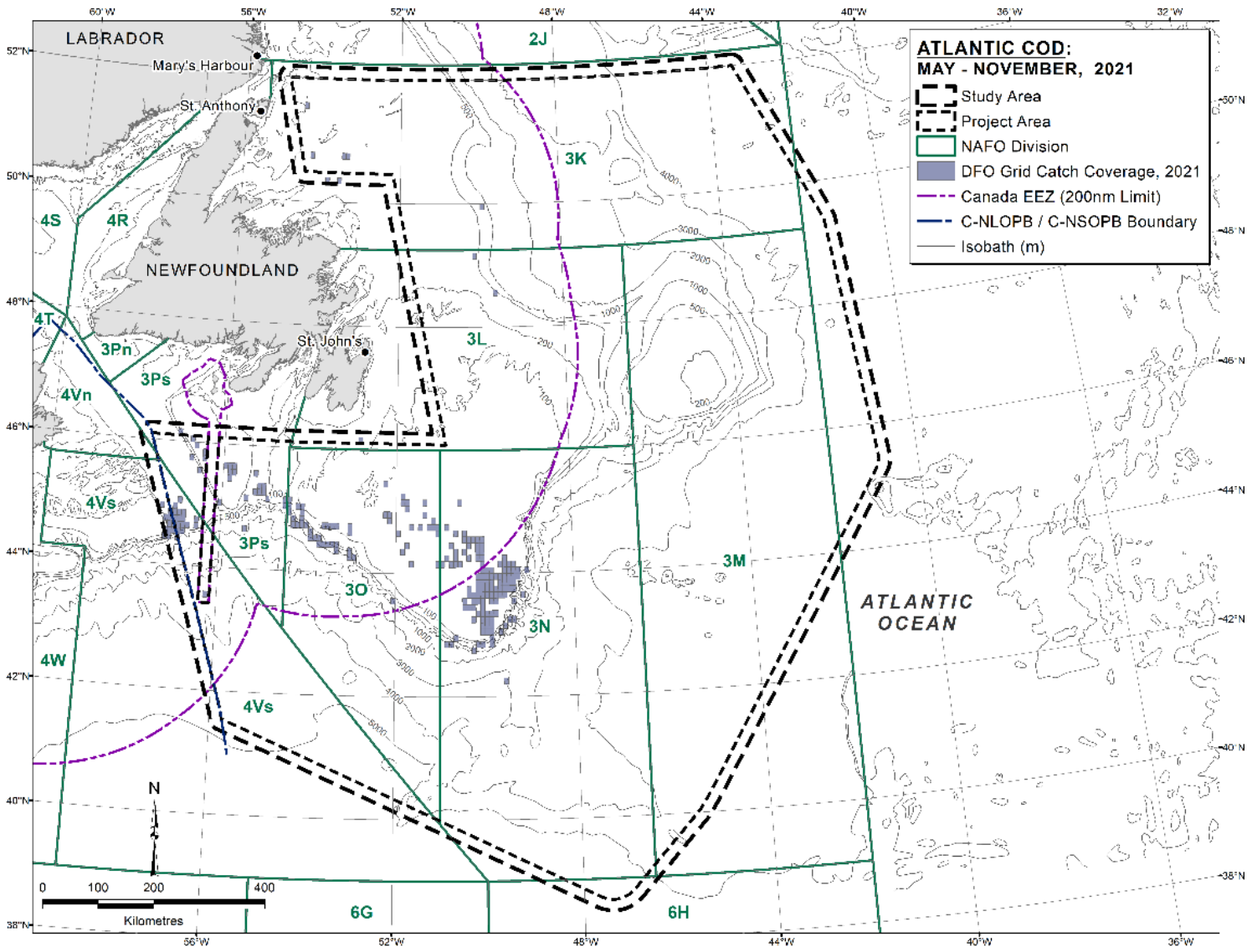
Source: DFO commercial landings database, 2018–2023.
Notes:
Sum of quartile catch ranges is the summation of catch weight quartile ranges (i.e., 1–4) for all catch records for all species; the greater the sum of quartile range counts, the greater the catch weight for a given year.

Figure 4.17. Total sum of annual catch weight quartile codes for Atlantic cod, northern shrimp, Greenland halibut, redfish, and yellowtail flounder in the Study Area, May–November 2018–2023.



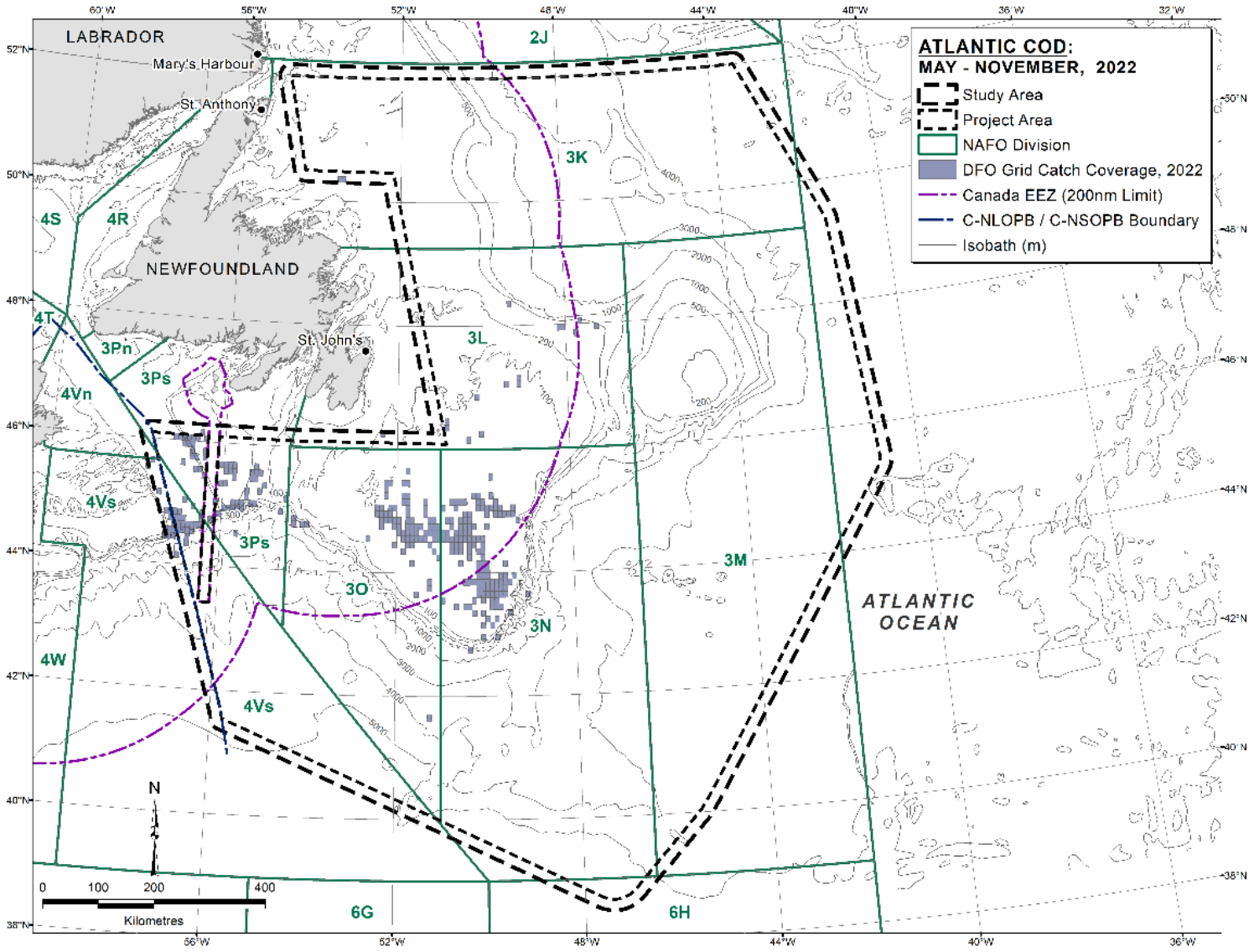
Source: DFO commercial landings database, 2018–2023.
Notes:
Sum of quartile catch ranges is the summation of catch weight quartile ranges (i.e., 1–4) for all catch records for all species; the greater the sum of quartile range counts, the greater the catch weight for a given month.

Figure 4.18. Total sum of monthly catch weight quartile codes for Atlantic cod, northern shrimp, Greenland halibut, redfish, and yellowtail flounder in the Study Area, May–November 2018–2023.



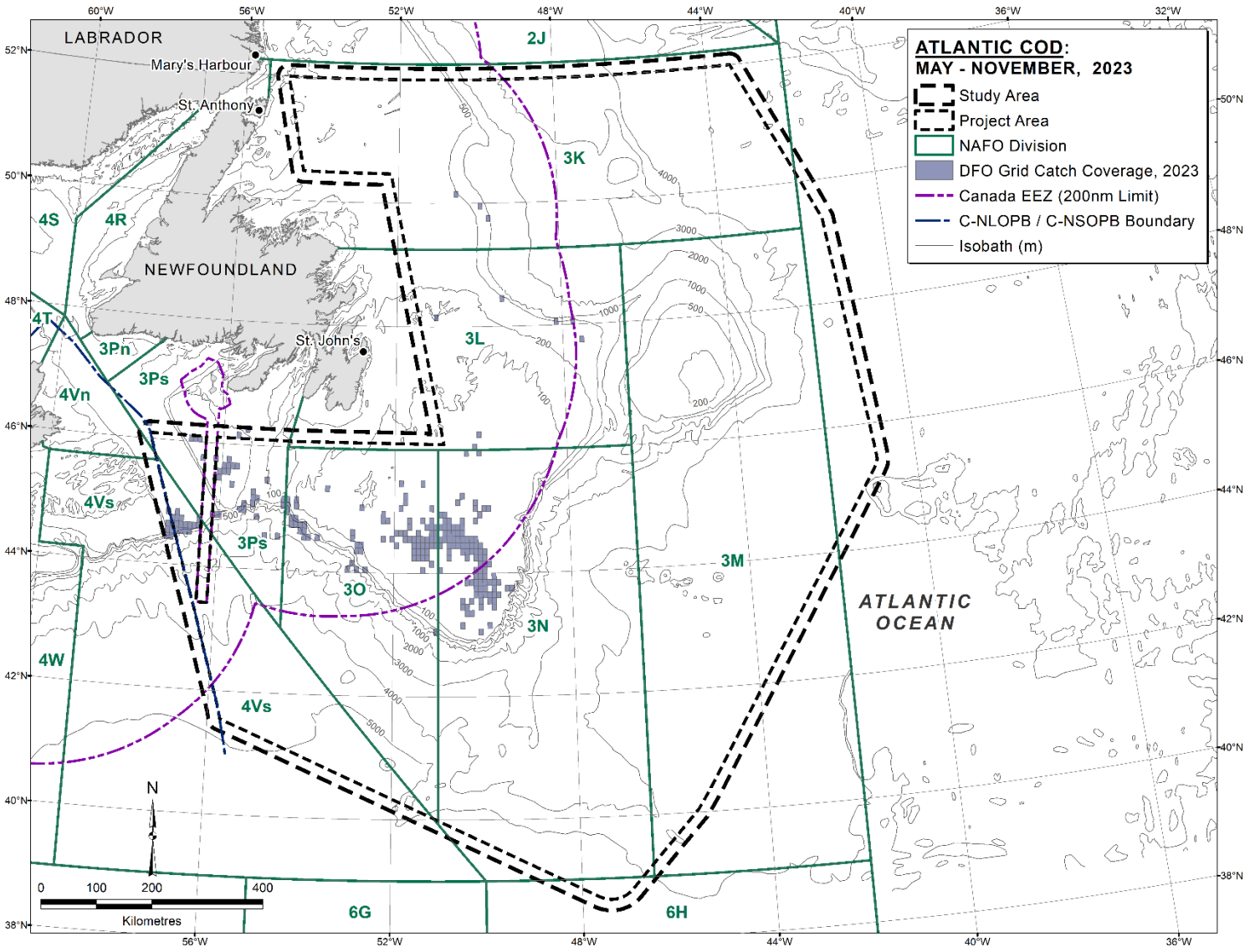
Source: DFO commercial landings database, 2021–2023.

Figure 4.19. Distribution of commercial harvest locations for Atlantic cod in the Study Area, May–November 2021, 2022, 2023.



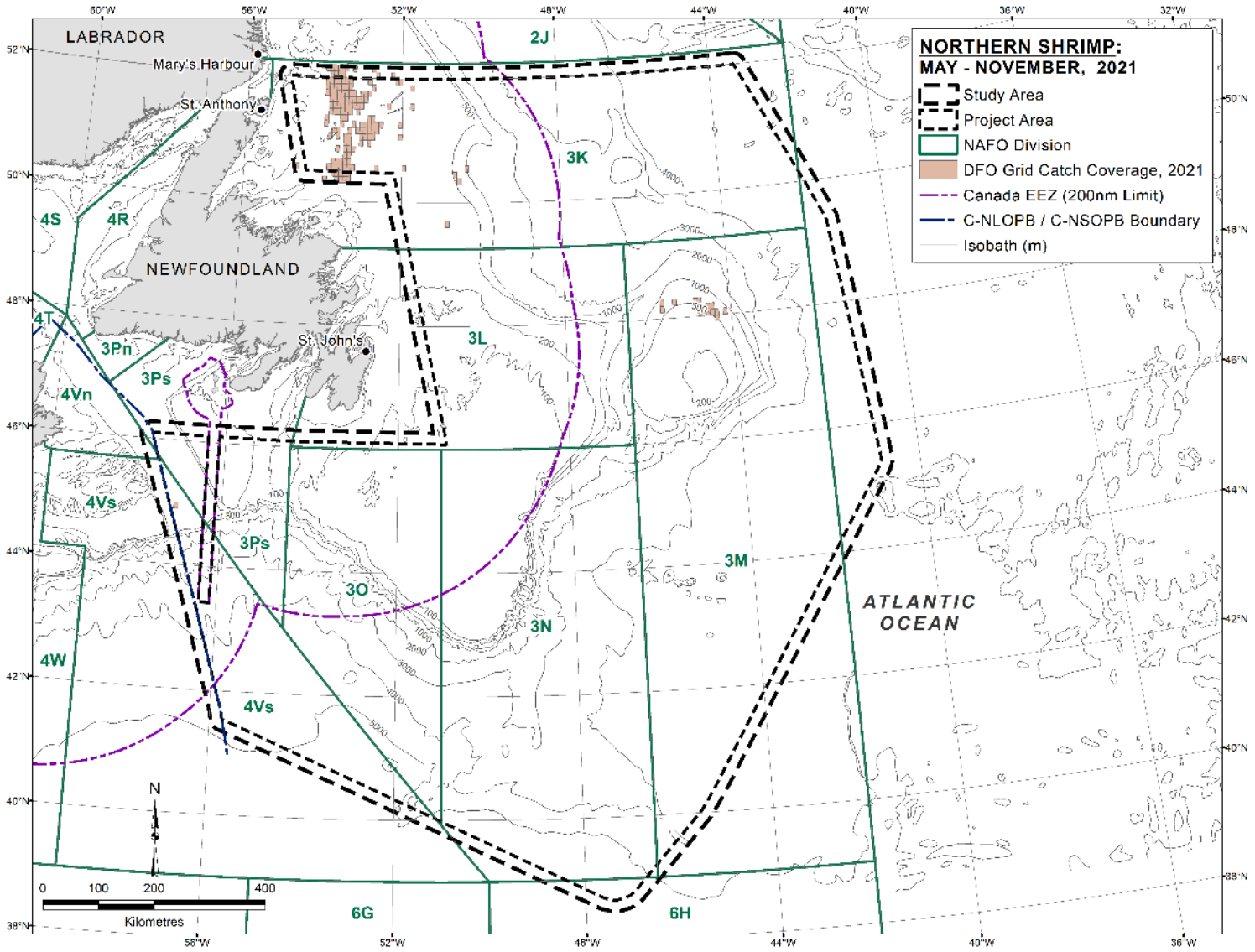
Source: DFO commercial landings database, 2021–2023.

Figure 4.19 (Continued). Distribution of commercial harvest locations for Atlantic cod in the Study Area, May–November 2021, 2022, 2023.



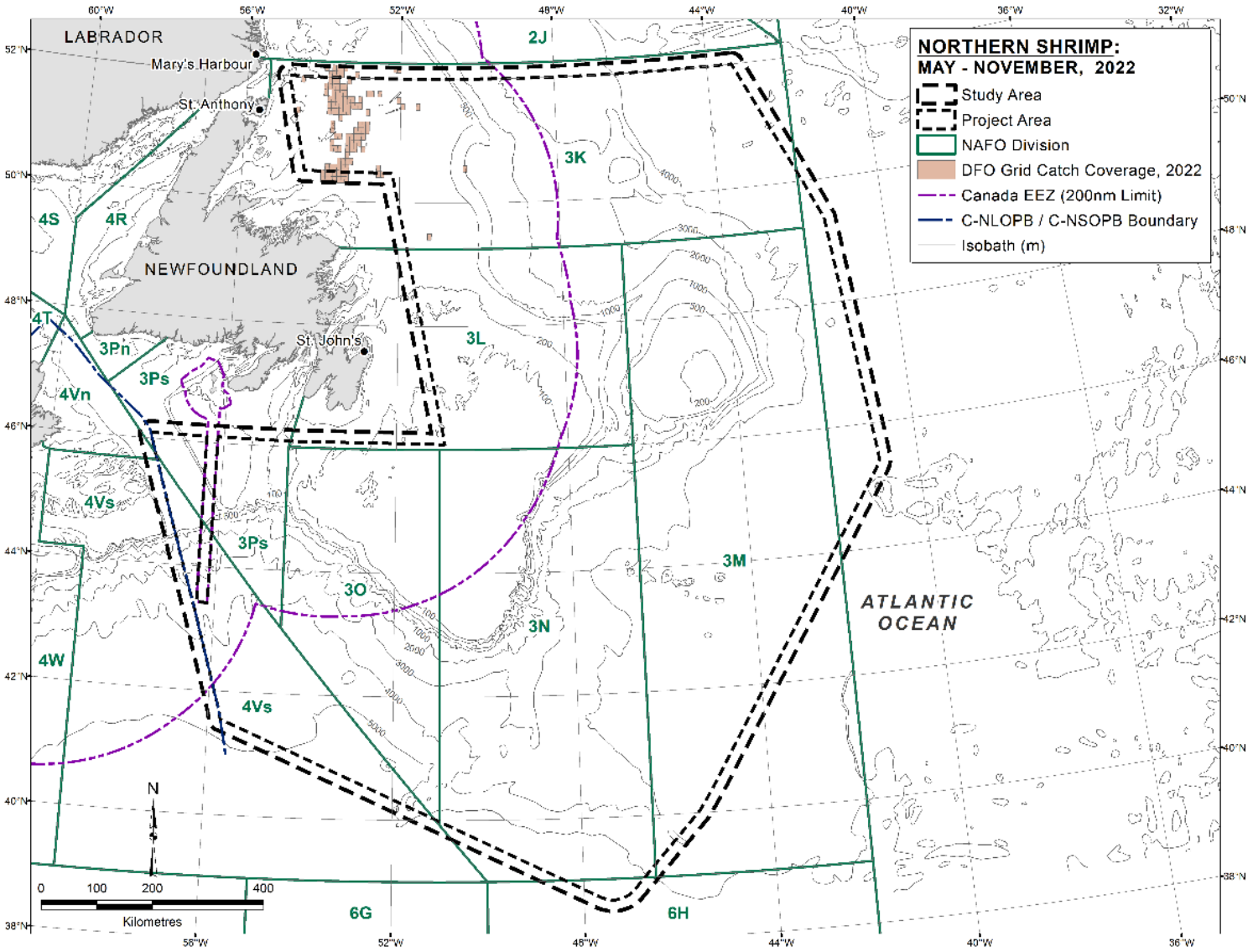
Source: DFO commercial landings database, 2021–2023.

Figure 4.19 (Continued). Distribution of commercial harvest locations for Atlantic cod in the Study Area, May–November 2021, 2022, 2023.



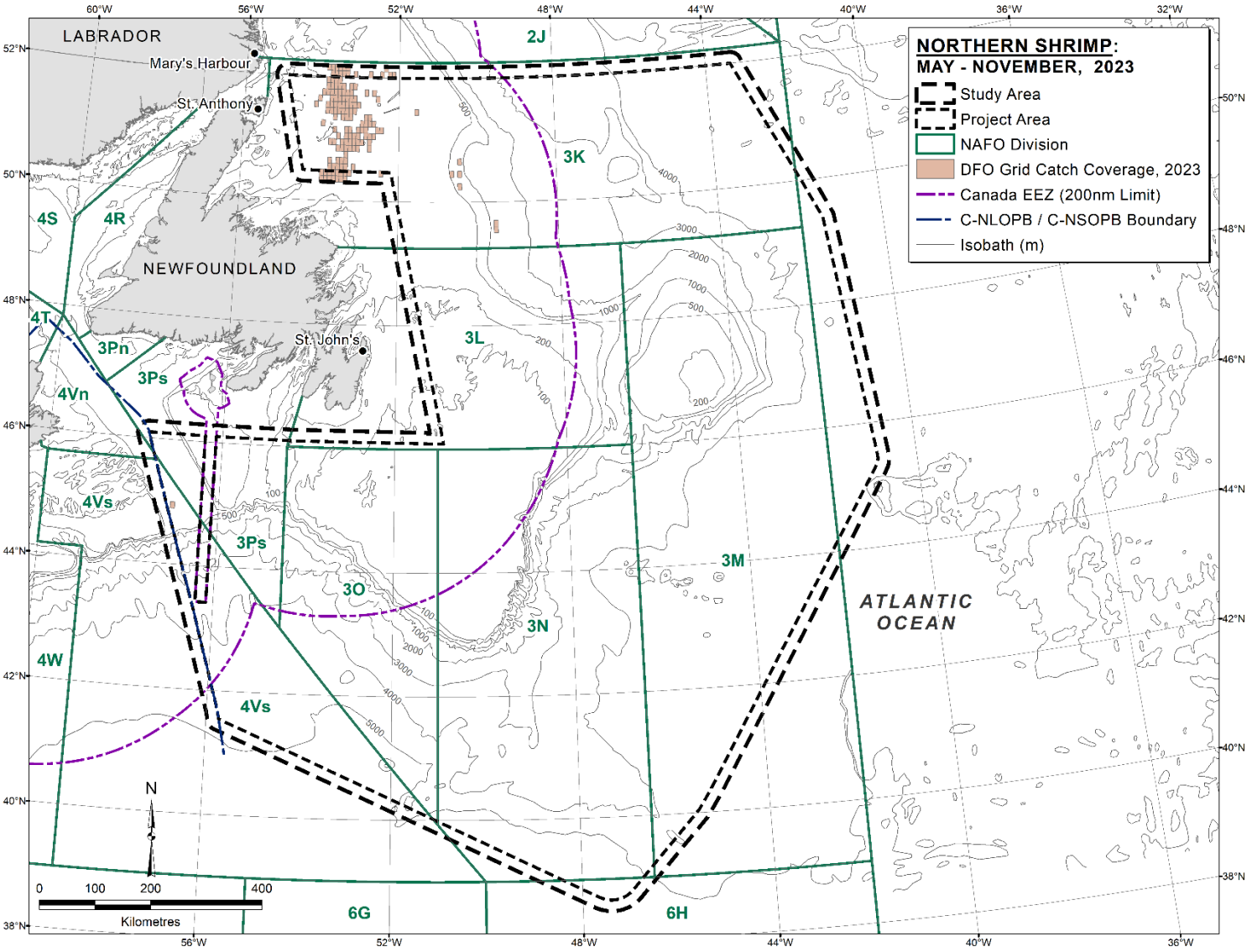
Source: DFO commercial landings database, 2021–2023.

Figure 4.20. Distribution of commercial harvest locations for northern shrimp cod in the Study Area, May–November 2021, 2022, 2023.



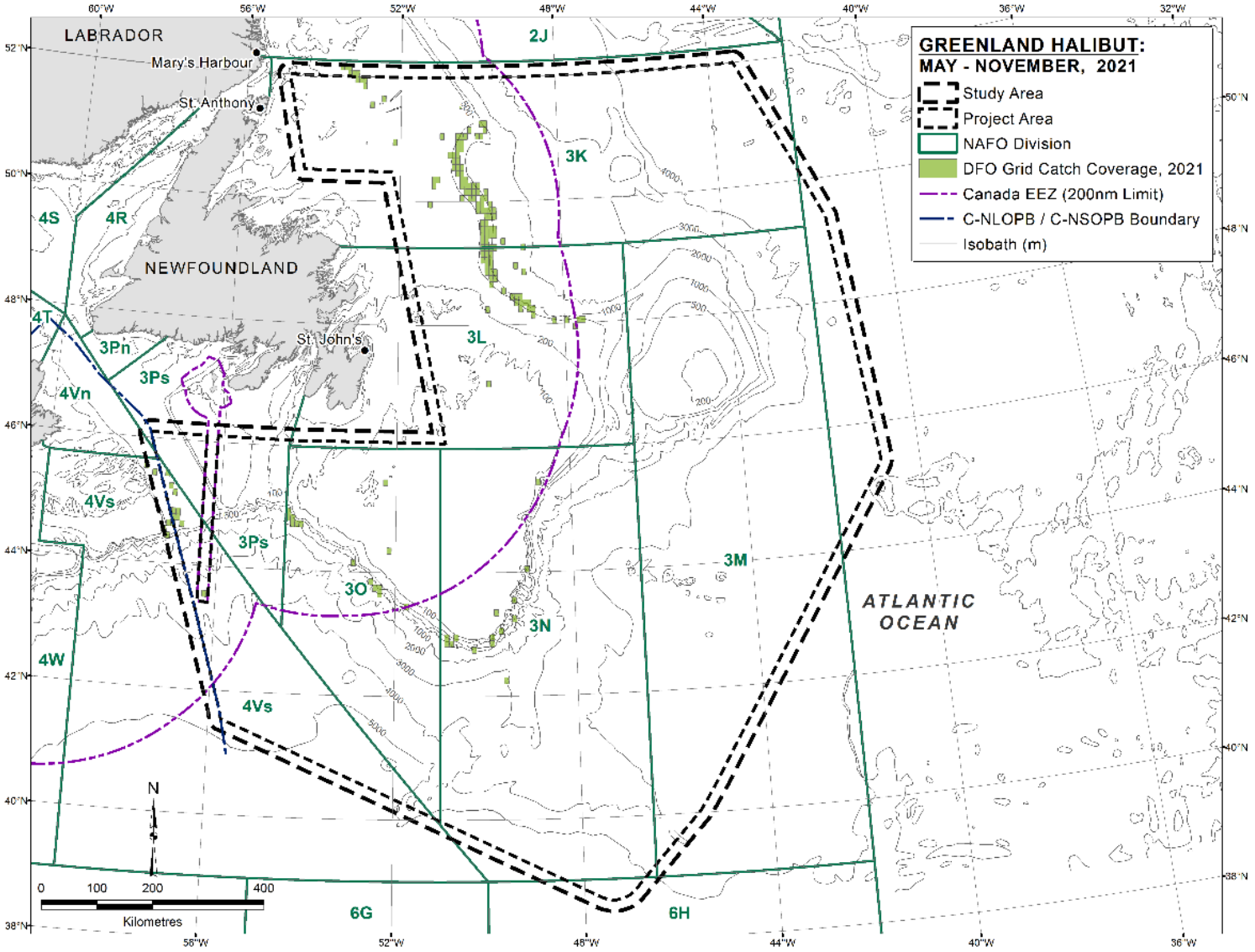
Source: DFO commercial landings database, 2021–2023.

Figure 4.20 (Continued). Distribution of commercial harvest locations for northern shrimp in the Study Area, May–November 2021, 2022, 2023.



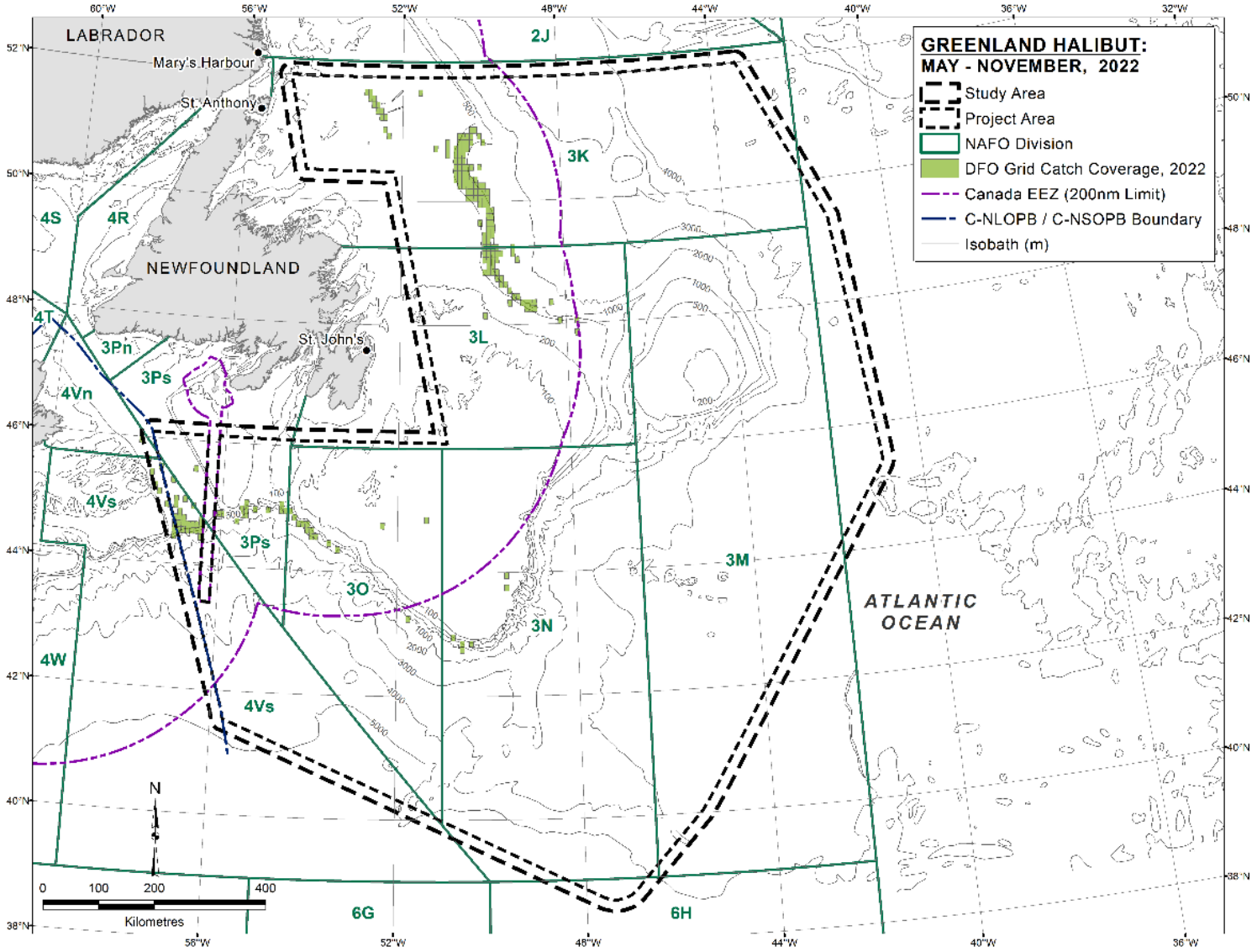
Source: DFO commercial landings database, 2021–2023.

Figure 4.20 (Continued). Distribution of commercial harvest locations for northern shrimp in the Study Area, May–November 2021, 2022, 2023.



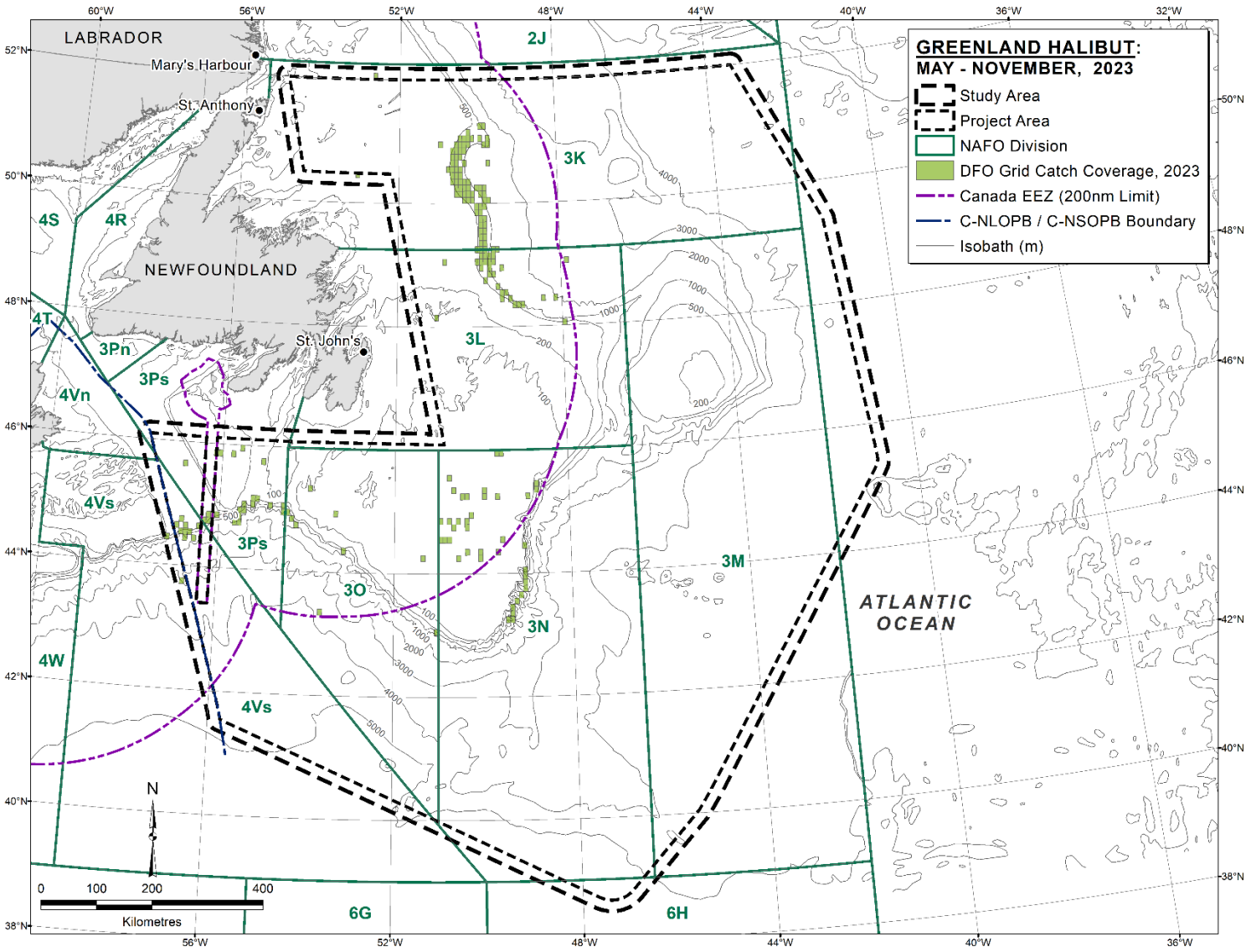
Source: DFO commercial landings database, 2021–2023.

Figure 4.21. Distribution of commercial harvest locations for Greenland halibut in the Study Area, May–November 2021, 2022, 2023.



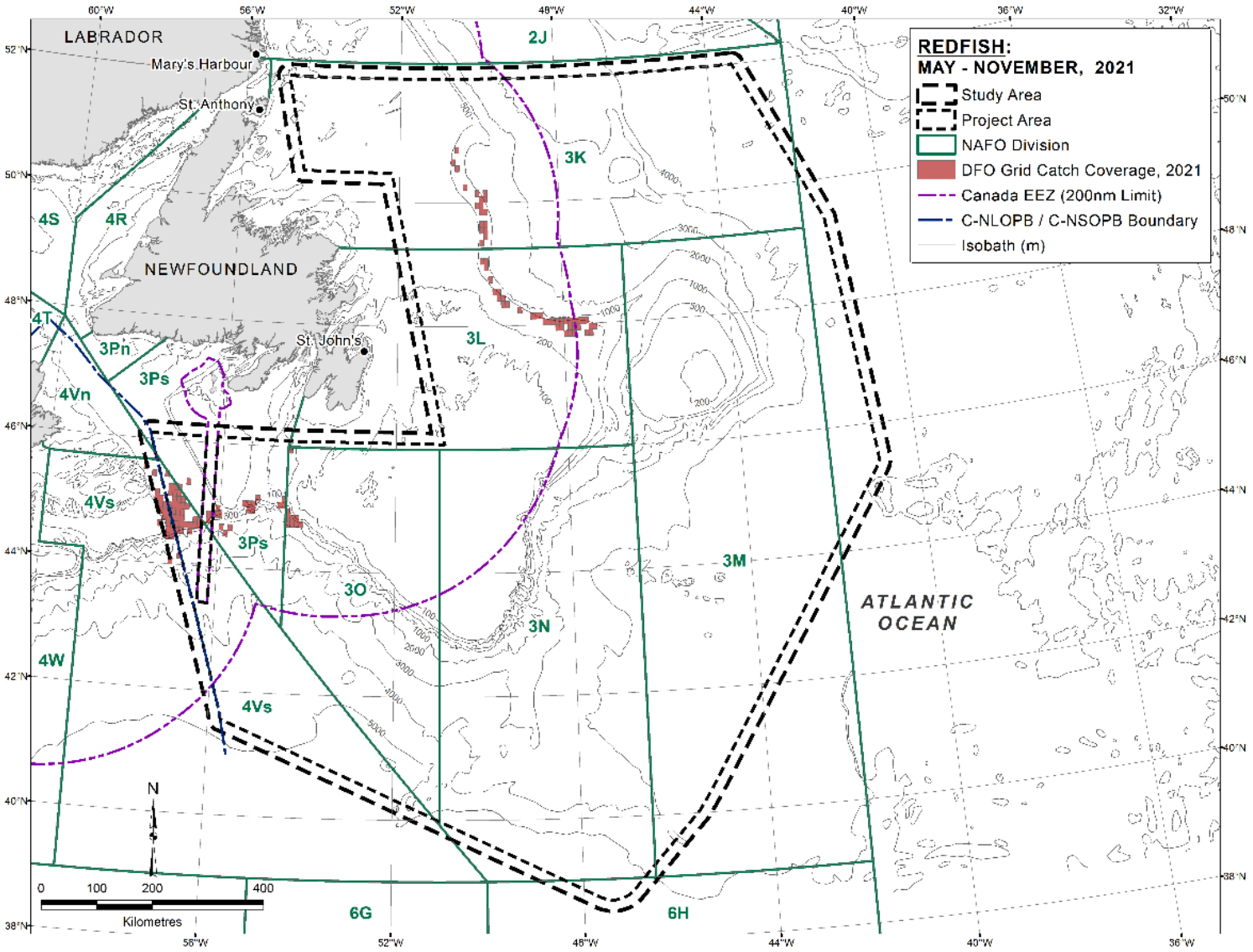
Source: DFO commercial landings database, 2021–2023.

Figure 4.21 (Continued). Distribution of commercial harvest locations for Greenland halibut in the Study Area, May–November 2021, 2022, 2023.



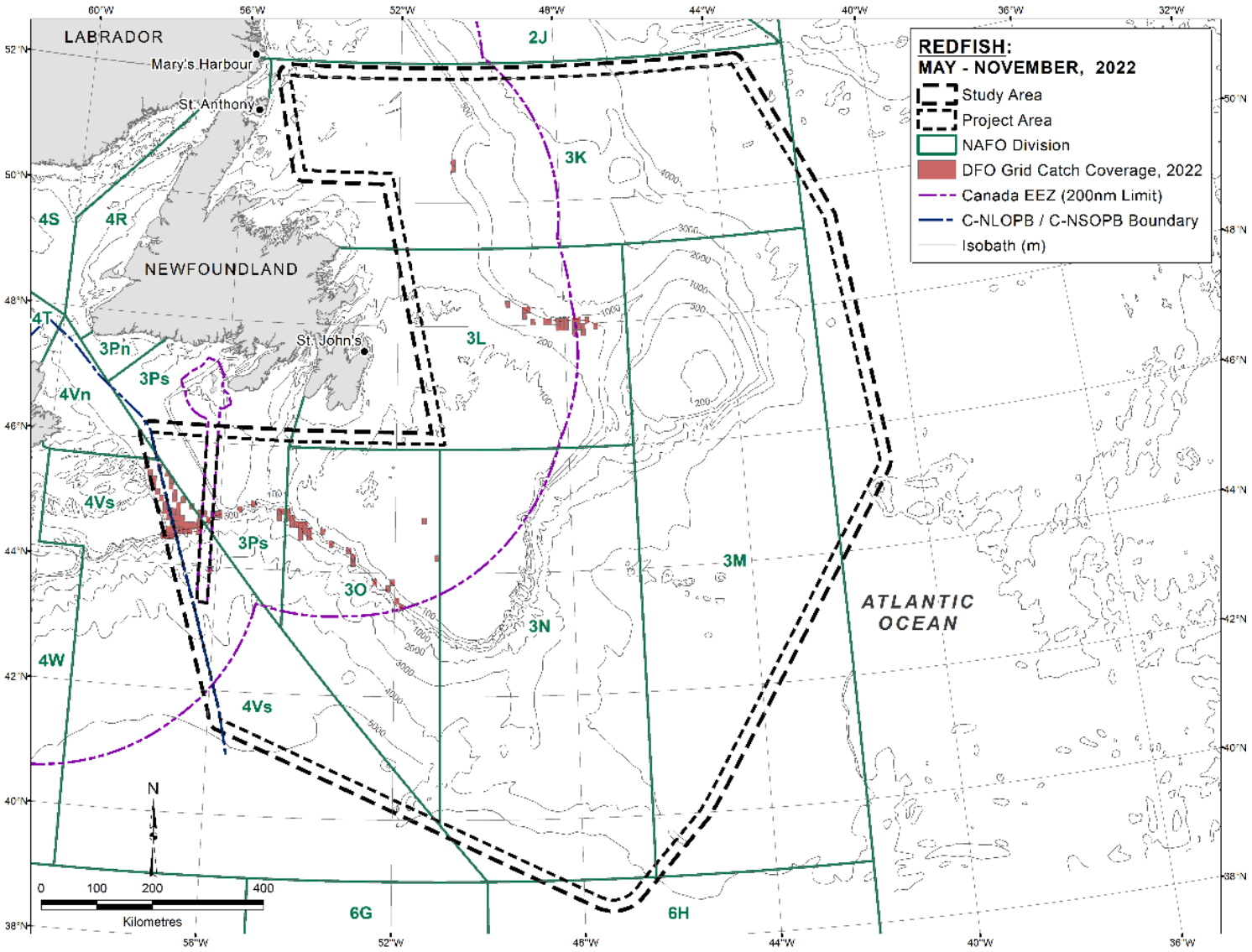
Source: DFO commercial landings database, 2021–2023.

Figure 4.21 (Continued). Distribution of commercial harvest locations for Greenland halibut in the Study Area, May–November 2021, 2022, 2023.



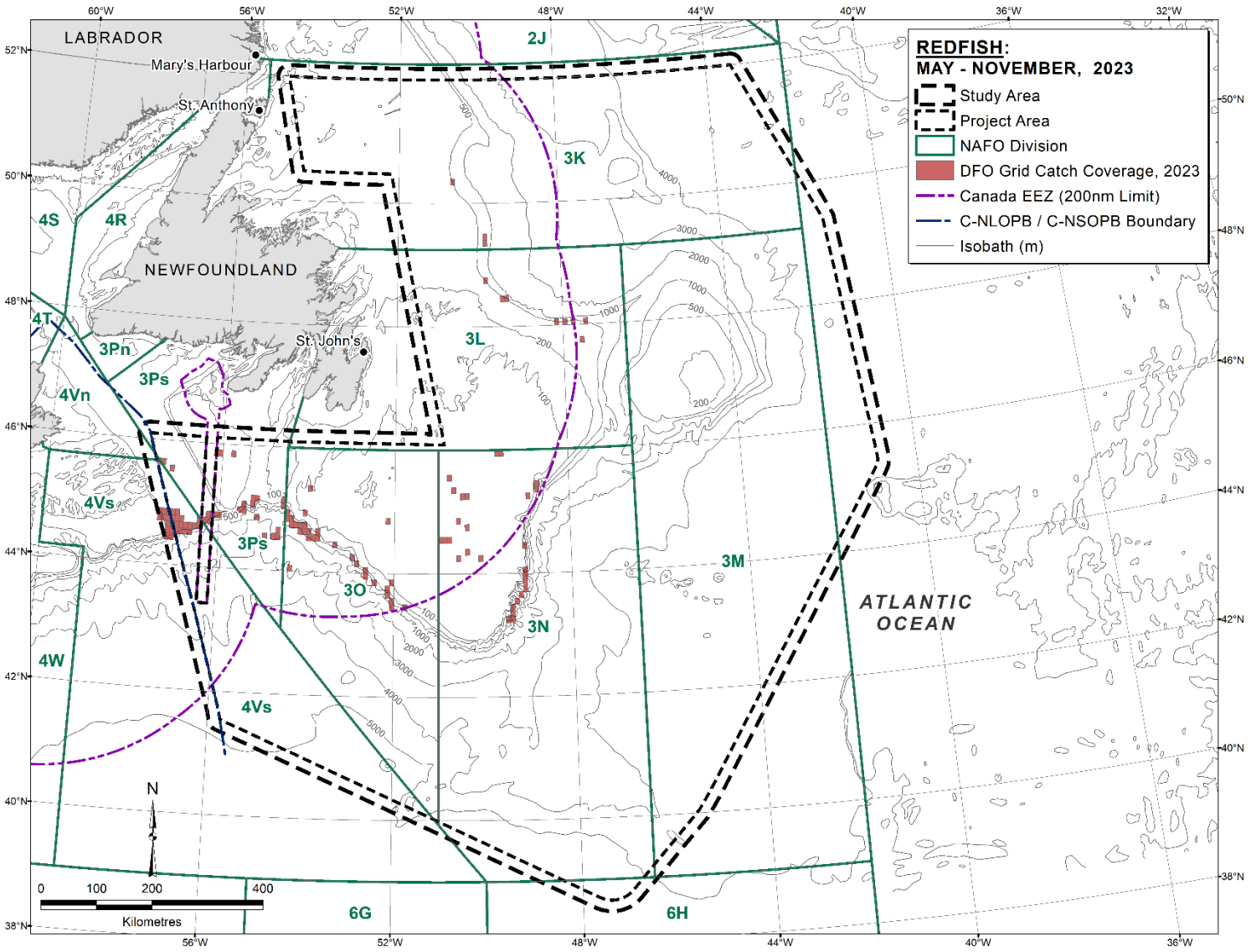
Source: DFO commercial landings database, 2021–2023.

Figure 4.22. Distribution of commercial harvest locations for redfish in the Study Area, May–November 2021, 2022, 2023.



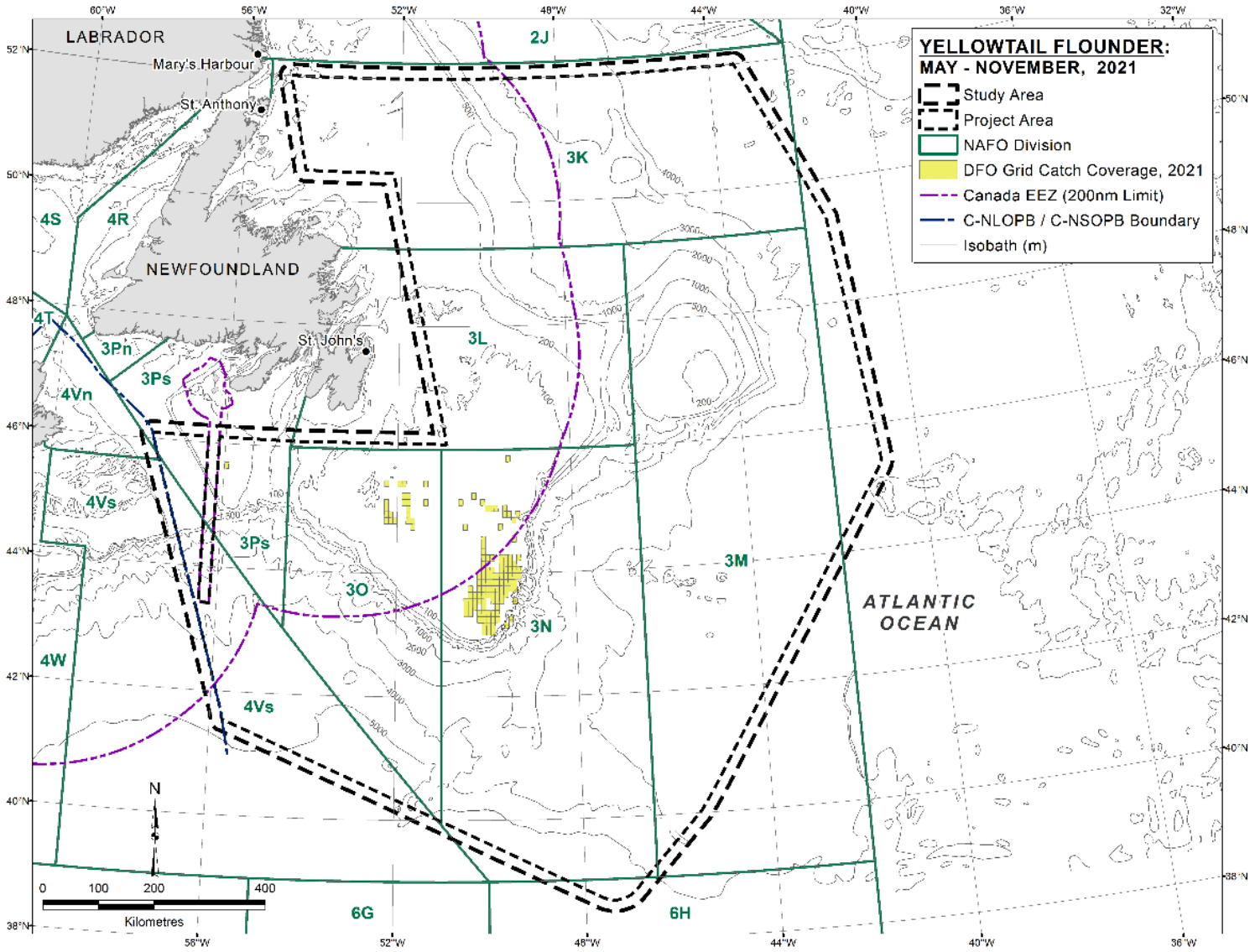
Source: DFO commercial landings database, 2021–2023.

Figure 4.22 (Continued). Distribution of commercial harvest locations for redfish in the Study Area, May–November 2021, 2022, 2023.



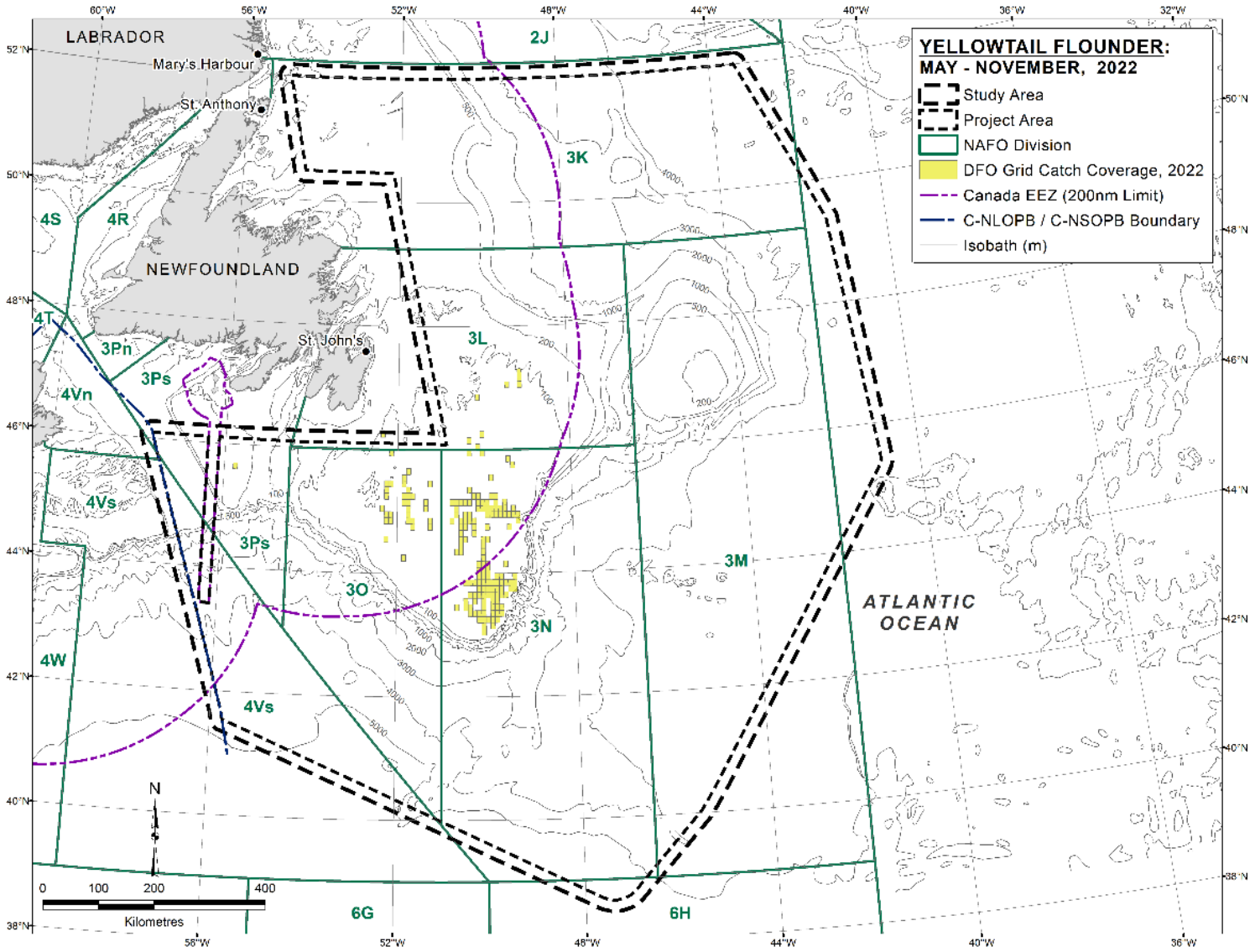
Source: DFO commercial landings database, 2021–2023.

Figure 4.22 (Continued). Distribution of commercial harvest locations for redfish in the Study Area, May–November 2021, 2022, 2023.



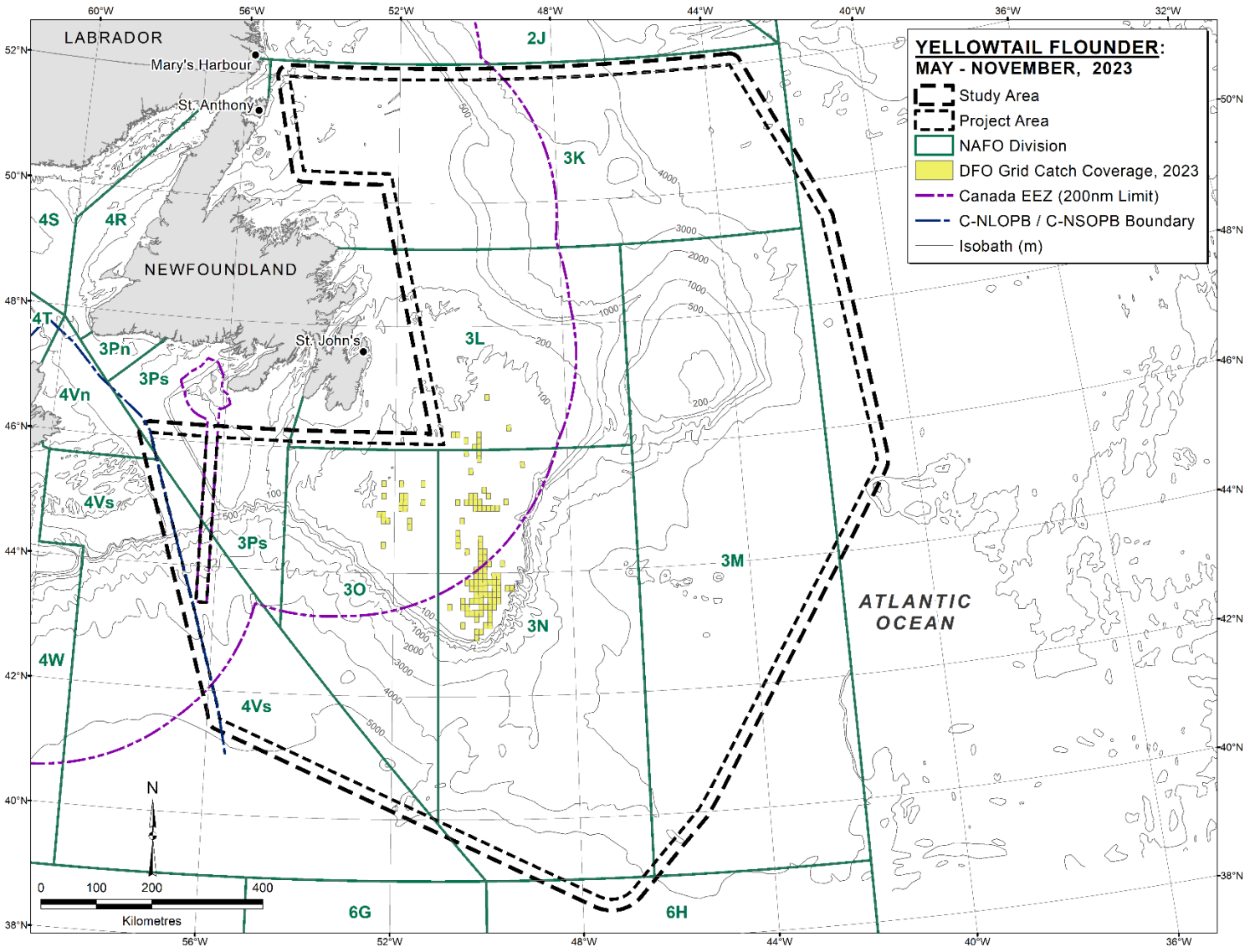
Source: DFO commercial landings database, 2021–2023.

Figure 4.23. Distribution of commercial harvest locations for yellowtail flounder in the Study Area, May–November 2021, 2022, 2023.



Source: DFO commercial landings database, 2021–2023.

Figure 4.23 (Continued). Distribution of commercial harvest locations for yellowtail flounder in the Study Area, May–November 2021, 2022, 2023.



Source: DFO commercial landings database, 2021–2023.

Figure 4.23 (Continued). Distribution of commercial harvest locations for yellowtail flounder in the Study Area, May–November 2021, 2022, 2023.

4.3.4 Indigenous Fisheries

Indigenous fisheries were reviewed in Section 3.3.4 of C-NLOPB (2010), Section 3.3.2 of IAAC (2020), and Section 4.3.4 of LGL (2018). The Indigenous Lands of Canada and First Nations Locations in Canada layers in IAAC (2024) indicate the locations of the Qalipu [Mi'kmaq] First Nation (QFN; Corner Brook) and Miawpukek (Conne River) locations in Newfoundland but do not include indication of marine use. The Canada Marine Planning Atlas (DFO 2025f) similarly provides locations for Corner Brook and Conne River but no marine indicators. There are multiple Indigenous enterprises that hold Communal Commercial Licences with fishing areas/authorized NAFO Divisions that overlap the Study Area (Table 4.11). As of 2024, most Communal Commercial Licences are for groundfish (~17%), snow crab (~14%), and scallop (~11%; Table 4.12). Harvests associated with these Communal Commercial Licences are included in DFO's domestic commercial landings database but are not differentiated from non-Communal Commercial Licence holders (see Section 4.3.3.2). There are no Food, Social, and Ceremonial (FSC) licenced fishing areas that overlap the Study Area (G. Rowe, Resource Manager, Indigenous Fisheries, DFO NL Region, pers. comm., 21 May 2025). However, the Miawpukek First Nation (MFN) holds a FSC licence for coastal waters near Conne River (within NAFO Division 3Ps) for various species that may transit/migrate through the Study Area, such as mackerel, herring, Atlantic cod, American eel (*Anguilla rostrata*), smelt (Osmeridae), and capelin (IAAC 2020).

Table 4.11. Communal Commercial Licences held by Indigenous enterprises in the NL Region, May 2025.

Enterprise Name	Species Licence	Authorized Fishing Gear (M = Mobile; F = Fixed)
Innu Nation		
Innu Nation 2	Shrimp	Shrimp Trawl (M)
Innu Nation 3	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Groundfish (except cod and lumpfish)	Otter Trawl (M)
	Mackerel	Purse/Bar Seine (M)
	Herring	Purse Seine (M)
	Bluefin Tuna	Tended Lines (M)
	Capelin	Purse Seine (M)
	Shrimp	Shrimp Trawl (M)
Innu Nation 4	Shrimp	Shrimp Trawl (M)
Harbour Grace Shrimp Co. Ltd. (NL-006, NL-009)	Groundfish	Unspecified (F)
Harbour Grace Shrimp Co. Ltd. (NL-022)	Shrimp	Unspecified
	Groundfish	
Ueushuk Fisheries Limited (NL-010)	Groundfish	Unspecified (F)
Ueushuk Fisheries Limited (NL-018)	Shrimp	Unspecified
Nunatukavut Community Council (NCC)		
NCC	Seal	Club/Rifle (F)
NCC/NDC Fisheries Limited 0	Groundfish	Gillnet, Trap, Longline (F)
	Scallop	Drag (M)
	Shrimp	Shrimp Trawl (M)
	Seal	Club/Rifle (F)
	Snow Crab	Pots (F)
NCC/NDC Fisheries Limited 1	Snow Crab	Pots (F)
	Capelin	2 Traps, 1 Bar Seine (F)
	Whelk	Pots (F)
	Bait	Gillnet (F)
NCC/NDC Fisheries Limited 2	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Snow Crab	Pots (F)
	Whelk	Pots (F)
	Shrimp	Shrimp Trawl (M)
	Bait	Gillnet (F)

Enterprise Name	Species Licence	Authorized Fishing Gear (M = Mobile; F = Fixed)
NCC/NDC Fisheries Limited 3	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Scallop	Drag (M)
	Snow Crab	Pots (F)
NCC/NDC Fisheries Limited 4	Groundfish (except lumpfish)	Gillnet, Trap, Longline (F)
	Whelk	Pots (F)
	Bait	Gillnet (F)
	Snow Crab	Pots (F)
NCC/NDC Fisheries Limited 5	Groundfish (except lumpfish)	Gillnet, Trap, Longline (F)
	Whelk	Pots (F)
	Toad Crab	Pots (F)
	Bait	Gillnet (F)
	Snow Crab	Pots (F)
NCC/NDC Fisheries Limited 6	Snow Crab	Pots (F)
	Groundfish	Gillnet, Trap, Longline (F)
	Whelk	Pots (F)
	Bait	Gillnet (F)
NCC/NDC Fisheries Limited 7	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Snow Crab	Pots (F)
NCC/NDC Fisheries Limited 8	Groundfish (except lumpfish)	Gillnet, Trap, Longline (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
NCC/NDC Fisheries Limited 9	Groundfish	Gillnet, Trap, Longline (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
NCC/NDC Fisheries Limited 10	Groundfish	Gillnet, Trap, Longline (F)
	Herring	Unspecified (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
NCC/NDC Fisheries Limited 11	Groundfish (except lumpfish)	Gillnet, Trap, Longline (F
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
NCC/NDC Fisheries Limited 12	Groundfish	Gillnet, Trap, Longline (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
NunatuKavut Community Council	Shrimp	Unspecified
IMAKPIK (NCC & LFUSC partnership)	Shrimp	Unspecified
Nunatsiavut Government (NG)		
NG 5	Groundfish	Gillnet, Longline (F)
NG 6	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Scallop	Drag (M)
	Seal	Club/Rifle (F)
	Snow Crab	Pots (F)
NG 7	Seal	Club/Rifle (F)
	Groundfish	Gillnet, Trap, Longline (F)
	Snow Crab	Pots (F)
NG 8	Groundfish	Gillnet, Longline (F)
	Scallop	Drag (M)
	Snow Crab	Pots (F)
NG 9	Scallop	Gillnet, Longline (F)
	Groundfish (except lumpfish)	Gillnet, Longline (F)
NG 10	Scallop	Drag (M)
	Groundfish	Gillnet, Longline (F)
NG 11-20	Scallop	Drag (M)
NG 21	Scallop	Drag (M)

Enterprise Name	Species Licence	Authorized Fishing Gear (M = Mobile; F = Fixed)
	Groundfish	Unspecified (F)
	Shrimp	Shrimp Trawl (M)
	Snow Crab (including exploratory)	Pots (F)
NG	Arctic Char	Unspecified
	Snow Crab (including exploratory)	
	Shrimp	
	Groundfish	
Nunatsiavut Group of Companies (part of the Northern Coalition)	Shrimp	Unspecified
Pikalujak Fisheries LTD (NG and Ocean Prawns Canada Ltd. partnership)	Shrimp	Unspecified
Miawpukek First Nation (MFN)		
MFN	Seal	Club/Rifle (F)
MFN 2	Groundfish	Gillnet, Trap, Longline (F)
	Snow Crab	Pots (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Swordfish	Longline, Harpoon (M)
	Bluefin Tuna	Unspecified (M; conditions associated with licence)
	Other Tuna sp.	Longline, Harpoon (M)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Sea Cucumber	Drag (M)
	Bait	Gillnet (F)
MFN 5	Groundfish	Gillnet, Trap, Longline (F)
	Snow Crab	Pots (F)
	Mackerel	Unspecified (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
	Sea Urchins	Scuba Diving (M)
MFN 7	Groundfish	Gillnet, Trap, Longline (F)
	Herring	Unspecified (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
	Bluefin Tuna	Tended Lines (M)
	Sea Cucumber	Drag (M)
MFN 12	Groundfish	Gillnet, Trap, Longline (F)
	Herring	Unspecified (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Sea Cucumber	Drag (M)
	Snow Crab	Pots (F)
MFN 14	Groundfish	Gillnet, Trap, Longline (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
	Lobster	Pots (F)
	Sea Cucumber	Drag (M)
MFN 15	Groundfish (except for lumpfish)	Otter Trawl (M)
	Groundfish (except cod and lumpfish)	Gillnet, Longline (F)
	Scallop	Drag (M)
MFN 16	Groundfish	Gillnet, Trap, Longline (F)
	Bluefin Tuna	Unspecified (M; conditions associated with licence)
	Whelk	Pots (F)
	Snow Crab	Pots (F)

Enterprise Name	Species Licence	Authorized Fishing Gear (M = Mobile; F = Fixed)
	Scallop	Drag (M)
	Sea Cucumber	Drag (M)
MFN 17	Groundfish	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Whelk	Pots (F)
	Bait	Gillnet (F)
	Snow Crab	Pots (F)
MFN 19	Groundfish (except lumpfish)	Otter Trawl (M)
	Groundfish (except cod and lumpfish)	Gillnet, Longline (F)
	Mackerel	Purse Seine (M)
	Capelin	Purse Seine (M)
MFN 20	Groundfish	Gillnet, Trap, Longline (F)
	Mackerel	Unspecified (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Scallop	Drag (M)
	Squid	Trap, Jigger (F)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
	Bluefin Tuna	Unspecified (M; conditions associated with licence)
	Bait	Gillnet (F)
MFN 21	Bluefin Tuna	Unspecified (M; conditions associated with licence)
MFN 22	Groundfish	Gillnet, Trap, Longline (F)
	Bluefin Tuna	Unspecified (M; conditions associated with licence)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
MFN 23	Groundfish	Gillnet, Longline (F)
	Bluefin Tuna	Unspecified (M; conditions associated with licence)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
	Bait	Gillnet (F)
MFN 24	Bluefin Tuna	Unspecified (M; conditions associated with licence)
MFN 27	Sea Cucumber	Drag (M)
MFN 28	Groundfish	Gillnet, Longline (fixed)
	Herring	Unspecified (F)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
	Bait	Gillnet (F)
MFN 29	Groundfish	Gillnet, Trap, Longline (F)
	Scallop	Drag (M)
	Whelk	Pots (F))
	Snow Crab	Pots (F)
MFN 30	Snow Crab	Unspecified
MFN 31	Groundfish	Gillnet, Trap, Longline (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
	Bait	Gill Net (fixed)
	Sea Cucumber	Drag (M)
MFN 32	Groundfish (except lumpfish)	Drag (M)
	Groundfish (except cod and lumpfish)	Gillnet, Longline (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)

Enterprise Name	Species Licence	Authorized Fishing Gear (M = Mobile; F = Fixed)
MFN 33	Groundfish	Gillnet, Longline (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Sea Cucumber	Drag (M)
	Snow Crab	Pots (F)
MFN 34	Groundfish	Gillnet, Longline (F)
	Scallop	Drag (M)
	Whelk	Pot (F)
	Sea Cucumber	Drag (M)
	Shrimp	Shrimp Trawl (M)
	Snow Crab	Pots (F)
MFN 35	Groundfish	Gillnet, Trap, Longline (F)
	Bluefin Tuna	Tended Lines (M)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Snow Crab	Pots (F)
	Bait	Gillnet (F)
MFN	Shrimp	Unspecified
Qalipu First Nation (QFN)		
QFN 1	Groundfish	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Lobster	Pots (F)
	Squid	Trap, Jigger (F)
QFN 2	Snow Crab	Pots (F)
	Groundfish	Gillnet, Longline (F)
	Mackerel	Unspecified (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
	Squid	Trap, Jigger (F)
QFN 3	Snow Crab	Pots (F)
	Groundfish	Gillnet, Longline (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
	Squid	Trap, Jigger (F)
QFN 4	Snow Crab	Pots (F)
	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
	Squid	Trap, Jigger (F)
	Whelk	Pots (F)
QFN 5	Snow Crab	Pots (F)
	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Squid	Trap, Jigger (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
QFN 6	Groundfish	Gillnet, Longline (F)
	Lobster	Pots (F)
	Bait	Gillet (F)
	Squid	Trap, Jigger (F)
QFN 7	Snow Crab	Pots (F)
	Groundfish (except lumpfish)	Gillnet, 1 Trap, Longline (F)
	Herring	Unspecified (F)
	Lobster	Pots (F)
QFN 8	Snow Crab	Pots (F)
	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)

Enterprise Name	Species Licence	Authorized Fishing Gear (M = Mobile; F = Fixed)
	Eels	Eel Pots, Fyke Nets (F)
	Smelts	Unspecified (M; with conditions)
	Scallop	Drag (M)
	Squid	Trap, Jigger (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
QFN 9	Snow Crab	Pots (F)
	Groundfish	Gillnet, 1 Trap, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Squid	Trap, Jigger (F)
	Whelk	Pots (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
QFN 10	Groundfish (except lumpfish)	Gillnet, 1 Trap, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Eels	Eel Pots, Fyke Nets (F)
	Lobster	Pots (F)
	Snow Crab	Pots (F)
	Bait	Gillnet (F)
QFN 11	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Mackerel	Unspecified (F)
	Lobster	Pots (F)
	Snow crab (banked)	Pots (F)
	Herring	Unspecified (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Squid	Trap, Jigger (F)
QFN 12	Herring	Purse Seine (M)
	Mackerel	Purse Seine (M)
	Capelin	Purse Seine (M)
	Scallop	Drag (M)
QFN 13	Herring	Purse Seine (M)
	Mackerel	Purse Seine (M)
	Capelin	Purse Seine (M)
QFN 14	Groundfish	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Squid	Trap, Jigger (F)
	Whelk	Pots (F)
	Lobster	Pots (F)
	Snow Crab	Pots (F)
	Bait	Gillnet (F)
QFN 15	Herring	Purse Seine (M)
	Mackerel	Purse Seine (M)
	Capelin	Purse Seine (M)
QFN 16	Groundfish	Gillnet, 2 Traps, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Snow Crab	Pots (F)
QFN 17	Capelin	Purse Seine (M)
QFN 18	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Purse Seine (M)
	Capelin	Purse Seine (M)
	Bait	Gillnet (F)

Enterprise Name	Species Licence	Authorized Fishing Gear (M = Mobile; F = Fixed)
QFN 19	Groundfish	Gillnet, Trap, Longline (F)
	Mackerel	Unspecified (F)
	Capelin	2 Traps & 1 Bar seine (F)
	Squid	Traps, Jigger (F)
	Snow Crab	Pots (F)
QFN 20	Herring	Purse Seine (M)
	Mackerel	Purse/Bar Seine (M)
	Capelin	Purse Seine (M))
QFN 21	Groundfish (except lumpfish)	Otter Trawl (M)
	Herring	Purse Seine (M)
	Mackerel	Purse Seine (M)
	Capelin	Purse Seine (M)
QFN 22-24	Sea Urchin	SCUBA Diving (M)
QFN 25	Groundfish	Gillnet, Trap, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Squid	Trap, Jigger (F)
	Lobster	Pots (F)
	Snow Crab	Pots (F)
QFN 26	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Herring	Purse Seine (M)
	Mackerel	Purse/Bar Seine (M)
	Capelin	Purse Seine (M)
	Lobster	Pots (M)
QFN 27	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Lobster	Pots (F)
	Snow Crab	Pots (F)
	Bait	Gillnet (F)
QFN 28	Groundfish	Gillnet, 1 Trap, Longline (F)
	Herring	Unspecified (F)
	Mackerel	Unspecified (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Whelk	Pots (F)
QFN 30	Groundfish	Gillnet, Trap, Longline (F)
	Herring	Purse Seine (M)
	Mackerel	Purse Seine (M)
	Capelin	Purse Seine (M)
	Squid	Trap, Jigger (F)
	Whelk	Pots (F)
	Lobster	Pots (F)
	Snow Crab	Pots (F)
	Bait	Gillnet (F)
QFN 31	Groundfish (except lumpfish)	Gillnet, Longline (F)
	Squid	Trap, Jigger (F)
	Lobster	Pots (F)
	Snow Crab	Pots (F)
	Bait	Gillnet (F)
QFN 32	Scallop	Drag (M)
Mi'kmaq Commercial Fisheries	Groundfish	Gillnet, Trap, Longline (F)
	Herring	Purse Seine (M)
	Mackerel	Unspecified (F)
	Mackerel	Purse Seine (M)
	Capelin	Purse Seine (M)
	Squid	Trap, Jigger (F)
	Lobster	Pots (F)
	Shrimp	Shrimp Trawl (M)
	Bait	Gillnet (F)

Enterprise Name	Species Licence	Authorized Fishing Gear (M = Mobile; F = Fixed)
	Snow Crab	Pots (F)
	Sea Cucumber	Drag (M)
Mi'kmaq Alsumk Mowimsikik Kogoey Association (MAMKA; MFN AND QFN)		
MAMKA (Mi'kmaq Alsumk Mowimsikik Kogoey Association) 1	Groundfish	Gillnet, Trap, Longline (F)
	Snow Crab	Pots (F)
	Herring	Unspecified (F)
	Capelin	2 Traps & 1 Bar Seine (F)
	Scallop	Drag (M)
	Whelk	Pots (F)
MAMKA 3	Herring	Unspecified (F)
	Snow Crab	Pots (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
MAMKA 4	Herring	Unspecified (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
MAMKA 5	Snow Crab	Pots (F)
	Groundfish	Gillnet, Longline (F)
	Herring	Unspecified (F)
	Lobster	Pots (F)
	Bait	Gillnet (F)
MAMKA 6	Snow Crab	Pots (F)
	Groundfish	Gillnet, Longline (F)
	Lobster	Pots (F)
	Squid	Trap, Jigger (F)
	Bait	Gillnet (F)
MAMKA 7	Scallop	Drag (F)
	Whelk	Pots (F)

Source: G. Rowe, Resource Manager, Indigenous Fisheries, DFO NL Region, pers. comm., 21 May 2025.

Table 4.12. Communal Commercial Licence counts by species for NL-based Indigenous Groups, 2024.

Species	Innu Nation	MAMKA	MFN	NCC	NG	QFN	Total No. Licences
Bait		4	8	5		14	**31**
Capelin	1	1	2	2		18	**24**
Eels						2	**2**
Groundfish – FG	1	3	19	12	7	22	**64**
Groundfish – MG	1		3			1	**5**
Herring	1	4	5	2		22	**34**
Lobster		4				18	**22**
Mackerel	1		5			23	**29**
Scallop		3	17	7	15	4	**46**
Sea cucumber			9				**9**
Sea Urchin			1			3	**4**
Seal			1	2	2		**5**
Shrimp	3		1	2	1	1	**8**
Smelts						1	**1**
Snow crab		4	17	13	5	17	**56**
Squid		1	1			15	**17**
Swordfish			1				**1**
Toad crab				1			**1**
Tuna, Bluefin	1		9				**10**
Tuna, Other			1				**1**
Whelk		2	18	10		6	**36**
Total	**9**	**26**	**118**	**56**	**30**	**167**	**406**

Source: G. Rowe, Resource Manager, Indigenous Fisheries, DFO NL Region, pers. comm., 21 May 2025.

4.3.5 Recreational Fisheries

Recreational fisheries in Newfoundland are described in Section 3.3.3 of C-NLOPB (2010), Section 4.3.4.4 of C-NLOPB (2014), Section 3.3.1.4 of IAAC (2020), and Section 4.3.5 of LGL (2018).

The NL recreational groundfish fishery occurs in NAFO Divisions 2GHJ, 3KLPsPn, and 4R (DFO 2025d). Of these areas, Divisions 3KLPs overlap the Study Area. The fishery is mainly conducted in coastal and inshore areas (C-NLOPB 2014). Species that are caught recreationally typically include groundfish (e.g., Atlantic cod), Atlantic salmon, trout, smelt, Arctic char, northern pike, and whitefish (DFO 2025a,e). It is prohibited for recreational fishers to retain Atlantic halibut, spotted or northern wolffish, or any shark species. Sculpins and cunners may be released, but all other groundfish must be retained and counted towards daily bag limits (DFO 2025d).

The 2025 summer recreational Atlantic salmon fishery in Newfoundland will be open for 98 days, from 1 June–7 September (DFO 2025a). Fall angling on Gander River, Exploits River, and Humber River will be open for 30 days, from 8 September–7 October. The 2025 recreational trout fishery in Newfoundland will open on 1 February and will close during early- to mid-September, depending on the fishing area (DFO 2025a). Decisions have not yet been made for the 2025 recreational groundfish fishery, but it was open for 39 days during 2024 (summer season: 29 June–2 September; fall season: 21–29 September; DFO 2025a). The 2022 and 2023 seasons were similarly open for 39 days. There is no requirement for licences or tags for the NL recreational groundfish fishery, although tour boat operators may apply for a licence for an increased groundfish retention limit per boat per trip and such a licence would require harvest reporting (DFO 2025a). Licences are required for trout angling and salmon fishing, and tags are required for salmon (DFO 2025d).

It is possible that recreational fisheries will be conducted within the shallower portions of the Study Area.

4.3.6 Aquaculture

Aquaculture operations in Newfoundland are described in Section 3.3.2 of C-NLOPB (2010), Section 4.3.4.3 of C-NLOPB (2014), and Section 3.3.1.1 of IAAC (2020). A visual indication and descriptions of active aquaculture sites are provided in the Canada Marine Planning Atlas (DFO 2025f). Currently, all aquaculture sites in the province are in coastal waters. There are no approved aquaculture sites within the Study Area (N. Penton, Manager, Aquaculture Licensing and Administration, Department of Fisheries, Forestry, and Agriculture, Government of NL, pers. comm., 18 January 2024).

4.3.7 Macroinvertebrates and Fishes Collected during DFO Research Vessel (RV) Surveys

DFO RV survey data collected during annual multi-species trawl surveys provide additional distributional information for predominant commercial species described in Section 4.3.3 as well as for species not discussed in that subsection, including those that may be considered underutilized or that have been under moratoria in certain NAFO Div. within the Study Area. A summary of DFO RV

survey data collected during the most recent six years with available data (2018–2023) relative to the Study Area is provided in this section. In previous years, DFO RV survey data were supplemented by Groundfish Enterprise Allocation Council (GEAC) surveys that focused on Atlantic cod and/or American plaice and witch flounder in NAFO Div. 3Ps and occurred in the fall between 1997–2007 (McClintock 2001; Varkey et al. 2024). Although these data are considered out-of-date for the purposes of presenting information published since the release of C-NLOPB (2010, 2014) or IAAC (2020, 2024), a GEAC survey consistency plot for Atlantic cod is provided in this section as the data were used in a recent modelling exercise by DFO (Varkey et al. 2024).

The total non-coral or sponge catch weight during the 2018–2023 spring (May, June, August) and fall (September–November) DFO RV surveys in the Study Area was 376 mt. The total catch weight in the Study Area during 2018–2023 DFO RV surveys for corals was 0.84 mt, and for sponges was 4 mt. Data collected during these surveys were analyzed, and catch weights, catch numbers, and mean catch depths of species/groups contributing ≥0.1% of the total non-coral or sponge catch weight as well as species at risk (Section 4.6), corals, and sponges are presented in Table 4.13. Across all non-coral or sponge species caught during the spring and fall 2018–2023 spring and fall RV surveys within the Study Area, the total catch weight ranged from 18–114 mt per year. The lowest catch weight years (2020 = 51 mt, 2021 = 18 mt) were likely due to reduced survey effort due to restrictions associated with the COVID-19 pandemic and/or vessel-related challenges (e.g., Withers 2022). During 2018–2023, coral catch weights ranged from 0.03–0.33 mt per year. Sponges were caught during 2019–2020 and 2022–2023 and catch weights were ~1 mt each year.

Table 4.13. Catch weights and numbers and mean catch depths of macroinvertebrates and fishes collected during DFO RV Surveys within the Study Area, May–November 2018–2023.

Species	Catch Weight (mt)	% Total Mass	Catch Number	Mean Catch Depth (m)	
				Spring	Fall
Non-coral or Sponge Species/Groups (Total Mass = 371 mt)					
Deepwater Redfish (*Sebastes mentella*)	149	40%	727,657	317	314
Thorny Skate (*Raja radiata*)	34	9%	18,091	206	224
Yellowtail Flounder (*Limanda ferruginea*)	33	9%	114,957	72	72
American Plaice (*Hippoglossoides platessoides*)	27	7%	166,411	153	186
Atlantic Cod (*Gadus morhua*)	20	5%	31,158	143	199
Offshore Sand Lance (*Ammodytes dubius*)	11	3%	818,690	88	
Greenland Halibut (*Reinhardtius hippoglossoides*)	11	3%	51,933	312	316
Silver Hake (*Merluccius bilinearis*)	10	3%	55,943	268	165
Capelin (*Mallotus villosus*)	8	2%	434,037	119	278
Sand Lance (*Ammodytes* sp.)	6	2%	579,395	102	
Invertebrate sp.	6	2%	33	236	524
Roughhead Grenadier (*Macrourus berglax*)	6	2%	13,978	461	453
Witch Flounder (*Glytocephalus cynoglossus*)	5	1%	16,226	304	298
Comb Jelly sp.	5	1%	144,721	87	82
Snow Crab (*Chionoecetes opilio*)	4	1%	25,092	164	216
Atlantic Halibut (*Hippoglossus hippoglossus*)	3	1%	259	212	307
White Hake (*Urophycis tenuis*)	3	1%	4987	290	210
Orange-footed Sea Cucumber (*Cucumaria frondosa*)	2	1%	17,594	85	109
Northern Shrimp (*Pandalus borealis*)	2	1%	398,994	292	278
Shrimp (Natantia)	2	1%	2	253	518
Atlantic (striped) Wolffish (*Anarhichas lupus*)	2	0.5%	2178	184	227
Sand Lance sp.	2	0.4%	121,023	82	
Jellyfish sp.	2	0.4%	44	398	271
Northern Wolffish (*Anarhichas denticulatus*)	1	0.3%	365	502	450

Species	Catch Weight (mt)	% Total Mass	Catch Number	Mean Catch Depth (m)	
				Spring	Fall
Basket Star (*Gorgonocephalus arcticus*)	1	0.3%	210	143	185
Marlin Spike (*Nezumia bairdi*)	1	0.3%	18,338	426	546
Longfin Hake (*Urophycis chesteri*)	1	0.3%	14,226	414	
Striped Shrimp (*Pandalus montagui*)	1	0.3%	305,813	89	113
Sea Anemone sp.	1	0.2%	14,472	300	298
Spinytail Skate (*Raja [Bathyraja] spinicauda*)	1	0.2%	121	535	432
Green Sea Urchin (*Strongylocentrotus droebachiensis*)	1	0.2%	59,763	104	122
Monkfish (*Lophius americanus*)	1	0.2%	262	264	189
Blue Hake (*Antimora rostrata*)	1	0.2%	4053	609	953
Spotted Wolffish (*Anarhichas minor*)	1	0.2%	305	333	295
Haddock (*Melanogrammus aeglefinus*)	1	0.2%	617	137	131
Spiny Dogfish (*Squalus acanthias*)	1	0.2%	285	213	127
Black Dogfish (*Centroscyllium fabricii*)	1	0.2%	1057	528	697
Sculpin sp.	1	0.1%	23,434	121	309
Shorthorn Sculpin (*Myoxocephalus scorpius*)	0.5	0.1%	717	84	
Moustache Sculpin (*Triglops murrayi*)	0.5	0.1%	59,662	101	
Atlantic Herring (*Clupea harengus*)	0.5	0.1%	3649	146	130
Roundnose Grenadier (*Coryphaenoides rupestris*)	0.5	0.1%	4076	610	760
Eelpout sp.	0.5	0.1%	2581	256	382
Shortfin Squid (*Illex illecebrosus*)	0.5	0.1%	3134	289	268
Golden Redfish (*Sebastes marinus*)	0.4	0.1%	232	356	349
Eel sp.	0.4	0.1%	7451	454	957
Hake (*Urophycis* sp.)	0.4	0.1%	3522	404	439
Longhorn Sculpin (*Myoxocephalus octodecemspinosus*)	0.3	0.1%	1417	69	
Arctic Argid Shrimp (*Argis dentata*)	0.3	0.1%	52,086	108	130
Squid (*Illex* sp.)	0.3	0.1%	1816	331	267
Sand Dollar (*Echinarachnius parma*)	0.3	0.1%	13,680	134	163
Arctic Cod (*Boreogadus saida*)	0.3	0.1%	29,957	159	309
Mud Star (*Ctenodiscus crispatus*)	0.2	0.1%	27,901	218	232
Brittle Star (*Ophiura sarsi*)	0.2	0.1%	5585	163	201
Sea Raven (*Hemitripterus americanus*)	0.2	0.1%	157	68	
Longnose Eel (*Synaphobranchus kaupi*)	0.2	0.1%	5023	487	
Argentine sp.	0.2	0.1%	1416	317	437
Pollock (*Pollachius virens*)	0.2	0.1%	93	160	410
Winter Skate (*Leucoraja ocellata*)	0.05	0.01%	15	157	72
Atlantic Mackerel (*Scomber scombrus*)	0.01	0.002%	18	211	
Cusk (*Brosme brosme*)	0.01	0.002%	2	288	646
Corals (Total Mass = 0.84 mt)					
Soft Corals	0.27	32%	-	243	351
Large Gorgonians	0.27	32%	-	383	495
Sea Pens	0.16	19%	-	383	633
Stony Cup Corals	0.11	14%	-	455	545
Mushroom Corals	0.02	3%	-	535	675
Small Gorgonians	0.01	1%	-	435	496
Corals	0.01	1%	-	202	397
Black Corals	0.002	0%	-	453	511
Zoanthids	0.00002	0.003%	-		472
Sponges (Total Mass = 4 mt)					
Sponge (Porifera spp.)	4	-	-	337	319

Source: DFO RV Survey Data, 2018–2023.

Notes:

Table includes non-coral or sponge species/groups contributing ≥0.1% of their total catch weight, species at risk, corals, and sponges. Corals and sponges include all survey months rather than just May–November, as these species are caught relatively rarely during RV surveys and restricting months would have resulted in missing the only catches of soft corals during 2018–2023.

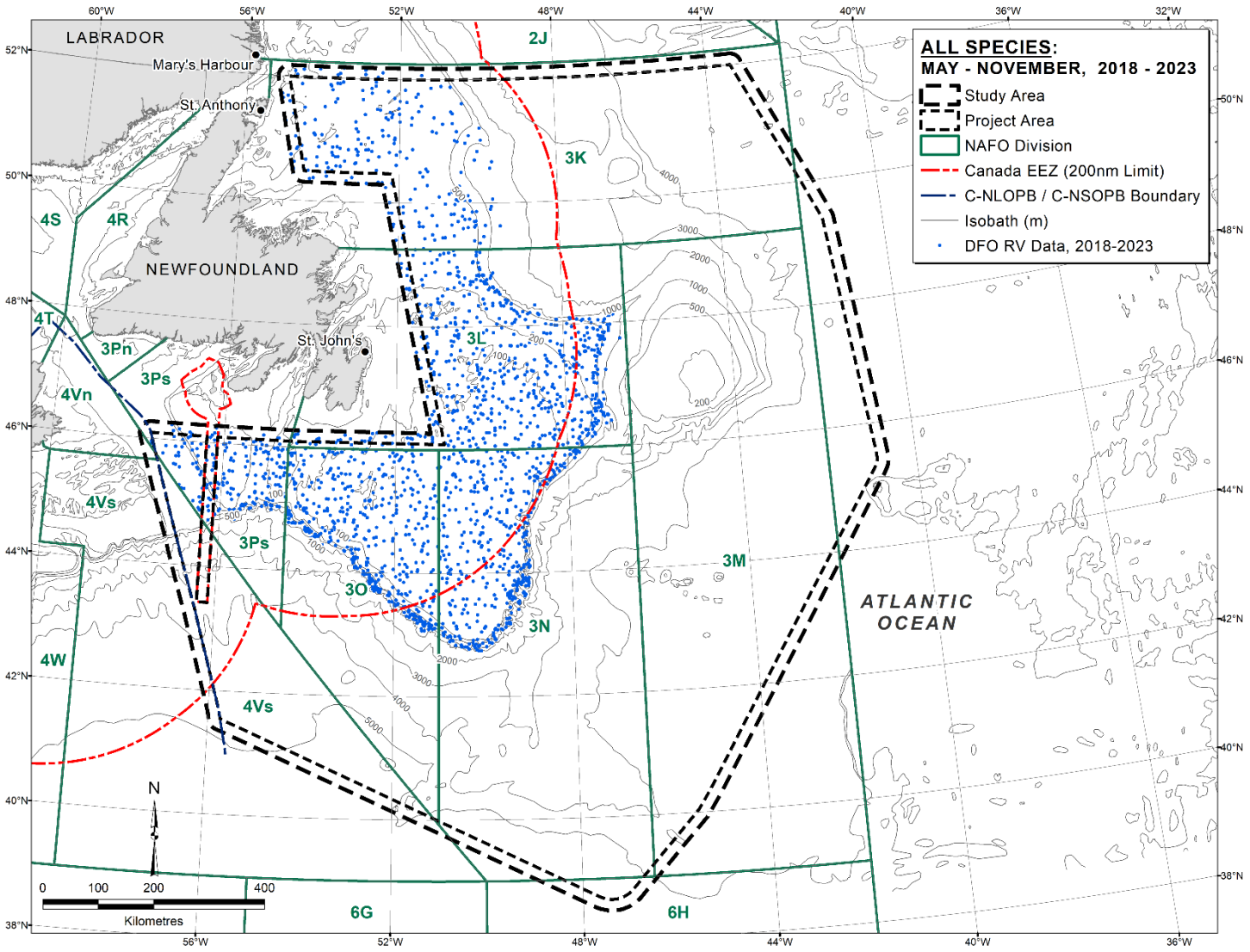
Red font = at-risk species designated as *Endangered* or *Threatened* under Schedule 1 of SARA.

Green font = candidate species for assessment by COSEWIC.

In terms of total catch weight, predominant non-coral or sponge species/groups caught during 2018–2023 spring and fall DFO RV surveys were deepwater redfish (40%), thorny skate and yellowtail flounder (9% each), American plaice (7%), and Atlantic cod (5%). These species were representative of predominant species targeted using similar mobile gear (i.e., bottom trawls) in the commercial fishery in recent years (see Section 4.3.3.2). Various sand lance species represented a combined ~2–3% of the total catch weight; however, as there is no market for this species, they are not known or expected to occur as significant bycatch in commercial fisheries (e.g., bottom trawl, pelagic seine; DFO 2010a), and they were not reported in commercial fisheries within the Study Area during 2018–2023 (see Section 4.3.3.2), sand lance is not considered underutilized at this time. Species at risk generally comprised ≤1% of the total catch weight. The coral functional groups caught during 2018–2023 spring and fall DFO RV surveys were representative of those typically found in the offshore Newfoundland region (e.g., Edinger et al. 2007; Kenchington et al. 2016). Sponges were identified to the Porifera phylum, which has been the standard for DFO RV surveys.

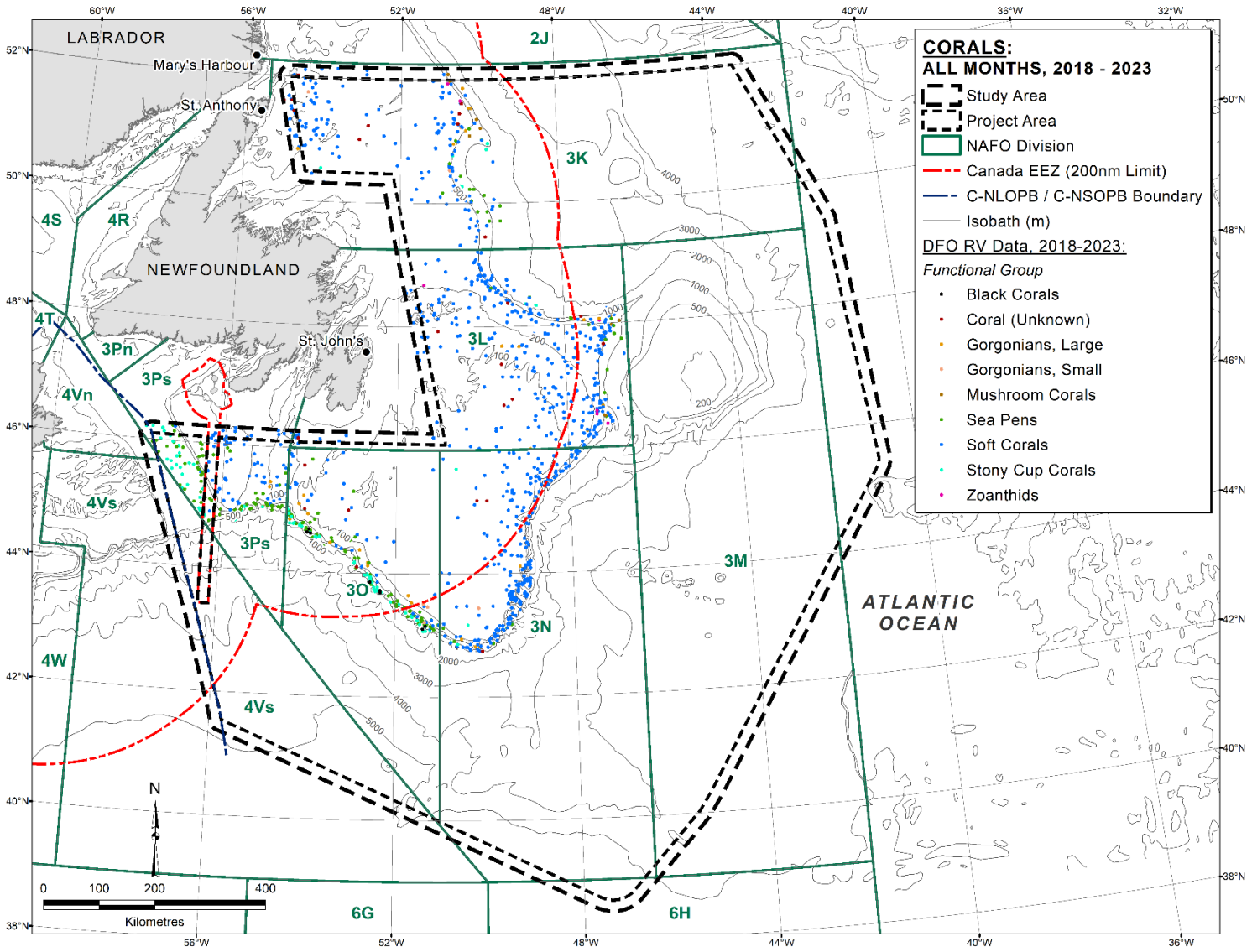
DFO RV survey catch locations for 2006–2007 for redfish, yellowtail flounder, thorny skate, American plaice, and Atlantic cod are provided in Section 3.2.4.2 of C-NLOPB (2010). DFO RV survey catch locations for 2000–2012 for corals and for 2005–2009 for redfish, yellowtail flounder, American plaice, and Atlantic cod are provided in Sections 4.1.2.5 and 4.2.1.6, respectively, of C-NLOPB (2014). DFO RV survey catch locations for 2014 for redfish, yellowtail flounder, thorny skate, American plaice, and Atlantic cod are provided in Section 4.3.7 of LGL (2018). DFO RV survey catch locations within the Study Area for all species combined, corals, and sponges during 2018–2023 are provided in Figures 4.24–4.26, respectively. Catch locations for predominant non-coral or sponge species caught during 2018–2023 (i.e., deepwater redfish, thorny skate, yellowtail flounder, American plaice, and Atlantic cod) are provided in Figures 4.27–4.31. DFO RV catch locations during 2018–2023 surveys for primary commercial fisheries species not already presented in the aforementioned figures are provided in Figures 4.32–4.35. Finally, DFO RV catch locations during 2018–2023 surveys for at-risk species not already presented in the preceding figures are provided in Figures 4.36–4.45. Fauna were mainly captured within the western portions of the Study Area during the 2018–2023 DFO spring and fall RV surveys, in water depths <2000 m (predominantly <1000 m).

Spring and fall surveys accounted for 53% and 47% of the total non-coral or sponge catch weight, respectively. The average of mean depths of catch for non-coral or sponge species during spring and fall surveys during 2018–2023 were 219 m (min = 54 m; max = 695 m) and 261 m (min = 45 m; max = 1215 m), respectively. The average of mean catch depths for 2018–2023 for coral functional groups was 320 m during spring surveys (min = 202 m; max = 535 m) and 440 m during fall surveys (min = 351 m; max = 675 m), and for sponges was 337 m and 319 m during spring and fall surveys, respectively.



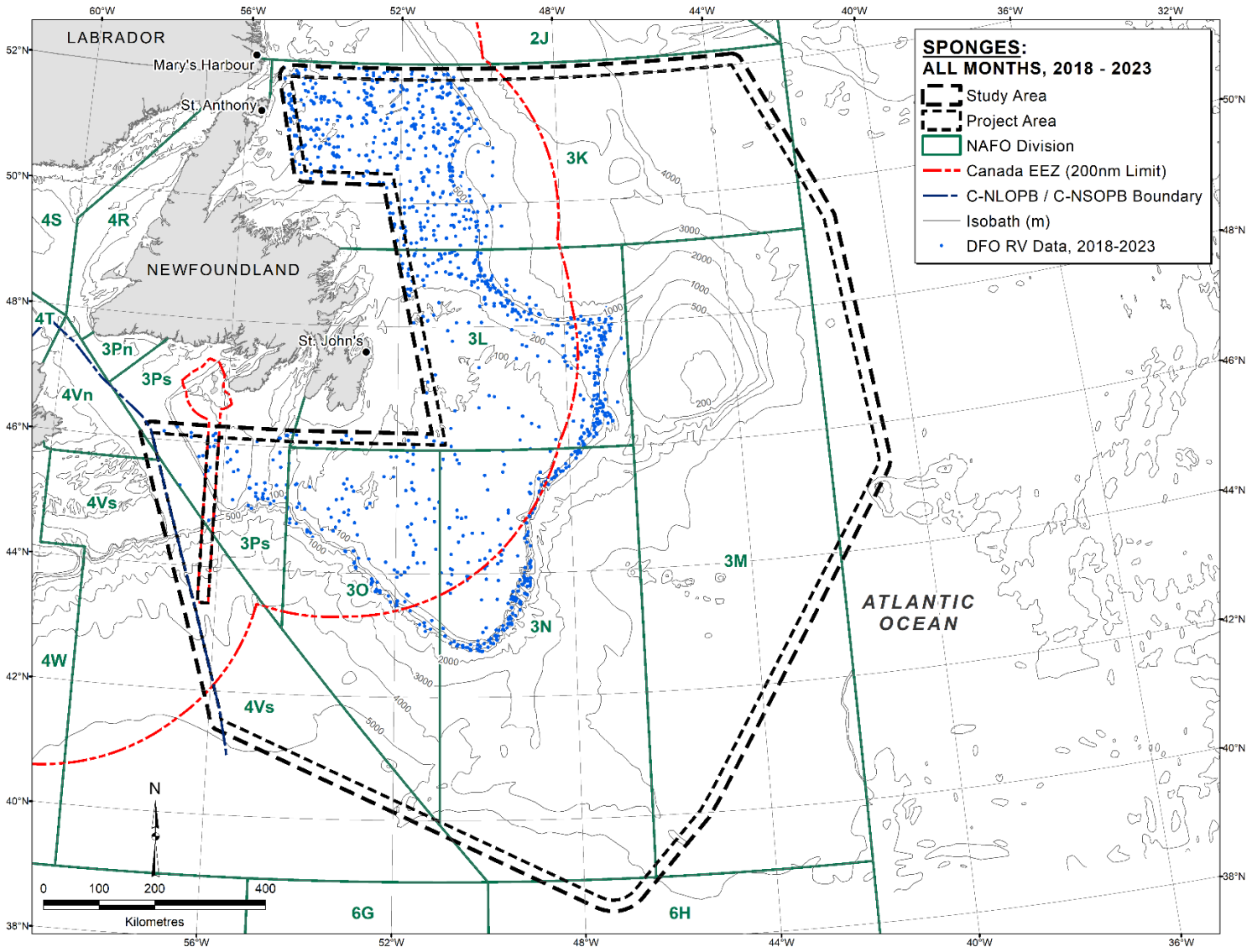
Source: DFO RV Survey Data, 2018–2023.

Figure 4.24. Distribution of DFO RV survey catch locations in the Study Area, all species (non-coral or sponge), May–November 2018–2023.



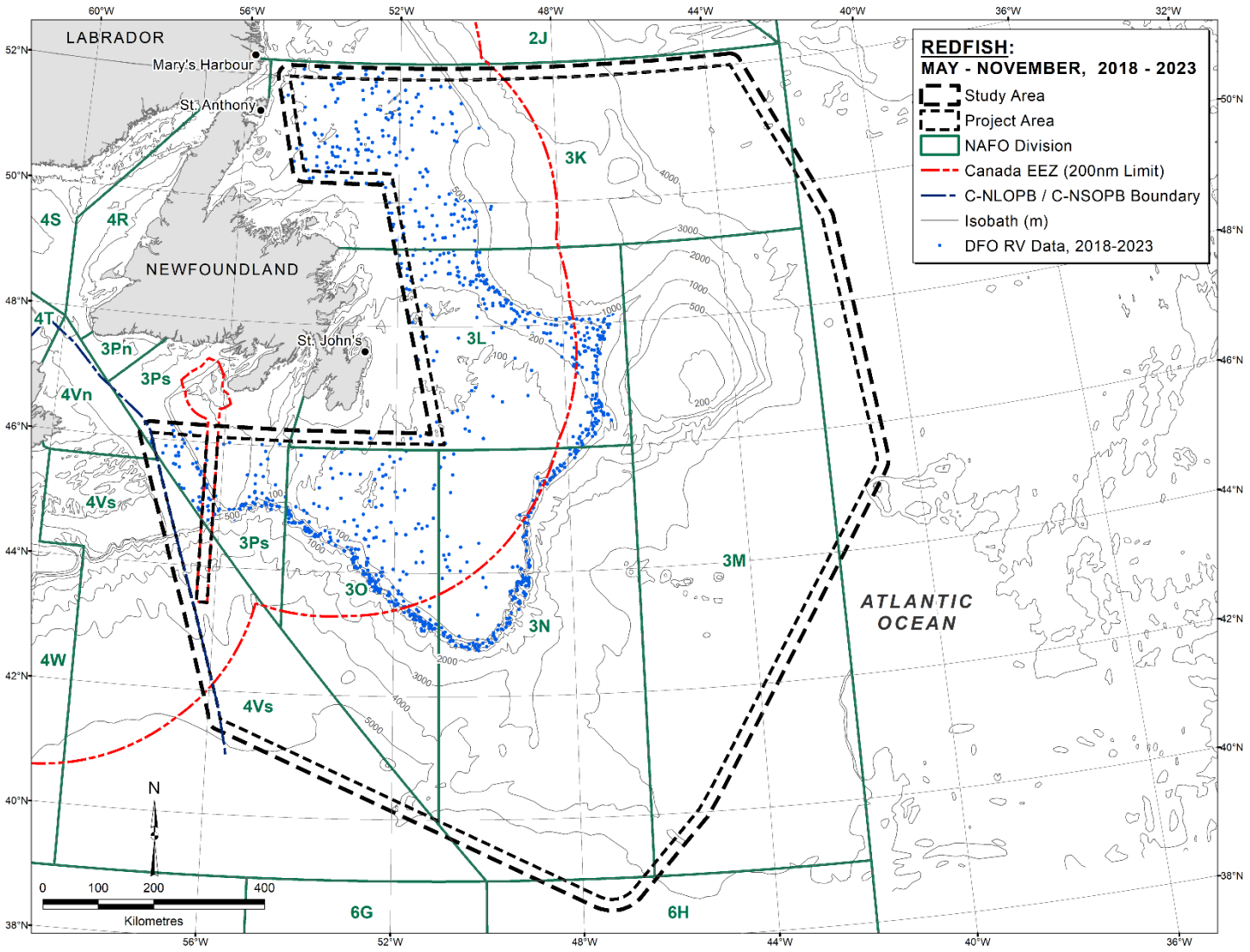
Source: DFO RV Survey Data, 2018–2023.

Figure 4.25. Distribution of DFO RV survey catch locations of corals in the Study Area, May–November 2018–2023.



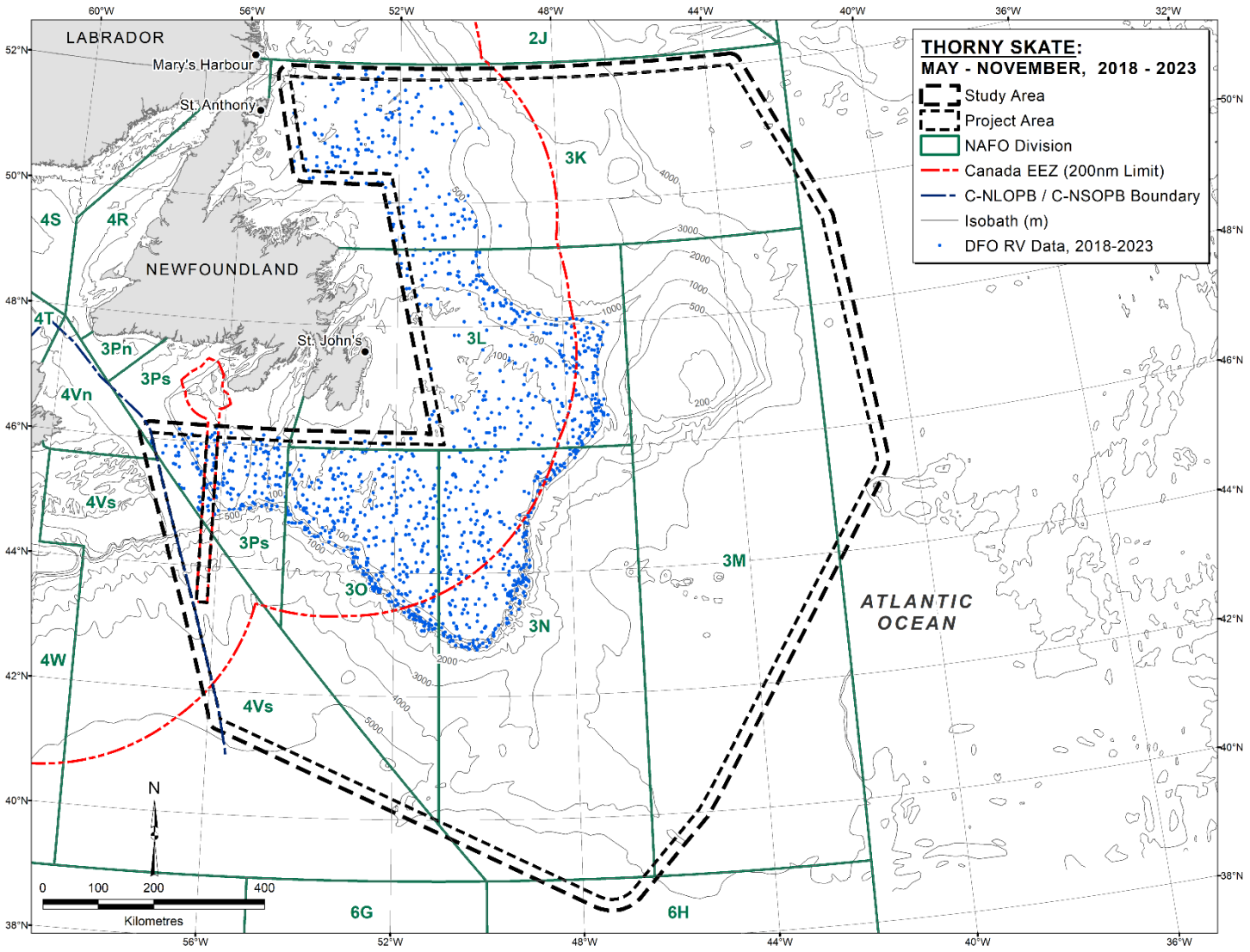
Source: DFO RV Survey Data, 2018–2023.

Figure 4.26. Distribution of DFO RV survey catch locations of sponges in the Study Area, May–November 2018–2023.



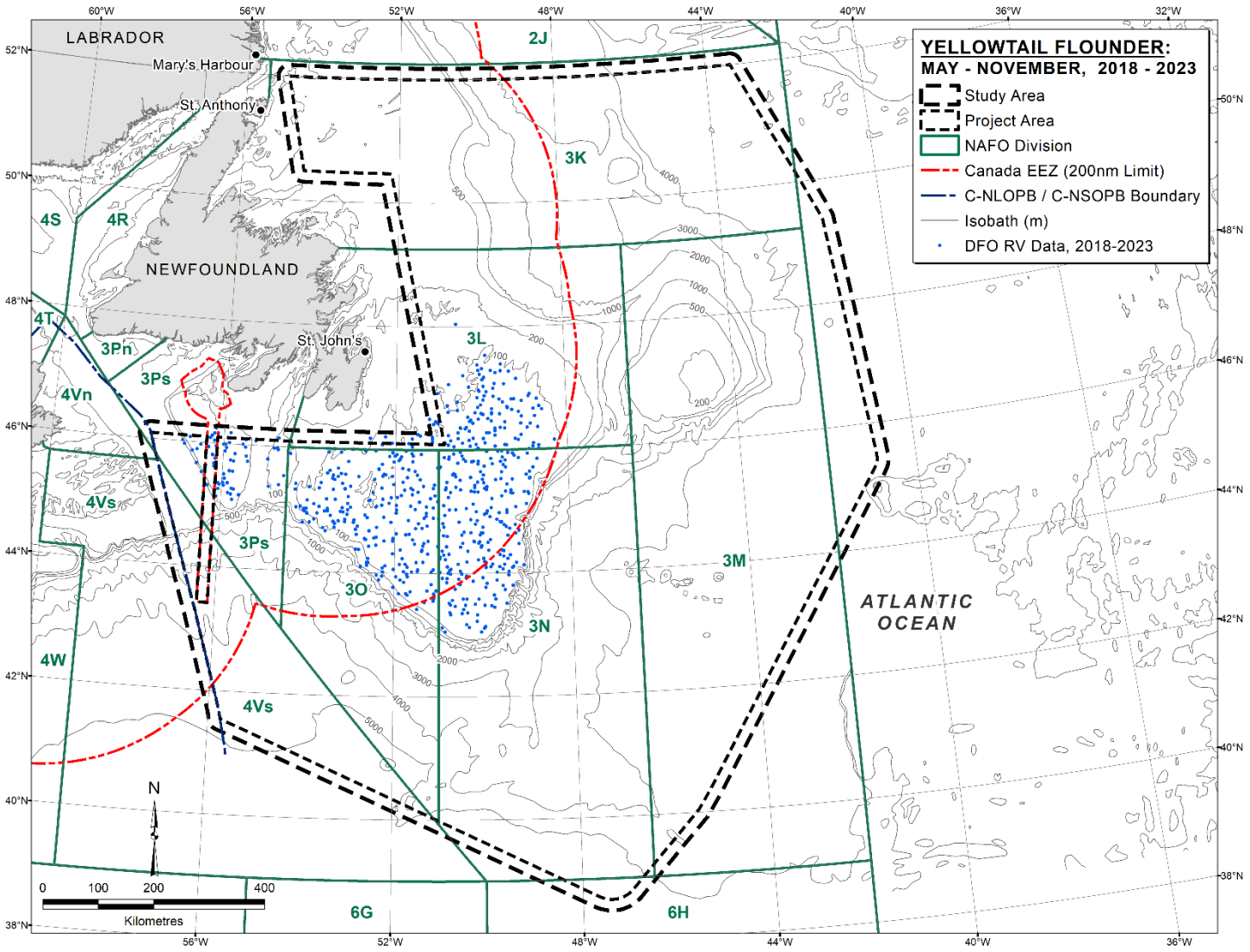
Source: DFO RV Survey Data, 2018–2023.

Figure 4.27. Distribution of DFO RV survey catch locations of redfish in the Study Area, May–November 2018–2023.



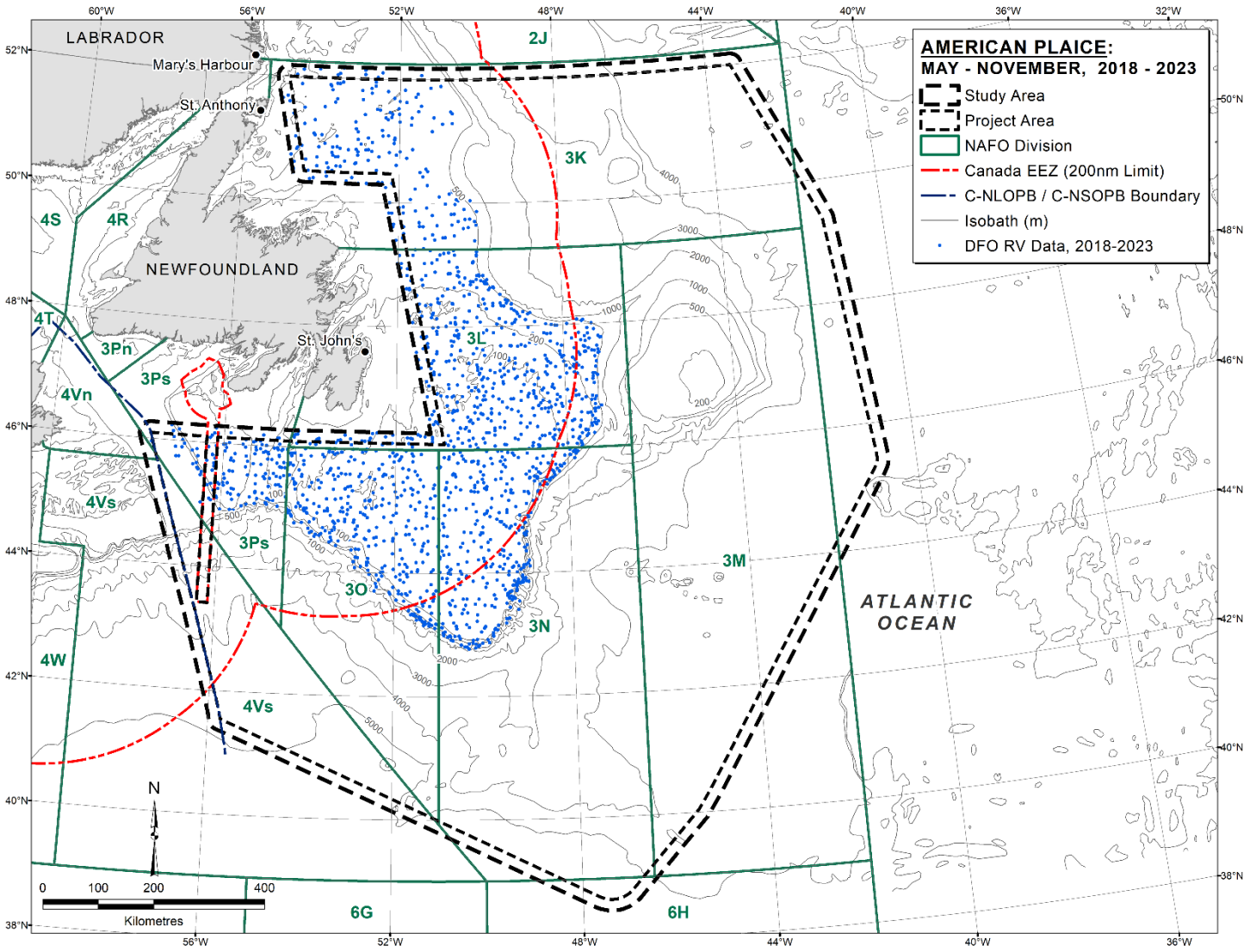
Source: DFO RV Survey Data, 2018–2023.

Figure 4.28. Distribution of DFO RV survey catch locations of thorny skate in the Study Area, May–November 2018–2023.



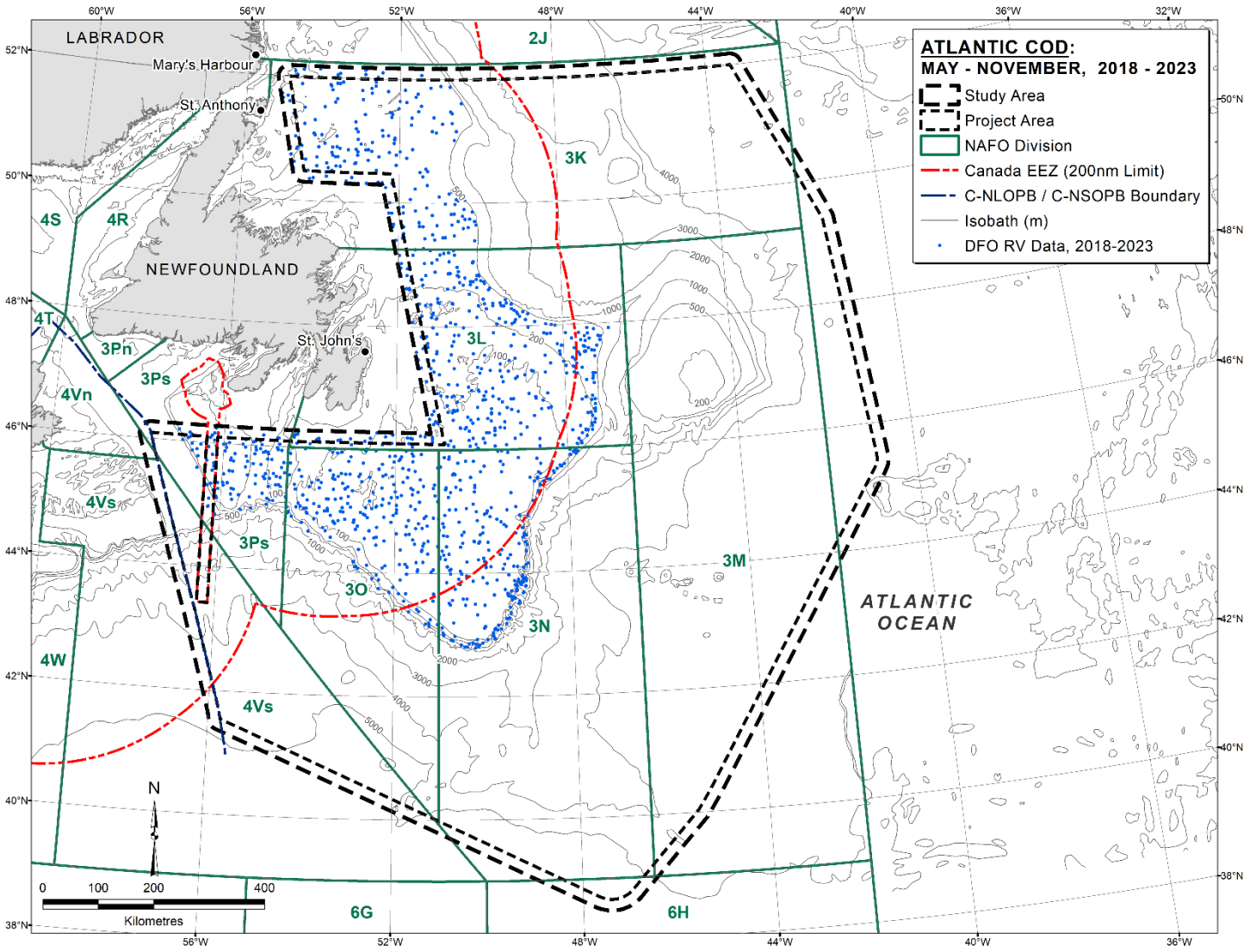
Source: DFO RV Survey Data, 2018–2023.

Figure 4.29. Distribution of DFO RV survey catch locations of yellowtail flounder in the Study Area, May–November 2018–2023.



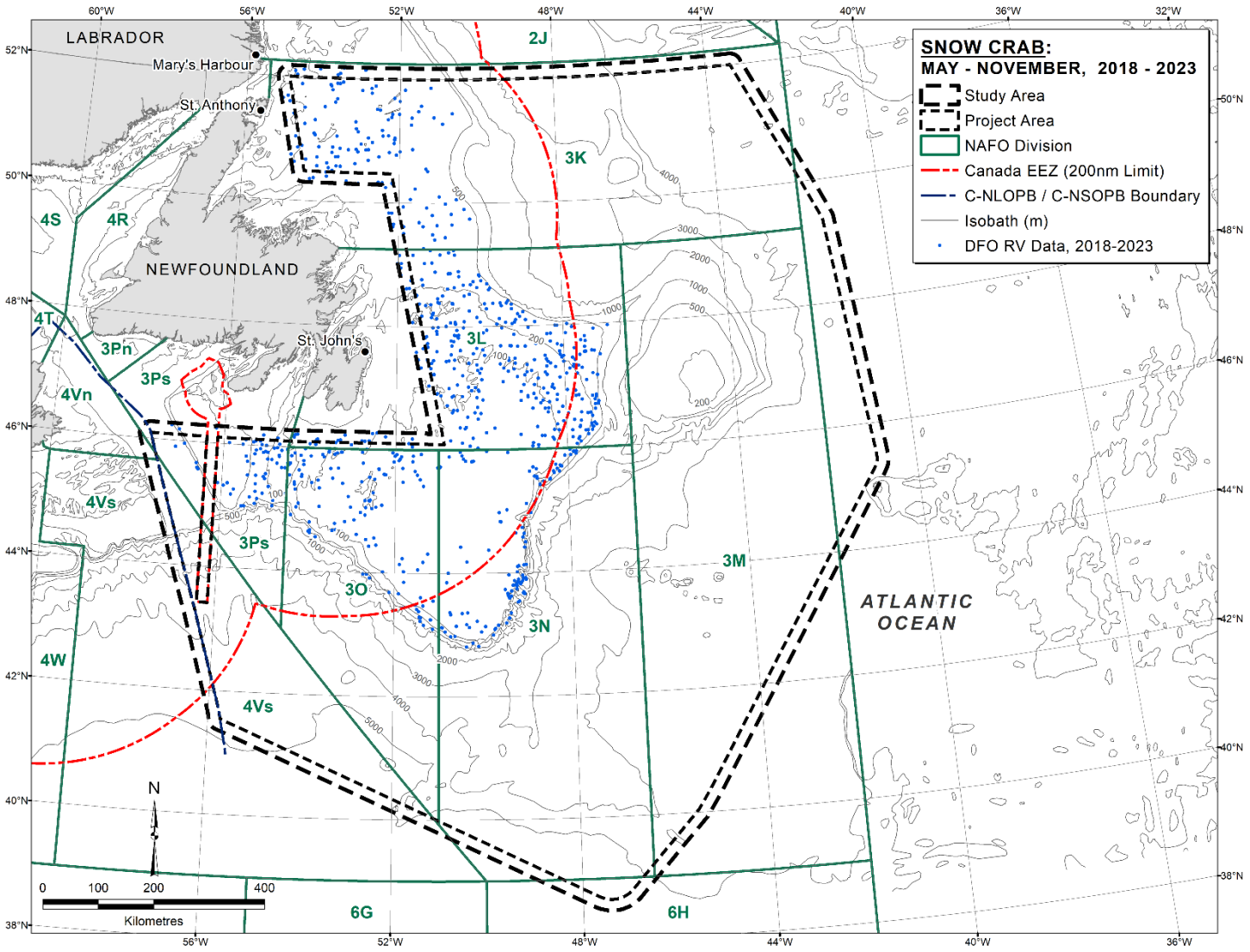
Source: DFO RV Survey Data, 2018–2023.

Figure 4.30. Distribution of DFO RV survey catch locations of American plaice in the Study Area, May–November 2018–2023.



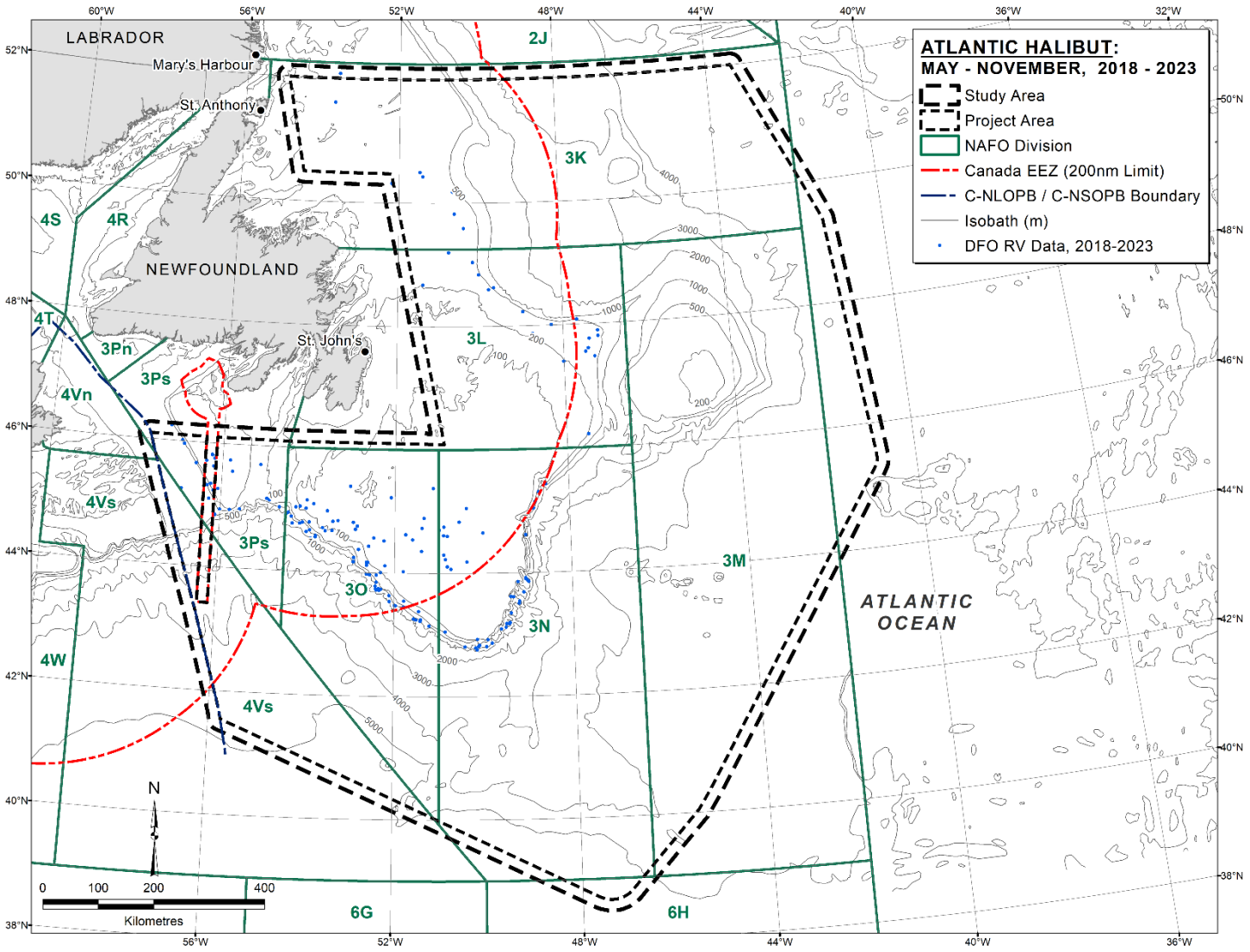
Source: DFO RV Survey Data, 2018–2023.

Figure 4.31. Distribution of DFO RV survey catch locations of Atlantic cod in the Study Area, May–November 2018–2023.



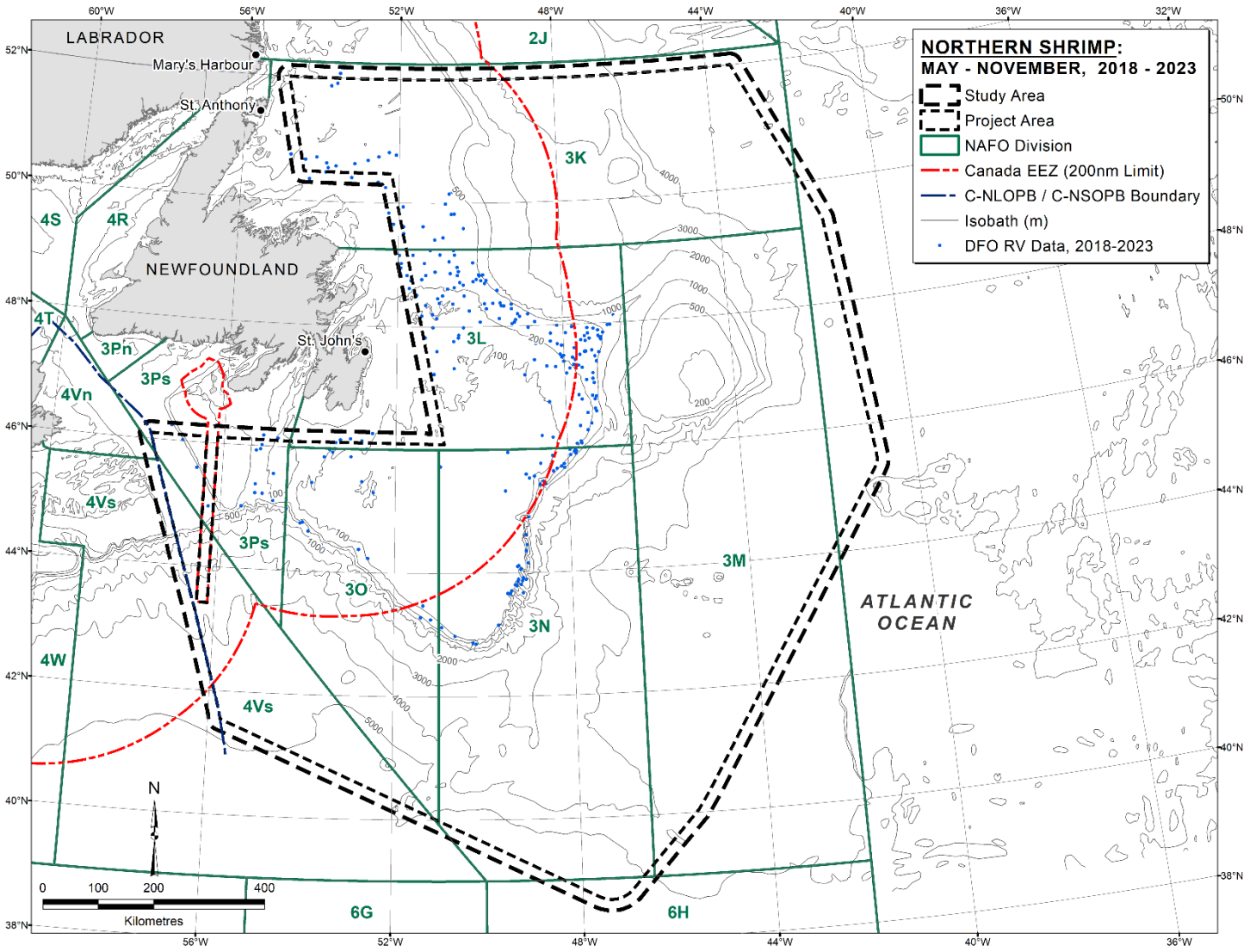
Source: DFO RV Survey Data, 2018–2023.

Figure 4.32. Distribution of DFO RV survey catch locations of snow crab in the Study Area, May–November 2018–2023.



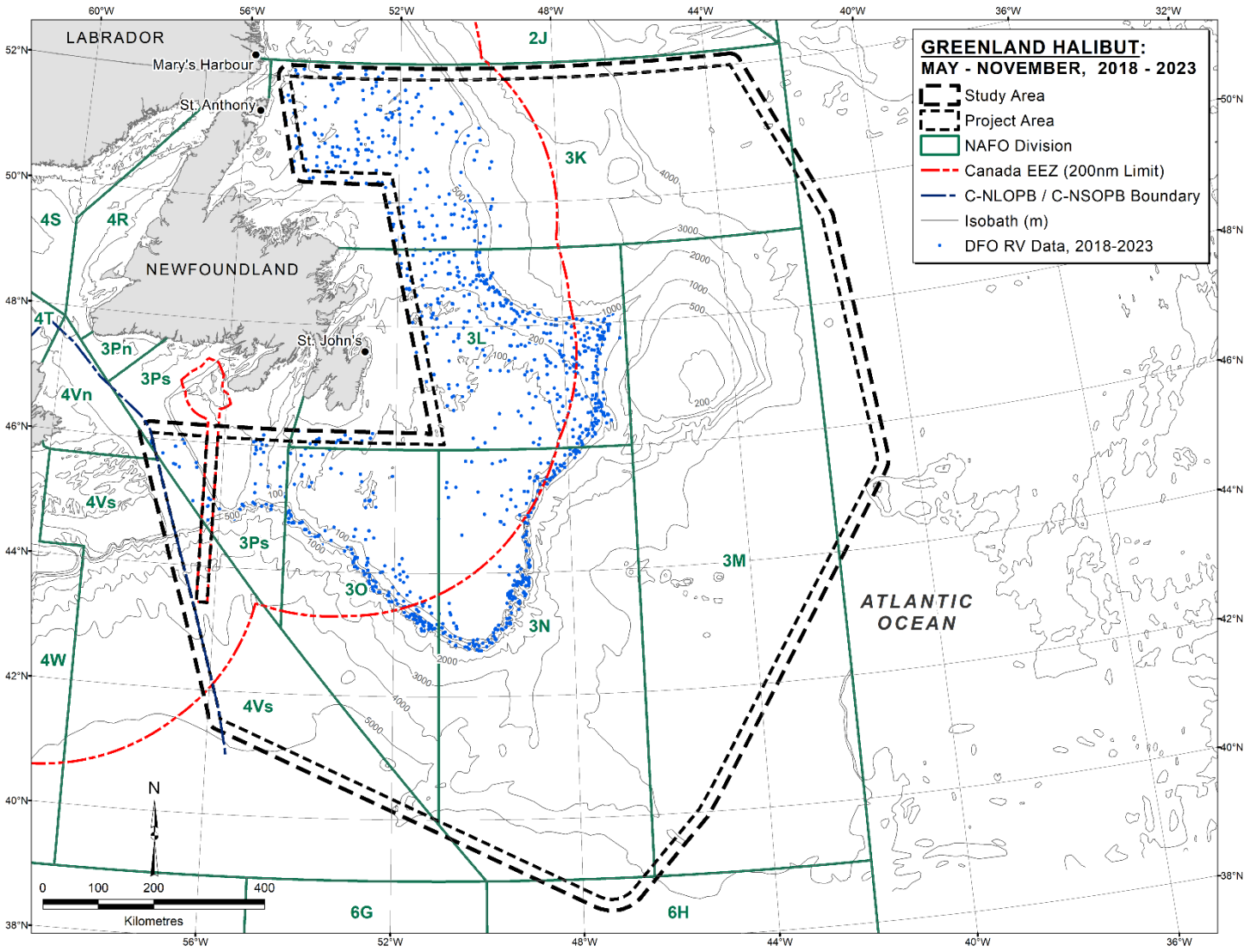
Source: DFO RV Survey Data, 2018–2023.

Figure 4.33. Distribution of DFO RV survey catch locations of Atlantic halibut in the study area, May–November 2018–2023.



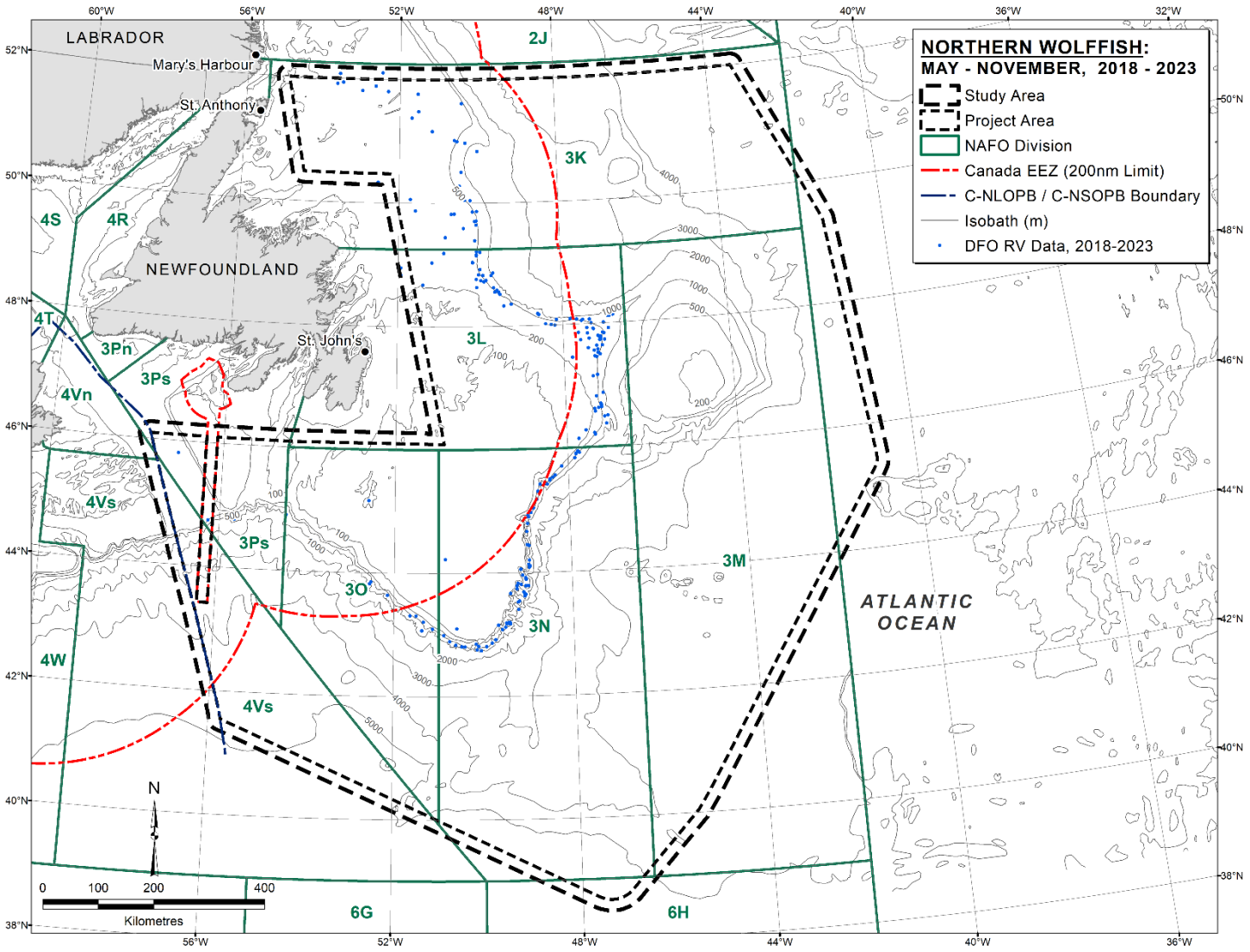
Source: DFO RV Survey Data, 2018–2023.

Figure 4.34. Distribution of DFO RV survey catch locations of northern shrimp in the Study Area, May–November 2018–2023.



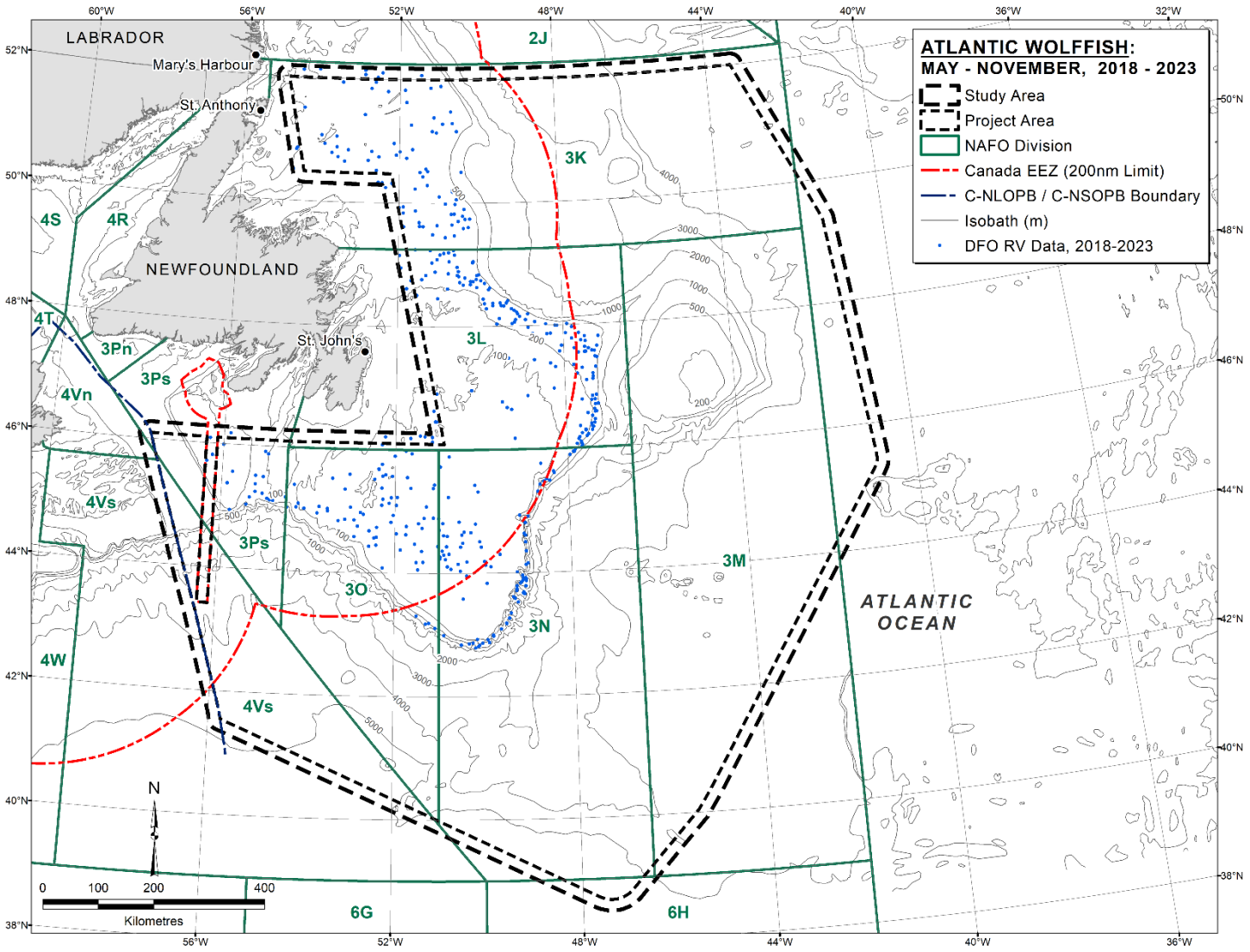
Source: DFO RV Survey Data, 2018–2023.

Figure 4.35. Distribution of DFO RV survey catch locations of Greenland halibut in the Study Area, May–November 2018–2023.



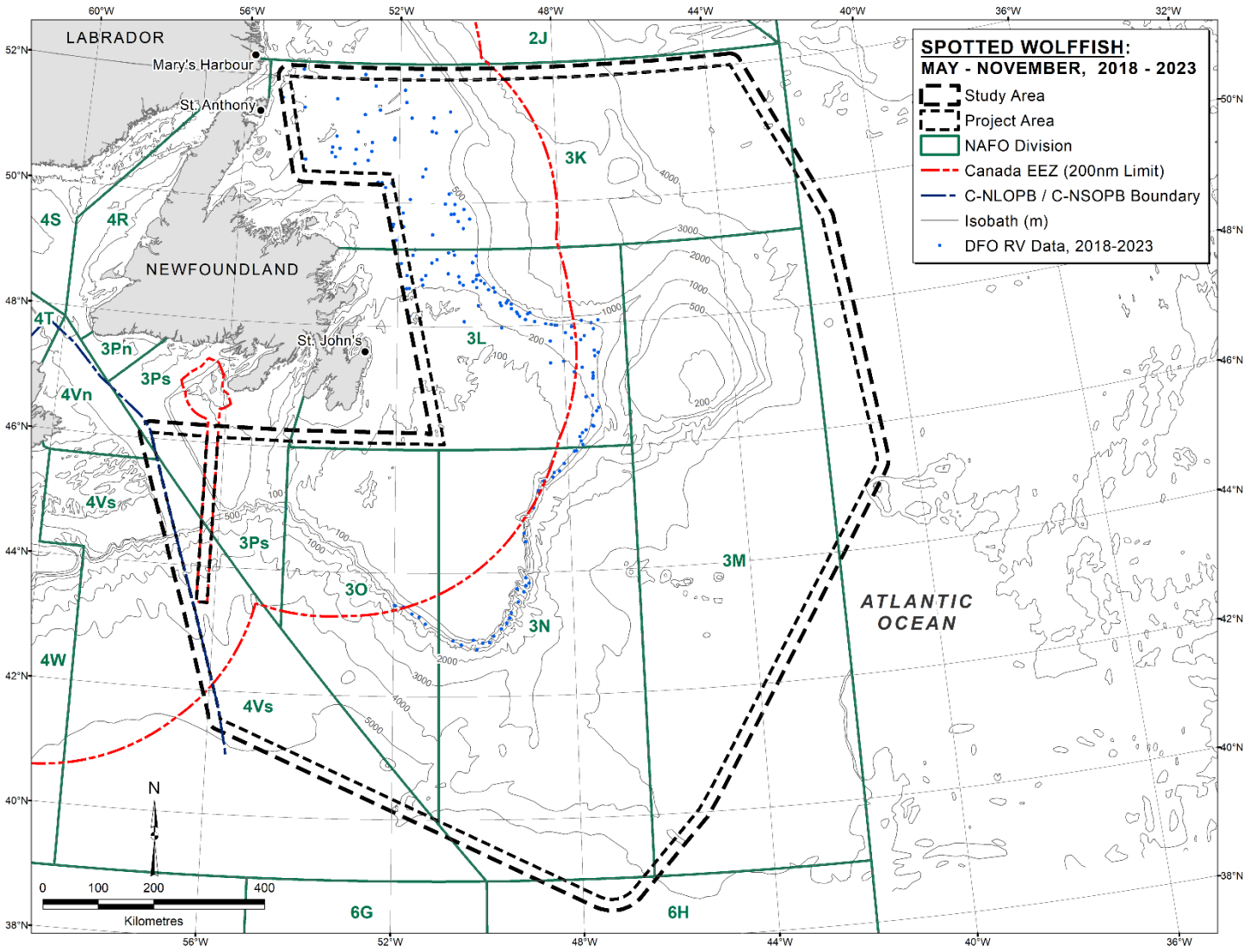
Source: DFO RV Survey Data, 2018–2023.

Figure 4.36. Distribution of DFO RV survey catch locations of northern wolffish in the Study Area, May–November 2018–2023.



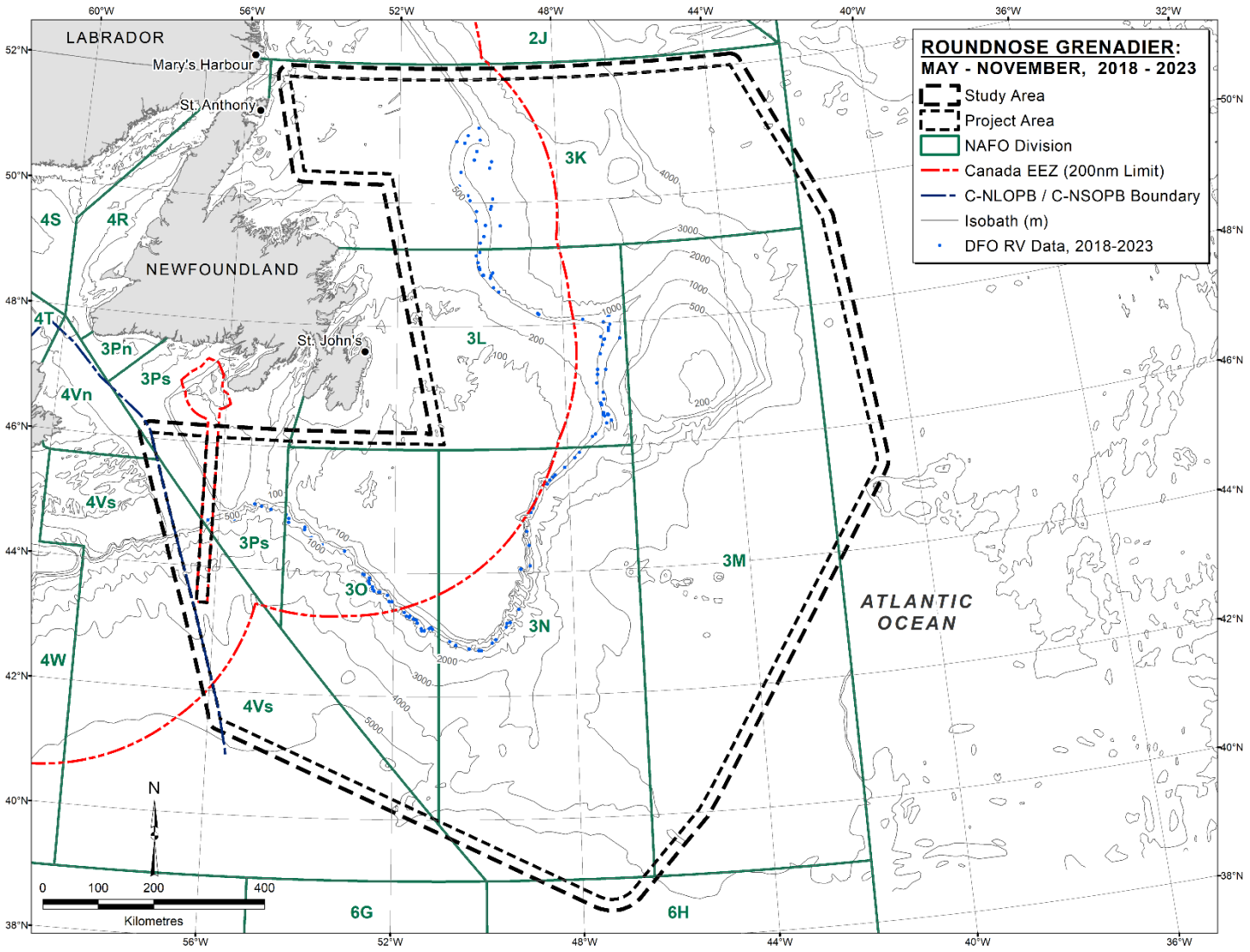
Source: DFO RV Survey Data, 2018–2023.

Figure 4.37. Distribution of DFO RV survey catch locations of Atlantic (striped) wolffish in the Study Area, May–November 2018–2023.



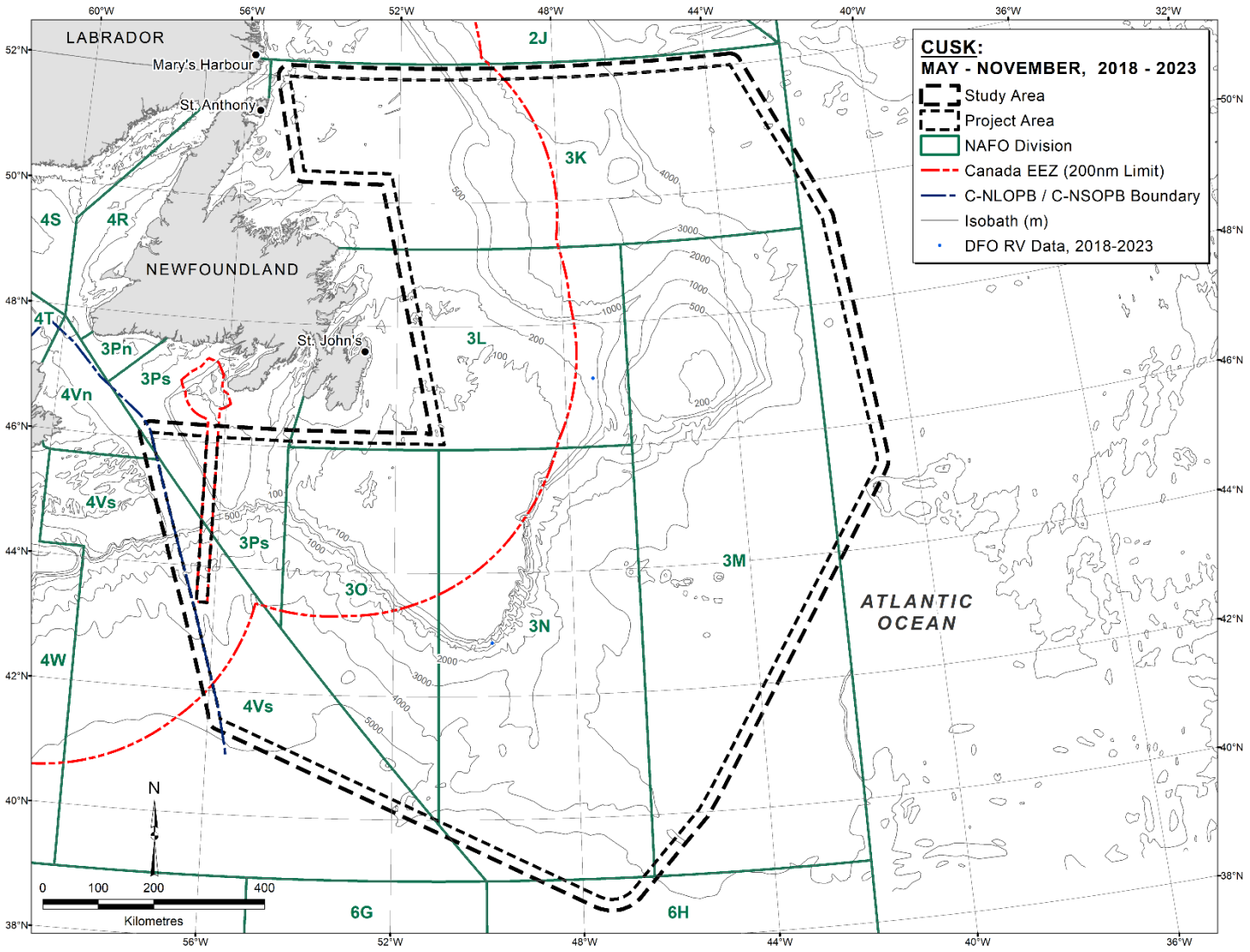
Source: DFO RV Survey Data, 2018–2023.

Figure 4.38. Distribution of DFO RV survey catch locations of spotted wolffish in the Study Area, May–November 2018–2023.



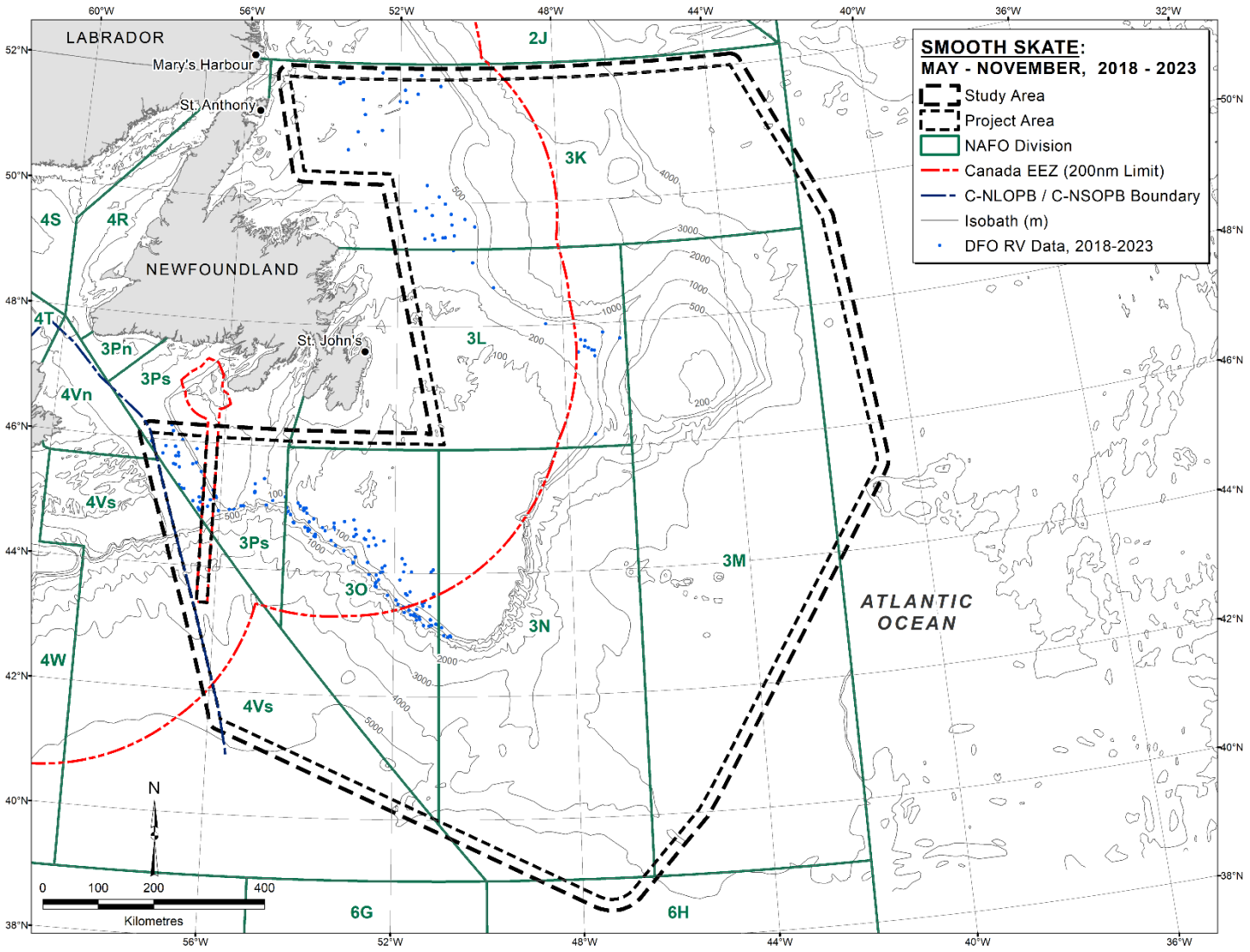
Source: DFO RV Survey Data, 2018–2023.

Figure 4.39. Distribution of DFO RV survey catch locations of roundnose grenadier in the Study Area, May–November 2018–2023.



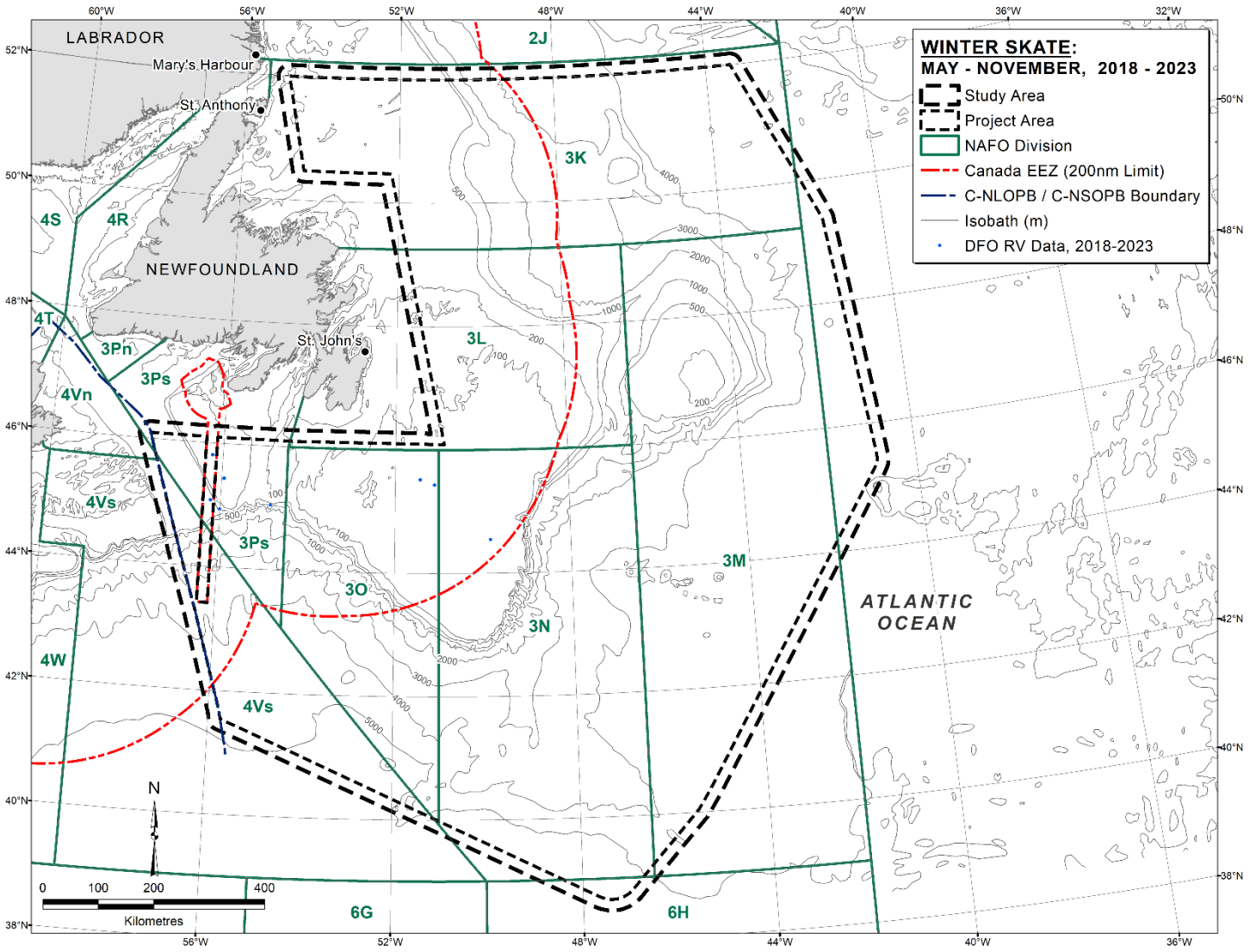
Source: DFO RV Survey Data, 2018–2023.

Figure 4.40. Distribution of DFO RV survey catch locations of cusk in the Study Area, May–November 2018–2023.



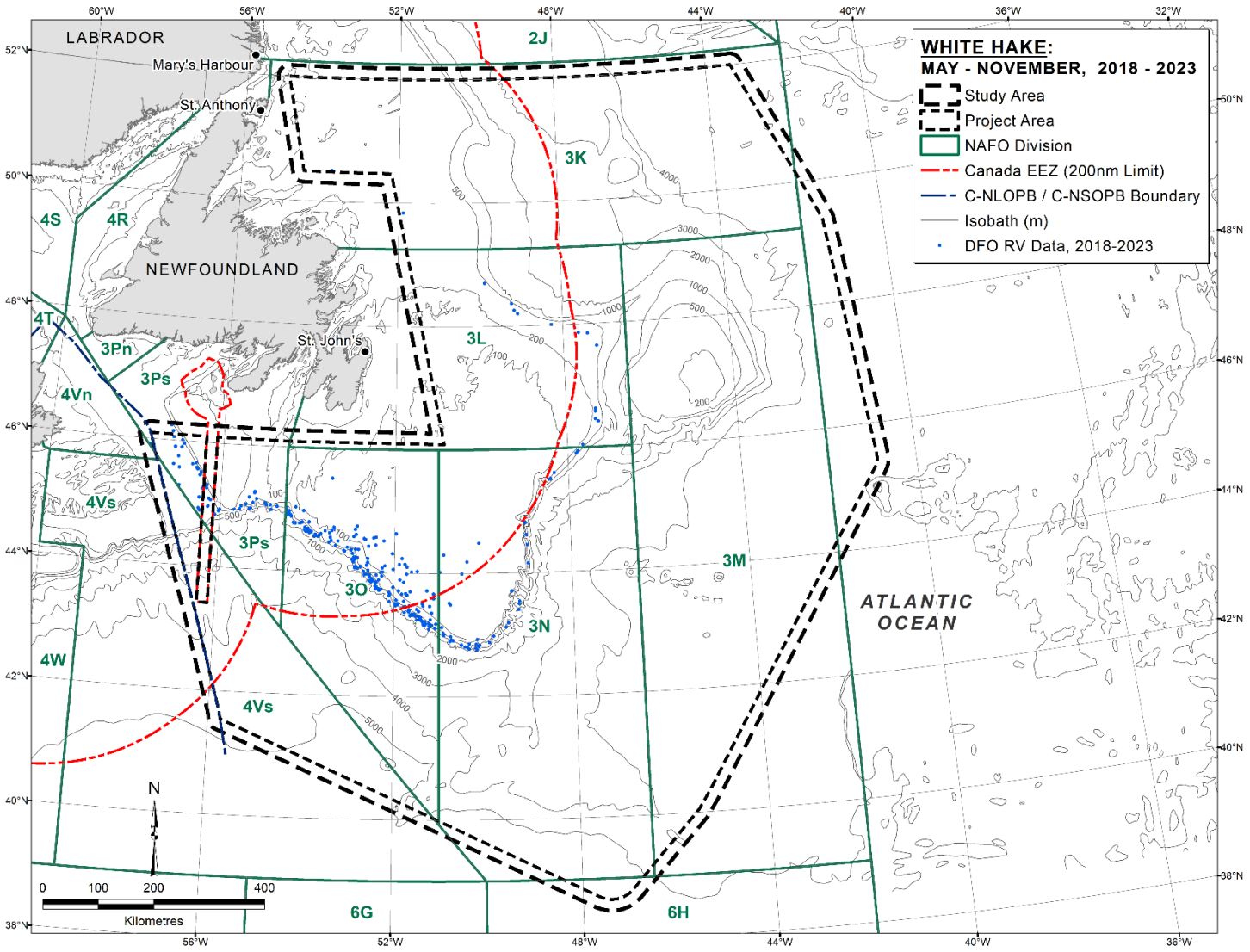
Source: DFO RV Survey Data, 2018–2023.

Figure 4.41. Distribution of DFO RV survey catch locations of smooth skate in the Study Area, May–November 2018–2023.



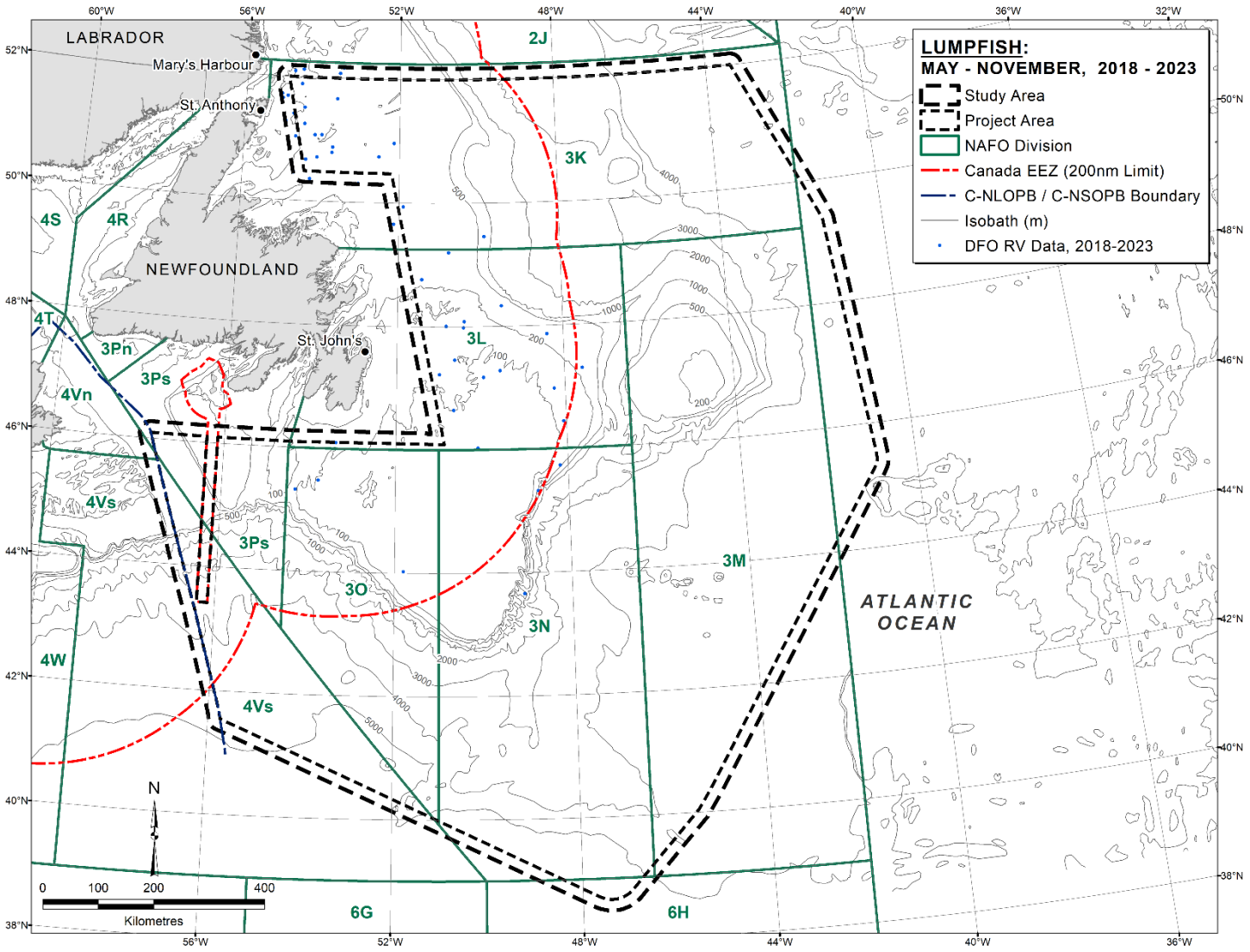
Source: DFO RV Survey Data, 2018–2023.

Figure 4.42. Distribution of DFO RV survey catch locations of winter skate in the Study Area, May–November 2018–2023.



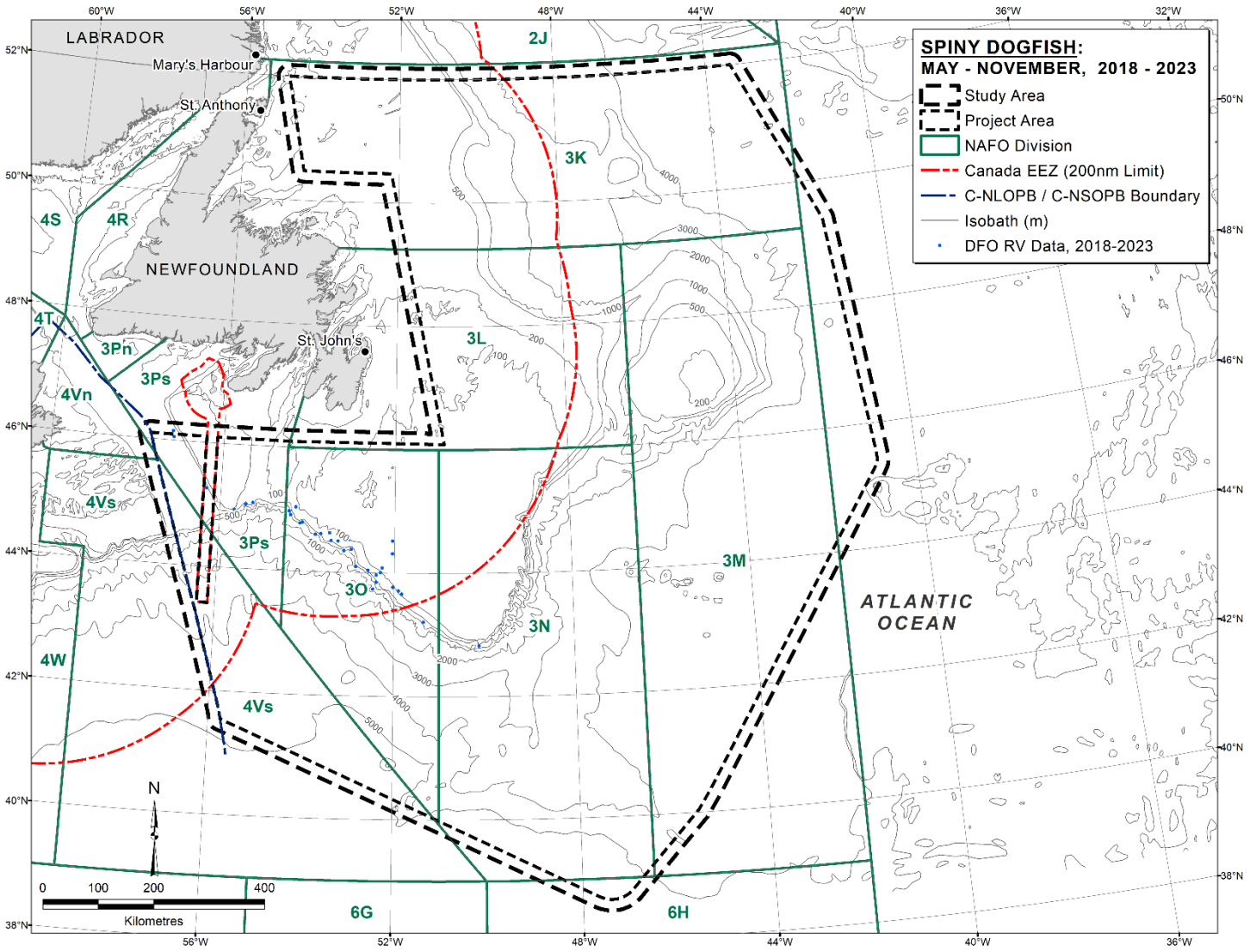
Source: DFO RV Survey Data, 2018–2023.

Figure 4.43. Distribution of DFO RV survey catch locations of white hake in the Study Area, May–November 2018–2023.



Source: DFO RV Survey Data, 2018–2023.

Figure 4.44. Distribution of DFO RV survey catch locations of lumpfish in the Study Area, May–November 2018–2023.



Source: DFO RV Survey Data, 2018–2023.

Figure 4.45. Distribution of DFO RV survey catch locations of spiny dogfish in the Study Area, May–November 2018–2023.

In descending order, the top five non-coral or sponge species/groups in terms of catch weight during the 2018–2023 spring surveys were deepwater redfish, thorny skate, yellowtail flounder, offshore sand lance (*Ammodytes dubius*), and Atlantic cod; and during the fall surveys were deepwater redfish, American plaice, yellowtail flounder, thorny skate, and Atlantic cod. DFO RV surveys have experienced variabilities in occurrence in recent years, such as either spring or fall surveys not or incompletely occurring in some locations during some years (e.g., due to vessel issues), reduced permissible survey efforts related to restrictions during the COVID-19 pandemic during 2020/2021, and planned (but not always necessarily realized) concurrent, comparative surveys between outgoing and incoming survey vessels (see Section 4.3.8; e.g., Withers 2022). Due to these recent interannual variations, further comparison of annual species catches is precluded for currently available data, but such comparisons can resume in future EA updates, namely when the new RV fleet is fully operational and comparative survey data are finalized by DFO.

Catches at various mean depth ranges are also examined in this subsection. Table 4.14 presents total catch weights and predominant non-coral or sponge species/groups, corals, and sponges caught within each mean depth range in the Study Area during the 2018–2023 period. Corals were only caught in mean depth ranges between 300–699 m, and sponges were only caught within mean depths of 300–399 m. Predominant commercial species (2018–2023) mainly targeted using mobile gear were caught at mean depths of ~100–300 m (yellowtail flounder = 72 m; Atlantic cod = 171 m; Atlantic halibut = 253 m; northern shrimp = 284 m; redfish = 315 m).

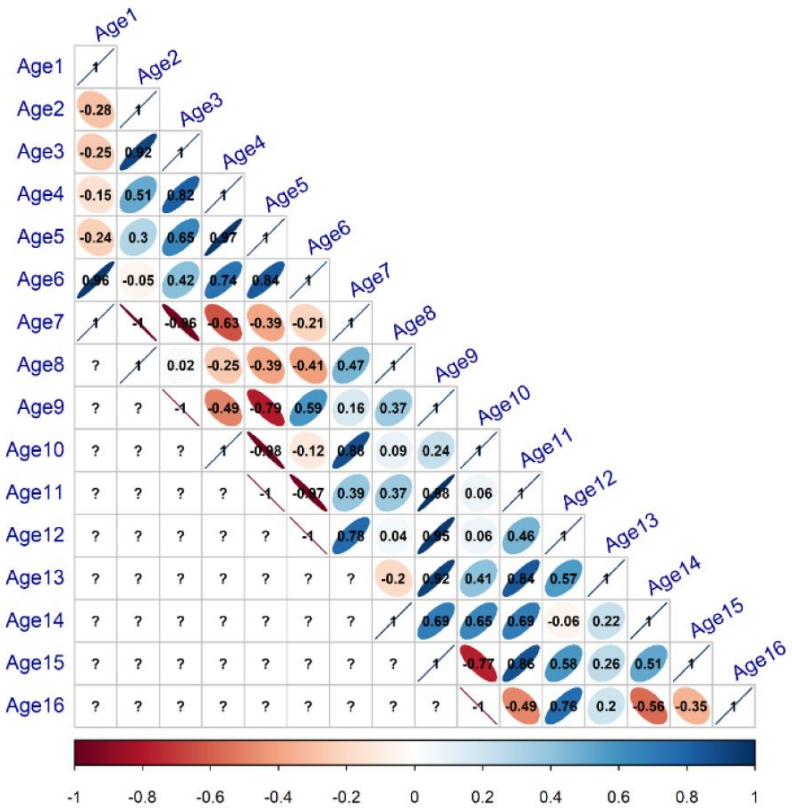
Table 4.14. Total catch weights and predominant non-coral or sponge species/groups, corals, and sponges caught at various mean catch depth ranges during DFO RV surveys within the Study Area, May–November 2018–2023.

Mean Catch Depth Range (m)	Total Catch Weight (mt)	Predominant Species/Groups (% of Total Catch Weight)
Non-coral or Sponge Species/Groups		
<100	54	Yellowtail Flounder (61%) Offshore Sand Lance (20%)
100–199	72	American Plaice (37%) Atlantic Cod (28%) Capelin (10%)
200–299	65	Thorny Skate (53%) Silver Hake (16%) Invertebrate sp. (9%)
300–399	170	Deepwater Redfish (88%) Greenland Halibut (6%)
400–499	11	Roughhead Grenadier (51%) Northern Wolffish (11%) Marlin Spike (10%) Longfin Hake (9%)
500–599	1	Black Dogfish (42%) Eel sp. (32%)
600–699	0.6	Roundnose Grenadier (75%)
700–799	0.9	Blue Hake (89%)
800–899	<0.1	Smoothhead sp. (85%)
900–999	<0.1	Skate sp. (86%)
≥1,000	<0.1	Cat Shark sp. (98%)
Corals		
<100	-	-
100–199	-	-
200–299	-	-

Mean Catch Depth Range (m)	Total Catch Weight (mt)	Predominant Species/Groups (% of Total Catch Weight)
300–399	0.3	Soft Corals (98%) Corals (2%)
400–499	1	Large Gorgonians (49%) Sea Pens (29%) Stony Cup Corals (21%)
500–599	-	-
600–699	<0.1	Mushroom Corals (100%)
700–799	-	-
800–899	-	-
900–999	-	-
≥1000	-	-
Sponges		
<100	-	-
100–199	-	-
200–299	-	-
300–399	4	Porifera spp. (100%)
400–499	-	-
500–599	-	-
600–699	-	-
700–799	-	-
800–899	-	-
900–999	-	-
≥1000	-	-

Source: DFO RV Survey Data, 2018–2023.
Notes:
Corals and sponge catches are during all months and rather than restricted to May–November, as these species are caught relatively rarely during RV surveys and restricting months would have resulted in missing the only catches of soft corals during 2018–2023.

Although GEAC surveys occurred during 1997–2007, recent modelling undertaken by DFO for the 3Ps cod stock only utilized data from 1998–2006 as the data from 1997 and 2007 were incomplete due to vessel/coverage issues (Varkey et al. 2024). During the period of analysis, no correlation was observed between age 1 and 2 cod, but correlations did occur between ages 2–5 and several higher ages (Figure 4.46).



Source: Figure 13 in Varkey et al. (2024).

Figure 4.46. GEAC survey consistency plot (includes data from 1998–2006).

4.3.8 Industry and DFO Science Surveys

Fisheries research surveys conducted by DFO and the fishing industry are important to the commercial fisheries in determining stock status, particularly during recent years when some DFO surveys have not been possible.

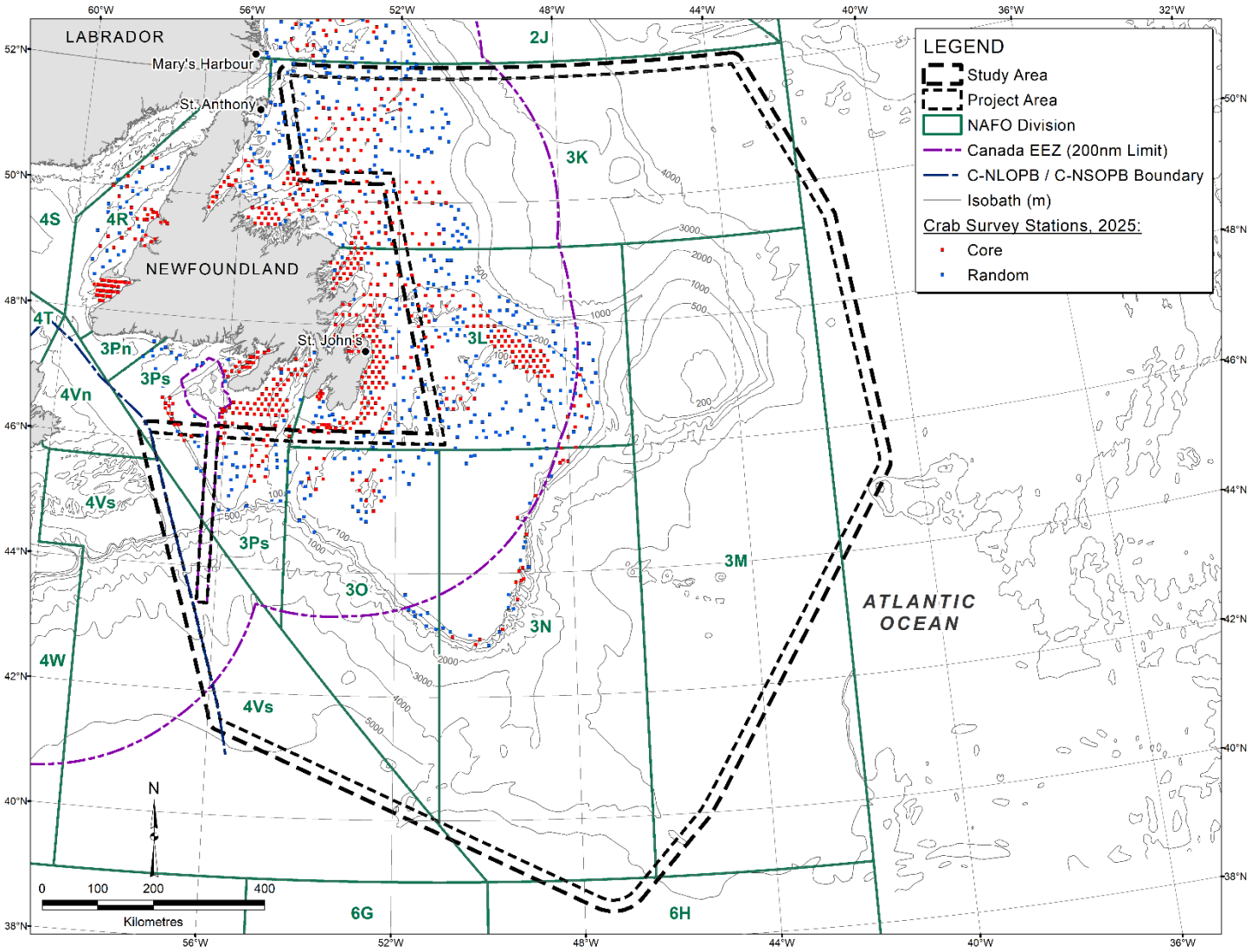
In a given year, there may be spatial overlap between the Study Area and research surveys in NAFO Divisions 3KLMNOPs. DFO expects to have four CCG vessels operating in offshore NL waters during 2025–2026 (P. Upward, Aquatic Science Biologist, DFO, pers. comm., 13 May 2025). During past years, two CCG vessels, *Alfred Needler* and *Teleost*, were chartered by DFO for annual spring and fall RV surveys. The *Alfred Needler* has since been retired but the *Teleost* is still in operation for other surveys (P. Upward, Aquatic Science Biologist, DFO, pers. comm., 13 May 2025). In preparation for these vessel retirements, RV surveys in recent years have largely consisted of "Comparative Missions" between incoming (*Capt Jacques Cartier* ['*Cartier*'] and *John Cabot* ['*Cabot*']) and outgoing CCG vessels rather than full spring and fall surveys. Spring RV (i.e., multispecies) surveys within the Study Area are tentatively scheduled to commence 3 April and continue until 19 June 2025 (Table 4.15). Fall RV surveys are set to occur in the Study Area from 1 October until 20 December.

Table 4.15. Tentative 2025–2026 schedule of DFO RV surveys in the vicinity of the Study Area.

Activity	NAFO Division	Start Date	End Date	Vessel
NL Spring/Fall RV Surveys				
Spring Multispecies Survey	3LNOPs	3 Apr	28 Apr	*Cartier*
Spring Multispecies Survey	3NLOPs	9 Apr	19 Jun	*Cabot*
Fall Multispecies Survey	3LNO	1 Oct	19 Dec	*Cabot*
Fall Multispecies Survey	2HJ3K	1 Oct	20 Dec	*Cartier*
Other Surveys				
May (April) Station 27	Station 27	14 Apr	14 Apr	*Vladykov*
NL Spring AZMP Oceanographic Survey	Atlantic Region	4 Apr	26 Apr	*Teleost*
3Ps Cod Tagging Spring	3Ps	16 Apr	29 Apr	*Vladykov*
Oceanographic and Marine Environmental Monitoring along the Coast of Bays	South Coast, NL	2 May	17 May	*Vladykov*
Spring Calibration and Capelin Survey	Unspecified	2 May	25 May	*Cartier*
Snow Crab Survey	Fortune Bay, NL	19 May	31 May	*Vladykov*
Snow Crab Survey	St. Mary's Bay, NL	2 Jun	10 Jun	*Vladykov*
June Station 27	Station 27	12 Jun	12 Jun	*Vladykov*
Cod Tagging Summer	3KL	1 Jul	14 Jul	*Vladykov*
NL Summer AZMP Oceanographic Survey	Atlantic Region	9 Jul	1 Aug	*Cabot*
Snow Crab Survey	Bonavista Bay, NL	15 Jul	24 Jul	*Vladykov*
Snow Crab Survey	Trinity Bay, NL	26 Jul	4 Aug	*Vladykov*
August Station 27	Station 27	7 Aug	7 Aug	*Vladykov*
Capelin Late Larval Survey	3L	11 Aug	19 Aug	*Vladykov*
Snow Crab Survey	White Bay, NL	23 Aug	3 Sep	*Vladykov*
Snow Crab Survey	Notre Dame Bay, NL	4 Sep	15 Sep	*Vladykov*
Capelin Late Larval Survey	3L	18 Sep	28 Sep	*Vladykov*
Snow Crab Survey	Conception Bay, NL	1 Oct	14 Oct	*Vladykov*
October Station 27	Station 27	15 Oct	15 Oct	*Vladykov*
3L Cod Tagging Fall	3L	16 Oct	29 Oct	*Vladykov*
NL coastal baseline, aquaculture, and oceanographic monitoring	South Coast, NL	2 Nov	24 Nov	*Vladykov*
December Station 27	Station 7	14 Dec	14 Dec	*Vladykov*

Source: P. Upward, Aquatic Science Biologist, DFO, pers. comm., 13 May 2025.
Notes:
Start/end dates subject to change as trip plans are still being finalized (P. Upward, Aquatic Science Biologist, DFO, pers. comm., 13 May 2025).
AZMP = Atlantic Zone Monitoring Program.

Members of the FFAW have been involved in a DFO-industry collaborative post-season snow crab trap survey annually since 2003. This collaboration is invaluable for the accurate evaluation of the snow crab resource; during 2021–2022, data collected by harvesters were the only basis for annual snow crab updates as DFO was unable to conduct their Science surveys (FFAW|Unifor 2023). The post-season snow crab survey typically begins during mid-August or early-September (J. Pantin, Aquatic Science Biologist – Shellfish, DFO, pers. comm., 26 September 2023) and concludes during November. The annual TAC for this survey was 450 t during 2025, unchanged from the previous two years (DFO 2025a). Sampling is completed at 1250 stations within NAFO Div. 2J, 3KLMNOPsPn, and 4R each year by >80 vessels, including 650 core stations that are sampled every year and 600 randomly allocated stations which change between years (J. Pantin, Aquatic Science Biologist – Shellfish, DFO, pers. comm., 26 September 2023). During 2025, of the 1250 stations, 510 occur in the Project Area (204 core stations, 306 random stations) and 66 are within 30 km of the Project Area (i.e., spatial buffer for stations; 27 core stations, 39 random stations; Figure 4.47).



Source: K. Charmley, Biologist, Shellfish Division, DFO, pers. comm., 13 June 2025.

Figure 4.47. Locations of DFO-Industry collaborative post-season snow crab trap survey stations in relation to the Study Area and Project Area.

4.3.9 Data Gaps associated with the Fisheries VC

The following data gaps associated with the Fisheries VC were identified in Section 3.4.2.2 in IAAC (2020):

- DFO datasets provide spatial resolution to the NAFO Unit Area level or grid cells (6′ x 6′ latitude x longitude);
- DFO gridded datasets (format since 2011) do not include specific weight or values associated with harvests;
- Details are substantially redacted for confidentiality reasons for DFO data available in recent years, which hinders the provision of "an accurate and complete picture of important fisheries" and between-year and across fisheries comparisons;
- The most recent DFO datasets available are at least two years old;
- International fisheries data available through the NAFO STATLANT 21A dataset are at the resolution of NAFO Div., which limits analyses at finer spatial scales and combines inshore and offshore data;
- For the first time, NAFO provided vessel monitoring system (VMS) data for fishing vessels for the IAAC (2020) report; however, the data do not indicate information beyond fishing vessel activity (e.g., species, gear type); and
- Commercial fisheries in the region are "geographically extensive, dynamic, and complex in nature".

The following data gaps associated with the Fisheries VC were identified in Section 6.1.6 in C-NLOPB (2014):

- DFO datasets are known not to be entirely comprehensive, particularly with regard to important inshore fisheries.

The following data gaps associated with the Fisheries VC were identified in Section 3.3.6 in C-NLOPB (2010):

- DFO data related to certain inshore fisheries (e.g., lobster) are lacking; and
- Data related to foreign fisheries outside the 200-nm limit have poor spatial resolution. These data are currently only available on a NAFO Division basis.

In addition to the data gaps identified above, there is uncertainty regarding the spatial and/or temporal extent of potential reduction in catch rates of shrimp and groundfish species associated with nearby seismic activity, a concern reported by stakeholders during consultations for LGL (2017a), an EA for which the offshore Newfoundland portion of its Project Area encompassed the same area as the Project Area of the current EA (e.g., see questions from Mary's Harbour, Appendix A in LGL 2017a). During the late 2010s, there were plans for the implementation of a licence and tag regime for recreational fishery participants in NL to improve the gathering of data, but this never came to fruition.

All the above data gaps still exist, although the novel use of international fishing vessel data from NAFO and supplementation of data with "input from the fishing industry, based on consultations with harvesters and fishing organizations regarding key species, areas, and times" are important steps to help address these gaps (IAAC 2020). In addition, DFO is in the process of developing and applying a state-space production model for commercially important species off eastern Canada to assess relative impacts of fishing activities and environmental effects (Regular et al. 2025). Preliminary results indicate that biomass estimates are improved by accounting for species interactions and various widespread collapses were mainly due to environmental factors rather than fishing pressures (Regular et al. 2025). Although filling these data gaps could result in changes to the data presented in Section 4.3, it is unlikely that increased data accuracy would alter the overall results, such as predominant species caught within the Study Area. As such, these data gaps are unlikely to limit the assessment of potential interactions between the Project and the Fisheries VC. MKI will revise the Fisheries VC and associated assessments as needed as new fisheries data become available and will reflect these changes in future EA Updates.

4.4 Marine-associated Bird VC

The Marine-associated Bird VC for the Study Area has been described in Section 3.4 in C-NLOPB (2010), Section 4.2.2 in C-NLOPB (2014), Section 3.2.2 in IAAC (2020), and Section 6.2 in LGL (2022; a project-specific EA Update for the Study Area). An overview of the marine-associated birds of the Study Area, based on the aforementioned documents, is provided below. Newly available information since publication of the SEAs and EIS is also summarized. Data gaps regarding marine-associated birds identified in the two SEAs are reviewed in terms of current status.

The Atlantic Ocean off eastern and southeastern Newfoundland is a rich area for marine bird life. Seabirds tend to concentrate over oceanographic features, such as continental shelf edges and convergences of warm and cold currents, both of which occur in the Study Area. The Labrador Current running southward along the edge of continental shelf edge from the northern tip of Labrador to the northern Grand Banks creates areas of upwelling and water mixing that brings mineral nutrients to the surface, thereby resulting in high phytoplankton productivity which forms the basis for increased productivity at higher trophic levels (e.g., seabirds). South of Flemish Cap and the Grand Banks, the Gulf Stream meets the Labrador Current, causing more mixing of different water types and potentially rich zones for marine productivity (Brown 1986; Lock et al. 1994; Fifield et al. 2009). The nutrient rich water column results in substantial biomass production that ultimately supports a large and diverse population of breeding and non-breeding wintering and summering marine birds (Brown 1986; Lock et al. 1994; Fifield et al. 2009). Recently, a hotspot for seabirds has been recognized between the Flemish Cap and the Mid-Atlantic Ridge at the convergence of the Subpolar Frontal System and the North-Atlantic Current. A discrete area of the Subpolar Frontal zone is used annually by 2.9–5 million seabirds from ≥56 colonies in the Atlantic Ocean (Davies et al. 2021a). Many seabirds using this rich feeding area pass through the Study Area during migration.

Pelagic seabird abundance data in the shelf areas off Newfoundland are available from the ECCC-CWS Programme Intégré de Recherches sur les Oiseaux Pélagiques (PIROP) shipboard surveys conducted during 1967–1994 (Lock et al. 1994). Since the late 1990s, seabird observations have been collected on the NE Grand Banks for the offshore oil and gas industry from drilling platforms and

support vessels (Baillie et al. 2005; Burke et al. 2005; Fifield et al. 2009). Beginning in the early 2000s, at-sea surveys have been conducted in the region for the oil and gas industry from vessels undertaking geophysical surveys to fulfill marine bird monitoring required by the C-NLOPB (e.g., Moulton et al. 2005, 2006a; Lang et al. 2006; Lang 2007; Lang and Moulton 2008; Abgrall et al. 2008a, 2009; Abgrall 2014; Holst and Lang 2014). Starting in 2005, CWS has been conducting at-sea surveys with the ECSAS program, partly funded by the Environmental Studies Research Fund (ESRF), with a mandate to improve knowledge of the abundance and distribution of seabirds at-sea in areas of oil industry activity in eastern Canada (Fifield et al. 2009; ECCC-CWS 2022). The more recent (2006–2009) ECCC-CWS ECSAS survey program sampled areas off eastern and southern Newfoundland (Fifield et al. 2009). ECSAS density maps and associated shapefiles based on data collected from 2006–2020 are published online as the "Atlas of Seabirds at Sea in Eastern Canada" (ECCC-CWS 2022). In the Atlas, the year is divided into three seasons: April–July (spring migration and nesting period), August–November (moult, chick-rearing period) and December–March (fall migration and wintering). The most current census data related to important seabird nesting colonies in Newfoundland have been acquired from the ECCC-CWS and are incorporated into this EA (S. Wilhelm, Wildlife Biologist, ECCC-CWS, pers. comm., November 2024). Additionally, several tracking studies of marine birds have been recently published and were consulted for details of bird movements between nesting colonies and wintering areas.

4.4.1 Seasonal Occurrence and Abundance

The global range, seasonal occurrence and seasonal abundance of seabirds occurring regularly in the Study Area are described below. There are 30 species of marine-associated birds occurring regularly off the east and south coast of Newfoundland (Table 4.16). Some species are seasonal while others are present year-round. Large numbers of seabirds occur in parts of the Study Area at all times of the year.

Table 4.16. Monthly occurrences and abundances of pelagic seabirds offshore Newfoundland and south of the Grand Banks (38°N to 52°N).

Species	Scientific Name	J	F	M	A	M	J	J	A	S	O	N	D
Northern Fulmar*	*Fulmarus glacialis*	C[1]	C	C	C	U	U	U	U	C	C	C	C
Cory's Shearwater	*Calonectris diomedea*						S	S	S	S			
Great Shearwater	*Ardenna gravis*					U	C	C	C	C	C	S	
Sooty Shearwater	*Ardenna grisea*					S	U	U	U	U	U	S	
Manx Shearwater*	*Puffinus puffinus*					S	S	S	S	S	S		
Wilson's Storm-Petrel	*Oceanites oceanicus*						S	S	S	S	R		
Leach's Storm-Petrel*	*Hydrobates leucorhous*				U-C	C	C	C	C	C	C	S	
Northern Gannet*	*Morus bassanus*			U	U	U	U	U	U	U	U		
Red-necked Phalarope*	*Phalaropus lobatus*					S	S	S	S	S	R		
Red Phalarope	*Phalaropus fulicarius*					S	S	S	S	S	S		
Great Skua	*Stercorarius skua*	R	R	R	R	S	S	S	S	S	S	S	R
South Polar Skua	*Stercorarius maccormicki*					S	S	S	S	S	S		
Pomarine Jaeger	*Stercorarius pomarinus*				S	S	S	S	S	S	S	S	
Parasitic Jaeger	*Stercorarius parasiticus*					S	S	S	S	S	S		
Long-tailed Jaeger	*Stercorarius longicaudus*					S	S	S	S	S			
Dovekie	*Alle alle*	C	C	C	C	U	R	R	R	S	C	C	C
Common Murre*	*Uria aalge*	C	C	C	C	C	C	C	C	C	C	C	C
Thick-billed Murre*	*Uria lomvia*	C	C	C	C	C	S	S	S	U	C	C	C
Razorbill*	*Alca torda*	S	S	S	U	R	R	R	R	U	U	U	S
Black Guillemot*	*Cepphus grylle*	R	R	R	R	R	R	R	R	R	R	R	R
Atlantic Puffin*	*Fratercula arctica*	C	C	C	C	U	U	U	U	C	C	C	C
Black-legged Kittiwake*	*Rissa tridactyla*	C	C	C	C	U	U	U	U	C	C	C	C
Ivory Gull	*Pagophila eburnea*	R-S	R-S	R-S	R								

Species	Scientific Name	J	F	M	A	M	J	J	A	S	O	N	D
Herring Gull*	*Larus argentatus*	U	U	U	U	U	S	S	S	S	U	U	U
Iceland Gull	*Larus glaucoides*	C	C	C	C	S					S	C	C
Lesser Black-backed Gull	*Larus fuscus*				R	R	R	R	R	R	R	R	R
Glaucous Gull*	*Larus hyperboreus*	C	C	C	C	U	R				S	U	C
Great Black-backed Gull*	*Larus marinus*	U	U	U	U	U	S	S	U	U	U	U	U
Common Tern*	*Sterna hirundo*					R	R	R	R	R			
Arctic Tern*	*Sterna paradisaea*					S	S	S	S	S			

Source: Brown (1986); Lock et al. (1994); Baillie et al. (2005); Moulton et al. (2005, 2006a,b); Lang et al. (2006); Lang (2007); Lang and Moulton (2008); Abgrall et al. (2008a,b, 2009).

[1] Abundance definitions valid for at least part of Study Area but not necessarily the whole Study Area.

Notes:

* = Breeds in NL.

C = Common - likely present daily in moderate to high numbers; U = Uncommon - likely present daily in small numbers; S = Scarce - likely present regularly in very small numbers; R = Rare - usually absent, individuals occasionally present. Blank spaces indicate not expected to occur in that month. Predicted monthly occurrences derived from 2004, 2005, 2006, 2007, and 2008 monitoring studies in the Orphan Basin, Jeanne d'Arc Basin, and Laurentian Sub-basin, and extrapolation of marine bird distribution at sea in eastern Canada in Brown (1986); Lock et al. (1994) and Fifield et al. (2009).

4.4.2 Breeding Seabirds in Newfoundland and Labrador

There are seabird breeding colonies of worldwide significance in eastern Newfoundland (Table 4.17). Over 4 million pairs of seabirds nest on the southeast coast of Newfoundland, including 2.7 million pairs of Leach's Storm-Petrels (*Hydrobates leucorhous*) and 748,000 pairs of Common Murres (*Uria aalge*; Sabina Wilhelm, ECCC-CWS, pers. comm., September 2023; Table 4.17). Funk Island, Baccalieu Island, and Witless Bay are the largest seabird breeding colonies in Atlantic Canada, hosting more than 3.4 million pairs of seabirds nests (Sabina Wilhelm, ECCC-CWS, pers. comm., November 2024; Table 4.17). These include the largest Atlantic Canadian colonies of Leach's Storm-Petrel (1.97 million pairs on Baccalieu Island), Common Murre (>470,000 pairs on Funk Island), Black-legged Kittiwake (*Rissa tridactyla*; 11,873 pairs on Witless Bay Islands), and Atlantic Puffin (*Fratercula arctica*; 353,736 pairs on Witless Bay Islands; Sabina Wilhelm, ECCC-CWS, pers. comm., September 2023). After the nesting season, seabirds disperse over a wider area of the NL offshore area, including most of the Study Area (Lock et al. 1984). Large numbers of seabirds nesting outside of NL also spend part of their non-breeding season within the Study Area (Lock et al. 1984). Several million Great Shearwater (*Ardenna gravis*) and Sooty Shearwater (*A. grisea*) migrate from breeding islands in the South Atlantic to waters offshore NL in summer. Many of the 3.8 million Thick-billed Murres (*U. lomvia*) breeding in the eastern Canadian Arctic, as well as up to 10 million Dovekies (*Alle alle*) from Greenland, either winter in the Labrador Sea and Grand Banks or migrate through these areas on the way to the continental shelf waters of NS and areas farther south. Large numbers of sub-adults of Northern Fulmar (*Fulmarus glacialis*) and Black-legged Kittiwake from breeding colonies in the eastern Canadian Arctic, Greenland, and Europe spend the early years of their lives in the Labrador Sea and off the Grand Banks.

Table 4.17. Number of pairs of seabirds nesting at colonies in northern and eastern Newfoundland (52°N to 46°N).

Species	Little Fogo Islands	Wadham Islands	Coleman Island	Funk Island	North & South Penguin Islands	Bonavista Peninsula[1]	Baccalieu Island	Witless Bay Islands	Cape St. Mary's	Middle & Offer Lawn Islands	Corbin Island	Green Island[2]	Grand Colombier Island	Miquelon Cape
Northern Fulmar	-	-	-	40p[a]	-	2p[a]	-	51p[a]	Present[a]	-	-	-	-	-
Manx Shearwater	-	-	-	-	-	-	-	-	-	7p[b]	-	-	-	-
Leach's Storm-Petrel	396p[a]	1,578p[a]	2,906p[a]	150p[a]	8,537p[a]	60p[a]	1,929,091p[a]	313,902p[a]	-	11,014p[a]	100,000p[a]	48,000p[a]	363,787p[c]	-
Northern Gannet	-	-	-	6,813p[a]	-	-	3,780p[a]	-	7,544p[a]	-	-	-	-	-
Herring Gull	355i[a,d]	30p[a]	35p[a]	-	350i[a]	511i[a]	46p[a]	2,068p[a]	39p[a]	805i[a]	50p[a]	Present[a]	60p[e]	265p[f]
Great Black-backed Gull	7i[a]	8p[a]	-	75i[a]	25i[a]	70i[a]	2p[a]	131p[a]	Present[a]	3i[a]	25p[a]	-	10p[e]	-
Black-legged Kittiwake	750i[a,d]	-	5p[a]	126p[a]	-	2,172p[a]	5,096p[a]	11,873p[a]	4,391p[a]	50i[a]	50p[a]	-	196p[e]	2,415p[f]
Arctic and Common Terns	21i[a]	17i[a]	4p[a]	-	45i[a]	-	-	-	-	-	-	Present[a]	-	-
Common Murre	-	23[a]	-	472,259p[a]	5p[a]	460i[a]	1,440p[a]	250,000p, 14,599i[a]	15,484p[a]	-	-	-	7,176p[g]	-
Thick-billed Murre	-	-	-	250p[a]	-	-	73p[a]	243i[a]	1,000p[b]	-	-	-	-	-
Razorbill	-	2,757p[a]	1,346p[a]	200p[a]	35p[a]	143i[a]	406p[a]	684p, 43i[a]	100p[a]	1p[a]	-	-	1,443p[g]	-
Black Guillemot	-	50p[a]	25i[a]	1p[a]	-	11i[a]	113p[a]	3p, 38i[a]	Present[a]	94i[a]	-	-	95p[g]	Present[f]
Atlantic Puffin	4,089p[a]	16,859p[a]	12,649p[a]	2,000p[a]	8,881p[a]	9,391p[a]	75,000p[b]	393,716p[a]	-	-	-	-	9,543p[g]	-
TOTAL	**4,485p 1,133i**	**21,282p 17i**	**16,945p 25i**	**484,839p 75i**	**17,458p 420i**	**11,625p 1,195i**	**2,015,047p**	**972,428p 14,923i**	**28,558p**	**11,022p 952i**	**100,125p**	**48,000p**	**382,310p**	**2,680p**

Source: [a] Sabina Wilhelm, ECCC-CWS, pers. comm., November 2024, unpublished data; [b] Fraser et al. (2013); [c] Lormée et al. (2012); [d] Boyne et al. (2011); [e] Lormée et al. (2008); [f] Cairns et al. (1989), [g] Lormée et al. (2015).

[1] Elliston Cove, Elliston Point Is., Green & Gull Is. (Cape Bonavista), N. & S. Bird Is., and Spillers Point.

[2] Fortune Bay.

Notes:

p = number of pairs; i = number of individuals.

4.4.2.1 Anatidae (Ducks and Geese)

Common Eider (*Somateria mollissima*) nests on the Newfoundland coast and occurs during migration and winter in open water along the same coastlines (Lock et al. 1994). Significant numbers of Surf (*Melanitta perspicillata*), Black (*M. americana*), and White-winged (*M. deglandi*) Scoters occur on the coast during spring and fall migration (Lock et al. 1994). Barrow's Goldeneye (*Bucephala islandica*) and Harlequin Duck (*Histrionicus histrionicus*) both have *special concern* status under Schedule 1 of SARA (GC 2025). Very small numbers of Barrow's Goldeneyes winter along the coastlines (Lock et al. 1994). Harlequin Duck nests in the rivers and brooks of the Northern Peninsula and winters along the coastlines, especially along the southern Avalon Peninsula (Lock et al. 1994). Detailed profiles of Barrow's Goldeneye and Harlequin Duck are provided in Section 6.2.4 of LGL (2022). All sea duck species occupy nearshore habitats and are considered very unlikely to occur in offshore areas, including the Study Area.

4.4.2.2 Procellariidae (Fulmarine and Gadfly Petrels and Shearwaters)

Northern Fulmar and four species of shearwaters include the Study Area as part of their normal range and are profiled below.

Northern Fulmar

Large numbers of fulmars from Arctic and sub-Arctic nesting colonies in Canada, Greenland, and Europe winter from the Labrador Sea to New England, including the Study Area (Huetmann and Diamond 2000; Mallory et al. 2008). Small numbers of Northern Fulmar and Manx Shearwater (*Puffinus puffinus*; see below) nest in Newfoundland (see Table 4.17). During the breeding season, the numbers of these species are augmented by non-breeding sub-adults (Lock et al. 1994). Northern Fulmar occurs throughout the Study Area year-round, although densities are higher in the northern half of the Study Area, especially during the August–November period (Figure 4.48). Densities along the northern edge of the Grand Banks and the Sackville Spur range from 39.5–91.9 birds/km² to 91.9–200.3 birds/km² during the moult/chick-rearing period (Figure 4.48). During May–November, the highest densities generally occur along shelf breaks.

Shearwaters

Great and Sooty Shearwaters from nesting colonies in the Southern Hemisphere spend the austral winter in the Northern Hemisphere (Carboneras et al. 2020a,b). Most of the world's population of Great Shearwater migrates to offshore Newfoundland waters to feed and moult their flight feathers (Brown 1986). Most of the Sooty Shearwaters moult in the deep, warm waters west of the Mid-Atlantic Ridge from April to early-June before moving into the cooler waters of the Grand Banks for the June–October period (Hedd et al. 2012). Shearwater densities in the Study Area are highest in northeast section of the Study Area, mostly on the slopes of Orphan Basin during April–July and on the southern Grand Banks during August–November, with densities of 13.2–29.9 birds/km² commonly recorded (Figure 4.49). High densities (29.9–66.7 birds/km²) have been recorded on the Sackville Spur and southeast (SE) edge of the Grand Banks during August–November. Shearwaters are generally absent from most of the Study Area during December–March, except on the Tail of the

Grand Banks (Figure 4.49). Most shearwaters observed during at-sea surveys conducted from seismic vessels were sighted from June–September (Abgrall et al. 2008b, 2009; Abgrall 2014; Holst and Lang 2014). During the December–March period, no shearwaters were recorded on-transect during ECSAS surveys in most of the Study Area.

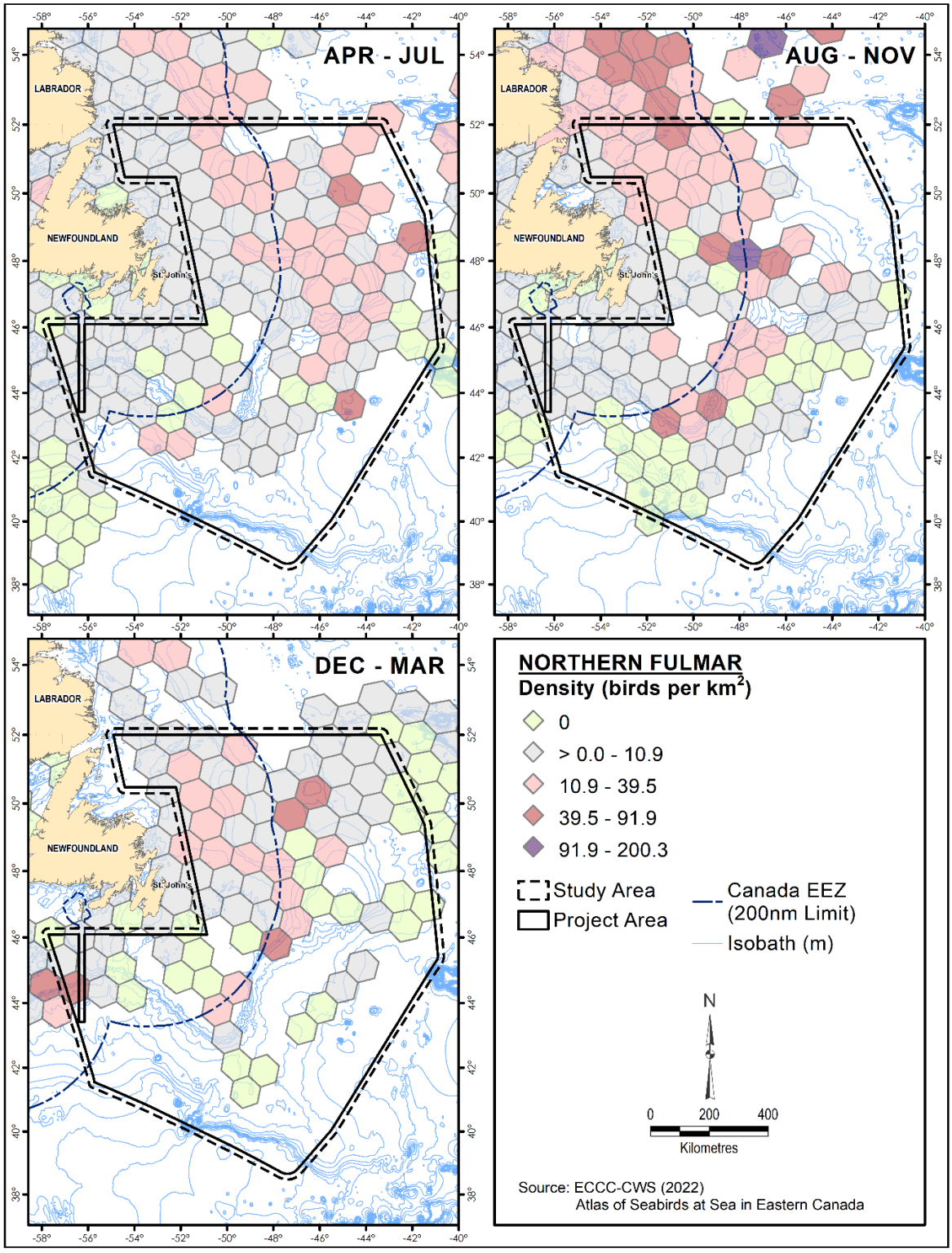
Shearwaters may cover a large area during their time (May–November) in Canadian waters. From 2013–2018, 58 Great Shearwaters in the southwest Gulf of Maine were outfitted with transmitters during the summer and fall seasons (June–November; Powers et al. 2020). Approximately 55% stayed within the Gulf of Maine during the wintering season and the remainder moved eastward to the Scotian Shelf and northeastwards to the Grand Banks off Newfoundland. Most birds (89%) were young (0–2 years) based on gonadal development and molt score. Great and Sooty Shearwaters are the primary bird species that consume fish on the Grand Banks during summer and fall (Hedd et al. 2012). Shearwaters and Northern Fulmars (see above) forage on the surface. Shearwaters also practise pursuit plunging to capture fish, squid, and offal (Statoil 2017). Tracking of Sooty Shearwaters shows that they spend most of their time on the water during their residence in the Northwest Atlantic, making them more vulnerable to oil pollution at this time of the year (Hedd et al. 2012). Great Shearwaters and sub-adult Northern Fulmars (see above) are also more susceptible to contact with oil pollution because they undergo the annual moult of their flight feathers during the summer while in the waters of the Study Area (Lock et al. 1994; Huetmann and Diamond 2000).

The small colony of Manx Shearwater nesting on Middle Lawn Island off the Burin Peninsula is the only confirmed nesting site in North America (Lee et al. 2023). The most recent survey recorded just seven nesting pairs, but larger numbers are found prospecting for nest sites (Roul 2010; Fraser et al. 2013). Manx Shearwater is considered a widespread, uncommon species on the shelf waters of Newfoundland from April–October (Mactavish et al. 2016) and has been recorded during the summer and fall in the Jeanne d'Arc Basin in small numbers (Abgrall et al. 2008b, 2009; Abgrall 2014; Holst and Lang 2014).

The northern edge of the range of Cory's Shearwater (*Calonectris borealis*) reaches Atlantic Canada (Brown 1986). It originates from nesting colonies on Berlengas, Madeira, Desertas, Salvages, Azores, and Canary Islands (Onley and Scofield 2007). Small numbers occur on the edge of the southern Grand Banks (Brown 1986) and east of the Grand Banks (ECCC-CWS 2022).

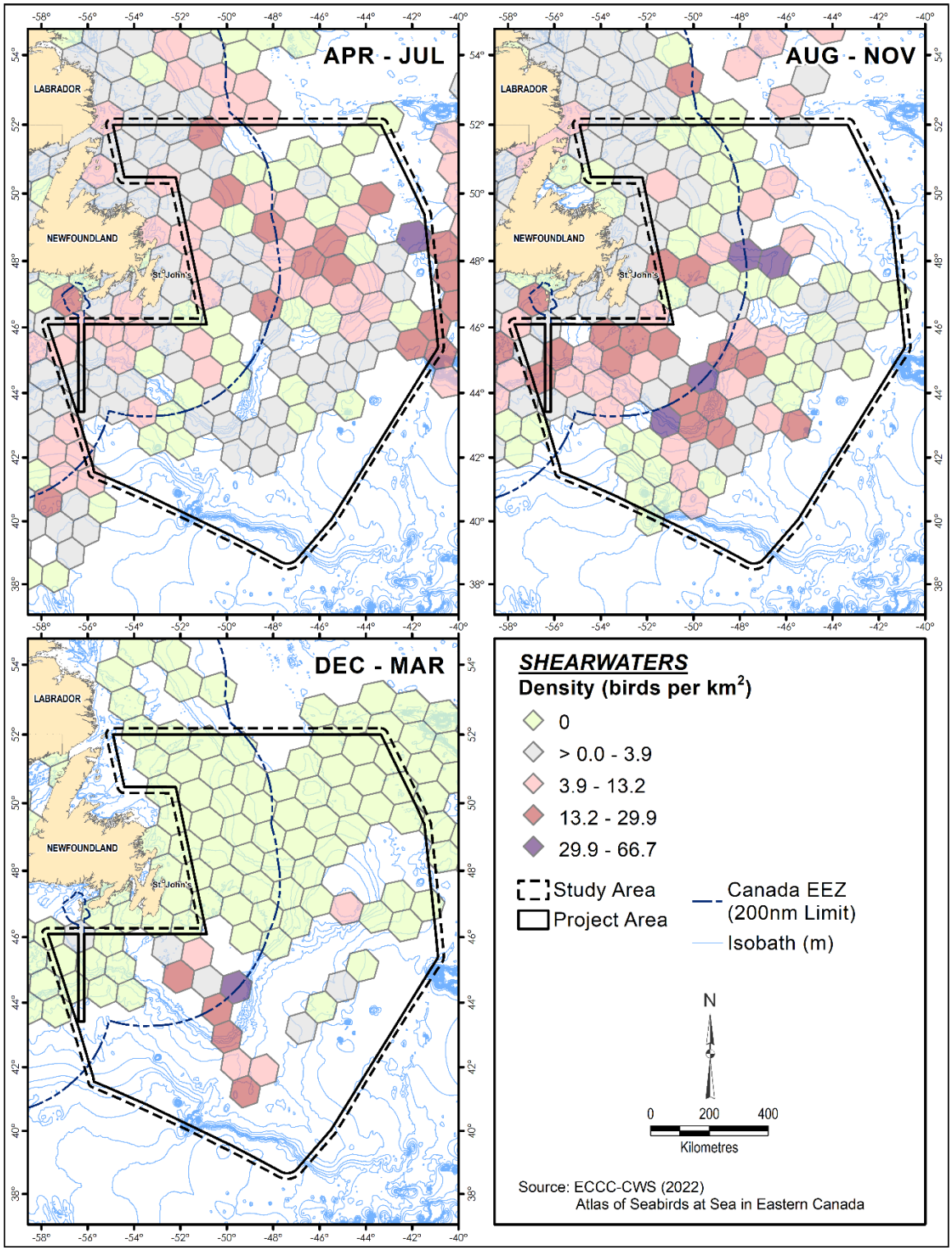
Gadfly Petrels

The distributions of three species of gadfly petrels (*Pterodroma* spp.) reach the southern and eastern portions of the Study Area during fall and winter. Bermuda Petrel (*P. cahow*), Zino's Petrel (*P. madeira*), and Desertas Petrel (*P. deserta*) have low populations worldwide and the Study Area includes the northwestern limits of their ranges. Bermuda Petrel has been tracked via data logger to the southern Grand Banks and the southeastern portion of the Study Area (Madeiros et al. 2014; Campioni et al. 2023). Zino's and Desertas Petrels have been tracked to the eastern and southeastern portions of the Study Area during summer (Ramirez et al. 2013; Ramos et al. 2016).



Source: ECCC-CWS (2022).

Figure 4.48. Seasonal distribution and abundance of ECSAS Northern Fulmar observations in waters off eastern Newfoundland (2006–2020).



Source: ECCC-CWS (2022).

Figure 4.49. Seasonal distribution and abundance of ECSAS Shearwater (Great, Sooty, Manx, and Unidentified combined) observations in the waters off eastern Newfoundland (2006–2020).

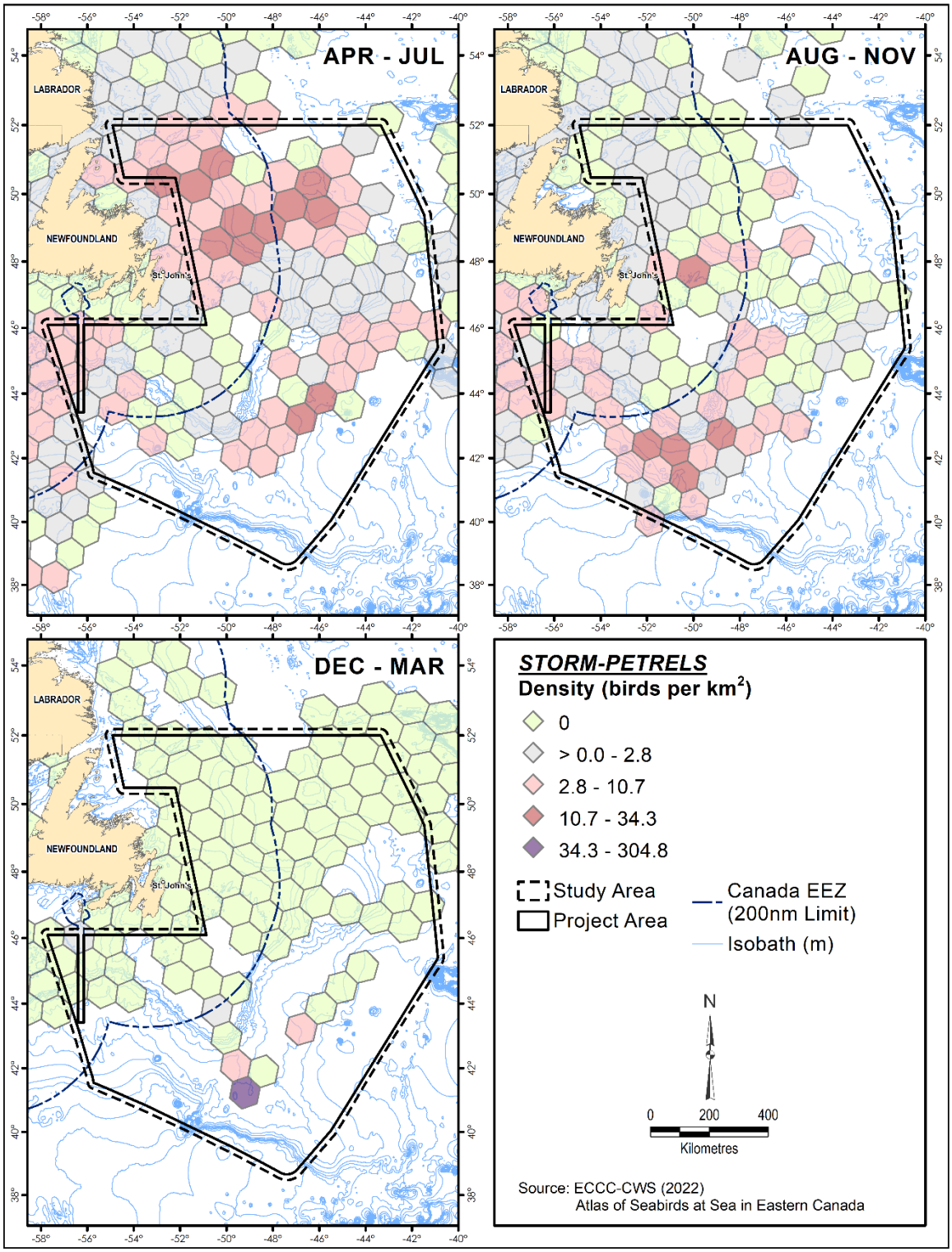
4.4.2.3 Hydrobatidae (Northern Storm-Petrels) and Oceanitidae (Southern Storm-Petrels)

Storm-petrels feed primarily by picking food items from the surface (Drucker et al. 2020; Pollet et al. 2021). Two species of storm-petrel occur regularly in the Study Area. Leach's Storm-Petrel is common in the Northwest Atlantic from spring to fall and Newfoundland supports the world's largest nesting colonies (Wilhelm et al. 2015). Wilson's Storm-Petrel (*Oceanites oceanicus*) occasionally dives beneath the sea surface to feed, and nests in sub-Antarctic and Antarctic regions and winters in the Northern Hemisphere up to 77°N in the North Atlantic (Onley and Scofield 2007; Drucker et al. 2020). These two species are profiled below (see also Section 3.4.1.4 in C-NLOPB 2010, Section 4.2.2.1 in C-NLOPB 2014, and Section 3.2.2.1 in IAAC 2020).

Leach's Storm-Petrel

Leach's Storm-Petrel is common in the Study Area during April–October, and scarce during November (see Table 4.16). The ECSAS surveys show the highest densities of Leach's Storm-Petrel are present in the April–July period, with a concentration of polygons with densities of 10.7–34.3 birds/km² in the Orphan Basin (Figure 4.50). During August–November, storm-petrels were widespread in the Study Area with the highest densities present in the southern areas. Storm-petrels were nearly absent during December–March, except for a small number in the southernmost extremity of the Study Area. Leach's Storm-Petrels have been observed in small numbers during at-sea surveys conducted from geophysical vessels between June and October within the Study Area (Abgrall et al. 2008b, 2009; Abgrall 2014; Holst and Lang 2014).

Tracking studies show that Leach's Storm-Petrels nesting at the Baccalieu Island (Hedd et al. 2018), and Gull Island, Witless Bay (Collins et al. 2022) colonies forage in the deep water beyond the Grand Banks. They generally transit non-stop across the Grand Banks to reach and return from their feeding destination beyond the shelf edge, where they feed on mesopelagic fish that migrate to the surface at night. Leach's Storm-Petrels fitted with geolocators have been shown to travel up to 1,015 ± 238 km during foraging trips from nesting colonies to deep waters off the continental shelf in NS (Pollet et al. 2014a,b). A bird outfitted with a geolocator in the Gull Island, Newfoundland colony flew to Cape Verde Islands off the west coast of Africa in early-December, averaging 420 km/day over 12 days of migration (Pollet et al. 2014b).



Source: ECCC-CWS (2022).

Figure 4.50. Seasonal distribution and abundance of ECSAS Storm-Petrel observations in the waters off eastern Newfoundland (2006–2020).

More than two million pairs of Leach's Storm-Petrels nested on the Avalon Peninsula in the recent past (Wilhelm et al. 2019). However, declines in the numbers of nesting pairs of Leach's Storm-Petrels at Atlantic colonies have been reported in recent years (Deakin et al. 2021). A 2013 survey of nesting Leach's Storm-Petrel on Baccalieu Island, NL, the largest breeding colony of Leach's Storm-Petrels in the world, yielded an estimate of 1.95 million pairs, a decline of 42% from the first population estimate in 1984 (Wilhelm et al. 2019). Surveys of Gull Island (in Newfoundland's Witless Bay Ecological Reserve) indicated a 51% decline from 352,000 breeding pairs in 2001 to 180,000 pairs in 2012 (ECCC-CWS, unpublished data). The number of nesting pairs at the Great Island, Witless Bay colony has declined by 55% from about 300,000 in 1979 to 134,000 in 2011 (Wilhelm et al. 2015). A 2015 population estimate update for Green Island, Fortune Bay (near St. Pierre et Miquelon), was 48,000 pairs (ECCC-CWS, unpublished data), down from a previous estimate of 103,833 pairs (Russell 2008). Declines have also been recorded in major Leach's Storm-Petrel breeding colonies in NS, New Brunswick, Iceland, and Scotland (Pollet and Shutler 2018; d'Entremont et al. 2020; Deakin et al. 2021). The cause of the Leach's Storm-Petrel population decline has not yet been determined.

Wilson's Storm-Petrel

Wilson's Storm-Petrel is expected to be either rare or scarce during June–October in the Study Area (Table 4.16). Wilson's Storm-Petrel occurs in much lower densities than Leach's Storm-Petrel in Newfoundland waters.

4.4.2.4 Sulidae (Gannets)

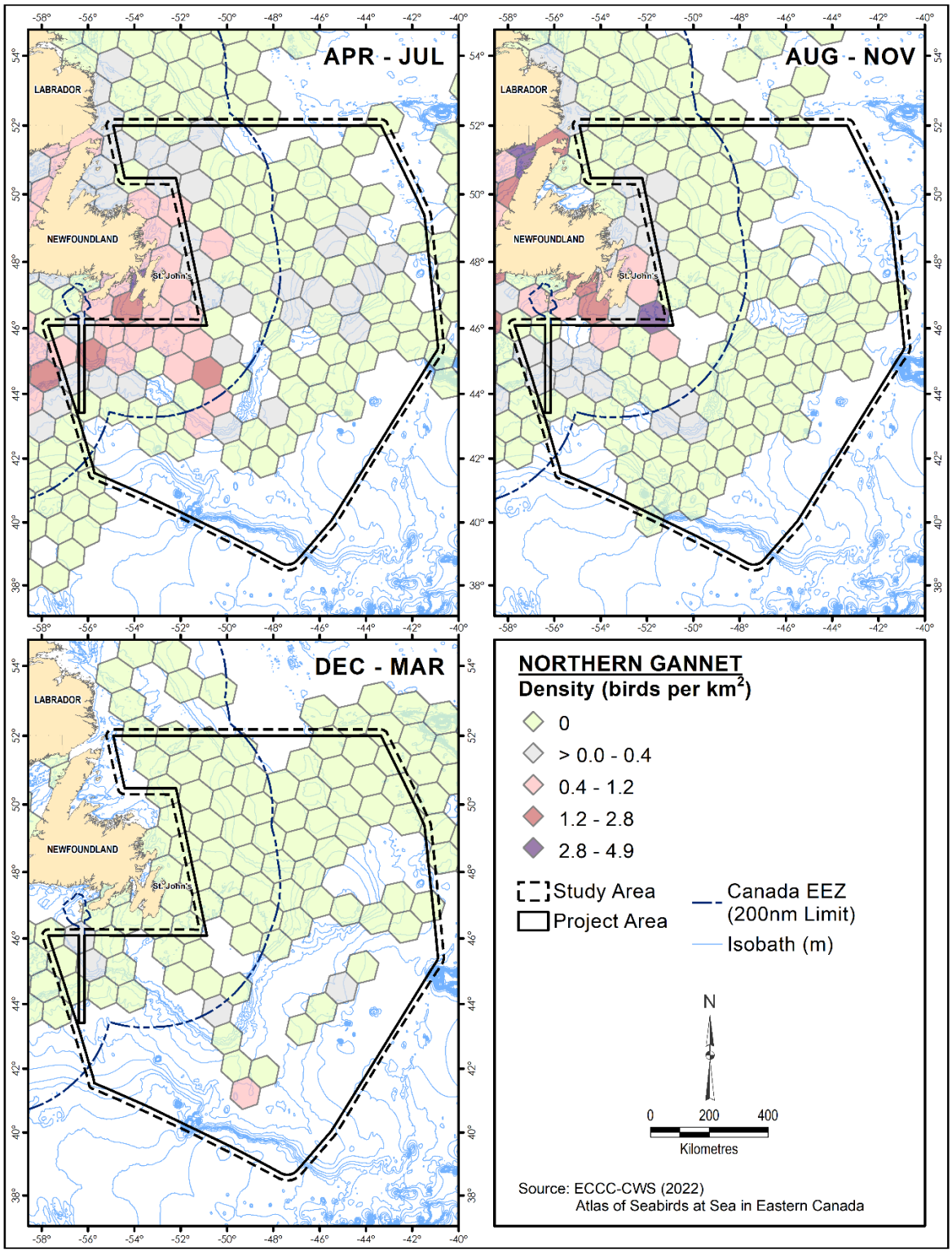
Northern Gannet

Northern Gannet (*Morus bassanus*) nests in six large colonies in Atlantic Canada, of which three are in eastern Newfoundland (see Table 4.17). Northern Gannet nesting populations at three of these nesting colonies declined by a combined 33% between 2018 and 2023 (S. Wilhelm, Wildlife Biologist, ECCC-CWS, pers. comm., September 2023; Table 4.18). The effects of the avian influenza outbreak in summer 2022 had a significant impact on current breeding populations (Lane et al. 2023), and study is ongoing regarding the relationship between Northern Gannet breeding success and warming sea surface temperatures (Montevecchi et al. 2021). Most individuals winter along the Atlantic coast of the U.S. and Gulf of Mexico (Fifield et al. 2014). Gannets were recorded at low density on the southern Grand Banks during April–July during ECSAS surveys but rarely elsewhere in the Study Area at any time (Figure 4.51). Northern Gannets forage nearshore in continental shelf waters off Newfoundland during mid-March–November. Gannets feed by plunge-diving from a height of 10–40 m above the surface, descending to depths of 15 m (Mowbray 2020). They may travel over 200 km from breeding colonies to coastal waters to forage on pelagic fish (herring, mackerel, and capelin) that spawn in the shallows (Garthe et al. 2007).

Table 4.18. Number of nesting pairs of Northern Gannets at three colonies in Newfoundland, 2018 and 2023.

Colony	Census Year 2018 (pairs)	Census Year 2023 (pairs)
Funk Island	10,964	7,622
Baccalieu Island	3,488	3,975
Cape St. Mary's	14,598	7,622
Total	**29,050**	**19,219**

Source: Sabina Wilhelm, Wildlife Biologist, ECCC-CWS, pers comm., September 2023 (unpublished data).



Source: ECCC-CWS (2022).

Figure 4.51. Seasonal distribution and abundance of ECSAS Northern Gannet observations in the waters off eastern Newfoundland (2006–2020).

4.4.2.5 Phalaropodinae (Phalaropes)

Red and Red-necked Phalarope

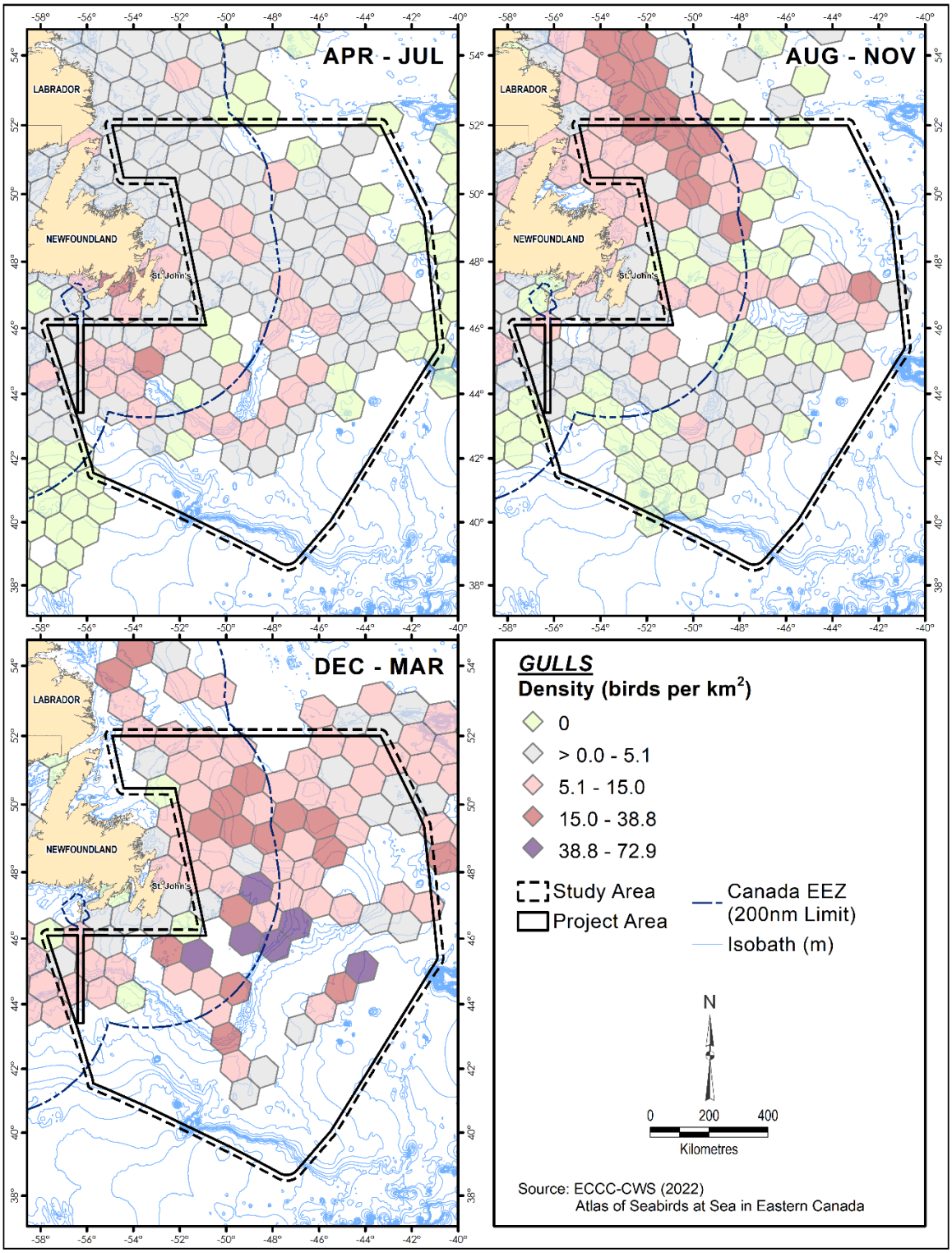
During May–October, Red Phalarope (*Phalaropus fulicarius*) and Red-necked Phalarope (*P. lobatus*) are expected to be scarce and rare in the Study Area, respectively (see Table 4.16). They may be overlooked at sea because of their small size. Phalaropes occur in the Study Area as passage migrants during spring and fall (Abgrall et al. 2008b, 2009; Abgrall 2014; Holst and Lang 2014). Eight Red-necked Phalaropes outfitted with geolocators on their nesting grounds in Greenland, Iceland, and Scotland wintered in the northern Humboldt Current in the Pacific Ocean off Central America (van Bemmelen et al. 2019). They migrated off the east coast of North America and crossed over land at Central America to reach the Pacific Ocean. Both the spring and fall migration routes took the birds through the Labrador Sea and the Grand Banks.

Both Red and Red-necked Phalaropes nest in the Arctic and Subarctic and winter in pelagic waters of the tropics and sub-tropics (Rubega et al. 2020; Tracy et al. 2020). During the non-breeding season, they favour areas of upwelling caused by ocean currents converging with shelf edges or other currents, where they feed on zooplankton at the surface (Rubega et al. 2020; Tracy et al. 2020). Red-necked Phalarope is designated as *Special Concern* on Schedule 1 of SARA and is listed as *Threatened* under the NL *Endangered Species Act* (ESA; see Section 4.7).

4.4.2.6 Laridae (Gulls and Terns)

Large Gulls: Great Black-backed, Herring, Iceland, Glaucous, Ring-billed, and Lesser Black-backed Gulls

Large gulls are primarily land-based birds. However, a small percentage of Great Black-backed (*Larus marinus*), Herring (*L. argentatus*), Iceland (*L. glaucoides*), Glaucous (*L. hyperboreus*), and Lesser Black-backed (*L. fuscus*) Gulls do live at sea, feeding primarily by picking food from the surface or plunge-diving from a low height (Burger et al. 2020; Snell et al. 2020; Weiser and Gilchrist 2020; Weseloh et al. 2020; Good 2022). Large gulls combined from the ECSAS surveys show the highest concentration of gulls in the offshore occurring in winter (Figure 4.52). Winter concentrations reach 38.8–72.9 birds/km^2 on the eastern Grand Banks and in the vicinity of existing oil producing platforms (Figure 4.52). Large gulls are at their lowest numbers in the Study Area during April–July. During the August–November period, densities were highest in the northern part of the Study Area, with densities up to 15.0–38.8 birds/km^2 recorded (Figure 4.52). Great Black-backed and Herring Gulls are common, widespread breeding birds in NL and are present year-round in Newfoundland (Mactavish et al. 2016). Offshore, they are expected to be scarce but locally common around fishing boats and oil installations within the Study Area (Figure 4.52). Glaucous and Iceland Gulls nest north of Newfoundland in the Arctic and sub-Arctic and spend the winter in Newfoundland (Mactavish et al. 2016). They are generally expected to be uncommon to scarce/absent during May–November in the Study Area (see Table 4.16). Lesser Black-backed Gull is mainly a European species with an increasing presence in North America (Burger et al. 2020). It is expected to be rare in the Study Area during April–December (see Table 4.16). Ring-billed Gull is common on land and seashores but rarely ventures beyond sight of land (Pollet et al. 2020).



Source: ECCC-CWS (2022).

Figure 4.52. Seasonal distribution and abundance of ECSAS gull observations, excluding Kittiwakes, in the waters off eastern Newfoundland (2006–2020).

Small Gulls: Black-legged Kittiwake, Ivory, Sabine's, Ross's, and Black-headed Gulls

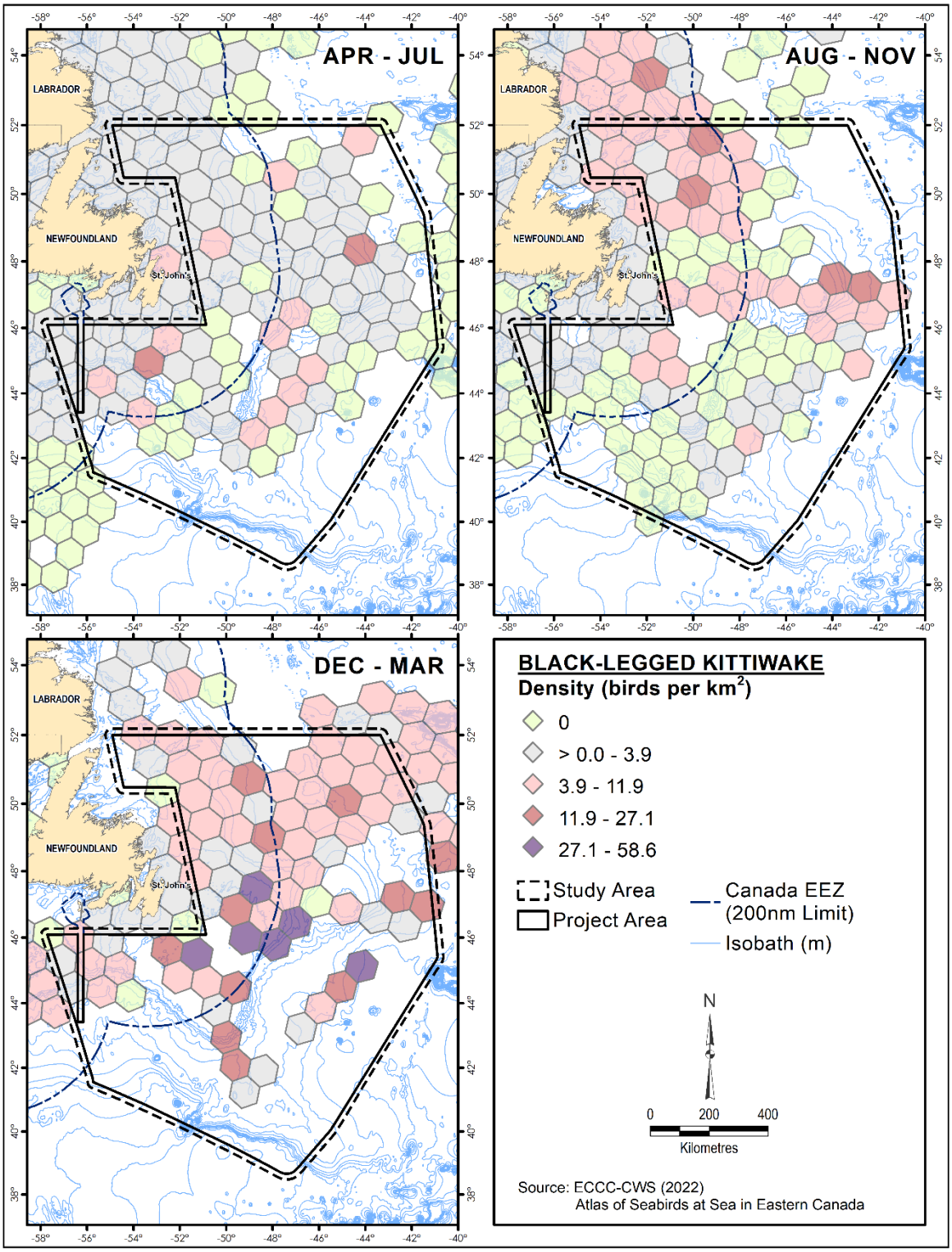
Black-legged Kittiwake is expected to be uncommon during May–August and otherwise common year-round in the Study Area (see Table 4.16). Kittiwake is a pelagic species, coming to land only to nest (Hatch et al. 2020a). Large colonies of kittiwakes nest on islands and coastal cliffs on the southern and the eastern Avalon Peninsula and north along the coast to Fogo Island (see Table 4.16). Tracking kittiwakes with geolocators showed that 80% of the 4.5 million adult kittiwakes nesting in the North Atlantic, including most European colonies, spend the winter off Newfoundland, including the Study Area and areas extending to the Mid-Atlantic Ridge and the Labrador Sea (Frederiksen et al. 2012). ECSAS surveys showed the lowest densities of Black-legged Kittiwakes in the Study Area during April–July and the highest during December–March (ECCC-CWS 2022). Densities averaged 3.9–11.9 birds/km^2 across the northern half of the Study Area during the time periods of August–November and December–March, respectively (Figure 4.53). Densities were the highest in the eastern Grand Banks, with 27.1–58.8 birds/km^2 during December–March.

Ivory Gull (*Pagophila eburnea*) nests in small, isolated colonies in the high Arctic (Mallory et al. 2020b). It spends most of its life on or near sea ice (Mallory et al. 2020b). During winter, Ivory Gull ranges south among the pack ice at sea off Labrador and northern Newfoundland, including the northern part of the Study Area (Mallory et al. 2020b). It is expected to occur occasionally in the northern part of the Study Area in late winter when pack ice traditionally reaches its southern maximum (Gilg et al. 2010; Spencer et al. 2016; Mallory et al. 2020b). Ivory Gull feeds on small fish and various other marine life, including by scavenging, and is designated *Endangered* under both Schedule 1 of SARA and the NL ESA (see Section 4.7).

Sabine's Gull (*Xema sabini*) migrates through the pelagic waters of the Labrador Sea on its way between nesting grounds in the Canadian Arctic and wintering areas in the pelagic waters of the tropics (Davis et al. 2016). Small numbers have been observed during geophysical surveys off southeast Labrador in August and September (Beland and Mactavish 2014) and in the Orphan Basin/Flemish Pass from late-May to late-September (Moulton et al. 2005, 2006a; Abgrall et al. 2008a; Mactavish et al. 2012; Jones and Lang 2013; Holst and Mactavish 2014). Sabine's Gull is expected to be rare in the Study Area from May–September (Mactavish et al. 2016).

Ross's Gull (*Rhodostethia rosea*) winters in very small numbers offshore from the Labrador Sea to Orphan Basin after migrating from nesting areas in the Canadian Arctic (Maftei et al. 2015). This species is designated as *Threatened* on Schedule 1 of SARA (see Section 4.7).

Black-headed Gull (*Chroicocephalus ridibundus*) nests in small numbers at a few sites in Newfoundland (Cotter et al. 2012; B. Mactavish, Senior Technician, LGL Limited, pers. comm., May 2019). Black-headed Gulls banded in Iceland have been found wintering on Newfoundland coastlines (B. Mactavish, Senior Technician, LGL Limited, pers. comm., May 2019). However, Black-headed Gull is rare in the Study Area (B. Mactavish, Senior Technician, LGL Limited, pers. comm., October 2023).



Source: ECCC-CWS (2022).

Figure 4.53. Seasonal distribution and abundance of ECSAS Black-legged Kittiwake observations in the waters off eastern Newfoundland (2006–2020).

Arctic and Common Terns

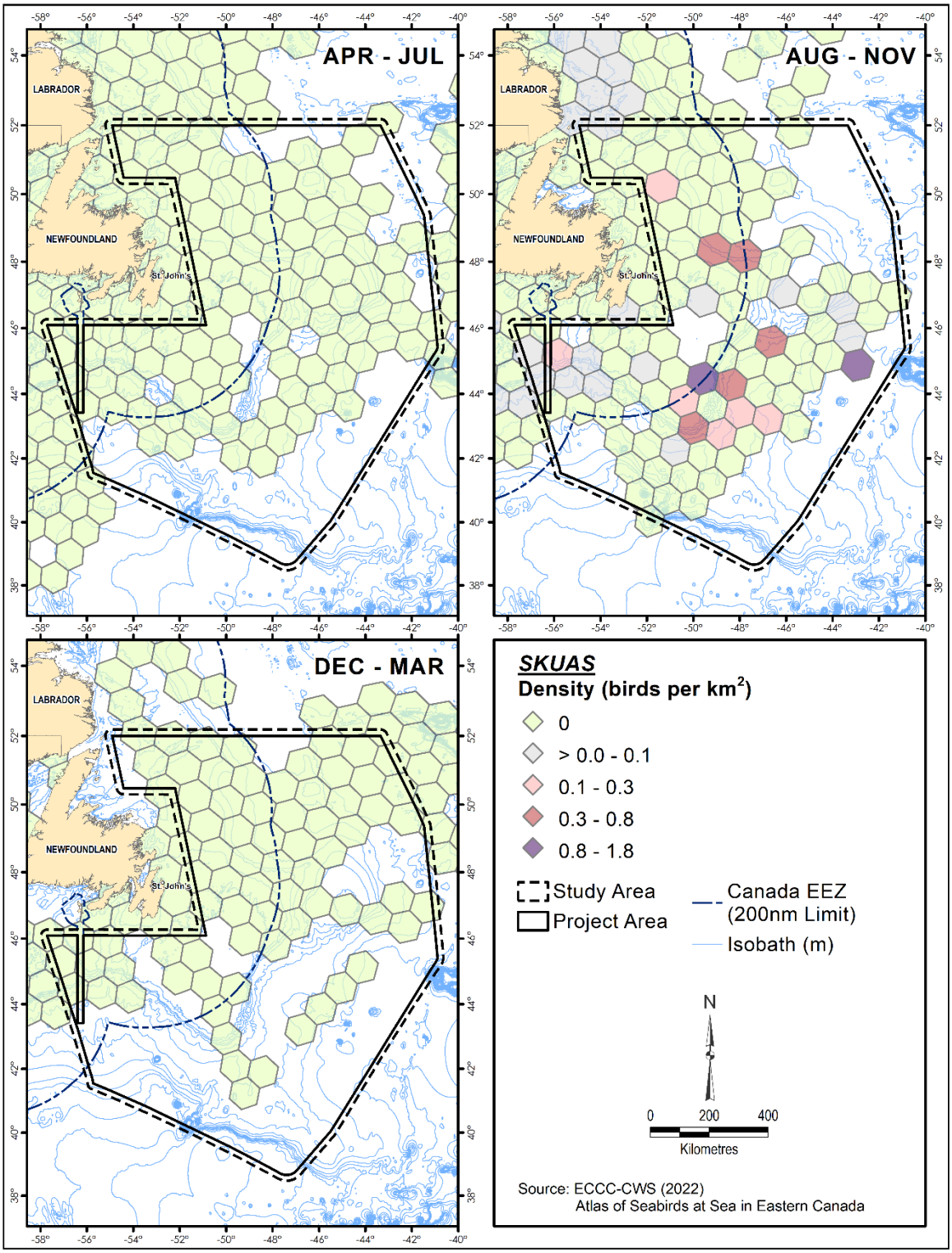
Arctic Tern (*Sterna paradisaea*) and Common Tern (*S. hirundo*) are the two widespread nesting species of tern in Newfoundland (see Table 4.16). Arctic Tern also nests along the entire Labrador coast and throughout much of the Arctic (Hatch et al. 2020b). Arctic Tern lives at sea during the non-breeding season and is encountered in the Newfoundland offshore areas in low densities during spring and fall migration (Abgrall et al. 2008a, 2009; Abgrall 2014; Holst and Lang 2014). Common Tern lives on inland water bodies and along coastal waters while nesting (Arnold et al. 2020). It is rarely encountered in the offshore (B. Mactavish, Senior Technician, LGL Limited, pers. comm., October 2023), although this species must spend brief periods of time transiting through the offshore areas during spring and fall migration. Terns were infrequently recorded on-transect during ECSAS surveys in the northeast portion of the Study Area; densities ranged from 0.1–0.2 birds/km² during the April–July and August–November periods (ECCC-CWS 2022).

4.4.2.7 Stercorariidae (Skuas and Jaegers)

During the non-breeding season jaegers and skuas procure much of their food via kleptoparasitism (piracy of other seabirds' prey; Wiley and Lee 1998, 1999, 2000). During this season they live at sea. Skuas and jaegers that occur within the Study Area are profiled below.

Great and South Polar Skuas

Both Great (*Stercorarius skua*) and South Polar (*S. maccormicki*) Skua occur in low densities in the Study Area during their respective non-breeding seasons (Abgrall et al. 2008b, 2009; Abgrall 2014; Holst and Lang 2014). Skuas were recorded during the ECSAS surveys in the Study Area only during the August–November period (Figure 4.54). The highest densities were recorded in the southern Orphan Basin with 0.3–0.8 birds/km², and on the southeastern edge of the Grand Banks with densities ranging from 0.1–0.3 to 0.8–1.8 birds/km² (Figure 4.54). Great Skua breeds in the NE Atlantic (Iceland, Scandinavia, United Kingdom) and winters at sea north of the equator (Furness et al. 2020a). A large proportion of the Iceland population winters in the waters located over the Mid Atlantic Ridge and west to the southeastern portion of the Study Area (Magnusdottir et al. 2012). Great Skua also occurs in the Study Area during spring and fall migration, with small numbers of subadults summering (Abgrall et al. 2008b, 2009; Abgrall 2014; Holst and Lang 2014). South Polar Skua nests in the South Atlantic and spends the austral winter in the pelagic waters of the Northwest Atlantic (Furness et al. 2020b). It occurs throughout the Study Area in low densities from May–October (Abgrall et al. 2008b, 2009; Abgrall 2014; Holst and Lang 2014).



Source: ECCC-CWS (2022).

Figure 4.54. Seasonal distribution and abundance of ECSAS Skua (Great, South Polar and Unidentified skuas combined) observations in the waters off eastern Newfoundland (2006–2020).

Pomarine, Parasitic, and Long-tailed Jaegers

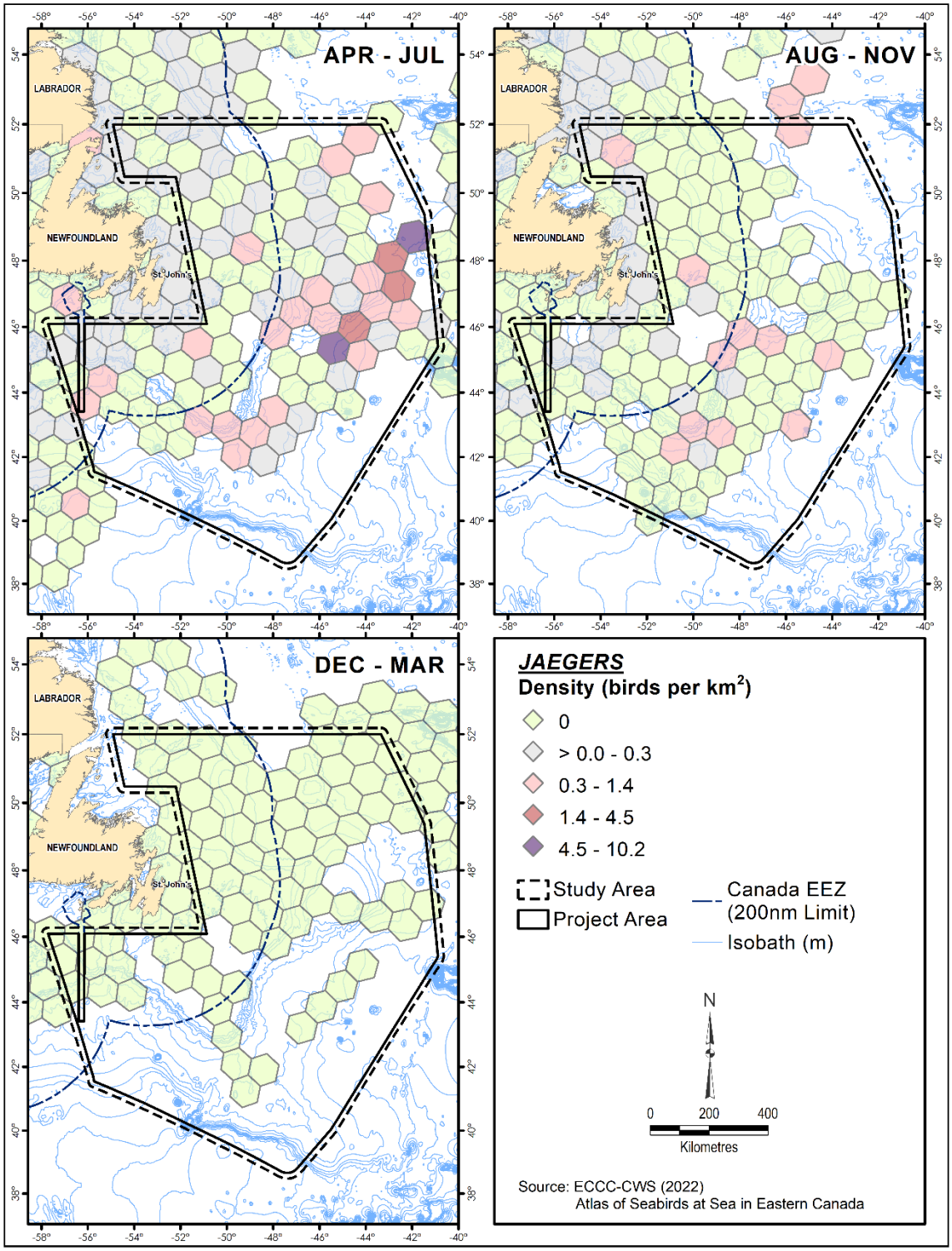
Pomarine (*Stercorarius pomarinus*), Parasitic (*S. parasiticus*), and Long-tailed (*S. longicaudus*) Jaegers nest in the Arctic and winter at sea south of the Study Area (Wiley and Lee 2020a,b,c). They all migrate through the Study Area in spring and fall while sub-adults migrate no farther north than the Study Area, where they spend the summer (B. Mactavish, Senior Technician, LGL Limited, pers. comm., October 2023). Migration movements of adult Long-tailed Jaegers between nesting sites in the Canadian Arctic at Bylot Island and Igloolik Island and wintering grounds in the South Atlantic showed routes of spring and fall migrating that included the Grand Banks and waters off eastern NL (Seyer et. al 2021). Jaegers occur in low densities in the Study Area from late-April to early-November (Abgrall et al. 2008b, 2009; Abgrall 2014; Holst and Lang 2014). Jaegers were recorded in low densities during the ECSAS surveys in the Study Area for the April–July and August–November times periods; they are absent offshore Newfoundland during December–March (Figure 4.55).

4.4.2.8 Alcidae (Dovekie, Murres, Atlantic Puffin, Razorbill, Black Guillemot)

There are six species of alcids that breed in the North Atlantic: Dovekie, Common and Thick-billed Murres, Atlantic Puffin, Razorbill (*Alca torda*), and Black Guillemot (*Cepphus grylle*). All of these, except for Dovekie and Thick-billed Murre, nest in large numbers in eastern Newfoundland (see Table 4.16). Common Murre, Thick-billed Murre, Dovekie, and Atlantic Puffin occur in the Study Area during much of the year (see Table 4.16). Black Guillemot and Razorbill are more coastal and are expected to be scarce within most of the Study Area. During winter, alcids concentrate mostly around relatively productive areas, such as the continental shelf slope of the Labrador Shelf and Grand Banks (Gaston et al. 2011; Hedd et al. 2011; Montevecchi et al. 2012b). Globally significant numbers of alcids are attracted to these habitats during winter (Fort et al. 2013; McFarlane Tranquilla et al. 2013). Alcids that may occur in the Study Area are profiled below.

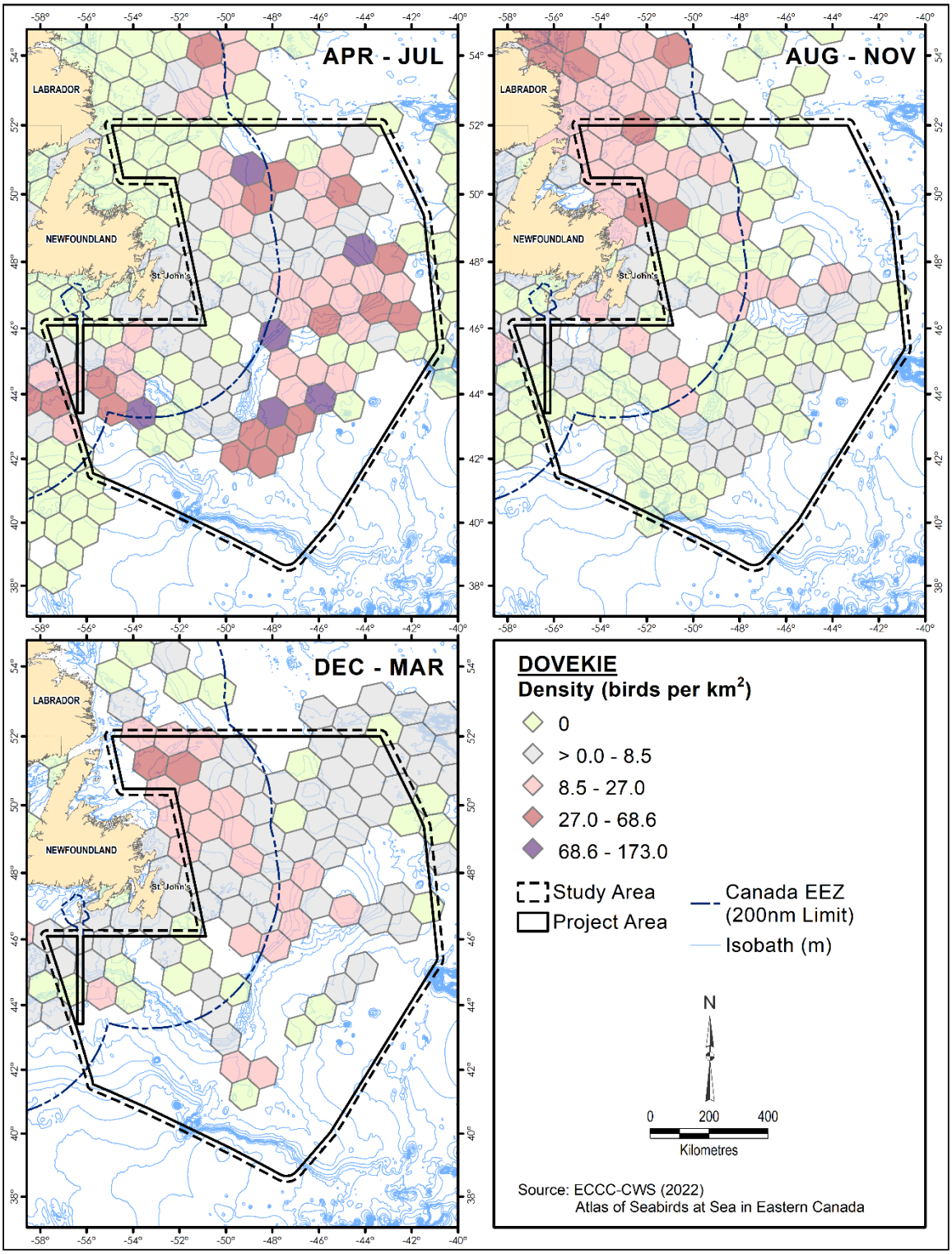
Dovekie

Dovekie nests primarily in Greenland and the eastern Canadian Arctic (Gaston and Jones 1998). Dovekie can be locally common anywhere within the Study Area from October–April. The core distribution of the 30 million Dovekies that nest along the west and east coasts of Greenland during winter off eastern Newfoundland overlaps the shelf slope and deeper waters of the Study Area (Fort et al. 2013). The densities of Dovekie during the ECSAS April–July period surveys were highest (27.0–68.6 and 68.6–173.0 birds/km^2) on shelf edges and in the deep water beyond the southeast Grand Banks (Figure 4.56). However, these densities would have occurred in April and May as Dovekie is very rare by June, having departed for Arctic nesting colonies (Abgrall et al. 2009). During the August–November and December–March periods, the densities were highest in the northern part of the Study Area, in the range of 8.5–27.0 birds/km^2 (Figure 4.56).



Source: ECCC-CWS (2022).

Figure 4.55. Seasonal distribution and abundance of ECSAS Jaeger (Pomarine, Parasitic, Long-tailed, and Unidentified jaegers combined) observations in the waters off eastern Newfoundland (2006–2020).



Source: ECCC-CWS (2022).

Figure 4.56. Seasonal distribution and abundance of ECSAS Dovekie observations in the waters off eastern Newfoundland (2006–2020).

Common and Thick-billed Murres

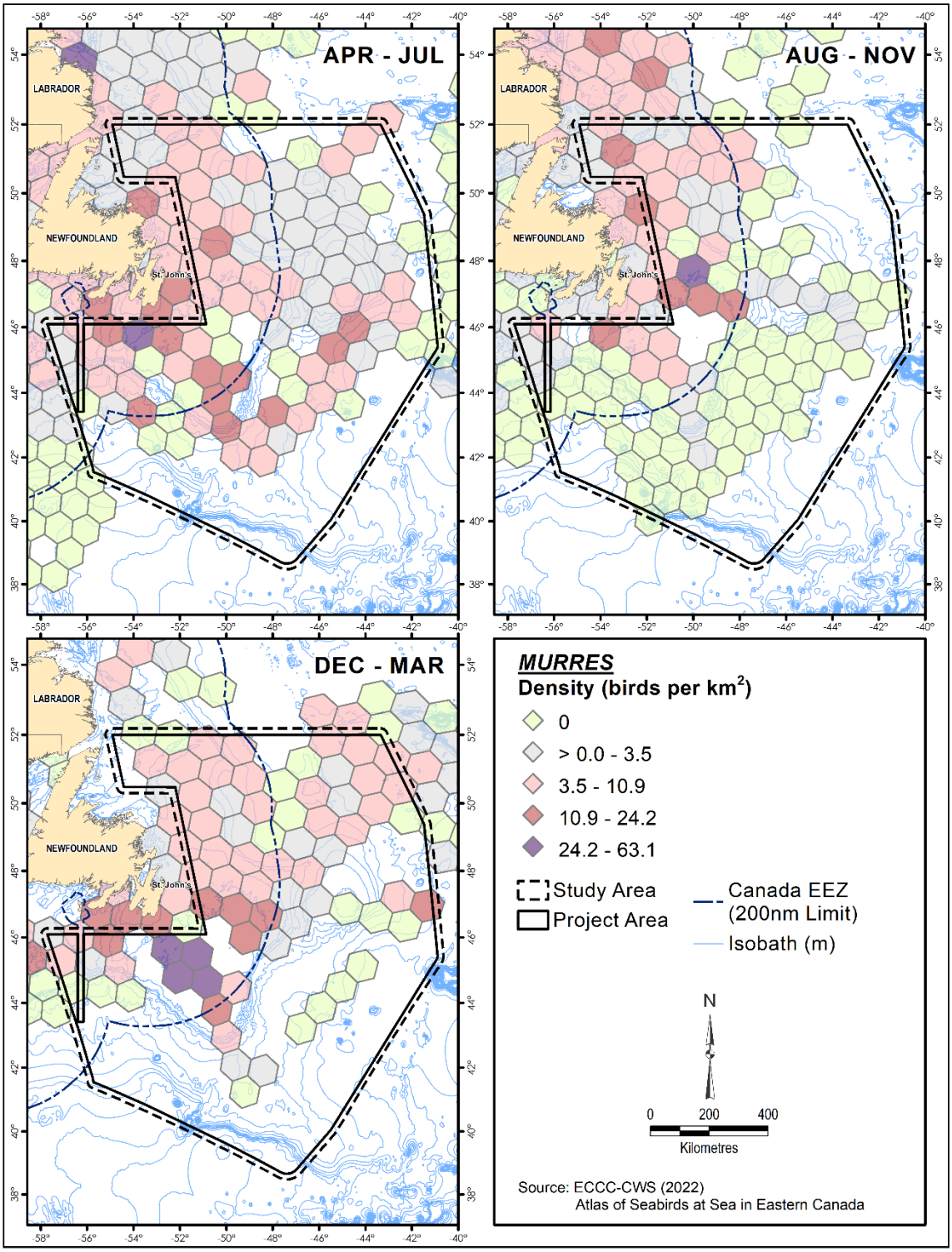
More than 730,000 pairs of Common Murres nest in eastern Newfoundland (see Table 4.17). Thick-billed Murre nests in large numbers in Labrador, the eastern Canadian Arctic, Greenland, the Northeast Atlantic (Iceland), and northern Russia (Gaston and Jones 1998). The core wintering range for North Atlantic Thick-billed Murre breeding populations is the Labrador Sea and Grand Banks (McFarlane Tranquilla et al. 2013), making the Study Area an important wintering area. These wintering birds originate mostly from nesting colonies on Baffin Bay and Hudson Bay, with a minority from Spitsbergen, Norway (McFarlane Tranquilla et al. 2015; Frederiksen et al. 2016). Studies using geolocators attached to 19 Thick-billed Murres and 20 Common Murres from five nesting colonies in the NW Atlantic revealed that murres exhibit a combination of site fidelity and flexibility during both migration and the winter (McFarlane Tranquilla et al. 2014). During the non-breeding season, Thick-billed Murres occurred in the offshore from Davis Strait south to the Flemish Cap and Southeast Grand Banks (McFarlane Tranquilla et al. 2014). Common Murres were found off eastern Newfoundland to the Flemish Cap and the Southeast Grand Banks during migration and winter (McFarlane Tranquilla et al. 2014). The combined density for Common Murre and Thick-billed Murre during ECSAS surveys during the April–July period showed the highest densities in the southern portion of the Study Area, particularly along the edge of the Grand Banks (Figure 4.57). Densities in the Study Area during August–November were highest (average 3.5–10.9 birds/km^2) along the western and northern portions of the Study Area (Figure 4.57). In the December–March period, densities were generally 3.5–10.9 birds/km^2 in the northern portions of the Study Area and peak densities (24.2–63.1 birds/km^2) occurred on the southern Grand Banks (Figure 4.57).

Razorbills, Atlantic Puffin, and Black Guillemot

Razorbills spend most of their time in nearshore Newfoundland waters (ECCC-CWS 2022). Very few have been detected in offshore waters within the Study Area (Abgrall et al. 2008b, 2009; Abgrall 2014; Holst and Lang 2014). No Razorbills and few Atlantic Puffins were detected during ECSAS surveys in the Study Area (ECCC-CWS 2022). One of nine Atlantic Puffins from a breeding colony in NW Greenland outfitted with data loggers spent part of the winter on the Grand Banks (Burnham et al. 2021). Black Guillemot is common in nearshore waters in NL (Mactavish et al. 2016). Unlike the other members of the Alcidae family, it is rarely found more than a few kilometres from shore or from pack ice (Gaston and Jones 1998).

4.4.3 Prey and Foraging Habits

Seabirds in the Study Area consume a variety of prey, ranging from small fishes to zooplankton. Different foraging methods include plunge-diving from a height of as much as 30 m into the water (Mowbray 2020), feeding on the surface (surface-seizing), and sitting on the water then diving (surface-plunging). The estimated head submergence times and diving depths of various seabird species are provided in Table 4.19.



Source: ECCC-CWS (2022).

Figure 4.57. Seasonal distribution and abundance of ECSAS Murre (Common, Thick-billed, and Unidentified murres combined) observations in the waters off eastern Newfoundland (2006–2020).

Table 4.19. Prey, prey capture method, time with head submerged, and dive depth of seabirds in the Study Area.

Species	Prey	Prey Capture Method	Time with Head Submerged (s)	Depth (m)
Procellariidae				
Northern Fulmar [a]	Fish, cephalopods, crustaceans, zooplankton, offal	Surface-seizing, surface-dipping, surface-plunging, pursuit-plunging	≤6	1–3
Great Shearwater [b]	Fish, offal, cephalopods, crustaceans	Mainly plunge-diving, also pursuit-plunging, surface-seizing	Typically <12	1–19
Sooty Shearwater [c]	Fish, cephalopods, planktonic crustaceans, offal	Mainly pursuit-diving and plunge-diving	Brief	30–40
Manx Shearwater [d]	Fish, cephalopods, crustaceans, zooplankton, offal	Surface-seizing, pursuit-plunging, plunge-diving	5–10	1–30
Hydrobatidae				
Leach's Storm-Petrel [e]	Fish, crustaceans, cephalopods, jellyfish	Surface-seizing	0	0
Oceanitidae				
Wilson's Storm-Petrel [f]	Crustaceans, fish, mollusks, nereids, oil	Surface-seizing, occasional plunge-diving, surface-plunging	Brief	<0.5
Sulidae				
Northern Gannet [g]	Fish, squid	Plunge-diving	5-10	10–40
Phalaropodinae				
Red Phalarope [h]	Zooplankton, crustaceans	Surface-seizing, surface-dipping	Brief	0
Red-necked Phalarope [i]	Zooplankton, crustaceans	Surface-seizing, surface-dipping	Brief	0
Laridae				
Herring Gull [j]	Fish, crustaceans, offal	Surface-seizing, surface-dipping, plunge-diving, surface-plunging	Brief	<0.5
Iceland Gull [k]	Fish, crustaceans, offal	Surface-seizing, occasional plunge-diving	Brief	<0.5
Glaucous Gull [l]	Fish, crustaceans, offal	Surface-seizing, occasional plunge-diving	Brief	<1
Great Black-backed Gull [m]	Fish, crustaceans, offal	Surface-seizing, dipping, plunge-diving	Brief	<2
Ivory Gull [n]	Fish, crustaceans, offal	Contact-dipping, surface-dipping, surface-plunging, surface-seizing, plunge-diving	Brief	<0.5
Black-legged Kittiwake [o]	Fish, crustaceans, offal	Surface-plunging, surface-seizing, surface-dipping	1–2	<1
Arctic and Common Terns [p,q]	Fish, crustaceans, zooplankton	Plunge-diving, contact-dipping, surface-seizing	Brief	<0.5
Stercorariidae				
Great Skua [r]	Fish, cephalopods, offal, seabirds	Surface-plunging, surface-seizing, aerial-seizing	Brief	<0.5
South Polar Skua [s]	Fish, seabirds, offal, krill	Surface-plunging, surface-seizing, aerial-seizing	Brief	<0.5
Pomarine Jaeger [t]	Fish, seabirds	Surface-seizing, aerial-seizing, plunge-diving, surface-plunging	Brief	<0.5
Parasitic Jaeger [u]	Fish, crustaceans, birds	Surface-seizing, aerial-seizing	Brief	<0.5

Species	Prey	Prey Capture Method	Time with Head Submerged (s)	Depth (m)
Long-tailed Jaeger [v]	Fish, crustaceans, birds	Surface-seizing, plunge-diving, surface-dipping	Brief	<0.5
Alcidae				
Dovekie [w]	Crustaceans, zooplankton, fish	Pursuit-diving	≤41	Max 30, average <30
Common Murre [w]	Fish, crustaceans, zooplankton	Pursuit-diving	≤153	Max 100, average 20-50
Thick-billed Murre [w]	Fish, crustaceans, zooplankton	Pursuit-diving	Prolonged	Max 100, average 20-60
Razorbill [w]	Fish, crustaceans, zooplankton	Pursuit-diving	Average 35	Max 120, average 25
Atlantic Puffin [w]	Fish, crustaceans, zooplankton	Pursuit-diving	≤115	Max 60, average <60

Source: [a] Mallory et al. (2020a), [b] Carboneras et al. (2020a), [c] Carboneras et al. (2020b), [d] Lee et al. (2023), [e] Pollet et al. (2021), [f] Drucker et al. (2020), [g] Mowbray (2020), [h] Tracy et al. (2020), [i] Rubega et al. (2020), [j] Weseloh et al. (2020), [k] Snell et al. (2020), [l] Weiser and Gilchrist (2020), [m] Good (2022), [n] Mallory et al. (2020b), [o] Hatch et al. (2020a), [p] Hatch et al. (2020b), [q] Arnold et al. (2020), [r] Furness et al. (2020a), [s] Furness et al. (2020b), [t] Wiley and Lee (2020a), [u] Wiley and Lee (2020b), [v] Wiley and Lee (2020c), [w] Gaston and Jones (1998).

4.4.4 Marine-associated Bird Data Gaps Identified in Relevant SEAs

The following data gap associated with the Marine-associated Bird VC was identified in Section 6.1.6 in C-NLOPB (2014):

- Detailed information on the occurrence, abundance and distribution of marine-associated birds is not available for all locations and times in the Study Area.

The following data gaps associated with the Marine-associated Bird VC were identified in the Section 3.4.9 in C-NLOPB (2010):

- Knowledge of the offshore distribution and abundance of seabirds is incomplete;
- Seabird data for areas that have been surveyed typically do not cover all seasons;
- Pelagic seabird distribution data are lacking during winter on much of the continental shelf and the deep waters beyond the shelf; and
- Much of the existing data on seabirds are dated.

The following data gaps associated with the Marine-associated Bird VC were identified in the Section 3.4.1.2 in IAAC (2020):

- The ECSAS database has spatial and temporal gaps, especially in NAFO Divisions 3O and 3N (southern part of the Grand Banks) throughout the year, in 3L (northern part of the Grand Banks) in autumn, and in the Flemish Cap area in August–November and December–March;
- The ECSAS survey coverage along the shelf break and deeper waters is incomplete; and
- The ECSAS Atlas at the time used data only up to and including those collected in 2016.

Some of the data gaps indicated above still exist and thus limit the certainty of impact predictions made in Section 5.7.6. Where available, information partially bridging the above data gaps have been provided here. ECCC-CWS ECSAS bird density data for the region have been updated to include 2006–2020; the ECSAS surveys are ongoing and continue to include sampling in areas offshore Newfoundland (Fifield et al. 2009; ECCC-CWS 2022). In addition, opportunistic efforts are being made during geophysical surveys to collect more distribution and abundance data for seabirds within and/or near the Study Area.

4.5 Marine Mammal VC

The Marine Mammal VC of the Study Area has been described in Section 3.5 in C-NLOPB (2010), Section 4.2.3 in C-NLOPB (2014), Section 5.0d in IACC (2020), and (Section 4.5 in LGL 2018). An overview of marine mammals that occur in the Study Area, based primarily on the aforementioned documents, is provided below. New information not included in the SEAs and regional drilling EA is also summarized. DFO research and scientific documents and COSEWIC species assessment and status reports also served as primary sources of information on the occurrence, distribution, abundance, and life history of marine mammals in the Study Area. Historical and more recent

sightings of cetaceans within NL waters have been compiled and made available by DFO in St. John's (Section 4.5.1). Marine mammal data gaps identified in the two SEAs and the regional drilling EA are also discussed in terms of current status.

Twenty-four marine mammal species are known to occur near or within the Study Area, including 20 species of cetaceans (whales, dolphins, and porpoises) and four species of phocids (true seals). Some marine mammals use the area seasonally, while others occur there year-round. The region likely represents important foraging habitat for many marine mammals.

Information on the occurrence, habitat, and conservation status for each of the marine mammal species that could occur near or within the Study Area is presented in Table 4.20. Four cetacean species that have been reported within or near the Study Area (bowhead whale *Balaena mysticetus*; beluga whale *Delphinapterus leucas*; pygmy sperm whale *Kogia breviceps*; false killer whale *Pseudorca crassidens*), three pinniped species (ringed seal *Phoca hispida*; bearded seal *Erignathus barbatus*; Atlantic walrus *Odobenus rosmarus rosmarus*), and the polar bear (*Ursus maritimus*) are considered unlikely to occur in the Study Area during the seismic program and are not discussed further.

Table 4.20. Marine mammals with reasonable likelihood of occurrence in the Study Area.

Species	Study Area		Habitat	SARA Status [a]	COSEWIC Status [b]
	Occurrence	Season			
Baleen Whales (Mysticetes)					
North Atlantic Right Whale (*Eubalaena glacialis*)	Rare	Summer-fall	Coastal, shelf & pelagic	E	E
Humpback Whale (*Megaptera novaeangliae)* Western North Atlantic population	Common	Year-round, but mostly May-Sep	Coastal & banks	NS	NAR
Common Minke Whale (*Balaenoptera acutorostrata acutorostrata*) North Atlantic subspecies	Common	Year-round, but mostly May-Oct	Coastal, shelf, & banks	NS	NAR
Sei Whale (*B. borealis*) Atlantic population	Uncommon	May-Nov	Pelagic	NS *	E
Fin Whale (*B. physalus physalus*) Atlantic population	Common	Year-round, but mostly summer	Shelf breaks, banks & pelagic	SC	SC
Blue Whale (*B. musculus*) Atlantic population	Uncommon	Year-round	Coastal & pelagic	E	E
Toothed Whales (Odontocetes)					
Sperm Whale (*Physeter macrocephalus*)	Common	Year-round, but mostly summer	Slope, canyons & pelagic	NS	MPC
Northern Bottlenose Whale (*Hyperoodon ampullatus*) Scotian Shelf and Davis Strait-Baffin Bay-Labrador Sea populations	Uncommon	Year-round	Slope, canyons & pelagic	E [c] NS [d] *	E [c] SC [d]
Cuvier's Beaked Whale (*Ziphius cavirostris*)	Uncommon	Year-round	Slope, canyons & pelagic	NS	MPC
Sowerby's Beaked Whale (*Mesoplodon bidens*)	Rare	Year-round	Slope, canyons & pelagic	SC	SC
Striped Dolphin (*Stenella coeruleoalba*)	Rare	Summer	Shelf & pelagic	NS	NAR

Species	Study Area		Habitat	SARA Status [a]	COSEWIC Status [b]
	Occurrence	Season			
Atlantic Spotted Dolphin (*Stenella frontalis*)	Rare	Summer	Shelf, slope & pelagic	NS	NAR
Short-beaked Common Dolphin (*Delphinus delphis*)	Common	Summer	Shelf & pelagic	NS	NAR
White-beaked Dolphin (*Lagenorhynchus albirostris*)	Common	Year-round, but mostly June-Sept	Shelf & pelagic	NS	NAR
Atlantic White-sided Dolphin (*Lagenorhynchus acutus*)	Common	Year-round, but mostly summer-fall	Coastal & shelf	NS	NAR
Common Bottlenose Dolphin (*Tursiops hocoena*)	Rare	Summer	Coastal & pelagic	NS	NAR
Risso's Dolphin (*Grampus griseus*)	Rare	Year-round	Continental slope	NS	NAR
Killer Whale (*Orcinus orca*) Northwest Atlantic/Eastern Arctic population	Uncommon	Year-round	Coastal & pelagic	NS *	SC
Long-finned Pilot Whale (*Globicephala melas*)	Common	Year-round, but mostly spring-fall	Shelf break, pelagic & slope	NS	NAR
Harbour Porpoise (*Phocoena hocoena hocoena*) Northwest Atlantic population	Uncommon	Year-round, but mostly spring-fall	Coastal, shelf & pelagic	NS	SC
True Seals (Phocids)					
Harp Seal (*Pagophilus groenlandicus*)	Common	Year-round, but mostly winter-spring	Pack ice & pelagic	NS	HPC
Hooded Seal (*Cystophora cristata*)	Common	Year-round, but mostly winter-spring	Pack ice & pelagic	NS	HPC
Grey Seal (*Halichoerus grypus*)	Uncommon	Year-round, but mostly summer	Coastal & shelf	NS	NAR
Harbour Seal (*Phoca vitulina concolor*) Atlantic and Eastern Arctic subspecies	Uncommon	Year-round	Coastal	NS	NAR

* Under consideration for addition to Schedule 1 of SARA.
[a] Species designation under Schedule 1 of SARA (GC 2025).
[b] Species assessment by COSEWIC (COSEWIC 2025).
[c] Scotian Shelf population.
[d] Davis Strait-Baffin Bay-Labrador Sea population.
Notes
E = Endangered; T = Threatened; SC = Special Concern; NAR = Not at Risk; NS = No Status; HPC = High-priority Candidate; MPC = Mid-priority Candidate.

4.5.1 Sightings Databases and Additional Sighting Data

The Eastern Newfoundland SEA (Section 4.2.3 in C-NLOPB 2014), the Southern Newfoundland SEA (Section 3.5 in C-NLOPB 2010), and the regional drilling EA (Section 5.0d in IACC 2020), used similar marine mammal sighting databases (Table 4.21) to present distribution maps and to provide insight on the time when marine mammals occur offshore Newfoundland. For the purposes of this EA and as per the Scoping Document, we have focused on newly available information to update information on marine mammal occurrence (location/timing) within the Study Area (Table 4.21).

The sightings in the DFO and OBIS databases have been opportunistically gathered and provide no information on survey effort. Therefore, while these data can be used to indicate what species may occur and when they occur in the Study Area, they cannot be used to predict species abundance, distribution, or fine-scale habitat use in the area. Additional caveats that should be considered when using data from DFO sightings databases are provided in IAAC (2020).

Table 4.21. Summary of marine mammal sighting databases used in the Eastern Newfoundland SEA, Southern Newfoundland SEA, the regional drilling EA, and the present EA.

Environmental Assessment	Marine Mammal Database(s) Used	Years Included	Section in EA
Eastern Newfoundland SEA	DFO NL Cetacean Sighting Database [a]	Not reported	4.2.3
Southern Newfoundland SEA	DFO NL Cetacean Sighting Database [a]	1975–2007	3.5
Regional Drilling EA	DFO NL Cetacean Sighting Database [a]	Late 1940s–2016	5.0d
Regional Drilling EA	Trans North Atlantic Sighting Survey	2007 (Jul–Aug)	5.0d
Present EA	DFO Maritimes Region Whale Sightings Database	2016–2020	4.5
Present EA	OBIS (seals only) [b]	2016–2017	4.5
Present EA	ESRF study (Smith et al. 2020)	August 2017	4.5
Present EA	MKI seismic monitoring programs for marine mammals (Penney-Belbin 2020a,b; Bishop and Lang 2021, 2022)	Late spring-summer 2020–2022	4.5

[a] Cetacean sightings in NL waters have been compiled from various sources by DFO in St. John's (J. Lawson, Section Head and Research Scientist, Marine Mammal Section, DFO, pers. comm., September 2023); data are available from 1950–2016. Given that these data have been included in the regional drilling EA, these data have not been presented here.

[b] The Ocean Biodiversity Information System (OBIS) was used for describing seal species, but not cetaceans, as most cetacean records are included in the DFO databases.

Additional cetacean and seal sighting data within the Study Area are available from a study off southern Newfoundland during August 2017 (Smith et al. 2020) and from three PGS/MKI marine mammal monitoring programs during 2020–2022 (Penney-Belbin 2020a,b; Bishop and Lang 2021, 2022). These additional data, as well as those from the DFO (Maritimes) and OBIS databases, were combined to describe species sightings within the Study Area. Sightings in the Study Area within the temporal boundary of the Project (May–November) compiled from the various sightings databases noted above are summarized below.

4.5.1.1 Baleen Whales (Mysticetes)

Six species of baleen whales are known to occur in the Study Area, three of which occur commonly (Table 4.20). Given that the Atlantic population of blue whale and the North Atlantic right whale each have *Endangered* status under Schedule 1 of SARA, they are described in Section 4.7. Although some individual baleen whales may be present in offshore waters of NL year-round, most baleen whale species presumably migrate to lower latitudes during the winter months (C-NLOPB 2014).

Humpback Whale

Humpbacks are the most commonly reported mysticete (173 sightings; 550 individuals based on newly available sightings databases; see Table 4.21 above) in the Study Area (Table 4.22). Most sightings occur in water <1000 m, with fewer sightings in deeper water, such as the Orphan Basin (Figure 4.58). While humpback sightings occur year-round off Newfoundland, they are most often reported during June–July. Habitat-density modeling by Roberts et al. (2023) and Mannocci et al. (2017) for April–November showed the highest densities (up to 0.63 whales/100 km^2) in the southeastern portion of the Study Area. Except for the Flemish Pass, Orphan Basin, and areas south of the Grand Banks, distribution models by Gomez et al. (2020) showed relatively high occurrence rates in the Study Area from spring through fall. Humpback whales are expected to be common throughout the Study Area.

Table 4.22. Cetacean sightings in the Study Area during May–November 2016–2022 (compiled from various sightings databases; see above).

Species	Number of Sightings	Number of Individuals	Months Sighted
Mysticetes			
North Atlantic Right Whale*	4	15	May, Aug, Oct
Humpback Whale	173	550	May-Oct
Minke Whale	106	min. 119	May-Nov
Blue Whale	21	24	Jul-Sep
Fin Whale	114	min. 250	May-Oct
Fin/Sei Whale	6	8	Jun-Jul
Sei Whale	6	8	Jun-Aug
Unidentified Baleen Whale	109	184	Jun-Sep
Odontocetes			
Sperm Whale	73	116	May-Nov
Northern Bottlenose Whale	106	343	May-Nov
Atlantic White-sided Dolphin*	84	At least 1575	May-Nov
Bottlenose Dolphin	2	45	May, Aug
Short-beaked Common Dolphin	125	1572	May-Aug
Common Dolphin	22	159	Jul, Sep-Nov
Striped Dolphin	3	92	Jul-Sep
Risso's Dolphin	14	90	Aug
Killer Whale*	9	41	Jun-Oct
Long-finned Pilot Whale	191	2051	May-Nov
Harbour Porpoise*	2	At least 5	Jul
Unidentified Dolphin	150	1575	May-Sep
Unidentified Dolphin/ Harbour Porpoise*	56	At least 636	May-Nov
Unidentified Beaked Whale	1	3	Jul
Unidentified Toothed Whale	2	16	Aug
Unidentified Whale*	95	At least 185	May-Nov
Other			
Unidentified Cetacean	2	2	Jul

* Only numbers of sightings not numbers of individuals were available for the DFO Maritimes database; thus, numbers of individuals for some species are expected to be greater.

Notes:

See Section 4.5.1 for a description of sightings databases that were used.

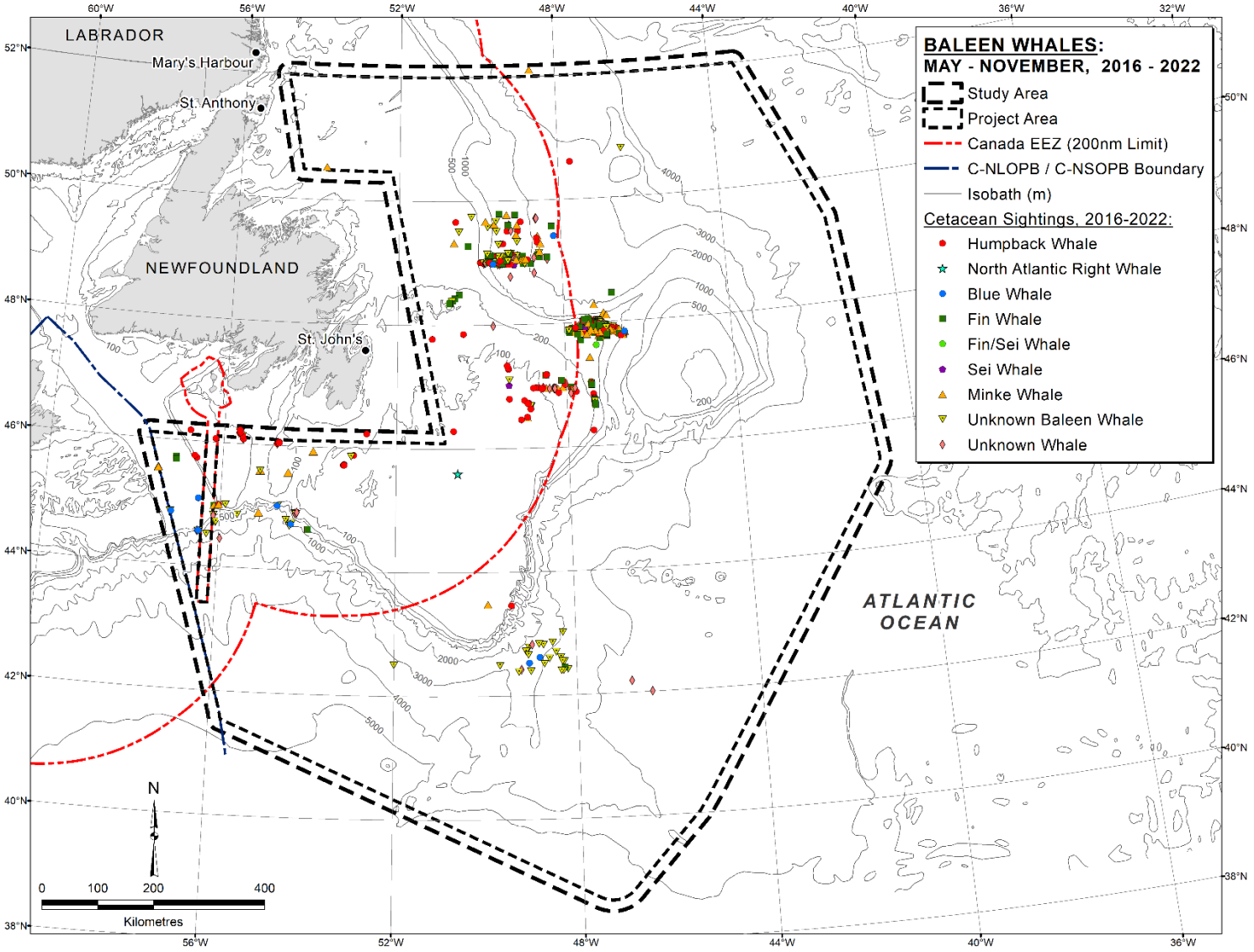


Figure 4.58. Baleen whale sightings in the Study Area from May–November 2016–2022 (compiled from multiple sightings databases, as described in Section 4.5.1).

Humpback whale distribution along the east coast of Newfoundland is influenced by the timing of capelin spawning, with humpbacks tending to occur slightly later than capelin (Johnson and Davoren 2021). During marine mammal monitoring in MKI's Blomidon 3D Survey Area in the Orphan Basin region from 25 May–23 July 2020, four sightings of six humpbacks were made (Penney-Belbin 2020a). Humpback whales were also seen (82 sightings totalling 170 individuals) during marine mammal monitoring programs in 2021 for MKI seismic surveys located on the Orphan Basin (Cape Anguille MC3D survey area), Flemish Pass (Cambriol MC3D survey area), Sackville Spur (Lewis Hills survey area), and Jeanne d'Arc Basin (Phase II survey area) (Bishop and Lang 2021). One female humpback that was satellite-tagged off Norway migrated to the West Indies just east of the Study Area in 2019 (Kettemer et al. 2022). During June 2012, a humpback outfitted with a satellite transmitter off the Dominican Republic travelled through the Study Area, across the Grand Banks (Kennedy et al. 2014). Humpbacks were also sighted within the Study Area along the edge of the Orphan Basin and in the southern Laurentian Channel during July 2012 (Ryan et al. 2013). In addition, sightings were made just west of the Study Area during 2000–2011 (Davoren 2013).

Humpback whales were acoustically detected year-round in the Study Area from May 2015–November 2017, with the highest detection rates on the Grand Banks during fall (Delarue et al. 2018, 2022). The Flemish Pass region also appears to be an important area for this species based on the number of detections; the northern portion of the Flemish Pass and possibly the Flemish Cap may be a migration transit point (Delarue et al. 2022). Humpback whale calls were also detected on the northeastern Scotian Shelf in all seasons during acoustic monitoring in 2004–2014 (Davis et al. 2020).

Kowarski et al. (2022) examined when and where humpbacks begin to sing in the NW Atlantic. They found that the first day of singing occurred as early as September in the Strait of Belle Isle and during October on the Grand Banks, with regular singing occurring there during November; regular singing off Labrador also started in October. The Newfoundland, and part of the Labrador shelves, as well as the Scotian Shelf, have been identified as priority areas to target and enhance monitoring efforts for humpbacks (Gomez et al. 2020).

Minke Whale

The minke whale is the third most commonly recorded mysticete in the Study Area (106 sightings; 119 individuals based on newly available sightings databases; see Table 4.22). It has been sighted throughout the Study Area, with most sightings recorded during June–August in the Jeanne d'Arc Basin, Orphan Basin, and northern Flemish Pass (Figure 4.58). Habitat-density modeling by Roberts et al. (2023) and Mannocci et al. (2017) showed the highest year-round densities (up to 1.6 whales/100 km^2) in the southeastern part of the Study Area. Distribution models by Gomez et al. (2020) indicted relatively high occurrence rates during summer and fall throughout much of the Study Area, except for the Orphan Knoll and areas south and east of the Grand Banks. Minke whales are considered common throughout the Study Area.

Minke whales were seen (86 sightings totalling 96 individuals) and detected acoustically during late-May to early-September 2021 marine mammal monitoring for the MKI seismic surveys located at the Orphan Basin, Flemish Pass, Sackville Spur, and Jeanne d'Arc Basin (Bishop and Lang 2021). Three minke whales were seen in the southwestern part of the Study Area during August 2017 (Smith et

al. 2020). Acoustic recorders deployed off NS and Newfoundland from May 2015–November 2017 only detected minke whales in the southwestern part of the Study Area; calls were detected sporadically between late-July and mid-December (Delarue et al. 2018, 2022). Minke whales were commonly recorded in the central part of the Study Area in Jeanne d'Arc Basin during seismic monitoring programs in 2013 and 2015 (Holst and Lang 2014; Keats 2015).

Sei Whale

The Atlantic population of sei whale is currently under consideration for addition to Schedule 1 of SARA (GC 2025); it was assessed as *endangered* by COSEWIC (2019a). Genetic studies have shown low divergence among North Atlantic sei whales suggesting a single rather than multiple stocks; however, the data showed high uncertainty, and there could be a Nova Scotian stock (Huijser et al. 2018).

Based on newly available sightings databases, there have been at least six sighting records (eight individuals) of sei whales in the Study Area (see Table 4.22; Figure 4.58); sightings occurred during June–August. COSWIC (2019a) and Gomez et al. (2020) reported sightings and acoustic detections throughout the Study Area. Habitat-density modeling for March–September by Roberts et al. (2023) and Mannocci et al. (2017) also indicated that sei whales are likely to occur throughout the Study Area with the highest densities (up to 2.5 whales/100 km^2) along the eastern margin of the Study Area, in particular north of the Flemish Cap; densities for October–February were near zero. Distribution models by Gomez et al. (2020) showed relatively high occurrence rates during summer at the Flemish Cap, western edge of Orphan Knoll, and southeastern edge of the Grand Banks, but low occurrence throughout the rest of the Study Area. Overall, sei whales are considered uncommon in the Study Area.

A sei whale that was tagged in the Azores during 2005 (Olsen et al. 2009) and seven individuals that were tagged in the Azores during 2008–2009 travelled to the Labrador Sea, where they spent extended periods of time on the northern shelf, presumably to feed (Prieto et al. 2010, 2014); at least one of the whales transited through the eastern Study Area. A sei whale sighting was made off the east coast of Newfoundland, just west of the Study Area, during surveys in 2000–2002 (Davoren 2013). The Flemish Cap, Scotian Shelf, Bay of Fundy, and northern Labrador Shelf have been identified as priority areas to target and enhance monitoring efforts for sei whales (Gomez et al. 2020).

Sei whales (5 sightings totalling 7 individuals) were seen during the 2021 marine mammal monitoring program for the MKI seismic surveys located on the Orphan Basin, Flemish Pass, and Sackville Spur (Bishop and Lang 2021). One sei whale sighting was recorded in Jeanne d'Arc Basin during seismic monitoring programs in each of 2008 and 2013 (Abgrall et al. 2009; Holst and Lang 2014). Sei whales were occasionally sighted in the Orphan Basin during seismic monitoring programs in 2004 and 2005 (6 and 15 sightings, respectively; Moulton et al. 2005, 2006a).

Sei whales were detected acoustically in the Flemish Pass during April–July 2021 (Kowarski et al. 2021). Sei whale calls were detected year-round throughout the Study Area on acoustic recorders deployed from May 2015–November 2017 off Newfoundland (Delarue et al. 2018, 2022; Macklin 2022). Orphan Basin was a region with particularly high call rates, especially from May through November (Delarue et al. 2018, 2022). Peaks in vocalizations off Newfoundland occurred during October, with a

smaller peak during June (Macklin 2022). Sei whale calls were also detected on the northeastern Scotian Shelf in all seasons during acoustic monitoring in 2004–2014 (Davis et al. 2020). Differences in vocalizations between sei whales detected in NS and Newfoundland suggest that two different populations may occur in Atlantic Canada (Macklin 2022).

Fin Whale

The Atlantic population of fin whale currently has a *special concern* status under Schedule 1 of SARA (GC 2025) and COSEWIC (COSEWIC 2019b), and a management plan was released in 2017 (DFO 2017a). Delarue et al. (2014) suggested that there are four distinct stocks in the NW Atlantic based on geographic differences in fin whale calls.

Based on recently available sightings data, fin whales are the second most commonly recorded mysticete in the Study Area (at least 114 sightings; 250 individuals; see Table 4.22; Figure 4.58), with most sightings reported during June–September. According to Edwards et al. (2015), the highest densities of fin whales occur in offshore waters off Newfoundland during June–August. Habitat-density modeling by Roberts et al. (2023) and Mannocci et al. (2017) for May–November indicated that fin whales are likely to occur throughout the Study Area with densities as high as 1.6 whales/100 km^2. Distribution models by Gomez et al. (2020) showed relatively high occurrence rates throughout the Study Area during summer and fall, except for the Grand Banks, Orphan Knoll, and Flemish Cap. Fin whales are expected to be common throughout the Study Area during late-spring to fall.

One fin whale was sighted during a May to early-September 2022 marine mammal monitoring program for MKI's Cameron Canyon MC3D seismic surveys located off the southeastern Grand Banks in deep waters (Bishop and Lang 2022). Fin whales were regularly seen (78 sightings totalling 173 individuals) and detected acoustically during the 2021 marine mammal monitoring for the MKI seismic surveys located on the Orphan Basin, Flemish Pass, Sackville Spur, and Jeanne d'Arc Basin (Bishop and Lang 2021). During marine mammal monitoring for MKI's 2020 Blomidon 3D Survey Area in the Orphan Basin region, six sightings totalling ten fin whales were made (Penney-Belbin 2020a). Fin whales were commonly observed during a seismic monitoring program in the Jeanne d'Arc Basin in 2013 (Holst and Lang 2014) and were seen within the Study Area south of the Grand Banks during July 2012 (Ryan et al. 2013). In addition, sightings were made during surveys off the northeastern coast of Newfoundland, west of the Study Area, during 2000 and 2009–2011 (Davoren 2013). Based on species distribution models, Gomez et al. (2020) reported that the entire Study Area is predicted to be a priority area to target and enhance monitoring efforts for fin whales; however, deep waters of the Flemish Cap had lower priority.

Fin whale vocalizations were detected year-round throughout the Study Area from May 2015–November 2017, with the highest detection rates on the Grand Banks; detections during summer were generally low (Delarue et al. 2018, 2022). The Flemish Pass region appears to be an important area for this species; during spring, vocalizations occurred in this region more frequently than most other locations monitored off Newfoundland (Delarue et al. 2022). Fin whales were also detected acoustically in Flemish Pass during April–July 2021 (Kowarski et al. 2021) and on the

northeastern Scotian Shelf in all seasons during acoustic monitoring during 2004–2014 (Davis et al. 2020).

4.5.1.2 Toothed Whales (Odontocetes)

Fourteen species of toothed whales are likely to occur in the Study Area (see Table 4.20), ranging from the largest, the sperm whale, to one of the smallest, the harbour porpoise. Several of these species only occur in the Study Area seasonally, but in general, there is little information about the distribution and abundance of these species. DFO is working on abundance estimates based on sightings data collected during the Northwest Atlantic International Sightings Surveys (NAISS) during 2016 off the east coast of Canada (Lawson and Gosselin 2018); previous abundance estimates were based on surveys that took place in 2007 (Lawson and Gosselin 2009) and are not reported here. Two genetically distinct populations of northern bottlenose whales have been identified in Canada (Dalebout et al. 2006). The Scotian Shelf population of northern bottlenose whale has *Endangered* status under Schedule 1 of SARA. The Davis Strait-Baffin Bay-Labrador Sea population of northern bottlenose whales could also occur in the Study Area.

Sperm Whale

Based on newly available sightings databases, there have been 73 sightings (116 individuals) of sperm whales in the Study Area (see Table 4.22), particularly in slope waters and the Orphan Basin (Figure 4.59). Sightings have been recorded year-round, with most sightings during June–August. Roberts et al. (2023) and Mannocci et al. (2017) presented year-round habitat-density modelling for sperm whales, showing higher densities (6.3 whales/100 km^2) in deep, offshore waters of the Study Area. Similarly, distribution models by Gomez et al. (2020) showed relatively high occurrence rates for summer in slope waters of the Study Area. Sperm whales are expected to be common in deep waters of the Study Area.

Fourteen sightings totalling 31 sperm whales were made during the May to early-September 2022 marine mammal monitoring program for MKI's Cameron Canyon MC3D seismic surveys located in deep waters off the southeastern Grand Banks (Bishop and Lang 2022). Sperm whales (17 sightings totalling 20 individuals) were seen and detected acoustically during the 2021 marine mammal monitoring programs for the MKI seismic surveys located on the Orphan Basin and Flemish Pass (Bishop and Lang 2021). During marine mammal monitoring in MKI's South Bank 3D Survey Area, south of the Grand Banks, from 29 June–11 August 2020, 16 sightings of 23 sperm whales were made (Penney-Belbin 2020b). Three sperm whale sightings were made in the southwestern part of the Study Area during August 2017 (Smith et al. 2020). Oyarbide et al. (2023) reported interactions of sperm whales with deep-water trawling vessels offshore Newfoundland during summer 2007 along the eastern edge of the Grand Banks and Flemish Pass. Sperm whales were regularly sighted in the deep waters of the Orphan Basin during the summers of 2004–2007 (Moulton et al. 2005, 2006a; Abgrall et al. 2008b), but were not observed in the shallower waters of Jeanne d'Arc Basin in 2005–2008, 2013, or 2015 (Lang et al. 2006; Lang and Moulton 2008; Abgrall et al. 2008a, 2009; Holst and Lang 2014; Keats 2015). There were two sightings in the Flemish Pass Basin during a monitoring program in 2014 (Thomas et al. 2014).

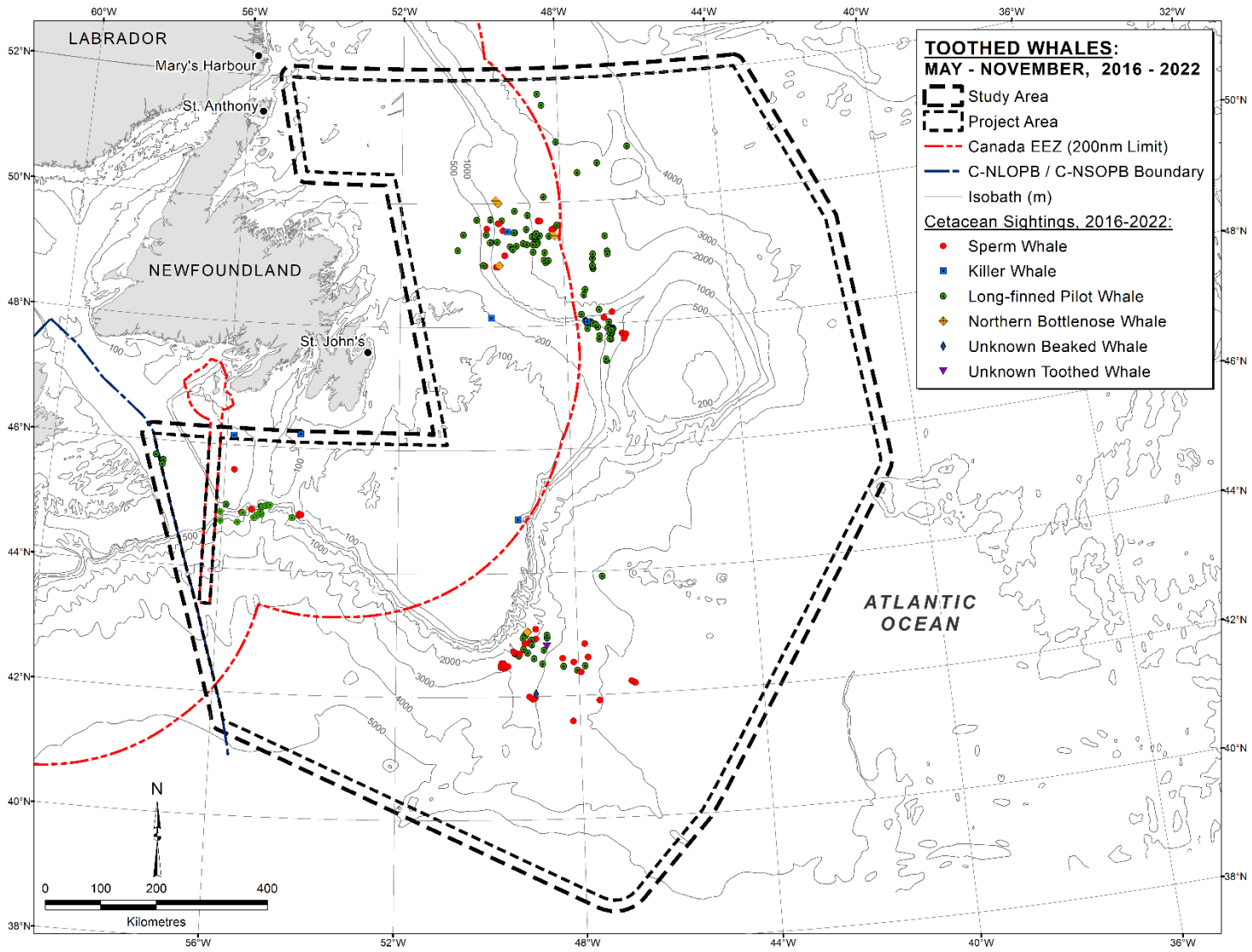


Figure 4.59. Toothed whale sightings in the Study Area from May–November 2016–2022 (compiled from multiple sightings databases, as described in Section 4.5.1).

Sperm whale vocalizations were detected year-round throughout the Study Area from August 2015–July 2017 (Delarue et al. 2018). There was a general seasonal decline in detection rates, except at sites in and adjacent to the Flemish Pass and along the eastern slope of the Grand Banks, where high detection rates were recorded year-round; this suggests that these regions may be important to sperm whales. They were also detected acoustically in Flemish Pass during April–July 2021 (Kowarski et al. 2021).

Northern Bottlenose Whale

A recent genomic assessment revealed three subgroups of northern bottlenose whales in the North Atlantic – Scotian Shelf, western North Atlantic, and Jan Mayen (de Greef et al. 2022). Two of these subgroups occur in Canada and are considered Designatable Units (DUs) – the Davis Strait-Baffin Bay-Labrador Sea population (part of the western North Atlantic subgroup) and the Scotian Shelf population (COSEWIC 2011). The Davis Strait-Baffin Bay-Labrador Sea population or DU is under consideration for addition to Schedule 1 of SARA (GC 2025) and has *special concern* status under COSEWIC (COSEWIC 2011).

Based on newly available sightings databases, there have been six sightings (18 individuals) of northern bottlenose whales in the Study Area (see Table 4.22; Figure 4.59); sightings occurred during May–July. Historically, and most recently, sightings are typically made in deeper waters and near the shelf break (Harris et al. 2013). Roberts et al. (2023) presented year-round habitat-density modelling for northern bottlenose whales, with the highest densities (0.1 whales/100 km^2) in deep, offshore waters of the Study Area. Northern bottlenose whales are expected to be uncommon in the Study Area—however, in deepwater regions, they have been regularly detected in low numbers during monitoring programs (see below).

One northern bottlenose whale was sighted during the 2022 marine mammal monitoring program for MKI's Cameron Canyon MC3D seismic surveys located off the southeastern Grand Banks in deep waters (Bishop and Lang 2022). Northern bottlenose whales (4 sightings totalling 16 individuals) were also seen during the 2021 marine mammal monitoring program for the MKI seismic surveys located in the Orphan Basin, (Bishop and Lang 2021). Oyarbide et al. (2023) reported interactions of northern bottlenose whales with deep-water trawling vessels offshore Newfoundland during summer 2007 along the eastern edge of the Grand Banks and the Flemish Pass. Based on species distribution models, Gomez et al. (2017) indicated that the most suitable habitats and, therefore, priority areas for monitoring of northern bottlenose whales, occur on the edges of the eastern Scotian Shelf and NL shelves, canyons, and deep basins.

Acoustic recorders deployed off Newfoundland from May 2015–November 2017 revealed the highest detection rates of northern bottlenose whales along the shelf break, mainly north of the Flemish Cap, with nearly daily detections throughout the study period (Delarue et al. 2018, 2024). Northern bottlenose whales were also detected acoustically in the Flemish Pass during April–July 2021 (Kowarski et al. 2021).

Stanistreet et al. (2021) noted that the population structure of northern bottlenose whales occurring off eastern Canada is not completely known. Important habitat for northern bottlenose whales may

occur in slope areas extending from the Scotian Shelf to Newfoundland. Northern bottlenose whales have been seen along the Sackville Spur, near the Flemish Cap, in multiple years, but no photographic matches have been made between the Scotian Shelf population and northern bottlenose whales that occur in Newfoundland (Stanistreet et al. 2021; Oyarbide et al. 2023). Photo-ID work found that at least 78 different animals occurred in the Grand Banks, Flemish Pass, Flemish Cap, and Sackville Spur area during 2016–2017 (L.J. Feyrer, Dalhousie University, pers. comm., 5 February 2018). No matches were made between these individuals and those photographed elsewhere off Newfoundland and NS (Feyrer 2021). Genetic assignment analyses suggested at least one individual occurring in the region was from the Scotian Shelf population and at least seven were from the Davis Strait-Baffin Bay Labrador Sea population (Feyrer et al. 2019). Thus, the Flemish Pass and other waters off Newfoundland may be an area of mixing of the DUs or may represent a newly established population (Feyrer et al. 2019).

Sowerby's Beaked Whale

Sowerby's beaked whale has a *special concern* status under Schedule 1 of SARA (GC 2025) and COSEWIC (COSEWIC 2019c), and a management plan was released in 2017 (DFO 2017b). It is considered rare in the Study Area.

There are no sightings of Sowerby's beaked whales in the Study Area in the newly available DFO sightings database for May–November (see Table 4.22; Figure 4.59). A sighting of four individuals was made during a seismic survey in the Orphan Basin in September 2005 (Moulton et al. 2006a). COSEWIC (2019c) reported four sightings of Sowerby's beaked whale within the Study Area – one in the Orphan Basin, one in the Flemish Pass and two along the southwestern edge of the Grand Banks; shipboard acoustic detections were also reported along the southern edge of the Grand Banks and along the northern edge of the Study Area. There are also several stranding records for NL (DFO 2017b; COSEWIC 2019c). Delarue et al. (2018, 2024) detected Sowerby's beaked whales year-round in the Study Area, with most "clicks" recorded along the shelf edge of the Grand Banks and along the edge of the Scotian Shelf. Based on sighting data and acoustic data, Feyrer et al. (2024) identified important habitat for Sowerby's beaked whales on the continental shelf edge, at average water depths of 1200 m.

Cuvier's Beaked Whale

There are no sightings of Cuvier's beaked whale in the Study Area in the newly available DFO sightings databases (see Table 4.22; Figure 4.59). However, a sighting was made in slope waters southwest of the Study Area during July. Cuvier's beaked whale is considered rare in the Study Area. Nonetheless, Delarue et al. (2018, 2024) detected Cuvier's beaked whales throughout the year within the Study Area, in particular in Orphan Basin, but also along the eastern edge of the Grand Banks and in the southeastern Laurentian Channel. Acoustic recorders deployed at six sites at the edge of the northeastern Scotian Shelf from 2011–2015 also recorded Cuvier's beaked whale clicks year-round (Stanistreet et al. 2017).

Striped Dolphin

Based on newly available sightings databases, there have been three sightings (92 individuals) of striped dolphins in the Study Area; all sightings occurred during July–August (see Table 4.22; Figure 4.60). Habitat-density modeling by Roberts et al. (2023) and Mannocci et al. (2017) showed the highest year-round densities (40 dolphins/100 km^2) for striped dolphins in deep, offshore waters of the southern Study Area. Overall, striped dolphins are considered rare in the Study Area.

During marine mammal monitoring in MKI's South Bank 3D Survey Area, south of the Grand Banks, from 29 June–11 August 2020, three groups of 86 striped dolphins were seen (Penney-Belbin 2020b). Striped dolphins were also seen (1 sighting of 10 individuals) during the 2021 marine mammal monitoring for the MKI seismic surveys located on the Orphan Basin (Bishop and Lang 2021). Striped dolphins were seen off the southwestern shelf edge of the Grand Banks during opportunistic surveys of the North Atlantic Current and Evlanov Seamount candidate Marine Protected Area (MPA) during July 2013 (Wakefield 2018).

Atlantic Spotted Dolphin

Although there are no sightings in the Study Area based on the databases that were examined (see Section 4.5.1), Gomez et al. (2020) reported one sighting on the Grand Bank and another in the Laurentian Channel. Neither Whitehead (2013) nor Gomez-Salazar and Moors-Murphy (2014) reported any sightings along the northeastern edge of the Scotian Shelf. However, based on habitat-density modeling, Roberts et al. (2023) and Mannocci et al. (2017) reported relatively high year-round densities (up to 6.3 individuals/100 km^2) in the deeper waters of the southern part of the Study Area; densities in the northern Study Area were near zero. Atlantic spotted dolphins are considered rare in the Study Area.

Short-beaked Common Dolphin

Based on newly available sightings databases, there have been 125 sightings (1575 individuals) of short-beaked common dolphins in the Study Area (see Table 4.22); sightings occurred in shelf, upper slope, and deep-water regions (Figure 4.60) during June–August. Roberts et al. (2023) and Mannocci et al. (2017) presented modelled year-round densities of short-beaked common dolphins for the Study Area, with higher densities (up to 160 individuals/100 km^2) in slope waters. Distribution models by Gomez et al. (2020) showed relatively high occurrence rates for summer and fall in the southern part of the Study Area and west and south of the Orphan Knoll. The short-beaked common dolphin is considered common in the Study Area.

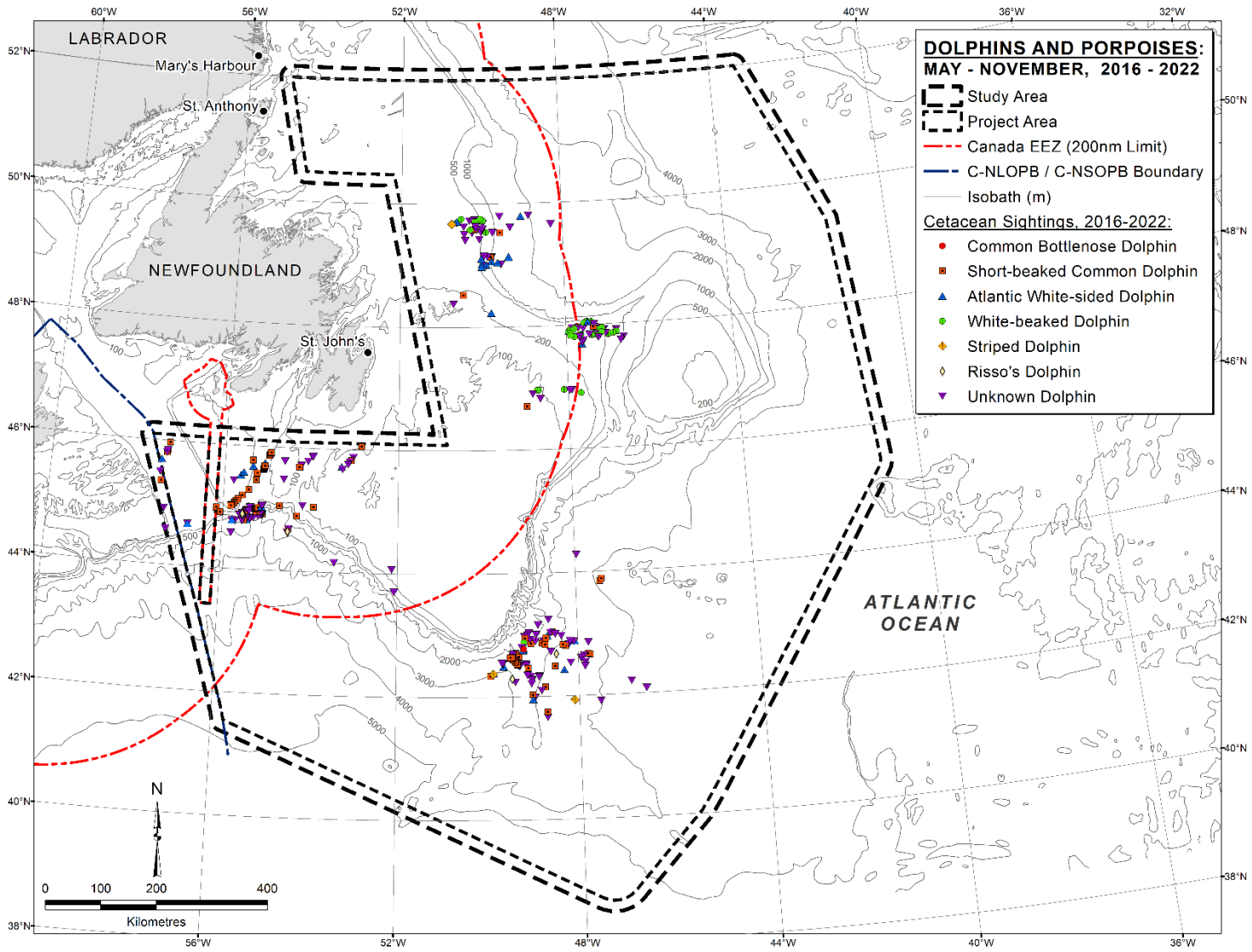


Figure 4.60. Dolphin and porpoise sightings in the Study Area from May–November 2016–2022 (compiled from multiple sightings databases, as described in Section 4.5.1).

Common dolphins have been regularly sighted during seismic monitoring programs offshore Newfoundland including in recent years. Fifteen groups totalling 182 common dolphins were seen during a 2022 marine mammal monitoring program off the southeastern Grand Banks in deep waters (Bishop and Lang 2022). Common dolphins were also seen (6 sightings totalling 95 individuals) during the 2021 marine mammal monitoring for the MKI seismic surveys located on the Orphan Basin, Flemish Pass, and Jeanne d'Arc Basin (Bishop and Lang 2021). In 2020, during a 3D seismic survey in the Orphan Basin region, one sighting of six short-beaked common dolphins was seen (Penney-Belbin 2020a). In that same year, 23 sightings of short-beaked common dolphin totalling 566 individuals were reported during a 3D seismic survey south of the Grand Banks, and acoustic detections were also made (Penney-Belbin 2020b). During the ESRF study in August 2017, 57 sightings were made in the southwestern portion of the Study Area (Smith et al. 2020). Oyarbide et al. (2023) reported interactions of short-beaked common dolphins with deep-water trawling vessels offshore Newfoundland during summer 2007 along the eastern edge of the Grand Banks and Flemish Pass.

White-beaked Dolphin

Based on newly available sightings databases, there have been 45 sightings (726 individuals) of white-beaked dolphins in the Study Area (see Table 4.22; Figure 4.60). Most sightings occurred during July. The white-beaked dolphin is considered common in the Study Area and was the most frequently and numerous species sighted during the NAISS in 2016 (Lawson and Gosselin 2018). Likewise, white-beaked dolphins have been regularly seen during seismic monitoring programs in the Study Area in recent years (Bishop and Lang 2021, 2022). Based on year-round habitat-density modeling, Roberts et al. (2023) showed that white-beaked dolphins are expected to occur throughout the Study Area with densities as high as 1 individual/100 km^2. Distribution models by Gomez et al. (2020) showed relatively low occurrence rates throughout the Study Area, except in the Flemish Pass.

Atlantic White-sided Dolphin

Based on newly available sightings databases, there have been 84 sightings (1575 individuals) of white-sided dolphins in the Study Area (see Table 4.22; Figure 4.60). Sightings occurred primarily during July–August. Based on habitat-density modelling by Roberts et al. (2023) and Mannocci et al. (2017), Atlantic white-sided dolphins are likely to occur throughout the Study Area year-round, with densities as high as 63 individuals/100 km^2 in July and August; density estimates were typically higher in the southern part of the Study Area. Similarly, distribution models by Gomez et al. (2020) showed relatively high occurrence rates during summer and fall throughout most of the Study Area, except for Orphan Knoll and Flemish Cap. Atlantic white-sided dolphins are considered common in the Study Area as further evidenced by sightings made during seismic monitoring (Penney-Belbin 2020b; Bishop and Lang 2021, 2022) and longer-term acoustic monitoring programs (Delarue et al. 2018).

Common Bottlenose Dolphin

Two morphologically and genetically distinct stocks of common bottlenose dolphins occur in the NW Atlantic, referred to as the coastal and offshore forms (Hoelzel et al. 1998; Costa et al. 2022). Only the offshore form is expected to occur in the Study Area. Based on newly available sightings databases,

there have been two bottlenose dolphin sightings (45 individuals) in the Study Area (see Table 4.22; Figure 4.60); they occurred during May and August. Based on habitat-density modeling, Roberts et al. (2023) and Mannocci et al. (2017) reported low densities throughout the Study Area, with higher year-round densities (up to 6.3 dolphins/100 km^2) in deeper, slope waters of the Study Area. Overall, the common bottlenose dolphin is considered uncommon in the Study Area.

Risso's Dolphin

Based on newly available sightings databases, there have been 14 sightings (90 individuals) of Risso's dolphins in the Study Area (see Table 4.22); sightings have occurred during August along the southern edge of the Grand Banks (see Figure 4.60). There have been limited sightings of this species during recent seismic monitoring programs offshore Newfoundland (Penney-Belbin 2020b; Bishop and Lang 2022). Based on habitat-density modeling, Roberts et al. (2023) and Mannocci et al. (2017) predicted the highest year-round densities (up to 25 dolphins/100 km^2) in the deeper, offshore waters of the Study Area, in particular, along the southeastern margin of the Grand Banks. Overall, Risso's dolphins are considered rare in the Study Area.

Killer Whale

Stable isotope analyses of killer whale specimens from the NW Atlantic indicate that there may be different ecotypes within this population with dietary and morphological differences (Matthews et al. 2021a,b). For example, high scarring rates on humpback whales indicate that killer whales may preferentially feed on marine mammals off Newfoundland (McCordic et al. 2014). The Northwest Atlantic/Eastern Arctic population is currently under consideration for addition to Schedule 1 of SARA (GC 2025) and was assessed as *special concern* by COSEWIC (COSEWIC 2008).

Based on newly available sightings databases, there have been nine sightings (at least 41 individuals) of killer whales in the Study Area (see Table 4.22; Figure 4.59). Most sightings off NL occur during May–September (Lawson and Stevens 2013). Based on habitat-density modelling, Roberts et al. (2023) predicted very low year-round densities (≤0.0025 individuals/100 km^2) in the southern part of the Study Area, and slightly higher densities (up to 0.063 individuals/100 km^2) north of 46°N. Killer whales are considered uncommon in the Study Area.

Killer whales that were outfitted with satellite tracking devices off northern Baffin Island during summer 2009 travelled southward and arrived in Newfoundland waters in the fall (Lefort et al. 2020), passing through the eastern portion of the Study Area. Matthews et al. (2021a,b) reported that killer whales occur off NL throughout the year, and there were several stranding records for Newfoundland, with the most recent one in 2002.

Killer whales have been sighted in small numbers during seismic monitoring programs offshore Newfoundland in recent years (Holst and Lang 2014; Thomas et al. 2014; Keats 2015. Penney-Belbin 2020a; Bishop and Lang 2021).

During acoustic monitoring in the Study Area during August 2015–July 2017, killer whale vocalizations were primarily recorded during the summer and fall; in the southwestern Study Area

and on the Grand Banks, killer whale vocalizations were also detected during April 2016 (Delarue et al. 2018).

Long-finned Pilot Whale

Long-finned pilot whales are the most commonly recorded odontocete (191 sightings, 2051 individuals in the newly available sightings databases) in the Study Area (see Table 4.22; Figure 4.59); sightings have been reported year-round but predominantly occur during July and August. This species has been regularly detected during recent seismic monitoring programs in slope and basin areas of the Study Area (Penney-Belbin 2020a,b; Bishop and Lang 2021, 2022). Likewise, 33 sightings were made in the southwestern portion of the Study Area during August 2017 (Smith et al. 2020). Roberts et al. (2023) and Mannocci et al. (2017) modelled year-round densities of pilot whales off Newfoundland, with highest densities in deeper, offshore areas (in particular slope waters), with densities up to 25 individuals/100 km^2, and low densities (≤1 individual/100 km^2) on the Grand Banks. Similarly, distribution models by Gomez et al. (2020) showed relatively high occurrence rates from spring through fall in the deep waters of the Study Area. Long-finned pilot whales are considered common in the Study Area.

Oyarbide et al. (2023) reported interactions of pilot whales with deep-water trawling vessels offshore Newfoundland during summer 2007 along the eastern edge of the Grand Banks and Flemish Pass. Acoustic monitoring also indicates that the Flemish Pass and southwestern edge of the Grand Banks throughout the year (Delarue et al. 2018; Kowarski et al. 2021).

Harbour Porpoise

Based on newly available sightings databases, there have been two sightings (at least five individuals) of harbour porpoises in the Study Area (see Table 4.22). Both sightings occurred in July. Harbour porpoises are generally considered uncommon in the offshore regions of the Study Area, although Roberts et al. (2023) and Mannocci et al. (2017) reported year-round densities (up to 40 individuals/100 km^2) on the northeastern Grand Banks. Distribution models by Gomez et al. (2020) showed relatively high occurrence rates during summer near the Flemish Pass and to the west and south of the Orphan Knoll.

Olsen et al. (2022) reported movement of a tagged harbour porpoise from western Greenland through the Study Area; the animal traveled in deep waters through the Flemish Pass. Harbour porpoise clicks were detected throughout the year on the Grand Banks, and during summer-fall in the northwestern portion of the Study Area (Delarue et al. 2018).

4.5.1.3 True Seals (Phocids)

Four seal species (harbour, grey, harp, and hooded seals) regularly occur in or near the Study Area (see Table 4.20; Figure 4.61). Given their preference for nearshore areas, grey and harbour seals are likely to be uncommon in the Study Area. Roberts et al. (2023) predicted combined seal densities of 6.3–10 seals/100 km^2 in shallow waters of the Study Area, and densities of 0.40–0.63 seals/100 km^2 in deep, offshore waters of the Study Area. These density estimates should be treated cautiously as they

were derived based primarily on survey effort offshore the eastern U.S. and NS with most sightings consisting of grey and harbour seals (Roberts et al. 2023).

Harbour Seal

There are five subspecies of harbour seal, one of which, the Northwest Atlantic harbour seal, occurs along the east coast of Canada (Liu et al. 2022). Based on newly available sighting data (see Table 4.22), there were no harbour seals recorded in the Study Area during May–November.

Aerial surveys conducted in July and August 2021 documented almost 3000 harbour seals in multiple coastal locations (beyond the Study Area) along the south coast of Newfoundland (Hamilton et al. 2023).

Grey Seal

There is a single population of grey seals in Canada divided into two herds –the Scotian Shelf and the Gulf of St. Lawrence (DFO 2022b). The growth rate of the population declined by 1.5% annually between 2016 and 2021, with a population size in 2021 estimated at 366,400 (DFO 2022b). Tagged grey seals were found to occur adjacent to the Study Area along the Laurentian Channel and the Scotian Shelf from June–October (Nowak et al. 2020). At least one male was documented to have traveled through the southern Study Area along the edge of the Grand Banks during fall. Their foraging behaviour appears to be associated with chlorophyll-a concentrations. Based on newly available sighting data, there was one grey seal recorded in the Study Area during May–November (Figure 4.61). Aerial surveys conducted in July and August 2021 documented 380 grey seals in multiple coastal locations (beyond the Study Area) along the south coast of Newfoundland (Hamilton et al. 2023).

Harp Seal

Harp seals pup in the Gulf of St. Lawrence and the Front off Newfoundland, west of the Study Area, during February and March (Stenson et al. 2020). During April and/or May, older harp seals form large moulting concentrations off southern Labrador /northeastern Newfoundland at the southern edge of the seasonal pack ice and in the northern Gulf of St. Lawrence, then eventually migrate northward to summer feeding grounds in the Arctic (DFO 2020b; Stenson et. al 2020). In 2017, 96% of harp seals pups (714,600) were born off the northeastern coast of Newfoundland (Front), an additional 18,300 pups were born in the southern Gulf of St. Lawrence, and another 13,600 pups were born in the northern Gulf of St. Lawrence, totaling 746,500 pups (DFO 2020b). The modeled pup production estimate for 2019 was 1.4 million, with a total population size of 7.6 million; the population size was based on a population model that included pup production estimates, annual estimates of age-specific reproductive rates, and removals and ice related mortality up to 2019 (DFO 2020b).

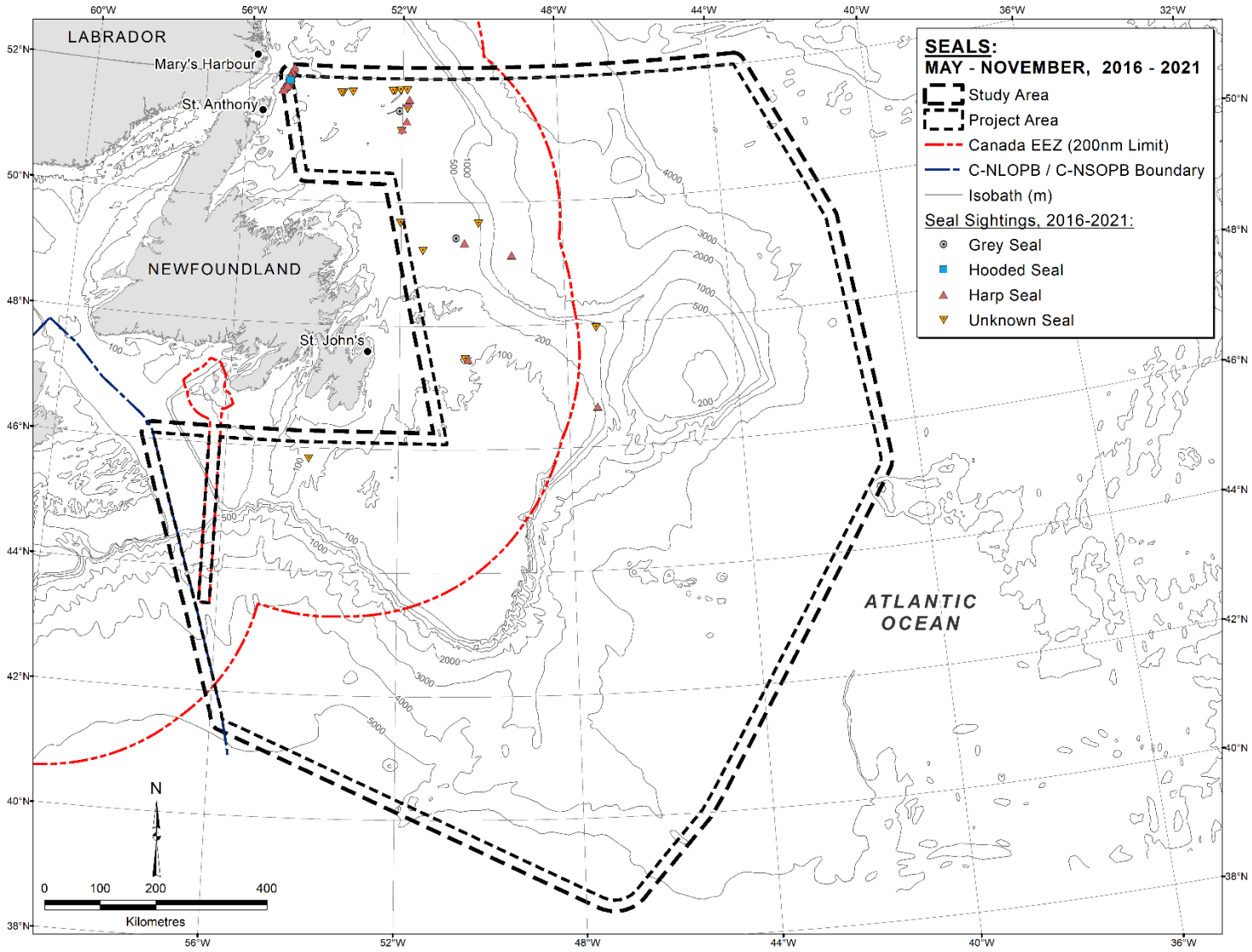


Figure 4.61. Seal records in the Study Area during May–November 2016–2021 (compiled from multiple sightings databases, as described in Section 4.5.1).

The harp seal population appears to have been relatively stable since the mid-1990s but has been increasing in recent years, likely due to higher reproductive rates and lower removals. Inter-annual fluctuations in reproductive rates of harp seals have increased over the previous decade. This change can be explained by population size approaching carrying capacity and ice conditions and/or prey availability affecting reproductive rates. At the current low levels of harvest, the Northwest Atlantic harp seal population is expected to continue to increase until the middle of the century (Hammill et al. 2021). Climate change is having an impact on ice-cover; the Gulf of St. Lawrence and the NE Newfoundland area is expected to be ice-free by the end of the century. This will have a negative impact on harp seals unless new areas for pupping are found north of current whelping areas (Hammill et al. 2021). Declines in sea ice associated with climate change may cause harp seals to use whelping areas farther to the north (Stenson and Hammill 2014).

Based on newly available sighting data, there were 153 harp seal records (totalling 413 seals) in the Study Area during May–November (see Figure 4.61). Harp seal calls were recorded during February and March on the northeastern edge of the Grand Banks (Delarue et al. 2018), which coincides with the whelping period.

Hooded Seal

There are limited sighting records of hooded seals in the Study Area during the summer and fall when seismic operations will likely occur. During spring and late-fall/winter, hooded seals outfitted with satellite relay data loggers showed movements throughout the Study Area during 2004–2008 (Andersen et al. 2013a,b, 2014). Andersen et al. (2013a) suggested that hooded seals prefer areas with topographic and oceanographic conditions off the coast of Newfoundland that produce good feeding conditions. During fall/winter, males showed greater search effort in areas with complex seabed relief, including areas in the Flemish Cap; whereas females spent more effort along the Labrador Shelf. Juveniles occurred off the east coast of Newfoundland between the Grand Banks and the Flemish Cap during spring. There is only one record of hooded seals (one seal) in the Study Area based on newly available data (see Figure 4.61).

4.5.2 Marine Mammal Data Gaps Identified in Relevant SEAs

The following data gaps associated with the Marine Mammal VC were identified in Section 3.5.7 in C-NLOPB (2010).

- Distribution and abundance of marine mammals;
- Potential migration routes and foraging areas of marine mammals are poorly understood;
- Basic life history characteristics of marine mammals which leads to uncertainty in the global and regional abundance estimates and population trends for many marine mammal species;
- Identification of marine mammal critical habitat; and
- Most available data on marine mammal and sea turtle species occurrence are opportunistic or incidental in nature (i.e., few directed surveys).

The following data gap associated with the Marine Mammal VC was identified in Section 6.1.6 in C-NLOPB (2014).

- Occurrence, abundance, and distribution of marine mammals is not available for all locations and times in the Study Area.

The Regional Assessment (IAAC 2020) did not identify specific data gaps for the Marine Mammal VC but acknowledged that the DFO marine mammal sighting database could not be used to derive densities or abundance estimates.

Although there have been some newly acquired sightings data since publication of the SEAs and Regional Assessment, the data gaps noted above are still relevant and limit the certainty of impact predictions—see Section 5.7.7.

4.6 Sea Turtle VC

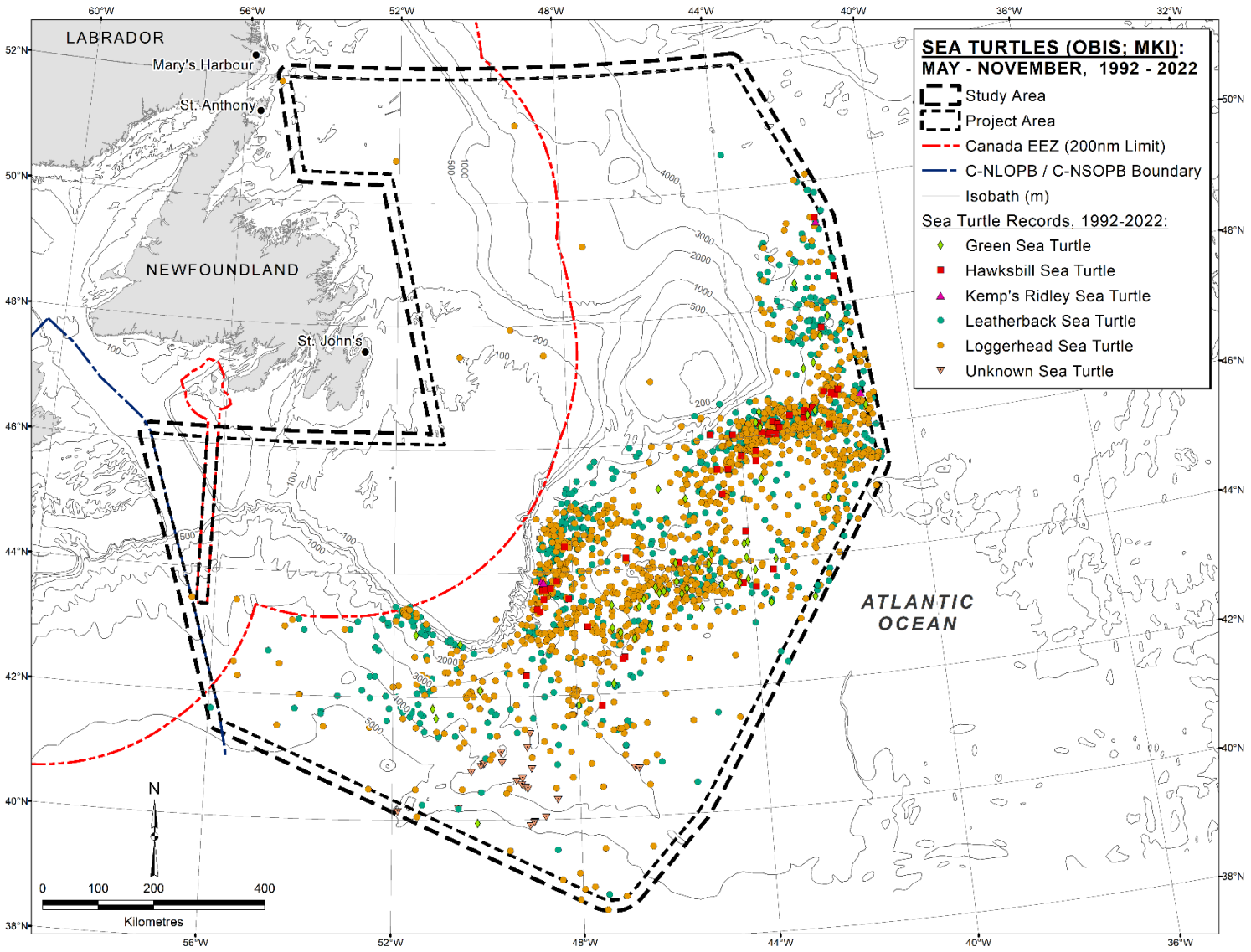
Five species of sea turtles have been reported in Newfoundland waters; however, only three are considered likely to occur in the Study Area—the leatherback, loggerhead, and green sea turtle (Table 4.23). Kemp's ridley sea turtle (*Lepidochelys kempii*) and hawksbill sea turtle (*Eretmochelys imbricata*) are considered unlikely to occur in the Study Area and are not discussed further. Leatherback and loggerhead sea turtles have an *Endangered* status under Schedule 1 of SARA. The Sea Turtle VC has been described in Section 3.6 in C-NLOPB (2010), Section 4.2.3 in C-NLOPB (2014), and Section 5.4 in IAAC (2020); the information provided here [and in Section 4.7] updates these documents.

Table 4.23. Sea turtles with reasonable likelihood of occurrence in the Study Area.

Species	Study Area		Habitat	SARA Status [a]	COSEWIC Status [b]
	Occurrence	Season			
Leatherback Sea Turtle (*Dermochelys coriacea*) Atlantic population	Rare	April–December	Shelf & pelagic	E	E
Loggerhead Sea Turtle (*Caretta caretta*)	Rare	Summer and fall	Pelagic	E	E
Green Sea Turtle (*Chelonia mydas*)	Rare	Summer	Pelagic	NS	LPC

[a] Species designation under Schedule 1 of SARA (GC 2025).
[b] Species assessment by COSEWIC (COSEWIC 2025).
Notes: E = Endangered; NS = No Status; LPC = Low-priority Candidate.

The OBIS sighting database (1992–2018) and recent seismic monitoring reports (Penney-Belbin et al. 2020a,b; Bishop and Lang 2021, 2022) were reviewed and used to map sea turtle sightings (Figure 4.62), which updates information presented in the SEAs and regional drilling EA. Sightings data, representing 2586 records, were extracted for the May–November period when seismic surveys may occur. Most (2000+) of the OBIS records for sea turtles are from NOAA Southeast Fisheries Science Center (SEFSC) fisheries logbooks (which presumably primarily represent fisheries by-catch). There were ~400 separate fisheries bycatch records; 114 telemetry records (from 112 unique telemetry tags/turtles); and 25 visual sightings during an academic research cruise in 2004.



Source: OBIS (2023) and MKI seismic monitoring programs (Penney-Belbin et al. 2020a,b; Bishop and Lang 2021, 2022).

Figure 4.62. Sea turtle sightings in the Study Area during May–November 1992–2022.

4.6.1 Green Sea Turtle

Green sea turtles are considered rare in most of the Study Area. Based on the OBIS database, there were 47 green sea turtle records from 1992–2018 in the southern and eastern portions of the Study Area with the vast majority in waters depths >4000 m (see Figure 4.52). Most records were from July through September (~79% of records) and from 1992–1994 (~80% of records).

4.6.2 Sea Turtle Data Gaps Identified in Relevant SEAs

The following data gaps associated with the Sea Turtle VC were identified in Section 3.6.4 in C-NLOPB (2010):

- Distribution and abundance of sea turtles;
- Potential migration routes and foraging areas of sea turtles are poorly understood;
- Basic life history characteristics of sea turtles which leads to uncertainty in the global and regional abundance estimates and population trends for sea turtle species;
- Identification of sea turtle critical habitat; and
- Most available data on sea turtle species occurrence are opportunistic or incidental in nature (i.e., few directed surveys).

The following data gap associated with the Sea Turtle VC was identified in Section 6.1.6 in C-NLOPB (2014):

- Occurrence, abundance, and distribution of sea turtles is not available for all locations and times in the Study Area.

The Regional Assessment (IAAC 2020) did not identify specific data gaps for the Sea Turtle VC but acknowledged that the DFO sighting database could not be used to derive densities or abundance estimates.

Although there have been some newly acquired sightings data since publication of the SEAs and Regional Assessment, the data gaps noted above are still relevant and limit the certainty of impact predictions—see Section 5.7.8.

4.7 Species at Risk VC

The Species at Risk (SAR) VC has been described in Section 3.7 in C-NLOPB (2010), Sections 4.2.1.7, 4.2.2.5, and 4.2.3.5 in C-NLOPB (2014), Sections 3.2.1.5, 3.2.2.4, and 3.2.3 in IAAC (2020), and Section 4.6 in LGL (2018). The following sections provide an overview of new information for SAR in the Study Area released since the above reports were published. Relevant data gaps identified in C-NLOPB (2010, 2014) and IAAC (2020) are also addressed in terms of current status.

4.7.1 Species at Risk in the Study Area

The DFO Species at Risk Critical Habitat 2025 layer in IAAC (2020) indicates the boundaries of critical habitat for SAR with *Endangered* or *Threatened* at-risk status under the *Species at Risk Act* (SARA) in Canada (see Section 4.8). The Species at Risk data layer in the Canada Marine Planning Atlas (DFO 2025f) also indicates critical habitat in addition to distribution patterns for aquatic species at risk (updated in 2024).

The SARA was assented to in December 2002, with certain provisions coming into force in June 2003 (e.g., independent assessments of species/populations by the Committee on the Status of Endangered Wildlife in Canada [COSEWIC]) and June 2004 (e.g., prohibitions against harming or harassing species/populations with either *Endangered* and *Threatened* status or damaging or destroying their critical habitat). The information presented in this subsection is current as of May 2025 (COSEWIC 2025; GC 2025). Species/populations listed as either *Endangered* or *Threatened* under Schedule 1 of SARA – Canada's official list of wildlife species/populations at risk – have immediate legal implications. Once a species/population is designated, measures to protect and recover that species/population are implemented. Four fish species/populations, two seabird species, three cetacean species/populations, and two sea turtle species that have the potential to occur in the Study Area are legally protected under SARA (see Table 4.21). Although the Atlantic salmon population from the Inner Bay of Fundy is among those four fish species, they are unlikely to be present in the Study Area. In addition, Sowerby's beaked whale, the Atlantic population of fin whale, the Eastern population of Barrow's Goldeneye, the Eastern population of Harlequin Duck, Red-necked Phalarope, and Atlantic wolffish have *Special Concern* status under Schedule 1 of SARA. However, Barrow's Goldeneye and Harlequin Duck tend to prefer coastal habitats and, therefore, are less likely to occur in the offshore Study Area. Species/populations that potentially occur in the Study Area and are considered at risk but have not received specific legal protection (i.e., prescribed penalties and legal requirements for recovery strategies and plans) under SARA are also listed in Table 4.24, as are species/populations assessed as *Endangered*, *Threatened*, or *Special Concern* by COSEWIC.

Table 4.24. SARA-listed and COSEWIC-assessed marine species that potentially occur in the Study Area.

SPECIES		SARA [a]			COSEWIC [b]		
Common Name	Scientific Name	E	T	SC	E	T	SC
Marine Fish							
White Shark Atlantic population	*Carcharodon carcharias*	S1			X		
Atlantic Salmon Inner Bay of Fundy population	*Salmo salar*	S1			X		
Anticosti Island population [c]					X		
Outer Bay of Fundy population [c]					X		
Eastern Cape Breton population [c]					X		
Nova Scotia Southern Upland population [c]					X		
South Newfoundland population [c]						X	
Quebec Eastern North Shore population [c]							X
Quebec Western North Shore population [c]							X
Inner St. Lawrence population [c]							X
Gaspé-Southern Gulf of St. Lawrence population [c]							X
Northern Wolffish	*Anarhichas denticulatus*		S1			X	
Spotted Wolffish	*Anarhichas minor*		S1			X	
Atlantic Wolffish	*Anarhichas lupus*			S1			X

SPECIES		SARA [a]			COSEWIC [b]		
Common Name	Scientific Name	E	T	SC	E	T	SC
Atlantic Cod Laurentian North Population [c]	*Gadus morhua*				X		
Newfoundland and Labrador population [c]					X		
Atlantic Bluefin Tuna	*Thunnus thynnus*				X		
Deepwater Redfish Gulf of St. Lawrence - Laurentian Channel population [c]	*Sebastes mentella*				X		
Northern population [c]						X	
Porbeagle Shark [c]	*Lamna nasus*				X		
Roundnose Grenadier [c]	*Coryphaenoides rupestris*				X		
Cusk	*Brosme brosme*				X		
Smooth Skate Funk Island Deep population [c]	*Malacoraja senta*				X		
Laurentian-Scotian population [c]							X
Winter Skate Eastern Scotian Shelf-Newfoundland population [c]	*Leucoraja ocellata*				X		
Shortfin Mako Shark Atlantic population [c]	*Isurus oxyrinchus*				X		
Acadian Redfish Atlantic population [c]	*Sebastes fasciatus*					X	
American Plaice Newfoundland and Labrador population [c]	*Hippoglossoides platessoides*					X	
Maritime population [c]						X	
White Hake Atlantic and Northern Gulf of St. Lawrence population [c]	*Urophycis tenuis*					X	
Lumpfish [c]	*Cyclopterus lumpus*					X	
American Eel [c]	*Anguilla rostrata*					X	
Atlantic Sturgeon Maritimes populations [c]	*Acipenser oxyrinchus*					X	
Basking Shark Atlantic population [c]	*Cetorhinus maximus*						X
Spiny Dogfish Atlantic population [c]	*Squalus acanthias*						X
Thorny Skate [c]	*Amblyraja radiata*						X
Greenland Shark [c]	*Somniosus microcephalus*						X
Atlantic Mackerel	*Scomber scombrus*						HPC
Yellowtail Flounder	*Limanda ferruginea*						HPC
Marine-associated Birds							
Ivory Gull	*Pagophila eburnea*	S1			X		
Red Knot *rufa* subspecies Tierra del Fuego/Patagonia wintering population	*Calidris canutus rufa*	S1			X		
Southeastern USA/Gulf of Mexico/Caribbean wintering population [c]					X		
Northeastern South America wintering population [c]							X
Harlequin Duck Eastern population	*Histrionicus histrionicus*			S1			X
Barrow's Goldeneye Eastern population	*Bucephala islandica*			S1			X
Red-necked Phalarope	*Phalaropus lobatus*			S1			X
Hudsonian Godwit [c]	*Limosa haemastica*					X	
Leach's Storm Petrel Atlantic population [c]	*Oceanodroma leucorhoa*					X	
Northern Gannet	*Morus bassanus*						HPC
Bermuda Petrel	*Pterodroma cahow*						HPC

SPECIES		SARA [a]			COSEWIC [b]		
Common Name	Scientific Name	E	T	SC	E	T	SC
Arctic Tern	*Sterna paradisaea*						HPC
Black-legged Kittiwake	*Rissa tridactyla*						MPC
Great Black-backed Gull	*Fratercula arctica*						MPC
Atlantic Puffin	*Fratercula arctica*						LPC
Glaucous Gull	*Larus hyperboreus*						LPC
Marine Mammals							
Blue Whale Atlantic population	*Balaenoptera musculus*	S1			X		
North Atlantic Right Whale	*Eubalaena glacialis*	S1			X		
Northern Bottlenose Whale Scotian Shelf population	*Hyperoodon ampullatus*	S1			X		
Davis Strait-Baffin Bay-Labrador Sea population [c]							X
Fin Whale Atlantic population	*Balaenoptera physalus*			S1			X
Sowerby's Beaked Whale	*Mesoplodon bidens*			S1			X
Harbour Porpoise Northwest Atlantic population	*Phocoena phocoena phocoena*						X
Sei Whale Atlantic population [c]	*Balaenoptera borealis*				X		
Killer Whale Northwest Atlantic/Eastern Arctic population [c]	*Orcinus orca*						X
Atlantic Walrus Central / Low Arctic population [c]	*Odobenus rosmarus rosmarus*						X
Bearded Seal	*Erignathus barbatus*						HPC
Hooded Seal	*Cystophora cristata*						HPC
Harp Seal	*Phoca groenlandica*						HPC
Sperm Whale	*Physeter macrocephalus*						MPC
Cuvier's Beaked Whale	*Ziphius cavirostris*						MPC
Sea Turtles							
Leatherback Sea Turtle Atlantic population	*Dermochelys coriacea*	S1			X		
Loggerhead Sea Turtle	*Caretta caretta*	S1			X		
Green Sea Turtle	*Chelonia mydas*						LPC

[a] SARA website (GC 2025) accessed May 2025.
[b] COSEWIC website (COSEWIC 2025), accessed May 2025.
[c] Under consideration for addition to Schedule 1 of SARA.
Notes:
E = Endangered; T = Threatened; SC = Special Concern; S = Schedule; HPC = High Priority Candidate; MPC = Mid Priority Candidate; LPC = Low Priority Candidate.

Under SARA, a 'recovery strategy' and corresponding 'action plan' must be prepared for *Endangered*, *Threatened*, and *Extirpated* species/populations under Schedule 1 of SARA. A 'management plan' must be prepared for species/populations listed as *Special Concern* under Schedule 1 of SARA. Final recovery strategies have been prepared for nine species/populations currently with *Endangered* or *Threatened* status under Schedule 1 which may occur in the Study Area: (1) northern wolffish (DFO 2020c); (2) spotted wolffish (DFO 2020c); (3) Inner Bay of Fundy population of Atlantic salmon (DFO 2010b); Ivory Gull (ECCC 2014); (4) Red Knot (ECCC 2017a); (5) Atlantic population of blue whale (Beauchamp et al. 2009); (6) North Atlantic right whale (DFO 2014a); (7) Scotian Shelf population of northern bottlenose whale (DFO 2016b); (8) Atlantic population of leatherback sea turtle (ALTRT 2006); and (9) loggerhead sea turtle (DFO 2020d). An amended recovery strategy is in

preparation for leather back sea turtles (DFO 2022c). A proposed recovery strategy for white shark (Atlantic population) has been released but has not yet been finalized (DFO 2024f).

Action plans have been released for (1) northern wolffish (DFO 2020e); (2) spotted wolffish (DFO 2020e); (3) Inner Bay of Fundy population of Atlantic salmon (DFO 2019b); (4) Atlantic population of leatherback sea turtle (DFO 2020f); (5) Atlantic population of blue whale (DFO 2020g); (6) North Atlantic right whale (DFO 2021b); and (7) Scotian Shelf population of northern bottlenose whale (DFO 2017c).

Management plans have been prepared for (1) Atlantic wolffish (DFO 2020c); (2) Eastern population of Harlequin Duck (ECCC 2007); (3) Eastern population of Barrow's Goldeneye (ECCC 2013); (4) Red-necked Phalarope (ECCC 2023); (5) Red Knot (ECCC 2017a); (6) Atlantic population of fin whale (DFO 2017a); and (7) Sowerby's beaked whale (DFO 2017b).

MKI acknowledges the possibility of other marine species/populations receiving *Endangered* or *Threatened* status under Schedule 1 of SARA throughout the Project (e.g., species/populations currently under consideration for addition to Schedule 1) and will monitor SAR updates/issues through the Canadian Association of Petroleum Producers (CAPP), law gazettes, SARA and COSEWIC websites (COSEWIC 2025; GC 2025), and communication with DFO and ECCC. MKI will adaptively manage any issues that may arise in the future and comply with the relevant SARA recovery strategy and action plan regulations.

4.7.2 Profiles of Marine Species/Populations with *Endangered* or *Threatened* Status under Schedule 1 of SARA

The at-risk status of all species/populations profiled below are current as of May 2025.

4.7.2.1 Fishes

Four fish species/populations are listed as *Endangered* or *Threatened* under Schedule 1 of SARA: (1) Atlantic salmon (Inner Bay of Fundy population); (2) white shark (Atlantic population); (3) northern wolffish; and (4) spotted wolffish. These four species are profiled in this section. Several of the fish species/populations that are included in Table 4.24 that are listed as *Special Concern* under SARA (e.g., Atlantic wolffish) or that are important for cultural, economic, and/or ecological reasons (e.g., Atlantic cod) are described in Section 4.2 above.

Atlantic Salmon (Inner Bay of Fundy Population)

Many populations of Atlantic salmon are undergoing a drop in abundance with low return rates to their natal rivers to spawn (Mills et al. 2013). Of the 16 metapopulations/DUs in Eastern Canada, COSEWIC (2010) has assessed five as *Endangered*, one as *Threatened*, and four as *Special Concern* (see Table 4.24). Among these, the Inner Bay of Fundy population is the only Atlantic salmon population with legal protection as *Endangered* under Schedule 1 of SARA. However, the remaining nine assessed populations are currently under consideration for addition to SARA (GC 2025; see Table 4.24).

All the Atlantic salmon populations mentioned above have the potential to occur in the Study Area during at least one life stage in the marine environment, most likely as a transitory presence during migration or feeding when conditions are favourable. Evidence from pop-up satellite tags deployed on Atlantic salmon Kelts from the Outer Bay of Fundy suggests that after leaving the Gulf of Maine, they moved through the Scotian Shelf and Laurentian Channel in June, then across the Grand Banks of Newfoundland and up along the coast of Labrador in July (Lacroix 2013). Based on a recent study, the thermal influence of the Labrador Current shapes the homing migration routes of North American Atlantic salmon traveling from the waters off southern Greenland to North America, creating two distinct pathways: a primary route southward along the shelf break, or a secondary route crossing onto the Newfoundland shelf near Funk Island Bank (Dufresne et al. 2025). During May and June, salmon migrate using either the shorter path briefly along the shelf or the longer route through the Flemish Pass, indicating a presence within the Study Area (Dufresne et al. 2025).

White Shark (Atlantic Population)

The Atlantic population of white shark is currently listed as *Endangered* under Schedule 1 of SARA and was assessed as *Endangered* by COSEWIC. The species is highly mobile, and individuals that occur within the Study Area are likely seasonal migrants belonging to a widespread northwest Atlantic population. It occurs in both inshore and offshore waters, ranging in depth from just below the surface to just above the seabed, down to a depth of at least 1,280 m (LGL 2015; COSEWIC 2021). See Section 4.6.1 of LGL (2015) for further description of this population.

An adult female white shark, 'Katharine,' tagged initially in August 2013 off Cape Cod, was present within the southern portion of the Study Area from November 2015 through February 2016 (OCEARCH 2023). A second adult female, 'Lydia,' tagged initially in March 2013 off Jacksonville, Florida, was present within the southern and eastern portions of the Study Area from December 2014–February 2015 (OCEARCH 2023). Two sub-adult females, Caroline and Helena, tagged initially in Hilton Head, South Carolina, and an adult male, George, who was tagged in Nantucket, Massachusetts, were also recorded in the Study area during recent years (OCEARCH 2023).

Northern and Spotted Wolffishes

Northern and spotted wolffishes are listed/assessed as *Threatened* under Schedule 1 of SARA and by COSEWIC. Profiles of these species were provided in Section 4.6.1 of LGL (2015).

During DFO RV surveys conducted in the Study Area during May–November 2018–2022, northern and spotted wolffishes were caught primarily between 200 m and 1000 m depths within the northern, central, and southern portions of the Study Area (see Figures 4.36 and 4.38 in Section 4.3.7). Critical habitats for the northern and spotted wolffishes have been identified within the Gulf of St. Lawrence, the edge of the Grand Banks, and the Labrador Shelf (DFO 2020c). These critical habitats overlap with the Study Area (see Figure 4.65 in Section 4.8).

4.7.2.2 Marine-associated Birds

Two marine-associated birds that may occur in the Study Area are listed as *Endangered* under Schedule 1 of SARA: (1) Ivory Gull and (2) Red Knot. These species are profiled in this section. Detailed profiles for other bird species listed under Schedule 1 of SARA that may occur in the Study Area (see Table 4.24), including Harlequin Duck (Eastern population) and Barrow's Goldeneye (Eastern population), are available in Section 4.6 of LGL (2014) and/or Section 4.4 of this EA. Red Phalarope and Red-necked Phalarope are described in Section 4.4.2.5 of this EA.

Ivory Gull

Ivory Gull was profiled in Section 4.6.1 of LGL (2015) and Section 4.4.2.6 of this EA. According to tracking data, they are unlikely to occur within the majority of the Study Area but during the winter they may travel as far south as the northern portion of the Study Area, offshore northern and northeastern Newfoundland (Spencer et al. 2016).

Red Knot

Red Knot was profiled in Section 4.2.2.5 in Section 3.7.2.6 in C-NLOPB (2010) and in Section 4.2.2.5 in C-NLOPB (2014). Red Knot have been sighted at St. Pierre and Miquelon Islands during the latter portion of the Fall migration period; therefore, they are likely to fly over the Study Area during their southward migration (Baker et al. 2020).

4.7.2.3 Marine Mammals

There are three marine mammal species listed as *Endangered* under Schedule 1 of SARA that are known to occur in the Study Area: (1) blue whale (Atlantic population); (2) North Atlantic right whale; and (3) northern bottlenose whale (Scotian Shelf population). Marine mammal species listed as *Special Concern* under SARA and/or considered at risk by COSEWIC (e.g., Atlantic population of fin whale, Sowerby's beaked whale) were reviewed in Section 4.5 above. As required in the Scoping Document, only new and updated information available since publication of the SEAs (see Section 3.5 in C-NLOPB 2010 and Section 4.2.3 in C-NLOPB 2014) and regional drilling assessment (see Section 3.2.3 in IAAC 2020) is provided below.

Blue Whale

The Atlantic population of blue whale is listed/assessed as *Endangered* under Schedule 1 of SARA and by COSEWIC. Recently, whole genome sequencing was used to elucidate the poorly understood population structure of North Atlantic blue whales (Jossey et al. 2021). Despite the severe reduction in the population (due to whaling), North Atlantic blue whales have retained high genetic variability. The authors note that high genetic diversity within the species is promising for species recovery if low population numbers do not persist for an extended period. Knowledge of genetic diversity and structure is essential for developing conservation strategies for endangered species (Jossey et al. 2021).

Based on newly available sightings information (OBIS, DFO Maritimes, and Newfoundland seismic monitoring programs; May–November 2016–2022), there have been 21 blue whale sightings (totalling 24 whales) in the Study Area. Sightings have mainly occurred in slope waters of the Study Area (see Figure 4.58 in Section 4.5). Habitat-density modeling predicted year-round densities of 0.0016–0.0025 blue whales/100 km² in the Study Area (Roberts et al. (2023). These density estimates should be treated cautiously as they were derived based primarily on survey effort offshore the eastern U.S. and NS (Roberts et al. 2023). Overall, blue whale are considered uncommon in the Study Area (see Table 4.20 in Section 4.5).

One blue whale that was tagged in the St. Lawrence Estuary during November 2014 travelled close to the southwestern edge of the Study Area during March 2014. An additional blue whale that was tagged in the Estuary in September 2013 was recorded along the southern Grand Banks during December 2013, where it was likely foraging (Lesage et al. 2016, 2017). A separate individual tagged in the Gulf of St. Lawrence during September 2013 also travelled close to the southwestern edge of the Study Area during October 2013 (Lesage et al. 2016, 2017). Results from Lesage et al. (2016, 2017, 2018) suggest that underwater seamounts and the deep ocean structures along the shelf edge may be important habitats for blue whales.

Whitehead (2013) reported five sightings in Haldimand Canyon and nine in Shortland Canyon, at the edge of the Scotian Shelf near the Study Area. Blue whales have also been sighted along the northeastern edge of the Scotian Shelf and in the southern Laurentian Channel within and near the Study Area (Lesage et al. 2018; Gomez et al. 2020). During July 2012, sightings were made in and near the Study Area, including the southern Laurentian Channel and south of the Grand Banks (Ryan et al. 2013). In addition, two sightings of blue whales were made at Orphan Basin during August–September 2007 (Abgrall et al. 2008), and 49 sightings (totaling 53 individuals) were made during a 3D seismic program that occurred during June–September 2005 in the Laurentian Sub-basin (Moulton et al. 2006b).

Year-round acoustic detections have also been made in the southern parts of the Study Area (e.g., Clark 1995 *in* Lesage et al. 2018; Moors-Murphy et al. 2019; Delarue et al. 2018, 2022). When acoustic recorders were deployed off Newfoundland from May 2015–November 2017, blue whale were detected year-round throughout the Study Area, with the highest detection rates along the southern edge of the Grand Banks and in the Flemish Pass during fall and winter (Delarue et al. 2018, 2022). Based on high detection rates, Delarue et al. (2022) suggested that the Flemish Pass, as well as the Orphan Basin, may be important areas to the blue whale. Blue whale were also detected acoustically in the Flemish Pass during April–July 2021 by Kowarski et al. (2021). Blue whale vocalizations were also detected throughout the year in the deep waters along the northeastern edge of the Scotian Shelf (Davis et al. 2020; Wingfield et al. 2022).

Gomez et al. (2017) conducted species distribution modeling for blue whale and indicated that the most suitable habitats – and, therefore, priority areas for monitoring blue whales – are on the Scotian Shelf and the shelf break off southern Newfoundland, which are also areas that overlap with anthropogenic activities. Lesage et al. (2018) reported that the continental shelf edge off NS, southern Newfoundland, and the Grand Banks are important blue whale foraging areas. Similarly, based on information gathered from systematic surveys, opportunistic sighting platforms, acoustic monitoring,

and species distribution modelling, five potentially important areas for blue whale in the NW Atlantic outside the Gulf of St. Lawrence have been identified: (1) deep water areas along the continental slope of the Scotian Shelf; (2) deep water areas along the continental slope of the Grand Banks south of Newfoundland; (3) deep water areas of the Laurentian Channel; (4) shallower water areas off the SW coast of Newfoundland; and (5) shallower areas on the western Scotian Shelf (Moors-Murphy et al. 2019). Some of these areas overlap with the southwestern portion of the Study Area.

North Atlantic Right Whale

The North Atlantic right whale is listed/assessed as *Endangered* under Schedule 1 of SARA and by COSEWIC. The species has declined in abundance since 2010 (Pace et al. 2017; Pettis et al. 2023), and the most recent estimate for the entire western population is 340 whales (Pettis et al. 2023). NOAA declared an Unusual Mortality Event for North Atlantic right whales in 2017; as of November 2023, 121 individuals were affected (36 dead, 34 seriously injured, and 51 sub-lethally injured or ill); entanglements or vessel strikes were the primary causes of mortality, severe injury, and morbidity for most of these whales (NOAA 2023). All mortalities between 2003 and 2018 for which cause of death was known were attributed to vessel collision or entanglement (Sharp et al. 2019). However, Pace et al. (2021) cautioned that many deaths could go unseen; for example, observed carcasses only accounted for 36% of all estimated deaths during 1990–2017. In addition, poor body condition is thought to play a factor in the population decline (Christiansen et al. 2020). A profile of this species is provided in Section 4.6.1.3 of LGL (2015).

The North Atlantic right whale is expected to be rare in the Study Area (see Table 4.20 in Section 4.5). During 2017–2022, there were nine opportunistic sightings off the Newfoundland coast and one sighting near the Laurentian Channel recorded in the WhaleMap online database (Johnson et al. 2025b). Additionally, there was a recent sighting of two individuals during September 2023 on the Labrador Basin according to the WhaleMap database (Johnson et al. 2025b). The WhaleMap database also reported several acoustic detections that were made in the Cabot Strait (Johnson et al. 2025b). The DFO NS sightings database includes four confirmed sightings of at least 15 individuals in the Study Area, which occurred during 1999, 2000, 2002 and 2018. These sightings were made in the Laurentian Basin, and Grand Banks. Right whale sightings have also been made in the Laurentian Channel (Gomez-Salazar and Moors-Murphy 2014; DFO 2019c). During July 2016, one individual was seen off the southeastern Avalon Peninsula, outside of the Study Area (LGL, unpublished data). The occurrence of North Atlantic right whales within or near the Study Area largely depends on the availability of their prey, namely copepods of the genus *Calanus* (COSEWIC 2013). Recent studies suggest that rising ocean temperatures in the Gulf of St. Lawrence could potentially compromise the suitability of foraging grounds for right whales, shifting them farther east to shelf waters east of NL in search of dense *Calanus* sp. patches (Gavrilchuk et al. 2021; Hayes et al. 2022).

During acoustic monitoring off southern Newfoundland during 2017–2019, acoustic detections of North Atlantic right whale were made off southeastern Newfoundland, particularly in Placentia Bay, during the summer/early fall each year of monitoring (DFO 2020h). An unconfirmed right whale detection was made during October 2018 in the Flemish Pass, one unconfirmed vocalization was recorded at St. Pierre Bank on July 2018, and several unconfirmed vocalizations were reported for southwestern Newfoundland during the winter. Acoustic detections of right whale calls were also

made in Newfoundland waters during summer and fall, 2015–2017, including within the southern Study Area (Delarue et al. 2018, 2022; Durette-Morin et al. 2022). Although no detections were made on acoustic recorders off Eastern Newfoundland in the northern part of the Study Area, right whale calls were detected in the southern part of the Study Area (south of 48°N) on one day during September 2015, and on one day each month from August–December 2016; no calls were detected during 2017 (Durette-Morin et al. 2022).

Northern Bottlenose Whale

The Scotian Shelf population is listed/assessed as *Endangered* under Schedule 1 of SARA and by COSEWIC. A profile of northern bottlenose whale was provided in Section 4.6.1.3 of LGL (2015).

Northern bottlenose whale sightings within the Study Area during recent MKI seismic surveys and the DFO sightings database are summarized in Section 4.5 above (see Table 4.22). Sightings occur primarily in deeper waters and near the shelf break (Harris et al. 2013). Roberts et al. (2023) also predicted the highest year-round densities (0.1 whales/100 km^2) for deep, offshore waters of the Study Area. Northern bottlenose whale are expected to be uncommon in the Study Area (see Table 4.20).

Based on species distribution models, Gomez et al. (2017) indicated that the most suitable habitats – and, therefore, priority areas for monitoring of northern bottlenose whales – occur on the edges of the eastern Scotian Shelf and Newfoundland and Labrador shelves, canyons, and deep basins. Stanistreet et al. (2021) also suggested that important habitat for northern bottlenose whales may occur in slope areas extending from the Scotian Shelf to Newfoundland.

Acoustic recorders deployed off Newfoundland from 2015–2017 indicated that northern bottlenose whale occurrence was at its highest along the shelf break, mainly north of the Flemish Cap and off the southern Labrador coast, with nearly daily detections throughout the study period (Delarue et al. 2018). Northern bottlenose whales were also detected acoustically in the Flemish Pass during April–July 2021 by Kowarski et al. (2021). Acoustic evidence also indicates that the Scotian Shelf population occurs within the Gully and adjacent submarine canyons throughout most of the year, with peak detection during spring (Stanistreet et al. 2021).

Stanistreet et al. (2021) noted that the population structure of northern bottlenose whale occurring off eastern Canada is not completely known. Recent genetic analyses of tissues collected from northern bottlenose whales in the Flemish Pass and Orphan Basin suggest that these regions could be an area of mixing between the two known populations (i.e., Scotian Shelf and Davis Strait-Baffin Bay-Labrador Sea) and other unknown populations or possibly represent a new population (Feyrer et al. 2019).

4.7.2.4 Sea Turtles

Two sea turtle species/populations that have some likelihood of occurrence in the Study Area are listed as *Endangered* under Schedule 1 of SARA: (1) leatherback sea turtle; and (2) loggerhead sea turtle. Profiles of these species are provided in this section (see also Section 4.6 above).

Leatherback Sea Turtle

The Atlantic population of leatherback sea turtle is listed/assessed as *Endangered* under Schedule 1 of SARA and by COSEWIC. A profile for the leatherback sea turtle was provided in Section 4.6.1.4 of LGL (2015).

The most recent index abundance is estimated at 20,659 mature nesting females, utilizing consistently monitored beaches from the southeastern US through the Wider Caribbean (NMFS-USFWS 2020; DFO 2022c). These turtles migrate predictably into eastern Canadian waters, primarily from April–December, with peak occurrences in August (COSEWIC 2012; Mosnier et al. 2019). Their seasonal presence aligns with jellyfish prey abundance (Nordstrom et al. 2020).

There are 1045 Leatherback turtle sightings recorded in OBIS database within the Study Area between 1992 and 2014 and most of these sightings are in the eastern, southeastern, and southern portions of the Study Area off Flemish Cap and Grand Banks (OBIS 2025; see Figure 4.62 in Section 4.6). Most sightings were made in deeper waters in the southern Study Area during July–September. Additional records include a 2008 sighting in the Jeanne d'Arc Basin (Abgrall et al. 2009) and satellite-tagged turtles near/in the southwestern portion of the Study Area (e.g., DFO 2012, 2022c; Howard 2012; Dodge et al. 2014; Archibald and James 2016; Bond and James 2021; Wallace et al. 2023). Leatherback interactions with fisheries have also been documented for the Study Area (Hamelin et al. 2017; DFO 2020i).

Analyses (1946–2011 sightings; 2007 aerial surveys) suggest a progressive seasonal shift in leatherback distribution off Newfoundland: turtles arrive south/west of the Scotian Shelf in June, move eastward along NS in July–August, and reach southern/eastern Newfoundland shelves by August–September (Mosnier et al. 2019). Recent research identifies two primary Canadian foraging zones: 1) waters south/east of Newfoundland's Burin Peninsula (including Placentia Bay), and 2) the southeast Gulf of St. Lawrence/east of Cape Breton Island. A third potential zone exists southeast of Georges Bank for early/late season feeding (Mosnier et al. 2019; DFO 2020j). These areas are informing critical habitat designation in recovery planning (DFO 2020f).

Recent research efforts in Atlantic Canadian waters (e.g., Mosnier et al. 2019; DFO 2020j) have yielded new insight into the foraging and movements of leatherback sea turtles. These studies suggest two main high use feeding zones in Canadian waters: 1) the waters south and east of the Burin Peninsula, Newfoundland, including some of Placentia Bay; and 2) the southeast Gulf of St. Lawrence and waters off eastern Cape Breton Island. A third, possibly less significant, high use feeding area has also been identified east and southeast of Georges Bank, which could be relevant for the early or late feeding season (Mosnier et al. 2019; DFO 2020j). The information regarding high use feeding areas is being used to inform the identification of critical habitat in a forthcoming amended Recovery Strategy (DFO 2020f).

Foraging in NS and the Grand Banks is vital for population growth, supplying significant energy (Wallace et al. 2018; Mosnier et al. 2019). Leatherbacks feed visually on jellyfish during daylight, primarily within the top 30 m of the water column (DFO 2016c). Distribution models link their presence in eastern Canada to sea surface temperatures >15°C, flat bathymetry, low primary

productivity, sea surface height, and co-occurrence with ocean sunfish (another jellyfish predator; Mosnier et al. 2019).

DFO's (2022c) recovery goal focuses on increasing adult/sub-adult numbers in the NW Atlantic by reducing human-induced mortality in Canada, safeguarding foraging habitats, and monitoring distributions. The highest-ranked threat is bycatch in fishing gear, followed by marine pollution (plastics), harvesting, and coastal development (DFO 2020f). Entanglement risk is highest in fixed gear with surface lines and pelagic longlines along the Scotian Shelf edge, with interactions likely underreported (DFO 2022d). Enhanced monitoring of turtle-fishery interactions remains essential (DFO 2022c).

Loggerhead Sea Turtle

Loggerhead sea turtle is listed/assessed as *Endangered* under Schedule 1 of SARA and by COSEWIC. A profile for the loggerhead sea turtle was provided in Section 4.5.2.1 of LGL (2015).

Loggerhead sea turtles are documented in Atlantic Canadian waters ranging from Georges Bank to the southern Grand Banks (DFO 2020d). Within the specific Study Area, the DFO sightings database lists three occurrences: two observed in deep waters (>4000 m) near the Flemish Cap (eastern Study Area) between May and July, and one within the Laurentian Channel during August (LGL 2018). There are also 1408 records in the OBIS database during 1992–2018 (OBIS 2025) and in general, 1284 sightings (totaling 1286 individuals) have been recorded in the eastern Newfoundland offshore area (BHP 2020). Satellite telemetry studies confirm loggerhead presence in the southern Study Area (SWOT 2023), including tagged neonates from Florida tracked near the tail of the Grand Banks in depths exceeding 4000 m after their 2009–2011 release (Mansfield et al. 2014), and a juvenile tagged in the Canary Islands located near the Study Area's southeastern boundary (Varo-Cruz et al. 2016). Modeling work by Putman et al. (2020) further supports that oceanic-stage loggerheads originating from southern nesting beaches have the potential to distribute northwards as far as the Grand Banks. Overall, loggerhead turtles are considered likely uncommon within the Study Area.

4.7.3 Data Gaps associated with the Species at Risk VC

The following data gaps associated with the Species at Risk VC were identified in Section 3.7.6 in C-NLOPB (2010):

- Understanding the migration routes, breeding grounds, feeding areas, and seasonal distribution of marine mammal species to predict the impact of noise on their behaviour;
- The use of shutdown radii for seismic sound sources is unclear due to limited knowledge of marine mammal hearing capabilities and understanding of sound exposure characteristics and intensity that result in hearing or behavioural changes; and
- Biological and ecological information, including critical habitat, the behaviour of critical life stages, inter-species relationships and the effects of ongoing human activities.

The Eastern Newfoundland SEA (C-NLOPB 2014) specified no data gaps associated with the Species at Risk VC. However, the following general data gaps identified in Sections 5.7 and 6.1.6 in C-NLOPB (2014) apply to the Species at Risk VC:

- The lack of data on deep water habitats beyond the continental slope is a significant issue, with limited understanding of many species not of commercial importance;
- Studies of benthic invertebrate communities are limited and do not provide a comprehensive understanding of overall regions, components, and key relationships that have implications throughout the food chain, depending on a particular species' ecological role and importance;
- Detailed information on the occurrence, abundance, and distribution of marine birds, mammals, and sea turtles is not available for all locations and times throughout the SEA Study; and
- Continued research efforts on how climate change and regime shifts affect the distribution, behaviour, abundance, ecological importance, and sensitivity of species and their interactions.

The following data gaps were identified in Section 3.4 in IAAC (2020) that apply to the Species at Risk VC:

- DFO RV data collected by bottom trawl are biased toward certain species/habitats. Bottom trawls can only be used on certain substrates and therefore, data on larval or pelagic life stages of certain species of fish, or data on fish that are found in the pelagic zone or upper water column (i.e. capelin or Atlantic salmon) is lacking;
- Poor understanding of Atlantic Salmon life history once they leave their natal rivers and undertake at-sea migrations to their overwintering grounds in the North Atlantic Ocean. While there is some information available on the spatial and temporal distribution of Atlantic salmon at sea, the data is low-resolution and dated;
- Phalarope migration routes to Arctic breeding colonies are poorly understood, and insufficient tracking data for pre-/post-breeding migration timing (e.g., Leach's Storm-petrels, Glaucous Gulls); and
- The data provided by the DFO marine mammal sightings database is non-standardized and provides unquantified survey effort, preventing reliable abundance or density estimates. Data quality is uncertain due to variable observer expertise and lack of error-checking, while opportunistic sightings may reflect vessel presence rather than true distribution. Additionally, many records lack species-level identification due to distance or visibility constraints.

All of the above data gaps still exist. Any new information made available since the two SEAs and IAAC (2020) were completed and for areas beyond the scope of those documents is noted throughout Sections 4.2, and 4.4–4.6 of this EA.

These data gaps limit the assessment of potential interactions between the Project and the Species at Risk VC until updated species distributional information is available and there is an improved

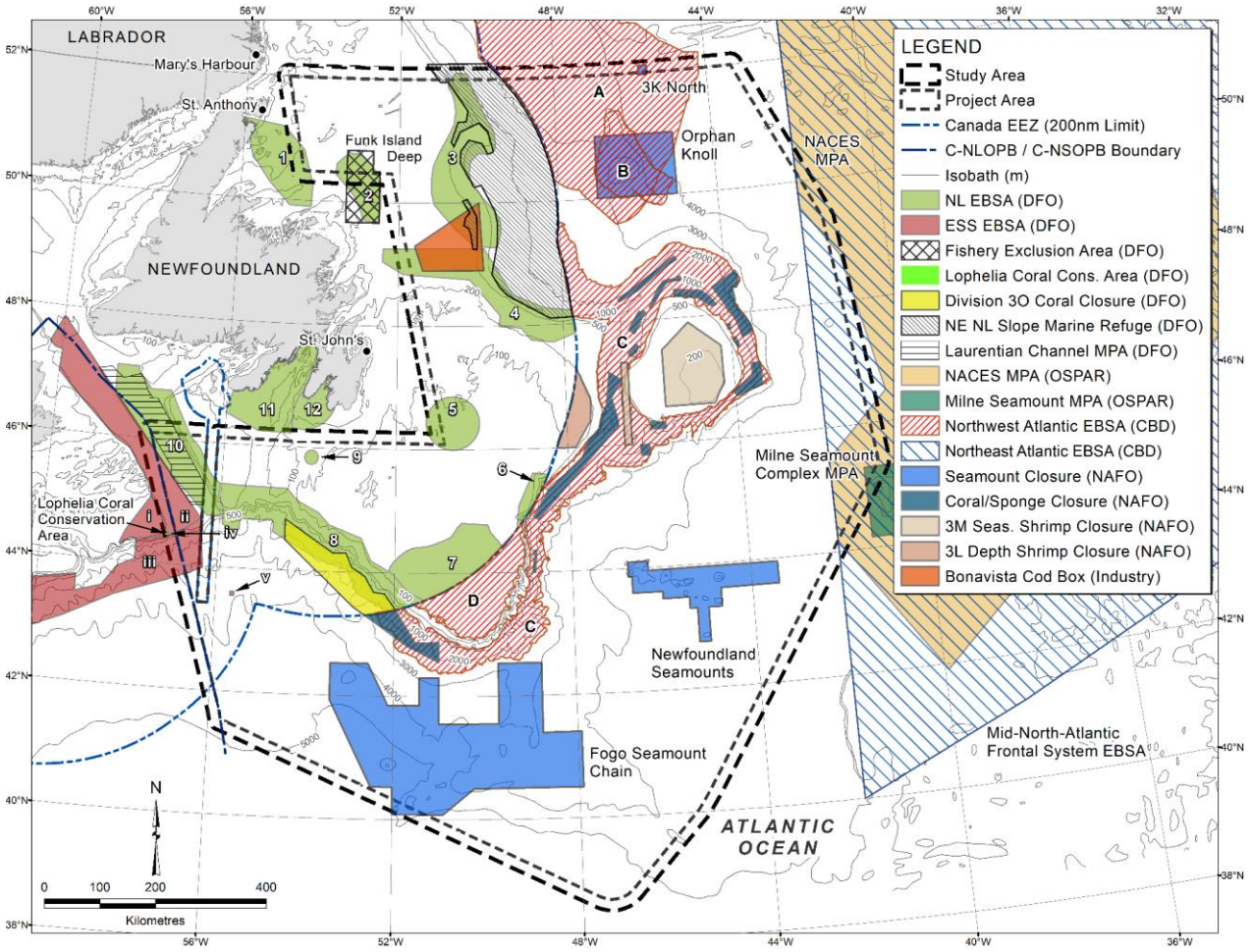
understanding of essential behaviour(s) and reaction to sound exposure. MKI will revise assessments if new data becomes available and incorporate any necessary revisions into future EA Updates.

4.8 Sensitive Areas VC

The Sensitive Areas VC of the Study Area was described in Section 3.8 in C-NLOPB (2010), Section 4.2.4 in C-NLOPB (2014), Section 3.2.4 in IAAC (2020), and Section 4.7 in LGL (2018). An overview of the sensitive areas of the Study Area, based on new information published since the above reports were released is provided below. Sensitive areas listed but not otherwise described below were previously described in the reports mentioned above. Relevant data gaps identified in the two SEAs are also discussed in terms of current status.

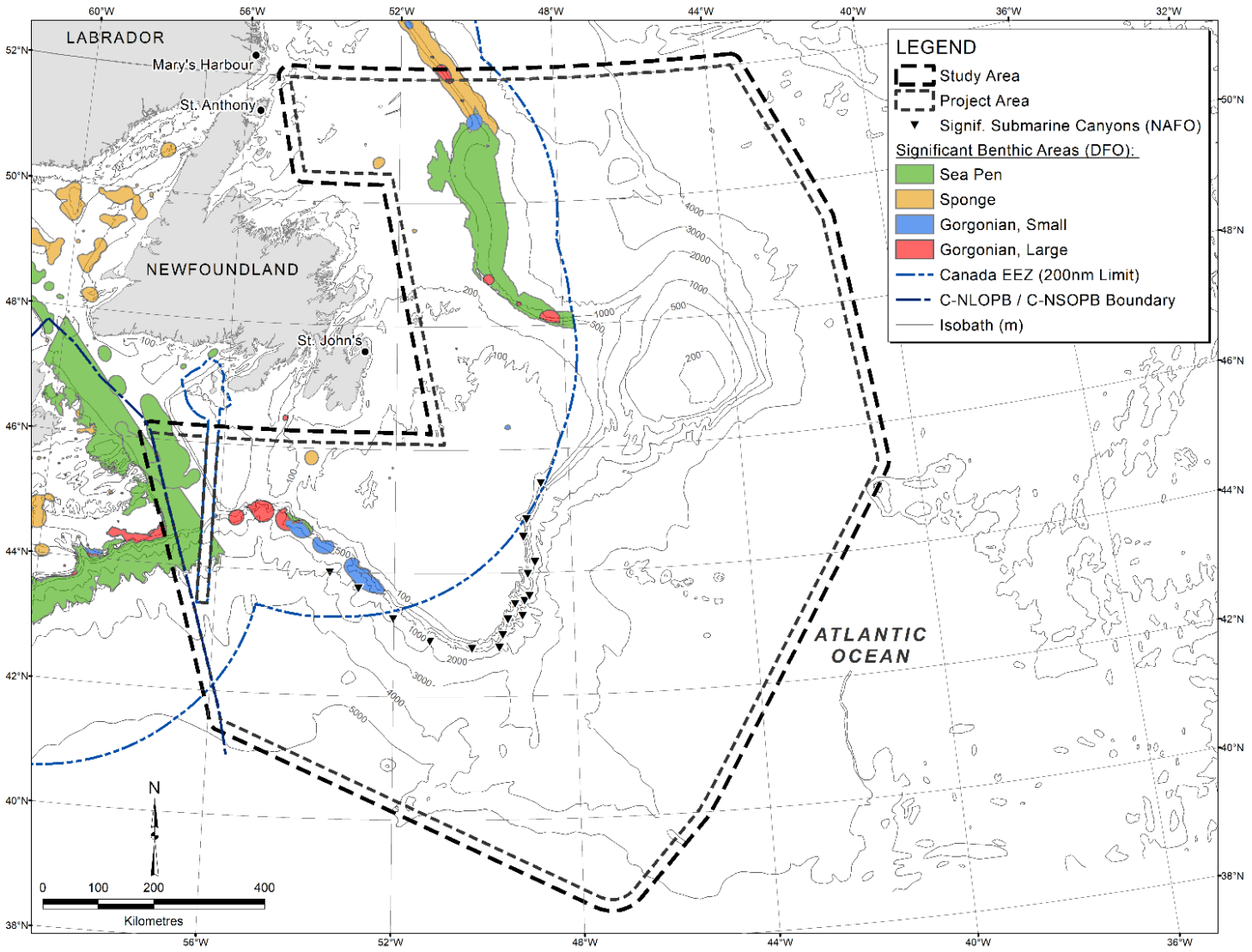
4.8.1 Sensitive Areas Associated with the Study Area

The Conserved Areas, WDPA – World Database of Protected Areas, and Canadian Protected and Conserved Areas Database (CPCAD) layers available through IAAC (2024) indicate the location and extent of numerous sensitive areas within and near the Study Area. The Canada Marine Planning Atlas (DFO 2025f) indicates the same sensitive areas as IAAC (2024) along with several others in their Important Ecological Areas and Protected and Conservation Areas data layers/data layer themes. Sensitive areas that overlap or are adjacent to the Study Area are shown in Figures 4.63–4.64 and listed in Table 4.25.



Source: DFO (2014b); DFO (2019d); CBD (2025); DFO (2025f); NAFO (2025a); ODIMS (2023).
Notes:
NL (Bioregion) EBSA: 1 = Grey Islands; 2= Notre Dame Channel; 3 Orphan Spur; 4 = Northeast Slope; 5 = virgin Rocks; 6 = Lilly Canyon-Carson Canyon; 7 = Southeast Shoal; 8 = Southwest Slope; 9 = Haddock Channel Sponges; 10 = Laurentian Channel; 11 = Placentia Bay; 12 = St. Mary's Bay.
ESS (Eastern Scotian Shelf) EBSA: i = Eastern Shoal; ii =Laurentian Channel Slope; iii = Scotian Slope; iv = Stone Fence and Laurentian Environs; v = Laurentian Channel Cold Seep Communities.
CBD EBSA: A = Seabird Foraging Zone in the Southern Labrador Sea; B = Orphan Knoll; C = Slopes of the Flemish Cap and Grand Bank; D = Southeast Shoal and Adjacent Areas on the Tail of the Grand Bank.

Figure 4.63. Location of sensitive areas that overlap the Study Area.



Source: Kenchington et al. (2018a, b); J. Murillo-Perez, Research Scientist, Fisheries and Oceans Canada, Bedford Institute of Oceanography, pers. comm., 2 Nov 2023.

Figure 4.64. Sensitive areas that overlap or are adjacent to the Study Area (continued): Submarine canyons and Significant Benthic Areas (SBAs).

Table 4.25. Sensitive areas that overlap or are near the Study Area (areas indicated by an * fully or partially overlap the Study Area).

Governing Body	Area Type	Area Name
NAFO	Vulnerable Marine Ecosystem (VME)	3O Coral Protection Zone *
		Coral/Sponge Fishery Closure Area (14 total) *
		Seamount Closure Area Orphan Knoll Seamount * Newfoundland Seamount * Fogo Seamount Chain * 3K North *
	Seasonal Fishery Closure	3M Seasonal 3M Shrimp Closure Area *
		3L Depth Shrimp Closure (<200m Depth) *
	Submarine Canyons	Shelf Indenting Canyons (Div. 3N) *
		Canyons with head >400 m (Div. 3MN) *
		Canyons with head >200 m (Div. 3O) *
OSPAR	Marine Protected Area (MPA)	North Atlantic Current and Evlanov Sea (NACES) basin (overlaps and extends beyond the former Milne Seamount Complex) *
DFO	MPA	Laurentian Channel Marine Protected Area *
	Significant Benthic Area (SBA)	Large Gorgonians *
		Small Gorgonians *
		Sea Pens *
		Sponges *
	Marine Refuge (Fishery Exclusion Area)	Funk Island Deep Closure *
		Division 3O Coral Closure (Same boundary as NAFO 3O Coral Protection Zone) *
		Northeast Newfoundland Slope Closure *
		Lophelia Coral Conservation Area *
	NL Shelves Bioregion Ecologically and Biologically Significant Areas (EBSAs)	Grey Islands *
		Fogo Shelf
		Notre Dame Channel *
		Bonavista Bay
		Smith Sound
		Baccalieu Island
		Orphan Spur *
		Northeast Slope *
		Virgin Rocks *
		Lilly Canyon-Carson Canyon *
		Southeast Shoal *
		Southwest Slope *
		Haddock Channel Sponges *
		Laurentian Channel *
		South Coast

Governing Body	Area Type	Area Name
		Placentia Bay *
		St. Mary's Bay *
	Eastern Scotian Shelf (ESS) EBSA	Eastern Shoal *
		Laurentian Channel Slope *
		Scotian Slope *
		Stone Fence and Laurentian Environs *
		Laurentian Channel Cold Seep Communities *
Convention on Biological Diversity (CBD)	North-west Atlantic EBSA	Southeast Shoal and Adjacent Areas on the tail of the Grand Bank *
		Slopes of the Flemish Cap and Grand Bank *
		Orphan Knoll *
		Seabird Foraging Zone in the Southern Labrador Sea *
	North-east Atlantic Ocean and Adjacent Areas EBSA	Mid-North-Atlantic Frontal System *
		Charlie-Gibbs Fracture Zone
		North Azores Plateau
Fishing Industry	Voluntary Fishery Closure Area	Bonavista Cod Box *

The boundaries and size of the former Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) Milne Seamount Complex Marine Protected Area (MPA; area = 20,914 km^2) were recently modified and significantly extended. The new MPA, the North Atlantic Current and Evlanov Sea (NACES) basin, was designated in 2021 (OSPAR 2021). In the NACES MPA, the water column is collectively protected by all OSPAR Contracting Parties, while the seabed remains unprotected. It encompasses a ~600,000-km^2 area established to protect an important feeding and foraging area for seabirds (OSPAR 2021). It is estimated that the NACES MPA is used by 2.5–5 million seabirds throughout the year, travelling from more than 56 colonies across 16 countries in both the North and South Atlantic, making this site one of the most important concentrations of migratory seabirds in the high seas (Davies et al. 2021a,b). Of the 21 seabird species known to use the NACES basin, 18 are experiencing population declines, including the globally *Endangered* Bermuda Petrel (*Pterodroma cahow*) and Zino's Petrel (*Pterodroma madeira*), as well as globally *Vulnerable* Desertas Petrel (*Pterodroma deserta*), Black-legged Kittiwake (*Rissa tridactyla*), and Atlantic Puffin (*Fratercula arctica*; OSPAR 2021; Davies et al. 2021b).

Prior to 2022, there were 13 NAFO Coral/Sponge Closure VMEs offshore Newfoundland; since then, the number of VMEs has increased to 14 and VME Closures 7, 11, and 14 were each subdivided into two areas with different boundaries based on regulatory end dates (NAFO 2025a). All the VME Closures (1 to 14b) are closed to bottom fishing until 31 December 2026 (NAFO 2025a). The closures are primarily due to the presence of high concentrations of corals, sponges, sea pens, and seamounts, which may provide habitat for VME indicator species. Since the Study Area encompasses the NAFO Fishing Footprint, all these VME Closures fall within the Study Area.

MPAs provide legal protection for marine ecosystems and associated resources in areas considered important, which may contain species or ecological processes that require special consideration and protection. The process of creating an MPA begins with the identification of Areas of Interest (AOIs) within the different bioregions in Canada. There are currently three MPAs within NL's waters, including the Eastport MPA in Bonavista Bay, the Laurentian Channel MPA on the southern coast of Newfoundland, and an MPA in Gilbert Bay along the Labrador coast (IAAC 2024; DFO 2025g). The

Laurentian Channel MPA is the only MPA overlapping the Study Area, in the southwestern portion. The MPA is >1,200-km long, extending from the intersection of the St. Lawrence and Saguenay Rivers to the edge of the Newfoundland continental shelf, and encompasses the seabed, subsoil to 5-m depth, and water column above the seabed. A deep submarine valley occupies 11,580 km^2 of its 35,800-km2 area (DFO 2019e). Oil and gas exploration and exploitation, commercial and recreational fisheries, and the anchoring or laying of submarine cables are prohibited within the MPA (DFO 2019e). The MPA serves as a critical habitat for several marine species and hosts a high abundance of black dogfish, juvenile smooth skate, and porbeagle and basking sharks during the spring and summer, along with northern wolffish, leatherback sea turtle, and at least 20 species of whales and dolphins (DFO 2019e). The MPA includes one of only two known porbeagle mating grounds, is a critical feeding area and migration route for marine animals transiting to/from the Gulf of St. Lawrence, and features the highest sea pen concentrations of the NL Shelves Bioregion (DFO 2019e).

Significant Benthic Areas (SBAs) are significant areas of cold-water corals and sponge-dominated communities (DFO 2017d). These areas are not legally protected, although they identify key marine species distribution and may indicate areas of future restoration activities. The SBAs that occur within/near the Study Area are situated primarily along the NE Newfoundland Slope and Southwestern edge of the Grand Banks and include areas associated with sea pens, sponges, and large and small gorgonian corals (DFO 2017d).

Ecologically and Biologically Significant Areas (EBSAs) are marine areas identified by DFO as having high ecological and biological productivity considered important for marine species or ecological processes. These areas are not legally protected through existing legislation but inform processes that may result in future protection or management measures. Currently, 29 EBSAs have been identified within the NL Shelves Bioregion area, with 12 occurring within or overlapping the Study Area. Five of the Eastern Scotian Shelf (ESS) EBSAs also occur within or overlap the western border of the Study Area.

Five Convention on Biological Diversity (CBD) EBSAs are located within or partially within the Study Area. The Seabird Foraging Zone in the Southern Labrador Sea EBSA is a crucial habitat for seabirds, including Black-legged Kittiwake, Thick-billed Murre, and breeding Leach's Storm-petrels. The Orphan Knoll EBSA is a sub-sea island of hard substratum and unique, complex habitats arising from the seafloor, surrounded by the deep, soft sediments of the Orphan Basin. This EBSA comprises unique habitats and marine fauna, including larvae and fragile and long-lived corals and sponges (CBD 2025). The Slopes of the Flemish Cap and Grand Bank EBSA encompass all 14 NAFO coral/sponge closure areas and overlap portions of the NAFO 3O Coral Protection Zone and Southwest Shelf Edge and Slope NL Shelves Bioregion EBSA. This EBSA also includes a component of the Greenland halibut fishery grounds and supports numerous SAR (CBD 2025). The Southeast Shoal and Adjacent Areas on the Tail of the Grand Bank EBSA contain a portion of the Greenland international halibut fishery grounds and support SAR and high biodiversity. The Mid-North-Atlantic Frontal System's intense mesoscale activity (near-stationary eddies, zonal fronts) enhances and concentrates productivity through retention and fine-scale mixing. This enhanced productivity creates a vital foraging hotspot that supports a high density and diversity of marine predators, including numerous seabird species (several of which are *Endangered* or *Vulnerable*), whales, sharks, and tunas, as extensively documented by biological tracking and remote sensing data (CBD 2025).

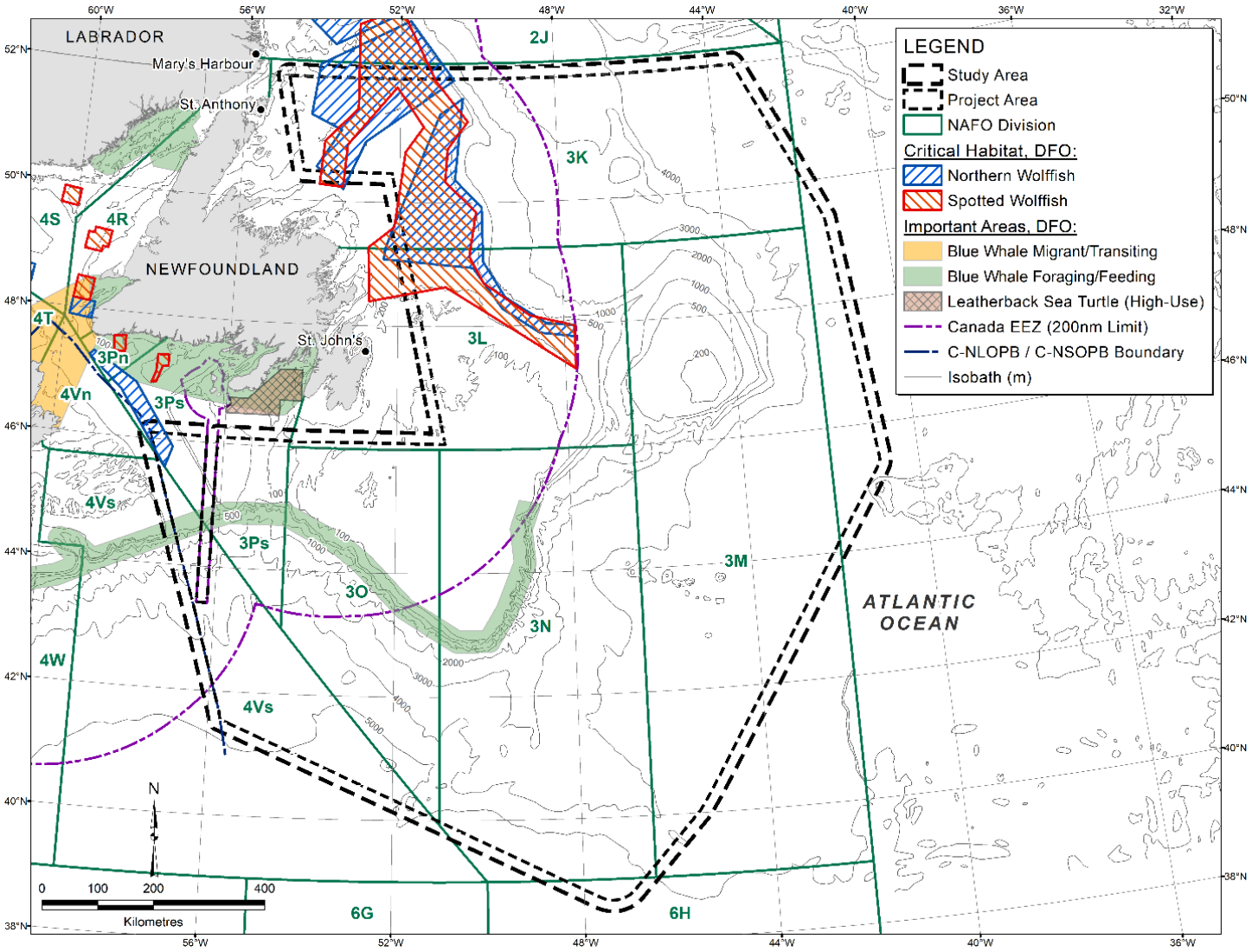
Currently, there are no designated National Marine Conservation Areas (NMCAs) within NL waters. However, designating Representative Marine Areas (RMAs) is the first step in the process of creating a NMCA and Parks Canada has identified various RMAs that have the potential, after further study, analysis, and engagement, to become or contain NMCAs in the future (Parks Canada 2023). Current proposed NMCA locations include the South Coast Fjords Study Area and coastal and marine areas of northern Labrador and adjacent to Torngat Mountains National Park (in the Torngat Area of Interest Inuit [Indigenous] protected area [Torngat-AOI]), both of which are outside of the proposed Study Area (Parks Canada 2023). Parks Canada is also considering several candidate NMCA Reserves, including the Bonavista Bay (which overlaps the Northwestern portion of the Study Area), although the site is currently inactive (Danny Major, Project Manager, Parks Canada, pers. comm., February 2024).

4.8.2 Critical Habitat

Critical habitats for northern and spotted wolffishes overlap the western boundary and north and northwestern portions of the Study Area (Figure 4.65). These critical habitats include deep channels and edges of the Grand Banks and Labrador Shelf and support all portions of wolffish life history (DFO 2020c). Northern and spotted wolffishes do not exhibit large-scale movements (DFO 2020c) and may be present within the proposed critical habitats year-round. Project activities within the Project Area, including the use of OBNs that have small individual footprints (~0.20–0.25 m^2) and short deployment times (60–90 days), are not expected to affect the benthic and thermal environment or cause destruction to these critical habitats.

As of February 2024, no critical habitat has been officially designated for the Atlantic population of leatherback sea turtles. However, DFO (2020j) has identified that one of two primary high-use feeding areas for leatherback sea turtles is in Placentia Bay, Newfoundland, just north of the western boundary of the Study Area (Figure 4.65).

DFO identified important foraging and transiting areas for the Atlantic population of blue whale (DFO 2018). Of the four foraging habitats and two transit corridors identified in the Newfoundland and Gulf of St. Lawrence regions, the continental shelf edge feeding area overlaps the southwestern portion of the Study Area. The south and southwestern Newfoundland feeding area and Cabot Strait transit corridor are adjacent to but beyond the Study Area boundaries (Figure 4.65). No critical habitat has yet been identified for the Atlantic population of blue whale (DFO 2018).



Source: DFO (2018, 2020c,j, 2022d).

Figure 4.65. Critical habitats for northern and spotted wolffishes, high-use feeding areas for leatherback sea turtles, and important areas for blue whales.

4.8.3 Data Gaps associated with the Sensitive Areas VC

The following data gaps associated with the Sensitive Areas VC were identified in Section 3.8.8 in C-NLOPB (2010):

- Detailed delineation of special areas, their relative importance, and their eventual legal status.
- Future uncertainty regarding special areas, some overlapping biologically, geographically, and jurisdictionally.

The Eastern Newfoundland SEA did not explicitly identify data gaps associated with the Sensitive Areas VC (see Section 5.4 in C-NLOPB 2014). However, the same data gaps identified from the SEA for the Species at Risk VC (see Section 4.7 above) apply to the Sensitive Areas VC.

No specific data gaps were identified in Section 3.4.1.4 in IAAC (2020), but it was noted that sensitive areas are always subject to change in time, as new areas are identified and delineated, the boundaries of existing areas are modified, or existing areas are removed altogether. IAAC (2020) indicates that attention should be paid to potential new AOIs within the Study Area that may become MPAs in time.

Although there has been some progress addressing special area delineation and research (as noted throughout Section 4.7), the data gaps described above hinder the assessment of potential interactions between the Sensitive Areas VC and the Project, owing to the limited ecological and distributional understanding of diverse species that use these areas. MKI will continue to monitor for updated information, including the alteration of current sensitive areas and the introduction of new sensitive areas within/around the Study Area, and will include newly available data in future EA Updates.

5.0 Effects Assessment Methodology

MKI is required to prepare an EA for the Newfoundland Offshore and Environmental Data Collection Program, 2025–2029 as outlined in the Scoping Document issued by the C-NLOPB (2024).

Two general types of effects are considered as per the Scoping Document:

1. Effects of the Project on the environment; and
2. Effects of the environment on the Project.

This section describes the approach, scoping considerations, and methods used to assess the effects of routine Project activities, accidental events, and cumulative effects of the Project; and the effects of the environment on the Project that could occur. The methods used to prepare the EIS were developed in consideration of IAAC (2015) and previous EAs of offshore NL seismic surveys.

5.1 Scoping

The C-NLOER provided a Final Scoping Document (C-NLOPB 2024; dated 1 November 2024) for the Project which outlined the factors to be considered in the assessment. In addition, various stakeholders were contacted for input (see Section 2.6 previously). Another aspect of scoping for the effects assessment involved reviewing relevant SEAs (C-NLOPB 2010, 2014) and EAs (IAAC 2020; LGL 2015, 2016, 2018).

5.2 Consultations

MKI's approach to consultation on marine projects is to, whenever possible, consult (primarily through in-person meetings) with relevant agencies, stakeholders, and rights-holders (e.g., beneficiaries) during the presurvey and survey stages. MKI will initiate meetings and respond to requests for meetings with the interested groups throughout this period. After the survey is complete, MKI will conduct follow-up communications. The same approach would be followed before, during, and after any survey work conducted in 2025–2029. The in-person meetings include direct participation of MKI's Project Manager. In summary, each year, MKI will consult with stakeholders before the survey is permitted, during survey activities, and after survey completion as outlined below.

- Before the survey is permitted: provide Project information, gather information about area fisheries, determine issues or concerns, discuss communications and mitigation measures, and discuss potential solutions;
- During survey activities: provide forward looking acquisition plans for discussion in a weekly meeting, communicate current and projected vessel positions every 12 hours via email, and maintain communication with active stakeholders to ensure concerns are addressed rapidly; and
- After the survey is completed: provide an update on the Project, discuss any issues that arose, and present results of the MMSO and FLO reports.

5.3 Valued Components

The VC approach was used to focus the assessment on those biological resources of most potential concern and value to society. VCs include the following groups:

- Rare or at-risk species/habitats (as defined by the SARA and COSEWIC);
- Species/habitats that are unique to an area and/or valued for their aesthetic properties;
- Marine species that are harvested by people (e.g., commercial and/or Indigenous fishery target species); and
- Marine species with some potential to be affected by the Project.

The VCs used in this EA were identified based, in part, on the scoping exercise as described in Section 5.1. The VCs and their associated rationale for inclusion are described below.

5.3.1 Fish and Fish Habitat

For the Fish and Fish Habitat VC, emphasis was placed on principal commercial species (e.g., snow crab, northern shrimp, Atlantic cod) and SARA species (e.g., wolffishes) within the Study Area. These species represent the range of species relevant to the issues concerning the potential effects of seismic surveys on fish and invertebrate populations within the Study Area that are important for commercial, Indigenous, recreational, and/or ecological purposes.

5.3.2 Fisheries

As an impact on fish/invertebrates or their habitat could affect fishery success for a given species, the Fisheries VC is directly linked to the Fish and Fish Habitat VC; however, the Fisheries VC is considered separately due to the potential for interference with fishing activities themselves. For example, sound produced by the source array could affect fish and/or invertebrate behaviours, resulting in affects on fisheries catch success. Also, the seismic vessels/streamers could directly interact with fixed fishing gear. All fisheries are considered, including commercial, Indigenous, and recreational, as they are recognized as important elements to the culture and societal, economic, and aesthetic environment of NL. Aquaculture, an expanding sector in the province, is also considered, along with research surveys conducted by DFO and jointly between DFO and industry. The Fisheries VC is of primary concern from both a public and scientific perspective, ranging from local to international scales.

5.3.3 Marine-associated Birds

Those species most sensitive to seismic activities (e.g., deep divers, such as murres) or vessel stranding (e.g., petrels) were emphasized in this EA. NL waters support globally significant seabird colonies, and the Study Area hosts large populations of both migratory and year-round residents. Seabirds have social, cultural, economical, aesthetical, ecological, and scientific importance for NL. The Marine-associated Bird VC is a primary public and scientific concern at local, national, and international scales.

5.3.4 Marine Mammals

Marine mammals that are most sensitive to low frequency sound (e.g., baleen whales) received the most emphasis in this EA. Whales and seals are key social and biological components of NL. The economic and aesthetic importance of whales, in particular, is evidenced by the large numbers of whale watching tour boats that are part of the local industry. Overall, the Marine Mammal VC is of concern from both public and scientific perspectives, at local to international scales.

5.3.5 Sea Turtles

Although uncommon in the Study Area, most sea turtle species that may occur in the region are *threatened* or *endangered* on a global scale. The Atlantic population of leatherback sea turtle forages in eastern Canadian waters and is *endangered* under Schedule 1 of SARA. Overall, the Sea Turtle VC is of concern from scientific perspectives, at local to international scales.

5.3.6 Species at Risk

Species that may occur within the Study Area listed as *endangered* or *threatened* on Schedule 1 of SARA are the focus of this EA, although species listed as *special concern* or designated under COSEWIC are also considered. All species at risk in waters offshore NL are captured in the above VCs. However, owing to their special status, they are assessed separately as their own VC.

5.3.7 Sensitive Areas

Areas considered to be unique due to their ecological and/or conservational sensitivities are included in this VC. The Sensitive Areas VC considers both designated areas with legal protections and specified allowable/prohibited activities (e.g., MPAs) and areas recognized for their ecological importance but that do not receive legislated protection (e.g., EBSAs). This VC includes sensitive areas within or that overlap the Study Area.

5.4 Boundaries

For the purposes of the EA, the following temporal and spatial boundaries are defined.

5.4.1 Temporal

The temporal boundaries of the Project are 1 May–30 November during 2026–2030. These dates encompass the periods seismic surveys would occur and when FLS would be deployed. The FLS will collect data year-round with maintenance occurring approximately every 3–6 months.

5.4.2 Spatial

The spatial boundaries for the Project and Study areas were detailed in Section 2.1 and are summarized here.

5.4.2.1 Project Area

The 'Project Area' is defined as the area where seismic and environmental data could be acquired and vessel movements with deployed equipment will occur (see Figure 1.1). The coordinates of the Project Area (WGS84, unprojected geographic coordinates) are provided in Section 2.1.

5.4.2.2 Affected Area

The 'Affected Area' varies according to the specific vertical and horizontal distributions and sensitivities of the VCs of interest and is defined as that area within which effects (physical and/or relevant behavioural effects) have been reported to occur.

5.4.2.3 Study Area

The Study Area includes the Project Area plus a 20-km buffer around the Project Area to account for the propagation of seismic survey sound that could potentially affect marine biota (see Figure 1.1; Table 2.1). The coordinates of the Study Area (WGS84, unprojected geographic coordinates) are provided in Section 2.1.

5.4.2.4 Regional Area

The 'Regional Area' is an area larger than the Study Area and is typically used when assessing cumulative effects.

5.5 Effects Assessment Procedures

The systematic assessment of the potential effects of the Project involved the following key steps:

1. Preparation of interaction matrices (between Project activities and the VCs);
2. Identification and evaluation of potential effects of Project activities on VCs, including description of mitigation measures and residual effects;
3. Preparation of residual effects summary tables; and
4. Evaluation of cumulative effects.

5.5.1 Identification and Evaluation of Environmental Effects

Interaction matrices identifying possible Project activities that could interact with any of the VCs were prepared. The interaction matrices were used only to identify potential interactions; they made no assumptions about the potential effects of the interactions.

Interactions were then evaluated for their potential to cause effects, and the various effects or factors identified in the interaction matrix for each VC were assessed. In instances where the potential for an effect of an interaction was deemed improbable or remote, these interactions were not considered further. In this way, the assessment focused on key issues and the more substantive environmental effects (see subsequent assessments for each VC).

In the assessment of biological VCs, an interaction was considered a potential effect if it could change the abundance or distribution of VCs or change the prey species or habitats used by VCs. In the fisheries assessment, an interaction was considered to be a potential effect if it could change the current capacity of the potentially affected fishery for commercial operators and/or recreational activity participants; result in noncompliance with applicable regulatory guidelines/standards; or, in the case of Indigenous fisheries, result in a loss of culturally or commercially important aquatic resources. The potential for an effect was assessed by considering:

- Outcomes of the issues scoping and consultation sessions;
- Location and timing of the interaction;
- Baseline information;

- Literature on similar interactions and associated effects;
- Professional judgement and consultation with other experts (when necessary); and
- Results of similar effects assessments.

When data were insufficient to allow certain or precise effects evaluations, predictions were made based on professional judgement. In such cases, the uncertainty is documented to account for data gaps.

5.5.2 Mitigation Measures

Mitigation measures applicable for each Project activity included in the matrix for a VC were identified and the effects of various Project activities (i.e., within Project cumulative effects) were then evaluated assuming that appropriate mitigation measures are applied. Effects predictions were made taking into consideration both standard and Project-specific mitigations and can thus be considered "residual effects".

5.5.3 Evaluation Criteria for Assessing Environmental Effects on Valued Components

Residual negative environmental effects are determined for each Project activity as well as the planned Project overall. Residual effects that were characterized as negative were considered further in terms of their significance and were carried forward to the cumulative effects assessment (CEA). Positive effects from the Project were considered further in terms of their environmental, economic, and/or social benefits. A general description of the assessment criteria are summarized in Table 5.1.

Table 5.1. Summary of assessment criteria.

Assessment Criteria	General Description
Nature	The long-term trend of the residual effect.
Magnitude	The overall amount or degree of change in a measurable parameter, or variable, related to existing conditions that are expected.
Geographic Extent	The range or scale of approximate geographic areas over which any potential interaction and effect is anticipated to occur.
Timing	Refers to the effects of seasonal variability on the VC.
Frequency	How often the residual effect being assessed is expected to occur.
Duration	The length of time a potential residual effect may occur.
Reversibility	Refers to the ability of the VC to return to its original state once the stressor is removed.
Ecological/Socio-economic Context	Existing condition and trends in the area where residual environmental effects occur.
Level of Confidence	The general level of confidence in the knowledge used to describe the potential environmental effect.

5.5.3.1 Biological Valued Components

The evaluation criteria used to describe the potential residual effects of Project activities on biological VCs are described here.

Nature

Nature refers to the long-term trend of the residual effect relative to existing or baseline conditions. This can be neutral, positive, or negative.

Magnitude

Magnitude describes the extent of the environmental effects for each activity. The biological measures to be included in the definition of magnitude are not clearly established and provided in any single document of authority. Definitions of magnitude are similar to those used for industry EAs in Atlantic Canada including assessments of projects in Newfoundland's offshore. For this EA, the magnitude of effects can be rated as:

- **High** - An effect from the Project on a VC is rated high if it is judged to result in a 10%, or greater, change in the size or health of a population or the carrying capacity of its habitat. A change in a population can result from an absolute reduction in population size or from displacement of animals to areas outside the area of consideration.
- **Moderate** - An effect from the Project on a VC is rated moderate if it is judged to result in a 1% to less than 10% change in the size or health of a population or the carrying capacity of its habitat.
- **Low** - An effect from the Project on a VC is rated low if it is judged to result in a less than 1% change in the size or health of the population or the carrying capacity of its habitat.
- **Negligible** - Negligible effects are from those interactions that are judged to have either no or minimal non-observable effects.

It is recognized that in most cases, it is not possible to precisely measure such percent changes. However, these percentage levels are used to provide the reader with an understanding of the expected relative magnitude of potential effects from the Project based upon existing information and professional judgement.

When evaluating the magnitude of predicted effects, certain VCs have special status. Project activities (planned) are not expected to result in the mortality of species listed on Schedule 1 of SARA. A reduction in population size of species listed as Endangered or Threatened on Schedule 1 of SARA (i.e., mortality of an individual) is considered "high" in magnitude.

The categorization of magnitude includes consideration of scientific literature and the use of professional judgement. The magnitude ranking contributes to the assessment of significance.

Geographic Extent

The geographic extent or scale of effects refers to the specific area (km^2) affected by the project activity, which may vary depending on the activity and the relevant VC. Geographic extent can be categorized as:

- <1 km²
- 1–10 km²
- 11–100 km²
- 101–1,000 km²
- 1,001–10,000 km²
- >10,000 km²

It should be noted that an area of 100 km² is a circle with a radius of 5.6 km around a defined point. A circular area of 1,000 km² would have a radius of about 17.8 km and an area of 10,000 km² would have a radius of about 56 km.

Timing

Timing categories were used to evaluate whether a predicted residual effect on a VC was sensitive to seasonality:

- Negligible Sensitivity – Residual effect is not sensitive to seasonality.
- Moderate Sensitivity – Residual effect may be influenced by seasonality, but the assessment of attribute parameters is unchanged (i.e., magnitude, geographic extent, duration, frequency, reversibility)
- High Sensitivity – The assessment of the residual effect (i.e., magnitude, geographic extent, duration, frequency, reversibility) is changed based on seasonality.

Duration and Frequency of Effects

Duration refers to how long a residual effect may occur and categories include:

- Short-term – Residual effect restricted to the duration of the Project activity.
- Medium-term – Residual effect extends through project operations but is expected to subside when operations cease.
- Long-term – Residual effect extends beyond the life of the Project.

The duration of an effect might be longer than the duration of the project activities that cause it. Therefore, one should not assume that once a project activity has ceased, its effects on the environment are no longer of concern. Where appropriate, finer-scale quantifications of duration of an effect is provided.

Frequency for biological effects addresses how often a residual effect may occur and is generally linked to frequency of a given Project activity; categories include:

- Single Event – Residual effect occurs once during the Project.
- Irregular Events – Residual effect occurs sporadically at an irregular interval and is not predictable.

- Regular Events – Residual effect occurs regularly and may be at predictable intervals or specific times.
- Continuous – Residual effect occurs continuously.

Reversibility

Reversibility refers to the ability of a VC to return to either an equal or improved condition at the end of the Project. It should be noted that a biological effect may be irreversible at the individual level (e.g., mortality of an individual animal) but reversible at the population level.

Ecological/Socio-Economic Context

The ecological, socio-economic context describes the current status of the area affected by the proposed Project in terms of existing environmental effects. Two levels were considered:

- Undisturbed – Area is relatively undisturbed or not adversely affected by human activity.
- Disturbed – Area has previously been substantially disturbed by human development or human development is still present.

Significance of Environmental Effects

Significant biological effects are those that are considered to be of sufficient magnitude, duration, and geographic extent to cause a change in the VC that will alter its status or integrity beyond an acceptable level. Establishment of the criteria is based on professional judgement but should be transparent and repeatable. An effect can be considered significant (negative by definition), not significant, or positive. A significant residual negative effect on biological VCs is defined as a residual Project-related *change in the VC population and/or habitat in the Study Area where recovery to baseline condition is unlikely.*

Level of Confidence

An assessment of level of confidence (i.e., low, moderate, and high levels) is provided based on confidence in the scientific information available when an effect is judged to have a particular negative effect on a VC. Level of confidence can be assessed as:

- Low: Based on incomplete understanding of cause-effect relationships and/or incomplete data specific to the Study Area and/or species in the Study Area.
- Moderate: Based on good understanding of cause-effect relationships using data from elsewhere or incompletely understood cause-effect relationships using data specific to the Study Area and/or species in the Study Area.
- High: Based on good understanding of cause-effect relationships and data specific to the Study Area and/or species in the Study Area.

5.5.3.2 Fisheries Valued Component

In accordance with the Scoping Document, an assessment of predicted environmental effects of the Project on the Fisheries VC was conducted, including the commercial, recreational, and Indigenous fisheries. The evaluation criteria used to describe the potential residual effects of Project activities on the Fisheries VC are described here.

Nature

The nature of a residual effect on Fisheries considers its long-term trend in terms of improvement and desirability relative to stakeholders and/or resource users. Nature includes measurable factors, such as changes in overall fisheries catch volumes and access to preferred fishing areas. The nature of residual effects can be rated as:

- **Neutral –** A residual effect from the Project on the Fisheries VC is rated neutral if it is evaluated to have no measurable impacts on stakeholders relative to commercial, recreational, and/or Indigenous fisheries.
- **Positive –** A residual effect from the Project on the Fisheries VC is rated positive if it is considered to result in a measurable change that is positive or desirable for fisheries stakeholders, operators, or participants.
- **Negative –** A residual effect from the Project on the Fisheries VC is rated negative if it considered to result in a measurable change that is negative or undesirable for fisheries stakeholders, operators, or participants.

The categorization of nature includes considerations of available data (e.g., DFO Commercial Landings Database) and the use of professional judgment. The nature ranking contributes to the assessment of significance – a neutral residual effect would be rated not significant, and a negative residual effect would be significant by nature, whereas a positive residual effect does not receive a significance rating.

Magnitude

Magnitude describes the extent of Fisheries VC capacity change associated with each Project activity. Such changes are measurable and involve consideration of whether changes are within normal variability (e.g., seasonal, inter-annual) and within the boundaries of any applicable regulatory standards or guidelines (e.g., fishing licence bounds, seasons, temporary closures), and whether fisheries activities may proceed as normal within the Project Area (e.g., fishing or recreational boating access). The magnitude of residual effects can be rated as:

- **Negligible –** A residual effect from the Project on the Fisheries VC is rated negligible if interactions are evaluated to have no measurable effect.
- **Low –** A residual effect from the Project on the Fisheries VC is rated low if there is a measurable effect but the anticipated use capacity change is less than stakeholders, operators, or participants would expect relative to normal/historical variability (e.g., due to weather events, climate change, poor fishery species stock recruitment years), within

the bounds of applicable regulatory standards/guidelines (e.g., no change in access to licensed fishing areas or seasons, or the change is less than what would be expected from a fisheries closure or a facility closure due to regulatory maintenance), and fisheries activities can continue to occur as they normally would within the Project Area.

- **Moderate –** A residual effect from the Project on the Fisheries VC is rated moderate if there is a measurable effect and the anticipated use capacity change exceeds what stakeholders, operators, or participants would expect relative to normal/historical variability, but use capacity remains within the bounds of applicable regulatory standards/guidelines and activities can continue to occur as they normally would within the Project Area.
- **High –** A residual effect from the Project on the Fisheries VC is rated high if there is a measurable effect and the anticipated use capacity change exceeds both normal/historical variability and/or relevant regulatory standards/guidelines and use activities cannot occur as they normally would within the Project Area.

Geographic Extent

The geographic extent or scale of residual effects refers to the specific area affected by a Project activity. For the Fisheries VC, geographic extent can be categorized as:

- **Project Area –** Within the bounds of the Project Area.
- **Study Area –** Within the bounds of the Study Area.
- **Regional Area –** The island of Newfoundland.

Timing

The timing categories account for the temporal occurrence of a predicted residual effect impacting the occurrence of fisheries activities. The timing categories account for the sensitivity of a VC to the temporal occurrence of a given Project activity and may include:

- **Negligible Sensitivity –** Timing does not impact fisheries activities.
- **Moderate Sensitivity –** Timing may impact fisheries activities.
- **High Sensitivity –** Timing will impact fisheries activities.

Frequency and Duration of Effects

The frequency for the Fisheries VC considers how often a residual effect may occur and is typically linked with the occurrence of a given Project activity. Frequency categories include:

- **Single Event –** Residual effect occurs once during the Project.
- **Irregular Events –** Residual effect occurs sporadically at an irregular interval and is not predictable.
- **Regular Events –** Residual effect occurs regularly and may be at predictable intervals or times.
- **Continuous –** Residual effect occurs continuously.

The duration for the Fisheries VC assessment considers how long a residual effect may impact VC activities. It is of note that the duration of an effect may be longer than the duration of the Project activity/activities that caused it, so it should not be assumed that once Project activity has ceased, its effects on the environment are no longer occurring or of concern. Duration categories include:

- **Short-term –** Residual effect restricted to the Project activity.
- **Medium-term –** Residual effect extends through Project operations but is expected to subside when operations cease.
- **Long-term –** Residual effect extends beyond the life of the Project.

Reversibility

Reversibility refers to the ability of a VC to return to either an equal or improved condition at the end of the Project.

Ecological/Socio-economic Context

The ecological/socio-economic context describes the present status of the area affected by the proposed Project in terms of existing environmental effects. Two levels were considered:

- **Undisturbed –** Area is relatively pristine or not adversely affected by anthropogenic activity.
- **Disturbed –** Area has previously been considerably disturbed by anthropogenic activity.

Level of Confidence

An assessment of level of confidence or certainty of knowledge (i.e., low, moderate, and high levels) is provided based on confidence in the available scientific data when an effect is evaluated to have a negative residual effect on a VC. Level of confidence can be assessed as:

- High – Based on good understanding of cause-effect relationships and data specific to the Study Area.
- Moderate – Based on good understanding of cause-effect relationships using data from elsewhere or incompletely understood cause-effect relationships using data specific to the Study Area.
- Low – Based on incomplete understanding of cause-effect relationships and/or incomplete data specific to the Study Area.

Significance Definition

A significant residual negative effect on the Fisheries VC is considered to be of sufficient magnitude, duration, geographic extent, and/or irreversibility that will result in a change/disruption of fisheries activities to the extent that activities cannot occur as per the norm and there is concern or altered well-being of stakeholders (e.g., loss of access to a historically or culturally-important area or resource,

loss of income/revenue). The determination of significance is based on professional judgment but should be transparent and repeatable. A residual effect can be considered:

- Significant (negative by definition);
- Not Significant; or
- Positive.

5.5.4 Cumulative Effects

Cumulative effects refer to the effect a project or activity has on the environment when combined with the effects of other past, existing, and reasonably foreseeable projects and activities. Projects and activities that will be considered in the cumulative effects assessment include other anthropogenic activities (i.e., fisheries, other geophysical activities, and oil/gas activities, and marine transportation) in and adjacent to the Study Area. The assessment also considers the cumulative effects of within-Project activities. The assessment of cumulative effects is consistent with the principles outlined in the Impact Assessment Agency of Canada (IAAC) "Assessing Cumulative Environmental Effects under the Canadian Environmental Assessment Act, 2012"[6].

5.5.5 Assessment of Accidental Events

As per the Scoping Document (C-NLOPB 2024) a discussion of the potential for spill events, mitigation measures to reduce or prevent accidental events, and contingency plans to be implemented are provided. In addition, consideration of cumulative effects from a MKI spill event and illegal bilge disposal is provided.

5.5.6 Follow-up Monitoring

Follow-up monitoring is designed to confirm effects predictions and to establish the effectiveness of mitigation measures. MKI will conduct monitoring as outlined in Section 6.0.

5.5.7 Effects of the Environment on the Project

The assessment considers potential effects of the environment (i.e., weather, ice, and oceanographic parameters) on the Project.

6.0 Mitigation Measures and Monitoring

The effects assessments that follow (see Sections 7.0–9.0) consider the potential effects of the proposed Newfoundland offshore seismic and environmental data collection program in consideration of the specific mitigation measures that will be applied during this Project. The purpose of these measures is to eliminate or reduce the potential effects on VCs. MKI recognizes that the careful and thorough

[6] https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/assessing-cumulative-environmental-effects-under-canadian-environmental-assessment-act-2012.html

implementation of, and adherence to, these measures is essential for ensuring that the Project does not result in unacceptable environmental consequences.

This section details the various measures that will be established and applied for this Project. Collectively, they are based on several sources, including:

- Discussions and advice received during consultations for this Project (Section 2.6), and for other relevant EAs;
- The C-NLOPB Final Scoping Document (C-NLOPB 2024);
- DFO's Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment;
- National and international acts, regulations, or conventions, such as the SARA, *Fisheries Act* and Regulations (including the Marine Mammal Regulations [MMR]), *International Convention for the Prevention of Pollution from Ships* (MARPOL), and International Maritime Organization (IMO) standards;
- Other standards and guidance, such as the One Ocean *Protocol for Seismic Survey Programs in Newfoundland and Labrador* (One Ocean 2013);
- Industry best practices; and
- Expert judgement/experience from past seismic surveys.

Proposed mitigation measures are organized under the following principal categories:

- Survey layout and location;
- Communications and liaison;
- Fisheries avoidance;
- Fishing gear damage program;
- Avoidance of sensitive benthic habitat;
- Marine mammal, sea turtle, and seabird monitoring and mitigation; and
- Pollution prevention and emergency response.

Several of the mitigation measures listed under these categories are designed to mitigate potential effects on more than one VC (e.g., seismic array ramp-up/soft start can, in theory, deter marine mammals, sea turtles, and fish). Table 6.1 summarizes the measures by VC and type of effect. These measures will be adhered to during each survey year, with necessary adjustments based on monitoring and follow-up.

Table 6.1. Summary of mitigations measures by potential effect for each VC.

VC	Potential Effects	Primary Mitigation Measures
Fisheries	Interference with fishing vessels/mobile and fixed gear fisheries	• Pre-seismic survey communications, liaison, and planning to avoid fishing activity • Continuing communications throughout the seismic program • FLOs • Single Point of Contact (SPOC) • Advisories and communications • VMS data • Avoidance of actively fished areas by seismic surveys

VC	Potential Effects	Primary Mitigation Measures
		• Start-up meetings on ships that discuss fishing activity and communication protocol with fishers
Fisheries	Fishing gear damage	• Pre-seismic survey communications, liaison, and planning to avoid fishing gear • Use of escort vessel • SPOC • Advisories and communications • FLOs • Compensation program • Reporting and documentation • Start-up meetings on ships that discuss fishing activity, communication protocol with fishers, and protocol in the event of fishing gear damage
Fisheries [Other Ocean Users]	Interference with shipping [a]	• Advisories and at-sea communications for seismic surveys and placement of FLS • FLOs (fishing vessels) • Use of escort vessel • SPOC (fishing vessels) • VMS data
Fisheries	Interference with DFO/FFAW research program	• Communications and scheduling • MKI will work cooperatively with FFAW|Unifor and DFO in an effort to avoid survey stations prior to their sampling to the best extent possible. DFO does not indicate an official spatial and/or temporal buffer mitigation method for seismic operations in the vicinity of survey stations.
Fish and Fish Habitat Marine Mammals and Sea Turtles Marine-associated Birds	Temporary or permanent hearing damage/disturbance to marine animals (marine mammals, sea turtles, seabirds, fish, invertebrates) Damage to corals and sponges from OBNs	• "Pre-watch" (minimum 30 minute but 60 minutes in deep water areas) of 500 m safety zone using visual monitoring (daylight) and PAM (day/night) • Delay start-up if any marine mammals or sea turtles are detected within 500 m safety zone via visual monitoring/PAM • Ramp-up of airguns over a minimum of 30 minutes (during standard airgun operations and Gemini sound source) • Use of experienced, qualified MMSO(s) to monitor for marine mammals and sea turtles during all daylight periods when airguns are in use • Minimum separation distance of 30 km for simultaneous seismic surveys in the Project Area based on separation distances required in other jurisdictions (i.e., Gulf of Mexico [G. Morrow, PGS, Senior Contract Manager, pers. comm., June 2017 in LGL 2018] and Greenland [LGL 2012b] in LGL 2018) • Use of ROV to avoid corals and sponges during placement of OBNs.
Species at Risk Sensitive Areas	Temporary or permanent hearing damage/disturbance to Species at Risk or other key habitats	• "Pre-watch" (minimum 30 minute) of 500 m safety zone using visual monitoring (daylight) and PAM (day/night) • Delay start-up if any marine mammals or sea turtles are detected within 500 m safety zone via visual monitoring/PAM • Ramp-up of airguns over a minimum of 30 minutes (during standard airgun operations and Gemini sound source) • Shutdown of airgun arrays for *endangered* or *threatened* marine mammals and sea turtles, as well as beaked whales, within 500 m safety zone • Use of experienced, qualified MMSO(s) to monitor for marine mammals and sea turtles during daylight seismic operations. • Use of PAM for cetaceans (details to be provided in EA Updates)

VC	Potential Effects	Primary Mitigation Measures
		• Minimum separation distance of 30 km for simultaneous seismic surveys in the Project Area based on separation distances required in other jurisdictions (see above)
Marine-associated Birds	Injury (mortality) to stranded seabirds	• Daily search of seismic and support vessels based on ECCC-CWS guidance • Implementation of handling and release protocols • Minimize lighting if safe
Marine-associated Birds	Seabird oiling	• Adherence to MARPOL • Adherence to conditions of ECCC-CWS Scientific Permit (issued under the CWS *Migratory Birds Regulations*) • Spill contingency and response plans • Use of solid streamer

[a] MKI will engage Commander, Task Force (CTF) 84, through Director General Naval Strategic Readiness (DGNSR), to ensure de-confliction with possible Allied submarine activities.

There will be full opportunity for adaptive mitigation during MKI's proposed five-year program. If there are new techniques developed during the five-year period that may help to further mitigate environmental effects, they will be investigated and incorporated into the program if feasible. Annual updates of the EA that will be prepared during the five-year scope of the Project will include any relevant new information related to mitigation not provided in the EA. Typically, seismic surveys offshore Newfoundland do not require follow-up monitoring to verify the accuracy of EA predictions. The Environmental Report (see Section 6.1.6 below) will include an analysis of the efficacy of mitigation measures and include analyses examining the differences in marine mammal (and sea turtles if sighted) distribution and relative abundance during periods with and without airgun activity.

6.1.1 Planning Survey Layout and Location

Early planning of the layout of survey transect lines helps to reduce the probability of effects of VCs. A certain level of spatial and temporal flexibility associated with this planning serves as a mitigation measure for numerous VCs. Survey lines are more widely spaced for 2D versus 3D seismic surveys; therefore, potential exposures of VCs to activities within a survey area will occur more frequently for 3D surveys. However, the typical long and overall widely spaced lines of seismic surveys will result in only one-time close exposure to Project activities on the order of up to several hours, with potentially days or weeks between potential repeat exposure at a given point (e.g., where perpendicular lines cross or during line re-shoots).

6.1.2 Communications and Liaison

Communications and liaison will ensure that the Project does not operate in the area of active fisheries. A number of strategies associated with communications and liaison are available to serve as mitigation measures, including:

- Information exchange (information flow about current fishing activities must be a regular, continuous process).
- Weekly status updates.

- FLOs (primary at-sea liaisons between the commercial fishing industry and seismic program; communicate with fishing vessels from on board a seismic vessel; provide assistance if there are fishing gear damage incidents).
- SPOC (facilitates communication between the Project and other marine users, particularly those involved in the fisheries; assists if there are fishing gear damage incidents; broadcasts information via in Coast Guard Navigational Warnings [NAVWARNS; formerly Notices to Shipping, NOTSHIPs] and to fishers through their organizations).
- FFAW/One Ocean petroleum industry liaison contacts (primary means of information exchange regarding operational activities between the fishing and oil and gas industries in the region).
- VMS data (satellite based, near real time positional tracking system [i.e., coordinates] provided by DFO to One Ocean and accessed by the proponent to help avoid fishing locations and monitor other marine activities in the area for logistical and safety purposes).
- NAVWARNs (provided by the proponent to the CCG Radio/Eastern Canada Vessel Traffic Services Zone [ECAREG] advising updated information of the seismic survey's general operating area for the period covered by the NAVWARN and providing contact information [email and toll-free phone number] for the survey's Fishing Gear Damage Program [see below]).
- Survey start-up sessions (meetings between the proponent and at-sea personnel for all Project vessels prior to program start to ensure all personnel are informed of the environmental issues/concerns, commitments, and regulatory requirements in the survey area, safety protocols, emergency response, duties/authority of the MMSOs and FLOs, and cultural importance and legal status of Indigenous interests in the area).
- Consultation (see Section 2.6).
- Communications follow-up (the proponent will consult with fisheries groups and other stakeholders before and during the survey and conduct post-survey follow-up discussions with all interested groups; communications include reporting on survey progress, monitoring mitigation effectiveness, addressing survey-related issues that arose, and presenting monitoring results after survey completion. The proponent will also employ the latest technology in at-sea communications with/between survey ships [e.g., Very High Frequency (VHF) and High Frequency (HF) marine radios, satellite phone/internet, VMS] and provide information to the Canadian Broadcasting Corporation [CBC] Fisheries Broadcast).

6.1.3 Fisheries Avoidance

There are a number of measures MKI will implement to avoid interactions with fisheries as outlined below.

- Temporal avoidance of active fishing areas, to the best of the proponent's ability (related to communications with FFAW and fishers; fishers are not required to move their vessels/gear from the seismic survey program area and will not be told to do so);

- No seismic gear deployment until arrival within the Project Area (all gear deployments will occur within the Project Area; the FLOs will also advise the vessel while en route to the survey area to ensure avoidance of fishing gear);
- Spatial and temporal avoidance of active fisheries science surveys (reliant upon detailed information exchange between the proponent and DFO/Industry [depending on science survey type]; and
- Use of an escort vessel (local support vessel that accompanies the seismic vessel while on site during most of the program [may occasionally depart for re-fueling, crew change, repairs]; scouts ahead of the seismic vessel for fishing vessels/gear, hazards [e.g., ice, debris])
- During acquisition MKI has procedures in place to communicate activity to limit interactions with fishing vessels/gear:

12 Hour Look Ahead email

- Circulated to stakeholders directly from the vessel twice a day (0600 and 1800)
- Vessel position at start and end of period
- Current operational status (production, standby, etc.)

Weekly meeting (Teleconference)

- Typically, between MKI and FFAW and other stakeholders can be added as required
- Discuss any issues and the week ahead

Single Point of Contact

- Issues notice to shipping
- Hotline for harvesters
- Will be the communication point for disputes and damage claims

Fisheries Liaison Officer

- Onboard the vessel communicating with harvesters from the bridge
- Weekly report

6.1.4 Fishing Gear Damage Program

The proponent will prepare a Fisheries Compensation Plan in case the seismic survey activities result in gear/vessel damage and/or loss. This process involves the FLO and contact with the SPOC. A protocol developed by One Ocean (One Ocean 2013) describes responses to a gear conflict to be followed by those on a Project vessel.

Any incidents of contact with fishing gear with any identifiable markings will be reported to the C-NLOER within 24 h of the contact (in accordance with the C-NLOER Incident Reporting and Investigation Guidelines). Fishing gear may only be retrieved from the water by the gear owner (i.e., fishing license owner). This includes buoys, radar reflectors, ropes, nets, pots, etc., associated with fishing gear and/or activity. If gear contact is made during seismic operations, it should not be

retrieved or retained by the seismic vessel. There are conditions that may warrant gear being retrieved or retained if it becomes entangled with seismic gear; however, further clarification on rules and regulations regarding fishing gear should be directed to the DFO (NL Region). MKI will advise the C-NLOER prior to compensating and settling all valid lost gear/income claims promptly and satisfactorily.

6.1.5 Avoidance of Sensitive Benthic Habitat

During survey operations, OBNs may be deployed in a given year for acquiring imaging data. OBNs are deployed on to the seafloor in a grid pattern by a node installation vessel using an ROV. Each OBN will have a relatively small footprint (approximately 0.1 m^2) on the seafloor but their placement may impact sessile habitat forming species, such as corals and sponges. Deep-sea corals and sponges are slow growing, long-lived, fragile species that are important for fish habitat and susceptible to physical damage. To mitigate potential impacts with corals and sponges, the ROV will conduct a visual survey for a suitable deployment location for each OBN (within approximately 5 m of the planned deployment location). A suitable location will be selected to avoid contact with sensitive corals and sponges (e.g., gorgonians or black corals) to the extent possible. Deployment with ROV will aim to have OBNs positioned at least 2 m from habitat forming corals and sponges (as outlined in Annex A in DFO 2023e). When deploying/retrieving OBNs on the seafloor by ROV, the ROV will make all efforts to avoid contact with corals and sponges.

6.1.6 Marine Mammals and Sea Turtles

The following mitigation measures meet or exceed the requirements for marine fauna included in the *Statement of Canadian Practice*.

- The establishment of a safety zone with at least a 500-m radius measured from the airgun source array.
- The seismic vessel's bridge will be used by MMSOs to conduct visual observations (i.e., good sight lines all around the vessel), and the use of reticle binoculars and/or other distance estimators to accurately estimate the location of the animal with respect to the safety zone. MMSOs will watch for marine mammals and sea turtles during daylight periods and use standardized data collection protocols to record the location and behaviour of marine mammals and sea turtles.
- Implementation of a pre-start up watch ('pre-watch') of the safety zone by a qualified and experienced MMSO and PAM Operator for at least 30 minutes prior to array start-up. If a marine mammal or sea turtle is detected within the safety zone during the 30-minute pre-watch, ramp up cannot commence until the animal leaves the zone or the animal has not been seen (MMSO)/detected (PAM) for at least 30 minutes (1 hour for beaked whales). These mitigation measures will also be implemented if the MMSO or PAM Operator believes that there is a reasonable chance a marine mammal or sea turtle seen 500 m ahead/to the side of the vessel will subsequently fall within 500 m of the airguns.
- If array activation is permitted, based on the pre-watch, a gradual ramp up/soft start of the airgun source array may take place over a minimum period of 30 minutes, starting with the smallest airgun and gradually adding airguns at evenly spaced intervals until all

airguns are active. Ramp up is intended to provide a warning to marine fauna before they are exposed to the higher sound levels from the full airgun array. Ramp-up procedures should be implemented when airgun(s) have been off for ≥20 minutes. If applicable, a ramp up will be implemented during the transition from single airgun use between lines ('mitigation gun') to operation of the full airgun array.

- The airgun source array(s) will be shut down immediately if a marine mammal or sea turtle with either *endangered* or *threatened* status on Schedule 1 of SARA is detected within the safety zone. For the Study Area, this currently includes North Atlantic right whales, blue whales, northern bottlenose whales, leatherback sea turtles, and loggerhead sea turtles. Note that MKI also commits to implementing shut downs for all sea turtle species and all beaked whales, including Sowerby's beaked whale. The airgun array will be shut down until the animal has left the safety zone or has not been seen (MMSO)/detected (PAM) for 30 minutes (1 hour for beaked whales). If the shut down occurs for ≥20 minutes, ramp up procedures will be implemented.
- When seismic surveying ceases during line changes, maintenance or other operational reasons, the airgun source array(s) will either be shut down completely or reduced to a single source element (i.e., mitigation gun in the case of the standard airgun array).
- Marine mammal, sea turtle, and seabird observations will be made by qualified and experienced MMSOs during operations, including those related to marine mammal behavioural responses to the vessels and airgun source array(s). Visual observations will be made by the MMSOs during all daylight periods, including when airguns are active, pre-watch, and all other daylight periods when possible. PAM will be conducted during pre-watch (day/night), during periods of poor visibility during daytime (e.g., dense fog), and during nighttime periods.
- Any dead or distressed marine mammals or sea turtles will be recorded and reported to the C-NLOER (and DFO as required).

The results of the marine mammal and seabird monitoring program will be included in an Environmental Report to be submitted to the C-NLOER. This report will be submitted to the C-NLOER by 31 January the following year as per C-NLOPB (2024) or withing 90 days after the seismic survey ends (CNSOPB and C-NLOPB 2024); whichever, the C-NLOER requires. Observational data for marine mammals, sea turtles, and seabirds will be analyzed, and raw data will be provided. The report will include a description of the mitigation measures and monitoring protocols identified in the EA and implemented in the field (i.e., ramp ups, shut downs, and ramp-up delays) with an assessment of the efficacy of these measures. The Environmental Report will include analyses examining the differences in marine mammal (and sea turtles if sighted) distribution and relative abundance during periods with and without airgun activity—this will offer some insight into behavioural responses of these animals, which can be compared to information presented in the EA. The report will also include a summary of the monitoring program performance relative to reducing environmental risk.

In the unlikely event that marine mammals, sea turtles, or birds are injured/killed by Project equipment or accidental fuel spills, a report will be immediately filed with the C-NLOER and the need for follow-up monitoring will be assessed.

6.1.7 Seabird Monitoring and Mitigation

A daily search of the seismic vessel will be conducted by a qualified and experienced MMSO and other Project vessels will be searched by the ship's crew in accordance with *Guidance for Developing Systematic Stranded Bird Survey Protocols for Vessels and Platforms* (ECCC-CWS 2021). Any seabirds that become stranded on vessels during Project activities will be released or sent to shore (as appropriate) using mitigation methods consistent with *Procedures for Handling and Documenting Stranded Birds Encountered on Infrastructure Offshore Atlantic Canada* (ECCC 2017b), *ECCC-CWS Guidance for Developing Systematic Stranded Bird Survey Protocols for Vessels and Platforms* (ECCC-CWS 2021), and the ECCC-CWS Scientific Permit (which will be acquired by MKI). Bird stranding data will be submitted in the required format and within the timeline stipulated on the Scientific Permit for handling stranded birds.

Seabird surveys (i.e., standardized counts) will be conducted throughout the seismic program from the seismic vessel by MMSOs experienced in the identification of seabirds at sea in accordance with the latest ECCC-CWS protocols (e.g., Gjerdrum et al. 2012). Each seabird survey will be conducted from a port or starboard bridge wing and consist of a series of consecutive, 5-minute watch periods (ideally for a total of 1 hour) at least three times per day (morning, mid-day, late afternoon/early evening) and opportunistically during periods of high bird abundance when conditions allow (e.g., visibility ≥300 m, no overlap with pre-watch/ramp up).

6.1.8 Pollution Prevention / Emergency Response

MKI has an established Environmental Management Procedure. Regarding pollution prevention the environmental issues that will be considered in this procedure are waste generation and disposal, effluent discharges to sea, emissions to air and spills. Key relevant components are summarized below.

6.1.8.1 Waste Management

Wastes produced during activities, including hazardous and non-hazardous material, will be managed in accordance with MARPOL 73/78 regulations and the Waste Management and Disposal and the specific Waste Management Plan for the vessel. All solid wastes will be sorted by type, compacted where practical, and stored on board until disposal at an appropriate certified reception facility.

6.1.8.2 Discharge Prevention and Management

Project vessel discharges will not exceed those of standard vessel operations and will adhere to all applicable regulations. The primary discharges include grey water (e.g., wastewater from washing, bathing, laundry, and food preparation), black water (e.g., human wastes), bilge water, deck drainage and discharge from machinery spaces.

6.1.8.3 Atmospheric Emission Control

Project vessels will have an International Air Pollution Prevention Certificate issued under the provisions of the Protocol of 1997 as amended by resolutions MEPC 328 (76) in 2021 and MEPC 176 (58) in 2008, to amend MARPOL, 1973, as modified by the Protocol of 1978. Air emissions will be those associated with standard operations of marine vessels in general.

6.1.8.4 Response to Accidental Events

MKI will implement the measures outlined in the Shipboard Oil Pollution Emergency Plans (SOPEPs) which will be filed with the C-NLOER. In addition, MKI has an Emergency Response Procedure in place which bridges the emergency plans of all Project entities and vessels to the local facilities and the Halifax Search and Rescue Region. The vessels also carry Spill Kits and in the event of a spill, the seismic and support (i.e., picket) vessel(s) would work together to respond to and contain the released hydrocarbons.

6.1.8.5 Use of Streamers with a Solid Core

MKI will use a solid core streamer, thereby removing any risk of fluid leakage.

7.0 Effects of the Environment on the Project

Project activities may be affected by environmental conditions in the Project Area—particularly ice conditions; weather, sea state, and currents; and in rare cases the presence of sharks that may damage seismic equipment. In addition, given that OBNs and FLS will contact the seafloor, the presence of shipwrecks and Unexploded Explosive Ordnance (UXO) are of relevance.

7.1 Ice Conditions

Seismic surveys will occur during the 1 May–30 November period; the likelihood of sea ice in the Project Area during this period is low and ice coverage levels are trending downwards (see Section 3.4.1). Likewise, iceberg numbers in the Project Area have decreased in recent years with most (87%) icebergs present during March through May. MKI will plan surveys to avoid areas with ice and icebergs. It is possible that seismic survey lines may need to be altered due to ice early in the survey period, but survey modifications are not uncommon and would have minimal effect on the overall Project. It is possible that the FLS may be installed in an area that experiences sea ice and/or icebergs but based on previous experience the FLS can manage some ice so the risk of damaging the FLS is considered very low.

7.2 Weather and Sea State

Most environmental constraints on seismic surveys on in the Project Area are those imposed by wind and wave conditions. In general, the quality of seismic data can be compromised by noise when the Beaufort Wind Force is seven (i.e., wind speeds of 50–61 km/h) or higher. In the Study Area, these

conditions are uncommon during most of the survey period. If the sea state exceeds 3.0 m or wind speed exceeds 40 kt (74.1 km/h), then continuation/termination of seismic surveying is evaluated. Based on a review of multi-year data in the Study Area (see Section 3.2), these wave limits are typically approached during the October–April period. Seismic vessels typically suspend surveys once wind and wave conditions reach certain levels because the ambient noise affects the data. They also do not want to damage towed gear which would cause costly delays. However, these issues may be offset by the possible use of OBNs. The Project scheduling avoids most of the continuous extreme weather conditions.

Poor visibility (e.g., due to inclement weather or fog) can constrain streamer repair if required and deployment, maintenance, and retrieval of equipment (OBNs, FLS). It also will negatively affect the detection of marine mammals and sea turtles within and near the 500-m safety zone as well as other vessels and fishing gear. These constraints are mitigated by weather forecasting, the use of radar and FLOs to detect fishing vessels and gear, and the use of PAM for marine mammal vocalizations during certain periods.

Environmental effects on other Project vessels (e.g., support and supply vessels) are likely less than on the seismic vessel, which is constrained by safety of towed gear and data quality issues.

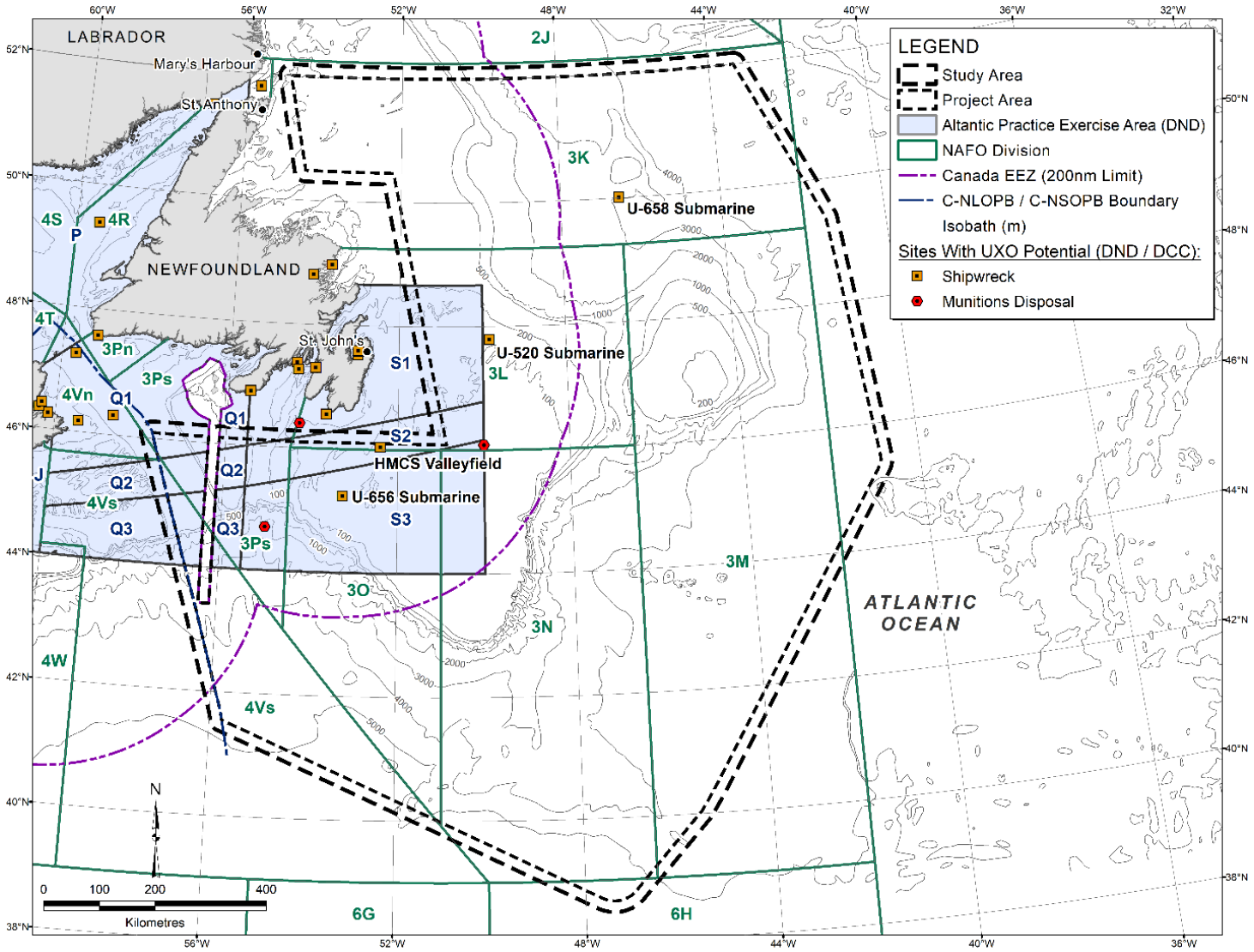
7.3 Sharks

Effects of the biological environment on the Project are unlikely although there are accounts of sharks attacking and damaging streamers (e.g., Rølvåg et al. 2020). If a streamer is damaged by a shark, it will be recovered and either repaired or replaced.

7.4 Shipwrecks and UXO

The Department of National Defence (DND) records indicate that there are at least two Unexploded Explosive Ordnance (UXO) sites of concern in the Project Area and one just outside of the Study Area (Figure 7.1). In addition, there are four known naval shipwrecks in the Project Area with at least one (U-520 Submarine) having potential munitions (Figure 7.1). MKI will avoid deployment of OBNs and FLR in areas with known UXO and shipwrecks. Due to the inherent dangers of associated UXO and the fact that the NW Atlantic Ocean was exposed to many naval engagements during World War II (WWII), any suspected UXO encountered during Project operations will be geo-referenced, immediately reported to the Coast Guard (Joint Rescue Centre), and left undisturbed.

In summary, residual effects of the environment on the Project are predicted to be *not significant* for the reasons discussed above.



Source: N. Monteiro, UXO Legacy Sites Program Manager, DND, pers. comm., November 2023.

Figure 7.1. Unexploded Explosive Ordnance (UXO) sites of concern within the Study Area.

8.0 Effects of the Project Activities on the Environment

This effects assessment is organized so that potential effects generic to ship activity in the Study Area are discussed first. The detailed effects assessment that follows focuses on the effects of noise (primarily on marine mammals, fish/invertebrates, and fisheries) from the airgun array(s) and the towed seismic streamers/OBNs (primarily on fishing gear), which is the major distinction between the effects of seismic surveys versus those of other marine vessels. In addition, the potential effects of FLS are assessed. The applicable mitigation measures (Section 6.0) are also noted for the relevant activity and effects relevant to climate change are discussed where applicable. Detailed literature reviews of the effects of seismic airgun sound on marine invertebrates, fish, marine mammals, and sea turtles are provided in Appendices A-D. The detailed assessments consider the generic effects in the criteria ratings and predictions tables but do not discuss these generic issues in detail.

8.1.1 Generic Vessel Activities - Air Quality

The atmospheric emissions from Project activities will be those from the Project vessels' engines, generators, and incinerators. Project atmospheric emissions will be within the range of emissions from typical marine vessels on the east coast, such as fishing, research, or offshore supply vessels.

Most (~90%) of greenhouse gas emissions (GHG) from ships are from international shipping (Bodansky 2018). An analysis of GHG emissions at ports in four countries (Sweden, U.S., Japan, and Australia) identified four primary mitigation measures to reduce GHG-emissions by vessels, including reduced speeds, using an on-shore power supply while in port, minimizing turnaround times at port, and using alternative fuels to heavy marine diesel (Styhre et al. 2017). Project seismic vessels would typically only be in port to receive regulatory clearance and local crew embarkation at the start of a given data collection season and possibly once at season end for local crew to disembark; otherwise, support vessels would typically be in port approximately once per week for ~1–2 days for refuel/resupply/crew change purposes. Overall, Project vessel turnaround times at port are minimized to the extent possible for operational efficiency. Project vessels would also typically use economic speeds while transiting to minimize fuel consumption, and seismic vessels use slow speeds (generally ~4.4–4.9 knots) while collecting 2D, 3D, or 4D data. Given that the Project will use low sulphur content (no more than 0.1%) fuel (following Canadian 2015 sulphur emissions standards [Transport Canada Ship Safety Bulletin No. 08/2014] for vessels in Canadian waters south of 60^{o}N) and that it will add negligible atmospheric emissions (relative to total NW Atlantic ship traffic) to a windy oceanic environment, there will be no measurable negative effects on VCs in the Study Area.

Recently, machine learning has been suggested as a means by which to reduce emissions and potential impacts on climate change, such as developing algorithms to optimize fuel consumption for vessels (Durlik et al. 2023). Additionally, although not applicable to the Project at this time, it is of note that new shipping vessel builds in some countries are increasingly focussing on vessels being able to use green fuels, including over half of all new builds in Denmark commissioned as of late 2023 (Prevljak 2023). Should any new such technologies become relevant to the Project, they will be addressed in future EA Updates.

8.1.2 Generic Vessel Activities - Marine Users

In a given year, Project-related traffic will typically include one to two seismic survey vessels, one support/supply vessel, and one to two escort vessels (see Section 2.2 for additional details). During OBN deployment and retrieval, a dedicated node installation vessel will be used. Likewise, during FLS deployment, servicing, and retrieval a support vessel will be utilized. The seismic and support vessels will operate within the Project Area (see Figure 1.1), except when transiting to or from the survey area and FLS installation sites. During transit, a direct route will be taken to the extent possible. The support and escort vessels will transit to and from the Project Area for re-provisioning, re-fuelling, and crew changes. The escort vessel will be onsite with the seismic vessel when the seismic vessel is acquiring data. If the escort vessel is to be unavoidably absent from the operational area and/or is unable to perform its duties for any reason, the seismic operator will perform a risk assessment of their ongoing operations and plan and implement risk mitigation measures to minimize the potential for negative interaction with commercial fishers. The risk assessment and type of mitigations expected were previously communicated to MKI by the C-NLOPB (LGL 2017a).

Other ships operating in the area could include freighters, tankers, fishing vessels, research vessels, naval vessels, and private yachts (see Section 9.1.2). Mitigation measures (detailed in Section 6.0) intended to minimize potential negative interactions with other vessels include the following:

- At sea communications (VHF, HF, Satellite, radar etc.);
- Utilization of FLOs for advice and coordination regarding avoiding fishing vessels and fishing gear;
- Escort vessel(s) to alert other vessels of towed gear in water;
- Posting of advisories with the CCG and CBC Fisheries Broadcast (e.g., NAVWARNs, Notices to Mariners, Notice to Airmen [NOTAM]);
- Compensation program in the event any Project vessels damage fishing gear; and
- SPOC.

MKI will also coordinate with DFO, St. John's to avoid any potential conflicts with research vessels that may be operating in the area, and will engage with CTF 84, through DGNSR, to ensure de-confliction with possible Allied naval activities. Given the expected number of vessels in the Project Area and mitigation measures described above, there should be *negligible* adverse effects on other marine users of the Project Area.

8.1.3 Generic Vessel Activities - Waste Management

Project waste will be generated by about 55–85 personnel at a given time, depending on total crew sizes for all vessels combined as well as wastes generated from typical vessel operations. Waste will include the following.

- Gray/black water;
- Galley waste; and
- Solid waste.

Vessel discharges will not exceed those of standard vessel operations and will adhere as a minimum to all applicable regulations and international standards. The main discharges include grey water (wastewater from washing, bathing, laundry, and food preparation), black water (human wastes), bilge water, deck drainage, and discharges from machinery spaces. Wastes produced from Project vessels, including hazardous and non-hazardous waste material, will be managed in accordance with MARPOL and with the vessel specific waste management plans.

Waste produced by the Project will be managed and treated appropriately and, therefore, will have *negligible* effect on the environment and VCs in the Project Area, including the Marine-associated Bird VC.

8.1.4 Fish and Fish Habitat VC

The potential effects of seismic survey activities on fish and fish habitat have previously been reviewed in Section 4.5 in C-NLOPB (2010), Section 5.1 in C-NLOPB (2014), Section 4.2.1 in IAAC (2020), as well as previous EAs for seismic programs offshore Newfoundland and Labrador (e.g., LGL 2015; 2016; 2018). The assessment also includes consideration of potential interactions of the FLS with fish and fish habitat.

Potential interactions between Project activities and the FFH VC are shown in Table 8.1. Given that Project activities will variably interact with different components/life stages of the FFH VC (Table 8.1), these details are highlighted and discussed as appropriate. Note that ichthyoplankton, invertebrate eggs and larvae, and macrobenthos are considered part of the 'fish' component of the FFH VC.

Table 8.1. Potential interactions between Project activities and the Fish and Fish Habitat VC.

VC: Fish and Fish Habitat							
Project Activities	Water and Sediment Quality	Feeding		Reproduction		Adult Stage [b]	
		Plankton	Benthos	Eggs and Larvae	Juveniles [a]	Pelagics	Groundfish
Sound							
Airgun Array		X	X	X	X	X	X
Project Vessels		X	X	X	X	X	X
Echo Sounder/ Side Scan Sonar						X	
Vessel/Equipment Presence							
Seismic Vessel and Streamers							
OBNs			X		X		X
Project Support Vessels							
Vessel Lights		X				X	
ROVs					X		X
Floating LiDAR Systems			X		X	X	X
Sanitary/Domestic Waste	X	X		X		X	
Atmospheric Emissions	X	X		X		X	
Accidental Releases	X	X	X	X	X	X	X
Garbage [c]							
Shore Facilities [d]							

VC: Fish and Fish Habitat							
Project Activities	Water and Sediment Quality	Feeding		Reproduction		Adult Stage [b]	
		Plankton	Benthos	Eggs and Larvae	Juveniles [a]	Pelagics	Groundfish
Other Projects and Activities in Region of the Study Area							
Oil and Gas Activities	X	X	X	X	X	X	X
Fisheries	X	X	X	X	X	X	X
Marine Transportation	X	X	X	X	X	X	X

[a] Juveniles are young fish that are no longer planktonic and are often closely associated with the sea bottom.
[b] Includes fish and shellfish species.
[c] Not applicable as garbage will be brought ashore.
[d] There will not be any new onshore facilities. Existing infrastructure will be used.

8.1.4.1 Sound

The potential effects of exposure to airgun sound on invertebrates and fishes can be categorized as either physical (includes both pathological and physiological) or behavioural. Pathological effects include lethal and sub-lethal damage; physiological effects include temporary primary and secondary stress responses. Behavioural effects refer to deviations from normal behavioural activity. Physical and behavioural effects are very likely related in some instances and should therefore not be considered as completely independent of one another.

Sound detection and production by marine invertebrates and fishes and potential effects of sound from routine activities on fish habitat and fish and invertebrates are provided in Sections 4.5.1.1–4.5.1.2 in C-NLOPB (2010), Section 5.1 in C-NLOPB (2014), Section 4.2.1 in IAAC (2020). As per the Scoping Document, information previously published in these reports is not repeated here. Updated literature-based reviews on the potential effects of seismic airgun sounds on marine invertebrates and fish and overviews of known acoustic abilities (current as of May 2025) are provided in Appendices A and B, respectively.

Sound Exposure Effects Assessment

As in previous seismic program EAs for the Study Area, the assessment focused on key issues by selecting (1) the sound source with the highest sound pressure level, in this case the non-Gemini configuration of seismic airgun array, and (2) species that are both representative of the different types of sensitivities to underwater sound and have been scientifically studied with respect to effects of underwater sound, such as snow crab and Atlantic cod. These two species are also culturally and socio-economically important for the region, including for commercial, recreational, and Indigenous fisheries. It is recognized that noise generated by Project vessels could result in at least temporary avoidance by sensitive species (see Table 5.1 in C-NLOPB 2014) and some species (e.g., herring family) may exhibit minor behavioural responses to echosounder and side scan sonar use (the hearing range of most fish does not include frequencies used by echosounders; Kok et al. 2021; DOSITS 2025), effects are considered negligible—particularly relative to sound produced by the airgun arrays.

The primary factors considered in the assessment include (1) distance between airgun array and animal under normal conditions (post-larval snow crabs remain on bottom, post-larval cod occur in the water column, and larvae of both snow crab and cod are planktonic in upper water column);

(2) motility of the animal (post-larval snow crabs are much less motile than post-larval cod, and larvae of both are essentially passive drifters); (3) absence or presence of a swim bladder (i.e., auditory sensitivity; snow crabs are without a swim bladder and cod possess a swim bladder); and (4) reproductive strategy (snow crabs carry fertilized eggs at the seabed until larval hatch, and cod eggs are planktonic).

Potential effects on other marine invertebrate and fish species are inferred from the assessment using snow crab and Atlantic cod as representative species of the FFH VC.

Although research on the effects of exposure to airgun sound on marine invertebrates and fishes is increasing (e.g., Solé et al. 2023; McQueen et al. 2025 [seismic sparker]), data gaps remain, including but not limited to the effects of anthropogenic underwater sound on marine invertebrate larvae (Hawkins et al. 2015; Solé et al. 2023).

Physical and Physiological Effects

Considering typical source levels associated with commercial seismic airgun arrays, invertebrates or fish (all life stages) could be exposed to high sound levels. Pelagic egg and larval stages cannot actively move away from the sound source and may be physically affected by exposure to airgun sound at close range (see Sections 5.1.2–5.1.4 in Appendix A and Section 3.1.2 in Appendix B), but mobile juveniles and adults can actively avoid exposure, including Atlantic cod. While developing snow crab embryos, juveniles, and adults are benthic and typically too far from the sound source to receive effect-inducing energy levels, their fertilized eggs are pelagic and may experience physical effects. However, in terms of eggs and larvae, it is likely that the numbers potentially negatively affected by exposure to seismic sound would be negligible when compared to those succumbing to natural mortality (see Section 5.1.2 in Appendix A and Section 3.1.2 in Appendix B). In-situ field experiments in the NL Region with adult male snow crab eligible for the commercial fishery involved multi-year sampling on commercial fishing grounds offshore NL before and after seismic surveying was conducted (Morris et al. 2019). No significant differences were observed relative to the short-term (i.e., hours to days) passage of seismic survey vessels with active airguns for catch rate, behaviour (i.e., movement patterns), physical injury (i.e., to internal organs), or genomics (Morris et al. 2019). Although interannual variability was observed in terms of catch rates, movement, physiology, and genomic response, these were only measurably attributable to variables such as water temperature, depth, time of day, and specific location. The authors concluded that if there were impacts on commercial male snow crab from seismic surveying, they were indistinguishable from and within the range of natural variability (Morris et al. 2019).

Particle motion is the component of underwater acoustic stimuli generated partly by hydrodynamic flow near the acoustic stimulus source and partly by the oscillations associated with the sound pressure waves as they propagate from the acoustic source as a cyclic compression and rarefaction of water molecules (Higgs et al. 2006 in LGL 2018). Some seismic interface waves can be propagated in seabed substrates, including particle motion in the sediment and water (Solé et al. 2023). Sensitive marine invertebrates species generally experience impacts resulting from the in-body vibration caused by particle motion moving through the water or substrate (Solé et al. 2023). New Zealand scallop (*Pecten novaezelandiae*) larvae have recently been observed to experience negative effects from

exposure to high levels of airgun noise, high in-situ mortality has been observed for some small copepod and krill species, and hatchlings of three copepod species (*Sepia officinalis*, *Loligo vulgaris*, *Illex coindetii*) have been found to be more at risk of damage to sensory epithelia in the statocyst and lateral line system compared to older individuals, while low in-situ mortality has been observed for larger-sized *Calanus* spp. copepods (Solé et al. 2023). These findings, along with those from older studies noted in Solé et al. (2023; see also Appendix A), highlight the considerable variability in terms of sound sensitivity that exist between different life stages and invertebrate species, even those that are closely taxonomically-related.

Although there remains a data gap regarding the effects of exposure of benthos to substrate vibration and energy waves associated with the water-substrate interface and substrate, recent studies investigating the effects of substrate-borne vibrations from impulsive pile driving have indicated measurable effects. Giant scallop (*Placopecten magellanicus*) demonstrated increased energy expenditure (and, therefore, increased vulnerability to predation) in the form of valve closure induction (Jézéquel et al. 2023) and fiddler crab (*Austruca lactea*) evidenced movements with increased velocity and overall shorter durations, suggesting such vibrations could be a stressor for sensitive species (Joo and Kim 2024). The applicability of these studies to species in the Study exposed to Project seismic sound is unknown.

Fish with swim bladders, such as Atlantic cod, are generally more sensitive to underwater sounds than those without this organ. The mitigation measures of avoiding critical life history periods and associated important areas (e.g., known spawning aggregations) and ramping-up of the airgun array should mitigate risks associated with this increased sensitivity, particularly at the population level. Snow crab are thought to only be sensitive to the particle motion component of sound (see Sections 3.0 and 3.2 in Appendix A), but benthic life stages are unlikely to be affected by water-column particle motion resulting from airgun discharge owing to their distance from the airguns. Although there is a lack of knowledge regarding potential effects for benthos to substrate vibration and energy waves associated with the water-substrate interface and substrate (as noted above), in situ studies in the NL offshore suggest minimal sensitivity for species/life stages such as adult male snow crab (Morris et al. 2019).

As indicated above and in Appendices A and B, some studies have suggested that marine invertebrate and fish species and/or life stages sensitive to sounds <500 Hz may experience physiological or pathological effects from exposure to airgun sound. However, most studies include unrealistic conditions involving high level exposures at very close range without means of escape (for mobile fauna) and focus on the effects of exposure on individuals rather than populations. Physical effects tend to be most obvious after intense exposure at close range.

Behavioural Effects

In terms of behavioural changes for fish and invertebrates, depending on the species/life stage, activity of individuals when exposed to low frequency sound (e.g., spawning, feeding, resting, transiting), testing scenario (i.e., in situ vs. laboratory-based), and characteristics of the sound, effects tend to be temporary with variable durations. Documented behavioural effects from airgun sound exposure have included startle or alarm responses (e.g., altered movement patterns, displacement

from/movement within an area, tightening of schools, random movement/orientation) that have been found to last anywhere from minutes or hours up to several days before normal behaviour/distribution was re-established (see Section 5.3 in Appendix A and Section 3.2 in Appendix B). Depending on the behaviour of a fish or invertebrate at the time of exposure, it is possible that biota may have a higher (e.g., while spawning/feeding) or lower (e.g., while migrating) response threshold to anthropogenic sound (see Section 5.1.4 in Appendix A and Section 3.2 in Appendix B). Spawning Atlantic cod did not abandon spawning grounds off Norway following exposure to simulated seismic surveys (i.e., intermittent activation of two, 40-in^3 airguns, 110 bar pressure, 223 dB re 1 µPa m every 10 s) for one week during two consecutive spawning years; McQueen et al. 2022). Sound exposure levels were up to ~145 dB re 1 µPa^2 s, which was considered representative of a seismic survey occurring several kilometres away from the site. Additional study of cod on their spawning grounds using the same equipment off Norway, revealed variable but weak responses by individuals, including swimming at a slightly deeper average depth during exposure relative to silent periods (McQueen et al. 2023). There were no longer-term effects detected for swimming depth, and there were no observed changes in swimming acceleration, displacement, or area use, suggesting that cod behaviour during spawning is not substantially affected from somewhat distant (i.e., sound exposure levels 115–145 dB re 1 µPa^2 s) seismic surveys over a five-day period (McQueen et al. 2023). McQueen et al. (2025) did not observe behavioural responses in wild, free-ranging, feeding Atlantic cod off Norway exposed to near continuous (pulse every 0.5 s; 2-h exposure durations) sparker seismic sound exposure levels up to 130 dB re 1µPa^{2}s over 10 s (~0.1–10 kHz frequency) from a moving research vessel (it should be noted the study involved a low number of wild tagged cod, n = 12). The sound signals produced by seismic sparkers have lower exposure levels than airguns but considerably higher frequencies, and these devices are typically used in shallower waters than airguns (e.g., Keen et al. 2018).

Some studies have reported interspecies differences in terms of catchability following exposure to seismic sound, including decreased catch rates in trawls and longlines (e.g., Engås et al. 1996), and higher catches in gillnets but lower on baited hooks (Løkkeborg et al. 2012). For the gillnets and baited hooks, these differences were possibly due to increased random movement by fish resulting in a higher incidence of catch in gillnets but lower for fish targeting baited hooks (Løkkeborg et al. 2012). No changes in catch rates attributable to the passage of a seismic vessel with active airguns were observed from multiple years of study on adult male snow crab of commercial size on commercial fishing grounds off NL (Morris et al. 2019).

Assessment of Effects of Exposure to Sound

It is anticipated that in most survey years, MKI will conduct a single seismic survey. However, it is possible that three 3D/4D seismic surveys and one 2D seismic survey may occur simultaneously (worst-case scenario). MKI seismic vessels used for simultaneous 3D/4D and 2D surveys will maintain a minimum separation distance (>30 km) when operating airgun arrays in the Project Area. This is expected to decrease the probability of synergistic effects on fishes and invertebrates. Relative to the effects predictions made for a single 2D or 3D/4D seismic survey, the potential residual effects on the FFH VC related to sound from three simultaneous 3D/4D seismic surveys and one 2D seismic survey (worst-case scenario) is predicted to occur over a larger area (i.e., maximum geographic extent of *1001–10,000 km^2* vs. *101–1000 km^2*; Table 8.2). With mitigation measures in place (see Table 6.1),

residual effects on the FFH VC associated with sound from the Project during simultaneous 3D/4D and 2D seismic surveys are predicted to range from *negligible to low* in magnitude for a *short-term* duration (i.e., restricted to duration of Project activity) over a geographic extent of *<1 km² to 1001–10,000 km²*, and to be *regular* to *continuous* in frequency. Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on the life stage (e.g., hatchling vs. adult; pelagic vs. benthic) and seasonal activity of fish and invertebrates (e.g., reproduction vs. migration), and effects are considered *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of underwater sound on the FFH VC are predicted to be *not significant* (Table 8.3). The level of confidence associated with this prediction is *low* to *high* given the scientific data gaps, particularly those involving the effects of airgun sound and in-sediment vibration on species in the Study Area and effects at the population level.

8.1.4.2 Vessel/Equipment Presence

The reader is referred to Section 4.5.9.1 in C-NLOPB (2010), Section 5.1 in C-NLOPB (2014), and Section 4.2.1.1 in IAAC (2020) for potential interactions/effects relating to vessel/equipment presence on fish and fish habitat. New and/or additional information relative to these reports is provided below.

Seismic Vessel and Streamers

The presence and passage of the seismic vessel(s) and streamers cause temporary, small-scale physical disturbance to the water surface and upper water column, including displacement from the vessel and equipment themselves, their wake, and propeller wash. Given the water depth range in the Study Area and distance from shore, the presence of seismic vessels and streamers would not result in alterations to or resuspension of sediment from the seabed or in shoreline erosion. The Study Area regularly experiences the presence and passage of large vessels, particularly shipping vessels, vessels associated with oil and gas production facilities, and larger fishing vessels (see Section 9.1.2). Surface water disturbance from the passage of a seismic vessel and streamers would be well within the normal, natural disturbance/mixing regularly experienced in the offshore Newfoundland region, which frequently has or is subject to moderate to high sea states and storm conditions, even during the relatively calmer spring through early fall months.

With mitigation measures in place, residual effects on the FFH VC from the presence of seismic vessel(s) and streamers are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km² to 11–100 km²*, and *continuous* in frequency (Table 8.2). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on the life stage and seasonal activity of fish or invertebrates at or near the surface, and be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of seismic vessel(s) and streamers on the FFH VC are predicted to be *not significant* (Table 8.3). The level of confidence associated with this prediction is *high*.

Table 8.2. Assessment of effects of Project activities on the Fish and Fish Habitat VC.

VC: Fish and Fish Habitat									
Project Activity	Nature of Environmental Effect (Neutral, Positive [P], or Negative [N])	Mitigation	Evaluation Criteria for Assessing Environmental Effects						
			Magnitude	Geographic Extent	Timing	Frequency	Duration	Reversibility	Ecological / Socio-Economic Context
Sound									
Airgun Array	Physical Effects (N); Disturbance (N)	Ramp-up of array; Spatial & temporal avoidance	N-L	1-5	N-M	R	ST	R	D
Project Vessels	Disturbance (N)	Spatial & temporal avoidance	N-L	1-2	N-M	C	ST	R	D
Echo Sounder/ Side Scan Sonar	Disturbance (N)	Spatial & temporal avoidance	N-L	1	N-M	C	ST	R	D
Vessel/Equipment Presence									
Seismic Vessel and Streamers	Disturbance at Surface (N)	Limited footprint (vessel/wake); Short residence in any given location; Slow speeds while streamers deployed	N	1-3	N-M	C	ST	R	D
OBNs	Benthic Disturbance (N)	Small footprint for each OBN; Short deployment time; Visual inspection for corals/sponges before installation if using ROV	N	1-4	N	C	ST	R	D
Project Support Vessels	Disturbance (N)	Limited footprint (vessel/wake); Short residence in any given location; Slow speeds while accompanying seismic vessel	N	1-2	N-M	C	ST	R	D
Vessel Lights	Attraction (Neutral)	-	-	-	-	-	-	-	-
ROVs	Disturbance (N); Physical Effects (N); Attraction to lights (Neutral)	Limited footprint (ROV, water displacement from thrusters); Short residence at a given deployment site; Slow speeds	N	1	N	R	ST	R	D
Floating LiDAR Systems	Disturbance at Surface (N); Benthic Disturbance (seabed	Small footprint (unit at surface; seabed frame); Powered by	N	1	N	C	ST	R	D

VC: Fish and Fish Habitat									
Project Activity	Nature of Environmental Effect (Neutral, Positive [P], or Negative [N])	Mitigation	Evaluation Criteria for Assessing Environmental Effects						
			Magnitude	Geographic Extent	Timing	Frequency	Duration	Reversibility	Ecological / Socio-Economic Context
	frame; N)	renewable energy sources; Stationary year-round; Minimal maintenance periods (1-2 times annually); Reasonably slow deployment/retrieval speeds							
Sanitary/Domestic Waste	Pathological Effects (N); Contamination (N)	Treatment	N	1	N-M	R	ST	R	D
Atmospheric Emissions	Pathological Effects (N); Contamination (N)	Equipment maintenance	N	1	N-M	R	ST	R	D
Accidental Releases	Pathological Effects (N); Contamination (N)	Prevention protocols; Response plan	N-L	1-2	N-H	S	ST-LT	R	D

Notes:
Magnitude: N = Negligible; L = Low; M = Moderate; H = High.
Geographic Extent: 1 = <1 km^2; 2 = 1-10 km^2; 3 = 11-100 km^2; 4 = 101-1000 km^2; 5 = 1001-10,000 km^2; 6 = >10,000 km^2.
Timing: N = Negligible Sensitivity; M = Moderate Sensitivity; H = High Sensitivity.
Frequency: S = Single Event (occurs once during the Project); I = Irregular Events (occur sporadically at irregular intervals and not predictable); R = Regular Events (occur regularly and may be predictable or scheduled); C = Continuous (occurs continuously).
Duration: ST = Short-term (restricted to duration of Project activity); MT = Medium-term (extends through Project operations but expected to subside when operations cease); LT = Long-term (extends beyond the life of the Project).
Reversibility (refers to population): R = Reversible; I = Irreversible.
Ecological/Socio-cultural and Economic Context: U = Undisturbed (area relatively undisturbed or not adversely affected by human activity); D = Disturbed (area previously been substantially disturbed by human development or human development is still present).

Table 8.3. Significance of potential residual environmental effects of Project activities on the Fish and Fish Habitat VC.

VC: Fish and Fish Habitat				
Project Activity	Significance of Predicted Residual Environmental Effects		Likelihood [a]	
	Significance Rating	Level of Confidence	Probability of Occurrence	Scientific Certainty
Sound				
Airgun Array	NS	L-M	-	-
Project Vessels	NS	M-H	-	-
Echo Sounder/ Side Scan Sonar	NS	M-H	-	-
Vessel Equipment/Presence				
Seismic Vessel and Streamers	NS	H	-	-
OBNs	NS	H	-	-
Project Support Vessels	NS	H	-	-
Vessel Lights	NS	M-H	-	-
ROVs	NS	H	-	-
Floating LiDAR Systems	NS	H	-	-
Sanitary/Domestic Wastes	NS	H	-	-
Atmospheric Emissions	NS	H	-	-
Accidental Releases	NS	M-H	-	-

[a] Considered only in the case where 'significant negative effect' is predicted.

Notes:

Significance is defined as of sufficient magnitude, duration, and geographic extent to cause a change in the VC that will alter its status or integrity beyond an acceptable level. A Significant residual effect on biological VCs is defined as a change in the VC population and/or habitat in the Study Area where recovery to baseline conditions in unlikely.

Significance Rating: S = Significant negative environmental effect; NS = Not-significant environmental effect; P = Positive environmental effect.

Level of Confidence (based on professional judgement): L = Low; M = Medium; H = High.

Probability of Occurrence (based on professional judgement): L = Low; M = Medium; H = High.

Scientific Certainty (based on scientific information and statistical analysis/professional judgement): L = Low; M = Medium; H = High.

Ocean Bottom Nodes (OBNs)

If there are years in which OBNs are not used, seismic surveys would not result in any direct physical disturbance of the bottom substrate. During surveys with OBN use, given the small footprint (~0.1 m^2) of an individual OBN along with their autonomous and non-intrusive nature, OBNs would not be expected to have a measurable effect on sediment quality, disturbance, or available habitat quantity for benthos relative to the surrounding habitat (e.g., Ogu et al. 2022). OBNs do not have aquatic emissions and, thus, would not impact the quality of the water column.

OBNs will be deployed with a ROV. Prior to each OBN deployment, a ROV will be used to conduct a visual survey within ~5 m of each planned deployment location for suitable placement. Avoidance of contact with sensitive corals (e.g., gorgonians, black corals) or sponges to the extent possible (see Section 6.1.5) will be part of standardized deployment protocols. The aim will be to position OBNs at least 2 m from habitat forming corals and sponges and make all efforts to avoid contact with corals and sponges during OBN deployment/retrieval. This same visual monitoring would by its nature assist in minimizing the probability of deploying an OBN directly on visible sessile macrofauna, such as sea pens or large basket stars/ascidians (i.e., tunicates, sea squirts); it is anticipated that mobile benthos (e.g., snow crab, wolffish) will move away from the OBN during the deployment process. Given the low profile of the OBNs (see Figure 2.3 and Section 2.2.7) and the fact they do not require

anchors or mooring lines/chains, no risk of entanglement by marine fauna is expected (e.g., see NOAA 2021).

Following application of mitigation measures, residual effects from the use of OBNs on the FFH VC are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km²* (individual node) to *101–1000 km²* (node network), with a *continuous* frequency (see Table 8.2). Residual effects are predicted to have *negligible* sensitivity to seasonality (timing) as no measurable residual effects on fauna populations are anticipated from their presence, regardless of life stage or activity of species in the Study Area. Residual effects are predicted to be fully *reversible*, and the Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of OBN use on the Fish and Fish Habitat VC are predicted to be *not significant* (see Table 8.3). The level of confidence associated with this prediction is *high* given the increasingly prevalent use of OBNs for seismic surveys (e.g., Tellier and Herrmann 2023).

Project Support Vessels

The presence of Project support vessels would be expected to have the same potential effects as that of a seismic vessel(s) (both a vessel itself and its propeller wash). Therefore, the predicted residual effects are based on the same mitigation measures and reasoning as indicated above for seismic vessel(s) and streamers, except for a smaller geographic footprint given no gear would be towed. With mitigation measures in place, residual effects on the FFH VC from the presence of Project support vessels are predicted to *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km² to 1–10 km²*, and *continuous* in frequency (see Table 8.2). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on the life stage and seasonal activity of fish or invertebrates at or near the surface, and be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of Project support vessels on the FFH VC are predicted to be *not significant* (see Table 8.3). The level of confidence associated with this prediction is *high*.

Vessel Lights

Artificial light from ships at night may be detected by organisms at the surface and in the upper water column, which could result in "altered behaviour, disorientation, and/or the displacement of species from their habitats"; however, these effects are mainly applicable to marine mammals or birds (DFO 2015b). In the absence of ambient natural light (i.e., during periods of darkness), vessel lights may attract plankton and some crustaceans or pelagic fishes towards the vessel or upper water column (e.g., McConnell et al. 2010). However, seismic vessels and their support vessels are constantly moving, minimizing the potential attraction effect and rendering it not spatially static. Additionally, Project vessels will minimize lighting (without compromising safety). The overall residual effect of vessel lights on the FFH VC is considered *neutral* and are predicted to be *not significant* (see Tables 8.2–8.3). The level of confidence associated with this prediction is *medium* to *high* based on available knowledge and professional judgment (see Table 8.3).

Remotely Operated Vehicles (ROVs)

A ROV will be used to retrieve and deploy OBNs. In some circumstances, the presence and use of a ROV can induce attraction (e.g., to artificial lighting), repulsion/displacement (e.g., due to water disturbances/noise from the thrusters or artificial lighting), stress, or changes in movement patterns in fish and invertebrates (Thomson et al. 2018; Sward et al. 2019; Button et al. 2021; SM 2025). Small-bodied fauna present offshore Newfoundland, such as shrimp, may also experience injury or mortality if they are drawn into the thrusters while a ROV is underway at depth (S. Penney-Belbin, Senior Biologist, LGL Limited, pers. obs., 16 June 2025). Behaviour types may range from attraction or avoidance to no reaction, with the type and intensity of behaviours influenced by species type, age group, and trophic level, body size, an animal's position relative to the seafloor, and characteristics of the ROV (e.g., size; lighting type, intensity, and colour; speed; thruster noise level; Stoner et al. 2008; Sward et al. 2019; Jessop et al. 2024). Typically, fish that react to the presence of ROVs are either smaller-bodied, generally occur >1 m above the seafloor, or are species that usually form aggregations (Sward et al. 2019). The intensity or frequency of responses tends to increase with increased ROV speed (Sward et al. 2019). Sablefish (*Anoplopoma fimbria*) were observed to exhibit greater avoidance of white light compared to red light during an ROV experiment (Widder et al. 2005 in Sward et al. 2019).

A ROV used to deploy and retrieve OBNs would be expected to be a standard, industrial sized ROV typically used in the offshore Newfoundland region, which would have a limited physical footprint (ROV unit; temporary, small-scale water displacement from thrusters; tether cable). A ROV would have a short residence time at a given deployment site (i.e., sufficient duration to undertake a brief visual survey to avoid deploying an OBN on sensitive fauna and for OBN deployment; or OBN retrieval). A ROV conducting Project activities would also be anticipated to operate at slow speeds near the seabed to conduct operations in general and to prevent or minimize sediment resuspension (i.e., obscured visibility for operators). A ROV would be piloted by trained operators who would include tether management as part of standard operating procedures (i.e., reeling in tether to avoid excess tether contacting the seabed and sensitive fauna, such as corals or sponges).

With mitigation measures in place, residual effects on the FFH VC associated with the presence of an ROV are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km²*, and to be *regular* in frequency (see Table 8.2). Residual effects are predicted to have *negligible sensitivity* to seasonality (timing), as their low speeds and minimal residence times at each deployment site are not expected to result in measurable changes in fish or invertebrates populations or their habitats, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of an ROV on the FFH VC are predicted to be *not significant* (see Table 8.3). The level of confidence associated with this prediction is *high* based on a combination of available literature and professional judgment.

Floating LiDAR Systems (FLS)

FLS can affect fish habitat at the seabed due to the installation/removal and presence of its seabed frame and to the physical presence of the anchor chain/rope in the water column and the unit itself at the sea surface. While unlikely, it is possible that a FLS could become detached from its seabed

anchor, in which case recovery operations could be undertaken for retrieval, which could theoretically include dragging lines (e.g., hooks, trawls) on the seabed to catch on lost equipment and recover it to the surface (BOEM 2023, 2024). Although fish (e.g., large sharks) could conceivably collide with or become entangled in the FLS mooring line, this would be considered a highly unlikely event (BOEM 2023, 2024) and possibly more applicable to larger fauna, such as marine mammals, or diving sea birds. Although such entanglement could result in injury or mortality of an individual fish, it would not have an impact at the population level. The FLS marine lantern would not be expected to result in measurable or meaningful potential light attraction by fish or invertebrates.

Deployment of the seabed anchor for an FLS would involve lowering the anchor to the surface and ultimately down to the seabed from an anchor handling or support vessel. When the seabed anchor contacts the seabed, this will result in displaced sediment for habitats with soft substrates (e.g., silt, sand), which could result in localized burial of immobile/sessile benthos (BOEM 2023, 2024). In the same action, the seabed anchor could impact benthos unable to move out of the way when contact with the seabed is made. If the seabed anchor were to be deployed on habitat forming benthos, such as coral or sponge gardens, this would result in small-scale habitat loss for associated fauna; conversely, the presence of the seabed anchor could serve as an artificial reef habitat and attract benthic fish or invertebrates (BOEM 2023, 2024). Depending on deployment conditions and configuration, it is possible the habitat in the immediate vicinity of the seabed anchor could be subject to chain scour should the mooring line contact the seabed – this could result in contact with some benthic eggs, mobile larvae, juveniles, or adults undertaking sensitive life functions (e.g., reproduction), or sessile macrofauna (e.g., corals, sponges; BOEM 2023). Although contact with the seabed anchor or chain scour could impact individual marine fauna, its small footprint would not be expected to result in measurable impacts at the population level. Sediment resuspension could occur upon retrieval of the seabed anchor, and anchor removal would represent a small-scale loss of habitat if it serves as artificial reef habitat during its deployment. For either activity, the resuspension of sediments would be localized to the surrounding area and would be expected to be of limited duration following deployment/retrieval (BOEM 2023). Given its relatively small footprint compared to the surrounding environment, habitat conditions would be expected to return to the historic norm following removal of the seabed anchor.

Whether man-made or comprised of natural materials (e.g., plant debris, floating kelp), various marine species are known to aggregate beneath and/or near floating objects at the sea surface (Hunter and Mitchell 1968; Moreno et al. 2016; Rumpa et al. 2022). Marine species could be using the floating objects as shelter or shade or, for algae, as substrate. Temporal differences in age structure in aggregating fish have been observed, with some studies noting initial aggregations mainly comprised of younger/smaller juveniles and later by more larger juveniles and adults (e.g., Hunter and Mitchell 1968). Fish that have aggregated near floating objects would not necessarily be expected to remain there for the duration of the object's presence; at some point they would be expected to depart to complete life stages or essential life functions, such as feeding, reproduction, or switching from a pelagic to benthic lifestyle. For example, tunas have been observed and modelled to exhibit residence times between 1–10 days or several weeks around fish aggregating devices (i.e., man-made floating objects used by fishers to attract fish and increase catch rates; Nooteboom et al. 2023). Drifting floating objects with associated biological communities have also been known to facilitate long-distance species dispersal, including into regions where some species do not normally occur (e.g., Benadon et

al. 2023). The FLS surface unit could attract marine species; however, given its temporary nature (restricted to a given Project activity year), small footprint, and stationary deployment, and the general transitory nature of fish that may associate with it, no measurable impact on fish populations or habitat are anticipated and the FLS would not be involved in fish dispersion.

FLS used for the Project would be fully autonomous and powered by renewable energy sources. A FLS would be stationary for the full duration of the Project's temporal scope each year and would be serviced for regular maintenance (likely via an anchor handling or other support vessel) only one to three times per year (i.e., every 3–6 months). It is anticipated that the FLS would be lowered/retrieved relatively slowly in the water column, which would reduce risk to mobile fish and invertebrates. It is also expected that Project planning for seasons including FLS use would consider and avoid sensitive areas (e.g., coral/sponge closure areas) and life stages (e.g., known reproduction sites and times) to the extent possible. FLS used for Project data collection would be expected to have similar, low-level, spatially-limited impacts as other long-term weather and/or current collection buoys in the offshore Newfoundland region, such as those used in the MSC buoy network or those that may be deployed near offshore oil and gas production facilities.

Based on mitigation measures and the general nature of the presence and operation of FLS, residual effects on the FFH VC from the presence of FLS are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km²*, and to be *continuous* in frequency (for the duration of deployment; see Table 8.2). Residual effects are predicted to have *negligible sensitivity* to seasonality (timing) and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of FLS on the FFH VC are predicted to be *not significant* (see Table 8.3). The level of confidence associated with this prediction is *high* based on available literature and professional judgment.

Sanitary/Domestic Waste

Sanitary and domestic waste will be properly managed, as indicated in Section 8.1.3, including appropriate mitigation measures and an established environmental management system for waste management and discharge prevention/management (see Section 6.1.8). Appropriate treatment and handling of wastes produced by the Project will result in residual effects on the FFH VC that are *negligible* in magnitude for a *short-term* duration over a geographic area of *<1 km²*, and to be *regular* in frequency (see Table 8.2). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on the life stage and activity of species that may be exposed to allowable wastes, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of sanitary/domestic wastes produced during the Project on the FFH VC are predicted to be *not significant* (see Table 8.3). The level of confidence associated with this prediction is *high*, given the implementation of standardized, international regulations.

Atmospheric Emissions

Project atmospheric emissions would be like those produced by other standard marine vessels not directly related to the Project and multiple mitigation measures will be in place (see Section 8.1.1). In addition, project vessels will have an International Air Pollution Prevention Certificate and operate in

accordance with MARPOL protocols (see Section 6.1.8), including regular equipment maintenance. With mitigation measures in place, residual effects on the FFH VC associated with Project atmospheric emissions are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km²*, and to be *regular* in frequency (see Table 8.2). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on the life stage and activity of species that may be exposed to emissions, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of atmospheric emissions produced during the Project on the FFH VC are predicted to be *not significant* (see Table 8.3). The level of confidence associated with this prediction is *high*, considering the scale of vessel use and implementation of standardized mitigation measures.

Accidental Releases

Given the implementation of standardized mitigation measures for vessels, the probability of an accidental event involving the release of hydrocarbons from a Project vessel in the Project Ares is considered very low.

There is an extensive body of literature regarding the effects of exposure to hydrocarbons on eggs, larvae, juvenile, and adult fish and invertebrates (see Sections 4.6.4.1–4.6.4.2 in C-NLOPB 2010; Section 5.1 in C-NLOPB 2014; Section 4.3 in IAAC 2020). A high-level summary of the effects and relative sensitivities of different species/life stages was also provided in Section 5.7.4.2 in LGL (2018). The concentrations and compositions of oil droplets and dissolved components from hydrocarbon spills are highly spatially and temporally variable depending on environmental factors influencing oil transport and fate (e.g., attenuation, biodegradation, dissolution, dispersion; French-McCay et al. 2024; Bi et al. 2025). Toxic effects on marine biota also vary widely, with potential impacts dependent upon species/life stage sensitivity, spill component concentration, environmental conditions, and frequency and duration of exposure. For example, increasing water temperature was correlated with decreasing toxicity for the temperate amphipod *Gammarus locusta* exposed to water accommodated fractions of fuel oil (Heuvel-Greve et al. 2024). Recent modelling highlighted the importance of accuracy in the criteria used to generate toxicity predictions, as focusing on total measured compounds and improperly incorporating dynamic exposure factors has been found to produce inaccurate results (French-McCay et al. 2024) that could misinform spill planning and response measures.

Polycyclic aromatic hydrocarbons (PAHs) can disrupt growth, metabolism, genetic stability, and membrane integrity for susceptible marine biota, while some microorganisms and aquatic plants can break down PAHs and accelerate spill component degradation (Sharma et al. 2025). Although plankton (e.g., ichthyoplankton, phytoplankton, zooplankton, larvae, jellyfish) are generally considered highly susceptible to hydrocarbon exposure, most research on natural plankton populations indicates a swift (within several days to weeks) return to normal community density and composition once in-water oil concentrations return to background levels (Maurya and Gupta 2024). This rapid recovery of various species is generally owing to their "short generation times, prolific egg and juvenile production, and widespread distribution, and swift water exchange" (Maurya and Gupta 2024). Should a spill occur during spawning or otherwise while eggs/larvae are present, considerable mortality could occur, but even so, the likelihood of a spill resulting in a significant,

detectable impact on fish populations is low (Maurya and Gupta 2024). For example, there is no indication of consequences on the Atlantic bluefin tuna population in the Gulf of Mexico following the 2010 Macondo well blowout, even though this species breeds in the spill-impacted area and lays buoyant eggs (Maurya and Gupta 2024).

The susceptibility of benthic ecosystems to surface oil spills is dependent upon depth, as ecologically significant volumes/concentrations of dissolved or dispersed oil from surface slicks are generally limited to the upper 10 m of the water column (Maurya and Gupta 2024). Higher concentrations of oil from surface slicks also seldom persist on the seabed for a prolonged period (Maurya and Gupta 2024). If hydrocarbon concentrations beyond the threshold for ecological effects reach the seabed, benthos most at risk for negative effects include epibiota (i.e., those that live on the seabed surface and are exposed to the water column) and burrowing fauna that filter-feed or irrigate their burrows (Maurya and Gupta 2024). Sessile invertebrates that have a mucilaginous coating tend to be more resilient to elevated oil concentrations near the seabed, and some filtering or particle capturing sessile fauna (e.g., sponges, sea squirts) have been found to survive oil exposure with seemingly no or minimal effects (Maurya and Gupta 2024). Although marine oil spills can have lethal or sub-lethal negative impacts, benthos in water depths within the range of the Study Area are more likely to experience elevated oil exposure from a subsea spill (e.g., blowout from an active drill site) compared to a surface spill which, would be the case for an [unlikely] accidental release associated with the Project.

With proper mitigation measures in place, including SOPEPs, MKI's Emergency Response Procedure, and carrying Spill Kits (see Section 6.1.8), and given the relatively low potential spill volume (compared to a subsea blowout), the residual effects of an accidental release on the FFH VC are predicted to be *negligible* to *low* in magnitude for a *short-term* to *long-term* duration (depending on the persistence of spilled compounds in the environment) over a geographic extent of *<1 km²* to *1–10 km²*, and to be a *single event* (see Table 8.2). Residual effects are predicted to have *negligible* to *high sensitivity* to seasonality (timing), mainly depending on whether eggs/larvae or high abundances of plankton are present (e.g., during a bloom) and exposed to spill compounds, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings and consideration that the probability of accidental hydrocarbon releases during the proposed seismic program are very low, the residual effects of an accidental release on the FFH VC are predicted to be *not significant* (see Table 8.3). The level of confidence associated with this prediction is *medium* to *high* based on a growing body of knowledge on the effects of oil exposure on marine biota in combination with data gaps regarding effects specifically relevant to the Study Area.

8.1.5 Fisheries VC

The potential interactions of the Project activities and the Fisheries VC are indicated in Table 8.4. Given that Project activities will variably interact with different types of fisheries and fishing gear (Table 8.4), these interactions are highlighted and discussed as appropriate. Note that DFO and joint DFO/Industry Research Surveys are included in the assessment of the Fisheries VC.

Table 8.4. Potential interactions of Project activities and the Fisheries VC.

VC: Fisheries			
Project Activities	**Mobile Fish and Invertebrates (fixed [e.g., gillnet] and mobile [e.g., trawl] gear)**	**Sedentary Benthic Invertebrates (fixed gear [e.g., crab pot])**	**Research Surveys (mobile gear [trawls]; fixed gear [crab pots])**
Sound			
Airgun Array	X	X	X
Project Vessels	X	X	X
Echo Sounder/ Side Scan Sonar	X		X
Vessel/Equipment Presence			
Seismic Vessel and Streamers	X	X	X
OBNs	X	X	X
Project Support Vessels	X	X	X
Vessel Lights			
ROVs	X	X	X
Floating LiDAR Systems	X	X	X
Sanitary/Domestic Waste	X	X	X
Atmospheric Emissions			
Accidental Releases	X	X	X
Garbage [a]			
Shore Facilities [b]			
Other Projects and Activities in Region of the Study Area			
Oil and Gas Activities	X	X	X
Marine Transportation	X	X	X

[a] Not applicable as garbage will be brought ashore.
[b] There will not be any new onshore facilities. Existing infrastructure will be used.

Behavioural changes relating to catchability of commercial species, and conflict with harvesting activities, fishing gear and lost fishing time were raised as potential issues during consultations and issues scoping for recent EAs for the Study Area (see Section 5.1.1 in LGL 2016, 2018). Interactions between seismic vessels and associated gear and fishing activities/gear have occurred in the past in Atlantic Canada when seismic vessels were operating in areas with high levels of fishing activity. This is particularly relevant in relation to fixed gear, such as crab pots and gillnets. Other potential sources of interference from seismic survey activities may include temporal and spatial conflicts with DFO and DFO-Industry research surveys if both are being conducted concurrently in the same general area. An accidental release of hydrocarbons from a Project vessel, which may result in tainting (or perceived tainting) and affect product quality and marketing, is also considered in the assessment.

MKI will employ standard industry practices that have been used during offshore Newfoundland seismic programs. The primary means of mitigating potential effects on the Fishery VC is to avoid active fishing areas, particularly fixed gear zones, to the extent possible. For commercial fisheries, compensation for damaged gear provides a means of final mitigation of impacts, in the event a conflict occurs (e.g., accidental contact of fishing gear with the survey airgun array, seismic vessel, streamers, or OBNs). More information regarding mitigation measures, including those associated with the Fisheries VC, is provided in Section 6.0.

There would be no interactions with recreational fisheries as the Project Area does not overlap nearshore waters (see Section 4.3.5). Likewise, no interactions would be expected between the Project and non-commercial Indigenous fisheries (see Section 4.3.4). Indigenous fisheries under Communal

Commercial Licences are included in the overall assessment of commercial fisheries, as catches are not considered separately for DFO's domestic commercial landings database (see Section 4.3.4).

8.1.5.1 Sound

The key potential effect on fisheries related to sound from airgun array(s) is the reduction in catch rates, which could be attributable to behavioural effects on fish and/or invertebrates from exposure to seismic survey sound. The potential for effects on fish harvesting are dependent on the location and timing of the surveying activities in relation to fishing areas, the type of fishing gear used in any given season, and the harvested species involved. If the survey work is situated away from active fishing areas or occurs at different times, the likelihood of any impacts on harvesting is substantially reduced.

The DFO and joint DFO-Industry research surveys are also conducted using fishing gear. As such, the issues related to potential interference with DFO and joint DFO-Industry research surveys are much the same as for commercial/Indigenous Communal Commercial fish harvesting (i.e., potential effects on catch rates and conflicts with research vessel operations).

Potential effects on marine fish and invertebrates are assessed in Section 8.1.4.1 (see also Section 4.5.1.3 in C-NLOPB 2010; Section 5.5 in C-NLOPB 2014; and Section 4.2.4 in IAAC 2020). While adult fish (i.e., commercially-viable) could be injured by airgun sound if they are within a few metres of a sound source, this is unlikely since fish are expected to disperse during array ramp-up and/or vessel approach. Seismic surveys have been found to cause negligible mortality and minimal physiological effects on groundfish (Nguyen et al. 2025). The most likely type of effect will be behavioural (Nguyen et al. 2025) for both pelagic and benthic fisheries species. Seismic surveys could cause reduced trawl and longline catches during and following a survey if the fish exhibit behavioural changes (e.g., horizontal and vertical dispersion). There are various research studies on this subject, as discussed in Section 8.1.4.1. While some of the behavioural effects studies report decreases in catch rates near seismic survey areas, there is some disagreement on the duration and geographical extent of the effect. Other studies report no changes in catch rates of snow crab (a key species for this assessment) on commercial grounds (e.g., Morris et al. 2019, 2020). In situ recorded seabed video on the NE Newfoundland Slope (within the Study Area) during a 2021 3D seismic survey conducted by PGS via the *Ramform Titan* (one of the sister ships to the *Ramform Atlas*, which may be used for the Project) indicated no changes in abundance for Atlantic cod, roughhead grenadier, redfish (*S. marinus*), smooth skate, or northern wolffish (Nguyen et al. 2025). This suggests there were no measurable displacement effects because of seismic surveying, including groundfish of different size classes (Nguyen et al. 2025). There were short-duration changes observed in feeding and foraging behaviour for Atlantic cod (i.e., longer to arrive at and consume bait compared to a control site), but cod did ultimately arrive and feed at baited stations both during and several days after seismic surveying (Nguyen et al. 2025).

Mitigation measures are discussed in Section 6.1.3. The primary measures intended to minimize the effects of Project activities on the Fisheries VC include:

- Spatial and temporal avoidance of active fishing areas;
- Good communication between the Operator and fishers/researchers;

- Deployment of a FLO on each seismic vessel;
- No seismic gear deployment until arrival within the Project Area (vessel route during gear deployment and while en route to a survey area will avoid fishing gear on the advice of the FLO); and
- Use of an escort vessel to scout ahead for fishing vessels/gear.

It is imperative that detailed temporal and spatial information regarding seismic and fishing/research surveying operations be exchanged between the various parties. This will allow the establishment of temporal and spatial separation plan, as has been successfully done with DFO NL/Industry in past seasons.

With mitigation measures in place, residual effects on the Fisheries VC associated with sound from the Project during simultaneous 3D/4D and 2D seismic surveys are predicted to be *negligible* to *low* in magnitude for a *short-term* duration over a geographic extent of *<1 km² to 1001–10,000 km²*, and to be *regular* to *continuous* in frequency (Table 8.5). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on whether seismic activities occur concurrently and in the same location as fisheries activities, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of underwater sound on the Fisheries VC are predicted to be *not significant* (Table 8.6). The level of confidence associated with this prediction is *medium* to *high* given the data gaps and variable catchability result study findings associated with the effects of sound associated with seismic surveys on fisheries species in the Study Area.

8.1.5.2 Vessel/Equipment Presence

The reader is referred to Section 4.5 in C-NLOPB (2010), Section 5.5 in C-NLOPB (2014), and Section 4.2.4 in IAAC (2020) for potential interactions/effects relating to vessel/equipment presence on fish and fish habitat. New and/or additional information relative to these reports and relevant to fisheries is provided below.

Seismic Vessel and Streamers

In the Study Area, commercial fish harvesting activities occur throughout the May–November temporal scope for the Project. Fishing with fixed gear (e.g., pot fishery for snow crab) poses the highest potential for conflict with the presence of the seismic vessel(s) and streamers (see Section 4.3.3.2). Seismic surveying operations would be conducted continuously, barring interruptions from bad weather or technical issues. A Project 3D/4D survey vessel would be anticipated to be 104.2-m in length with a 70-m beam, a 2D survey vessel would be expected to be ~76-m long with a 23-m beam (see Section 2.2.5), and the maximum number of streamers that could be towed by a single vessel (16; 3D/4D seismic) would have a total span of 1500 m in width (at a separation distance of 100 m between each streamer) and maximum length of 12,000 m (see Section 2.2.7). As such, the seismic vessel(s) with deployed streamers would have restricted maneuverability; therefore, other more mobile vessels, including fishing vessels, would need to give way under Transport Canada's *Collision Regulations*.

Table 8.5. Assessment of effects of Project activities on the Fisheries VC.

VC: Fisheries									
Project Activity	Nature of Environmental Effect (Neutral, Positive [P], or Negative [N])	Mitigation	Evaluation Criteria for Assessing Environmental Effects						
			Magnitude	Geographic Extent	Timing	Frequency	Duration	Reversibility	Ecological / Socio-Economic Context
Sound									
Airgun Array	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance; Communication	N-L	1-5	N-M	R	ST	R	D
Project Vessels	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance; Communication	N	1	N-M	C	ST	R	D
Echo Sounder/ Side Scan Sonar	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance; Communication	N	1	N-M	C	ST	R	D
Vessel/Equipment Presence									
Seismic Vessel and Streamers	Conflict with gear (N)	FLO; Communication	N [a]	1-3	N-M	C	ST	R	D
OBNs	Conflict with gear (N)	FLO; Communication	N [a]	1-4	N-M	C	ST	R	D
Project Support Vessels	Conflict with gear (N)	FLO; Communication	N [a]	1-2	N-M	C	ST	R	D
ROVs	Conflict with gear (N)	FLO; Communication	N [a]	1	N-M	R	ST	R	D
Floating LiDAR Systems	Conflict with gear (N)	FLO; Communication; Bright colouring; Radar reflector; Marine lantern; AIS signal broadcast	N [a]	1	N	C	ST	R	D
Sanitary/Domestic Waste	Taint (N); Perceived taint (N)	Treatment	N	1	N-M	R	ST	R	D
Accidental Releases	Taint (N); Perceived taint (N); Change in site access (N); Equipment damage (N)	Prevention protocols; Response plan; Communication	N-L	1-2	N-H	S	ST-LT	R	D

[a] Considered *negligible* since, if a conflict with gear occurs, compensation would be expected to eliminate economic impact.

Notes:

Magnitude: N = Negligible; L = Low; M = Moderate; H = High.

Geographic Extent: 1 = <1 km^2; 2 = 1-10 km^2; 3 = 11-100 km^2; 4 = 101-1000 km^2; 5 = 1001-10,000 km^2; 6 = >10,000 km^2.

Timing: N = Negligible Sensitivity; M = Moderate Sensitivity; H = High Sensitivity.

Frequency: S = Single Event (occurs once during the Project); I = Irregular Events (occur sporadically at irregular intervals and not predictable); R = Regular Events (occur regularly and may be predictable or scheduled); C = Continuous (occurs continuously).

Duration: ST = Short-term (restricted to duration of Project activity); MT = Medium-term (extends through Project operations but expected to subside when operations cease); LT = Long-term (extends beyond the life of the Project).

Reversibility (refers to population): R = Reversible; I = Irreversible.

Ecological/Socio-cultural and Economic Context: U = Undisturbed (area relatively undisturbed or not adversely affected by human activity); D = Disturbed (area previously been substantially disturbed by human development or human development is still present).

Table 8.6. Significance of potential residual environmental effects of Project activities on the Fisheries VC.

VC: Fisheries				
Project Activity	Significance of Predicted Residual Environmental Effects		Likelihood [a]	
	Significance Rating	Level of Confidence	Probability of Occurrence	Scientific Certainty
Sound				
Airgun Array	NS	M-H	-	-
Project Vessels	NS	H	-	-
Echo Sounder/ Side Scan Sonar	NS	M-H	-	-
Vessel Equipment/Presence				
Seismic Vessel and Streamers	NS	H	-	-
OBNs	NS	H	-	-
Project Support Vessels	NS	H	-	-
ROVs	NS	H	-	-
Floating LiDAR Systems	NS	H	-	-
Sanitary/Domestic Wastes	NS	H	-	-
Accidental Releases	NS	M-H	-	-

[a] Considered only in the case where 'significant negative effect' is predicted.

Notes:

Significance is defined as of sufficient magnitude, duration, and geographic extent to cause a change in the VC that will alter its status or integrity beyond an acceptable level. A Significant residual effect on biological VCs is defined as a change in the VC population and/or habitat in the Study Area where recovery to baseline conditions in unlikely.

Significance Rating: S = Significant negative environmental effect; NS = Not-significant environmental effect; P = Positive environmental effect.

Level of Confidence (based on professional judgement): L = Low; M = Medium; H = High.

Probability of Occurrence (based on professional judgement): L = Low; M = Medium; H = High.

Scientific Certainty (based on scientific information and statistical analysis/professional judgement): L = Low; M = Medium; H = High.

Mitigation measures relevant to the Fisheries VC are described in Sections 6.1.2–6.1.4. Key mitigation measures to minimize the effects of seismic vessel and streamer presence on the Fisheries VC include:

- Spatial and temporal avoidance of active fishing areas to the best of the Proponent's ability;
- Only deploying gear within the Project Area;
- Good communications between the Operator and fishers/fisheries researchers;
- Deployment of at least one FLO on each seismic vessel;
- Use of a Single Point of Contact (SPOC); and
- Compensation for gear/vessel damage and/or loss (MKI's Fisheries Compensation Plan).

With the application of the mitigation measures provided in Sections 6.1.2–6.1.4 and above, the residual effects on the Fisheries VC associated with the presence of seismic vessel(s) and streamers are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1* to *11–100 km²*, and to be *continuous* frequency (see Table 8.5). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on whether seismic activities occur concurrently and in the same location as fisheries activities, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of seismic vessel(s) and streamers on the Fisheries VC are predicted to be *not significant* (see Table 8.6). The level of confidence associated with this prediction is *high* based on previously successful seismic survey programs in the offshore Newfoundland region that utilized the same mitigation measures.

Ocean Bottom Nodes (OBNs)

The primary potential effects of the presence of OBNs on the Fisheries VC are gear interaction should bottom contact mobile fishing gear (e.g., trawls, dredges) snag on or catch an OBN unit. Given an OBN's small size, rounded shape, smooth surfaces, and low profile relative to the seabed (see Figure 2.4), while it is possible to become snagged on fishing gear, the risk of damage to the gear is considered low. Even if there is no damage to fishing gear, should an OBN become caught in fishing gear, it would mean the fisher must spend time removing the OBN at the surface and possibly dealing with its return to the Proponent, which represents lost time a fisher could otherwise dedicate to their harvest.

Mitigation measures relevant to the Fisheries VC are effectively the same as those noted above for the presence of seismic vessels and streamers – namely, good communications, avoidance of active fishing areas to the extent possible when planning OBN placement, and compensation in the event of gear damage or loss.

With mitigation measures in place, residual effects on the Fisheries VC associated with the presence of OBNs are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km²* to *101–1000 km²*, and to be *continuous* in frequency (for the duration of deployment; see Table 8.5). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on whether OBNs were deployed in the same location as active fisheries activities, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of OBNs on the Fisheries VC are predicted to be *not significant* (see Table 8.6). The level of confidence associated with this prediction is *high* given the increasingly prevalent use of OBNs for seismic activity.

Project Support Vessels

The presence of Project support vessels would be expected to have the same potential effects as that of seismic vessel(s) and streamers, except to a lesser extent because support vessels would have a smaller physical footprint and it would not be towing equipment. Therefore, the predicted residual effects are based on the same mitigation measures and reasoning as indicated above for seismic vessel(s) and streamers, except for a smaller geographic footprint given no gear would be towed. With mitigation measures in place, residual effects on the Fisheries VC from the presence of Project support vessels are predicted to *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km² to 1–10 km²*, and *continuous* in frequency (see Table 8.2). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on whether Project support vessel activities occur concurrently and in the same location as fisheries activities, and be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of Project support vessels on the Fisheries VC are predicted to be *not significant* (see Table 8.3). The level of confidence associated with this prediction is *high* based on previously successful seismic survey programs in the offshore Newfoundland region that utilized the same mitigation measures.

Remotely Operated Vehicles (ROVs)

A ROV will be used to deploy/retrieve OBNs. The use of a ROV would require the presence of a vessel capable of deploying and retrieving the ROV and equipped with a ROV control centre, such as a node installation vessel. The presence of the ROV and its control vessel would present the same types of potential effects as the presence of Project support vessels or seismic vessels and submerged streamers – i.e., avoidance of the immediate area of operations by fishing vessels and avoidance of gear placement when and where there will be active ROV operations, to prevent collisions and gear entanglement. An assessment for the presence of Project support vessels is provided above.

ROVs are routinely used offshore Newfoundland in support of oil and gas exploratory activities. A ROV used for OBN deployment/retrieval would have a limited footprint in terms of the unit itself and the limitations of the tether cable. A ROV would have a short residence time at a given deployment/retrieval site and information regarding activities involving ROV use would be clearly communicated ahead of time. A ROV would be piloted by trained operators who would avoid contact with set fixed fishing gear should OBN deployment occur in an area used by fishers.

With mitigation measures in place, residual effects on the Fisheries VC associated with the presence of ROVs are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km²*, and to be *regular* in frequency (see Table 8.5). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on whether ROV and fishing activities occurred concurrently at the same location, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria, the residual effects of the presence of ROVs on the Fisheries VC are predicted to be *not significant* (see Table 8.6). The level of confidence associated with this prediction is *high* given the routine use of ROVs within the Study Area in association with oil and gas activities without reported issue and on professional judgment.

Floating LiDAR Systems (FLS)

The primary potential effects of the presence of FLS on the Fisheries VC are avoidance of the surface unit/mooring line by fishing vessels and towed gear, small-scale restriction on the placement of pots on the seabed (i.e., avoidance of the seabed anchor), and gear interaction should mobile bottom contact gear snag on the seabed anchor. In the unlikely event the surface unit or a component of the FLS should detach from the surface unit and sink, it would represent an additional gear snag source with potential for interaction with fishing gear depending on the physical properties of the sunken piece (e.g., angled vs. rounded and overall size; see Figure 2.5; BOEM 2023). Should retrieval efforts occur for a lost FLS/component that overlap with active fixed gear fishing areas, fishing gear (e.g., pots, lines) could be snagged by the hook/trawl FLS retrieval gear as it was towed along the seabed seeking the lost gear.

The position of Project FLS would be properly communicated prior to deployment (see Section 6.1.2). A FLS would be stationary for the full duration of the Project's temporal scope each year and would be serviced for regular maintenance every 3–6 months. The surface unit would be brightly coloured, have a radar reflector and marine lantern, and broadcast an AIS signal. It is expected that Project planning for seasons including FLS use would consider and avoid active fishing areas to the extent

possible. A compensation plan would be in place for fishers in the event of gear/vessel damage or gear loss. FLS used for Project data collection would be expected to have similar, low-level, spatially-limited impacts as other long-term weather and/or current collection buoys in the offshore Newfoundland region.

With mitigation measures in place, residual effects on the Fisheries VC from the presence of Project FLS are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km²*, and to be *continuous* in frequency (for the duration of deployment; see Table 8.5). Residual effects are predicted to have *negligible* sensitivity to timing, given the small footprint of a FLS relative to surrounding fishing grounds, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of FLS on the Fisheries VC are predicted to be *not significant* (see Table 8.6). The level of confidence associated with this prediction is *high* based on the lack of issues reported in the literature relating to long-term environmental buoys in the offshore Newfoundland region and on professional judgment.

Sanitary/Domestic Wastes

If improperly treated sanitary or domestic wastes were to be released into the Study Area, there could be actual or perceived taint of exposed commercially targeted fish or invertebrate species. However, sanitary and domestic waste will be properly managed, as indicated in Sections 6.1.8 and 8.1.3. Therefore, appropriate treatment and handling of wastes produced by the Project will result in residual effects on the Fisheries VC that are *negligible* in magnitude for a *short-term* duration over a geographic area of *<1 km²*, and to be *regular* in frequency (see Table 8.5). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on whether Project vessels are operating concurrently and in the same location as fisheries, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of sanitary/domestic wastes produced during the Project on the Fisheries VC are predicted to be *not significant* (see Table 8.6). The level of confidence associated with this prediction is *high*, based largely on previous seismic surveys in the offshore Newfoundland region and the prevalence of shipping and other large vessel marine traffic in the Study Area that abide by similar mitigation methods.

Accidental Releases

The effects of accidental releases on invertebrates and fishes from Project vessels are discussed in Section 8.1.4.2. With respect to the Fisheries VC, an accidental release of hydrocarbons (e.g., fuel spill) could result in actual or perceived tainting of invertebrate and fish resources in the proximity of a release. Perceived tainting alone can have economic effects for fishers if the invertebrates/fish lose marketability. Fishers could also temporarily lose access to fishing grounds should closure areas be enacted for safety reasons during spill response activities, or experience damage to exposed fishing equipment deployed at the time of a release.

Preventative measures/protocols, response plans, and good communications are essential mitigation measures to minimize the effects of any accidental hydrocarbon release. In the unlikely event of a release, the length of time that fish/invertebrates are exposed is a determining factor in whether their health is substantially affected or if there is an actual or perceived tissue tainting. Any effect on access

to fishing grounds would be of relatively short duration, based on the advice of regulators. In the unlikely event of a substantial hydrocarbon release, the need of compensation for commercial fishers would be determined in accordance with established requirements.

With the application of mitigation measures, residual effects on the Fisheries VC associated with an accidental release of hydrocarbons during the Project are predicted to have a *negligible* to *low* magnitude for a *short-term* to *long-term* duration (depending on the persistence of spilled compounds in the environment or area closure durations) over a geographic extent of *<1* to *1–10 km*^{2} (see Table 8.5). Residual effects are predicted to have *negligible* to *high sensitivity* to seasonality (timing), depending on whether a release or associated closures occurred during peak fishing periods and on important fishing grounds, and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of accidental releases from the Project on the Fisheries VC are predicted to be *not significant* (see Table 8.6). The level of confidence associated with this prediction is *medium* to *high*, based on a growing body of knowledge on the effects of oil exposure on marine biota in combination with data gaps regarding effects specifically relevant to the Study Area.

8.1.6 Marine-associated Bird VC

Potential interactions between Project activities and the Marine-associated Bird VC are indicated in Table 8.7. The routine Project activity that has the highest probability of affecting marine-associated birds is 'vessel lights'.

Table 8.7. Potential interactions between Project activities and the Marine-associated Bird VC.

Project Activities	VC: Marine-associated Birds
Sound	
Airgun Array	X
Project Vessels	X
Echo Sounder/ Side Scan Sonar	X
Vessel/Equipment Presence	
Seismic Vessel and Streamers	X
OBNs	
Project Support Vessels	X
Vessel Lights	X
ROVs	
Floating LiDAR Systems	X
Sanitary/Domestic Waste	X
Atmospheric Emissions	X
Accidental Releases	X
Garbage [a]	
Shore Facilities [b]	
Other Projects and Activities in Region of the Study Area	
Oil and Gas Activities	X
Fisheries	X
Marine Transportation	X

[a] Not applicable as garbage will be brought ashore.
[b] There will not be any new onshore facilities. Existing infrastructure will be used.

8.1.6.1 Sound

Section 4.5.1.4 in C-NLOPB (2010) and Section 5.2.1 in C-NLOPB (2014) describe the interaction between birds and sound. As in previous seismic program EAs for the Study Area, the assessment focuses on potential effects of the airgun array(s) on marine-associated birds given that sound levels are much higher than those from Project vessels and the echo sounder and side scan sonar. Seabird hearing sensitivity and the effects of airgun sound and other loud, impulsive sounds on seabird behaviour and hearing have received little research. Mooney et al. (2019) measured in-air auditory brainstem response in Common Murre and Atlantic Puffin to sounds of frequencies from 0.125–6 kHz and found the greatest sensitivity to the frequencies 1–2 kHz. Until recently, few bird species had been tested for their underwater hearing sensitivity, most of which are coastal species that do not occur in the Study Area regularly. Underwater psychoacoustic testing of a Common Murre showed responses to a 1 kHz, 1 s pure tone with a received level of 130 dB re 1 µPa rms (Anderson Hansen et al. 2023).

Sound levels that cause injury to marine birds have not been tested. However, temporary hearing impairment can occur in terrestrial birds exposed to sound in air (Saunders and Dooling 1974; Ryals et al. 1999). Terrestrial bird species vary in their susceptibility to hearing damage resulting from sound exposure (Ryals et al. 1999), although they are generally thought to be more resistant to damage than mammals (Dooling and Popper 2007). Birds can regenerate sensory hair cells in the ear, unlike mammals (Ryals et al. 1999; Dooling and Popper 2007). Underwater hearing of birds is thought to be poorer than in air, because the middle ear constricts under the increased pressure associated with diving (Dooling and Therrien 2012). Unlike some other marine animals, seabirds are not known to communicate vocally underwater, and a heightened auditory sensitivity in water is thus unlikely to have evolved. Permanent physiological damage, i.e., hearing loss (permanent acoustic threshold shift), is unlikely to result from a seismic survey. However, temporary auditory impairment from exposure to loud impulse sound may last days (Hashino et al. 1988), which may impede some activities, such as a bird's ability to find their kin at nest sites.

Most field studies of the effects of underwater sound on bird behaviour have found no substantial effects (see LGL 1998; Minerals Management Service 2004). Moulting Long-tailed Ducks in the Beaufort Sea showed no changes in movements or diving behaviour during geophysical surveys, although the authors noted that smaller-scale behavioural changes could not be ruled out (Flint et al. 2003; Lacroix et al. 2003). In the Davis Strait, Stemp (1985) found no evidence of effects of geophysical surveys on Thick-billed Murre, Northern Fulmar, or Black-legged Kittiwake distribution or mortality in the offshore. These species are found in the Study Area, although kittiwake and Thick-billed Murre are rare in summer. Stemp (1985), citing a personal communication with another researcher, also reported that shearwaters show no behavioural response close to a geophysical sound array even with their heads underwater. Evans et al. (1993) observed no evidence that marine birds are attracted to or repelled by offshore seismic survey activity in the Irish Sea. However, a five-year study (2009–2013) using Global Positioning System (GPS) tracking reported avoidance of a 2D seismic survey by African Penguins when foraging close to breeding colonies that were located less than 100 km from the seismic survey (Pichegru et al. 2017). The air source array had a total volume of 4230 in^3 and nominally operated at 2000 psi during an approximate one-month period in 2013. It could not be determined whether the penguins (flightless birds that dive to depths of 30 m on average) were responding directly to air source sound or potential changes in the distribution of their prey. The birds

reverted to normal foraging behaviour when the seismic source array was shut down. The results of at-sea seabird surveys aboard a seismic survey vessel during a survey on the Argentine Shelf suggests that the abundance of several species is lower when the airguns are active than when they are inactive (Pon et al. 2019). This includes both plunge-diving and surface-plunging species. Three of those species (Great Shearwater, Sooty Shearwater, Wilson's Storm-Petrel) occur in the Study Area during the boreal summer and migration.

With mitigation measures in place, residual effects on the Marine-associated Bird VC associated with sound from the Project during simultaneous 3D/4D and 2D seismic surveys are predicted to range from *negligible* to *low* in magnitude for a *short-term* duration over a geographic extent of *<1* to *1–10 km²*, and to be *regular* to *continuous* in frequency (Table 8.8). Residual effects are predicted to have *negligible* to *moderate sensitivity* to timing, depending on the seasonal activity of marine-associated birds (e.g., migration, feeding), and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of underwater sound on the Marine-associated Bird VC are predicted to be *not significant* (Table 8.9). The level of confidence associated with this prediction is *medium* to *high* given the data gaps associated with the effects of sound on marine-associated birds in the Study Area.

8.1.6.2 Vessel/Equipment Presence

The reader is referred to Section 4.5 in C-NLOPB (2010), Section 5.2 in C-NLOPB (2014), and Section 4.2.1 in IAAC (2020) for potential interactions/effects relating to vessel/equipment presence for marine-associated birds. New and/or additional information relative to these reports is provided below.

Seismic and Project Vessels and Streamers

The potential effects of the physical presence of seismic and Project vessels and streamers are likely to be minimal. Seabirds may be attracted to a seismic, support/escort, or supply vessel while prospecting for fish wastes associated with fishing vessels. Since there is little or no food made available by these vessels, seabirds are temporarily interested in the vessels and soon move elsewhere in search of food. Seabirds sitting on the water in the path of these vessels can easily evade the vessels and any equipment associated with the vessels (T. Lang, Senior Biologist, LGL, pers. obs., 26 June 2025). The vessels and streamers would have a limited physical footprint, would have a short residence time in any singular location, and operate at slow speeds while streamers are deployed. Systematic daily searches for stranded birds on seismic and Project vessels would be completed and appropriate stranded seabird handling and release protocols would be followed (see Section 6.1.7).

Table 8.8. Assessment of potential effects of Project activities on the Marine-associated Bird VC.

VC: Marine-associated Birds									
Project Activity	Nature of Environmental Effect (Neutral, Positive [P], or Negative [N])	Mitigation	Evaluation Criteria for Assessing Environmental Effects						
			Magnitude	Geographic Extent	Timing	Frequency	Duration	Reversibility	Ecological / Socio-Economic Context
Sound									
Airgun Array	Disturbance (N)	Ramp-up of array	N-L	1-2	N-M	R	ST	R	D
Project Vessels	Disturbance (N)	Daily dedicated searches for stranded seabirds; Seabird handling and release	N-L	1	N-M	C	ST	R	D
Echo Sounder/ Side Scan Sonar	Disturbance (N)	-	N-L	1	N-M	C	ST	R	D
Vessel/Equipment Presence									
Seismic Vessel and Streamers	Disturbance (N)	Limited footprint; Short residence in any given location; Slow speeds while streamers deployed	N	1-3	N-M	C	ST	R	D
Project Support Vessels	Disturbance (N)	Limited footprint; Short residence in any given location; Slow speeds while accompanying seismic vessel	N	1	N-M	C	ST	R	D
Vessel Lights	Attraction (N)	Reduce lighting (if possible); Monitoring; Seabird handling and release	N-L	1-3	N-M	C	ST	R	D
Floating LiDAR Systems	Available staging (Neutral); Entanglement in underwater mooring line (N)	Small footprint (unit at surface; seabed frame); Powered by renewable energy sources; Stationary year-round; Minimal maintenance periods (1-2 times annually); Single mooring line	N	1	N	C	ST	R	D
Sanitary/Domestic Waste	Increased Food (N/P)	Treatment	N	1	N-M	R	ST	R	D
Atmospheric Emissions	Air Contaminants (N)	Equipment maintenance	N	1-2	N-M	R	ST	R	D
Accidental Releases	Mortality (N)	Prevention protocols; Response plan; Solid streamer	L-M	1-2	N-H	S	ST-LT	R	D

Notes:
Magnitude: N = Negligible; L = Low; M = Moderate; H = High.
Geographic Extent: 1 = <1 km^2; 2 = 1-10 km^2; 3 = 11-100 km^2; 4 = 101-1000 km^2; 5 = 1001-10,000 km^2; 6 = >10,000 km^2.
Timing: N = Negligible Sensitivity; M = Moderate Sensitivity; H = High Sensitivity.
Frequency: S = Single Event (occurs once during the Project); I = Irregular Events (occur sporadically at irregular intervals and not predictable); R = Regular Events (occur regularly and may be predictable or scheduled); C = Continuous (occurs continuously).
Duration: ST = Short-term (restricted to duration of Project activity); MT = Medium-term (extends through Project operations but expected to subside when operations cease); LT = Long-term (extends beyond the life of the Project).
Reversibility (refers to population): R = Reversible; I = Irreversible.
Ecological/Socio-cultural and Economic Context: U = Undisturbed (area relatively undisturbed or not adversely affected by human activity); D = Disturbed (area previously been substantially disturbed by human development or human development is still present).

Table 8.9. Significance of potential residual environmental effects of Project activities on the Marine-associated Bird VC.

VC: Marine-associated Birds				
Project Activity	Significance of Predicted Residual Environmental Effects		Likelihood [a]	
	Significance Rating	Level of Confidence	Probability of Occurrence	Scientific Certainty
Sound				
Airgun Array	NS	M-H	-	-
Project Vessels	NS	H	-	-
Echo Sounder/ Side Scan Sonar	NS	H	-	-
Vessel Equipment/Presence				
Seismic Vessel and Streamers	NS	H	-	-
Project Support Vessels	NS	H	-	-
Vessel Lights	NS	M-H	-	-
Floating LiDAR Systems	NS	H	-	-
Sanitary/Domestic Wastes	NS	H	-	-
Atmospheric Emissions	NS	H	-	-
Accidental Releases	NS	M	-	-

[a] Considered only in the case where 'significant negative effect' is predicted.

Notes:

Significance is defined as of sufficient magnitude, duration, and geographic extent to cause a change in the VC that will alter its status or integrity beyond an acceptable level. A Significant residual effect on biological VCs is defined as a change in the VC population and/or habitat in the Study Area where recovery to baseline conditions in unlikely.

Significance Rating: S = Significant negative environmental effect; NS = Not-significant environmental effect; P = Positive environmental effect.

Level of Confidence (based on professional judgement): L = Low; M = Medium; H = High.

Probability of Occurrence (based on professional judgement): L = Low; M = Medium; H = High.

Scientific Certainty (based on scientific information and statistical analysis/professional judgement): L = Low; M = Medium; H = High.

With mitigation measures in place and based on the lack of food that would be available for seabirds from seismic and other Project vessels, residual effects on the Marine-associated Bird VC associated with the presence of seismic and Project vessels and streamers are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1* to *11–100 km²*, and to be *continuous* in frequency (see Table 8.8). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on the seasonal activity of marine-associated birds (e.g., migration, feeding), and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of seismic and Project vessels and streamers on the Marine-associated Bird VC are predicted to be *not significant* (see Table 8.9). The level of confidence associated with this prediction is *high* based on professional judgment.

Vessel Lights

The most important potential interaction between marine-associated birds and marine geophysical surveys result from the attraction of nocturnally-active birds to artificial light at night (ALAN) on vessels. This phenomenon has often been implicated in the mortality of nocturnally active seabirds and nocturnally migrating land- and water-birds as a result of stranding (resulting in dehydration or starvation), collisions, predation, and exposure to other vessel-based threats (e.g., Montevecchi 2006; Ronconi et al. 2015; Gilmour et al. 2023). Disoriented birds may also circle around lights for long

periods of time, depleting energy resources, delaying foraging or migration, and potentially increasing their exposure to predation (e.g., Bourne 1979; Wiese et al. 2001; Ronconi et al. 2015).

ALAN has been documented in 73 seabird species, most of which are cavity-nesting procellariiform species, representing most families of procellariforms (i.e., fulmarine and gadfly petrels, shearwaters, and prions Procellariidae, northern storm-petrels Hydrobatidae, southern storm-petrels Oceanitidae, and diving-petrels Pelecanoididae; Urmston et al. 2022; Gilmour et al. 2023; Rodríguez et al. 2023). This suggests that some aspect of the orientation system common to procellariform birds may be disoriented by artificial light. Attraction to ALAN has also been reported in the Atlantic Puffin in coastal areas near nesting colonies in both Scotland and Newfoundland (Miles et al. 2010; Wilhelm et al. 2013; Brown et al. 2024). The habit of burrow-nesting delays the full development of juvenile seabirds' vision until after about two weeks of exposure to light following departure from the burrow, suggesting that undeveloped vision may be an important cause of ALAN attraction in these species (Atchoi et al. 2020).

Marine bird attraction to ALAN has been recorded throughout the year but occurs most commonly at the end of the nesting season (Telfer et al. 1987; Le Corre et al. 2002; Miles et al. 2010). In the Newfoundland area, most strandings of Leach's Storm-Petrels on offshore geophysical vessels and drilling and production platforms occur from mid-September to mid-October, when the young fledge and the adults abandon their nesting colonies (LGL 2017b; Gjerdrum et al. 2021; Burt et al. 2023, 2024). A study of coastal lighting in Newfoundland showed that a large majority of stranded Leach's Storm-Petrels during the peak stranding period are juveniles (Burt et al. 2024). In other species, when the age of the grounded seabirds has been determined, most individuals are recently fledged juveniles, especially those stranding near seabird nesting colonies. This suggests that undeveloped vision (discussed above) or juvenile inexperience contributes to attraction to ALAN (Miles et al. 2010; Gilmour et al. 2023).

An increasing number of studies confirm that the number of seabirds, including those of Leach's Storm-Petrels, stranding at artificial lights is higher on nights with low moon illumination than on nights with a full or nearly full moon (e.g., Rodríguez et al. 2022; Urmston et al. 2022; Rodríguez et al. 2023). The available evidence suggests that this is due to birds being less attracted or disoriented by artificial light on nights when the level of ambient light is high because of moon illumination, rather than lower numbers of birds in flight on moonlit nights due to predator avoidance (Rodríguez et al. 2023; Burt et al. 2024). Flight speed is lower, and flight tortuosity is greater in Cory's Shearwater when flying over areas of light pollution on nights without significant moonlight illumination, perhaps due to disorientation caused by the electrical lighting (Rodriguez et al. 2022). The number of birds stranding is also higher on nights with strong winds in Wedge-tailed Shearwater (*Ardenna pacifica*; Urmston et al. 2022).

The visual system of diving seabirds is most sensitive to blue light, which is the portion of the light spectrum that predominates below the sea surface (Martin 2017). Because of this, some authors have suggested that research should be directed toward determining whether the blue light component of artificial light affects seabird attraction (e.g., Marangoni et al. 2022). However, fledgling Leach's Storm-Petrels tested in a field experiment showed higher activity levels when exposed to high pressure sodium or warm white LED lighting than to darkness, but when exposed to cool white LED

lighting showed no difference in activity compared with darkness or the other two types of light (Brown et al. 2025). In contrast, in a laboratory experiment Atlantic Puffin fledglings were more active when exposed to high pressure sodium light than LED lights with warm white, cool white, blue, and orange colour (Brown et al. 2024).

Experts on North Atlantic seabirds rank ALAN as the human activity with the third highest risk of negative impacts on seabirds in Atlantic Canadian waters, following fisheries by-catch and oiling (Lieske et al. 2019). Experts on Leach's Storm-Petrel, the most stranded species on vessels, offshore oil/gas installations, and coastal infrastructure in Newfoundland (Gjerdrum et al. 2021), regard ALAN as the threat with the second-highest risk to this species' populations in Atlantic Canada and within Newfoundland waters, following avian predators at nesting colonies (Bond et al. 2023; Pollet et al. 2023). Its populations have undergone significant declines recently at Atlantic colonies (Wilhelm et al. 2019; d'Entremont et al. 2020; Deakin et al. 2021). As a result, this species was assessed as *Threatened* by COSEWIC in 2020 and the Atlantic population is currently under consideration for addition to Schedule 1 of SARA (GC 2025). The extent of Leach's Storm-Petrel mortality due to attraction to ALAN on the numerous fishing, cargo, cruise, and other vessels operating in Newfoundland waters is virtually unknown (Pollet et al. 2023).

Bird attraction to ALAN at sea may be mitigated in a variety of ways. Recovering grounded seabirds and returning them to sea after their plumage has sufficiently dried greatly reduces mortality (e.g., ECCC 2017b; LGL 2017b; Raine et al. 2020; Rodríguez 2023). During the general May–November period between 2012–2017, LGL biologists on board seismic survey and oil support vessels offshore Newfoundland conducted consistent, systematic, daily, thorough searches for stranded birds on all the decks open to the outside (LGL 2017b). During those 38 voyages totalling a combined 2197 days (6 years), only 15.7% of 994 storm-petrels were found dead or died in care, suggesting that if searches are done properly and mitigation measures are implemented, mortality of birds stranded at ALAN offshore is low, especially after releasing these birds. Because the proportion of stranded Leach's Storm-Petrels that are found alive and released is so large, Pollet et al. (2023) stress the potential for mitigation of light attraction through search and release. Reducing, shielding, or eliminating skyward radiation from electrical lights also appears to reduce the number of stranded birds (Reed et al. 1985; Rodríguez and Rodríguez 2009; Miles et al. 2010).

With the implementation of mitigation measures, residual effects on the Marine-associated Bird VC associated with vessel lights are predicted to be *negligible* to *low* in magnitude for a *short-term* duration over a geographic extent of *<1* to *11–100 km²*, and to be *continuous* in frequency (see Table 8.8). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on the physical development of individuals (fledgling to adult) and seasonal activity of marine-associated birds (e.g., migration), and to be fully *reversible*. Based on these criteria ratings, the residual effects of vessel lights on the Marine-associated Bird VC are predicted to be *not significant* (see Table 8.9). The level of confidence associated with this prediction is *medium* to *high* given the data gaps (see Section 4.4.4) in combination with available literature and first-hand experience of the EA authors.

Floating LiDAR Systems (FLS)

The presence of the surface unit of the FLS can provide a physical staging perch for marine-associated birds at-sea (e.g., Maxwell et al. 2022) and the mooring line can represent an – albeit low – entanglement risk for diving seabirds (e.g., Garavelli 2020). The surface unit of the FLS would not be anticipated to represent a collision risk given its relatively low profile relative to the sea surface and it does not have any large moving parts (compared to wind turbines, for example).

The FLS would have a small footprint at the surface and there would be no separate, external power supply equipment, as the unit is typically powered by renewable energy sources (with back-up ethanol fuel cells). The FLS would be stationary for the duration of deployment and receive minimal vessel traffic in the form of maintenance every 3–6 months. It is anticipated the FLS would have a single mooring line, either of rope or chain, depending on water depth. If a marine-associated bird were to utilize the surface unit of the FLS as a perch, it would not be expected to remain overlong before resuming normal activities (e.g., feeding, migration). As an interaction, a bird resting on the FLS would not be expected to be any different than a seabird resting on the water surface or any other floating hard substrate (e.g., man-made debris, such as fish pans or coolers that may be lost from other vessels). Regardless whether rope or chain, there would be no sharp protuberances (e.g., hooks, barbs) on the mooring line and the mooring line would be expected to be relatively taught, which minimizes the potential for entanglement by diving seabirds. However, in the unlikely event a bird were to become entangled in the mooring line, it would probably drown.

With mitigation measures in place, residual effects on the Marine-associated Bird VC associated with the presence of FLS are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *< 1 km²*, with a *continuous* frequency (for the duration of deployment; see Table 8.8). Residual effects are predicted to have *negligible sensitivity* to seasonality (timing), given the neutrality of possible use as a perch and the low probability of individual birds becoming entangled in the mooring line, and to be fully *reversible* (*irreversible* at the individual level should a bird become entangled in the mooring line and drown). The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of FLS on the Marine-associated Bird VC are predicted to be *not significant* (see Table 8.9). The level of confidence associated with this prediction is *high* based on a lack of reported issue associated with other long-term marine buoys deployed in the offshore Newfoundland region and professional judgment.

Sanitary/Domestic Waste

Sanitary waste generated by the vessels will be macerated before subsurface discharge (see Section 6.1.8). While it is possible that seabirds, primarily gulls, may be attracted to the sewage particles, the small amount discharged below surface over a limited period will not likely increase the far-offshore gull populations. Thus, any increase in gull predation on Leach's Storm-Petrels, as suggested by Wiese and Montevecchi (1999), is likely to be minimal. If this event occurs, the number of smaller seabirds involved will likely be low.

With treatment mitigation measures in place, residual effects from sanitary/domestics waste on the Marine-associated Bird VC are predicted to be *negligible* in magnitude for a *short-term* duration over a

geographic extent of *<1 km²*, and to be *regular* in frequency (see Table 8.8). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on life stage and seasonal activity (e.g., migration), and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of sanitary/domestic waste on the Marine-associated Bird VC are predicted to be *not significant* (see Table 8.9). The level of confidence associated with this prediction is *high* based on previous seismic surveys in the Study Area and professional judgment.

Atmospheric Emissions

Although atmospheric emissions could, in theory, affect the health of some resident seabirds, measurable effects are not anticipated considering that emissions consisting of potentially harmful materials will be low and will rapidly disperse to undetectable levels. As indicated in Section 6.1.8.3, atmospheric emission levels produced by the Project will be like those produced by other marine vessels not related to the Project.

With mitigation measures in place and given the nature of Project-related atmospheric emissions, residual effects on the Marine-associated Bird VC associated with atmospheric emissions are predicted to be *negligible* for a *short-term* duration over a geographic extent of *<1* to *1–10 km²*, and with a *regular* frequency (see Table 8.8). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on life stage and seasonal activity (e.g., migration), and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of atmospheric emissions on the Marine-associated Bird VC are predicted to be *not significant* (see Table 8.9). The level of confidence associated with this prediction is *high* based on previous seismic surveys in the Study Area and professional judgment.

Accidental Releases

An accidental release of hydrocarbons can result in the physical exposure of birds to oil in the affected area. Such discharges, and even routine operational discharges from vessels and platforms, may lead to slicks or sheens of crude oil and other substances on the water's surface, to which avifauna (especially pelagic seabirds) may be exposed (Wiese and Robertson 2004; O'Hara and Morandin 2010; Morandin and O'Hara 2016). Oiling has the potential to result in water penetrating plumage and displacing the layer of insulating air, resulting in loss of buoyancy and hypothermia. Even small amounts of oil from sheens have been shown to affect the structure and function of seabird feathers (O'Hara and Morandin 2010; Matcott et al. 2019). Contour body feathers of Manx Shearwater exposed to various thicknesses of surface crude oil show changes in resistance to water permeation from sheens as thin as 0.1 µm (Murphy et al. 2022). Dark coloured sheens 3 µm thick have the greatest effect on feather permeability. Thicker oil slicks cause an increase in feather mass by up to 1000%, which may have a significant effect on wing loading and energy expenditure. As a result of oiling, there would be an increased risk of mortality for individual birds that encountered the sheen (particularly for diving birds and those that spend large amounts of time on the water), as well as potential sublethal toxicity effects, including impacts on metabolic rate and chick growth. The possible physical effects of oil exposure on birds include heightened metabolic rate (increased energy expenditure) and potential starvation due to increased energy needs to compensate for heat loss resulting from oiling and loss of

insulation (hypothermia) and buoyancy (drowning) due to feather matting (Clark 1984; Montevecchi et al. 1999; Cunningham et al. 2017; Maggini et al. 2017a; Mathewson et al. 2018; Hunter et al. 2019). Behavioural changes may include increased time spent preening at the expense of foraging and breeding (Morandin and O'Hara 2016), an increase in foraging time per day during the breeding season that has the potential for population effects (Dorr et al. 2020), physiological effects of oil ingestion from excessive preening (Hartung 1995). The effects of oil on feather structure and function also affect flight efficiency, requiring increased energy demand during flight (Maggini et al. 2017a,b,c; Perez et al. 2017a,b,c). Depending on severity and circumstance, these possible physical and behavioural effects may ultimately result in death.

Acute toxic effects from exposure to sheens are considered unlikely (Morandin and O'Hara 2016), and some studies have found little or no effects from exposure to low doses of oil on adult seabirds (Ainley et al. 1981; Stubblefield et al. 1995; Alonso-Alvarez et al. 2007; Camphuysen 2011), while others have shown effects from this kind of exposure (e.g., Alonso-Alvarez et al. 2007; Barron 2012; Bursian et al. 2017; Takeshita et al. 2021). For example, Common Loon wintering in coastal Louisiana that had higher blood concentrations of PAHs after the Deepwater Horizon blowout had lower body mass (Paruk et al. 2016). Oil ingested through diet and through preening can cause hemolytic anemia, which causes fatigue and reduction in energy available for metabolic processes (e.g., Pritsos et al. 2017; Fallon et al. 2018, 2021). Effects on internal organs have also been observed. Damage has been found to liver (Khan and Ryan 1991; Harr et al. 2017a,b; Bonisoli-Alquati et al. 2020), brain (Lawler et al. 1978), gastrointestinal tract (Fallon et al. 2021), lung (pneumonia; Hartung and Hunt 1966; Harr et al. 2017a), heart (Harr et al. 2017a), and thyroid gland (Troisi et al. 2016) tissues. Oil exposure can also cause toxic effects on the immune system of birds (e.g., Goodchild et al. 2020a; Fallon et al. 2021; Paruk et al. 2021), metabolism of carbohydrates, proteins, and fats, and anti-inflammatory activity (Takeshita et al. 2021). Plasma and liver metabolites of lightly oiled seabirds are affected, suggesting potential impacts on thermoregulation, cardiac function, and hematologic parameters (Takeshita et al. 2021). Oiled Common Eider are more likely to have higher production of uropygial gland secretions, which correlates with an increased diversity of antibacterial defenses in its uropygial gland (Møller et al. 2021). Oil transferred from the plumage of adults to eggs can have sublethal toxic effects on embryos (Butler et al. 1988; Dubansky et al. 2018; Goodchild et al. 2020b; do Amaral-Silva et al. 2021) and sublethal toxic effects of oil ingestion on adult birds may affect reproductive success (Bautista et al. 2021; Hart et al. 2021). These effects have the potential to reduce survival and lifetime reproductive success (Burger 2018). Most seabird species have a long lifespan, delayed sexual maturation, small clutch size (one egg in most species), and, in some species, long intervals between breeding. Consequently, a significant increase in mortality of adults of reproductive age results in a significant decrease in the number of juveniles recruited into a population, making these species vulnerable to long-term population effects from oil exposure (Esler et al. 2002; Wiese and Robertson 2004; Darrah et al. 2021).

The possible effects of oil exposure on birds vary between species, as well as with different types of oil (Gorsline et al. 1981), weather conditions, times of year, variation in distribution and abundance of prey, and migratory patterns (Wiese et al. 2001; Montevecchi et al. 2012a). Hydrocarbon spills can also result in a change in habitat quality and use for marine and migratory birds (Day et al. 1997; Bianchini and Morrissey 2018). An analysis of 45 spills found a weak correlation between spill volume and reported bird mortality (Burger 1993); however, more recently, an analysis of 90 spills for which

wildlife mortality was reported found no clear relationship between spill size and mortality (Chilvers et al. 2021). As a result, the effects of oil spills on bird populations are difficult to predict.

All seabirds expected to occur in the Study Area, except Arctic Tern, spend considerable time resting on the water. Birds that spend most of their time on the water, such as the two murre species, Dovekie and Atlantic Puffin, are at the greatest risk of suffering negative effects from an accidental release of hydrocarbons. In addition, species such as Northern Fulmar, shearwaters, and storm-petrels, may experience some attraction to sheens, as the visual appearance of a hydrocarbon sheen resembles a sheen of biological origin (Hutchison and Wenzel 1980; Nevitt 1999). However, these species also search for food by olfaction, relying on the odour of chemicals found in their foods, such as dimethyl sulfide (e.g., Leach's Storm-Petrel; Hutchison and Wenzel 1980; Nevitt and Haberman 2003). In controlled experiments, hydrocarbon sheens attracted only a small fraction of the number of Leach's Storm-Petrel, Northern Fulmar, Sooty Shearwater, and other procellariiform species that biological oil sheens attract (Hutchison and Wenzel 1980). This suggests that in the event of an accidental hydrocarbon release, storm-petrels, fulmars, and shearwaters can distinguish hydrocarbon sheens from biological sheens, perhaps aided by olfaction, thereby reducing the risk of them coming into contact with an accidental release. As a result, these birds would be unlikely to come in contact with a sheen during foraging. However, flocks of seabirds resting on the water would not necessarily leave the water if they drifted into an area with hydrocarbons.

Despite the potential negative effects on seabirds of an accidental release of hydrocarbons, the potential for accidental releases of hydrocarbons during the proposed seismic program is very low and the evaporation/dispersion rate of any released hydrocarbons would be high, both of which result in a low risk of effects on seabirds. In addition, the Project would follow prevention protocols and MKI's response plan, and the streamers will be solid.

With mitigation measures in place, residual effects on the Marine-associated Bird VC associated with accidental releases from the Project are predicted to range from *low* to *moderate* in magnitude (mainly depending on species sensitivity) for a *short-term* to *long-term* duration (depending on the persistence of hydrocarbons in the environment following an accidental release) over a geographic extent of *<1* to *1–10 km²*, and to be a *single event* (see Table 8.8). Residual effects are predicted to have *negligible* to *high sensitivity* to seasonality (timing), depending on the life stage, species, and seasonal activity (e.g., feeding, migration) of an exposed bird, and to be fully *reversible* (*irreversible* at the individual level should a bird suffer mortality). The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of accidental releases on the Marine-associated Bird VC are predicted to be *not significant* (see Table 8.9). The level of confidence associated with this prediction is *medium* given the data gaps (see Section 4.4.4) and the paucity of spill events and associated seabird data for offshore Newfoundland.

8.1.7 Marine Mammal VC

The potential effects of seismic survey activities on marine mammals have previously been reviewed in the Eastern Newfoundland SEA (see Section 5.3 in C-NLOPB 2010), Southern Newfoundland SEA (see Section 4.5.1.5 in C-NLOPB 2014), the regional drilling EIS (IAAC 2020), as well as previous EAs

for seismic programs offshore Newfoundland and Labrador (e.g., LGL 2015; 2016; 2018). The assessment also includes consideration of potential interactions of the FLS with marine mammals.

We have discussed potential effects separately for toothed whales, baleen whales, and seals given their different hearing abilities and sensitivities to sound (see Section 1.2 in Appendix C). Potential interactions between Project activities and marine mammals are shown in Table 8.10.

Table 8.10. Potential interactions of Project activities and the Marine Mammal VC.

VC: Marine Mammals			
Project Activities	**Toothed Whales**	**Baleen Whales**	**Seals**
Sound			
Airgun Array	X	X	X
Project Vessels	X	X	X
Echo Sounder /Side Scan Sonar	X	X	X
Vessel/Equipment Presence			
Seismic Vessel and Streamers	X	X	X
OBNs			
Project Support Vessels	X	X	X
Vessel Lights			
ROVs			
Floating Lidar Systems	X	X	X
Sanitary/Domestic Wastes	X	X	X
Atmospheric Emissions			
Accidental Releases	X	X	X
Garbage [a]			
Shore Facilities [b]			
Other Projects and Activities in Regional Area			
Oil and Gas Activities	X	X	X
Fisheries	X	X	X
Marine Transportation	X	X	X

[a] Not applicable as garbage will be brought ashore.
[b] There will not be any new onshore facilities. Existing infrastructure will be used.

The presence of the ROV used for deployment of OBNs, presence of OBNs, vessel lights, and atmospheric emissions from vessels will not interact with marine mammals in a substantive way and effects from these activities are not considered further in the EIS.

8.1.7.1 Airgun Sound

The potential effects of sound from airgun arrays on marine mammals constitute a common concern associated with seismic surveys. Airgun arrays used during marine seismic operations introduce strong sound pulses into the water (see Section 1.2 in Appendix C for a review[7]). These sound pulses

[7] From the U.S. Federal Register (2023): "*The Gemini source operates on the same basic principles as a traditional airgun source in that it uses compressed air to create a bubble in the water column which then goes through a series of collapses and expansions creating primarily low-frequency sounds. However, the Gemini source consists of one physical element with two large chambers of 4,000 (in^3) each (total volume of 8,000 in^3). This creates a larger bubble resulting in more of the energy being concentrated in low frequencies, with a fundamental frequency of 3.7 Hertz. In addition to concentrating energy at lower frequencies, the Gemini source is expected to produce lower overall sound levels than the conventional airgun proxy source. The number of airguns in an array is highly influential on overall sound energy output, because the output increases approximately*

could have several types of effects on marine mammals, and are the main issue associated with the proposed seismic surveys. The effects of human-generated noise on marine mammals are quite variable and depend on numerous factors, including but not limited to species, activity of the animal when exposed to the noise, and distance of the animal from the sound source. A detailed and updated review of airgun sounds on marine mammals is provided in Appendix C. The effects assessment presented in this section provides a summary of key literature and refers the reader to key sections in the detailed literature review provided in the appendix.

Descriptions of the hearing abilities of marine mammals are provided in Appendix C (see Section 1.2). The potential effects of airgun sounds considered in this assessment include: (1) masking of natural sounds; (2) behavioural disturbance; (3) non-auditory physical or physiological effects; and (4) at least in theory, temporary or permanent hearing impairment (see Section 1.6 in Appendix C). Although the possibility cannot be entirely excluded, it is unlikely that the program would result in any cases of permanent hearing impairment or any significant non-auditory physical or physiological effects. If marine mammals encounter the survey while it is underway, behavioural effects may occur, but effects are generally expected to be localized and short-term.

Masking

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies. Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species if the frequency of the source is close to that used as a signal by the marine mammal, and if the anthropogenic sound is present for a significant fraction of the time (see Section 1.4 of Appendix C for a review). Based on past and current reviewed research, the potential for masking of marine mammal calls and/or important environmental cues from the proposed seismic program is considered low. The duty cycle of airguns is low; the airgun sounds from a standard array and the Gemini source are pulsed, with relatively quiet periods between pulses. In most situations, strong airgun sound will only be received for a brief period (<1 s), with these sound pulses being separated by at least several seconds of relative silence, and longer in the case of deep-penetration surveys or refraction surveys. A single airgun array would cause strong masking when propagation conditions are such that sound from each airgun pulse reverberates strongly and persists for much or all of the interval up to the next airgun pulse (e.g., Simard et al. 2005; Clark and Gagnon 2006). Situations with prolonged strong reverberation have been considered infrequent, but there are increased indications that this may be more of a concern for marine mammals than previously thought, particularly in consideration of multiple, concurrent seismic surveys. It is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Gedamke 2011; Guerra et al. 2011, 2016; Klinck et al. 2012; Guan et al. 2015), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree.

In order to compensate for increased ambient noise, some cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, shift their peak frequencies, or otherwise

linearly with the number of airgun elements. In this case, because the same air volume is used to operate two very large guns, rather than tens of smaller guns, the array produces lower sound levels than a conventional array of equivalent total volume." See Grooms et al. (2019, 2020) for a description of sound levels from the Gemini sound source.

change their vocal behaviour in response to airgun sounds (e.g., Blackwell et al. 2015). It is not known how often these types of vocal responses occur upon exposure to airgun sounds. If cetaceans exposed to airgun sounds sometimes respond by changing their vocal behaviour, this adaptation, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking by seismic pulses.

Disturbance

Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react briefly to an underwater sound by changing its behaviour or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or population. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on individuals and populations could be significant (Nowacek et al. 2015).

Baleen Whales.—Although baleen whales generally tend to avoid operating airguns, avoidance radii are variable (see Section 1.5.1 in Appendix C for a review). Stone (2015) examined data from 1,196 seismic surveys in the UK and adjacent waters and reported significant responses to airgun arrays of 500 in^3 or more in volume for minke and fin whales. This included lateral displacement, change in swimming or surfacing behaviour, and indications that cetaceans remained near the water surface. Dunlop et al. (2015, 2016) reported that humpback whales responded to a vessel operating a 20 in^3 airgun by decreasing their dive time and speed of southward migration. However, the same responses were obtained during control trials without an active airgun, suggesting that humpbacks responded to the source vessel rather than the airgun. Matos (2015) reported no change in sighting rates of minke whales in Vestfjorden, Norway during ongoing seismic surveys outside of the fjord. Similarly, no large changes in grey whale movement, respiration, or distribution patterns were observed during a 4D seismic survey off Sakahlin Island, Russia (Bröker et al. 2015; Gailey et al. 2016). Although sighting distances of gray whales from shore increased slightly during a two-week seismic survey, this result was not significant (Muir et al. 2015). However, there may have been a possible avoidance response to high sound levels in the area (Muir et al. 2016). Vilela et al. (2016) cautioned that environmental conditions should be taken into account when comparing sighting rates during seismic surveys, given that spatial modeling showed that differences in sighting rates of rorquals (fin and minke whales) during seismic periods and non-seismic periods during a survey in the Gulf of Cadiz could be explained by environmental variables.

Subtle but statistically significant changes in surfacing–respiration–dive cycles were shown by traveling and socializing bowheads exposed to airgun sounds in the Beaufort Sea, including shorter surfacing, shorter dives, and decreased number of blows per surfacing (Robertson et al. 2013). Bowhead whales continue to produce calls of the usual types when exposed to airgun sounds on their summering grounds, although numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Blackwell et al. 2015). Thus, bowhead whales in the Beaufort Sea apparently decreased their calling rates in response to seismic operations, although movement out of the area could also have contributed to the lower call detection rate (Blackwell et al. 2015).

Toothed Whales.—Overall, odontocete reactions to large arrays of airguns are variable and, at least for delphinids and some porpoises, seem to be confined to a smaller radius than has been observed for some mysticetes (see Section 1.5.2 in Appendix C for a review). However, other data suggest that some odontocetes species, including beluga whales, narwhals, and harbour porpoises, may be more responsive than might be expected given their poor low-frequency hearing. Reactions at longer distances may be particularly likely when sound propagation conditions are conducive to transmission of the higher-frequency components of airgun sound to the animals' location (DeRuiter et al. 2006; Goold and Coates 2006; Tyack et al. 2006; Potter et al. 2007).

Seals.—Seals tend to be less responsive to airgun sounds than many cetaceans and are not likely to show a strong avoidance reaction to the airgun array (see Section 1.5.3 in Appendix C for a review). Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behaviour. These studies show that many pinnipeds do not avoid the area within a few hundred metres of an operating airgun array. However, based on the studies with large sample size, or observations from a separate monitoring vessel, or radio telemetry, it is apparent that some phocid seals do show localized avoidance of operating airguns. The limited nature of this tendency for avoidance is a concern. It suggests that one cannot rely on pinnipeds to move away, or to move very far away, before received levels of sound from an approaching seismic survey vessel approach those that may cause hearing impairment.

Hearing Impairment

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. Temporary Threshold Shift (TTS) has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (see review in Section 1.6.1 of Appendix C). However, there has been no specific documentation of TTS let alone permanent hearing damage (i.e., Permanent Threshold Shift [PTS]; see Section 1.6.2 in Appendix C), in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions. However, it is acknowledged that this is difficult to study. There is evidence supporting the idea that auditory effects in a given animal are not a simple function of received acoustic energy (Finneran 2015). Frequency, duration of the exposure, and occurrence of gaps within the exposure can also influence the auditory effect (e.g., Finneran 2015; Kastelein et al. 2015, 2016; Supin et al. 2016).

Toothed Whales.— Kastelein et al. (2015) reported that exposure to multiple pulses with most energy at low frequencies can lead to TTS at higher frequencies in some cetaceans, such as the harbour porpoise. Several studies on TTS in porpoises indicate that received levels that elicit onset of TTS are lower in porpoises than in other odontocetes (e.g., Kastelein et al. 2015; Tougaard et al. 2016). Popov et al. (2016) reported that TTS produced by exposure to a fatiguing noise was larger during the first session (or naïve subject state) with a beluga whale than TTS that resulted from the same sound in subsequent sessions (experienced subject state). Similarly, several other studies have shown that some marine mammals (e.g., bottlenose dolphins, false killer whales) can decrease their hearing sensitivity in order to mitigate the impacts of exposure to loud sounds (e.g., Nachtigall and Supin 2014, 2015).

Seals.—When Reichmuth et al. (2016) exposed captive spotted and ringed seals to single airgun pulses with SELs of 165–181 dB and Sound Pressure Levels (SPLs) (peak to peak) of 190–207 re 1 µPa, no

low-frequency TTS was observed. Hermannsen et al. (2015) concluded that there is little risk of hearing damage to pinnipeds (and porpoises) when using a single airgun in shallow water. Similarly, it is unlikely that a marine mammal would remain close enough to a large airgun array for sufficiently long to incur TTS, let alone PTS. There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns.

According to Nowacek et al. (2013), current scientific data indicate that seismic airguns have a low probability of directly harming marine life, except at close range. Several aspects of the planned monitoring and mitigation measures for this Project are designed to detect marine mammals occurring near the airgun array and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment. In addition, many cetaceans and, to a limited degree, seals show some avoidance of the area where received levels of airgun sound are high enough such that hearing impairment could potentially occur. In those cases, the avoidance responses of the animals themselves will reduce the possibility of hearing impairment.

Non-auditory Physical Effects

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound (see Section 1.6.4 in Appendix C for a review). Possible types of non-auditory physiological effects or injuries that might theoretically occur include stress (e.g., Lyamin et al. 2016), neurological effects, and organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds. However, there is no definitive evidence that any of these effects occur even for marine mammals or sea turtles in close proximity to large arrays of airguns. Nonetheless, ten cases of strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings (Castellote and Llorens 2016).

Sound Criteria for Assessing Impacts

Impact zones for marine mammals are commonly defined by the areas within which specific received sound level thresholds are exceeded. Up until summer 2016, the U.S. National Marine Fisheries Service (NMFS) regulated that cetaceans should not be exposed to pulsed underwater noise at received levels exceeding 180 dB re 1 μPa_{rms}. The corresponding limit for seals was set at 190 dB re 1 μPa_{rms} (NMFS 1995, 2000). According to NMFS, these sound levels were the received levels above which one cannot be certain that there will be no injurious effects, auditory or otherwise, to marine mammals. An additional criterion that is often used in predicting "disturbance" impacts for pulsed underwater sound is 160 dB re 1 μPa_{rms}.

NMFS (2024) released technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing, taking into account recommendations made by Southall et al. (2007, 2019), as well as those presented by Finneran (2016). The guidance revised thresholds for permanent threshold shift (PTS) onset (i.e., injury), for marine mammal species. The noise exposure criteria for marine mammals account for newly-available scientific data on TTS, the expected offset between TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive (e.g., frequency weightings for various groups of marine mammals, allowing for their

functional bandwidths), and other relevant factors. For impulsive sounds, such as airgun pulses, the guidance incorporates marine mammal auditory weighting functions, and dual metrics of cumulative sound exposure level (SEL_{cum} over 24 hours) and peak sound pressure levels (SPL_{flat}). The onset of PTS is assumed to be 15 dB or 6 dB higher than TTS when considering SEL_{cum} and SPL_{flat}, respectively. Different thresholds have been provided for the various hearing groups, including low-frequency cetaceans (e.g., baleen whales), mid-frequency cetaceans (e.g., most delphinids), high-frequency cetaceans (e.g., porpoise and *Kogia* spp.), and phocids underwater (as well as otariids underwater). NMFS requires that these thresholds be used to establish safety zones around industrial activities including seismic surveys. DFO has not yet adopted any noise exposure criteria (Theriault and Moors-Murphy 2015; Wright et al. 2022a,b).

For marine seismic programs in Newfoundland and Labrador, DFO's *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment* (CNSOPB and C-NLOPB 2024) will be used as the basis for the marine mammal (and sea turtle) monitoring and mitigation program for the seismic surveys. The Statement does not include noise criteria as part of the recommended mitigation measures; rather it defines (see Point 6.a) a safety zone as "a circle with a radius of at least 500 metres as measured from the centre of the air source array(s)".

Assessment of Effects of Sound on Marine Mammals

The assessment of the effects of sound on marine mammals is presented below. The effects of underwater sound from vessels, the echo sounder, and the side scan sonar are not discussed further as the effects are generally considered minimal relative to sounds from airgun arrays. The reader is referred to Sections 11.2.4.1 and 11.2.5.1 in Equinor (2020) for a review of the effects of underwater sound from vessels and echo sounders/side scan sonars on marine mammals that occur in the Study Area.

Several environmental assessments of offshore oil exploration activities have undertaken acoustic modelling to estimate sound levels from airguns (e.g., Equinor 2020). Furthermore, acoustic monitoring has provided information on sound levels from distant seismic surveys in the Study Area (Delarue et al. 2018).

Toothed Whales

Despite the relatively poor hearing sensitivity of toothed whales (at least the smaller species that have been studied) at the low frequencies that contribute most of the energy in seismic pulses (even more so with the Gemina sound source), sounds are sufficiently strong that they remain above the hearing threshold of odontocetes at tens of kilometres from the source. Species of most concern are those that are designated under SARA Schedule 1 and that may occur in and near the Project Area (i.e., northern bottlenose and Sowerby's beaked whales). The killer whale and harbour porpoise have special status under COSEWIC (the harbour porpoise is also listed as threatened under Schedule 2 of SARA) but are not expected to occur in large numbers in the Project Area.

The PTS onset acoustic thresholds for impulsive sounds for mid-frequency (MF) cetaceans consist of a peak SPL_{flat} of 230 dB and a SEL_{cum} of 193 dB. The PTS onset thresholds for high-frequency (HF)

cetaceans are a peak SPL_{flat} of 202 dB and a SEL_{cum} of 159 dB. These sound level thresholds occur in close proximity to airgun arrays that are used offshore Newfoundland—typically well within the 500 m safety zone (see for example, Equinor 2020). Modelling of the Gemini source in the Gulf of Mexico indicated that the radial distances for PTS thresholds were estimated as 7 m (L_E 155 dB SEL) or 90 m (L_{pk} 202 dB pk) for high-frequency cetaceans. Sound levels from the Gemini source were not predicted to reach or exceed PTS thresholds for mid-frequency cetaceans.

NMFS assumes that disturbance effects for toothed whales may occur at received impulsive sound levels at or above 160 dB re 1 μPa_{rms}. This sound threshold is commonly used in EAs for Canadian projects to provide an indication of where potential behavioural effects may be experienced by marine mammals including odontocetes. The distance ranges where sound levels meet or exceed the 160 dB rms level can be quite variable. The propagation of airgun sound is complex, particularly in deep waters. Different sound frequencies contribute to the received energy at various distance ranges and water depths. Multiple impulsive arrivals can result when sound reflects off the seabed and sea surface multiple times in deep waters. For context, based on acoustic modelling of a 5085 in^3 airgun array, the 160 dB rms behavioural response criteria for impulsive sounds were predicted to be exceeded at maximum distances ranging from 9.3 km in August to 20.1 km in February in the Flemish Pass area (Equinor 2020). These are maximum distances at any point in the water column. Using more representative estimates, the 160 dB threshold typically would be reached at 7.5 km and 15.4 km from the 5085 in^3 array in August and February, respectively. Modelling of the Gemini source in the Gulf of Mexico indicated that the radial distances for the 160 dB thresholds were estimated to range from 3.4 km to 4.9 km.

Hearing Impairment and Physical Effects

Table 8.11 provides the details of the assessment of the effects of exposure to Project-related sound on marine mammals. As indicated in Table 8.11, sound produced as a result of the proposed Project (airgun array sound during three concurrent 3D surveys and a 2D survey being the worst-case scenario) is predicted to have residual hearing impairment/physical effects on toothed whales that are *negligible* to *low* in magnitude for a *short-term* duration over a geographic area of *<1* to *1–10 km²*. Based on these criteria ratings, the *reversible* residual hearing impairment/physical effects of sound associated with MKI's proposed 2D/3D/4D seismic program on toothed whales are predicted to be *not significant* (Table 8.12). The level of confidence associated with this prediction is *medium* (Table 8.12) given the data gaps associated with hearing impairment in marine mammals.

Table 8.11. Assessment of effects of Project activities and accidental releases on marine mammals.

VC: Marine Mammals									
Project Activity	Potential Positive (P) or Negative (N) Environmental Effect	Mitigation	Evaluation Criteria for Assessing Environmental Effects						
			Magnitude	Geographic Extent	Timing	Frequency	Duration	Reversibility	Ecological/ Socio-Cultural and Economic Context
Sound									
Airgun Array	Hearing Impairment (N); Physical Effects (N)	Pre-watch; Ramp-up; Delay start [a]; Shutdown [b]	N-L	1-2	M-H	R	ST	R	2
Airgun Array	Disturbance (N)	Pre-watch; Ramp-up; Delay start [a]; Shutdown [b]	L-M	1-5	M-H	R	ST	R	2
Project Vessels	Disturbance (N)	Steady speed and heading whenever possible	N-L	1-2	M-H	C	ST	R	2
Echo Sounder / Side Scan Sonar	Disturbance (N)		N-L	1	M-H	C	ST	R	2
Vessel/Equipment Presence									
Seismic Vessel and Streamers	Disturbance (N)	Steady, slow speed and heading	N-L	1-3	M-H	C	ST	R	2
Project Support Vessels	Disturbance (N); Injury/Mortality (N)	Steady speed and heading whenever possible	N-L	1	M-H	S	ST	R	2
Floating LiDAR Systems	Potential Entanglement (N)		N	1	M-H	C	ST	R	2
Sanitary/Domestic Waste	Increased Food (N/P)	Treatment; Containment	N	1	M-H	R	ST	R	2
Atmospheric Emissions	Surface Contaminants (N)	Low sulphur fuel, equipment maintenance	N	1	M-H	R	ST	R	2
Accidental Releases	Injury/Mortality (N)	Solid streamer [c]; Prevention protocols; Spill response	L	1-2	M-H	S	ST-LT	R	2

[a] Ramp-up will be delayed if any marine mammal is sighted within the 500 m safety zone.

[b] The airgun arrays will be shutdown if an *endangered* (or *threatened*) marine mammal is sighted within 500 m of the array.

[c] A solid streamer will be used for all seismic surveys.

Notes:

Magnitude: N = Negligible; L = Low; M = Moderate; H = High.

Geographic Extent: 1 = <1 km^2; 2 = 1-10 km^2; 3 = 11-100 km^2; 4 = 101-1000 km^2; 5 = 1001-10,000 km^2; 6 = >10,000 km^2.

Timing: N = Negligible Sensitivity; M = Moderate Sensitivity; H = High Sensitivity.

Frequency: S = Single Event (occurs once during the Project); I = Irregular Events (occur sporadically at irregular intervals and not predictable); R = Regular Events (occur regularly and may be predictable or scheduled); C = Continuous (occurs continuously).

Duration: ST = Short-term (restricted to duration of Project activity); MT = Medium-term (extends through Project operations but expected to subside when operations cease); LT = Long-term (extends beyond the life of the Project).

Reversibility (refers to population): R = Reversible; I = Irreversible.

Ecological/Socio-cultural and Economic Context: U = Undisturbed (area relatively undisturbed or not adversely affected by human activity); D = Disturbed (area previously been substantially disturbed by human development or human development is still present).

Table 8.12. Significance of potential residual environmental effects of Project activities on marine mammals.

VC: Marine Mammals				
Project Activity	Significance of Predicted Residual Environmental Effects		Likelihood [a]	
	Residual Environmental Effect Rating	Level of Confidence	Probability of Occurrence	Scientific Certainty
Sound				
Airgun Array: hearing/physical effects	NS	M	-	-
Airgun Array: behavioural effects	NS	L-M	-	-
Project Vessels	NS	H	-	-
Echo Sounder / Side Scan	NS	H	-	-
Vessel/Equipment Presence				
Seismic Vessel and Streamers	NS	H	-	-
Project Support Vessels	NS	H	-	-
Floating LiDAR Systems	NS	H	-	-
Sanitary/Domestic Wastes	NS	H	-	-
Atmospheric Emissions	NS	H	-	-
Accidental Releases	NS	M	-	-

[a] Considered only in the case where 'significant negative effect' is predicted.

Notes:

Significance is defined as having sufficient magnitude, duration, and geographic extent to cause a change in the VC that will alter its status or integrity beyond an acceptable level. A Significant residual effect on biological VCs is defined as a change in the VC population and/or habitat in the Study Area where recovery to baseline conditions in unlikely.

Significance Rating: S = Significant negative environmental effect; NS = Not-significant environmental effect; P = Positive environmental effect.

Level of Confidence (based on professional judgement): L = Low; M = Medium; H = High.

Probability of Occurrence (based on professional judgement): L = Low; M = Medium; H = High.

Scientific Certainty (based on scientific information and statistical analysis/professional judgement): L = Low; M = Medium; H = High.

Disturbance

Table 8.11 provides the details of the assessment of the effects of exposure to Project-related sound on marine mammals. As indicated in Table 8.11, sound produced as a result of the proposed Project (airgun array sound during three concurrent 3D surveys and a 2D survey being the worst-case scenario) is predicted to have residual disturbance effects on toothed whales that are *low* to *medium* in magnitude for a *short-term* duration over a geographic area of *<1 km²* to *1001–10,000 km²*. Based on these criteria ratings, the *reversible* residual disturbance effects of sound associated with MKI's proposed 2D/3D/4D seismic program on toothed whales are predicted to be *not* significant (see Table 8.12). Given the data gaps in baseline scientific data and the uncertainties of the effects of multiple simultaneous seismic surveys, the level of confidence associated with this prediction is *low to medium* (see Table 8.12).

Baleen Whales

Baleen whales are thought to be sensitive to low-frequency sounds such as those that contribute most of the energy in seismic pulses. Species of most concern are those that are designated under SARA Schedule 1 and that may occur in and near the Project Area (i.e., North Atlantic right, blue, and fin whale). The PTS onset acoustic thresholds for impulsive sounds for low-frequency (LF) cetaceans consist of a peak SPL_{flat} of 222 dB and a SEL_{cum} of 183 dB. These sound level thresholds occur in close proximity to airgun arrays that are used offshore Newfoundland—typically well within the 500 m safety zone (for example, <200 m for a 5085 in^3 airgun array; Equinor 2020). Modelling of the Gemini source in the Gulf of Mexico indicated that the radial distance for the PTS threshold for low-frequency cetaceans was estimated as 16 m (L_E 183 dB SEL); the L_{pk} threshold was not reached. For all baleen whale species, NMFS assumes that disturbance effects (avoidance) may occur at sound levels greater than 160 dB re 1 μPa_{rms}.

Hearing Impairment and Physical Effects

Table 8.11 provides the details of the assessment of the effects of exposure to Project-related sound on marine mammals. As indicated in Table 8.11, sound produced as a result of the proposed Project (airgun array sound during three concurrent 3D surveys and a 2D survey being the worst-case scenario) is predicted to have residual hearing impairment/physical effects on baleen whales that are *negligible* to *low* in magnitude for a *short-term* duration over a geographic area of *<1 km²* to *1–10 km²*. Based on these criteria ratings, the *reversible* residual hearing impairment/physical effects of sound associated with MKI's proposed 2D/3D/4D seismic program on baleen whales are predicted to be *not significant* (see Table 8.12). The level of confidence associated with this prediction is *medium* (see Table 8.12) given the data gaps associated with hearing impairment effects.

Disturbance

Table 8.11 provides the details of the assessment of the effects of exposure to Project-related sound on marine mammals. As indicated in Table 8.11, sound produced as a result of the proposed Project (airgun array sound during three concurrent 3D surveys and a 2D survey being the worst-case scenario) is predicted to have residual disturbance effects on baleen whales that are *low* to *medium* in magnitude for a *short-term* duration of over a geographic area of *<1* to *1001–10,000 km²*. Based on these criteria ratings, the *reversible* residual disturbance effects of sound associated with MKI's proposed 2D/3D/4D seismic program on baleen whales are predicted to be *not* significant (see Table 8.12). Given the data gaps in baseline scientific data and the uncertainties of the effects of multiple simultaneous seismic surveys, the level of confidence associated with this prediction is *low to medium* (see Table 8.12).

Seals

The PTS onset acoustic thresholds for impulsive sounds for phocids in water (PW) consist of a peak SPL_{flat} of 223 dB and a SEL_{cum} of 183 dB. For all phocids, NMFS assumes that disturbance effects (avoidance) may occur at sound levels greater than 160 dB re 1 μPa_{rms}. However, seals are not expected

to be abundant within the Study Area, particularly during the time period when seismic operations will likely occur.

Hearing Impairment and Physical Effects

Table 8.11 provides the details of the assessment of the effects of exposure to Project-related sound on marine mammals. As indicated in Table 8.11, sound produced as a result of the proposed Project (airgun array sound during three concurrent 3D surveys and a 2D survey being the worst-case scenario) is predicted to have residual hearing impairment/physical effects on seals that are *negligible* to *low* in magnitude for a *short-term* duration over a geographic area of *<1* to *1–10 km²*. Based on these criteria ratings, the *reversible* residual hearing impairment/physical effects of sound associated with MKI's proposed 2D/3D/4D seismic program on seals are predicted to be *not significant* (see Table 8.12). The level of confidence associated with this prediction is *medium* (see Table 8.12) given the data gaps associated with hearing impairment effects.

Disturbance

Table 8.11 provides the details of the assessment of the effects of exposure to Project-related sound on marine mammals. As indicated in Table 8.11, sound produced as a result of the proposed Project (airgun array sound during three concurrent 3D surveys and a 2D survey being the worst-case scenario) is predicted to have residual disturbance effects on seals that are *low* in magnitude for a *short-term* duration over a geographic area of *<1 km²* to *101–1000 km²*. Based on these criteria ratings, the *reversible* residual disturbance effects of sound associated with MKI's proposed 2D/3D/4D seismic program on seals are predicted to be *not significant* (see Table 8.12). The level of confidence associated with this prediction is *medium* given the data gaps regarding seal response to airgun sound (see Table 8.12).

8.1.7.2 Vessel and Equipment Presence

Information on interactions between vessel/equipment presence and marine mammals is available in Section 5.3.1 of the Eastern Newfoundland SEA (C-NLOPB 2014) and Section 4.5.9.3 of the Southern Newfoundland SEA (C-NLOPB 2010). A more recent review of potential vessel interactions with marine mammals (i.e., ship strikes) is provided in Section 11.3.4.1 of Equinor (2020).

During the proposed Project, there will typically be one seismic ship and an escort vessel on site during most of the program; a supply vessel will also regularly be present. There is some risk for collision between marine mammals and vessels but given the slow surveying speed (~4.5 knots; 8.3 km/h) of the seismic vessel (and its support vessels), this risk is considered minimal. In some years, there could be multiple seismic survey vessels, escort vessels, support, and supply vessels in the Project Area. Project vessels will maintain constant course and speed whenever possible, and in most cases slow transit speeds, thereby minimizing the risk of vessel collisions.

As indicated in Table 8.11, vessel/equipment presence associated with the proposed Project is predicted to have residual effects on marine mammals that are *negligible* to *low* in magnitude for a *short-term* duration over a geographic area of *<1 km²* to *11–100 km²*. Based on these criteria ratings, the

reversible residual effects of vessel/equipment presence associated with MKI's proposed 2D/3D/4D seismic program on marine mammals are predicted to be *not significant* (see Table 8.12). The level of confidence associated with this prediction is *high* (see Table 8.12).

There is some limited potential that marine mammals may interact with FLS and the associated mooring chains/lines. Potential impacts on marine mammals during FLS installation, operation, and removal include associated vessel traffic (i.e., vessel strike risk discussed above) and possible entanglement in the mooring chains/lines. High tension of the buoy chain/line for the FLS would reduce risk of entanglement (see BOEM 2024).

Based on mitigation measures and the general nature of the presence and operation of FLS, residual effects on marine mammals from the presence of FLS are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km²* (see Table 8.11). Based on these criteria ratings, the *reversible* residual effects of FLS presence associated on marine mammals are predicted to be *not significant* (see Table 8.12). The level of confidence associated with this prediction is *high* (see Table 8.12) based on available literature and professional judgment.

8.1.7.3 Other Project Activities

There is potential for marine mammals to interact with domestic and sanitary wastes, and atmospheric emissions from the seismic ship and other Project vessels. Any effects from these interactions are predicted to be *negligible* (see Table 8.12).

Accidental Releases

All petroleum hydrocarbon handling and reporting procedures on board Project vessels will be consistent with MKI's policy, and handling and reporting procedures. A fuel spill may occur from the seismic ship and/or the support vessels. Spills would likely be small and quickly dispersed by wind, wave, and ship's propeller action. The effects of hydrocarbon spills on marine mammals were reviewed in Section 5.3 of the Eastern Newfoundland SEA (C-NLOPB 2014) and Section 4.6.4.5 of the Southern Newfoundland SEA (C-NLOPB 2010). A more recent review of potential effects of hydrocarbon exposure on marine mammals is provided in Section 16.7.6.3 of Equinor (2020). Section 4.3.2 of IAAC (2020) notes that "Marine mammals and sea turtles may experience a change in mortality or injury (acute or immediate effects) if directly exposed to accidentally released hydrocarbons or associated volatiles and aerosols. They may experience a change in health (sub-lethal effects) from direct contact with hydrocarbons or consumption of contaminated prey."

As indicated in Table 8.12, accidental releases of hydrocarbons associated with the proposed Project are predicted to have residual effects on marine mammals that are *low* in magnitude for a *short-term to long-term* duration over a geographic area of *<1 km²* to *1–10 km²*. Based on these criteria ratings, the *reversible* residual effects of accidental releases of hydrocarbons associated with MKI's Project on marine mammals are predicted to be *not significant* (see Table 8.13). The level of confidence associated with this prediction is *medium* (see Table 8.13) given the uncertainties with a vessel spill and data gaps on effects of oiling.

8.1.8 Sea Turtle VC

The potential effects of seismic survey activities on sea turtles have previously been reviewed in the Eastern Newfoundland SEA (see Section 5.3 in C-NLOPB 2010), Southern Newfoundland SEA (see Section 4.5.1.6 in C-NLOPB 2014), the regional drilling EIS (IAAC 2020), as well as previous EAs for seismic programs offshore Newfoundland and Labrador (e.g., LGL 2015; 2016; 2018). The assessment also includes consideration of potential interactions of the FLS with sea turtles (Table 8.13).

Table 8.13. Potential interactions of Project activities and the Sea Turtle VC.

Project Activities	VC: Sea Turtles
Sound	
Airgun Array	X
Project Vessels	X
Echo Sounder /Side Scan Sonar	X
Vessel/Equipment Presence	
Seismic Vessel and Streamers	X
OBNs	
Project Support Vessels	X
Vessel Lights	
ROVs	
Floating Lidar Systems	X
Sanitary/Domestic Wastes	X
Atmospheric Emissions	
Accidental Releases	X
Garbage [a]	
Shore Facilities [b]	
Other Projects and Activities in Regional Area	
Oil and Gas Activities	X
Fisheries	X
Marine Transportation	X

[a] Not applicable as garbage will be brought ashore.
[b] There will not be any new onshore facilities. Existing infrastructure will

The presence of the ROV used for deployment of OBNs, presence of OBNs, vessel lights, and atmospheric emissions from vessels will not interact with sea turtles in a substantive way and effects from these activities are not considered further in the EIS.

8.1.8.1 Airgun Sound

Sea turtles have received very little research attention when compared to studies on the potential effects of airgun sounds on marine mammals and fishes (Nelms et al. 2016). A detailed and updated literature review of sea turtle hearing and potential airgun sound effects on sea turtles is provided in Appendix D. The effects assessment presented in this section provides a summary of key literature and refers the reader to key sections in the detailed literature review provided in the appendix. The effects of underwater sound from vessels, the echo sounder, and the side scan sonar are not further discussed as their potential effects are considered minimal relative to airguns including the Gemini source.

Hearing Impairment and Physical Effects

There is substantial overlap in the frequencies that sea turtles detect vs. the frequencies in airgun pulses (see Section 2 in Appendix D). Although it is possible that exposure to airgun sounds could cause either mortality or mortal injuries in sea turtles close to the source, this has not been demonstrated and seems highly unlikely (Popper et al. 2014). Nonetheless, Popper et al. (2014) proposed sea turtle mortality/mortal injury criteria of 210 dB SEL or >207 dB_{peak} for sounds from seismic airguns. Sounds from an airgun array might cause temporary hearing impairment in sea turtles if they do not avoid the immediate area around the airguns (see Section 5 in Appendix D). However, monitoring studies show that some sea turtles exhibit localized movement away from approaching airguns. Furthermore, sea turtles are considered uncommon in the Study Area. If a sea turtle is detected near the seismic vessel (i.e., approaching or in the 500 m safety zone), ramp up will be delayed and airguns would be shut down, as appropriate.

As indicated in Table 8.14, sound produced as a result of the proposed Project (airgun array sound during three concurrent 3D surveys and a 2D survey being the worst-case scenario) is predicted to have residual hearing impairment/physical effects on sea turtles that are *negligible* to *low* in magnitude for a *short-term* duration over a geographic area of *<1* to *1–10 km²*. Based on these criteria ratings, the *reversible* residual hearing impairment/physical effects of sound associated with MKI's proposed 2D/3D/4D seismic program on sea turtles are predicted to be *not significant* (Table 8.15). The level of confidence associated with this prediction is *medium* (Table 8.15) given the data gaps on the effects of airgun sounds.

Table 8.14. Assessment of effects of Project activities and accidental releases on sea turtles.

VC: Sea Turtles									
Project Activity	Potential Positive (P) or Negative (N) Environmental Effect	Mitigation	Evaluation Criteria for Assessing Environmental Effects						
			Magnitude	Geographic Extent	Timing	Frequency	Duration	Reversibility	Ecological/ Socio-Cultural and Economic Context
Sound									
Airgun Array	Hearing Impairment (N); Physical Effects (N)	Pre-watch; Ramp-up; Delay start [a]; Shutdown [b]	N-L	1-2	M-H	R	ST	R	2
Airgun Array	Disturbance (N)	Pre-watch; Ramp-up; Delay start [a]; Shutdown [b]	L	1-4	M-H	R	ST	R	2
Project Vessels	Disturbance (N)	Steady speed and heading whenever possible	N-L	1-2	M-H	C	ST	R	2
Echo Sounder / Side Scan Sonar	Disturbance (N)		N-L	1	M-H	C	ST	R	2
Vessel/Equipment Presence									
Seismic Vessel and Streamers	Disturbance (N)	Steady, slow speed and heading	N-L	1-3	M-H	C	ST	R	2
Project Support Vessels	Disturbance (N); Injury/Mortality (N)	Steady speed and heading whenever possible	N-L	1	M-H	S	ST	R	2
Floating LiDAR Systems	Potential Entanglement (N)		N	1	M-H	C	ST	R	2
Sanitary/Domestic Waste	Increased Food (N/P)	Treatment; Containment	N	1	M-H	R	ST	R	2
Atmospheric Emissions	Surface Contaminants (N)	Low sulphur fuel, equipment maintenance	N	1	M-H	R	ST	R	2
Accidental Releases	Injury/Mortality (N)	Solid streamer [c]; Prevention protocols; Spill response	L	1-2	M-H	S	ST-LT	R	2

[a] Ramp-up will be delayed if a sea turtle is sighted within the 500 m safety zone.

[b] The airgun arrays will be shutdown if a sea turtle is sighted within 500 m of the array.

[c] A solid streamer will be used for all seismic surveys.

Notes:

Magnitude: N = Negligible; L = Low; M = Moderate; H = High.

Geographic Extent: 1 = <1 km^2; 2 = 1-10 km^2; 3 = 11-100 km^2; 4 = 101-1000 km^2; 5 = 1001-10,000 km^2; 6 = >10,000 km^2.

Timing: N = Negligible Sensitivity; M = Moderate Sensitivity; H = High Sensitivity.

Frequency: S = Single Event (occurs once during the Project); I = Irregular Events (occur sporadically at irregular intervals and not predictable); R = Regular Events (occur regularly and may be predictable or scheduled); C = Continuous (occurs continuously).

Duration: ST = Short-term (restricted to duration of Project activity); MT = Medium-term (extends through Project operations but expected to subside when operations cease); LT = Long-term (extends beyond the life of the Project).

Reversibility (refers to population): R = Reversible; I = Irreversible.

Ecological/Socio-cultural and Economic Context: U = Undisturbed (area relatively undisturbed or not adversely affected by human activity); D = Disturbed (area previously been substantially disturbed by human development or human development is still present).

Table 8.15. Significance of potential residual environmental effects of Project activities on sea turtles.

VC: Sea Turtles				
Project Activity	Significance of Predicted Residual Environmental Effects		Likelihood [a]	
	Residual Environmental Effect Rating	Level of Confidence	Probability of Occurrence	Scientific Certainty
Sound				
Airgun Array: hearing/physical effects	NS	M	-	-
Airgun Array: behavioural effects	NS	M	-	-
Project Vessels	NS	H	-	-
Echo Sounder / Side Scan	NS	H	-	-
Vessel/Equipment Presence				
Seismic Vessel and Streamers	NS	H	-	-
Project Support Vessels	NS	H	-	-
Floating LiDAR Systems	NS	H	-	-
Sanitary/Domestic Wastes	NS	H	-	-
Atmospheric Emissions	NS	H	-	-
Accidental Releases	NS	M	-	-

[a] Considered only in the case where 'significant negative effect' is predicted.

Notes:

Significance is defined as having sufficient magnitude, duration, and geographic extent to cause a change in the VC that will alter its status or integrity beyond an acceptable level. A Significant residual effect on biological VCs is defined as a change in the VC population and/or habitat in the Study Area where recovery to baseline conditions in unlikely.

Significance Rating: S = Significant negative environmental effect; NS = Not-significant environmental effect; P = Positive environmental effect.

Level of Confidence (based on professional judgement): L = Low; M = Medium; H = High.

Probability of Occurrence (based on professional judgement): L = Low; M = Medium; H = High.

Scientific Certainty (based on scientific information and statistical analysis/professional judgement): L = Low; M = Medium; H = High.

Disturbance

Based on available data, it is likely that sea turtles would exhibit behavioural changes and/or localized avoidance near a seismic vessel (see Section 4 in Appendix D). In addition, Nelms et al. (2016) suggested that sea turtles could be excluded from critical habitats. However, turtles are considered uncommon in the Study Area. Note that there are few systematic studies on sea turtle reactions to ships and boats but it is thought that response would be minimal relative to responses to seismic sound.

As indicated in Table 8.14, sound produced as a result of the proposed Project (airgun array sound during three concurrent 3D surveys and a 2D survey being the worst-case scenario) is predicted to have residual disturbance effects on sea turtles that are *low* in magnitude for a *short-term* duration over a geographic area of *<1 km²* to *101–1000 km²*. Based on these criteria ratings, the *reversible* residual disturbance effects of sound associated with MKI's proposed 2D/3D/4D seismic program on sea

turtles are predicted to be *not significant* (see Table 8.15). The level of confidence associated with this prediction is *medium* (see Table 8.15) given the data gaps on the effects of airgun sounds.

8.1.8.2 Vessel/Equipment Presence

Information on interactions between vessel/equipment presence and sea turtles is available in Section 5.3.1 of the Eastern Newfoundland SEA (C-NLOPB 2014) and Section 4.5.9.3 of the Southern Newfoundland SEA (C-NLOPB 2010). A more recent review of potential vessel interactions with sea turtles (i.e., ship strikes, propeller injuries) is provided in Section 11.3.4.1 of Equinor (2020).

During the proposed Project, there will typically be one seismic ship and an escort vessel on site during most of the program; a supply vessel will also regularly be present. There is some risk for collision between sea turtles and vessels but given the slow surveying speed (~4.5 knots; 8.3 km/h) of the seismic vessel (and its support vessels), this risk is considered minimal. In some years, there could be multiple seismic survey vessels, escort vessels, support, and supply vessels in the Project Area. Project vessels will maintain constant course and speed whenever possible, and in most cases slow transit speeds, thereby minimizing the risk of vessel collisions. Sea turtles may also become entangled with seismic gear, such as cables, buoys, or streamers (Nelms et al. 2016) but the risk is considered minimal offshore Newfoundland.

As indicated in Table 8.14, vessel/equipment presence associated with the proposed Project is predicted to have residual effects on sea turtles that are *negligible* to *low* in magnitude for a *short-term* duration over a geographic area of *<1 km²* to *11–100 km²*. Based on these criteria ratings, the *reversible* residual effects of vessel/equipment presence associated with MKI's proposed 2D/3D/4D seismic program on sea turtles are predicted to be *not significant* (see Table 8.15). The level of confidence associated with this prediction is *high* (see Table 8.15).

There is some limited potential that sea turtles may interact with FLS and the associated mooring chains/lines. Potential impacts on sea turtles during FLS installation, operation, and removal include associated vessel traffic (i.e., vessel strike risk discussed above) and possible entanglement in the mooring chains/lines. High tension of the buoy chain/line for the FLS would reduce risk of entanglement (see BOEM 2024).

Based on mitigation measures and the general nature of the presence and operation of FLS, residual effects on sea turtles from the presence of FLS are predicted to be *negligible* in magnitude for a *short-term* duration over a geographic extent of *<1 km²* (see Table 8.14). Based on these criteria ratings, the *reversible* residual effects of FLS presence associated on sea turtles are predicted to be *not significant* (see Table 8.15). The level of confidence associated with this prediction is *high* (see Table 8.15) based on available literature and professional judgment.

8.1.8.3 Other Project Activities

There is potential for sea turtles to interact with domestic and sanitary wastes, and atmospheric emissions from the seismic ship and the support vessels. Any effects from these interactions are predicted to be *negligible* (see Table 8.14).

Accidental Releases

All petroleum hydrocarbon handling and reporting procedures on board will be consistent with MKI's policy, and handling and reporting procedures. A fuel spill may occur from the seismic ship and/or the support vessels. Spills would likely be small and quickly dispersed by wind, wave, and ship's propeller action. The effects of hydrocarbon spills on sea turtles were reviewed in Section 5.3 of the Eastern Newfoundland SEA (C-NLOPB 2014) and Section 4.6.4.5 and 4.6.4.6 of the Southern Newfoundland SEA (C-NLOPB 2010). A more recent review of potential effects of hydrocarbon exposure on marine mammals is provided in Section 16.7.6.4 of Equinor (2020). Section 4.3.2 of IAAC (2020) notes that "Marine mammals and sea turtles may experience a change in mortality or injury (acute or immediate effects) if directly exposed to accidentally released hydrocarbons or associated volatiles and aerosols. They may experience a change in health (sub-lethal effects) from direct contact with hydrocarbons or consumption of contaminated prey."

As indicated in Table 8.14, accidental releases of hydrocarbons associated with the proposed Project are predicted to have residual effects on sea turtles that are *low* in magnitude for a *short-term to long-term* duration over a geographic area of *<1 km²* to *1–10 km²*. Based on these criteria ratings, the *reversible* residual effects of accidental releases of hydrocarbons associated with MKI's Project on sea turtles are predicted to be *not significant* (see Table 8.15). The level of confidence associated with this prediction is *medium* (see Table 8.15) given the uncertainties with a vessel spill and data gaps on effects of oiling.

8.1.9 Species at Risk VC

Biological summaries of species with an *Endangered* or *Threatened* status under Schedule 1 of SARA and with reasonable likelihood of occurrence in the Study Area were provided in Section 4.7, while overviews of species with *Special Concern* status under Schedule 1 of SARA were provided in Sections 4.2 and 4.4–4.6 on fish and fish habitat, marine-associated birds, marine mammals, and sea turtles, respectively. Critical habitat for northern and spotted wolffish occurs within the northwest portion of the Study Area (see Figure 4.65). As indicated in Table 4.24 in Section 4.7, SARA Schedule 1 species/populations of relevance to the Study Area include:

- Fish: White Shark (Atlantic population), Atlantic salmon (Inner Bay of Fundy population), and northern, spotted and Atlantic wolffishes;
- Marine-associated Birds: Ivory Gull, Red Knot *rufa* spp. (Tierra del Fuego/Patagonia wintering population), Harlequin Duck (Eastern population), Barrow's Goldeneye (Eastern population), and Red-necked Phalarope;
- Marine Mammals: Blue whale (Atlantic population), North Atlantic right whale, northern bottlenose whale (Scotian Shelf population), fin whale (Atlantic population), and Sowerby's beaked whale; and
- Sea Turtles: Leatherback (Atlantic population) and loggerhead sea turtles.

Species/populations currently without status on Schedule 1 of SARA but designated at-risk (*Endangered*, *Threatened*, or *Special Concern*) by COSEWIC are not included in this assessment of potential effects on the Species at Risk VC. Instead, potential effects on these species/populations have been assessed in the appropriate VC assessment section (i.e., Section 8.1.4 [Fish and Fish Habitat],

Section 8.1.6 [Marine-associated Birds], Section 8.1.7 [Marine Mammals], and Section 8.1.8 [Sea Turtles]) of this EA. Where potential effects are anticipated to be like those of other species within the same taxonomic group, the reader is referred to the relevant VC assessment section rather than repeating the information here (see also Section 4.5 in C-NLOPB 2010, Section 5 in C-NLOPB 2014, and Section 4 in IAAC 2020).

If species/populations currently without status do become listed on Schedule 1 of SARA during the temporal scope of the Project (2026–2030), the Proponent will re-assess these species/populations considering the prohibitions of SARA (including SARA sections 32(1) [Killing, harming, etc., listed wildlife species], 33 [damage or destruction of residence], and 58(1) [Destruction of critical habitat]), and any recovery strategies or action plans that may be in place. Possible mitigation measures as they relate to species at risk will be reviewed with DFO and ECCC. The potential effects of activities associated with the Project are not expected to contravene the prohibitions of SARA (Sections 32[1], 33, 58[1]). Potential interactions between Project activities and the Species at Risk VC are indicated in Table 8.16. Only those species species/populations with either *Endangered* or *Threatened* status under Schedule 1 of SARA (see Table 4.24) are included in the interactions table (see Table 8.16).

Table 8.16. Potential interactions of Project activities and the Species at Risk VC.

VC: Species at Risk					
Project Activities	**White Shark - Atlantic Salmon**	**Northern Wolffish – Spotted Wolffish**	**Ivory Gull – Red Knot**	**Blue Whale – North Atlantic Right Whale – Northern Bottlenose Whale**	**Leatherback Sea Turtle – Loggerhead Sea Turtle**
Sound					
Airgun Array	X	X	X	X	X
Project Vessels	X	X	X	X	X
Echo Sounder/ Side Scan Sonar	X	X	X	X	X
Vessel/Equipment Presence					
Seismic Vessel and Streamers			X	X	X
OBNs		X			
Project Support Vessels			X	X	X
Vessel Lights	X		X		
ROVs		X			
Floating LiDAR Systems	X	X	X	X	X
Sanitary/Domestic Waste	X	X	X	X	X
Atmospheric Emissions	X		X		
Accidental Releases	X	X	X	X	X
Garbage [a]					
Shore Facilities [b]					
Other Projects and Activities in Regional Area					
Oil and Gas Activities	X	X	X	X	X
Fisheries	X	X	X	X	X
Marine Transportation	X	X	X	X	X

[a] Not applicable as garbage will be brought ashore.
[b] There will not be any new onshore facilities. Existing infrastructure will be used.

8.1.9.1 Fish Species at Risk

The potential effects of underwater sound from seismic surveying, accompanying Project vessels, and equipment on white shark and Atlantic salmon are like those described in Section 8.1.4 – namely, avoidance of an area, disruptions to normal behaviour (e.g., foraging or migration due to displacement), or physiological stress. Sharks likely only detect the particle motion component of sound as they do not possess a swim bladder (Chapuis et al. 2019). White shark in South Australia exposed to continuous underwater playback of artificial sound with 95% of its energy <1 kHz spent less time at a bait station compared to silent controls but did not react to playback of orca calls (Chapuis et al. 2019). Atlantic salmon do have a swim bladder and a review of the potential effects from airgun exposure is provided in Section 6.0 of Appendix B. Both fish species are pelagic and would be expected to move from the immediate area in response to approaching vessels or ramping up of the airgun array, minimizing any potential effects. No critical habitat has been identified for white shark or Atlantic salmon in the Study Area, so even if temporary displacement occurred in response to Project sound, it would not be expected to measurably impact essential behaviours (e.g., foraging, migration). There would be no disruption associated with sound from seismic surveying, Project vessels, or related equipment to reproduction/spawning for white shark or Atlantic salmon, as white shark are thought to reproduce in southern environments and Atlantic salmon spawn in freshwater. Like sharks, wolffishes lack a swim bladder. There is a data gap regarding the effects of seismic activity on any life stage of wolffish (Kulka and Simpson 2004). However, given that both adults and eggs are benthic and would be ≥100 m deeper than potential Project sound sources in the Study Area, impacts, if any, would be anticipated to be minimal (Kulka and Simpson 2004). The abundance of northern wolffish was not affected by seismic surveying at depths between 350–500 m on the Newfoundland Slope (see Section 3.2 in Appendix B). Wolffish larvae inhabit near surface waters and, like other fish species, could be directly impacted by seismic activity (see Section 8.1.4), but there have been no directed studies for this species (Kulka and Simpson 2004).

Wolffish exhibit nest guarding behaviour and individual adults inhabit a limited spatial extent of the seabed. The presence of an OBN could impact individual wolffishes if it were deployed on a nest and caused damage/destruction to the nest or harm to the eggs or a guarding wolffish. A ROV will be used to deploy/retrieve OBNs for the Project, in which case benthic life stages of individual wolffishes could be disturbed by the physical presence of a ROV (see Section 8.1.4.2). The pre-deployment visual inspection of the ~5-m area immediately around the planned deploying location for OBNs would be expected to prevent interaction with nest guarding adults, nests, and eggs. Otherwise, it is expected that Project design for years that would include OBN and ROV use would consider wolffish critical habitat boundaries in planning.

Although white shark are seemingly not affected by lights (e.g., Ryan et al. 2017), salmonids may be attracted or repulsed, depending on light intensity (e.g., Matsuda 2024). However, seismic vessels and their support vessels are constantly in motion and do not persist in any one location, minimizing the potential attraction effect and rendering it not spatially static. Additionally, Project vessels will minimize lighting (without compromising safety; see Section 8.1.4.2).

While the surface unit of a FLS would not necessarily be expected to be a source of impact for white shark or Atlantic salmon, the mooring line could be a source for collision for larger fauna, including

sharks. Like OBN placement, the deployment of the seabed frame/anchor for a FLS could result in crushing or smothering damage to benthos, such a wolffish nest or individual adult wolffish if they do not move out of the way. Literature specific to these species is not currently available; however, given the stationary nature and small footprint of the FLS components, the overall likelihood of potential interaction with white shark, Atlantic salmon, or wolffish is considered low and the assessment for fish and fish habitat is applicable here (see Section 8.1.4.2).

The assessment for accidental releases of hydrocarbons on fish and fish habitat (see Section 8.1.4.2) is applicable to fish species at risk. There is a data gap regarding the effects of PAHs on sharks, rays, and skates (Monteiro et al. 2023), although sharks and rays are considered moderately ecologically vulnerable to oil spills (Romo-Curiel et al. 2022). Salmonids are sensitive to effects of hydrocarbon exposure, with decreasing vulnerability observed with increasing age (Bérubé et al. 2023). Embryos of Atlantic salmon are particularly vulnerable to hydrocarbon exposure (Bérubé et al. 2023), but, given the distance from freshwater sources, would not be present in the Study Area. As indicated in Section 8.1.4.2, the volume/concentration of spill components that could conceivably reach the seabed from a Project-related surface accidental release is unlikely to be high enough to induce effects in benthos, such as adult wolffishes or their eggs. Near-surface pelagic wolffish larvae could be impacted, although, providing adherence to appropriate regulations and guidelines, the impacts on wolffish are considered likely to be negligible (Kulka and Simpson 2004).

The mitigation measure of ramping up the airgun array combined with other measures identified in Sections 6.0 and 8.1.4 are expected to minimize potential effects on white shark, Atlantic salmon, and wolffishes.

With mitigation measures in place, residual effects on white shark, Atlantic salmon, and wolffishes associated with sound from the Project are predicted to range from *negligible* to *moderate* for a *short-term* duration over a geographic extent of *<1 km² to 1001–10,000 km²*, and to be *regular* to *continuous* in frequency (Table 8.17). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality, depending on the life stage (e.g., hatchling/adult; pelagic/benthic) and seasonal activity (e.g., reproduction, migration), and be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of underwater sound on white shark, Atlantic salmon, and wolffishes are predicted to be *not significant* (Table 8.18). The level of confidence associated with this prediction is *low* to *high* given the scientific data gaps, particularly those involving the effects of seismic exploration and in-sediment vibration for wild at-risk fish species within the Study Area in real-life scenarios and effects on populations rather than solely on individuals.

The residual effects on white shark, Atlantic salmon, and wolffishes associated with the presence of vessels/equipment are predicted to range from *negligible* to *low* in magnitude for a *short-term* duration over a geographic extent of *<1 km²* to *101–1000 km²*, and to be *regular* to *continuous* in frequency (*single event* for accidental release; Table 8.17). Residual effects are predicted to have *negligible* to *moderate* sensitivity depending on the life stage and seasonal activity of the at-risk species and be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of vessels/equipment on white shark, Atlantic salmon, and wolffishes are predicted to be *not significant* (Table 8.18). The level of confidence associated with this prediction is *medium* to *high* given the scientific data gaps.

Table 8.17. Assessment of effects of Project activities on the Species at Risk VC.

VC: Species at Risk									
Project Activity	Nature of Environmental Effect (Neutral, Positive [P], or Negative [N])	Mitigation	Evaluation Criteria for Assessing Environmental Effects						
			Magnitude	Geographic Extent	Timing	Frequency	Duration	Reversibility	Ecological / Socio-Economic Context
Sound									
Airgun Array	Disturbance (N); Hearing Impairment (N); Physical Effects (N)	Ramp-up of array; Spatial & temporal avoidance; Delay start [a]; Shutdown [b]	N-M	1-5	N-M	R	ST	R	D
Project Vessels	Disturbance (N)	Spatial & temporal avoidance	N-L	1-2	N-M	C	ST	R	D
Echo Sounder/ Side Scan Sonar	Disturbance (N)	Spatial & temporal avoidance	N-L	1	N-M	C	ST	R	D
Vessel/Equipment Presence									
Seismic Vessel and Streamers	Disturbance at Surface (N)	Limited footprint (vessel/wake); Short residence in any given location; Slow speeds while streamers deployed	N-L	1-3	N-M	C	ST	R	D
OBNs	Benthic Disturbance (N)	Small footprint for each OBN; Short deployment time; Visual inspection for species at risk before installation if using ROV	N	1-4	N-M	C	ST	R	D
Project Support Vessels	Disturbance (N)	Limited footprint (vessel/wake); Short residence in any given location; Slow speeds while accompanying seismic vessel	N-L	1	N-M	C	ST	R	D
Vessel Lights	Attraction (N); Mortality (N)	Reduce lighting (if safe); Search, Handling, and Release protocols	N-L	1-2	N-M	R	ST	R	D
ROVs	Disturbance (N); Physical Effects (N); Attraction to lights (Neutral)	Limited footprint (ROV, water displacement from thrusters); Short residence at a given deployment site; Slow speeds	N	1	N-M	R	ST	R	D
Floating LiDAR Systems	Disturbance at Surface (N); Benthic Disturbance (seabed frame; N)	Small footprint (unit at surface; seabed frame); Powered by renewable energy sources; Stationary year-round; Minimal maintenance periods (1-2 times annually); Reasonably slow deployment/retrieval speeds	N	1	N-M	C	ST	R	D
Sanitary/Domestic Waste	Pathological Effects (N); Contamination (N); Increased food (N/P)	Treatment	N-L	1	N-M	R	ST	R	D

VC: Species at Risk									
Project Activity	Nature of Environmental Effect (Neutral, Positive [P], or Negative [N])	Mitigation	Evaluation Criteria for Assessing Environmental Effects						
			Magnitude	Geographic Extent	Timing	Frequency	Duration	Reversibility	Ecological / Socio-Economic Context
Atmospheric Emissions	Pathological Effects (N); Contamination (N)	Equipment maintenance	N	1	N-M	R	ST	R	D
Accidental Releases	Pathological Effects (N); Contamination (N); Injury/Mortality (N)	Prevention protocols; Response plan; Solid streamer [c]	N-L	1-2	N-H	S	ST-LT	R	D

[a] Ramp-up will be delayed if a marine mammal or sea turtle is sighted within the 500-m safety zone during the pre-watch period prior to airgun activation.

[b] The airgun arrays will be shutdown if an *Endangered* or *Threatened* marine mammal or sea turtle is sighted within 500 m of the array.

[c] A solid streamer will be used for all seismic surveys.

Notes:

Magnitude: N = Negligible; L = Low; M = Moderate; H = High.

Geographic Extent: 1 = <1 km^2; 2 = 1-10 km^2; 3 = 11-100 km^2; 4 = 101-1000 km^2; 5 = 1001-10,000 km^2; 6 = >10,000 km^2.

Timing: N = Negligible Sensitivity; M = Moderate Sensitivity; H = High Sensitivity.

Frequency: S = Single Event (occurs once during the Project); I = Irregular Events (occur sporadically at irregular intervals and not predictable); R = Regular Events (occur regularly and may be predictable or scheduled); C = Continuous (occurs continuously).

Duration: ST = Short-term (restricted to duration of Project activity); MT = Medium-term (extends through Project operations but expected to subside when operations cease); LT = Long-term (extends beyond the life of the Project).

Reversibility (refers to population): R = Reversible; I = Irreversible.

Ecological/Socio-cultural and Economic Context: U = Undisturbed (area relatively undisturbed or not adversely affected by human activity); D = Disturbed (area previously been substantially disturbed by human development or human development is still present).

Table 8.18. Significance of potential residual environmental effects of Project activities on the Species at Risk VC.

VC: Species at Risk				
Project Activity	Significance of Predicted Residual Environmental Effects		Likelihood [a]	
	Significance Rating	Level of Confidence	Probability of Occurrence	Scientific Certainty
Sound				
Airgun Array	NS	L-H	-	-
Project Vessels	NS	M-H	-	-
Echo Sounder/ Side Scan Sonar	NS	M-H	-	-
Vessel Equipment/Presence				
Seismic Vessel and Streamers	NS	M-H	-	-
OBNs	NS	H	-	-
Project Support Vessels	NS	M-H	-	-
Vessel Lights	NS	M-H	-	-
ROVs	NS	H	-	-
Floating LiDAR Systems	NS	H	-	-
Sanitary/Domestic Wastes	NS	H	-	-
Atmospheric Emissions	NS	H	-	-
Accidental Releases	NS	M-H	-	-

[a] Considered only in the case where 'significant negative effect' is predicted.

Notes:

Significance is defined as of sufficient magnitude, duration, and geographic extent to cause a change in the VC that will alter its status or integrity beyond an acceptable level. A Significant residual effect on biological VCs is defined as a change in the VC population and/or habitat in the Study Area where recovery to baseline conditions in unlikely.

Significance Rating: S = Significant negative environmental effect; NS = Not-significant environmental effect; P = Positive environmental effect.

Level of Confidence (based on professional judgement): L = Low; M = Medium; H = High.

Probability of Occurrence (based on professional judgement): L = Low; M = Medium; H = High.

Scientific Certainty (based on scientific information and statistical analysis/professional judgement): L = Low; M = Medium; H = High.

8.1.9.2 Marine-associated Bird Species at Risk

Ivory Gull and Red Knot foraging behaviour would not likely expose them to underwater sound, and these species are unlikely to occur in the Study Area, particularly during the time when seismic surveys are likely to be conducted. Furthermore, Ivory Gull and Red Knot are not known to be prone to stranding on vessels. The mitigation measures of monitoring the seismic vessel, systematically searching for and releasing stranded birds (in the unlikely event that an Ivory Gull or Red Knot did strand on the vessel) and ramping up the airgun array will minimize the potential effects on these seabird species at risk. As such, the assessment for the Marine-associated Bird VC is directly applicable here (see Section 8.1.6).

With mitigation measures in place and as per the detailed effects assessment in Section 8.1.6, the predicted residual effects of sound from Project activities on Ivory Gull and Red Knot will range from *negligible* to *low* in magnitude for a *short-term* duration over a geographic extent of *<1* to *11–100 km²*, and to be *regular* to *continuous* in frequency (see Table 8.17). Residual effects are predicted to have *negligible* to *moderate sensitivity* to timing, depending on the seasonal activity of at-risk marine-associated birds (e.g., migration, feeding), and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of underwater sound on Ivory Gull and Red Knot are predicted to be *not significant* (see Table 8.18). The level of confidence associated

with this prediction is *medium* to *high* given the data gaps associated with the effects of sound on marine-associated birds in the Study Area.

The predicted residual effects on Ivory Gull and Red Knot associated with the presence of vessels and equipment are predicted to range from *negligible* to *low* in magnitude for a *short-term* duration over a geographic extent of *<1 km²* to *11–100 km²*, and to be *regular* to *continuous* in frequency (*single event* for accidental release; see Table 8.17). Residual effects are predicted to have *negligible* to *moderate* sensitivity depending on the life stage and seasonal activity of the at-risk species and be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of vessels/equipment on Ivory Gull and Red Knot are predicted to be *not significant* (see Table 8.18). The level of confidence associated with this prediction is *medium* to *high* given the scientific data gaps.

8.1.9.3 Marine Mammal Species at Risk

Based on available information, blue whale and North Atlantic right whale are not expected to occur regularly in the Study Area. Relatively speaking, northern bottlenose whale (possibly the Scotian Shelf population) are likely to occur more regularly in the Study Area, particularly in the slope and deep basin waters including off southern Newfoundland and the Flemish Pass area. Northern bottlenose whale have also been observed during seismic monitoring programs in the Orphan Basin (e.g., Moulton et al. 2005, 2006a). However, it is uncertain which population of northern bottlenose whales occurs in the Study Area. No critical habitat for these species/populations has been identified in the Study Area, although an important area for blue whale for foraging/feeding occurs roughly between the 100–1000 m depth contours in the southwestern portion of the Study Area (see Figure 4.65). An updated review of the effects of airgun sound on marine mammals is provided in Appendix C. The assessment of potential effects from Project interactions on the Marine Mammal VC is directly applicable here (see Section 8.1.7).

Mitigation and monitoring designed to minimize potential effects of airgun array noise on SARA-listed marine mammals will include:

- Ramp-up of the airgun array over a 30 min period (during standard airgun operations);
- Monitoring by experienced, qualified MMO(s) during daylight hours that the airgun array is active and the 30 minutes pre-ramp up (60 minutes in deep water areas);
- Shutdown of the airgun array when an *Endangered* or *Threatened* marine mammal or sea turtle is detected within the 500-m safety zone;
- Delay of ramp-up if any marine mammal or sea turtle is detected within the 500-m safety zone;
- Minimum separation distance of 30 km for simultaneous seismic surveys in the Project Area; and
- Use of PAM to detect cetaceans.

With these mitigation measures in place and as per the detailed effects assessment in Section 8.1.7, the predicted residual effects of Project-related sound on blue whale, North Atlantic right whale, and northern bottlenose whale are predicted to range from *negligible* to *medium* in magnitude for a

short-term duration over a geographic area of *<1 km²* to *1001–10,000 km²*, for a *regular* to *continuous* frequency (see Table 8.17). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing), depending on the life stage (e.g., calf/adult) and seasonal activity (e.g., feeding/migrating), and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of underwater sound associated with the Project on blue whale, North Atlantic right whale, and northern bottlenose whale are predicted to be *not significant* (see Table 8.18). The level of confidence associated with this prediction is *low* to *medium* given the data gaps.

The residual effects on blue whale, North Atlantic right whale, and northern bottlenose whale associated with the presence of vessels and equipment are predicted to range from *negligible* to *low* in magnitude for a *short-term* duration over a geographic extent of *<1 km²* to *11–100 km²*, and to be *regular* to *continuous* in frequency (*single event* for accidental release; see Table 8.17). Residual effects are predicted to have *negligible* to *moderate* sensitivity depending on the life stage and seasonal activity of the at-risk species and be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of vessels/equipment on blue whale, North Atlantic right whale, and northern bottlenose whale are predicted to be *not significant* (see Table 8.18). The level of confidence associated with this prediction is *medium* to *high* given the scientific data gaps.

8.1.9.4 Sea Turtle Species at Risk

Based on available information, leatherback and loggerhead sea turtles are not expected to occur regularly in the Study Area. No high-use areas for leatherback sea turtle or critical habitat for either species have been identified in the Study Area (see Figure 4.65). An updated review of the potential effects of airgun sound on sea turtles is provided in Appendix D. The assessment of potential effects from Project interactions on sea turtles is directly applicable here (see Section 8.1.8).

Mitigation and monitoring designed to minimize potential effects of airgun array noise on SARA-listed sea turtles will include:

- Ramp-up of the airgun array over a 30 min period (during standard airgun operations);
- Monitoring by experienced, qualified MMO(s) (with assistance from a FLO) during daylight hours that the airgun array is active and the 30 minutes pre-ramp up (60 minutes in deep water areas);
- Shutdown of the airgun array when an *Endangered* or *Threatened* sea turtle is detected within the 500-m safety zone;
- Delay of ramp-up if any sea turtle is detected within the 500-m safety zone; and
- Minimum separation distance of 30 km for simultaneous seismic surveys in the Project Area.

With these mitigation measures in place and as per the detailed effects assessment in Section 8.1.8, the predicted residual effects of Project-related sound on leatherback sea turtle and loggerhead sea turtle are predicted to range from *negligible* to *medium* in magnitude for a *short-term* duration over a geographic area of *<1* to *1001–10,000 km²*, for a *regular* to *continuous* frequency (see Table 8.17). Residual effects are predicted to have *negligible* to *moderate sensitivity* to seasonality (timing),

depending on seasonal activity (e.g., feeding/migrating), and to be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of underwater sound associated with the Project on leatherback sea turtle and loggerhead sea turtle are predicted to be *not significant* (see Table 8.18). The level of confidence associated with this prediction is *low* to *medium* given the data gaps and uncertainties regarding sea turtle distribution within the Study Area.

The residual effects on leatherback sea turtle and loggerhead sea turtle associated with the presence of vessels and equipment are predicted to range from *negligible* to *low* in magnitude for a *short-term* duration over a geographic extent of *<1 km²* to *11–100 km²*, and to be *regular* to *continuous* in frequency (*single event* for accidental release; see Table 8.17). Residual effects are predicted to have *negligible* to *moderate* sensitivity depending on seasonal activity and be fully *reversible*. The Study Area is considered *disturbed*. Based on these criteria ratings, the residual effects of the presence of vessels/equipment on leatherback sea turtle and loggerhead sea turtle are predicted to be *not significant* (see Table 8.18). The level of confidence associated with this prediction is *medium* to *high* given the scientific data gaps and uncertainties for sea turtle distribution within the Study Area.

8.1.10 Sensitive Areas VC

An overview of sensitive areas located either entirely or partially within the Study Area was provided in Section 4.8. The habitat preferences of biota potentially inhabiting these sensitive areas, including invertebrates, fish, marine mammals, sea turtles, and marine-associated birds, were detailed in Sections 4.2–4.6, and species at risk were described in Section 4.7. The reader is also referred to Section 4.5 in C-NLOPB (2010), Section 5.4 in C-NLOPB (2014), and Sections 4.2.2 and 4.3 in IAAC (2020).

Based on the conclusions of Sections 8.1.4–8.1.9, the residual effects of Project-related sound and the presence of Project vessels and equipment on the Sensitive Areas VC within the Study Area are predicted to be *not significant*. The level of confidence associated with this prediction is *medium*, given the relevant data gaps associated with each VC. When specific seismic survey areas are known, the Sensitive Areas VC will be considered further in EA Updates with detailed consideration of proximity and types of activities planned for a given area and year. It is anticipated that the boundaries and reasons for designation of sensitive areas (e.g., known concentrations of habitat-forming corals) will be taken into account during Project planning and that areas with known benthic sensitivities (e.g., SBAs) will be avoided where possible.

9.0 Cumulative Effects

This EA has assessed cumulative effects within the Project Area and thus, the residual effects described in preceding sections include any potential cumulative effects resulting from the MKI activities in the Project Area. This includes the potential residual effects of three concurrent 3D surveys and a 2D survey being conducted by MKI (see Section 2.0). Considering the size of the Project Area, the likely considerable separation of the concurrent surveys, and the predictions of significance presented in Section 8.0, the within-Project cumulative residual effects associated with concurrent

MKI seismic surveys are predicted to be *not significant*. The level of confidence associated with this prediction ranges from low to high, depending on the Project activity and VC.

It is also necessary to assess cumulative effects when considering other non-Project activities that have been or will occur in the region, including:

- Fisheries (commercial and research survey fishing);
- Marine transportation (e.g., cargo, defense, yachts, cruise ships); and
- Offshore oil and gas industry activities.

9.1.1 Fisheries

Commercial, Indigenous, and recreational fishing has been discussed and assessed in detail in Section 4.3 and Section 8.1.5. Fishing activities, by their nature, cause mortality and disturbance to fish populations and may cause incidental mortalities or disturbance to seabirds, marine mammals, and sea turtles. It is predicted that the Project will not cause any mortality to these VCs (with the potential exception of small numbers of petrels) and thus, there will be *negligible* cumulative mortality effect. There is some potential for cumulative disturbance effect (e.g., fishing vessel noise) but there will be directed attempts by both industries to mitigate such effects by avoiding each other's active areas and times as much as possible. The seismic surveying will also spatially and temporally avoid DFO research vessels during multi-species trawl surveys to the extent possible. Any cumulative effects associated with fisheries are predicted to be *not significant*. The level of certainty associated with this prediction is *medium*.

9.1.2 Marine Transportation

Marine transportation within the Study Area is discussed in Section 5.3 in C-NLOPB (2010), Section 4.3.5.1 in C-NLOPB (2014), and Section 3.3.3 in IAAC (2020).

There are several data layers available via IAAC (2024) that provide a visual display of vessel location data (January 2015–February 2021 combined), which effectively reveal main traffic routes/use areas in the Study Area:

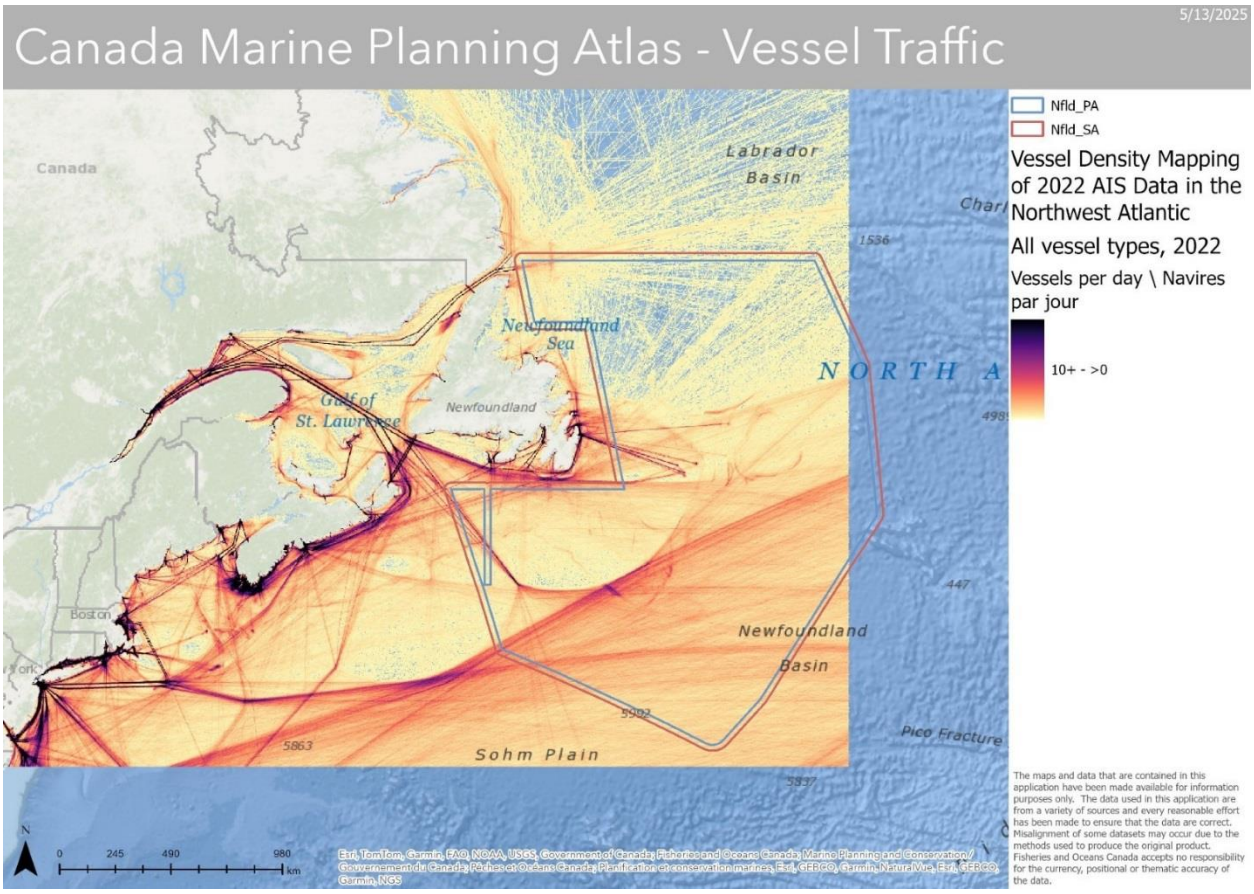
- Global Ship Density – All Vessels;
- Global Ship Density – Commercial Vessels;
- Global Ship Density – Fishing Vessels;
- Global Ship Density – Oil and Gas Vessels;
- Global Ship Density – Passenger Vessels; and
- Global Ship Density – Leisure Vessels.

The Canada Marine Planning Atlas (DFO 2025b) also has a Marine Transportation data layer theme, which was used to generate Figure 9.1. Cumulative vessel traffic data for all vessel types combined for 2022 indicate that marine traffic density within the Project Area is most concentrated in the southeast, near coastal areas of Newfoundland, and along shipping routes associated with oil and gas production facilities. There were relatively few vessel transits per day recorded in the northern portion

of the Project Area. The higher vessel transits in the southeastern portion of the Project Area are associated with international shipping routes.

To mitigate potential interactions between commercial shipping and the Project, MKI's seismic and escort vessels continuously monitor shipping activity and communicate with other vessels when appropriate to ensure appropriate separation distances are maintained for safe operations.

Project seismic survey and associated support vessels are not likely to add much marine traffic congestion. Ships may need to divert around the immediate seismic survey area, but this will not prevent or impede the passage of either vessel as the *Shipping Act* and standard navigation rules will apply. Thus, potential for cumulative effects with other shipping is predicted to be *low* and *not significant*. The level of certainty associated with this prediction is *medium*.



Source: DFO (2025b).

Figure 9.1. Marine shipping traffic density in the Project and Study Areas, 2022.

9.1.3 Other Oil and Gas Activities

Potential offshore oil and gas industry activities in the region based on current completed 'in-effect' EAs listed on the C-NLOER public registry (www.cnloer.ca/assessments/) are listed in Table 9.1.

Table 9.1. Offshore oil and gas industry activities in the Study Area as listed on the C-NLOER website.

Proponent	Oil and Gas Activity	Project	Timeframe
Suncor Energy	Exploration Drilling	Tilt Cove Exploration Drilling Project	2019–2028
Equinor Canada	Exploration Drilling	Central Ridge Exploration Drilling Project	2020–2029
BHP Canada	Exploration Drilling	West Flemish Pass and Central Ridge Exploration Drilling Project	2019–2028
Chevron Canada	Exploration Drilling	West Flemish Pass Exploration Drilling Project	2021–2030
BP Canada	Exploration Drilling	Orphan Basin Exploration Drilling Program	2017–2026
CNOOC	Exploration Drilling	Flemish Pass Exploration Drilling Project	2018–2028
ExxonMobil Canada	Exploration Drilling	Southeastern Newfoundland Offshore Exploration Drilling Project	2020–2029
ExxonMobil Canada	Exploration Drilling	Eastern Newfoundland Offshore Exploration Drilling Project	2018–2030
Husky Oil and ExxonMobil Canada	Exploration Drilling	Jeanne d'Arc Exploration Drilling Project	2019–2027
Equinor Canada	Exploration Drilling	Flemish Pass Exploration Drilling Project	2018–2028
Fugro GeoSurveys	Seafloor mapping and seep sampling	Offshore Seafloor and Seep Sampling Program	2017–2027
HMDC	Seismic Surveying	2D/3D/4D Seismic Projects for the Hibernia Oil and Gas Production Field	2013–2040
Husky Oil	Offshore Oil Development	White Rose Extension Project	2013 to ~2041
ExxonMobil Canada	Offshore Oil Development	Hebron Development Project	2008 to ~2025
HMDC	Offshore Oil Development	Hibernia Drill Centres Construction and Operations Program	2009–2036
Equinor Canada	Offshore Oil Development	Bay du Nord Development Project	~To be determined

There are four existing offshore production developments (Hibernia, Terra Nova, Hebron, and White Rose) on the northeastern part of the Grand Banks. The existing developments fall inside of the boundaries of MKI's Regional Area but do not create the same types and levels of underwater noise as seismic, geohazard, or VSP programs. Underwater sound generated from production installations and attending support vessels have lower source levels and are continuous in nature versus those produced during seismic surveys. There are numerous active exploration drilling EAs on the C-NLOER website but typically, in most years, there would be one to two concurrent drilling programs per year. As necessary, MKI commits to communicating closely with production and exploration drilling operators to ensure appropriate spatial separation of activities. There is some limited potential for cumulative effects with other seismic programs that could operate in future years (based on the above list). Different seismic programs could potentially be operating in relatively close proximity. During these periods, VCs may be exposed to noise from more than one of the seismic survey programs. It will be in the interests of the different parties to arrange for good coordination

between programs in order to provide sufficient buffers and to minimize acoustic interference. Assuming maintenance of sufficient separation of seismic vessels operating concurrently in the Project Area, cumulative effects of seismic sound on fish and fish habitat, fisheries, marine-associated birds, marine mammals, sea turtles, species at risk and sensitive areas are predicted to be *not significant*. However, there are uncertainties regarding this prediction, particularly regarding effects of masking on marine mammals from sound produced during multiple seismic surveys. The potential for temporal and spatial overlap of future activity of seismic programs (2026 and beyond) in the area will be considered in the EA update process. Uncertainty due to the large Study Area will be reduced as specific survey designs that will cover smaller areas become available.

As discussed in this EA, negative effects (auditory, physical, and behavioural) on key sensitive VCs, such as marine mammals, appear unlikely beyond a localized area from the sound source. In addition, all programs will use mitigation measures such as ramp-ups, delayed startups, shutdowns of the airgun arrays, and spatial separation between seismic surveys. Cumulative effects associated with other oil and gas activities in the Regional Area are predicted to be *not significant*. The level of certainty associated with this prediction is *low* to *medium*. The cumulative effects associated with this Project will be re-visited in each subsequent EA Update.

9.1.4 Consideration of Combined Activities

The primary concern associated with seismic surveys in combination with other projects or activities in the Study Area is the effects of underwater sound on VCs. As discussed in Section 8 and above, the cumulative effects of airgun sound from simultaneous seismic surveys on fish and fish habitat, fisheries, seabirds, marine mammals, sea turtles, species at risk, and sensitive areas are predicted to be not significant. However, there are uncertainties regarding these predictions, particularly including the effects of masking and disturbance on marine mammals, and the effects of disturbance on marine invertebrates and fishes from sound produced during multiple seismic surveys. Note that possible disturbance effects on marine invertebrates and fishes might not only impact key life history components but also commercial fisheries and science surveys. However, disturbance effects on fisheries are more readily mitigated primarily through communication and temporal and spatial avoidance of seismic surveys from fishing activity. The uncertainties with the effects of underwater sound increase with the number of seismic surveys and additional sources of underwater sound in the area (e.g., commercial shipping, fishing vessels, oil developments, and exploration drilling). Sound from vessels and sound associated with offshore production and drilling are generally continuous (vs. pulsed sound from airguns) and at much lower sound levels. There is little potential for hearing impairment or physical effects on VCs associated with underwater sound from vessels and offshore oil production. Any avoidance of vessels and offshore oil developments by VCs, including species at risk, is likely to be localized and temporary.

As discussed in the EA for this Project, negative effects (auditory, physical, and behavioural) on key sensitive VCs, such as marine mammals, appear unlikely beyond a localized area from the sound source. In addition, all seismic surveys will use mitigation measures such as ramp-ups, delayed startups, and shut-downs of the airgun arrays as well as spatial separation between concurrent seismic surveys. Marine mammal response (including species at risk) to commercial shipping noise is expected to be localized and temporary, especially for vessels maintaining a constant course and

speed, which is typical for transiting commercial vessels. Marine invertebrate and fish response to commercial shipping noise is also expected to be localized and temporary, especially given the much lower sound levels associated with commercial shipping. Thus, it seems likely that while some animals may receive sound from seismic surveys, other vessels, oil developments, and exploration drilling in the Study Area, the current prediction is that *no significant* residual effects will result from exposure to underwater sound. The level of confidence associated with this prediction is rated as *low* to *medium* given the scientific data gaps.

10.0 Assessment Summary

A summary of the significance ratings of residual effects of MKI's proposed seismic and environmental data collection program on the environment are shown in Table 10.1. The levels of confidence are also provided in the table. In summary, the residual effects of MKI's proposed seismic and environmental data collection program on the VCs are predicted to be *not significant*.

Table 10.1. Significance of potential residual environmental effects of MKI's proposed seismic and environmental data collection program on VCs in the Study Area.

VCs: Fish and Fish Habitat, Fisheries, Marine-associated Birds, Marine Mammals, Sea Turtles, Species at Risk, Sensitive Areas				
Project Activity	Significance of Predicted Residual Environmental Effects		Likelihood [a]	
	Significance Rating	Level of Confidence	Probability of Occurrence	Scientific Certainty
Sound				
Airgun Array	NS	L-H	-	-
Project Vessels	NS	M-H	-	-
Echo Sounder/ Side Scan Sonar	NS	M-H	-	-
Vessel Equipment/Presence				
Seismic Vessel and Streamers	NS	H	-	-
OBNs	NS	H	-	-
Project Support Vessels	NS	H	-	-
Vessel Lights	NS	M-H	-	-
ROVs	NS	H	-	-
Floating LiDAR Systems	NS	H	-	-
Sanitary/Domestic Wastes	NS	H	-	-
Atmospheric Emissions	NS	H	-	-
Accidental Releases	NS	M-H	-	-

[a] Considered only in the case where 'significant negative effect' is predicted.

Notes:

Significance is defined as of sufficient magnitude, duration, and geographic extent to cause a change in the VC that will alter its status or integrity beyond an acceptable level. A Significant residual effect on biological VCs is defined as a change in the VC population and/or habitat in the Study Area where recovery to baseline conditions in unlikely.

Significance Rating: S = Significant negative environmental effect; NS = Not-significant environmental effect; P = Positive environmental effect.

Level of Confidence (based on professional judgement): L = Low; M = Medium; H = High.

Probability of Occurrence (based on professional judgement): L = Low; M = Medium; H = High.

Scientific Certainty (based on scientific information and statistical analysis/professional judgement): L = Low; M = Medium; H = High.

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Appendix A:
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Review of Potential Effects of Seismic Airgun Sound on Marine Invertebrates

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Acronyms and Abbreviations

BACI	Before-after-control-impact
dB	Decibel
DFO	Fisheries and Oceans Canada
Hz	Hertz
KE	Kinetic energy
kHz	Kilohertz
PE	Potential energy
SEL	Sound exposure level
SPL	Sound pressure level
µPa	Micro Pascal

1.0 Introduction

This appendix provides an overview of the known acoustic capabilities of marine invertebrates and information related to the potential effects of exposure to seismic airgun sound on these animals. The number of studies on the acoustic capabilities of invertebrates and the potential effects of exposure to seismic sound on them are limited compared to same subject studies involving other marine biota. Crustaceans and molluscs represent the invertebrate groups most studied to date. This appendix includes results of studies of varying degrees of scientific veracity. Several review papers addressing the interaction of underwater sound and marine invertebrates have been published (Hawkins et al. 2015; Aguilar de Soto 2016; Edmonds et al. 2016; Hawkins and Popper 2016; Carroll et al. 2017; Elliott et al. 2019; Wale et al. 2021; Popper et al. 2022; Affatati and Camerlenghi 2023; Solé et al. 2023; Cones et al. 2024; Vereide and Kühn 2024). Fisheries and Oceans Canada (DFO) has also published internal documents that provide reviews of the effects of seismic and other underwater sound on marine invertebrates (e.g., Moriyasu et al. 2004; Payne et al. 2008).

Sound is generated by the movement or vibration of objects immersed in a compressible medium. As a sound source moves, kinetic energy is imparted to the medium and passed on, traveling as a propagated elastic wave within which particles of the medium are moved back and forth. Note that the particles of a medium do not travel with the propagating sound wave but rather move back and forth over the same location. At the same time, the medium particles transmit their oscillatory motion to neighbouring particles resulting in particle oscillation along the line of transmission in accompaniment with waves of compression (i.e., increase in pressure) and expansion (i.e., reduction in pressure) (Popper and Hawkins 2018).

It is important to note that there are two components to underwater sound: (1) sound pressure; and (2) particle motion. The total energy contained in a sound wave is the sum of its potential energy (PE) and its kinetic energy (KE). The PE results from the compression and expansion of the medium and is thereby related to the sound pressure component. The KE arises from the particle motion component. In the far-field (considerable distance from the sound source), the energies associated with acoustic pressure and acoustic particle motion are equal (i.e., PE=KE). However, in the near-field (close to sound source), the particle motion component contains more energy than the pressure component (i.e., KE>PE) (Popper and Hawkins 2018).

The to-and-fro particle displacements in sound are extremely small (order of nanometers) so it is much easier to measure the sound pressure component of sound and then estimate particle motion from that measure. This is acceptable in an acoustic free-field where boundaries are non-existent but close to acoustic boundaries (e.g., seabed, air-water interface at surface), the relationship between pressure and particle motion is much more complex (Pierce 1981 *in* Popper and Hawkins 2018; McCauley et al. 2021) so direct measurement of particle motion is necessary. Unlike the pressure component of sound, particle motion is inherently directional (i.e., vector quantity), typically along the axis of transmission. Pressure acts in all directions, making it a scalar quantity.

Underwater sound pressure levels (SPLs) are typically reported as a number of decibels referenced to a reference level, usually 1 micro-Pascal (µPa). However, the sound pressure dB number can represent multiple types of measurements, including "zero to peak [0-p]", "peak to peak [p-p]", or "averaged [rms]". Sound exposure levels (SEL) may also be reported as dB. The SEL is the integration of all the acoustic energy contained within the duration of a single sound event. Unless precise measurement types are reported, it is not possible to directly compare results of studies.

Until recently, the particle motion component of seismic airgun sound has not been typically measured. It is thought that marine invertebrates are sensitive to particle motion only given their lack of internal air-filled spaces that would make them sensitive to the pressure component. The particle motion component may be reported as particle displacement (m), particle velocity (ms^{-1}), or particle acceleration (ms^{-2}). Rogers et al. (2021) found that sounds from a seismic survey measured above ambient conditions up to 10 km away for particle acceleration and up to 31 km for sound pressure.

The information contained in the following sections reflects what is currently available in the scientific literature, both peer-reviewed and otherwise. However, many data gaps remain (Hawkins et al. 2015, 2021; Hawkins and Popper 2016, 2017; Carroll et al. 2017; Popper and Hawkins 2019; Wale et al. 2021; Hawkins 2022; Popper et al. 2022; Affatati and Camerlenghi 2023; Solé et al. 2023; Cones et al. 2024; Vereide and Kühn 2024). In particular, more information is needed on the particle motion component of airgun sounds and its effects on invertebrates (Hawkins and Popper 2017). Popper and Hawkins (2018) dedicated an entire paper on the importance of particle motion to invertebrates and fishes, including suggested foci of study, to improve knowledge of its potential effects on these animals. Recently, more studies addressing some of the known gaps associated with understanding how invertebrates detect sound and the potential effects of exposure to it have been conducted.

2.0 Acoustic Capabilities

Much of the available information on acoustic abilities of marine invertebrates pertains to crustaceans, specifically lobsters, crabs, and shrimps. A limited number of acoustic-related studies have also been conducted using cephalopods as experimental subjects. Limited studies have been conducted on the sensitivity of invertebrate species to underwater sound. Available data suggest that they are capable of detecting vibrations but are incapable of detecting pressure fluctuations.

3.0 Detection of Particle Motion

In contrast to fish and aquatic mammals, no physical structures have been discovered in aquatic invertebrates that are stimulated by the pressure component of sound. Rather than being pressure-sensitive, aquatic invertebrates appear to be most sensitive to particle motion

(Breithaupt 2002; Hawkins et al. 2021). Substrate vibrations caused by sounds can also affect the epibenthos, but sensitivities are largely unknown (Roberts and Elliott 2017).

Examples of structures of marine invertebrates involved in the detection of particle motion include body hairs that respond to mechanical stimulation via associated sensory cells, chordotonal organs associated with joints that may respond to low frequency sounds or, in some cases, vibrations transmitted through the exoskeleton from the substrate, and organs in crustaceans called statocysts which include dense structures (statoliths) associated with cells that resemble sensory hair cells in vertebrate ears (Cohen and Dijkgraaf 1961, Salmon et al. 1977, Breithaupt and Tautz 1990, Goodall et al. 1990, and Popper et al. 2001 *in* Popper and Hawkins 2018).

3.1 Molluscs

Marine invertebrates may be capable of detecting sounds traveling through and on the substrate (Roberts and Elliott 2017). Potential auditory systems in bivalves include paired statocysts, abdominal sense organs, and cilia-lined tentacles (Cones et al. 2023). Roberts et al. (2015) studied the responsiveness of blue mussels (*Mytilus edulis*) to sediment sound transmissions and found that these invertebrates do respond directly to these stimuli; they responded to sound in the frequency band of 5-410 Hz (Roberts et al. 2015). Pacific oysters (*Magallana gigas*) were found to be sensitive to sounds with frequencies of 10-1000 Hz (Charif et al. 2017), and the giant scallop (*Placopecten magelanicus*) responded to frequencies of 100-500 Hz (Jézéquel et al. 2023).

It is possible that statocyst hair cells of cephalopods are directionally sensitive in a way that is similar to the responses of hair cells of the vertebrate vestibular and lateral line systems (Budelmann and Williamson 1994; Budelmann 1996). Kaifu et al. (2008) provided evidence that the cephalopod (*Octopus ocellatus*) detects particle displacement with its statocyst. Studies by Packard et al. (1990), Rawizza (1995), Komak et al. (2005), and Mooney et al. (2010) have tested the sensitivities of various cephalopods to water-borne vibrations, some of which were generated by low-frequency sound. Using the auditory brainstem response (ABR) approach, Hu et al. (2009) showed that auditory evoked potentials can be obtained in the frequency ranges of 400 to 1,500 Hz for the squid (*Sepiotheutis lessoniana*) and 400 to 1000 Hz for the octopus (*Octopus vulgaris*), higher than frequencies previously observed to be detectable by cephalopods.

3.2 Crustaceans

More is known about the acoustic detection capabilities in decapod crustaceans than in any other marine invertebrate group. Roberts et al. (2016) studied the responsiveness of hermit crabs (*Pagurus bernhardus*) to sediment sound transmissions and found that these invertebrates respond directly to these stimuli. Earlier studies indicated that crustaceans appear to be most sensitive to sounds of low frequencies <1000 Hz (Budelmann 1992; Popper et al. 2001), whereas more recent studies have shown that they also respond to higher frequencies. A study by Lovell et al. (2005)

found that the prawn (*Palaemon serratus*) can detect sounds with frequencies of 100-3000 Hz. Lovell et al. (2006) showed that *P. serratus* is capable of detecting a 500 Hz tone regardless of its body size and the related number and size of statocyst hair cells. Studies involving American lobster (*Homarus americanus*) suggest that these crustaceans are more sensitive to higher frequency sounds than previously realized. Although Jézéquel et al. (2021) reported that American lobster responded to tone pips ranging from 80-250 Hz, Pye and Watson III (2004) found that American lobster had peak sensitivities at 20-300 Hz as well as at 1000-5000 Hz. Dinh and Radford (2021) recently showed that that snapping shrimp *Alpheus richardsoni* is sensitive to acoustic particle motion, with a maximum auditory detection ranging from 80 to 100 Hz.

3.3 Cnidarians

Vermeij et al. (2010) studied the movement of coral larvae in the laboratory and concluded that these larvae can detect and respond to underwater sound. This was the first description of an auditory response in the invertebrate phylum Cnidaria. The authors speculated that coral larvae may use reef sound as a cue for orientation. Laboratory and field experiments suggest that underwater sound has a significant effect on settlement rates by the Eastern oyster larvae (*Crassostrea virginica*) (Eggleston et al. 2013). Underwater sound has also been used to deter the settlement of some marine invertebrates (Branscomb and Rittschof 1984; Donskoy and Ludyanskiy 1995).

4.0 Sound Production

Many invertebrates are capable of producing sound, including barnacles, amphipods, shrimp, crabs, and lobsters (Au and Banks 1998; Tolstoganova 2002). Invertebrates typically produce sound by scraping or rubbing various parts of their bodies together, although they also produce sound in other ways. Sounds made by marine invertebrates may be associated with territorial behaviour, mating, courtship, and aggression. On the other hand, some of these sounds may be incidental and not have any biological relevance. Sounds known to be produced by marine invertebrates have frequencies ranging from 87 Hz to 200 kHz, depending on the species. The following paragraphs provide additional context around auditory processes in various invertebrate species.

Both male and female American lobsters produce a buzzing vibration with their carapace when grasped (Pye and Watson III 2004; Henninger and Watson III 2005; Jézéquel et al. (2021). Larger lobsters vibrate more consistently than smaller lobsters, suggesting that sound production may be involved with mating behaviour. Sound production by other species of lobsters has also been studied (Buscaino et al. 2011). Among deep-sea lobsters, sound level was more variable at night than during the day, with the highest levels occurring at the lowest frequencies.

While feeding, king crab (*Paralithodes camtschaticus*) produce impulsive sounds that appear to stimulate movement by other crabs, including approach behaviour (Tolstoganova 2002). King

crab also appeared to produce 'discomfort' sounds when environmental conditions were manipulated. These discomfort sounds differ from the feeding sounds in terms of frequency range and pulse duration.

Snapping shrimp (*Synalpheus parneomeris*) are among the major sources of biological sound in temperate and tropical shallow-water areas (Au and Banks 1998). By rapidly closing one of its frontal chela (claw), a snapping shrimp generates a forward jet of water and the cavitation of fast-moving water produces a sound. Both the sound and the jet of water may function as both offensive and defensive means in feeding and territorial behaviours of alpheidae shrimp. The measured source SPLs for snapping shrimp were 183-189 dB re 1 µPa $_{p-p}$ and extended over a frequency range of 2-200 kHz.

5.0 Potential Effects of Airgun Exposure

Sound emitted by underwater seismic survey equipment results in energy pulses with very high peak pressures (Richardson et al. 1995). Virtually all underwater seismic surveying conducted today uses airguns which typically have lower peak pressures and longer rise times than chemical explosives. Sound levels from underwater airgun discharges are sometimes high enough to potentially injure or kill animals located very close to the sound source. Less overt than physical effects are potential disturbances to normal behaviours that animals may experience when exposed to airgun sound.

There are essentially three main types of potential effects of exposure to airgun sound on marine invertebrates: (1) pathological (i.e., injury, mortality), (2) physiological, and (3) behavioural. Pathological effects include lethal and sub-lethal injury to the animals, physiological effects include temporary primary and secondary stress responses, and behavioural effects refer to changes in exhibited behaviours (i.e., disturbance). The three categories should not be considered as independent of one another and are likely interrelated in complex ways. While potential pathological effects on marine invertebrates remain important for scientific study, physiological and behavioural effects probably warrant the most attention, especially from the perspective of population effects. In addition to pathological, physiological and behavioural effects from noise, Jézéquel et al. (2021) reported that shipping noise can mask sounds produced by European lobster (*Homarus gammarus*) and that they may change their sound production in response to noise.

It is difficult to interpret results of many studies on the effects of exposure to seismic sound on marine invertebrates because authors often do not provide enough information on the received sound, including received sound levels, source sound levels, and specific characteristics of the sound (e.g., units and references, frequency range, continuous vs. impulsive). As discussed above, the pressure component of seismic airgun sound is less relevant to marine invertebrates than the particle motion component. Unfortunately, few studies to date that have examined the potential effects of exposure to seismic airgun sound on invertebrates even consider particle motion, much less measure received levels. Nonetheless, the available information suggests that invertebrates, particularly crustaceans, may be relatively resilient to airgun sounds (Day et al. 2016a,b).

Przeslawski et al. (2018a) examined a case study on marine seismic impacts on biota to assess the advantages and challenges of field-based methods in the context of future research and management priorities. They concluded that an interdisciplinary approach using both conventional and innovative experimental components results in more robust overall interpretations of the data. They also stated that there is a need for appropriate environmental baselines and time-series data to account for spatiotemporal variability of environmental and biological parameters that may mask effects, and for a standardized technique in sound monitoring and equipment calibration to ensure accuracy and comparability among studies.

Webster et al. (2018) described a workshop risk assessment of the potential impacts of seismic airgun surveys on marine invertebrates in Western Australia. The assessment's general conclusion was the greater the intensity of sound and the shallower the water depth, the greater the risk to marine invertebrates. In waters of >250 m depth, the impact of seismic surveying on invertebrates was assessed as acceptable, while in waters of <250 m depth, risk ranged from negligible to severe, depending on depth, resource-type, and sound intensity. Immobile organisms, such as molluscs, were deemed to be the invertebrates most at risk from seismic impacts.

5.1 Pathological Effects

In water, acute injury or death of organisms as a result of exposure to sound appears to depend on two features of the sound source: (1) received peak pressure and (2) time required for the pressure to rise and decay. Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of sound produced from seismic airgun arrays used today, the associated pathological zone for invertebrates would be expected to be small (i.e., within a few meters of the seismic source). Studies that have assessed the potential for pathological effects on marine invertebrates due to exposure to sound produced from seismic airgun arrays are discussed below.

5.1.1 Plankton

McCauley et al. (2017) conducted an experiment whereby they exposed zooplankton off the coast of Tasmania to a 150 in^3 airgun source. Observations from the study indicated that seismic surveys may have a greater effect on zooplankton communities than previously understood. Treatment samples of zooplankton exposed to the airgun exhibited an increase of two- to three-fold greater mortality than with the control group, and impacts on zooplankton were observed as far as 1.2 km away from the airgun source. The sample size and number of replications was relatively small however, since the study occurred over just two days. Therefore, more sampling is required in order to determine the full extent of the impact that seismic has on zooplankton mortality.

A companion study completed by Richardson et al. (2017) attempted to model the impact of an airgun survey on zooplankton over a larger temporal and spatial scale than what was originally considered by McCauley et al. (2017). In total, the modeled survey area was 80 km × 36 km, with a water depth range of 300-800 m. Airgun impact was considered for a 35-day period. Modeling results indicated that significant impacts to zooplankton populations would most likely occur only at a local scale, with less of an impact on a larger spatial scale, contradictory to results obtained by McCauley et al. (2017). Richardson et al. (2017) attributed potential avoidance behaviour of the zooplankton as a possible reason why McCauley et al. (2017) observed such a marked decrease in zooplankton abundance during their study.

Fields et al. (2019) conducted laboratory experimentation in 2009 and 2010 to study effects of exposure to airgun sound on the mortality, predator escape response, and gene expression of the copepod *Calanus finmarchicus*. Sound pressure produced by the airgun discharges were measured inside the plastic bags containing the copepods. The exposure distance between the two Bolt 1500 LL airguns (total volume of 520 in^3) and the copepods ranged from 0 to 25 m. The approximate sound exposure levels in the acoustic nearfield ranged between 221 dB re 1 μPa^2s at 0 m and 183 dB re 1 μPa^2s at 25 m. While immediate mortality of copepods exposed at 5 m or less was significantly higher than the controls, the increase in mortality relative to controls did not exceed 30% at any exposure distance. Mortality one week after exposure was 9% higher in those copepods exposed as far as 10 m from the airgun source compared to controls. The authors concluded that the seismic airgun sound had limited effects on the mortality and escape responses of the copepods exposed within 10 m of the airgun source but no measurable impact beyond this distance.

Vereide et al. (2023) conducted a field experiment that examined the effects of a seismic survey on the mortality and development of nauplii of the copepod *Acartia tonsa*. The nauplii were held in plastic bags that were suspended at a depth of 6 m; these were exposed at a distance of 50 m for 2.5 hours to discharges from two 40-in^3 airguns towed behind a vessel. Controls of the experiment included periods with vessel noise only (no airguns), as well as silence. After exposure, the nauplii were brought to the laboratory where greater immediate mortality (14%) was observed in the nauplii exposed to airgun sounds compared with those during the vessel only and silent controls. After 4 days, most of the exposed nauplii were dead, whereas most nauplii in the control groups were still alive 6 days after exposure. Exposed nauplii also had lower growth rates than those that were not exposed to airgun sounds.

Vereide et al. (2024) conducted a laboratory experiment on both *Acartia tonsa* and the copepod *Calanus finmarchicus* to investigate the effect of a rapid pressure drop associated with seismic airgun discharges. They recreated this pressure drop (~2 bar) in the laboratory using a pressure tube. The effects of the pressure drop on mortality were tested both immediately and 5 h after treatment. *Acartia* sp. exposed to the pressure drop had higher mortality rates (0 h: 5.6%; 5 h: 10%) than controls. In contrast, mortality in *Calanus* sp. was higher than controls only after 5 h (3.3%). These results indicate that *Acartia* sp. is more sensitive to the pressure drop than *Calanus* sp.

5.1.2 Molluscs

Aguilar de Soto et al. (2013) conducted a study involving the exposure of wild New Zealand scallop larvae to recorded seismic pulses. The results indicated significant developmental delays from trocophore to D-veliger larval stage, with 46% of the larvae exhibiting body abnormalities. It was suggested that the malformations could have been due to cumulative exposure. Day et al. (2017) found that exposure to seismic sound significantly increased mortality in the scallops, especially over a chronic time scale (i.e., months post-exposure), although not beyond naturally occurring rates of mortality.

Przeslawski et al. (2016, 2018b) studied the potential impacts of an industrial seismic survey on commercial (*Pecten fumatus*) and doughboy (*Mimachlamys asperrima*) scallops. *In situ* monitoring of scallops took place in the Gippsland Basin, Australia, using dredging, and autonomous underwater vehicle deployment before the seismic survey, as well as two, and ten months after the survey. The airgun array used in the study was a single 2530 in^3 array made up of 16 airguns operating at 2000 psi with a maximum SEL of 146 dB re 1 $\mu Pa^2 \cdot s$ at 51 m depth. Overall, there was little to no detectable impact of the seismic survey on scallop health as measured by scallop shell size, adductor muscle diameter, gonad size, or gonad stage (Przeslawski et al. 2016). No scallop mortality related to airgun sounds was detected two or ten months after the seismic survey (Przeslawski et al. 2016, 2018b).

Parsons et al. (2024) conducted a large-scale experiment at a pearl oyster holding lease site to examine the effect of a seismic survey on mortality and productivity of silverlip pearl oysters (*Pinctada maxima*). The oysters were exposed to four days of seismic survey sounds using a 2600 in^3 airgun array with a peak-to-peak source level of 252 dB re 1 µPa at 1 m and a sound exposure level of 228 dB re 1 μPa^2m^2s; the experiment also included one vessel-control day. The oysters were monitored for a full two-year production cycle. Only two of 16 groups showed reduced survival and pearl productivity; thus, the study found no conclusive evidence that the commercial important oyster was impacted by the seismic survey sounds.

In 2001 and 2003, there were two incidents of multiple strandings of the giant squid on the northern coast of Spain, and there was speculation that they were caused by exposure to sounds from geophysical seismic surveys occurring at about the same time in the Bay of Biscay (Guerra et al. 2004). A total of nine giant squid, either stranded or moribund surface-floating, were collected at these times. However, Guerra et al. (2004) did not present any evidence that conclusively linked the giant squid strandings and floaters to seismic activity in the area. Based on necropsies of seven (six females and one male) specimens, there was evidence of acute tissue damage. The authors suggested that one female with extensive tissue damage was affected by the impact of acoustic waves. However, little is known about the impact of underwater sound on cephalopods and the authors did not describe the seismic sources, locations, and durations of the Bay of Biscay surveys. In addition, there were no controls, the presence of seismic activity was entirely circumstantial, and the examined animals had been dead long enough for commencement of tissue degradation.

In addition, Leite et al. (2016) reported observing a dead giant squid while undertaking marine mammal observation work aboard a vessel conducting a seismic survey in offshore Brazil. Photographs were taken of the ~2 m squid floating near the surface of the water which was later identified as *Architeuthis dux* due to its size and morphology. The airgun array used in the survey consisted of 48 airguns with a total firing volume of 5085 in^3 and 2000 psi operating pressure. No SPLs were measured. The authors argue that while there is no conclusive proof that seismic activity caused the mortality of the giant squid, it is possible that there may be a link.

Caged cephalopods (*Sepioteuthis australis*) were exposed to sound from a single 20-in^3 airgun with maximum SPLs of >200 dB re 1 $\mu Pa_{0\text{-}p}$ (McCauley et al. 2000a,b; Fewtrell and McCauley 2012). Statocysts were removed and preserved, but results of the statocyst analyses were not reported. No squid mortalities were reported as a result of these exposures.

5.1.3 Crab

The pathological impacts of sound from seismic surveys on marine invertebrates were investigated in a pilot study on snow crabs (*Chionoecetes opilio*) (Christian et al. 2003, 2004). Under controlled field experimental conditions, captive adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs were exposed to variable SPLs (191-221 dB re 1 $\mu Pa_{0\text{-}p}$) and sound energy levels (SELs) (<130-187 dB re 1 μPa^2s). Neither acute nor chronic (12 weeks post-exposure) mortality was observed for the adult crabs. There was a significant difference in development rate noted between the exposed and unexposed fertilized eggs/embryos. The egg mass exposed to sound energy had a higher proportion of less-developed eggs than the unexposed mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable (Christian et al. 2003, 2004).

Another study of the effects of sound from seismic surveys on marine invertebrates had serious design problems that impacted the interpretation of some of the results (Chadwick 2004). In 2003, a collaborative study was conducted in the southern Gulf of St. Lawrence, Canada, to investigate the effects of exposure to sound from a commercial seismic survey on egg-bearing female snow crabs (DFO 2004). Caged animals were placed on the ocean bottom at a location within the survey area and at a location outside of the survey area. The maximum received SPL was ~195 dB re 1 $\mu Pa_{0\text{-}p}$. The crabs were exposed for 132 hr of the survey, equivalent to thousands of seismic pulses of varying received SPLs. The animals were retrieved and transferred to laboratories for analyses. Neither acute nor chronic lethal or sub-lethal injury to the female crabs or crab embryos was indicated. DFO (2004) reported that some exposed individuals had short-term soiling of gills, antennules, and statocysts, bruising of the hepatopancreas and ovary, and detached outer membranes of oocytes. However, these differences could not be conclusively linked to exposure to sound from the seismic survey. Boudreau et al. (2009) presented the proceedings of a workshop held to evaluate the results of additional studies conducted to answer some questions arising from the original study discussed in DFO (2004). The proceedings of the workshop did not include any more definitive conclusions regarding the original results.

In a field study, Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab (*Metacarcinus magister*) to single discharges from a seven-airgun array and compared their mortality and development rates with those of unexposed larvae. For immediate and long-term survival and time to moult, this study did not reveal any statistically significant differences between the exposed and unexposed larvae, even those exposed within 1 m of the seismic source.

5.1.4 Lobster

Payne et al. (2015) undertook two pilot studies that examined (i) the effects of a seismic airgun recording in the laboratory on American lobster (*Homarus americanus*) mortality, gross pathology, histopathology, serum biochemistry, and feeding, and (ii) prolonged or delayed effects of seismic airgun pulses in the laboratory on lobster mortality, gross pathology, histopathology, and serum biochemistry. For experiment (i), lobsters were exposed to peak-to-peak and root-mean-squared received sound levels of 180 dB re 1 µPa and 171 dB re 1 μPa_{rms}, respectively. Overall, there was no mortality, loss of appendages, or other signs of gross pathology observed in the treatment lobsters. No differences were observed in haemolymph, feeding, ovary histopathology, or glycogen accumulation in the hepatopancreas. The only observed differences were greater degrees of tubular vacuolation and tubular dilation in the hepatopancreas of the treatment lobsters when compared to the control lobsters. For experiment (ii), lobsters were exposed to 20 airgun shots per day for five successive days in a laboratory setting. The peak-to-peak and root-mean-squared received sound levels ranged from ~176 to 200 dB re 1 µPa and 148 to 172 dB re 1 μPa_{rms}, respectively. The lobsters were returned to their aquaria and examined after six months. No differences in mortality, gross pathology, loss of appendages, hepatopancreas/ovary histopathology or glycogen accumulation in the hepatopancreas were observed between treatment and control lobsters. The only observed difference was a slight statistically significant difference for calcium-protein concentration in the haemolymph, with lobsters in the treatment group having a lower concentration than the control group.

Day et al. (2016a,b, 2017) conducted a field study which exposed egg-bearing female southern rock lobsters (*Jasus edwardsii*) to three different airgun configurations: 45 in^3, 150 in^3 (low pressure), and 150 in^3 (high pressure), each with corresponding maximum peak-to-peak source levels of 209, 210, and 212 dB re 1 µPa; and maximum cumulative SEL source levels of 192, 193, and 199 dB re 1 μPa^2s. Female lobsters exposed to airguns were maintained in aquaria until their eggs hatched and the larvae emerged. Embryonic development of the lobster was assessed through the number, morphology, energy content, and competency of hatched larvae. It was determined that none of these variables were significantly different for the treatment larvae when compared to the control larvae (Day et al. 2016a,b). However, there were non-lethal effects, including changes in reflex behaviour time and haemolymph chemistry, as well as apparent damage to statocysts (Day et al. 2016b, 2017).

Fitzgibbon et al. (2017) also examined the impact of airgun exposure on *J. edwardsii* through a companion study to the Day et al. (2016a,b, 2017) studies. The same study site, experimental treatment methodologies, and airgun exposures were used for the lobsters in Fitzgibbon et

al. (2017) as in Day et al. (2016a,b, 2017). The objectives of the study were to examine the haemolymph biochemistry and nutritional condition of groups of lobsters over a period of up to 365 days post airgun exposure. Overall, no mortalities were observed across both the experimental and control groups; however, lobster total haemocyte count was determined to have decreased by 23% to 60% for all lobster groups up to 120 days post airgun exposure in the experimental group when compared to the control group. A lower haemocyte count increases the risk of disease through a lower immunological response. Also, the only other haemolymph parameter that was determined to have been significantly affected by airgun exposure was the Brix index of haemolymph at 120 and 365 post exposure in just one of the experiments involving egg-laden females.

Day et al. (2019, 2021, 2022) described additional field-based studies regarding the potential physical impacts of exposure to airgun sound on *J. edwardsii*. They exposed naïve rock lobster to the equivalent of a full-scale commercial seismic survey; maximum SELs were 155 dB re 1 μms^{-2} at 0 m, 139 dB re 1 μms^{-2} at 500 m, and 113 dB re 1 μms^{-2} at the control site. When the source passed within 100-500 m, adult and juvenile lobsters exhibited impaired righting and damage to the sensory hairs of the statocyst (Day et al. 2019, 2021). Lobsters that were exposed at a more distant range showed recovery, whereas those exposed at closer range had persistent impairment up to 365 days after exposures. Day et al. (2021, 2022) noted that there was indication, e.g., significantly longer intermoult duration, for slowed growth and physiological stress in juvenile lobsters after exposure. Adult lobsters that were collected from areas with high anthropogenic noise were shown to have pre-existing damage to the statocysts which were not damaged further upon exposure to airgun sounds (Day et al. 2020). However, lobsters from noisy environments appeared to be better able to cope with the damage than noise naïve lobsters; they did not show any disruption to the righting reflex (Day et al. 2020). The righting reflex and moult cycle of rock lobster puerulus larvae and juveniles were also negatively impacted by airgun sound exposure to a distance of at least 500 m (Day et al. 2022). This impairment in the righting reflex was persistent in lobsters exposed at 0 m, but individuals exposed at 500 m showed recovery, with delays similar to adult lobsters.

de Lestang et al. (2024) conducted a field experiment to study the effects of a seismic airgun survey on mortality, gross pathology, serum biochemistry, and behaviour in western rock lobster (*Panulirus cygnus*). Tagged lobsters were deployed in baskets along airgun transects. Treatment lobsters were deployed directly below airgun firing locations. Treatment lobsters were exposed to peak-to-peak received sound levels of 216 to 223 dB re 1 µPa. There was no significant difference between treatment and control lobsters in mortality or the likelihood of having lost at least one leg. When the analysis was restricted to only the lobsters with missing legs, the number of missing legs was greater in the treatment group. Treatment lobsters were less likely to be recaught in the commercial lobster fishery, suggesting a reduced survival rate or a reduced affinity for or ability to detect food.

5.1.5 Coral

Heyward et al. (2018) presented the results of the first *in situ* study of the effects of exposure to airgun sound emitted during a 3D seismic survey on corals. The footprint of the 2007 Australian seismic survey at Scott Reef overlapped with a coral dominated habitat. Scleractinian corals (i.e., stony/hard corals) were the most abundant coral-type in this habitat. The water depths in the reef lagoon ranged from 30 to 70 m. The coral monitoring sites were surveyed three times: (1) before any seismic activity, (2) immediately following the initial four-day seismic survey trial, and (3) two months after completion of the full 59-d 3D survey. Each survey included three transects at eight separate stations. During the initial four-day seismic survey trial, the maximum 24-h received sound exposure level (SEL_{24}) and received zero-to-peak SPL at the monitoring sites were 204 dB re 1µPa²s and 226 dB re $1\mu Pa_{0\text{-}p}$, respectively. The maximum levels of the same metrics at the reference sites located >3 km from the experimental sites were 144 dB re 1µPa²s and 163 dB re $1\mu Pa_{0\text{-}p}$, respectively. The maximum 24-h received sound exposure level (SEL_{24}) and received zero-to-peak SPL at the monitoring sites during the subsequent post-trial 59-d seismic survey were 197 dB re 1µPa²s and 220 dB re $1\mu Pa_{0\text{-}p}$, respectively. Note that the received particle motion levels at the experimental and reference monitoring sites were not measured. Heyward et al. (2018) did not detect any coral mortality or skeletal damage resulting from exposure to the seismic airgun sound.

5.2 Physiological Effects

Biochemical responses by marine invertebrates to acoustic stress have also been studied. The study of the biochemical parameters influenced by acoustic stress could possibly provide some indication of the acute extent of the stress and perhaps any subsequent chronic detrimental effects. Stress could potentially affect animal populations by reducing reproductive capacity and adult abundance.

5.2.1 Molluscs

Price (2007) found that blue mussels (*Mytilus edulis*) responded to a 10 kHz pure tone continuous signal by decreasing respiration. Smaller mussels did not appear to react until 30 min of exposure whereas larger mussels responded after 10 min of exposure. The larger mussels tended to lower the oxygen uptake rate more than the smaller animals.

Dang et al. (2024) assessed the impact of the Parsons et al. (2024) silverlip pearl oyster seismic experiment on this species' mantle tissue transcriptome. To identify candidate genes and pathways in the transcriptome impacted by seismic noise they used RNA-seq. Examining those candidates, hey then identified differentially expressed genes and pathways associated with seismic noise through the use of DESeq2 to compare quantified transcripts, and of KEGG Pathway to conduct pathway enrichment analysis. They found that the highest dysregulation in gene expression and pathways was found at distances up to 2000 m from the source after four

days of exposure, and at distances up to 1000 m one month after exposure. This dysregulation diminished after three months. At six months only oysters closest to the source level (at 0 and 1000 m) displayed different gene expression and pathway disruption. The results suggest that stress responses were mobilized by the oysters to mitigate damage from seismic exposure and to maintain cellular homeostasis and growth.

5.2.2 Crab

Stress indicators in the haemolymph of adult male snow crabs were monitored immediately after exposure of the animals to sound from seismic surveys (Christian et al. 2003, 2004) and at various intervals after exposure. No significant acute or chronic differences between exposed and unexposed animals in terms of the stress indicators (e.g., proteins, enzymes, cell type count) were observed.

Hall et al. (2021) collected tissue samples in conjunction with a study by Morris et al. (2018, 2020) and Cote et al. (2020) in order to investigate the potential impact of seismic surveying on the transcriptome responses of snow crab hepatopancreas. The hepatopancreas is an organ that aids in the absorption and storage of nutrients and produces important digestive enzymes and is therefore assumed to be a suitable indicator for determining the effect of sound exposure effects on crab physiology and health. Snow crabs were subjected to 2D seismic noise in 2016 for 2 h and sampled before, and 18 h and three weeks after exposure in Carson Canyon. In 2017, 2D seismic exposure was repeated, and samples were collected prior to seismic testing, and 1 day, 2 days, and 6 weeks after exposure (Morris et al. 2018). Additionally, in 2017 snow crabs were subjected 3D seismic noises at a site north of Carson Canyon for 2 months and were sampled 6 weeks after exposure (Morris et al. 2020; 2021). The study used Transcriptomic (RNA-seq) and qPCR analyses were used to identify and confirm expression levels of candidate molecular biomarkers associated with seismic noise exposure in field-collected snow crab hepatopancreas samples (Hall et al. 2021; Morris et al. 2021). The study identified nine transcripts with significantly higher expression after 2D seismic exposure, and 14 transcripts with significant differential expression between the test and control sites. These include transcripts with functional annotations related to oxidation-reduction, immunity, and metabolism. Changes for these transcripts were not observed in snow crab exposed to chronic longer duration 3D seismic survey sound. The authors concluded transcript expression changes in snow crab can be detected in response to seismic survey sound; however, the candidate molecular biomarkers identified in one field season (2016) were not reliable indicators in the next year (2017) and that further study is warranted (Hall et al. 2021; Morris et al. 2021).

Hall et al. (2023) conducted a laboratory study on crabs collected from the sites examined in the field studies described above (Morris et al. 2018, 2020; Hall et al. 2021) to examine the effect of seismic exposure on transcriptomes of hemocytes and hepatopancreas. Crabs were exposed for 22 weeks to a recording of seismic airguns with a noise level of > 200 dB re 1 $\mu Pa^2 \cdot s$ compared to control tanks in which they were exposed to a continuous noise level of 136 dB re 1 $\mu Pa^2 \cdot s$. One transcript (*rsg2*) showed significantly higher expression in response to seismic exposure in both

hemocytes and hepatopancreas. Five and seven other transcripts showed differential expression that was either significant or showed a non-significant trend in hemocytes (e.g., *cfb* upregulated, *sacs* and *myof* downregulated) and hepatopancreas (e.g., *gpx3* and *atf3* upregulated, *sult1c4* downregulated), respectively. To study the response of these candidate biomarkers in the field Hall et al. (2023) also studied field-collected crabs that were exposed to the commercial seismic surveys described by Morris et al. (2018, 2020) and Hall et al. (2021). They examined the expression levels of 25 selected transcripts in the hepatopancreas from crabs collected before, during, and after seismic surveying at two exposure sites and one control site. They found that few of these biomarkers showed results consistent with the laboratory study.

5.2.3 Lobster

Payne et al. (2007), in their study of the effects of exposure to sound from an airgun source on adult American lobsters, noted decreases in the levels of serum protein, particular serum enzymes, and serum calcium in the haemolymph of animals exposed. Statistically significant differences ($p=0.05$) were noted in serum protein at 12 days post-exposure, serum enzymes at 5 days post-exposure, and serum calcium at 12 days post-exposure. During the histological analysis conducted 4 months post-exposure, Payne et al. (2007) noted more deposits of PAS-stained material, likely glycogen, in the hepatopancreas of some of the exposed lobsters. Accumulation of glycogen could be due to stress or disturbance of cellular processes.

Results from the de Lestang et al. (2024) study (see Section 5.1.4 on pathological effects for study details) indicated no significant difference in blood protein concentration between treatment and control western rock lobsters.

5.2.4 Coral

Results presented by Heyward et al. (2018) (see preceding section on pathological effects for study details) indicated that there was no visible evidence of any immediate physiological damage or stress response in the hard and soft corals (e.g., mucous streaming) exposed to airgun sound from a full 3D seismic survey.

5.2.5 Echinoderms

Buscaino et al. (2019) exposed caged sea urchins (*Arbacia lixula*) and sea cucumbers (*Holothuria tubulosa*) to sounds from a seismic water gun with a peak pressure level of 122 dB re 1 $\mu Pa^2/Hz$ at 850 Hz and a peak particle speed of 207 dB re $(1\ nm/s)^2$ at 550 Hz. When the coelomic fluid was extracted from each animal (40 individuals of each species), there was evidence of stress as indicated by differences in esterase and peroxidase in sea urchins and total hemocyte count and total protein for the sea cucumbers.

Mauro et al. (2024) also studied the effects of a seismic water gun on the physiology of *A. lixula*. They exposed caged individuals to peak-peak and root-mean-square pressure levels of

178 dB re 1 µPa and 159 dB re 1 µPa, respectively, and a root-mean-square particle velocity of 227 to 233 dB re 1 $(nm/s)^2$. These levels were recorded 50 m from the source. The authors then evaluated total protein level, enzyme activity (esterase, alkaline phosphatase, peroxidase, and superoxide dismutase), and heat shock protein (HSP70) expression in the peristomial membrane. Total protein levels were decreased in treatment animals, suggesting impaired protein synthesis and or increased protein degradation, indicating possible nutritional or metabolic problems. There were significant increases in treatments in peroxidase activity and superoxide dismutase, which are important antioxidant enzymes. This result suggests that acoustic stress may cause oxidative stress in the peristomial membrane. Esterase and alkaline phosphatase activity also significantly increased. These enzymes may function in cellular defence mechanisms and adaptation to environmental stress. HSP70 showed an increased trend. Heat shock proteins (HSPs) are activated to protect cells from irreversible damage. During periods of stress, proteins can denature or fold incorrectly, negatively affecting cellular function. HSPs assist the correct folding of proteins, enable protein repair, and maintain proteins in a functional and stable state.

5.3 Behavioural Effects

Several studies have focused on the potential behavioural effects on marine invertebrates. Although not yet scientifically investigated, masking may also be considered a potential effect of exposure to anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005). The functions and biological relevance of these sounds are not understood (Jeffs et al. 2003, 2005; Lovell et al. 2005; Radford et al. 2007). Masking of produced sounds and received sounds (e.g., conspecifics and predators) could potentially have adverse effects on marine invertebrates.

5.3.1 Molluscs

McCauley et al. (2000a,b) provided the first evidence of the behavioural response of southern calamari squid exposed to sound from seismic surveys. McCauley et al. (2000a,b) reported on the exposure of caged cephalopods (50 squid and two cuttlefish) to sound from a single 20-in^3 airgun. The cephalopods were exposed to both stationary and mobile sound sources. The two-run total exposure times of the three trials ranged from 69 to 119 min at an activation interval of once every 10-15 sec. The maximum SPL was >200 dB re 1 $\mu Pa_{0\text{-}p}$. Some of the squid fired their ink sacs apparently in response to the first pulse of one of the trials and then moved quickly away from the airgun. In addition to the above-described startle responses, some squid also moved towards the water surface as the airgun approached. McCauley et al. (2000a,b) reported that the startle and avoidance responses occurred at a received SPL of 174 dB re 1 μPa_{rms}. They also simulated a soft-start or ramp-up scenario whereby squid were exposed to a received SPL which gradually increased over time. No strong startle response was observed (i.e., ink discharge), but alarm responses were observed once the received SPL reached a level in the 156-161 dB re 1 μPa_{rms} range (McCauley et al. 2000a,b; Fewtrell and McCauley 2012).

Hubert et al. (2022a) examined the response of wild-caught blue mussels to exposures of single pulses and pulse trains in an aquarium. They reported that the mussels responded to the sounds by partially closing their valves and that the response waned with repeated exposures. They could not determine whether the decay in response was due to habituation or a sensory adaptation. There was no difference in recovery time between exposures to single pulses or pulse trains. Hubert et al. (2022b) noted that the sound-induced valve closure varied with pulse train speed – mussels exposed to faster pulse trains returned to baseline conditions faster than those exposed to slower pulse trains; phytoplankton clearance rates were not impacted.

5.3.2 Crab

Christian et al. (2003) investigated the behavioural effects of exposure to sound from seismic surveys on snow crabs. Eight animals were equipped with ultrasonic tags, released, and monitored for multiple days prior to exposure and after exposure. Received SPL and SEL were ~191 dB re 1 μPa_{0-p} and <130 dB re 1 μPa^2s, respectively. The crabs were exposed to 200 discharges from a fixed source over a 33-min period. None of the tagged animals left the immediate area after exposure. Five animals were captured in the snow crab commercial fishery the following year, one at the release location, one 35 km from the release location, and three at intermediate distances from the release location.

Another study approach used by Christian et al. (2003) involved monitoring snow crabs with a remote video camera during their exposure to sound from a seismic source. The caged animals were placed on the ocean bottom at a depth of 50 m. Received SPL and SEL were ~202 dB re 1 μPa_{0-p} and 150 dB re 1 μPa^2s, respectively. The crabs were also exposed to 200 discharges over a 33-min period. They did not exhibit any overt startle response during the exposure period.

Christian et al. (2003) also investigated the pre- and post-exposure catchability of snow crabs during a commercial fishery. Received SPLs and SELs were not measured directly and likely ranged widely considering the area fished. Maximum SPL and SEL were likely to be similar to those measured during the telemetry study. There were seven pre-exposure and six post-exposure trap sets. Unfortunately, there was considerable variability in set duration because of poor weather. Results indicated that the catch-per-unit-effort did not decrease after the crabs were exposed to seismic survey sound. However, anecdotal information from Newfoundland, Canada, indicated that catch rates of snow crabs showed a significant reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, pers. comm.).

Morris et al. (2018) conducted a two-year (2015-2016) BACI (before-after-control-impact) study examining the effects of 2D seismic exploration on catch rates of snow crab along the eastern continental slope of the Grand Banks of Newfoundland (Lilly Canyon and Carson Canyon). The airgun array used during both years of the study was operated from a commercial seismic exploration vessel. The array had a total volume of 4880 in^3, with an operational pressure of 2000 psi, a horizontal zero-to-peak SPL of 251 dB re 1 µPa at 1 m and a source SEL of 229 dB re 1 μPa^2s at 1 m. The closest that the seismic source came within the vicinity of the sound recorders

of the study area was 1465 m in 2015, while it passed within only 100 m of the sound recorders in 2016. Overall, the findings of the study indicated that the noise from the commercial seismic survey did not significantly reduce snow crab catch rates in the short-term (i.e., days) or longer term (i.e., weeks) in which the study took place. For this particular study, the experimenters attribute the natural temporal and spatial variations in the marine environment as a greater influence on observed differences of catch rates of snow crab between control and experimental sites.

Building on the Morris et al. (2018) study, Cote et al. (2020) also conducted a study using the multi-year BACI approach in the Carson and Lilly Canyons to evaluate the potential of industry-scale seismic exposure to modify movement behaviour of free ranging adult male snow crab. The movements of adult male snow crabs were tracked using a hyperbolic acoustic positioning array and were exposed to same seismic source as in the Morris et al (2018) study. It was concluded that seismic exposure did not have any important effect on snow crab movement, as the best models to account for snow crab movement indicated that the magnitude of effects of seismic were small or were not statistically relevant. Snow crab are known to display highly variable movement behaviour and individual-specific tendencies can explain experimental variance (Cote et al. 2020).

A four-year field program (2015-2018) was led by DFO and funded through the Environmental Studies Research Fund (ESRF; Morris et al. 2021). In 2017 and 2018, a BACI study was conducted to investigate the effect of industrial 3D seismic exposure on the catch rate of snow crab on the slope of the Grand Banks, at Carson Canyon with a control site at Lilly Canyon (Morris et al. 2020, 2021). The duration of potential seismic exposure was nine and five weeks in 2017 and 2018, respectively. The airgun array (4130 in^3) used was operated from a commercial seismic vessel operated by PGS and was in operation for 8-10 days. Catch rates were inconsistent during 3D surveying; the catch rate of snow crabs at the experimental sites was reduced catches in 2017 and higher catch rates in 2018 in response to long-duration exposure (Morris et al. 2020, 2021). The study concluded the observed effects of seismic surveying on snow crab catch rates were driven by spatiotemporal variation external to exposure to the airgun source. The authors acknowledged that there is a possibility that seismic surveying may affect catch rates but that any effects remain unpredictable in magnitude and direction, and that effects occur at short temporal and localized spatial scales.

Another component of the multi-year ESRF program, was a BACI study of the effects of 2D seismic surveying on the movement behaviour of snow crabs (Cote et al. 2020; Morris et al. 2021). Building on a study by Morris et al. (2018), a BACI approach was used in to evaluate the potential of industry-scale 2D seismic exposure to modify movement behaviour of male snow crab (Cote et al. 2020). In total, 201 and 115 snow crab were tagged in Carson and Lilly canyons, respectively. Before, During, and After exposure periods to a single 2D seismic surveying line (5-8 hours duration) were matched in time across Control and Test sites—each site monitored an area 4 km^2. There were no obvious effects of seismic exposure on the movement ecology of adult male snow crab; variation in snow crab movement was primarily attributable to individual variation and

factors like handling, water temperature and time of day. The authors concluded that the effects of seismic exposure on the behaviour of adult male snow crab were at most subtle and are "not likely to be a prominent threat to the fishery." There was also no evidence of physical damage to internal organs based on histological examinations (Morris et al. 2021). The study concluded that seismic exposure did not have any important effects on snow crab movement direction, and any variance in the results were shown to be individual-specific. Snow crab have also been considered to be less vulnerable to physiological damages from noise due to their absence of gas filled organs such as swim bladders that are sensitive to seismic exposures (Cote et al. 2020).

Roberts and Laidre (2019) studied the effect of an impulsive sound source on the chemically mediated shell searching behaviour of the hermit crab (*Pagarus acadianus*). Although the sound source was not seismic airgun-related, it was impulsive. An underwater slide hammer was used to create vibration within the seabed, allowing the production of a fully controllable manually operated stimulus. Exposures consisted of repetitive low-frequency pulses, with most energy within the 500-700 Hz range. The average peak particle velocity ranges at 1-m and 5-m were 0.00001-0.0005 m/s and 0.00002-0.00009 m/s, respectively. Results of this study indicated the sound source used can act cross-modally and affect chemically guided search behaviour. The broad conclusion was that anthropogenic noise and seabed vibration may have effects on other behaviours mediated by other sensory modalities.

Caged female snow crabs exposed to sound associated with a recent commercial seismic survey conducted in the southern Gulf of St. Lawrence, Canada, exhibited a higher rate of 'righting' than those crabs not exposed to seismic survey sound (J. Payne, Research Scientist, DFO, St. John's, Newfoundland, pers. comm.). 'Righting' refers to a crab's ability to return itself to an upright position after being placed on its back. Christian et al. (2003) made the same observation in their study.

5.3.3 Lobster

Parry and Gason (2006) statistically analyzed data related to southern rock lobster commercial catches and seismic surveying in Australian waters between 1978 and 2004. They did not find any evidence that lobster catch rates were affected by seismic surveys. Payne et al. (2007), in their study of the effects of exposure to sound from a seismic source on adult American lobsters, noted a trend of increased food consumption by the animals exposed to sound.

Southern rock lobsters were either collected from an area that had been previously subjected to high anthropogenic sound and/or were collected from an area with little anthropogenic sound (Day et al. 2020). Rock lobsters were caught and contained within lobster pots while exposed to an airgun array deployed by a vessel ~1 km from the test pots. The lobsters contained within the pots were exposed to maximum received cumulative sound exposure level of 198 dB re 1µPa^{2}s. Lobsters were then evaluated for righting reflex in the seawater bins for 0, 2, and 14-days post-exposure where statocysts were then removed. The study concluded that lobsters were slower to right themselves after exposure in individuals collected from the noisy area compared

to those collected from the remote area, and that lobsters from both areas showed damage to their statocysts following airgun exposure. Thus, crustaceans that are routinely exposed to high anthropogenic noise such as shipping traffic or marine construction can still be negatively impacted by airgun exposure on a physiological level.

Results presented by de Lestang et al. (2024) (see Section 5.1.4 on pathological effects for study details) suggested differences in behaviour between treatment and control western rock lobsters. Treatment group lobsters took significantly longer to right themselves after being placed on their backs (13.6 s vs. 6.5 s). When released back into the wild, treatment lobsters displayed very slow or slow release behaviour in comparison with controls.

5.3.4 Shrimp

Andriguetto-Filho et al. (2005) investigated the impact of sound from seismic surveys on artisanal shrimp fisheries off Brazil. Bottom trawl yields were measured before and after multiple-day activation of an airgun array with a peak source SPL of 196 dB re 1 µPa ₘ. Water depth in the experimental area ranged between 2 and 15 m. Results of the study did not indicate any significant deleterious impact on shrimp catches. Anecdotal information from Newfoundland, Canada, indicated that a school of shrimp observed on a fishing vessel sounder shifted downwards and away from a nearby seismic sound source (H. Thorne, Newfoundland fisherman, pers. comm.). This observed effect was temporary.

In contrast, Spiga (2022) reported behavioural responses of snapping shrimp in the field to playbacks of impulses with frequencies of 50-600 Hz when exposed to sound pressure levels at or above to 130 re 1 µPa and particle motion of 2.06×10^{-6} m/s. Bigger shrimp snapped more for longer durations and moved away from the sound source; peak frequency of snaps decreased during exposure compared with before and after sound exposure.

5.3.5 Plankton

Results from the Vereide et al. (2024) study (see Section 5.1.1 on pathological effects for study details) suggested that there was a behavioural response. The swimming speed of *Acartia* sp. exposed to the pressure drop (0 h: 0.49 mm/s; 5 h: 0.52 mm/s) was lower than in the controls. However, in exposed *Calanus* sp. the swimming speed (2.64 mm/s) was lower only immediately after treatment. As was the case with mortality, these results suggest that *Acartia* sp. is more sensitive to the pressure drop than *Calanus* sp.

5.3.6 Coral

Results presented by Heyward et al. (2018) (see Section 5.1.5 on pathological effects for study details) indicated that there was no evidence of behavioural response, such as polyp withdrawal or flaccidity, in soft corals exposed to airgun sound from a full 3D seismic survey.

5.3.7 Echinoderms

Vazzana et al. (2020) conducted a laboratory study to determine the biochemical responses of the black sea urchin (*Arbacia lixula*) when exposed to high-frequency (100-200 kHz; linear sweeps) sound and measured protein concentration, enzyme activity, and cytotoxicity in the coelomic fluid. Sound pressure levels ranged between 145 and 160 dB re 1µPa in consecutive linear one-second sweeps generated from a single generator coupled with a projector within the experimental tank. After exposure to the acoustic stimulus, significant changes were found in enzyme activity, gene expression, and proteins compared to the control, which suggests high-frequency sound exposure elicits a physiological stress response. While the species of focus in the study is typically found in coastal Mediterranean waters, the physiology of the sea urchin may be similar to that of urchins found in offshore Atlantic waters.

5.3.8 Benthic Invertebrates

Wang et al. (2022) examined the effect of low-frequency noise on benthic invertebrates using noise eggs, which are dry boxes with mobile vibrators that produced frequencies of 100-200 Hz (non-impulsive). They reported that low-frequency noise lowered the bioturbation rates and affected the luminophore burial depths of the amphipod *Corophium volutator*, resulting in shallower burial depths; the effects of the sound on the polychaete *Arenicola marina* and bivalve *Limecola balthica* were inconclusive. In addition, Wang et al. (2023) found that continuous low-frequency noise also reduced the pumping behaviour of the tube-dwelling polychaete worm *Lanice conchilega.* Solan et al. (2015) also reported behavioural effects on sediment-dwelling invertebrates during sound exposure.

6.0 Summary of Potential Effects of Exposure to Airgun Sound on Marine Invertebrates

Some studies have suggested that particular marine invertebrates may be affected pathologically, physiologically and/or behaviourally due to exposure to airgun sound. However, most of the effects were observed under conditions involving high level exposures at very close range, resulting in exposures unrepresentative of those that would occur under natural conditions. Note that these studies have focused on the effects of exposure to seismic airgun sound on individuals, not populations.

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Appendix B:
Review of Potential Effects of Seismic Airgun Sound on Fishes

Review of Potential Effects of Seismic Airgun Sound on Fishes

May 2025

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Acronyms and Abbreviations

ABR	Auditory brainstem response
BACI	Before-after-control-impact
CPUE	Catch per unit effort
dB	Decibel
DFO	Fisheries and Oceans Canada
Hz	Hertz
KE	Kinetic energy
kHz	Kilohertz
OBR	Opercular beat rate
PE	Potential energy
SEL	Sound exposure level
SPL	Sound pressure level
TTS	Temporary threshold shift
µPa	Micro Pascal
UVC	Underwater visual census

1.0 Introduction

This appendix provides an overview of the known acoustic abilities of marine fishes and information related to the potential effects of exposure to seismic airgun sound on these animals. The number of studies on the acoustic abilities of fishes and the potential effects of exposure to seismic sound on them are limited compared to same subject studies involving other marine biota such as cetaceans. This appendix includes results of studies of varying degrees of scientific veracity. Numerous review papers addressing the interaction of underwater sound and marine fishes have been published (Fay and Popper 2000; Ladich and Popper 2004; Hastings and Popper 2005; Popper and Hastings 2009a,b; Popper et al. 2014; Hawkins and Popper 2016a; Kunc et al. 2016; Carroll et al. 2017; Popper et al. 2019a,b). Fisheries and Oceans Canada (DFO) has also published internal documents that review the effects of seismic and other underwater sound on marine fishes (e.g., Worcester 2006; Payne et al. 2008).

Sound is generated by the movement or vibration of objects immersed in a compressible medium. As a sound source moves, kinetic energy is imparted to the medium and passed on, traveling as a propagated elastic wave within which particles of the medium are moved back and forth. The particles of a medium do not travel with the propagating sound wave but rather move back and forth over the same location. At the same time, the medium particles transmit their oscillatory motion to neighbouring particles resulting in particle oscillation along the line of transmission in accompaniment with waves of compression (i.e., increase in pressure) and expansion (i.e., reduction in pressure) (Popper and Hawkins 2018).

There are two components to underwater sound: (1) sound pressure and (2) particle motion. The total energy contained in a sound wave is the sum of its potential energy (PE) and its kinetic energy (KE). The PE results from the compression and expansion of the medium and is thereby related to the sound pressure component. The KE arises from the particle motion component. In the far-field (considerable distance from the sound source), the energies associated with acoustic pressure and acoustic particle motion are equal (i.e., PE=KE). However, in the near-field (close to sound source), the particle motion component contains more energy than the pressure component (i.e., KE>PE) (Popper and Hawkins 2018).

The to-and-fro particle displacements in sound are extremely small (order of nanometers) so it is much easier to measure the sound pressure component of sound and then estimate particle motion from that measure. This is acceptable in an acoustic free-field where boundaries are non-existent but close to acoustic boundaries (e.g., seabed, air-water interface at surface), the relationship between pressure and particle motion is much more complex (Pierce 1981 *in* Popper and Hawkins 2018; McCauley et al. 2021) so direct measurement of particle motion is necessary. Unlike the pressure component of sound, particle motion is inherently directional (i.e., vector quantity), typically along the axis of transmission. Pressure acts in all directions, making it a scalar quantity.

Underwater sound pressure levels are typically reported as a number of decibels referenced to a reference level, usually 1 micro-Pascal (µPa). However, the sound pressure dB number can represent multiple types of measurements, including "zero to peak [0-p]", "peak to peak [p-p]", or 'averaged [rms]'. Sound exposure levels (SEL) may also be reported as dB. The SEL is the integration of all the acoustic energy contained within the duration of a single sound event. Unless precise measurement types are reported, it is not possible to directly compare results of studies.

Until recently, the particle motion component of seismic airgun sound has not been typically measured. All marine fishes are sensitive to particle motion while some with internal air-filled spaces are also sensitive to the pressure component. The particle motion component may be reported as particle displacement (m), particle velocity (ms-1), or particle acceleration (ms-2). Rogers et al. (2021) found that sounds from a seismic survey measured above ambient conditions up to 10 km away for particle acceleration and up to 31 km for sound pressure.

The information contained in the following sections reflects what is currently available in the scientific literature, both peer-reviewed and otherwise; however, many data gaps remain (Hawkins et al. 2015, 2020, 2021; Carroll et al. 2017; Popper and Hawkins 2019; Hawkins 2022a, 2023; Popper et al. 2022; Lessa et al. 2023). Study methods are continuously developing to address some of the gaps associated with knowledge of fish acoustic abilities and the potential effects of seismic airgun sound on fishes.

2.0 Acoustic Abilities of Fishes

Sensory systems, like those that allow for hearing, provide information about an animal's physical, biological, and social environments. Extensive work has been done to understand the structures, mechanisms, and functions of animal sensory systems in aquatic environments (Atema et al. 1988; Kapoor and Hara 2001; Collin and Marshall 2003). Popper et al. (2019a) and Popper and Hawkins (2021) reviewed the hearing ability of fish. All fish species have hearing and skin-based mechanosensory systems (inner ear and lateral line systems, respectively) that provide information about their surroundings (Fay and Popper 2000). Ladich (2019) reported on the ecology of sound communication in fishes. Fay (2009) and others refer to the ambient sounds to which fishes are exposed as 'underwater soundscapes'. Anthropogenic sounds can potentially have important negative consequences for fish survival and reproduction if they disrupt an individual's ability to sense its soundscape (Mauro et al. 2020), which often informs it of predation risk, prey presence, or mating opportunities. Radford et al. (2014), Putland et al. (2017), de Jong et al. (2020), Pine et al. (2020), and Jones et al. (2023) also noted that masking of key environmental sounds or social signals could be a potential negative effect from sound.

Fish hearing via the inner ear is typically restricted to low frequencies. As with other vertebrates, fish hearing involves a mechanism whereby the beds of hair cells (Howard et al. 1988; Hudspeth and Markin 1994) located in the inner ear are mechanically affected, causing a neural discharge

(Popper and Fay 1999). At least two major pathways for sound transmittance between sound source and the inner ear have been identified for fishes. The most primitive pathway involves direct transmission to the inner ear's otolith, a calcium carbonate mass enveloped by sensory hairs. The inertial difference between the dense otolith and the less-dense inner ear causes the otolith to stimulate the surrounding sensory hair cells. This motion differential is interpreted by the central nervous system as sound. Wei and McCauley (2022) determined that the angle of sound energy arrival at the otolith affects the extent of potential injury from noise.

The second transmission pathway between sound source and the inner ear of fishes is via the swim bladder, a gas-filled structure that is much less dense than the rest of the fish's body. The swim bladder, being more compressible and expandable than either water or fish tissue, will differentially contract and expand relative to the rest of the fish in a sound field. The pulsating swim bladder transmits this mechanical disturbance directly to the inner ear (discussed below). This secondary means of sound detection may be more or less effective at stimulating the inner ear depending on the amplitude and frequency of the pulsation, and the distance and mechanical coupling between the swim bladder and the inner ear (Popper and Fay 1993).

Popper and Fay (2011) discussed the designation of fishes based on sound detection abilities. They suggested that the designations 'hearing specialist' and 'hearing generalist' no longer be used for fishes because of their vague and sometimes contradictory definitions. Instead, they suggested a range of hearing abilities across species that is more like a continuum, presumably based on the relative contributions of pressure to the overall hearing abilities of a species. According to Popper and Fay (2011), one end of this continuum is represented by fishes that only detect particle displacement because they lack pressure-sensitive gas-filled body parts (e.g., swim bladder). These species include elasmobranchs (e.g., sharks) and jawless fishes, and some teleosts including flatfishes. The other end of the fish hearing continuum is represented by fishes with highly specialized otophysic connections between pressure receptive organs, such as the swim bladder, and the inner ear; fishes at this end of the continuum are typically capable of detecting sound frequencies less than 1,500 Hz (e.g., Casper et al. 2003: Casper and Mann 2006, 2007, 2009). They include some squirrelfish, mormyrids, herrings, and otophysan fishes (freshwater fishes with Weberian apparatus, an articulated series of small bones that extend from the swim bladder to the inner ear). Rather than being limited to 1.5 kHz or less in hearing, these fishes can typically hear up to several kHz. One group of fish in the anadromous herring sub-family Alosinae (shads and menhaden) can detect sounds with frequencies >180 kHz (Mann et al. 1997, 1998, 2001). This may be the widest hearing range of any vertebrate studied to date. While the specific reason for this ability to detect high frequency sound is not totally clear, there is strong evidence that this ability evolved for the detection of the ultrasonic sounds produced by echolocating dolphins to enable the fish to detect and avoid predation (Mann et al. 1997; Plachta and Popper 2003).

All other fishes have hearing abilities that fall somewhere between these two extremes of the continuum. Some have unconnected swim bladders located relatively far from the inner ear (e.g., salmonids, tuna) while others have unconnected swim bladders located relatively close to the inner ear (e.g., Atlantic cod, *Gadus morhua*). There has also been the suggestion that Atlantic

cod can detect 38 kHz (Astrup and Møhl 1993). However, the general consensus was that this was not hearing with the ear, but probably the fish responding to exceedingly high pressure signals of the 38-kHz source through some other receptor in the skin, such as touch receptors (Astrup and Møhl 1998).

It is important to recognize that the swim bladder itself is not a sensory end organ, but rather an intermediate part of the sound pathway between sound source and the inner ear of some fishes. The inner ear of fishes is ultimately the organ that translates the particle displacement component into neural signals interpreted by the brain as sound. Wiernicki et al. (2022) found that frequency detection is related to swim bladder specialization, with maximum and optimum frequencies detectable by fish increasing with swim bladder elaboration.

Another mechanosensory pathway found in most bony fishes and elasmobranchs (i.e., cartilaginous fishes) involves the lateral line system. It too relies on sensitivity to water particle displacement. The basic sensory unit of the lateral line system is the neuromast, a bundle of sensory and supporting cells whose projecting cilia, similar to those in the ears, are encased in a gelatinous cap. Neuromasts detect distorted sound waves in the immediate vicinity of fishes. Generally, fishes use the lateral line system to detect the particle displacement component of low frequency acoustic signals (up to 160 to 200 Hz) over a distance of one to two body lengths. The lateral line is used in conjunction with other sensory systems, including hearing (Sand 1981; Coombs and Montgomery 1999).

There has also been a study of the auditory sensitivity of settlement-stage fishes. Using the auditory brainstem response (ABR) technique in the laboratory, Wright et al. (2010) concluded that larvae of reef species (*Lutjanus carponotatus* and *Pomacentrus amboinensis*) had significantly more sensitive hearing than the larvae of pelagic species (*Elagatis bipinnulata* and *Gnathanodon speciosus*). All reef fish larvae, as well as the larvae of one of the pelagic species, detected frequencies in the 100-2,000 Hz range. The larvae of the other pelagic species did not detect frequencies higher than 800 Hz. The larvae of all species exhibited best hearing at frequencies between 100 and 300 Hz. The results of Wright et al. (2010) suggest that settlement-stage larval reef fishes may be able to detect reef sounds at distances of hundreds of metres. Other recent research also indicates that settlement-stage larvae of reef fishes may use sound as a cue to locate settlement sites (Tolimieri et al. 2004; Leis et al. 2003; Simpson et al. 2005; Leis and Locket 2005).

3.0 Potential Effects of Airgun Exposure on Marine Fishes

Sound emitted by underwater seismic airguns results in energy pulses with very high peak pressures (Richardson et al. 1995). Virtually all underwater seismic surveying conducted today uses airguns which typically have lower peak pressures and longer rise times than chemical explosives. Sound levels from underwater airgun discharges are sometimes high enough to potentially injure or kill animals located very close to the sound source. Less overt than physical effects are potential disturbances to normal behaviours of fishes exposed to airgun sound.

There are essentially three types of potential effects of exposure to airgun sound on marine fishes: (1) pathological (i.e., injury, mortality), (2) physiological, and (3) behavioural. Pathological effects include lethal and sub-lethal injury to the animals, physiological effects include temporary primary and secondary stress responses, and behavioural effects refer to changes in exhibited behaviours (i.e., disturbance). The three categories should not be considered as independent of one another and are likely interrelated in complex ways. While potential pathological effects on marine fishes remain important for scientific study, physiological and behavioural effects probably warrant the most attention, particularly in terms of population effects.

A number of review papers on the effects of anthropogenic sources of underwater sound on fishes have been published (Fay and Popper 2000; Ladich and Popper 2004; Hastings and Popper 2005; Popper 2009; Popper and Hastings 2009a,b; Fay and Popper 2012; Popper et al. 2014; Kunc et al. 2016; Mann 2016; Carroll et al. 2017; Hawkins and Popper 2018; Popper and Hawkins 2019; Popper et al. 2019b; Slabbekoorn et al. 2019; Hawkins 2022b). These papers consider various sources of anthropogenic sound, including seismic airguns. For the purposes of this review, only the effects of seismic airgun sound are considered. Note that many of the studies were conducted either in a laboratory or in the field using captive fishes and are therefore not representative of the natural scenario of fishes with the capability to move away from the sound source. Popper et al. (2014) provided overall guidelines for seismic airgun sound levels (in dB) that could cause negative effects to fishes of various hearing abilities as well as fish eggs and larvae. Some of the effects addressed include mortality, potential mortal injury, recoverable injury, temporary threshold shift (TTS), masking, and behavioural changes. Although TTS has been demonstrated in some fish species, it is unlikely to occur for free-swimming fish (Smith and Popper 2023).

de Jong et al. (2020) conducted a study on the predicted effects of anthropogenic noise on fish reproduction and found that continuous sounds with irregular amplitudes and/or frequency-content such as heavy ship traffic were likely to induce masking or hearing loss. The vulnerability of a species to noise-induced stressors was dependent on its ability to reallocate reproduction to a quieter location or time, and whether or not their reproductive strategy relied on sound communication.

It is difficult to interpret results of many studies on the effects of exposure to seismic sound on marine fishes because authors often do not provide enough information on the received sound, including received sound levels, source sound levels, and specific characteristics of the sound (e.g., units and references, frequency range, continuous vs impulsive). Unless precise measurement types are reported, it can be impossible to directly compare results from two or more independent studies. In addition to researchers presenting a complete description of anthropogenic sound levels in sound impact studies, Hawkins and Popper (2016b, 2017) outlined several other prerequisites that should be adhered to when evaluating the effects of anthropogenic sound, including seismic airgun sound, on fishes. These include knowledge of background sound levels in the environment, prediction of the transmission of sound from different anthropogenic sources, and consideration of the effects that the sound may have on fishes at different locations from the sound source. One of the major areas identified as requiring

study is the particle motion component of airgun sounds and its potential effects on fishes (Hawkins and Popper 2017; Popper and Hawkins 2018, 2019).

Przeslawski et al. (2018) examined a case study on marine seismic impacts on biota to assess the advantages and challenges of field-based methods in the context of future research and management priorities. They concluded that an interdisciplinary approach using both conventional and innovative experimental components results in more robust overall interpretations of the data. They also stated that there is a need for appropriate environmental baselines and time-series data to account for spatiotemporal variability of environmental and biological parameters that may mask effects, and for a standardized technique in sound monitoring and equipment calibration to ensure accuracy and comparability among studies.

Webster et al. (2018) described a workshop risk assessment of the potential impacts of seismic airgun surveys on marine fishes in Western Australia. The assessment's general conclusion was the greater the intensity of sound and the shallower the water depth, the greater the risk to marine fishes. In waters of >250 m depth, the impact of seismic surveying on fishes was assessed as acceptable, while in waters of <250 m depth, risk ranged from negligible to severe, depending on depth, resource-type and sound intensity. Pelagic fishes were deemed to be least at risk from seismic impacts.

3.1 Physical Effects

3.1.1 Juveniles and Adults

The relationship between sensory hair cell loss and hearing loss in fishes, as well as the negative effects of hair cell loss and potential recovery of damaged hair cells due to anthropogenic noise was reviewed by Smith (2016), Smith and Monroe (2016), and Smith and Popper (2023). In addition to providing examples of previous studies related to various anthropogenic noise sources and their effects on fish sensory hair cells and recovery, they reviewed the following McCauley (2003) study on seismic airgun damage to fish ears.

Evidence for airgun-induced damage to fish ears (i.e., pathological effect) has been provided in studies using pink snapper (*Pagrus auratus*) as subjects (McCauley et al. 2000a,b, 2003). In these experiments, fish were caged and exposed to the sound emitted by a single mobile seismic airgun every 10 s over a period of 1 h and 41 min. The approximate source sound pressure level (SPL) at 1 m was 223 dB re 1 μPa_{p-p}, and the received SPLs ranged from 165 to 209 dB re 1 μPa_{p-p}. The sound energy was highest over the 20-70 Hz frequency range. Pink snappers were exposed to more than 600 airgun discharges during the study. In some individual fish, the sensory epithelium of the inner ear sustained extensive damage as indicated by ablated hair cells. Damage was more extensive in fish examined 58 days post-exposure compared to those examined 18 h post-exposure. There was no evidence of repair or replacement of damaged sensory cells up to 58 days post-exposure. McCauley et al. (2000a,b, 2003) included the following caveats in the study

reports: (1) fish were caged and unable to swim away from the seismic source, (2) only one species of fish was examined, (3) the impact on the ultimate survival of the fish is unclear, and (4) airgun exposure specifics required to cause the observed damage were not obtained (i.e., a few high SPL signals or the cumulative effect of many low to moderate SPL signals).

In another study, caged European seabass (*Dicentrarchus labrax*) were exposed to multiple discharges from a moving seismic airgun array consisting of 16 airguns and a discharge volume of 2500 in^3. (Santulli et al. 1999). The airguns were discharged over a 2-h period. The minimum distance between fish and seismic source was 180 m. The authors did not indicate any observed pathological injury to the sea bass. Blood was collected from both exposed fish (6 h post-exposure) and control fish (6 h pre-exposure) and subsequently analyzed for cortisol, glucose, and lactate levels. Stress can cause the levels of these chemicals to fluctuate. Levels of cortisol, glucose, and lactate were significantly higher in the sera of exposed fish compared to sera of control fish. The elevated levels of all three chemicals returned to pre-exposure levels within 72 h of exposure.

Radford et al. (2016) conducted experiments examining how repeated exposures of European seabass to different sounds can reduce fish response to that sound. They exposed post-larval seabass to playback recordings of impulsive seismic survey noise (SEL for one pulse was 144 dB re 1 μPa^2s) in large indoor tanks containing underwater speakers. They found that short term exposure to seismic noise increased the ventilation rate (i.e., opercular beat rate [OBR]) of seabass not previously exposed to seismic relative to seabass in controlled, ambient sound conditions. While tank-reared fish that were repeatedly exposed to seismic sound over a 12-week period exhibited a reduced OBR response to that sound type, fish exposed over the same time period to pile-driving noise displayed a reduced response to both seismic and pile-driving noise. An increased ventilation rate is indicative of greater stress in the seabass. The experimenters found no evidence for mortality or effects on growth of the seabass throughout the 12-week study period.

3.1.2 Eggs and Larvae

Fertilized capelin (*Mallotus villosus*) eggs and monkfish (*Lophius americanus*) larvae were exposed to seismic airgun sound and subsequently examined and monitored for possible effects of the exposure (Payne et al. 2009). The laboratory exposure studies involved a single airgun at a fixed distance. Approximate received SPLs measured for the capelin egg and monkfish larvae exposures were 199 to 205 dB re 1 μPa_{p-p} and 205 dB re 1 μPa_{p-p}, respectively. The capelin eggs were exposed to either 10 or 20 airgun discharges, and the monkfish larvae were exposed to either 10 or 30 discharges. No statistical differences in mortality/morbidity between control and exposed subjects were found at 1 to 4 days post-exposure in any of the exposure trials for both the capelin eggs and the monkfish larvae.

In uncontrolled experiments, Kostyvchenko (1973) exposed the eggs of numerous fish species (anchovy, red mullet, crucian carp, blue runner) to various sound sources, including seismic airguns. With the seismic airgun discharge as close as 0.5 m from the eggs, over 75% of them

survived the exposure. Egg survival rate increased to over 90% when placed 10 m from the airgun sound source. The range of received SPLs was about 215 to 233 dB re 1 $\mu Pa_{0\text{-}p}$.

In a laboratory experiment, eggs, yolk sac larvae, post-yolk sac larvae, post-larvae, and fry of various commercially-important fishes (cod, saithe, herring, turbot, and plaice) were exposed to received SPLs ranging from 220 to 242 dB re 1 µPa (unspecified measure type), simulating sound levels resulting from seismic airgun discharges (Booman et al. 1996). The species chosen for this experiment are representative of fishes with closed swim bladders, open swim bladders, and no swim bladders. The authors reported some cases of injury and mortality but most of these occurred as a result of exposures at very close range. The rigor of anatomical and pathological assessments was questionable.

Saetre and Ona (1996) applied a "worst-case scenario" mathematical model to investigate the effects of seismic sound on fish eggs and larvae. They concluded that mortality rates due to exposure to seismic airgun sound are so low compared to the natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

3.2 Behavioural Effects

Generally, studies described in this subsection suggest that effects of exposure to seismic airgun sound on fish behaviour are temporary in nature, and that response thresholds for various groundfish and pelagic species are quite variable. There are essentially three different methods of studying the impacts of exposure to anthropogenic noise on fish behaviour, each one having its own pros and cons. These methods include: (1) captive laboratory in which fishes are maintained in tanks, (2) captive natural in which fish are restricted within a cage under natural conditions, and (3) free-range natural in which fish are unconstrained under natural conditions. The experimental control of these study methods is greatest for the captive laboratory scenario, progressively diminishing in studies gravitating towards free-range natural. The acoustic and behavioural validity in relation to real-life scenarios involving the interaction of anthropogenic noise and fish behaviour is most robust for the free-range natural scenario and least robust for the captive laboratory scenario given the difference in realistic conditions (i.e., what fishes experience under fully natural conditions) (Slabbekoorn 2016).

Chapman and Hawkins (1969) reported that after an hour of exposure to airgun sound, whiting (or silver hake, *Merluccius bilinearis*) appeared to habituate, indicated by their return to the pre-exposure depth range despite the continuing airgun discharge. Using an echosounder, they investigated the reactions of free ranging whiting to a discharging stationary airgun with a source SPL of 220 dB re 1 µPa $\cdot m_{0\text{-}p}$; received SPLs were estimated at 178 dB re 1 $\mu Pa_{0\text{-}p}$. Prior to any airgun discharge, the fish were located at a depth range of 25 to 55 m. In apparent response to the airgun sound, the fish descended, forming a compact layer at depths greater than 55 m. After airgun discharges were stopped for a time and the whiting returned to pre-exposure depths, sound resumption resulted in fish again descending to greater depths, suggesting temporary habituation.

Similarly, a study by Pearson et al. (1992) showed that behavioural effects on captive rockfishes (*Sebastes* spp.) were temporary. They investigated the effects of seismic airgun sound on rockfishes exposed to the sound of a single stationary airgun at various distances from the source. The airgun used in the study had a source SPL at 1 m of 223 dB re 1 µPa ·$m_{0\text{-}p}$, and measured received SPLs ranged from 137 to 206 dB re 1 $\mu Pa_{0\text{-}p}$. The authors reported that rockfish reactions to the airgun sounds included varying degrees of startle and alarm responses, depending on the species of rockfish and the received SPL. Startle responses were observed at a minimum received SPL of 200 dB re 1 $\mu Pa_{0\text{-}p}$, and alarm responses were exhibited at a minimum received SPL of 177 dB re 1 $\mu Pa_{0\text{-}p}$. Other observed behavioural changes included the tightening of schools, downward distributional shift, and random movement and orientation. While some rockfish ascended to the upper water column and commenced to mill (i.e., "eddy") at increased speed, others descended to the bottom of the enclosure and remained motionless. Pre-exposure behaviour was re-established 20 to 60 min after cessation of seismic airgun discharge. Pearson et al. (1992) concluded that received SPL thresholds for overt rockfish behavioural response and more subtle rockfish behavioural response were 180 dB re 1 $\mu Pa_{0\text{-}p}$ and 161 dB re 1 $\mu Pa_{0\text{-}p}$, respectively.

Using an experimental hook and line fishery approach, Skalski et al. (1992) studied the potential effects of seismic airgun sound on the distribution and catchability of rockfishes. The source SPL of the single airgun used in the study was 223 dB re 1 µPa ·$m_{0\text{-}p}$, resulting in received SPLs at the bases of the rockfish aggregations ranging from 186 to 191 dB re 1 $\mu Pa_{0\text{-}p}$. Characteristics of the fish aggregations were assessed using echosounders. During long-term stationary seismic airgun discharge, there was an overall downward shift in fish distribution. The authors also observed a significant decline in total catch of rockfishes during seismic discharge. It should be noted that the duration of the experimental exposure was much longer than what the fish would experience from a seismic survey under natural conditions.

Santulli et al. (1999) used underwater video cameras to monitor responses of caged European seabass to seismic airgun discharge. Resultant video indicated slight startle responses by some of the fish when the seismic airgun array discharged as far as 2.5 km from the cage. The proportion of seabass that exhibited startle responses increased as the discharging airgun source approached the cage. Once the seismic array was within 180 m of the cage, the seabass were densely packed at the middle of the enclosure, exhibiting random orientation and appearing more active than they had been under pre-exposure conditions. Normal behaviour resumed about 2 h after airgun discharges ceased. Neo et al. (2014, 2015, 2016, 2018) reported changes in fish (primarily European seabass) behaviour (e.g., dive depth, group cohesion, swim speed) upon exposure to impulsive sounds and noted that temporal structure of sound plays a large role in the potential response of fish to noise exposure. Neo et al. (2014) also postulated that intermittent sounds, such as from airguns, may elicit a stronger response by fish than continuous sounds, regardless of the cumulative sound exposure level.

Caged pink snapper and trevally (*Pseudocaranx dentex*) exposed to sound from a single airgun exhibited startle responses to short range start up and high-level airgun signals (i.e., with received

SPLs of 182 to 195 dB re 1 μPa_{rms}) (McCauley et al. 2000a,b; Fewtrell and McCauley 2012). Smaller fish displayed startle responses more often than larger fish. Responses were observed when received SPLs were >156 to 161 dB re 1 μPa_{rms}. The occurrences of both startle responses (e.g., classic C-turn response) and alarm responses (e.g., darting movements, flash school expansion, fast swimming) decreased over time. Other observations included downward distributional shifts that were restricted by containment in cages, increases in swimming speed, and the formation of denser aggregations. Fish behaviour appeared to return to pre-exposure state 15-30 min after cessation of seismic airgun discharge.

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun sound on the behaviour of captive lesser sand eel (*Ammodytes marinus*). The depth of the study enclosure used to hold the sand eel was about 55 m. The moving airgun array had an estimated source SPL of 256 dB re 1 µPa ·m (unspecified measure type); received SPLs were not measured. Exposures were conducted over a 3-day period in a 10 km × 10 km area with the cage at its center. The distance between airgun array and fish cage ranged from 55 m when the array was overhead to 7.5 km. Behaviour of the fish was monitored using underwater video cameras, echosounders, and commercial fishery data collected close to the study area. The approach of the seismic vessel appeared to cause an increase in tail-beat frequency although the sand eels still appeared to swim calmly. During seismic airgun discharge, many fish exhibited startle responses, followed by flight from the immediate area. The frequency of occurrence of startle response increased as the operating seismic array moved closer to the fish. The sand eels stopped exhibiting the startle response once the airgun discharge ceased. The sand eel tended to remain higher in the water column during the airgun discharge. None of the sand eel were observed burying themselves in the soft substrate. No mortality attributable to exposure to the airgun sound was noted.

Various species of demersal fishes, blue whiting (*Micromesistius poutassou*), and some small pelagic fishes were exposed to a moving seismic airgun array with a source SPL of about 250 dB re 1 µPa ·m (unspecified measure type) (Dalen and Knutsen 1986). Received SPLs, estimated using the assumption of spherical spreading, ranged from 200 to 210 dB re 1 µPa (unspecified measure type). Seismic sound exposures were conducted every 10 s during a one-week period. The study used echosounders and sonars to assess the pre- and post-exposure fish distributions. The acoustic mapping results indicated a significant decrease in abundance of demersal fish (36%) after airgun discharge although comparative trawl catches did not support this observed decrease. Non-significant reductions in the abundances of blue whiting and small pelagic fish were also indicated by post-exposure acoustic mapping.

La Bella et al. (1996) studied the effects of exposure to seismic airgun sound on fish distribution using echosounder monitoring, and changes in catch rate of hake by trawl and clupeoids by gill netting. The experimental seismic array was composed of 16 airguns and had a source SPL of 256 dB re 1 µPa ·m $_{0\text{-}p}$. The pulse interval was 25 s, and exposure durations ranged from 4.6 to 12 h. While horizontal distributions did not appear to change as a result of exposure to seismic discharge, there was some indication of a downward shift in the vertical distribution. The

experimental fishing catch rate did not differ significantly between pre- and post-seismic fishing periods.

Wardle et al. (2001) employed video and telemetry to monitor the behaviours of marine fishes (primarily juvenile saithe, adult pollock, juvenile cod, and adult mackerel) inhabiting an inshore reef off Scotland before, during, and after exposure to discharges of a stationary airgun. The received SPLs ranged from about 195 to 218 dB re 1 $\mu Pa_{0\text{-}p}$. Pollock did not move away from the reef in response to the seismic airgun sound, and their diurnal rhythm did not appear to be affected. However, there was an indication of a slight effect on the long-term day-to-night movements of the pollock. Video camera observations indicated that fish exhibited startle responses ("C-starts") to all received levels. There were also indications of behavioural responses to visual stimuli. If the seismic source was visible to the fish, they fled from it. However, if the source was not visible to the fish, they often continued to move toward it.

The potential effects of exposure to seismic sound on fish abundance and distribution were also investigated by Slotte et al. (2004). Twelve days of seismic survey operations over a period of one month involved a seismic airgun array with a source SPL of 222.6 dB re 1 $\mu Pa \cdot m_{p\text{-}p}$. The SPLs received by the fish were not measured. Acoustic surveys of the local distributions of various kinds of pelagic fish, including herring, blue whiting, and mesopelagic species, were conducted during the seismic surveys. There was no strong evidence to support short-term horizontal distributional effects. With respect to vertical distribution, blue whiting and mesopelagics were distributed deeper (20 to 50 m) during the seismic survey compared to pre-exposure. The average densities of fish aggregations were lower within the seismic survey area, and fish abundances appeared to increase in accordance with increasing distance from the seismic survey area.

Peña et al. (2013) studied the real-time behaviour of herring schools exposed to a full-scale 3D seismic survey off northern Norway using an omnidirectional fisheries sonar. The feeding herring were observed over a six-hour period as the seismic vessel and active airguns approached them from a distance of 27 km to about 2 km from the herring. The received SEL increased from about 125 to 155 dB re 1 μPa^2s during the vessel's approach. The investigators observed a lack of response by the herring and concluded that this observation was likely due to a combination of factors including a strong motivation for feeding, a gradual increase of the airgun stimulus, and an increased level of tolerance to the seismic sound.

Boeger et al. (2006) observed coral reef fishes in field enclosures before, during, and after exposure to seismic airgun sound. This Brazilian study used an array of eight airguns that was presented to the fishes as both a mobile and a static sound source. Minimum distances between the sound source and the fish enclosure ranged from 0 to 7 m. Received sound levels were not reported, but most of the airgun array discharges resulted in startle responses although these behavioural responses diminished with repeated exposures, suggesting habituation. Neither mortality nor external damage to the fishes was observed in any of the experimental scenarios.

The effects of seismic airguns on species richness and abundance of a coral reef fish community were studied in a Before-After-Control-Impact (BACI) seismic survey study completed by Miller and Cripps (2013) on Scott Reef in Western Australia. A 2055 in^3 dual airgun array was used in the survey which exposed the reef to SEL_{cum} levels that were approximately 187 dB re 1 μPa^2s. Underwater Visual Census (UVC) of the reef fish community was conducted via scuba at six locations on the reef. At each location, fish were surveyed along several 50 m × 5 m transects, at a depth of 6-11 m. No evidence of either direct or indirect mortality of reef fish from the seismic survey was observed. Modelling of results that considered spatial, temporal, and observer variability showed no significant effect of the seismic survey on species richness and abundance of Pomacentridae or non-Pomacentridae fishes (the most common family of fishes on the reef). In addition, the experimenters analyzed the six most abundant fish species on the reef to determine if the seismic survey had a noticeable effect on their abundances. They did not find a significant effect of the seismic survey on the abundances of any of the fish species.

Paxton et al. (2017) examined the effects of seismic noise on the distribution and behaviour of fish on a temperate reef during a seismic survey on the inner continental shelf of North Carolina, USA. Much of the survey occurred in deep water (>1000 m) off the continental shelf, although the survey ended in shallower (<35 m) inner continental waters. Two hydrophones were set up on two reefs located 0.7 km and 6.5 km from the linear path of the seismic vessel to measure sound pressure levels. A video camera was set up on a third reef 7.9 km away from the seismic track. Using a spherical spreading sound model, received SPLs were estimated to be between 202 to 230 dB re 1 µPa at the hydrophone located closest to the seismic track. A series of short, 10 second video clips were recorded every 20 mins by the video camera for a time period of three days before seismic, and one day of seismic activity. It was determined that overall abundances of fish declined by up to 78% on this reef during active seismic airgun activity compared to when no airgun discharges occurred. Only one fish was observed to exhibit a startle response to the airgun sound. The study concluded that although collected data were limited, there was evidence that normal use of reef ecosystems by fishes was reduced by exposure to seismic airgun sound.

Davidsen et al. (2019) outfitted Atlantic cod and saithe (*Pollachius virens*) with acoustic transmitters to monitor their behaviours (i.e., swimming speed, movement in water column) in response to exposure to seismic airgun sound. The study was conducted in Norway using a large sea cage with a 30 m diameter and 25 m depth. Both sound pressure and particle motion were measured within the sea cage. An airgun firing every 10 s was towed toward the sea cage from an initial distance of 6.7 km from the cage to a minimum distance of 100 m from the cage. The SEL_{cum} ranged from 172-175 dB re 1 μPa^2s. Although cod had a reduced heart rate in response to the sound exposure, there was no behavioural startle response. However, both the cod and saithe changed swimming depth and horizontal position more frequently during exposure to the sound; the saithe became more dispersed in response to elevated sound levels. Both species exhibited behavioural habituation to the repeated exposures to sound. Davidsen et al. (2019) concluded that the sound exposures over a 3-day period were unlikely to lead to long-term alterations in physiology or behaviour.

A series of studies by Hubert et al. (2019, 2020, 2021) have also examined the responses of wild-caught Atlantic cod to playbacks from a seismic airgun. Hubert et al. (2019) exposed wild-caught Atlantic cod to airgun playbacks in an experimental tank; the SPL was 150 dB re 1 $\mu Pa_{0\text{-}p}$ 80 cm from the speaker. Although the cod did not change the time spent foraging, they did increase the time spent swimming during exposure. Hubert et al. (2020) exposed Atlantic cod in an aquaculture net pen to playback of seismic airgun sounds to determine the effect on swimming patterns and behavioural states. The fish were exposed to sound recordings of a downscaled airgun with a volume of 10 in^3 and a pressure of 800 kPa. During the experimental trials, the fish were exposed to SPLs of 174, 169, and 152 dB re 1 $\mu Pa_{0\text{-}pk}$ (100-600 Hz bandpass filter) with the speaker at 2, 7.8, and 20 m from the net pen, respectively. Similar to Davidsen et al. (2019) who did not report a behavioural startle response by cod, the results showed that individual cod did not immediately change their swimming patterns during sound exposure, but that several individuals did change the amount of time they spent in three different behavioural states (transit, locally active, inactive) during the 1 h exposure; they exhibited more transiting behaviour (i.e., swimming at high speed with a low turning angle) during and after exposure.

The effects of a commercial seismic survey on the movement behaviour of free-swimming Atlantic cod in the southern North Sea were investigated by van der Knaap et al. (2021). A total of 51 Atlantic cod were caught and tagged with acoustic transmitters and released in the southern North Sea where they were exposed to towed airgun array 2.5 km from the tagged location over 3.5 days. The airgun array consisted of 36 airguns with a total volume of 2950 in^3 (48.3 L), which fired every 10 s during operation in continuous loops, with parallel tracks of 25 km. The cumulative sound exposure level (SEL_{cum}, re 1 μPa^2s) over the 3.5-day survey period at the receiver position was 186.3 dB in the 40-400 Hz band. During sound exposure, cod became less locally active (moving small distances, showing high body acceleration) and more inactive (moving small distances, showing low body acceleration) at dawn and dusk which interrupted their diurnal activity cycle. The authors concluded that the results showed that seismic surveying has the potential to affect energy budgets for a commercial fish species, which may have high population-level consequence.

Nguyen et al. (2025) also studied the effects of a commercial seismic survey on free-swimming Atlantic cod (and other groundfish species). They studied fish abundance and behaviour at baited video camera systems on the continental slope of Newfoundland at depths of 350 to 500 m. At the seismic exposure site the SPL varied from 131 to 162 dB re 1 μPa^2 (mean 145 dB re 1 μPa^2). The control site was about 70 km from the seismic survey area. Cod took a significantly longer average time to visit baited cameras stations and to consume all the bait at the seismic exposure site than at the control site. At the exposure site cod took longer to visit the bait and to consume all the bait after seismic exposure than before exposure. The proportion of large, medium and small sizes of cod was not significantly different before and after seismic surveying. The total counts of different species observed at the baited stations (cod, roughhead grenadier *Coryphaenoides rupestris*, redfish *Sebastes marinus*, smooth skate *Malacoraja senta*, and northern wolffish *Anarhichas denticulatus*) were not affected by seismic surveying.

Kok et al. (2021) examined the behaviour of pelagic fish to seismic surveys using echosounders; the received SPLs at the echosounder ranged from 123 to 195 dB re 1 $\mu Pa_{0\text{-}p}$. They found that there were fewer schools of fish during the seismic surveys, but the schools were more cohesive than before exposure. However, as this response was also observed at a control site, the results were inconclusive. When McQueen et al. (2022, 2023) exposed Atlantic cod on their spawning grounds to airgun sounds with received exposure levels of 115 to 145 dB re 1 μPa^2s, the fish showed weak responses by swimming slightly deeper during sound exposure; however, they did not change their swimming acceleration nor were they displaced from the exposed area. According to McQueen et al. (2023), the results suggest that distant seismic surveys 5 to >40 km away would not significantly change cod behaviour (McQueen et al. 2023).

Waddell and Širović (2023) examined larval fish behaviour in a linear acoustic chamber when exposed to airgun sounds. They found that larvae of drum (*Sciaenops ocellatus*), southern flounder (*Paralichthys lethostigma*), and spotted seatrout (*Cynoscion nebulosus*) actively avoided airguns sounds, but habituated to the noise within 10 min.

Sivle et al. (2017) examined the behavioural responses of wild captured mackerel in a net pen to sounds from a 90 in^3 airgun towed behind a vessel; SELs ranged from 146 to 171 re 1 $\mu Pa_{0\text{-}p}$. No overt responses (e.g., changes in swimming dynamics, swim speed, etc.) were recorded during sound exposure. When fish were exposed to airgun sounds at close range (90 m) at received SPLs of 184 dB re 1 $\mu Pa_{0\text{-}p}$, they swam rapidly. This suggests that the threshold between subtle reactions and avoidance responses occurs between 178 and 184 dB re 1 $\mu Pa_{0\text{-}p}$, and that ramp up of sound may be effective at minimizing initial responses to sound.

Meekan et al. (2021) studied the effects of a commercial seismic survey on an assemblage of tropical demersal fishes (*Lethrinus punctulatus*, *Lutjanus sebae*, *Lutjanus vitta*, *Abalistes stellatus*, *Epinephelus areolatus*, *E. multinotatus*, *Plectropomus maculatus*, *Nemipterus furcosus*, *Argyrops notialis*, *Saurida undosquamis*, *Sufflamen fraenatum*, *Scolopsis monogramma*, *Scarus hutchinsi*, *Choerodon cauteroma*, *Parupeneus indicus*) targeted by commercial fisheries on the North West Shelf of Western Australia. The source SPL of the airgun array was 231 dB re 1 µPa at 1 m_{rms}, 228 dB re 1 $\mu Pa^2/m^2/s$ SEL, 247 dB re 1 µPa $\cdot m_{p\text{-}p}$, and at 15° below the horizontal. Most of the acoustic energy occurred below 100 Hz and almost all of it below 1,000 Hz, with peaks at 10 and 50 Hz above an ambient pressure of 84 dB re 1 μPa_{rms}. Baited video camera systems at depths of 50 to 70 m were used to examine the fish assemblage's species composition, abundance, size structure, behaviour, and movement. The experimental design incorporated a combination of multiple BACI and dose-response in the monitoring of fish within seismic exposure and control sampling zones and at multiple sites at varying distances from the seismic source. There were no significant changes in fish assemblage structure or species richness, or in the relative abundance of any species or group. There was no change in the abundance of the entire assemblage, of combined species targeted by commercial fisheries, or of key families of commercial importance (Lutjanidae, Lethrinidae, Epinephelidae). Similarly, there was no change in the abundance of species that were abundant or were targets of commercial fishing. There was no significant trend in abundance with increasing distance from the seismic source. There was no consistent change

due to seismic exposure in the mean sizes of species that were abundant and valuable targets of the commercial fishery. The mean sizes of species that were abundant and valuable targets of the commercial fishery also showed no difference. There was no change in time to first feeding on baits by commercially important or abundant species or in the distance that fish approached the bait. Telemetry of tagged *L. sebae* showed that this species stayed in the seismic exposure and control zone during and following exposure.

Using telemetry from tagged individuals, Borland et al. (2024) studied the behaviour and movement of black rockfish (*Sebastes melanops*) and China rockfish (*S. nebulosus*) in response to an oceanographic seismic survey. During the survey received SPLs exceeded 160 dB re 1 µPa (particle velocity of 95 dB re 1 nm/s) at a depth of 36 m (Raghukumar et al. 2024). Both species showed greater swimming acceleration during and after seismic exposure than before. Black rockfish moved closer to the surface during seismic exposure, then deeper during the period after exposure. There was no significant difference due to seismic exposure in the average number of receivers that individual China rockfish were detected on, suggesting that this species did not relocate due to seismic exposure.

4.0 Indirect Effects on Fisheries

The initial comprehensive study of the effects of seismic airgun sound on catchability of fishes was conducted in the Barents Sea by Engås et al. (1993, 1996). They investigated the effects of seismic airgun sound on distributions, abundances, and catch rates of cod and haddock using acoustic mapping and experimental fishing with trawls and longlines. The maximum source SPL was about 248 dB re 1 µPa ·$m_{0\text{-}p}$ based on back-calculations from measurements collected via a hydrophone at a depth of 80 m. No measurements of the received SPLs were made. Davis et al. (1998) estimated the received SPL at the sea bottom immediately below the array and at 18 km from the array to be 205 dB re 1 $\mu Pa_{0\text{-}p}$ and 178 dB re 1 $\mu Pa_{0\text{-}p}$, respectively. Engås et al. (1993, 1996) concluded that there were indications of distributional change during and immediately following the seismic airgun discharge (45 to 64% decrease in acoustic density based on sonar data). The lowest densities were observed within 9.3 km of the seismic discharge area. The authors indicated that trawl catches of both cod and haddock declined after the seismic operations. While longline catches of haddock also showed decline after seismic airgun discharge, those for cod increased.

Løkkeborg (1991), Løkkeborg and Soldal (1993), and Dalen and Knutsen (1986) also examined the effects of seismic airgun sound on demersal fish catches. Løkkeborg (1991) examined the effects on cod catches. The source SPL of the airgun array used in his study was 239 dB re 1 µPa ·m (unspecified measure type), but received SPLs were not measured. Approximately 43 h of seismic airgun discharge occurred during an 11-day period, with a five-second interval between pulses. Catch rate decreases ranging from 55 to 80% within the seismic survey area were observed. This apparent effect persisted for at least 24 h within about 10 km of the survey area.

Løkkeborg et al. (2012) described a 2009 study of the effect of exposure to seismic sound on commercial fishes. Both gillnet and longline vessels fished for Greenland halibut, redfish, saithe and haddock for 12 days before the onset of seismic surveying, 38 days during seismic surveying, and 25 days after cessation of seismic surveying. Acoustic surveying was also conducted during these periods. Gillnet catches of Greenland halibut and redfish increased during seismic operations and remained higher after cessation of seismic surveying than they had been before the onset of seismic surveying. Longline catches of Greenland halibut decreased during seismic operations but increased again after the seismic surveying was completed. Gillnet catches of saithe decreased during seismic operations and remained low during the 25-day period following the seismic surveying. Longline catches of haddock before and during seismic operations were not significantly different although catches did decline as the seismic vessel approached the fishing area. The haddock fishery was conducted in an area with lower ensonification compared to the fishery areas of the other three species. Acoustic surveys indicated changes in saithe distribution in the area (i.e., lower abundance), while the distributional changes of the other three species were not observed. Løkkeborg et al. (2012) suggested that an increase in swimming activity as a result of exposure to seismic sound might explain why gillnet catches increased and longline catches decreased.

Skalski et al. (1992) used a 100-in^3 airgun with a source level of 223 dB re 1 µPa ·m_{0-p} to examine the potential effects of airgun sound on the catchability of rockfishes. The moving airgun was discharged along transects in the study fishing area, after which a fishing vessel deployed a set line, ran three echosounder transects, and then deployed two more set lines. Each fishing experiment lasted 1 h 25 min. Received SPLs at the base of the rockfish aggregations ranged from 186 to 191 dB re 1 μPa_{0-p}. The catch per unit effort (CPUE) for rockfish declined on average by 52.4% when the airguns were operating. Skalski et al. (1992) suggested that the reduction in catch resulted from a change in behaviour of the fishes. The fish schools descended towards the bottom and their swimming behaviour changed during airgun discharge. Although fish dispersal was not observed, the authors hypothesized that it could have occurred at a different location with a different bottom type. Skalski et al. (1992) did not continue fishing after cessation of airgun discharge. They speculated that CPUE would quickly return to normal in the experimental area, because fish behaviour appeared to normalize within minutes of cessation of airgun discharge. However, in an area where exposure to airgun sound might have caused the fish to disperse, the authors suggested that a lower CPUE might persist for a longer period. Turnpenny et al. (1994) examined results of this study as well as the results of other studies on rockfish. They used rough estimations of received SPLs at catch locations and concluded that catchability is reduced when received SPLs exceed 160 to 180 dB re 1 μPa_{0-p}. They also concluded that reaction thresholds of fishes lacking a swim bladder (e.g., flatfish) would likely be about 20 dB higher. Given the considerable variability in sound transmission loss between different geographic locations, the SPLs that were assumed in these studies were likely quite inaccurate.

Turnpenny and Nedwell (1994) also reported on the effects of seismic airgun discharge on inshore bass fisheries in shallow UK waters (5 to 30 m deep). The airgun array used had a source level of 250 dB re 1 µPa ·m_{0-p}. Received levels in the fishing areas were estimated to be 163–191 dB re 1

$\mu Pa_{0\text{-}p}$. Using fish tagging and catch record methodologies, they concluded that there was not any distinguishable migration from the ensonified area, nor was there any reduction in bass catches on days when seismic airguns were discharged. The authors concluded that effects on fisheries would be smaller in shallow nearshore waters than in deep water because attenuation of sound is more rapid in shallow water.

European seabass were exposed to sound from a seismic airgun array with a source SPL of 262 dB re 1 µPa ·$m_{0\text{-}p}$ (Pickett et al. 1994). The seismic survey was conducted over a period of four to five months. The study was intended to investigate the effects of seismic airgun sound on inshore bass fisheries. Information was collected through a tag and release program, and from the logbooks of commercial fishermen. Most of the 152 recovered fish from the tagging program were caught within 10 km of the release site, and it was suggested that most of these bass did not leave the area for a prolonged period. With respect to the commercial fishery, no significant changes in catch rate were observed.

Streever et al. (2016) completed a BACI study in the nearshore waters of Prudhoe Bay, Alaska, in 2014 which compared fish catch rates during times with and without seismic activity. The airgun arrays used in the geophysical survey had sound pressure levels of 237 dB re $1\mu Pa_{0\text{-}p}$, 243 dB re $1\mu Pa_{p\text{-}p}$, and 218 dB re $1\mu Pa_{rms}$. Received SPL_{max} ranged from 107 to 144 dB re 1 µPa, and received SEL_{cum} ranged from 111 to 141 dB re $1\mu Pa^2s$ for airgun pulses measured by sound recorders at four fyke net locations. They determined that fyke nets closest to airgun activities showed decreases in CPUE while nets further away from the airgun source showed increases in CPUE.

Bruce et al. (2018) examined the potential effects of a 2D seismic survey on fish behaviour (field-based telemetry study) and commercial fishery catch rates (desktop study) using three shark species (gummy shark, swell shark, and tiger flathead). The highest modelled peak particle velocity of sound was 171dB re 1nm/s at 40Hz and 166.7dB re 1nm/s at 80Hz, both values at 100 m from the sound source (Przeslawski et al. 2016 *in* Bruce et al. 2018). Since elasmobranchs are sensitive only to particle motion, this aspect of sound is most applicable to impact assessments on these taxa (Hawkins and Popper 2016). The flatheads exhibited some behavioural changes consistent with 'startle responses' but overall, there was little evidence for consistent behavioural or catch rate changes induced by exposure to seismic airgun sound.

5.0 Potential Effects of Airgun Exposure on Freshwater Fishes

Popper et al. (2005) tested the hearing sensitivity of three Mackenzie River fish species after exposing them to five discharges from a seismic airgun. The mean received peak SPL was 205 to 209 dB re 1 µPa, and the approximate mean received SEL was 176 to 180 dB re 1 μPa^2s. While the broad whitefish showed no TTS as a result of the exposure, adult northern pike and chub exhibited TTSs of 10 to 15 dB, followed by complete recovery within 24 h of exposure. The same animals were also examined to determine whether there were observable effects on the sensory cells of the inner ear as a result of exposure to seismic sound (Song et al. 2008). No damage to the

ears of the fishes was found, including those that exhibited TTS. Chub exposed to 20 airgun discharges experienced a greater threshold shift than those exposed to five discharges (Cott et al. 2012). Young-of-the-year northern pike exposed to either five or 20 discharges showed no evidence of hearing loss. Cott et al. (2012) speculated that this was due to juveniles having incomplete auditory development in comparison with the adults.

In another part of the same Mackenzie River project, Jorgenson and Gyselman (2009) investigated the behavioural responses of arctic riverine fishes to seismic airgun sound. They used hydroacoustic survey techniques to determine whether fish behaviour upon exposure to airgun sound can either mitigate or enhance the potential impact of the sound. The study indicated that fish behavioural characteristics were generally unchanged by the exposure to airgun sound. The tracked fish did not exhibit herding behaviour in front of the mobile airgun array and, therefore, were not exposed to sustained high sound levels.

Popper et al. (2016) conducted a study that examined the effects of exposure to seismic airgun sound on caged pallid sturgeon (*Scaphirhynchus albus*) and paddlefish (*Polyodon spathula*). The maximum received peak SPL in this study was 231 dB re 1 µPa. Results of the study indicated no mortality, either acute or after seven days post-exposure, and no statistical differences in effects on body tissues between exposed and control fish.

Réalis-Doyelle et al. (2025) studied the effects of exposure to seismic airgun sound on the physiology and behaviour of Lake Geneva fish communities. The source sound pressure levels of the airgun array were 180 and 230 dB re 1 µPa; received levels were not measured. Juveniles of roach (*Rutilus rutilus*), a hearing specialist, were examined for physiological effects. Roaches showed a significant increase in cortisol levels following seismic exposure. There was a significant increase in the expression of oxidative stress enzymes, which may be associated with hearing loss via the death of ciliate cells in the inner ear. There was also a significant increase in the size of neuromast sensory cells during seismic exposure, which may affect detection of environmental vibrations. Eyes were significantly smaller during seismic exposure but there was no measurable impact on the swim bladder. Examination of stomach contents revealed that the filling percentage was higher during seismic exposure but there was no clear pattern in the dry mass. The horizontal distance to shore and vertical distance to the lake bottom for all species was not affected by seismic exposure. Fish density within schools was higher during and after seismic exposure than before. The concentration of environmental DNA of roach, perch (*Perca fluviatilis*), and pike (*Esox lucius*) in the littoral area of the lake, where there was no seismic surveying, was not affected by seismic exposure. This suggests that fish did not seek refuge in the littoral area. Overall pelagic density of fish was higher before than during or after seismic exposure.

6.0 Potential Effects of Airgun Exposure on Anadromous Fishes

In uncontrolled experiments using a very small sample of different groups of young salmonids, including Arctic cisco, fish were caged and exposed to various types of sound. One sound type

was either a single pulse or a series of four pulses 10 to 15 s apart of a 300-in^3 seismic airgun at 2000 to 2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality was observed when fish were exposed within 1 to 2 m of an airgun source with source level, as estimated by Turnpenny and Nedwell (1994), of ~230 dB re 1 µPa ·m (unspecified measure).

Thomsen (2002) exposed rainbow trout and Atlantic salmon held in aquaculture enclosures to recordings of sounds from a small airgun array. Received SPLs were 142 to 186 dB re 1 μPa_{p-p}. The fish were exposed to 124 pulses over a 3-day period. Only eight of the 124 pulses appeared to evoke behavioural reactions by the salmonids, but overall impacts were minimal. No fish mortality was observed during or immediately after exposure. The author reported no significant effects on cod and haddock catch rates, and the behavioural effects were hard to differentiate from normal behaviour.

Weinhold and Weaver (1972 *in* Turnpenny et al. 1994) exposed caged coho salmon smolts to impulses from 330 and 660-in^3 airguns at distances ranging from 1 to 10 m, resulting in received levels estimated at ~214 to 216 dB (units not given). No lethal effects were observed.

It should be noted that in their comprehensive review, Hastings and Popper (2005) take issue with many of the authors cited above for problems with experimental design and execution, measurements, and interpretation. Hastings and Popper (2005) deal primarily with possible effects of pile-driving sounds (which, like airgun sounds, are impulsive and repetitive). However, that review provides an excellent and critical review of the impacts to fish from other underwater anthropogenic sounds.

Andrews et al. (2014) conducted genetic analyses and examined the behaviour of captive juvenile Atlantic salmon (*Salmo salar*) exposed to a 10 in^3 airgun at a distance of 2 m every 10 s for approximately 10 minutes. In order to replicate a worse-case scenario within several hundred metres of a survey vessel, the approximate average SPL was 204 dB re 1μPa_{p-p}. The received levels were measured using hydrophones placed directly in front of the cage. Behavioural observations of interest upon exposure included any changes in swimming direction/speed, reaction time to airgun blasts, and net avoidance. The right and left inner ears of the fish were sampled for genetic analyses 16 h following exposure and compared to control, non-exposed fish. The fish exhibited initial startle responses, generally for the first three airgun discharges, but little response activity for the remainder of the exposure. Increased swimming was observed for exposed fish, with rapid and erratic swimming activity during attempted capture (netting). Genetic analyses revealed numerous instances of up- or down-regulation for transcripts encoding oxygen transport, the glycolytic pathway, the Krebs cycle, and the electron transport chain, indicating both potentially damaged ear tissues as a result of exposure (e.g., ruptured cell membranes) and regeneration of ear tissues post-exposure (including auditory hair cells).

7.0 Summary of Potential Effects of Airgun Sound on Fishes

Some studies have shown that various life stages of particular fish species can be physically affected by exposure to airgun sound. In all these cases, the fish were subjected to exposures that would not likely occur under natural conditions. Studies that demonstrated physical effects on fishes typically involved either captive juvenile/adult subjects that were unable to move away from the sound source or passive ichthyoplankton that were located within a few metres of the sound source. The focus of study related to the potential effects of exposure to airgun sound on fishes has shifted to behavioural effects, particularly those that could result in a decrease in catch rate of the fishes. Fishes will exhibit both subtle and more overt behavioural changes in response to airgun sound and these effects appear to be quite variable both between and within species. Generally, the behavioural effects are localized and temporary, but can result in short-term effect on catch rates.

Note that these studies have focused on the effects of exposure to seismic airgun sound on individuals, not populations. Slabbekoorn et al. (2019) discuss two general strategies to better understand population-level effects of exposure to seismic airgun sound on fishes through modelling: (1) a bottom-up strategy that requires the building of a fully detailed, mechanistic, species-specific model that includes all effects of exposure on individuals and a realistic acoustic exposure scenario; and (2) a top-down strategy that begins with determining what would be considered a problematic population-level effect (i.e., threshold effect) and then modelling to assess to what extent the relevant model parameters can be changed before the threshold effect is reached.

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Appendix C:
Review of the Effects of Airgun Sounds on Marine Mammals[1]

[1] By **Meike Holst, Valerie D. Moulton, and W. John Richardson,** LGL Ltd., environmental research associates (updates to January 2025).

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1.0 Review of the Effects of Airgun Sounds on Marine Mammals

The following subsections review relevant information concerning the potential effects of sound from airguns on marine mammals. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

1.1 Categories of Sound Effects

The effects of sound on marine mammals are highly variable and have been reviewed by numerous authors including (but not limited to) Richardson et al. 1995; Southall et al. 2007; Gordon et al. 2014; Erbe et al. 2016, 2019, 2022; Weilgart 2017; Bröker 2019; Rako-Gospić and Picciulin 2019; and Burnham 2023. Effects can be categorized as follows (adapted from Richardson et al. 1995):

1. The sound may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient sound level, the hearing threshold of the animal at relevant frequencies, or both;
2. The sound may be audible but not strong enough to elicit any overt behavioural response, i.e., the mammal may tolerate it, either without or with some deleterious effects (e.g., masking, stress);
3. The sound may elicit behavioural reactions of variable conspicuousness and variable relevance to the well being of the animal; these can range from subtle effects on respiration or other behaviours (detectable only by statistical analysis) to active avoidance responses;
4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal may perceive as a threat;
5. Any anthropogenic sound that is strong enough to be heard has the potential to reduce (mask) the ability of marine mammals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds due to wave action or (at high latitudes) ice movement. Intermittent airgun, sonar or other activities that result in a pulse sound output may result in a strong masking effect for only a small proportion of the time, given the short duration of these pulses relative to the inter-pulse intervals. Mammal calls and other sounds are often audible during the intervals between pulses, but mild to moderate masking may occur during that time because of reverberation.
6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical or physiological effects. Received sound levels must far exceed the animal's hearing threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.

1.2 Hearing Abilities of Marine Mammals

The hearing abilities of marine mammals are functions of the following (Richardson et al. 1995; Au et al. 2000):

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise). The "best frequency" is the frequency with the lowest absolute threshold.
2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).
3. The ability to determine sound direction at the frequencies under consideration.
4. The ability to discriminate among sounds of different frequencies and intensities.

Marine mammals rely heavily on the use of underwater sounds to communicate and to gain information about their surroundings. Experiments and monitoring studies also show that they hear and may react to many man-made sounds including sounds made during seismic exploration (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Tyack 2008).

1.2.1 Toothed Whales (Odontocetes)

Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Chapter 8 of Richardson et al. [1995] and in Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are very few data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Cook et al. (2006) found that a stranded juvenile Gervais' beaked whale showed auditory evoked potentials (AEP) from 5 kHz up to 80 kHz (the entire frequency range that was tested), with best sensitivity at 40–80 kHz. An adult Gervais' beaked whale had a similar upper cutoff frequency (80–90 kHz; Finneran et al. 2009). For a sub-adult Blainville's beaked whale, Pacini et al. (2011) reported the best hearing range to be 40 to 50 kHz.

Most of the odontocete species have been classified as belonging to the "high-frequency" (HF) hearing group (Southall et al. 2019; NMFS 2024). The HF odontocetes (collectively) have functional hearing from about 150 Hz to 160 kHz (NMFS 2024). However, individual species may not have quite so broad a functional frequency range. Very strong sounds at frequencies slightly outside the functional range may also be detectable. Behavioural audiograms showed that the hearing range for killer whales is ~600 Hz to 114 kHz, with best hearing at ~34 kHz (Branstetter et al. 2017).

The remaining odontocetes—the porpoises, river dolphins, and members of the genera *Cephalo-rhynchus* and *Kogia*—are distinguished as the "very high frequency" (HF) hearing group

(Southall et al. 2019; NMFS 2024). They have functional hearing from about 200 Hz to 165 kHz (NMFS 2024). Using auditory brainstem responses, Ruser et al. (2016) found that the harbour porpoise could hear best between 120 and 130 kHz. Similarly, Kastelein et al. (2017a) reported a maximum sensitivity for harbour porpoise at 125 kHz, with a hearing range of ~16 to 140 kHz.

Airguns produce a small proportion of their sound at mid- and high-frequencies, although at progressively lower levels with increasing frequency. In general, most of the energy in the sound pulses emitted by airgun arrays is at low frequencies; strongest spectrum levels are below 200 Hz, with considerably lower spectrum levels above 1000 Hz, and smaller amounts of energy emitted up to ~150 kHz (Goold and Fish 1998; Sodal 1999; Goold and Coates 2006; Potter et al. 2007).

The hearing range for beluga whales is ~4–150 kHz (Castellote et al. 2014), but they hear best at frequencies of ~22–110 kHz (e.g., Mooney et al. 2016); the hearing threshold increases progressively (poorer hearing) outside of this range. Beluga whales are capable of hearing seismic and vessel-generated sounds at lower frequencies, but those sounds are not within their best hearing range. Sounds need to be at or above the hearing threshold to be readily detectable. Sounds must also be at or greater than ambient noise levels in order to be detected. There are no specific hearing data for narwhals, but it is assumed that belugas and narwhals have similar hearing abilities because of their taxonomic similarity; the two are the only species in the family Monodontidae.

Despite the relatively poor sensitivity of small odontocetes at the low frequencies that contribute most of the energy in pulses of sound from airgun arrays, airgun sounds are sufficiently strong, and contain sufficient mid- and high-frequency energy, that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometres (Richardson and Würsig 1997). Most small odontocetes do not show behavioural responses to airgun pulses at such long distances. However, beluga whales and narwhals do seem quite responsive at intermediate distances (10–20 km) where sound levels are well above the ambient noise level, and narwhals have shown changes in diving behaviour in response to airgun sounds and ship noise more than 40 km away (see below).

In summary, even though odontocete hearing is relatively insensitive to the predominant low frequencies produced by airguns, sounds from airgun arrays are audible to odontocetes, sometimes to distances of 10s of kilometres.

1.2.2 Baleen Whales (Mysticetes)

The hearing abilities of baleen whales (mysticetes) have not been studied directly given the difficulties in working with such large animals. Behavioural and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Frankel and Stein (2020) noted that gray whales reacted to a 21–25 kHz signal from a whale-finding sonar, and Dunlop et al. (2023) reported responses of humpbacks to 16 kHz tonal signals. Some baleen

whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). In addition, baleen whales produce sounds at frequencies up to 8 kHz and, for humpback whales, with components up to >24 kHz (Au et al. 2006). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000; Parks et al. 2007b). Although humpback and minke whales (Berta et al. 2009) may have some auditory sensitivity to frequencies above 22 kHz, for baleen whales as a group, the functional hearing range is thought to be about 7 Hz to 36 kHz; baleen whales are said to constitute the "low-frequency" (LF) hearing group (Southall et al. 2007, 2019; NMFS 2024). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies (Clark and Ellison 2004). Ambient noise levels are higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small toothed whales that have been studied directly (e.g., MacGillivray et al. 2014). Thus, baleen whales are likely to hear airgun pulses farther away than can small toothed whales and, at closer distances, airgun sounds may seem more prominent to baleen than to toothed whales. However, baleen whales have commonly been seen well within the distances where sound from airguns (or other sources) would be detectable and often show no overt reaction to those sounds. Behavioural responses by baleen whales to seismic pulses have been documented, but received levels of pulsed sounds necessary to elicit behavioural reactions are typically well above the minimum levels that the whales are assumed to detect (see below).

1.2.3 Pinnipeds (Seals, Sea Lions, and Walrus)

Underwater audiograms have been determined for several species of phocinid seals, monachid seals, otariids, and the walrus (reviewed in Richardson et al. 1995: 211ff; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002, 2005, 2009, 2023a, 2023b; Reichmuth et al. 2013; Sills et al. 2014, 2015, 2020a; Cunningham and Reichmuth 2016; Pakhomov et al. 2023). The functional hearing range for pinnipeds in water is generally considered to extend from 40 Hz to 90 kHz (NMFS 2024), although a harbour seal, spotted seal, and California sea lion were shown to detect frequencies up to 180 kHz (Cunningham and Reichmuth 2016). However, some species—especially the eared seals—do not have that broad an auditory range (Richardson et al. 1995). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, better auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency.

At least some of the phocid seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to ~1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for harbour seals indicate that, below 1 kHz, their thresholds under quiet background conditions deteriorate gradually with decreasing frequency to ~75 dB re 1 µPa at 125 Hz (Kastelein et al. 2009). Measurements of underwater hearing for spotted seals (*Phoca largha*) showed a peak sensitivity

of ~51–53 dB re 1 µPa at 25.6 kHz, with the best hearing range at ~0.6 to 11 kHz, and good auditory sensitivity extending seven octaves (Sills et al. 2014).

For the otariid (eared) seals, the high frequency cutoff is lower than for phocinids, and sensitivity at low frequencies (e.g., 100 Hz) is poorer than for seals (harbour seal).

1.3 Characteristics of Airgun Sounds

Gisiner (2016) described marine seismic surveys in hopes of providing a better understanding of the technology and its implications. Airguns function by venting high-pressure air into the water. The pressure signature of an individual airgun consists of a sharp rise and then fall in pressure, followed by several positive and negative pressure excursions caused by oscillation of the resulting air bubble. The sizes, arrangement, and activation times of the individual airguns in an array are designed and synchronized to suppress the pressure oscillations subsequent to the first cycle. The resulting downward-directed pulse has a duration of only 10–20 ms, with only one strong positive and one strong negative peak pressure (Caldwell and Dragoset 2000). Most energy emitted from airguns is at relatively low frequencies. For example, typical high-energy airgun arrays emit most energy at 10–120 Hz. However, the pulses contain significant energy up to 500–1000 Hz and some energy at higher frequencies (Goold and Fish 1998; Potter et al. 2007; Hermannsen et al. 2015; Kyhn et al. 2019; Landrø and Langhammer 2020). Studies in the Gulf of Mexico have shown that the horizontally-propagating sound can contain significant energy above the frequencies that airgun arrays are designed to emit for geophysical purposes (DeRuiter et al. 2006; Madsen et al. 2006; Tyack et al. 2006a). Energy at frequencies up to 150 kHz was found in tests of single 60-in^3 and 250-in^3 airguns (Goold and Coates 2006). Nonetheless, the predominant energy is at low frequencies.

The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds (except those from explosions) to which whales and other marine mammals are routinely exposed. The nominal source levels of the 2- to 36-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* (now retired) and R/V *Marcus G. Langseth* (36 airguns) are 236–265 dB re 1 μPa_{p-p}. These are the nominal source levels applicable to downward propagation. The effective source levels for horizontal propagation are lower than those for downward propagation when the source consists of numerous airguns spaced apart from one another. Explosions are the only man-made sources with effective source levels as high as (or higher than) a large array of airguns. However, high-power sonars can have source pressure levels as high as a small array of airguns, and signal duration can be longer for a sonar than for an airgun array, making the source energy levels of some sonars more comparable to those of airgun arrays.

Several important mitigating factors need to be kept in mind. (1) Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with

lower peak levels, but their sounds are continuous or discontinuous but continuing for longer durations than airgun pulses. (2) Airgun arrays are designed to transmit strong sounds downward through the seafloor, and the amount of sound transmitted in near-horizontal directions is considerably reduced. Nonetheless, they also emit sounds that travel horizontally toward non-geophysical target areas. (3) An airgun array is a distributed source, not a point source. The nominal source level is an estimate of the sound that would be measured from a theoretical point source emitting the same total energy as the airgun array. That figure is useful in calculating the expected received levels in the far field, i.e., at moderate and long distances, but not in the near field. Because the airgun array is not a single point source, there is no one location within the near field (or anywhere else) where the received level is as high as the nominal source level.

The strengths of airgun pulses can be measured in different ways, and it is important to know which method is being used when interpreting or comparing quoted source or received levels. In geophysical exploration related literature, sound pressure level (SPL) is often quoted as peak-to-peak (p-p) levels, in bar-metres or (less often) dB re 1 µPa ·m. The zero to peak (0-p) level for the same pulse signal is typically ~6 dB less than the p-p level. In the biological-acoustic literature, levels of received airgun pulses are often described based on the "average" or "root-mean-square" (rms) level, where the average is calculated over the duration of the pulse. The rms value for a given airgun pulse is typically ~10 dB lower than the peak level, and 16 dB lower than the peak-to-peak value (Greene 1997; McCauley et al. 1998, 2000a), depending on the extent of the averaging window used in the rms calculation. A measure that is increasingly used to characterise sound energy is the Sound Exposure Level (SEL), in dB re 1 µPa^2 ·s. Because the pulses, even when stretched by propagation effects (see below), are usually <1 s in duration, the numerical value of the energy is usually lower than the rms pressure level. However, the units are different.[2] Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting or comparing any quoted sound level. For example, the U.S. National Marine Fisheries Service (NMFS) has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound pulses received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom sediments may travel faster than that in the water, and thus may, in some situations,

[2] The rms value for a given airgun array pulse, as measured at a horizontal distance on the order of 0.1 km to 1-10 km in the units dB re 1 µPa, usually averages 10–15 dB higher than the SEL value for the same pulse measured in dB re 1 µPa^2 ·s (e.g., Greene 1997). However, there is considerable variation, and the difference tends to be larger close to the airgun array, and less at long distances (Blackwell et al. 2007; MacGillivray and Hannay 2007a,b). In some cases, generally at longer distances, pulses are "stretched" by propagation effects to the extent that the rms and SEL values (in the respective units mentioned above) become very similar (e.g., MacGillivray and Hannay 2007a,b).

arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the received pulse, or may cause two or more received pulses from a single emitted pulse. Near the source, the predominant part of an airgun pulse is ~10–20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was ~300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

The rms level for a given pulse (when measured over the duration of that pulse) depends on the extent to which propagation effects have "stretched" the duration of the pulse by the time it reaches the receiver (e.g., Madsen 2005). As a result, the rms values for various received pulses are not perfectly correlated with the SEL (energy) values for the same pulses. There is increasing evidence that biological effects are more directly related to the received energy, which has resulted in a move towards using SEL rather than SPL rms values averaged over pulse duration (Southall et al. 2007) to assess the potential effects (at least hearing impairment) of sound on marine mammals. However, there is evidence that an auditory effect in a given animal is not a simple function of received acoustic energy (Finneran 2015). Frequency, duration of the exposure, and occurrence of gaps within the exposure can also influence the auditory effect (Kastak et al. 2005; Mooney et al. 2009a; Finneran and Schlundt 2010, 2011, 2013; Finneran et al. 2010a,b, 2023a; Popov et al. 2011, 2013; Ketten 2012; Finneran 2012, 2015; Kastelein et al. 2012a,b; 2013a,b, 2014, 2015a, 2016a,b, 2017b, 2018, 2019b,c,d, 2020a,b,c,d,e,f, 2021a,b, 2022a,b; Supin et al. 2016). Additionally, Gransier and Kastelein (2024) found that audiograms are not good predictors of frequency-dependent susceptibility to TTS.

Another important aspect of sound propagation is that received levels of low-frequency underwater sounds diminish close to the surface because of pressure-release and interference phenomena that occur at and near the surface (Urick 1983; Richardson et al. 1995; Potter et al. 2007). Paired measurements of received airgun sounds at depths of 3 vs. 9 or 18 m have shown that received levels are typically several decibels lower at 3 m (Greene and Richardson 1988). For a mammal whose auditory organs are within 0.5 or 1 m of the surface, the received level of the predominant low-frequency components of the airgun pulses would be further reduced. In deep water, the received levels at deep depths can be considerably higher than those at relatively shallow (e.g., 18 m) depths and the same horizontal distance from the airguns (Tolstoy et al. 2004a,b).

Pulses of underwater sound from open-water seismic exploration are often detected 50–100 km from the source location, even during operations in nearshore waters (Greene and Richardson 1988; Burgess and Greene 1999). At those distances, the received levels are usually low, <120 dB re 1 µPa on an approximate rms basis. However, faint seismic pulses are sometimes detectable at even greater ranges (e.g., Bowles et al. 1994; Fox et al. 2002). In fact, low-frequency airgun signals sometimes can be detected thousands of kilometres from their source. For example, sound from seismic surveys conducted offshore of Nova Scotia, the coast of western

Africa, and northeast of Brazil were reported as a dominant feature of the underwater noise field recorded along the mid-Atlantic ridge (Nieukirk et al. 2004).

1.4 Masking Effects of Airgun Sounds

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies. Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species • if the frequency of the source is close to that used as a signal by the marine mammal, and • if the anthropogenic sound is present for a significant fraction of the time (Richardson et al. 1995; Clark et al. 2009; Jensen et al. 2009; Gervaise et al. 2012; Hatch et al. 2012; Rice et al. 2014; Erbe et al. 2016; Tenessen and Parks 2016; Jones et al. 2017; Putland et al. 2017; Cholewiak et al. 2018; Dunlop 2018). Conversely, if little or no overlap occurs between the introduced sound and the frequencies used by the species, communication is not expected to be disrupted. Also, if the introduced sound is present only infrequently, communication is not expected to be disrupted much if at all. In addition to the frequency and duration of the masking sound, the strength, temporal pattern, and location of the introduced sound also play a role in the extent of the masking (Branstetter et al. 2013, 2016; Finneran and Branstetter 2013; Sills et al. 2017; Popov et al. 2020; Branstetter and Sills 2022). Yurk et al. (2023) suggested that killer whales could avoid masking by using adaptive call design or vocalizing at different frequencies depending on noise levels in their environment. The biological repercussions of a loss of communication space, to the extent that this occurs, are unknown.

The duty cycle of airguns is low; the airgun sounds are pulsed, with relatively quiet periods between pulses. In most situations, strong airgun sound will only be received for a brief period (<1 s), with these sound pulses being separated by at least several seconds of relative silence, and longer in the case of deep-penetration surveys or refraction surveys. A single airgun array would cause strong masking when propagation conditions are such that sound from each airgun pulse reverberates strongly and persists for much or all of the interval up to the next airgun pulse (e.g., Simard et al. 2005; Clark and Gagnon 2006). Situations with prolonged strong reverberation have been considered infrequent, but there are increased indications that this may be more of a concern for marine mammals than previously thought, particularly in consideration of multiple, concurrent seismic surveys. It is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Gedamke 2011; Guerra et al. 2011, 2016; Klinck et al. 2012; Guan et al. 2015), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree.

Guerra et al. (2016) reported that ambient noise levels between seismic pulses were elevated as a result of reverberation at ranges of 50 km from the seismic source. Based on measurements in deep water of the Southern Ocean, Gedamke (2011) estimated that the slight elevation of background levels during intervals between pulses reduced blue and fin whale communication space by as much as 36 to 51% when a seismic survey was operating 450–2800 km away. Based

on preliminary modelling, Wittekind et al. (2016) reported that airgun sounds may reduce the communication range of blue and fin whales 2000 km from the seismic source. Nieukirk et al. (2012), Blackwell et al. (2013), and Dunlop (2018) also noted the potential for masking effects from seismic surveys on large whales.

Although masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, there are few specific studies on this. Some whales continue calling in the presence of seismic pulses and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a,b; Nieukirk et al. 2004, 2012; Smultea et al. 2004; Holst et al. 2005a,b, 2006, 2011; Dunn and Hernandez 2009; Thode et al. 2012; Bröker et al. 2013; Cerchio et al. 2014; Sciacca et al. 2016). However, some of these studies found evidence of reduced calling (or at least reduced call detection rates) in the presence of seismic pulses. One report indicates that calling fin whales distributed in a part of the North Atlantic went silent for an extended period starting soon after the onset of a seismic survey in the area (Clark and Gagnon 2006). It is not clear from that paper whether the whales ceased calling because of masking, or whether this was a behavioural response not directly involving masking. Also, bowhead whales in the Beaufort Sea apparently decrease their calling rates in response to seismic operations (Thode et al. 2020), although movement out of the area also contributes to the lower call detection rate (Blackwell et al. 2013, 2015). Noad and Dunlop (2023) found that singing humpbacks exposed to airguns produced significantly longer songs than whales that were not exposed; however, humpbacks that started singing during the exposure period sung for significantly shorter periods.

In contrast, Di Iorio and Clark (2010) found that blue whales in the St. Lawrence Estuary *increased* their call rates during operations by a lower-energy seismic source; the sparker used during the study emitted frequencies of 30–450 Hz with a relatively low source level of 193 dB re 1 μPa_{pk-pk}. Fernandez-Betelu et al. (2021) also found that bottlenose dolphins increased their call rates during exposure to impulsive noise, including airgun pulses. There is some evidence that fin whale song notes recorded in the Mediterranean had lower bandwidths during periods with versus without airgun sounds (Castellote et al. 2012).

Among the odontocetes, there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994). However, more recent studies of sperm whales found that they continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006, 2011; Jochens et al. 2008; Nieukirk et al. 2012). Madsen et al. (2006) noted that airgun sounds would not be expected to cause significant masking of sperm whale calls given the intermittent nature of airgun pulses. (However, some limited masking would be expected due to reverberation effects, as noted above.) Dolphins and porpoises are also commonly heard calling while airguns are operating (Gordon et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2011; Potter et al. 2007). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocetes, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are the dominant components of airgun sounds.

Pinnipeds, sirenians and sea otters have best hearing sensitivity and/or produce most of their sounds at frequencies higher than the dominant components of airgun sound, but there is some overlap in the frequencies of airgun pulses and their calls. Airguns sounds at 1 km from the source may have masked the detection of low-frequency sounds by ringed and spotted seals completely at the onset of the airgun pulse when signal amplitude is variable, for example during the initial 200 ms (Sills et al. (2017). However, Kastelein et al. (2023b) reported masking release at various frequencies in harbor seals exposed to noise with fluctuating amplitude. Ghoul and Reichmuth (2016) reported that sea otter hearing is most sensitive underwater at 8–16 kHz; however, their hearing is not specialized to detect sounds in background noise. However, the intermittent nature of airgun pulses presumably reduces the potential for masking.

Some cetaceans are known to increase the source levels of their calls, shift their peak frequencies, or otherwise modify their vocal behaviour in response to increased noise (Dahlheim 1987; Au 1993; reviewed in Richardson et al. 1995:233*ff*, 364*ff*; also Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Scheifele et al. 2005; Parks et al. 2007a, 2009, 2011, 2012, 2016a,b; Hanser et al. 2009; Holt et al. 2009; McKenna 2011;Melcón et al. 2012; Risch et al. 2012; Tyack and Janik 2013; Luís et al. 2014; Sairanen 2014; Blackwell et al. 2015, 2017; Papale et al. 2015; Bittencourt et al. 2016; Dahlheim and Castellote 2016; Gospić and Picciulin 2016; Heiler et al. 2016; Martins et al. 2016; O'Brien et al. 2016; Robertson et al. 2017; Fornet et al. 2018; Tsujii et al. 2018; Brown et al. 2023). Harbour seals were also reported to increase the minimum frequency and amplitude of their calls in response to vessel noise (Matthews 2017), and spotted seals increased the source levels of their growls in response to increased ambient noise (Yang et al. 2022). However, harp seals did not increase the frequencies of their calls in areas with increased low-frequency sounds (Terhune and Bosker 2016). In addition, masking release mechanisms are used by marine mammals to enhance signal detection and reduce masking (Erbe et al. 2016). However, Holt et al. (2015) reported that changes in vocal modifications can have increased energetic costs for individual marine mammals. Ultimately, the potential biological "costs" of these changes in vocalizations are unknown.

It is not known how often these types of vocal responses occur upon exposure to airgun sounds. If cetaceans exposed to airgun sounds sometimes respond by changing their vocal behaviour, this adaptation, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking by seismic pulses.

1.5 Disturbance by Seismic Surveys

Disturbance includes a variety of effects, including subtle to conspicuous changes in behaviour, movement, and displacement. In some cases, behavioural responses to sound may in turn reduce the overall exposure to that sound (e.g., Finneran et al. 2015; Wensveen et al. 2015). Available detailed data on reactions of marine mammals to airgun sounds (and other anthropogenic sounds) are limited to relatively few species and situations (see Richardson et al. 1995; Gordon et

al. 2004; Nowacek et al. 2007; Southall et al. 2007). Behavioural reactions of marine mammals to sound are difficult to predict in the absence of site- and context-specific data (Ellison et al. 2018). Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007; Ellison et al. 2012, 2016; Harding et al. 2019; Rako-Gospić and Picciulin 2019; Hückstädt et al. 2020; Hastie et al. 2021; Southall et al. 2021; Booth et al. 2022; Miller et al. 2022). If a marine mammal reacts to an underwater sound by changing its behaviour or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or population (e.g., New et al. 2013a). However, numerous data gaps remain regarding the consequences of behavioral responses (Elliott et al. 2019). If a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on individuals and populations could be significant (Lusseau and Bejder 2007; Weilgart 2007, 2023; New et al. 2013b; Nowacek et al. 2015; Forney et al. 2017). Kastelein et al. (2019a) surmised that if disturbance by noise would displace harbor porpoises from a feeding area or otherwise impair foraging ability for a short period of time (e.g., 1 day), they would be able to compensate by increasing their food consumption following the disturbance.

Also, various authors have noted that some marine mammals that show no obvious avoidance or behavioural changes may still be adversely affected by sound (Brodie 1981; Richardson et al. 1995:317*ff*; Romano et al. 2004; Weilgart 2007; Wright et al. 2009, 2011; Gomez et al. 2016). For example, some research suggests that animals in poor condition or in an already stressed state may not react as strongly to human disturbance as would more robust animals (e.g., Beale and Monaghan 2004).

Studies of the effects of seismic surveys have focused almost exclusively on the effects on individual species or related groups of species, with little scientific or regulatory attention being given to broader community-level issues. Southall et al. (2023) proposed data collection and analysis methods to examine the potential effects, including at the population level, of seismic surveys on whales, and Booth et al. (2020) examined monitoring methods for population consequences. There have been several studies that have attempted modeling to assess consequences of effects from underwater noise at the population level; however, this has proven to be complicated by numerous factors including variability in responses amongst individuals (e.g., King et al. 2015; Costa et al. 2016a,b; Ellison et al. 2016; Harwood et al. 2016; Nowacek et al. 2016; Farmer et al. 2018; Dunlop et al. 2021; Gallagher et al. 2021; McHuron et al. 2021; Mortensen et al. 2021). Parente et al. (2007) suggested that the diversity of cetaceans near the Brazil coast was reduced during years with seismic surveys. However, a preliminary account of a more recent analysis suggests that the trend did not persist when additional years were considered (Britto and Silva Barreto 2009).

Given the many uncertainties in predicting the quantity and types of impacts of sound on marine mammals, it is common practice to estimate how many mammals would be present within a particular distance of human activities and/or exposed to a particular level of anthropogenic sound. In most cases, this approach likely overestimates the numbers of marine mammals that

would be affected in some biologically important manner. One of the reasons for this is that the selected distances/isopleths are based on limited studies indicating that some animals exhibited short-term reactions at this distance or sound level, whereas the calculation assumes that all animals exposed to this level would react in a biologically significant manner.

In 2024, NMFS issued updated technical guidance for injury or Level A harassment criteria, with guidelines based on exposure characteristics that are specific to particular groups of mammal species and to particular sound types. The current threshold for Level B harassment (behaviour) from pulsed sound is 160 dB re 1µPa_{rms}, although this criterion is also expected to be revised in the future (Scholik-Schlomer 2015). Although these criteria have not been adopted officially in Canada, nor have any other injury or behavioural thresholds (Wright and Moors-Murphy 2022), the behavioural threshold is often used in environmental assessments of seismic surveys in Canada as a guide for predicting behavioural responses of marine mammals. The limitations regarding the NMFS technical guidance regarding thresholds for permanent and temporary hearing thresholds (Level A) need to be considered before they can be implemented in Canada (Wright and Moors-Murphy 2022; Wright et al. 2022).The sound criteria used to estimate how many marine mammals might be disturbed to some biologically significant degree by seismic survey activities are primarily based on behavioural observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales, and on ringed seals. Less detailed data are available for some other species of baleen whales and small toothed whales, but for many species there are no data on responses to marine seismic surveys; many data gaps remain where exposure criteria are concerned (Southall 2021).

1.5.1 Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable among species, locations, whale activities, oceanographic conditions affecting sound propagation, etc. (reviewed in Richardson et al. 1995; Gordon et al. 2004). Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometres, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong sound pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some of the major studies and reviews on this topic are Malme et al. (1984, 1985, 1988); Richardson et al. (1986, 1995, 1999); Ljungblad et al. (1988); Richardson and Malme (1993); McCauley et al. (1998, 2000a,b); Miller et al. (1999, 2005); Gordon et al. (2004); Stone and Tasker (2006); Johnson et al. (2007); Nowacek et al. (2007); Weir (2008a); Moulton and Holst (2010); and Stone et al. (2017). Although baleen whales often show only slight overt responses to operating airgun arrays (Stone and Tasker 2006; Weir 2008a; Stone 2015; Stone et al. 2017), strong avoidance reactions by several species of mysticetes have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when large arrays of airguns were used. Experiments with a single airgun showed that bowhead, humpback and gray whales all

showed localized avoidance to a single airgun of 20–100 in^3 (Malme et al. 1984, 1985, 1986, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b).

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received levels of 160–170 dB re 1 μPa_{rms} SPL seem to cause obvious avoidance behaviour in a substantial portion of the animals exposed (Richardson et al. 1995). In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4–15 km from the source. More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa_{rms} SPL. The largest avoidance radii involved migrating bowhead whales, which avoided an operating seismic vessel by 20–30 km (Miller et al. 1999; Richardson et al. 1999). In the cases of migrating bowhead (and gray) whales, the observed changes in behaviour appeared to be of little or no biological consequence to the animals—they simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Malme et al. 1984; Malme and Miles 1985; Richardson et al. 1995). Feeding bowhead whales, in contrast to migrating whales, show much smaller avoidance distances (Miller et al. 2005; Harris et al. 2007), presumably because moving away from a food concentration has greater cost to the whales than does a course deviation during migration.

The following subsections provide more details on the documented responses of particular species and groups of baleen whales to marine seismic operations.

Humpback Whale

Responses of humpback whales to seismic surveys have been studied during migration, on the summer feeding grounds, and on Angolan winter breeding grounds; there has also been discussion of effects on the Brazilian wintering grounds. McCauley et al. (1998, 2000a) studied the responses of migrating humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun 2678-in^3 array, and to a single 20 in^3 airgun with a (horizontal) source level of 227 dB re 1 $\mu Pa \cdot m_{p-p}$ SPL. They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program, although localized displacement varied with pod composition, behaviour, and received sound levels. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance reactions (course and speed changes) began at 4–5 km for traveling pods, with the closest point of approach (CPA) being 3–4 km at an estimated received SPL of 157–164 dB re 1 μPa_{rms} (McCauley et al. 1998, 2000a). A greater stand-off range of 7–12 km was observed for more sensitive resting pods (cow-calf pairs; McCauley et al. 1998, 2000a). The mean received SPL for initial avoidance of an approaching airgun was 140 dB re 1 μPa_{rms} for humpback pods containing females, and at the mean CPA distance the received SPL was 143 dB re 1 μPa_{rms}. One startle response was reported for a SPL of 112 dB re 1 μPa_{rms}. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances of

100–400 m, where the maximum received SPL was 179 dB re 1 μPa_{rms}. The McCauley et al. (1998, 2000a,b) studies show evidence of greater avoidance of seismic airgun sounds by pods with females than by other pods during humpback migration off Western Australia.

Dunlop et al. (2015) reported that humpback whales responded to a vessel operating a 20 in^3 airgun by decreasing their dive time and speed of southward migration; however, the same responses were obtained during control trials without an active airgun, suggesting that humpbacks responded to the source vessel rather than the airgun. A ramp up was not superior to triggering humpbacks to move away from the vessel compared with a constant source at a higher level of 140 in^3, although an increase in distance from the airgun array was noted for both sources (Dunlop et al. 2016a). Avoidance was also shown when no airguns were operational, indicating that the presence of the vessel itself had an effect on the response (Dunlop et al. 2016a,b). Overall, the results showed that humpbacks were more likely to avoid active airgun arrays (of 20 and 140 in^3) within 3 km and at received levels of at least 140 dB re 1 $\mu Pa^2 \cdot s$ (Dunlop et al. 2017a). Responses to ramp up and use of a 3130 in^3 array elicited greater behavioural changes in humpbacks when compared with small arrays (Dunlop et al. 2016c). Humpbacks reduced their southbound migration, or deviated from their path thereby avoiding the active array, when they were within 4 km of the active large airgun source, where received levels were >130 dB re 1 $\mu Pa^2 \cdot s$ (Dunlop et al. 2017b, 2018). These results are consistent with earlier studies (e.g., McCauley et al. 2000a). However, some individuals did not show avoidance behaviours even at levels as high as 160 to 170 dB re 1 $\mu Pa^2 \cdot s$ (Dunlop et al. 2018). Dunlop et al. (2020) found that humpback whales were significantly less likely to interact socially (e.g., joining a group) in the presence of a vessel, whether it was towing an active airgun array or not, at greater ranges and received sound levels lower than the recommended thresholds.

Humpback whales on their summer feeding grounds in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100 in^3) airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received SPLs of 150–169 dB re 1 µPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle behavioural effects, at received SPLs up to 172 re 1 µPa on an approximate rms basis. Similarly, observations of humpback whales from seismic vessels off the U.K. during 1994 to 2010 indicated that detection rates were similar during seismic and non-seismic periods; however, sample sizes were small (Stone 2015; Stone et al. 2017). In contrast, Moulton and Holst (2010) reported that humpback whales monitored during seismic surveys in the Northwest Atlantic had significantly lower sighting rates and were most often seen swimming away from the vessel during seismic periods compared with periods when airguns were silent.

Among wintering humpback whales off Angola (n = 52 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the mean CPA (closest observed point of approach) distance of the humpback sightings when airguns were on vs. off (3050 m vs. 2700 m, respectively). Cerchio et al. (2014) suggested that the breeding display

of humpback whales off Angola may be disrupted by seismic sounds, as singing activity declined with increasing received levels.

It has been suggested that South Atlantic humpback whales wintering off Brazil may be displaced or even strand upon exposure to seismic surveys (Engel et al. 2004). The evidence for this was circumstantial and subject to alternative explanations (IAGC 2004). Also, the evidence was not consistent with subsequent results from the same area of Brazil (Parente et al. 2006), or with direct studies of humpbacks exposed to seismic surveys in other areas and seasons (see above). After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007, p. 236).

Bowhead Whale

Responsiveness of bowhead whales to seismic surveys can be quite variable depending on their activity (feeding vs. migrating). Bowhead whales on their summer feeding grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometres (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005). They also moved away when a single airgun was activated nearby (Richardson et al. 1986; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 µPa ·m at a distance of 7.5 km, and swam away when it came within ~2 km; some whales continued feeding until the vessel was 3 km away (Richardson et al. 1986). This work and subsequent summer studies in the same region showed that many feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales (see below) before showing an overt change in behaviour (e.g., Miller et al. 2005; Harris et al. 2007; Robertson et al. 2013). On the summer feeding grounds, bowhead whales are often seen from an operating seismic ship, though average sighting distances tend to be larger when the airguns are operating. Similarly, preliminary analyses of data from the Alaskan Beaufort Sea indicate that bowheads feeding there during late summer and autumn also did not display large-scale distributional changes in relation to seismic operations (Christie et al. 2009; Koski et al. 2009). However, some individual bowheads apparently begin to react at distances a few kilometres away, beyond the distance at which observers on the ship can sight bowheads (Richardson et al. 1986; Citta et al. 2007). The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away until the airguns are within a few kilometres.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to sound pulses from a distant seismic vessel compared to summering bowheads. Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km at received SPLs of around 120–130 dB re 1 μPa_{rms} from a medium-sized airgun source (Miller et al. 1999; Richardson et

al. 1999; see also Manly et al. 2007). Those results came from 1996–98, when a partially-controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward-migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic surveying stopped. Preliminary analysis of data on traveling bowheads in the Alaskan Beaufort Sea also showed a stronger tendency to avoid operating airguns than was evident for feeding bowheads (Christie et al. 2009; Koski et al. 2009). Additionally, subtle but statistically significant changes in surfacing–respiration–dive cycles were shown by traveling and socializing bowheads exposed to airgun sounds in the Beaufort Sea, including shorter surfacings, shorter dives, and decreased number of blows per surfacing (Robertson et al. 2013).

Bowhead whale calls detected in the presence and absence of airgun sounds have been studied extensively in the Beaufort Sea. Early work on the summering grounds in the Canadian Beaufort Sea showed that bowheads continue to produce calls of the usual types when exposed to airgun sounds, although numbers of calls detected may be somewhat lower in the presence of airgun pulses (Richardson et al. 1986). Studies during autumn in the Alaskan Beaufort Sea, one in 1996–1998 and another in 2007–2010, have shown that numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Greene et al. 1999a,b; Blackwell et al. 2013, 2015; Koski et al. 2009; see also Nations et al. 2009). Blackwell et al. (2013) reported that calling rates in 2007 declined significantly where received SPLs from airgun sounds were 116–129 dB re 1 μPa; at SPLs <108 dB re 1 μPa, calling rates were not affected. When data for 2007–2010 were analyzed, Blackwell et al. (2015) reported an initial increase in calling rates when airgun pulses became detectable; however, calling rates leveled off at a received $CSEL_{10\text{-min}}$ (cumulative SEL over a 10-min period) of ~94 dB re 1 $\mu Pa^2 \cdot s$, decreased at CSEL10-min >127 dB re 1 μPa2 · s, and whales were nearly silent at CSEL10-min >160 dB re 1 μPa2 · s. Thode et al. (2020) reported similar changes in bowhead whale vocalizations when data were analyzed for the period 2008–2014. Thus, bowhead whales in the Beaufort Sea apparently decreased their calling rates in response to seismic operations, although movement out of the area could also have contributed to the lower call detection rate (Blackwell et al. 2013, 2015). Aerial surveys showed that there was strong avoidance of the operating airguns during the 1996–98 study, when most of the whales appeared to be migrating (Miller et al. 1999; Richardson et al. 1999). In contrast, aerial surveys during 2007–2010 showed less consistent avoidance by the bowheads, many of which appeared to be feeding (Christie et al. 2009; Koski et al. 2009, 2011). The reduction in call detection rates during periods of airgun operation may have been more dependent on actual avoidance during the 1996–98 study and more dependent on reduced calling behaviour during 2007–2010.

A multivariate analysis of factors affecting the distribution of calling bowhead whales during their fall migration in 2009 noted that the southern edge of the distribution of calling whales was significantly closer to shore with increasing levels of airgun sound from a seismic survey a few hundred kilometres to the east of the study area (i.e., behind the westward-migrating whales; McDonald et al. 2010, 2011). It was not known whether this statistical effect represented a

stronger tendency for quieting of the whales farther offshore in deeper water upon exposure to airgun sound, or an actual inshore displacement of whales.

There are no data on reactions of bowhead whales to seismic surveys in winter or spring.

Gray Whale

Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100-in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales stopped feeding at an average received sound pressure level of 173 dB re 1 µPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB re 1 μPa_{rms}. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6–2.8 km from an airgun array with a source level of 250 dB re 1 μPa_{peak} in the northern Bering Sea.

Malme and Miles (1985) concluded that, during migration off California, gray whales showed changes in swimming pattern with received levels of ~160 dB re 1 µPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in^3 airgun array operating off central California. This would occur at an average received SPL of ~170 dB re 1 μPa_{rms}. Some slight behavioural changes were noted when approaching gray whales reached the distances where received sound pressure levels were 140 to 160 dB re 1 μPa_{rms}, but these whales generally continued to approach (at a slight angle) until they passed the sound source at distances where received levels averaged ~170 dB re 1 μPa_{rms} (Malme et al. 1984; Malme and Miles 1985).

There was no indication that western gray whales exposed to seismic sound were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) or 2001 (Johnson et al. 2007; Meier et al. 2007; Yazvenko et al. 2007a). However, there were indications of subtle behavioural effects among whales that remained in the areas exposed to airgun sounds (Würsig et al. 1999; Gailey et al. 2007; Weller et al. 2006a). Also, there was evidence of localized redistribution of some individuals within the nearshore feeding ground so as to avoid close approaches by the seismic vessel (Weller et al. 2002, 2006b; Yazvenko et al. 2007a). Despite the evidence of subtle changes in some quantitative measures of behaviour and local redistribution of some individuals, there was no apparent change in the frequency of feeding, as evident from mud plumes visible at the surface (Yazvenko et al. 2007b).

Similarly, no large changes in gray whale movement, respiration, or distribution patterns were observed during seismic programs conducted in 2010 (Bröker et al. 2015; Gailey et al. 2016). Although sighting distances of gray whales from shore increased slightly during a two-week seismic survey, this result was not significant (Muir et al. 2015). The lack of strong avoidance or other strong responses during the 2001 and 2010 programs was presumably in part a result of the comprehensive combination of real-time monitoring and mitigation measures designed to avoid

exposing western gray whales to received SPLs above ~163 dB re 1 µPa$_{rms}$ (Johnson et al. 2007; Nowacek et al. 2012, 2013). In contrast, in 2015 when the number and duration of seismic surveys exceeded those in previous years, some gray whales were displaced from the nearshore feeding area at sound levels lower than expected (Muir et al. 2016; Gailey et al. 2017, 2022a,b; Sychenko et al. 2017); this occurred despite rigorous monitoring and mitigation measures (Aerts et al. 2022; Rutenko et al. 2022).

Gray whales in British Columbia exposed to seismic survey sound levels up to ~170 dB re 1 µPa did not appear to be strongly disturbed (Bain and Williams 2006). The few whales that were observed moved away from the airguns but toward deeper water where sound levels were said to be higher due to propagation effects (Bain and Williams 2006).

Rorquals

Blue, sei, fin, and minke whales (all of which are members of the genus *Balaenoptera*) often have been seen in areas where airgun sources are active (Stone 2003, 2015; MacLean and Haley 2004; Stone and Tasker 2006; Stone et al. 2017), and calls from blue and fin whales have been localized in areas with airgun operations (e.g., McDonald et al. 1995; Dunn and Hernandez 2009; Castellote et al. 2012). Observations from seismic vessels using large-volume[3] airgun arrays off the U.K. from 1994 to 2010 showed that the detection rate for minke whales was significantly higher when airguns were not operating; however, during surveys with small arrays, the detection rates for minke whales were similar during seismic and non-seismic periods (Stone 2015; Stone et al. 2017). Sighting rates for fin and sei whales were similar when large arrays of airguns were active vs. silent (Stone 2015; Stone et al. 2017). All baleen whales combined tended to exhibit localized avoidance, remaining significantly farther (on average) from large arrays during seismic operations compared with non-seismic periods; the median CPA distances for baleen whales sighted when large airgun arrays were operating vs. silent were ~1.5 vs. 1.0 km (Stone 2015; Stone et al. 2017). In addition, fin and minke whales were more often oriented away from the vessel while a large airgun array was active compared with periods of inactivity (Stone 2015; Stone et al. 2017). Similarly, Castellote et al. (2012) reported that singing fin whales in the Mediterranean moved away from an operating airgun array and avoided the area for days after airgun activity had ceased. In addition, Stone (2015; Stone et al. 2017) noted that baleen whales were more likely to surface frequently during periods of seismic surveying. Vilela et al. (2016) cautioned that environmental conditions should be taken into account when comparing sighting rates during seismic surveys, as spatial modeling showed that differences in sighting rates of rorquals (fin and minke whales) during seismic periods and non-seismic periods during a survey in the Gulf of Cadiz could be explained by environmental variables.

Kavanagh et al. (2019) analyzed more than 8000 hr of cetacean survey data in the northeastern Atlantic Ocean to determine the effects of the seismic surveys on cetaceans. They found that

[3] Large volume means at least 500 in^3, small volume is <500 in^3.

sighting rates of baleen whales were significantly lower during seismic surveys compared with control surveys. Sighting rates of baleen whales were also significantly lower during seismic operations compared with non-seismic periods during seismic surveys in the northwest Atlantic (Moulton and Holst 2010). Baleen whales were seen on average 200 m farther from the vessel during airgun activities vs. non-seismic periods, and these whales more often swam away from the vessel when seismic operations were underway compared with periods when no airguns were operating (Moulton and Holst 2010). Blue whales were seen significantly farther from the vessel during single airgun operations, ramp up, and all other airgun operations compared with non-seismic periods (Moulton and Holst 2010). Similarly, the mean CPA distance for fin whales was significantly farther during ramp up than during periods without airgun operations; there was also a trend for fin whales to be sighted farther from the vessel during other airgun operations, but the difference was not significant (Moulton and Holst 2010). Minke whales were seen significantly farther from the vessel during periods with than without seismic operations (Moulton and Holst 2010). Minke whales were also more likely to swim away and less likely to approach during seismic operations compared to periods when airguns were not operating (Moulton and Holst 2010). However, MacLean and Haley (2004) reported that minke whales occasionally approached active airgun arrays where received sound levels were estimated to be near 170–180 dB re 1 µPa. Matos (2015) reported no change in sighting rates of minke whales in Vestfjorden, Norway, during ongoing seismic surveys outside of the fjord.

Discussion and Conclusions

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the sound levels from airgun pulses remain well above ambient noise levels out to much longer distances. However, studies done since the late 1990s of migrating humpback and migrating bowhead whales show reactions, including avoidance, that sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel can be biased. Observations over broader areas may be needed to determine the range of potential effects of some large-source seismic surveys where effects on cetaceans may extend to considerable distances (Richardson et al. 1999; Bain and Williams 2006; Moore and Angliss 2006). Longer-range observations, when required, can sometimes be obtained via systematic aerial surveys or aircraft-based observations of behaviour (e.g., Richardson et al. 1986, 1999; Miller et al. 1999, 2005; Yazvenko et al. 2007a,b) or by use of observers on one or more support vessels operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007). However, the presence of other vessels near the source vessel can, at least at times, reduce sight-ability of cetaceans from the source vessel (Beland et al. 2009), thus complicating interpretation of sighting data.

Some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioural changes become evident. Because responsiveness is variable and the responses become less obvious with diminishing received

sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which reactions to seismic become evident and, hence, how many whales are affected. Responsiveness depends on the situation (Richardson et al. 1995; Ellison et al. 2012).

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa_{rms} range seem to cause obvious avoidance behaviour in a substantial fraction of the animals exposed. In many areas, sound from seismic airgun pulses diminish to these levels at distances ranging from 4 to 15 km from the source. A substantial proportion of the baleen whales within such distances may show avoidance or other strong disturbance reactions to the operating airgun array. However, in other situations, various mysticetes tolerate exposure to full-scale airgun arrays operating at even closer distances, with only localized avoidance and minor changes in activities. At the other extreme, in migrating bowhead whales, avoidance often extends to considerably larger distances (20–30 km) and lower received SPLs (120–130 dB re 1 μPa_{rms}). Also, even in cases where there is no conspicuous avoidance or change in activity upon exposure to sound pulses from distant seismic operations, there are sometimes subtle changes in behaviour (e.g., surfacing–respiration–dive cycles) that are only evident through detailed statistical analysis (e.g., Richardson et al. 1986; Gailey et al. 2007).

Mitigation measures for seismic surveys, especially nighttime seismic surveys, typically assume that many marine mammals (at least baleen whales) tend to avoid approaching airguns, or the seismic vessel itself, before being exposed to levels high enough for there to be any possibility of injury. This assumes that the ramp-up (soft-start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As noted above, single-airgun experiments with three species of baleen whales show that those species typically do tend to move away when a single airgun is activated nearby, which simulates the onset of a ramp up. The three species that showed avoidance when exposed to the onset of pulses from a single airgun were *gray whales* (Malme et al. 1984, 1986, 1988); *bowhead whales* (Richardson et al. 1986; Ljungblad et al. 1988); and *humpback whales* (Malme et al. 1985; McCauley et al. 1998, 2000a,b). In addition, results from Moulton and Holst (2010) showed that, during operations with a single airgun and during ramp up, blue whales were seen significantly farther from the vessel compared with periods without airgun operations. Since startup of a single airgun is equivalent to the start of a ramp up (=soft start), this suggests that many baleen whales will begin to move away during the initial stages of a ramp-up. However, there is likely to be variation (i.e., species, context) in baleen whale response to ramp up.

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. Castellote et al. (2012) reported that fin whales avoided their potential winter ground for an extended period of time (at least 10 days) after seismic operations in the Mediterranean Sea had ceased. However, gray whales have continued to migrate annually along the west coast of North America despite

intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A *in* Malme et al. 1984; Richardson et al. 1995), and there has been a substantial increase in the population over recent decades (Allen and Angliss 2013). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a prior year (Johnson et al. 2007). Similarly, bowhead whales have continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987), and their numbers have increased notably (Allen and Angliss 2013). Bowheads also have been observed over periods of days or weeks in areas ensonified repeatedly by sound from seismic airgun pulses (Richardson et al. 1987; Harris et al. 2007). However, it is generally not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas.

Pirotta et al. (2018) used a dynamic state model of behaviour and physiology to assess the consequences of disturbance (e.g., seismic surveys) on whales (in this case, blue whales). They found that the impact of localized, acute disturbance (e.g., seismic surveys) depended on the whale's behavioural response, with whales that remained in the affected area having a greater risk of reduced reproductive success than whales that avoided the disturbance. Chronic, but weaker disturbance (e.g., vessel traffic) appeared to have less effect on reproductive success. Nonetheless, in the absence of some unusual circumstances, the history of coexistence between seismic surveys and baleen whales suggests that brief exposures to sound pulses from any single seismic survey are unlikely to result in prolonged disturbance effects.

1.5.2 Toothed Whales

Historically, little systematic information is available about reactions of toothed whales to sound pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales. However, there are systematic data on sperm whales (e.g., Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009) and narwhals (Heide-Jørgensen et al. 2021; Tervo et al. 2021, 2023). There is also an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring programs (e.g., Stone 2003, 2015; Smultea et al. 2004; Moulton and Miller 2005; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Potter et al. 2007; Hauser et al. 2008; Holst and Smultea 2008; Weir 2008a; Richardson et al. 2009; Moulton and Holst 2010; Wole and Myade 2014; Monaco et al. 2016; Stone et al. 2017; Barkaszi and Kelly 2024).

Delphinids (Dolphins and similar) and Monodontids (Beluga and Narwhal)

Seismic operators and marine mammal observers on seismic vessels regularly see dolphins and other small toothed whales near operating airgun arrays, but in general there is a tendency for most delphinids to show some avoidance of operating seismic vessels (e.g., Goold 1996a,b,c; Calambokidis and Osmek 1998; Stone 2003, 2015; Moulton and Miller 2005; Holst et al. 2006; Stone and Tasker 2006; Weir 2008a; Richardson et al. 2009; Moulton and Holst 2010; Wole and Myade 2014; Stone et al. 2017; Barkaszi and Kelly 2024). In most cases, the avoidance radii for

delphinids appear to be small, on the order of 1 km or less, and some individuals show no apparent avoidance. Studies that have reported cases of small toothed whales close to the operating airguns include Duncan (1985), Arnold (1996), Stone (2003), and Holst et al. (2006). When a 3959 in^3, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when a large array of airguns is firing (e.g., Moulton and Miller 2005). Nonetheless, small toothed whales more often tend to head away or maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Stone and Tasker 2006; Weir 2008a; Barry et al. 2012; Moulton and Holst 2010; Stone et al. 2017).

Weir (2008b) noted that a group of short-finned pilot whales initially showed an avoidance response to ramp up of a large airgun array, but that this response was limited in time and space. Moulton and Holst (2010) did not find any indications that long-finned pilot whales, or delphinids as a group, responded to ramp ups by moving away from the seismic vessel during surveys in the Northwest Atlantic. Although the ramp-up procedure is a widely-used mitigation measure, it remains uncertain how effective it is at alerting marine mammals (especially odontocetes) and causing them to move away from seismic operations (Weir 2008b; Cato et al. 2013; Weilgart 2014; Dunlop et al. 2016a). Exposure modeling may be useful to evaluate and optimize ramp-up procedures for intense sound sources (von Benda-Beckmann et al. 2013).

Goold (1996a,b,c) studied the effects on common dolphins of 2D seismic surveys in the Irish Sea. Passive acoustic surveys were conducted from the "guard ship" that towed a hydrophone. The results indicated that there was a local displacement of dolphins around the seismic operation. However, observations indicated that the animals were tolerant of the sounds at distances outside a 1-km radius from the airguns (Goold 1996a). Initial reports of larger-scale displacement were later shown to represent a normal autumn migration of dolphins through the area, and were not attributable to seismic surveys (Goold 1996a,b,c).

The beluga whale is a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys conducted in the southeastern Beaufort Sea in summer found that sighting rates of belugas were significantly lower at distances 10–20 km compared with 20–30 km from an operating airgun array (Miller et al. 2005). The low number of beluga sightings by marine mammal observers on the vessel seemed to confirm there was a strong avoidance response to the 2250 in^3 airgun array. More recent seismic monitoring studies in the same area have confirmed that the apparent displacement effect on belugas extended farther than has been shown for other small odontocetes exposed to airgun pulses (e.g., Harris et al. 2007). Preliminary findings of a monitoring study of narwhals in Melville Bay, Greenland (summer and fall 2012) showed no short-term effects of seismic survey activity on narwhal distribution, abundance, migration timing, and feeding habits (Heide-Jørgensen et al. 2013a). In addition, there were no reported effects on narwhal hunting. These findings do not seemingly support a suggestion by Heide-Jørgensen et al. (2013b) that seismic surveys in Baffin Bay may have delayed the migration timing of narwhals, thereby increasing the risk of narwhals to ice entrapment. More recently,

Heide-Jørgensen et al. (2021) did report avoidance reactions by narwhal at distances >11 km from an active seismic vessel, as well as an increase in travel speed and changes in direction of travel at distances up to 24 km from a seismic source; however, no long-term effects were reported. Tervo et al. (2021) reported that narwhal buzzing rates decreased in response to concurrent ship noise and airgun pulses (being 50% at 12 km from ship), and that the whales discontinued foraging at 7–8 km from the vessel. Tervo et al. (2023) also noted that narwhals showed increased shallow diving activity and avoided deeper diving, resulting in a reduction in foraging, when exposed to combined ship sounds and airgun pulses. Both studies found that exposure effects could still be detected >40 km from the vessel (Tervo et al. 2021, 2023).

Observers stationed on seismic vessels operating off the U.K. from 1994 to 2010 have provided data on the occurrence and behaviour of various toothed whales exposed to seismic pulses (Stone 2003, 2015; Gordon et al. 2004; Stone and Tasker 2006; Stone et al. 2017). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Detection rates of Atlantic white-sided dolphins, white-beaked dolphins, and killer whales were significantly lower during periods when large-volume arrays were active; detection rates during seismic vs. non-seismic periods were similar during seismic surveys using small arrays (Stone 2015; Stone et al. 2017). Detection rates for long-finned pilot whales, Risso's dolphins, bottlenose dolphins, and short-beaked common dolphins were similar during seismic (small or large array) vs. non-seismic operations (Stone 2015; Stone et al. 2017). CPA distances for killer whales, white-beaked dolphins, and Atlantic white-sided dolphins were significantly farther (>0.5 km) from large airgun arrays during periods of airgun activity compared with periods of inactivity, with significantly more animals traveling away from the vessel during airgun operation (Stone 2015; Stone et al. 2017). Observers' records suggested that fewer cetaceans were feeding and fewer delphinids were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating (Stone and Tasker 2006; Stone 2015; Stone et al. 2017).

Data collected during seismic operations in the Gulf of Mexico and off Central America show similar patterns. A summary of vessel-based monitoring data from the Gulf of Mexico during 2002–2015 showed that delphinids were seen significantly farther from the vessel during seismic than during non-seismic periods (Barkaszi and Kelly 2024). Similarly, during two NSF-funded L-DEO seismic surveys that used a large 20 airgun array (~7000 in^3), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during periods when the seismic source was active versus not active (Smultea et al. 2004; Holst et al. 2005a, 2006; Holst 2009; Richardson et al. 2009). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids was 991 m during seismic operations vs. 172 m when the airguns were not operational (Smultea et al. 2004). Surprisingly, nearly all acoustic detections via a towed passive acoustic monitoring (PAM) array, including both delphinids and sperm whales, were made when the airguns were operating (Smultea et al. 2004). Although the number of sightings during monitoring of a seismic survey off the Yucatán Peninsula, Mexico, was small (n = 19), the results showed that the mean CPA distance of delphinids there was 472 m during seismic operations vs. 178 m when the airguns were silent (Holst et

al. 2005a). The acoustic detection rates were nearly 5 times higher without than with seismic operations (Holst et al. 2005a). During a seismic survey off Taiwan for which the sample size was small (n = 14), Holst (2009) noted that the mean CPA distance of delphinids during seismic operations (1698 m) was greater compared with non-seismic periods (888 m).

For two additional NSF-funded L-DEO seismic surveys in the Eastern Tropical Pacific, both using a large 36-airgun array (~6600 in^3), the results are less easily interpreted (Richardson et al. 2009). During both surveys, the delphinid detection rate was lower during periods when the seismic source was active versus not active, as found in various other projects, but the mean CPA distance of delphinids was closer (not farther) during seismic periods (Hauser et al. 2008; Holst and Smultea 2008).

During seismic surveys in the Northwest Atlantic, delphinids as a group showed some localized avoidance of the operating array (Moulton and Holst 2010). The mean initial detection distance was significantly farther (by *ca.* 200 m) during seismic operations compared with periods when the seismic source was not active; however, there was no significant difference between sighting rates (Moulton and Holst 2010). The same results were evident when only long-finned pilot whales were considered.

Among Atlantic spotted dolphins off Angola (n = 16 useable groups), marked short-term and localized displacement was found in response to seismic operations conducted with a 24-airgun array (3147 in^3 or 5085 in^3) (Weir 2008a). Sample sizes were low, but CPA distances of dolphin groups were significantly larger when airguns were on (mean 1080 m) vs. off (mean 209 m). No Atlantic spotted dolphins were seen within 500 m of the airguns when they were operating, whereas all sightings when airguns were silent occurred within 500 m, including the only recorded "positive approach" behaviours.

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but in general tend to be less substantial than reactions to large airgun arrays (e.g., Stone 2003, 2015; Stone and Tasker 2006; Stone et al. 2017). Observations during seismic surveys using small arrays off the U.K. in 1994–2010 showed that detection rates of all small odontocetes combined were similar during periods with and without seismic; however, small odontocetes were more frequently observed to avoid or travel away from the vessel and positive interactions (e.g., bow-riding) occurred significantly less during seismic operations (Stone 2015; Stone et al. 2017). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during periods when the seismic source was active versus not active. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during another cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during periods when the source was not active during both surveys was small. Results from another two small-array surveys were

even more variable (MacLean and Koski 2005; Smultea and Holst 2008; Holst and Robertson 2009).

Captive bottlenose dolphins and beluga whales exhibited changes in behaviour when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002, 2005). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviours were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). Bottlenose dolphins exposed to multiple airgun pulses exhibited some anticipatory behaviour (Schlundt et al. 2016). It is uncertain what relevance these observed behaviours in captive, trained marine mammals exposed to single transient sounds may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound before exhibiting the aversive behaviours mentioned above.

Odontocete responses (or lack of responses) to sound pulses from underwater explosions (as opposed to airgun pulses) may be indicative of odontocete responses to very strong sound pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare beluga whales away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were "not always effective" in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish killed by explosions, and thus attracted rather than repelled by "scare" charges. Captive false killer whales showed no obvious reaction to single sound pulses from small (10 g) charges; the received level was ~185 dB re 1 µPa (Akamatsu et al. 1993). Jefferson and Curry (1994) reviewed several additional studies that found limited or no effects of sound pulses from small explosive charges on killer whales and other odontocetes. Aside from the potential for causing auditory impairment (see below), the tolerance to these charges may indicate a lack of effect, or the failure to move away may simply indicate a stronger desire to feed, regardless of circumstances.

Castellote and Llorens (2016) reported nine cases of toothed whale strandings (including pilot whales) coincident with seismic surveys; however, no conclusive link has been established between the seismic surveys and strandings. However, an analysis of stranding data found that the number of long-finned pilot whale stranding along Ireland's coast increased with seismic surveys operating offshore (McGeady et al. 2016).

Phocoenids (Porpoises)

Porpoises, like delphinids, show variable reactions to seismic operations, and reactions apparently depend on species. The limited available data suggest that harbour porpoises show stronger avoidance of seismic operations than do Dall's porpoises (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006). In Washington State waters, the harbour porpoise—despite being considered a high-frequency specialist—appeared to be the species affected by the lowest received SPL of airgun sound (<145 dB re 1 μPa_{rms} at a distance >70 km; Bain and Williams 2006). Similarly, during seismic surveys off the U.K. in 1994–2010, detection rates of harbour porpoises were significantly higher when airguns were silent vs. when large or small arrays were operating (Stone 2015; Stone et al. 2017). In addition, harbour porpoises were seen farther away from the array when it was operating vs. silent and were most often seen traveling away from the airgun array when it was in operation (Stone 2015; Stone et al. 2017). However, Matos (2015) reported no change in sighting rates of harbour porpoise in Vestfjorden, Norway, during ongoing seismic surveys outside of the fjord and up to 400 km away.

A captive harbour porpoise exposed to single sound pulses from a small airgun showed aversive behaviour upon receipt of a pulse with received SPL above 174 dB re 1 μPa_{pk-pk} or SEL >145 dB re 1 $\mu Pa^2 \cdot s$ (Lucke et al. 2009). Thompson et al. (2013) reported decreased densities and reduced acoustic detections of harbour porpoise in response to a seismic survey in Moray Firth, Scotland, at ranges of 5–10 km (SPLs of 165–172 dB re 1 µPa, SELs of 145–151 dB $\mu Pa^2 \cdot s$). For the same survey, Pirotta et al. (2014) noted that the probability of recording a porpoise buzz decreased by 15% within the ensonified area, and that the probability was positively related to the distance from the seismic ship; this is turn, may show decreased foraging efficiency. Nonetheless, animals returned to the area within a few hours (Thompson et al. 2013). Similar avoidance behaviour and/or decreases in echolocation signals during 3-D seismic operations were reported for harbour porpoise in the North Sea (Sarnocińska et al. 2020). In a captive facility, harbour porpoise showed avoidance of a pool with elevated sound levels, but search time for prey within that pool was no different than in a quieter pool (Kok et al. 2017).

Kastelein et al. (2013c) noted that a harbour porpoise showed no response to an impulse sound below an SEL of 65 dB, but a 50% brief response rate was noted at a SEL of 92 dB and an SPL of 122 dB re 1 $\mu Pa_{0\text{-}peak}$. In contrast, Kastelein et al. (2012c) reported a 50% detection threshold at a SEL of 60 dB to a similar impulse sound; this difference is likely attributable to the different transducers used during the two studies (Kastelein et al. 2013a). Van Beest et al. (2018) exposed five harbour porpoise to a single 10 in^3 airgun for 1 min at 2–3 s intervals at ranges of 420–690 m and levels of 135–147 dB $\mu Pa^2 \cdot s$. One porpoise moved away from the sound source but returned to natural movement patters within 8 h, and two porpoises had shorter and shallower dives but returned to natural behaviours within 24 h.

In contrast to harbour porpoise, Dall's porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006), although they too have been observed to avoid large arrays of operating airguns (Calambokidis and Osmek 1998; Bain and Williams 2006).

The apparent tendency for greater responsiveness in the harbour porpoise is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

Beaked Whales

There are very few data on the behavioural reactions of beaked whales to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998) and/or change behaviour in response to sound from vessels (e.g., Pirotta et al. 2012). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986), although it is uncertain how much longer such dives may be as compared to dives by undisturbed beaked whales, which also are often quite long (Baird et al. 2006; Tyack et al. 2006b). In any event, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel, regardless of whether or not the airguns are operating. Observations from seismic vessels off the U.K. from 1994 to 2010 indicated that detection rates of beaked whales were significantly higher (p<0.05) when airguns were not operating vs. when a large array was in operation; however, sample sizes were small (Stone 2015; Stone et al. 2017).

Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels not emitting airgun pulses (Reeves et al. 1993; Hooker et al. 2001). Detections (acoustic or visual) of northern bottlenose whales have been made from seismic vessels during seismic surveys in the Northwest Atlantic during periods with and without airgun operations (Potter et al. 2007; Moulton and Miller 2005). Similarly, other visual and acoustic studies indicated that some northern bottlenose whales remained in the general area and continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005). Data from multiple seismic surveys in the northern Gulf of Mexico from 2002–2015 showed no significant difference in beaked whale distances to the airgun array during full power versus silent periods, but the sample size was small, and the mean distance was larger than in other species groups (Barkaszi and Kelly 2024).

There are increasing indications that some beaked whales tend to strand when military exercises involving mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Barlow and Gisiner 2006; D'Amico et al. 2009; Filadelfo et al. 2009; see also the "Strandings and Mortality" subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries or other physiological effects may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. There have been three cases of beaked whale strandings coincident with seismic surveys, as well as seven cases of other cetacean strandings; however, no conclusive link has been established between the seismic surveys and strandings (Castellote and Llorens 2016). In addition, a multibeam echosounder was also in operation during the surveys that coincided with the beaked whale strandings, but this had much less potential than the aforementioned naval sonars to affect beaked whales, given its

downward-directed beams, much shorter pulse durations, and lower duty cycle. There was a stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) in September 2002 when the R/V *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002; Hildebrand 2005). However, NMFS did not establish a cause and effect relationship between this stranding and the seismic survey activities (Hogarth 2002). Cox et al. (2006) noted the "lack of knowledge regarding the temporal and spatial correlation between the [stranding] and the sound source". Hildebrand (2005) illustrated the approximate temporal-spatial relationships between the stranding and the *Ewing*'s tracks, but the time of the stranding was not known with sufficient precision for accurate determination of the CPA distance of the whales to the *Ewing*. Another stranding of Cuvier's beaked whales in the Galápagos occurred during a seismic survey in April 2000; however, "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry [ed.] 2002). The evidence was inconclusive for two Sowerby's beaked whales that stranded in Rota, Spain, when a seismic survey was being conducted in the area in September 2007 (Castellote and Llorens 2016).

Sperm Whales

All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998; McAlpine 2002; Baird 2005). However, most studies of the sperm whale *Physeter macrocephalus* exposed to airgun sounds indicate that this species shows considerable tolerance of airgun pulses. The whales usually do not show strong avoidance (i.e., they do not leave the area) and they continue to call.

There were some early and limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak airgun pulses from extremely distant (>300 km) seismic exploration. However, other operations in the area could also have been a factor (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Preliminary data from the Gulf of Mexico also show reduced sperm whale acoustic activity during periods with airgun operations (Sidorovskaia et al. 2014). Additionally, there was an early preliminary account of possible long-range avoidance of seismic vessels by sperm whales in the Gulf of Mexico (Mate et al. 1994). However, this has not been substantiated by subsequent more detailed work in that area (Gordon et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009).

More extensive data from vessel-based monitoring programs in U.K. waters and off eastern Canada and Angola suggest that sperm whales in those areas show little evidence of avoidance or behavioural disruption in the presence of operating seismic vessels (Stone 2003, 2015; Stone and Tasker 2006; Weir 2008a; Moulton and Holst 2010;). Among sperm whales off Angola (n = 96 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the CPA distances of the sperm whale sightings when airguns were on

vs. off (means 3039 m vs. 2594 m, respectively). Encounter rate tended to increase over the 10-month duration of the seismic survey. Similarly, in the Northwest Atlantic, sighting rates and distances of sperm whales did not differ between periods when airguns were on vs. off (Moulton and Holst 2010). Observations from seismic vessels off the U.K. from 1994 to 2010 indicated that detection rates for sperm whales were similar when large arrays of airguns were operating vs. silent; however, during surveys with small arrays, the detection rate was significantly higher when the airguns were not in operation (Stone 2015; Stone et al. 2017).

These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive animals, which may be beyond visual range. However, these results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel; received SPLs of the seismic pulses were up to 146 dB re 1 μPa_{p-p} (Madsen et al. 2002). Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behaviour of sperm whales (McCall Howard 1999). However, Barkaszi and Kelly (2024) found that sperm whales occurred at significantly farther distances from the airgun array during full array activity versus silence based on data from multiple seismic surveys in the northern Gulf of Mexico during 2002–2015; similar results were found for both dwarf and pygmy sperm whales.

A controlled study of the reactions of tagged sperm whales to seismic surveys was done in the Gulf of Mexico—the Sperm Whale Seismic Study or SWSS (Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). During SWSS, D-tags (Johnson and Tyack 2003) were used to record the movement and acoustic exposure of eight foraging sperm whales before, during, and after controlled exposures to sound from airgun arrays (Jochens et al. 2008; Miller et al. 2009). Whales were exposed to maximum received SPLs of 111–147 dB re 1 μPa_{rms} (131–162 dB re 1 μPa_{pk-pk}) at ranges of ~1.4–12.8 km from the sound source (Miller et al. 2009). Although the tagged whales showed no discernible horizontal avoidance, some whales showed changes in diving and foraging behaviour during full-array exposure, possibly indicative of subtle negative effects on foraging (Jochens et al. 2008; Miller et al. 2009; Tyack 2009). Two indications of foraging that they studied were oscillations in pitch and occurrence of echolocation buzzes, both of which tend to occur when a sperm whale closes-in on prey. "Oscillations in pitch generated by swimming movements during foraging dives were on average 6% lower during exposure than during the immediately following post-exposure period, with all 7 foraging whales exhibiting less pitching (P = 0.014). Buzz rates, a proxy for attempts to capture prey, were 19% lower during exposure…" (Miller et al. 2009). Although the latter difference was not statistically significant (P = 0.141), the percentage difference in buzz rate during exposure vs. post-exposure conditions appeared to be strongly correlated with airgun-whale distance (Miller et al. 2009: Fig. 5; Tyack 2009). Using a population consequences of disturbance (PCoD) framework, Farmer et al. (2018) suggested that changes in foraging behaviour associated with exposure to airgun sounds could have significant consequences on individual fitness.

Discussion and Conclusions

Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies near the U.K., Newfoundland and Angola, in the Gulf of Mexico, and off Central America have shown localized avoidance. Also, beluga whales summering in the Canadian Beaufort Sea showed larger-scale avoidance, tending to avoid waters out to 10–20 km from operating seismic vessels. In contrast, recent studies show little evidence of conspicuous reactions by sperm whales to airgun pulses, contrary to earlier indications.

There are almost no specific data on responses of beaked whales to seismic surveys, but given their response to vessels it is likely that most if not all species show avoidance. There is increasing evidence that some beaked whales may strand after exposure to strong sound from sonars. Whether they ever do so in response to seismic survey sound is unknown. Northern bottlenose whales seem to continue to call when exposed to pulses from distant seismic vessels.

Overall, odontocete reactions to large arrays of airguns are variable and, at least for delphinids and some porpoises, seem to be confined to a smaller radius than has been observed for some mysticetes. However, other data suggest that some odontocetes species, including beluga whales and harbour porpoises, may be more responsive than might be expected given their poor low-frequency hearing. Reactions at longer distances may be particularly likely when sound propagation conditions are conducive to transmission of the higher-frequency components of airgun sound to the animals' location (DeRuiter et al. 2006; Goold and Coates 2006; Tyack et al. 2006a; Potter et al. 2007).

For delphinids, and possibly the Dall's porpoise, the available data suggest that a ≥170 dB re 1 μPa_{rms} disturbance criterion (rather than ≥160 dB rms criterion used by NMFS and commonly used in EAs of seismic surveys in Canada) would be appropriate. With a medium-to-large airgun array, received SPLs typically diminish to 170 dB within 1–4 km, whereas levels typically remain above 160 dB out to 4–15 km (e.g., Tolstoy et al. 2009). Reaction distances for delphinids are more consistent with the typical 170 dB re 1 μPa_{rms} distances. The 160 dB (rms) criterion currently applied by NMFS was developed based primarily on data from gray and bowhead whales. Avoidance distances for delphinids and Dall's porpoises tend to be shorter than for those two mysticete species. For delphinids and Dall's porpoises, there is no indication of strong avoidance or other disruption of behaviour at distances beyond those where received levels would be ~170 dB re 1 μPa_{rms}. NMFS is developing new guidance for predicting behavioural effects (Scholik-Schlomer 2015). As behavioural responses are not consistently associated with received levels, some authors have made recommendations on different approaches to assess behavioural reactions (e.g., Gomez et al. 2016; Harris et al. 2017; Tyack and Thomas 2019).

1.5.3 Pinnipeds

Few studies of the reactions of pinnipeds to sound from open-water seismic exploration have been published (for review of the early literature, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies. Monitoring in the Beaufort Sea during 1996–2002 provided a substantial amount of information on avoidance responses (or lack thereof) and associated behaviour. Additional monitoring of that type has been done in the Beaufort and Chukchi Seas in 2006–2009. Pinnipeds exposed to seismic surveys have also been observed during seismic surveys along the U.S. west coast. Some limited data are available on physiological responses of pinnipeds exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

Early observations provided considerable evidence that pinnipeds are often quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, gray seals exposed to sound from airguns and linear explosive charges reportedly did not react strongly (J. Parsons *in* Greene et al. 1985). An airgun caused an initial startle reaction among South African fur seals but was ineffective in scaring them away from fishing gear (Anonymous 1975). Pinnipeds in both water and air sometimes tolerate strong sound pulses from non-explosive and explosive scaring devices, especially if attracted to the area for feeding or reproduction (Mate and Harvey 1987; Reeves et al. 1996). Thus, pinnipeds are expected to be rather tolerant of, or to habituate to, repeated underwater sounds from distant seismic sources, at least when the animals are strongly attracted to the area.

In the U.K., a radio-telemetry study demonstrated short-term changes in the behaviour of harbour (common) and gray seals exposed to airgun pulses (Thompson et al. 1998). Harbour seals were exposed to sound pulses from a 90-in^3 array (3 × 30 in^3 airguns), and behavioural responses differed among individuals. One harbour seal avoided the array at distances up to 2.5 km from the source and only resumed foraging dives after the source stopped. Another harbour seal exposed to the same small airgun array showed no detectable behavioural response, even when the array was within 500 m. Gray seals exposed to sound from a single 10-in^3 airgun showed an avoidance reaction: they moved away from the source, increased swim speed and/or dive duration, and switched from foraging dives to predominantly transit dives. These effects appeared to be short-term as gray seals either remained in, or returned at least once to, the foraging area where they had been exposed to sound pulses from airguns. These results suggest that there are interspecific as well as individual differences in seal responses to seismic sounds.

Off California, visual observations from a seismic vessel showed that California sea lions "typically ignored the vessel and array. When [they] displayed behaviour modifications, they often appeared to be reacting visually to the sight of the towed array. At times, California sea lions were attracted to the array, even when it was on. At other times, these animals would appear to be actively avoiding the vessel and array" (Arnold 1996). In Puget Sound, sighting

distances for harbour seals and California sea lions tended to be larger when airguns were operating; both species tended to orientate away whether or not the airguns were active (Calambokidis and Osmek 1998). Bain and Williams (2006) also stated that their small sample of harbour seals and sea lions tended to orientate and/or move away upon exposure to sounds from a large airgun array.

Observations from seismic vessels operating large arrays off the U.K. from 1994–2010 showed that the detection rate for gray seals was significantly higher when airguns were not operating; however, for surveys using small arrays, the detection rates were similar during seismic vs. non-seismic operations (Stone 2015; Stone et al. 2017). No significant differences in detection rates were apparent for harbour seals during seismic and non-seismic periods (Stone 2015; Stone et al. 2017). There were no significant differences in CPA distances of grey and harbour seals during seismic vs. non-seismic periods (Stone 2015; Stone et al. 2017).

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable information regarding the behaviour of seals exposed to sound pulses from seismic airguns (Harris et al. 2001; Moulton and Lawson 2002). Those seismic projects usually involved arrays of 6–16 airguns with total volumes of 560–1500 in^3. Subsequent monitoring work in the Canadian Beaufort Sea in 2001–2002, with a somewhat larger airgun system (24 airguns, 2250 in^3), provided similar results (Miller et al. 2005). The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings averaged somewhat farther away from the seismic vessel when the airguns were operating than when they were not (Moulton and Lawson 2002). Also, seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997. However, the avoidance movements were relatively small, on the order of 100 m to (at most) a few hundreds of metres, and many seals remained within 100–200 m of the trackline as the operating airgun array passed by.

The operation of the airgun array had minor and variable effects on the behaviour of seals visible at the surface within a few hundred metres of the airguns (Moulton and Lawson 2002). The behavioural data indicated that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim towards or parallel to the vessel during periods when the source was not active. No consistent relationship was observed between exposure to airgun sound and proportions of seals engaged in other recognizable behaviours, e.g., "looked" and "dove". Such a relationship might have occurred if seals seek to reduce exposure to strong sound pulses, given the reduced airgun sound levels close to the surface where "looking" occurs (Moulton and Lawson 2002).

Monitoring results from the Canadian Beaufort Sea during 2001–2002 were more variable (Miller et al. 2005). During 2001, sighting rates of seals (mostly ringed seals) were similar independent of source activity, including periods without airgun operations. However, seals tended to be seen closer to the vessel during periods when no source was active vs. active. In contrast, during 2002, sighting rates of seals were higher during, and seals were seen farther from

the vessel periods when no source was active vs. active (a marginally significant result). The combined data for both years showed that sighting rates were higher during periods when no source was active vs. active, and that sighting distances were similar independent of source activity. Miller et al. (2005) concluded that seals showed very limited avoidance to the operating airgun array.

Vessel-based monitoring also took place in the Alaskan Chukchi and Beaufort seas during 2006–2008 (Funk et al. 2010). These observations indicate a tendency for phocid seals to exhibit localized avoidance of the seismic source vessel when airguns are active (Funk et al. 2010). In the Chukchi Sea, seal sightings rates were greater when no source was active from source vessels at locations with received sound levels (RLs) ≥160 and 159–120 dB re 1 μPa_{rms}. Also, sighting rates were greater from source than monitoring vessels at locations with RLs <120 dB rms (Haley et al. 2010). In the Beaufort Sea, seal sighting rates in areas with RLs ≥160 dB rms were also significantly higher from monitoring than from seismic source vessels, and sighting rates were significantly higher from source vessels in areas exposed to <120 compared to ≥160 dB rms (Savarese et al. 2010). In addition, seals tended to stay farther away and swam away from source vessels more frequently than from monitoring vessels when RLs were ≥160 dB rms. Over the three years, seal sighting rates were greater from monitoring than source vessels at locations with received sound levels ≥160 and 159–120 dB rms, whereas seal sighting rates were greater from source than monitoring vessels at locations with RLs <120 dB rms, suggesting that seals may be reacting to active airguns by moving away from the source vessel.

Lalas and McConnell (2015) made observations of New Zealand fur seals from a seismic vessel operating a 3090 in^3 airgun array in New Zealand during 2009. However, the results from the study were inconclusive in showing whether New Zealand fur seals respond to seismic sounds. Reichmuth et al. (2016) exposed captive spotted and ringed seals to single airgun pulses with SELs of 165–181 dB and SPLs (peak to peak) of 190–207 dB re 1 µPa; only mild behavioural responses were observed.

Walruses near operating seismic surveys tend to swim away from the vessel (Hannay et al. 2011). Walrus calls were monitored during a low-energy shallow-hazards survey in 2009 and a 3-D seismic survey in 2010 (Hannay et al. 2011). During the shallow-hazard survey using a 40 in^3 airgun, walrus call detections stopped at SPLs >130 dB re 1 μPa_{rms} and declined at lower SPLs. During the large-array 3-D seismic survey, acoustic detections were negatively correlated with SPL at RLs of 110–140 dB, but no detections were made at SPLs >140 dB re 1 μPa_{rms}. Hannay et al. (2011) suggested that walruses likely reduced calling rates upon exposure to higher SPLs without leaving the area.

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behaviour. These studies show that many pinnipeds do not avoid the area within a few hundred metres of an operating airgun array. However, based on the studies with large sample size, or observations from a separate monitoring vessel, or radio telemetry, it is apparent that some phocid seals do show localized

avoidance of operating airguns. The limited nature of this tendency for avoidance is a concern. It suggests that one cannot rely on pinnipeds to move away, or to move very far away, before received levels of sound from an approaching seismic survey vessel approach those that may cause hearing impairment (see below).

1.6 Hearing Impairment and Other Physical Effects of Seismic Surveys

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. Temporary threshold shift (TTS) has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (reviewed in Southall et al. 2007, 2019; Finneran 2015). However, there has been no specific documentation of TTS let alone permanent hearing damage, i.e., permanent threshold shift (PTS), in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions. Canada has no policy regarding sound level criteria for PTS and TTS. Up until summer 2016, the U.S. NMFS policy regarding exposure of marine mammals to high-level sounds was that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and 190 dB re 1 μPa_{rms}, respectively (NMFS 1995, 2000). However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. The 180 and 190 dB re 1 μPa_{rms} levels were not considered to be the levels above which TTS might occur. Rather, they were the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals.

NMFS (2024) released technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing, taking into account recommendations made by Southall et al. (2007, 2019), as well as those presented by Finneran (2016). The guidance revised thresholds for permanent threshold shift (PTS) onset (i.e., injury), for marine mammal species. The noise exposure criteria for marine mammals account for newly-available scientific data on TTS, the expected offset between TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive (e.g., frequency weightings for various groups of marine mammals, allowing for their functional bandwidths), and other relevant factors. For impulsive sounds, such as airgun pulses, the guidance incorporates marine mammal auditory weighting functions, and dual metrics of cumulative sound exposure level (SEL_{cum} over 24 hours) and peak sound pressure levels (SPL_{flat}). The onset of PTS is assumed to be 15 dB or 6 dB higher than TTS when considering SEL_{cum} and SPL_{flat}, respectively. Different thresholds have been provided for the various hearing groups, including low-frequency cetaceans (e.g., baleen whales), mid-frequency cetaceans (e.g., most delphinids), high-frequency cetaceans (e.g., porpoise and *Kogia* spp.), phocids underwater, and otariids underwater (Table 1). These thresholds are currently used in establishing the safety (shut-down) radii for seismic surveys conducted under U.S. jurisdiction; NMFS (2024) requires that the largest distance of the dual criteria (SEL_{cum} or Peak SPL_{flat}) is used as the safety radius. It should be recognized that there are a number of

limitations and uncertainties associated with these injury criteria (Southall et al. 2007). Lucke et al. (2020) cautioned that some current thresholds may not be able to accurately predict hearing impairment and other injury to marine mammals due to noise. Tougaard et al. (2022) indicate that there is empirical evidence to support the thresholds for very-high frequency cetaceans and pinnipeds in water, but caution that above 10 kHz for porpoise and outside of 3–16 kHz for seals, there are differences between the TTS thresholds and empirical data. Tougaard et al. (2023) also noted that TTS-onset thresholds for harbor porpoise are likely impacted by the experimental methods used (e.g., behavioural vs. brain stem recordings, and stationary vs. free-swimming animals), in particular for noise exposure >10 kHz. Low or moderate degrees of TTS, up to at least 30 dB of elevation of the threshold, are not considered an injury (Southall et al. 2007; Le Prell 2012); beyond that level, TTS may grade into PTS (Le Prell 2012).

Table 1. *Permanent Threshold Shift (PTS) onset thresholds for various marine mammal hearing groups based on NMFS (2024).*

Hearing Group	Low-frequency Cetacean	Mid-frequency Cetacean	High-frequency Cetacean	Phocid Pinnipeds Underwater	Otariid Pinnipeds Underwater
SEL_{cum} Threshold (dB)	183	193	159	183	185
Peak SPL_{flat} Threshold (dB)	222	230	202	223	230

Nowacek et al. (2013) stated that sufficient scientific data exist to conclude that seismic airguns have a low probability of directly harming most marine life, except at close range where physical injury can occur. Several aspects of the monitoring and mitigation measures that are now often implemented during seismic survey projects are designed to detect marine mammals occurring near the airgun array, and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment. In addition, many cetaceans and (to a limited degree) pinnipeds show some avoidance of the area where received levels of airgun sound are high enough such that hearing impairment could potentially occur. In those cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid the possibility of hearing impairment. Aarts et al. (2016) noted that an understanding of animal movement is necessary in order to estimate the impact of anthropogenic sound on cetaceans.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur include stress, neurological effects, bubble formation, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds. The following subsections summarize available data on sound-induced hearing impairment and non-auditory physical effects.

1.6.1 Temporary Threshold Shift (TTS)

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. It is a temporary phenomenon, and (especially when mild) is not considered to represent physical damage or "injury" (Southall et al. 2007; Le Prell 2012). Rather, the onset of TTS has been considered an indicator that, if the animal is exposed to higher levels of that sound, physical damage is ultimately a possibility. However, research has shown that sound exposure can cause cochlear neural degeneration, even when threshold shifts and hair cell damage are reversible (Kujawa and Liberman 2009; Liberman 2016). These findings have raised some doubts as to whether TTS should continue to be considered a non-injurious effect (Weilgart 2014; Tougaard et al. 2015, 2016; Houser 2021).

The magnitude of TTS depends on the level and duration of sound exposure, and to some degree on frequency, among other considerations (Kryter 1985; Richardson et al. 1995; Southall et al. 2007). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the sound ends. Extensive studies on terrestrial mammal hearing in air show that TTS can last from minutes or hours to (in cases of strong TTS) days. More limited data from odontocetes and pinnipeds show similar patterns (e.g., Mooney et al. 2009a,b; Finneran et al. 2010a). However, none of the published data concern TTS elicited by exposure to multiple pulses of sound during operational seismic surveys (Southall et al. 2007, 2019).

Toothed Whales

There are empirical data on the sound exposures that elicit onset of TTS in captive bottlenose dolphins, belugas, and porpoise. The majority of these data concern non-impulse sound, but there are some limited published data concerning TTS onset upon exposure to a single pulse of sound from a watergun (Finneran et al. 2002) and multiple pulses from an airgun (Finneran et al. 2015). A detailed review of all TTS data from marine mammals can be found in Southall et al. (2007, 2019). The following summarizes some of the key results from odontocetes.

More recent information corroborates earlier expectations that the effect of exposure to strong transient sounds is closely related to the total amount of acoustic energy that is received. Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones (non-impulsive) for periods of 1, 2, 4 or 8 s, with hearing tested at 4.5 kHz. For 1-s exposures, TTS occurred with SELs of 197 dB, and for exposures >1 s, SEL >195 dB resulted in TTS (SEL is equivalent to energy flux, in dB re 1 $\mu Pa^2 \cdot s$). At an SEL of 195 dB, the mean TTS (4 min after exposure) was 2.8 dB. Finneran et al. (2005) suggested that an SEL of 195 dB is the likely threshold for the onset of TTS in dolphins and belugas exposed to tones of durations 1–8 s (i.e., TTS onset occurs at a near-constant SEL, independent of exposure duration). That implies that, at least for non-impulsive tones, a doubling of exposure time results in a 3 dB lower TTS threshold.

The assumption that, in marine mammals, the occurrence and magnitude of TTS is a function of cumulative acoustic energy (SEL) is probably an oversimplification (Finneran 2012). As noted earlier, frequency, duration of the exposure, and occurrence of gaps within the exposure can also influence the auditory effect on marine mammals. For example, Kastak et al. (2005) reported preliminary evidence from pinnipeds that, for prolonged non-impulse sound, higher SELs were required to elicit a given TTS if exposure duration was short than if it was longer, i.e., the results were not fully consistent with an equal-energy model to predict TTS onset. Mooney et al. (2009a) showed this in a bottlenose dolphin exposed to octave-band non-impulse sound ranging from 4 to 8 kHz at SPLs of 130 to 178 dB re 1 µPa for periods of 1.88 to 30 min. Similar to the study by Kastak et al. (2005), higher SELs were required to induce a given TTS if exposure duration was short than if it was longer. Exposure of the aforementioned bottlenose dolphin to a sequence of brief sonar signals showed that, with those brief (but non-impulse) sounds, the received energy (SEL) necessary to elicit TTS was higher than was the case with exposure to the more prolonged octave-band noise (Mooney et al. 2009b). Those authors concluded that, when using (non-impulse) acoustic signals of duration ~0.5 s, SEL must be at least 210–214 dB re 1 µPa^2 ·s to induce TTS in the bottlenose dolphin. Popov et al. (2011) examined the effects of fatiguing noise on the hearing threshold of Yangtze finless porpoises when exposed to frequencies of 32–128 kHz at 140–160 dB re 1 µPa for 1–30 min. They found that an exposure of higher level and shorter duration produced a higher TTS than an exposure of equal SEL but of lower level and longer duration.

On the other hand, the TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). Although Hastie et al. (2019) reported that the impulsive nature of sound is range-dependent, becoming less harmful over distance from the source, Martin et al. (2020) noted that sound retains its impulsive character at SPLs above the effective quiet threshold. The received energy level of a single seismic pulse that caused the onset of mild TTS in the beluga, as measured without frequency weighting, was ~186 dB re 1 µPa^2 ·s or 186 dB SEL (Finneran et al. 2002).[4] The rms level of an airgun pulse (in dB re 1 µPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few kilometres of the airguns. Thus, based on data from Finneran et al. (2002), a single airgun pulse might need to have a received level of ~196–201 dB re 1 µPa$_{rms}$ in order to produce brief, mild TTS. Exposure to several pulses from an airgun source that each has a flat-weighted received level near 190 dB$_{rms}$ (175–180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (weighted). According to current NMFS guidance, the PTS onset threshold for HF cetaceans is 193 dB SEL (weighted); the TTS threshold would be ~178 dB SEL

[4] If the low-frequency components of the watergun sound used in the experiments of Finneran et al. (2002) are down-weighted as recommended by Southall et al. (2007) using their weighting curve, the effective exposure level for onset of mild TTS was 183 dB re 1 µPa^2 ·s (Southall et al. 2007).

based on a 15 dB difference between PTS and TTS. Thus, based on the NMFS criterion, a single pulse with a received level of ~188–93dB re 1 μPa_{rms}, or a series of pulses for which the highest rms values are a few dB lower, could have resulted in TTS.

SEL_{cum} assumes that the TTS threshold upon exposure to multiple pulses is (to a first approximation) a function of the total received pulse energy, without allowance for any recovery between pulses. However, data have shown that the SEL required for TTS onset to occur increases with intermittent exposures, with some auditory recovery during silent periods between signals (Finneran et al. 2010b; Finneran and Schlundt 2011). Studies on bottlenose dolphins by Schlundt et al. (2016) and Finneran et al. (2015) indicate that the potential for seismic surveys using airguns to cause auditory effects on dolphins may be lower than previously thought. Based on behavioural tests, no measurable TTS was detected in three bottlenose dolphins after exposure to 10 impulses from a seismic airgun with a cumulative SEL of up to ~195 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2015; Schlundt et al. 2016). However, auditory evoked potential measurements were more variable; one dolphin showed a small (9 dB) threshold shift at 8 kHz (Finneran et al. 2015; Schlundt et al. 2016). Bottlenose dolphins exposed to 10-ms impulses at 8 kHz with SELs of 182–183 dB re 1 $\mu Pa^2 \cdot s$ produced a TTS of up to 35 dB (Mulsow et al. 2023).

The conclusion that the TTS threshold is higher for non-impulse sound than for impulse sound is somewhat speculative. The available TTS data for a beluga whale exposed to impulse sound are extremely limited, and the TTS data from the beluga whale and bottlenose dolphin exposed to non-pulse sound pertain to sounds at 3 kHz and above. Follow-on work has shown that the SEL necessary to elicit TTS can depend substantially on frequency, with susceptibility to TTS increasing with increasing frequency above 3 kHz (Finneran and Schlundt 2010, 2011, 2013; Finneran 2012; Mulsow et al. 2023). When beluga whales were exposed to fatiguing noise with sound levels of 165 dB re 1 µPa for durations of 1 to 30 min at frequencies of 11.2 to 90 kHz, the highest TTS with the longest recovery time was produced by the lower frequencies (11.2 and 22.5 kHz); TTS effects also gradually increased with prolonged exposure time (Popov et al. 2013). Additionally, Popov et al. (2015) demonstrated that the impacts of TTS include deterioration of signal discrimination. Kastelein et al. (2015b, 2017b) reported that exposure to multiple pulses with most energy at low frequencies can lead to TTS at higher frequencies in some cetaceans, such as the harbour porpoise. When a porpoise was exposed to 10 and 20 consecutive shots (mean shot interval ~17 s) from two airguns with a SEL_{cum} of 188 and 191 $\mu Pa^2 \cdot s$, respectively, significant TTS occurred at a hearing frequency of 4 kHz and not at lower hearing frequencies that were tested, despite the fact that most of the airgun energy was <1 kHz; recovery occurred within 12 min post exposure (Kastelein et al. 2017b).

Additionally, Popov et al. (2016) also reported that TTS produced by exposure to a fatiguing noise was larger during the first session (or naïve subject state) with a beluga whale than TTS that resulted from the same sound in subsequent sessions (experienced subject state). Similarly, several other studies have shown that some marine mammals (e.g., bottlenose dolphins, false killer whales) can decrease their hearing sensitivity or change orientation in order to mitigate the

impacts of exposure to loud sounds (e.g., Nachtigall and Supin 2013, 2014, 2015, 2016; Nachtigall et al. 2018; Finneran 2020; Kastelein et al. 2020g; Finneran et al. 2023b,c, 2024).

The above TTS information for mid-frequency cetaceans (odontocetes) is primarily derived from studies on the bottlenose dolphin and beluga. However, there have been several studies on TTS in porpoise (e.g., Lucke et al. 2009; Popov et al. 2011; Kastelein et al. 2012a, 2013a,b, 2014, 2015a) which indicate that received levels that elicit onset of TTS are lower in porpoise than for other odontocetes. Lucke et al. (2009) exposed a harbour porpoise to single pulses from a small (20 in^3) airgun, and auditory evoked potential methods were used to test the animal's hearing sensitivity at frequencies of 4, 32, or 100 kHz after each exposure. Based on the measurements at 4 kHz, TTS occurred upon exposure to one airgun pulse with received level ~200 dB re 1 μPa_{pk-pk} or an SEL of 164.3 dB re 1 $\mu Pa^2 \cdot s$. Based on studies that exposed harbour porpoises to one-sixth-octave noise bands ranging from 1 to 88.4 kHz, Kastelein et al. (2019c,d, 2020d,e,f) noted that susceptibility to TTS increases with an increase in sound less than 6.5 kHz but declines with an increase in frequency above 6.5 kHz. . Popov et al. (2011) reported a TTS of 25 dB for a Yangtze finless porpoise that was exposed to high levels of 3-min pulses of half-octave band noise centred at 45 kHz with an SEL of 163 dB.

Based on these studies with porpoises, the TTS onset thresholds are expected to be different for VHF cetaceans as compared with other odontocetes (Southall et al. 2007, 2019; NMFS 2024). The NMFS TTS onset threshold for VHF cetaceans is considered to be 144 dB SEL (NMFS 2024); that would be approximately equivalent to a single pulse with a received level of ~154–159 dB re 1 μPa_{rms}, or a series of pulses for which the highest rms values are a few dB lower. Tougaard et al. (2015) suggested an exposure limit for TTS for harbour porpoise as an SEL of 100–110 dB above the pure tone hearing threshold at a specific frequency; they also suggested an exposure limit of $L_{eq\text{-}fast}$ (rms average over the duration of the pulse) of 45 dB above the hearing threshold for behavioural responses (i.e., negative phonotaxis). Wensveen et al. (2014) and Tougaard et al. (2015) suggested that M-weighting may not be appropriate for harbour porpoise. Wensveen et al. (2014) developed six auditory weighting functions for harbour porpoise that may be useful in predicting TTS onset. Basing weighting functions on equal latency/loudness contours may be more appropriate than M-weighting for marine mammals (Mulsow et al. 2015; Southall et al. 2019). Simulation modeling to assess the risk of sound exposure to marine mammals (gray seal and harbour porpoise) showed that SEL is most strongly influenced by the weighting function (Donovan et al. 2017). Houser et al. (2017) and Tougaard and Beedholm (2019) provide a review of the development and application of auditory weighting functions, as well as recommendations for future work.

Insofar as we are aware, there are no published data confirming that the auditory effect of a sequence of airgun pulses received by an odontocete is a function of their cumulative energy. Southall et al. (2007, 2019) consider that to be a reasonable, but probably somewhat precautionary, assumption. It is precautionary because, based on data from terrestrial mammals, one would expect that a given energy exposure would have somewhat less effect if separated into discrete pulses, with potential opportunity for partial auditory recovery between pulses. However, as yet

there has been little study of the rate of recovery from TTS in marine mammals, and in humans and other terrestrial mammals the available data on recovery are quite variable. Southall et al. (2007) concluded that—until relevant data on recovery are available from marine mammals—it is appropriate not to allow for any assumed recovery during the intervals between pulses within a pulse sequence.

Additional data are needed to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. To determine how close an airgun array would need to approach in order to elicit TTS, one would (as a minimum) need to allow for the sequence of distances at which airgun pulses would occur, and for the dependence of received SEL on distance in the region of the seismic operation (e.g., Erbe and King 2009; Breitzke and Bohlen 2010; Laws 2012). At the present state of knowledge, it is also necessary to assume that the effect is directly related to total received energy even though that energy is received in multiple pulses separated by gaps. The lack of data on the exposure levels necessary to cause TTS in toothed whales when the signal is a series of pulsed sounds, separated by silent periods, remains a data gap, as is the lack of published data on TTS in odontocetes other than the beluga, bottlenose dolphin, harbour porpoise, and Yangtze finless porpoise.

Baleen Whales

There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale. The frequencies to which mysticetes are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). The NMFS TTS threshold for LF cetaceans is lower (168 dB SEL; NMFS 2024) than for HF cetaceans. That level would be approximately equivalent to a single pulse with a received level of ~178–183 dB re 1 μPa_{rms}, or a series of pulses for which the highest rms values are a few dB lower. Based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, Gedamke et al. (2011) suggested that some baleen whales whose closest point of approach to a seismic vessel is 1 km or more could experience TTS.

In practice during seismic surveys, few if any cases of TTS are expected given the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS (see above for evidence concerning avoidance responses by baleen whales). This assumes that the ramp-up (soft-start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As discussed earlier, single-airgun experiments with bowhead, gray, and humpback whales show that those species do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up.

Pinnipeds

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels of ~178 and 183 dB re 1 μPa_{rms} and total acoustic energy of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from exposures to non-pulses suggested that some pinnipeds (harbour seals in particular) incur TTS at somewhat lower received levels than do most small odontocetes exposed for similar durations (Kastak et al. 1999, 2005, 2008; Ketten et al. 2001; Kastelein et al. 2013a). Harbour seals appear to be equally susceptible to incurring TTS when exposed to sounds with frequencies between 2.5 and 40 kHz (Kastelein et al. 2020a,b), but at frequencies below 2 kHz, a higher SEL was required to elicit the same TTS (Kastelein et al. 2020c). However, harbor seals may be able to decrease their exposure to underwater sound by swimming just below the surface where sound levels are typically lower than at depth (Kastelein et al. 2018).

Kastak et al. (2005) reported that the amount of threshold shift increased with increasing SEL in a California sea lion and harbour seal. They noted that, for non-impulse sound, doubling the exposure duration from 25 to 50 min (i.e., a +3 dB change in SEL) had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. Mean threshold shifts ranged from 2.9–12.2 dB, with full recovery within 24 hr (Kastak et al. 2005). Kastak et al. (2005) suggested that, for non-impulse sound, SELs resulting in TTS onset in three species of pinnipeds may range from 183 to 206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity. Kastak et al. (2008) exposed a harbour seal to an underwater pure tone at 4.1 kHz for 60 s (SEL of 202 dB re 1 μPa^2) and reported an initial threshold shift in excess of 50 dB upon a second exposure to the sound. Kastelein et al. (2012b) exposed two harbour seals to octave-band white noise centred at 4 kHz at three mean received SPLs of 124, 136, and 148 dB re 1 µPa; TTS >2.5 dB was induced at SELs of 170 dB (136 dB SPL for 60 min), and the maximum TTS of 10 dB occurred after a 120-min exposure to 148 dB re 1 µPa or an SEL of 187 dB. Kastelein et al. (2013a) reported that a harbour seal unintentionally exposed to the same sound source with a mean received SPL of 163 dB re 1 µPa for 1 hr induced a 44 dB TTS. A maximum TTS >45 dB was elicited from a harbour seal exposed to 32 kHz at 191 dB SEL (Kastelein et al. 2020c). Reichmuth et al. (2016) exposed captive spotted and ringed seals to single airgun pulses with SELs of 165–181 dB and SPLs (peak to peak) of 190–207 re 1 µPa; no low-frequency TTS was observed. Similarly, no TTS was measured when a bearded seal was exposed to a single airgun pulse with an unweighted SEL of 185 dB and an SPL of 207 dB; however, TTS was elicited at 400 Hz when exposed to four to ten consecutive pulses with a cumulative unweighted SEL of 191–195 dB, and a weighted SEL of 167–171 dB (Sills et al. 2020b). Kastelein et al. (2021b) found that susceptibility of TTS of California sea lions exposed to one-sixth-octave noise bands centered at 2, 4, and 8 kHz is similar to that of harbour seals, but at 16 kHz, California sea lion haring is less susceptible to TTS than harbor seals (Kastelein et al. 2022). Kastelein et al. (2024) reported that TTS onset in California sea lions is not as closely associated with their hearing threshold as previously thought.

As noted above for odontocetes, it is expected that—for impulse as opposed to non-impulse sound—the onset of TTS would occur at a lower cumulative SEL given the assumed greater auditory effect of broadband impulses with rapid rise times. The threshold for onset of mild TTS upon exposure of a harbour seal (and other phocids) to impulse sounds has been estimated indirectly as being an SEL of 168 dB re 1 $\mu Pa^2 \cdot s$ (NMFS 2024). That would be approximately equivalent to a single pulse with a received level of ~178–183 dB re 1 μPa_{rms}, or a series of pulses for which the highest rms values are a few dB lower.

At least for non-impulse sounds, TTS onset occurs at appreciably higher received levels in California sea lions and northern elephant seals than in harbour seals (Kastak et al. 2005). Thus, the former two species would presumably need to be closer to an airgun array than would a harbour seal before TTS is a possibility. Insofar as we are aware, there are no data to indicate whether the TTS thresholds of other pinniped species are more similar to those of the harbour seal or to those of the two less-sensitive species. Nonetheless, the guidance by NMFS proposes slightly higher acoustic thresholds for otariids as compared with phocids; the TTS onset threshold is considered to be 170 dB SEL (NMFS 2024).

Likelihood of Incurring TTS

Most cetaceans show some degree of avoidance of seismic vessels operating an airgun array (see above). It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. TTS would be more likely in any odontocetes that bow- or wake-ride or otherwise linger near the airguns. However, while bow- or wake-riding, odontocetes would be at the surface and thus not exposed to strong sound pulses given the pressure-release and Lloyd Mirror effects at the surface. But if bow- or wake-riding animals were to dive intermittently near airguns, they would be exposed to strong sound pulses, possibly repeatedly.

If some cetaceans did incur mild or moderate TTS through exposure to airgun sounds in this manner, this would very likely be a temporary and reversible phenomenon. However, even a temporary reduction in hearing sensitivity could be deleterious in the event that, during that period of reduced sensitivity, a marine mammal needed its full hearing sensitivity to detect approaching predators, or for some other reason.

Some pinnipeds show avoidance reactions to airguns, but their avoidance reactions are generally not as strong or consistent as those of cetaceans. Pinnipeds occasionally seem to be attracted to operating seismic vessels. There are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. However, given the indirect indications of a lower TTS threshold for phocid than for otariid pinnipeds exposed to impulse sound (see above), it is possible that some pinnipeds (in particular phocids such as harbour seals), close to a large airgun array could incur TTS.

It has been shown that most large whales and many smaller odontocetes (especially the harbour porpoise) show at least localized avoidance of ships and/or seismic operations (see above). Even when avoidance is limited to the area within a few hundred metres of an airgun array, that should usually be sufficient to avoid TTS based on what is currently known about thresholds for TTS onset in cetaceans. An exception could be high-frequency cetaceans for which acoustic thresholds are lower than for other cetaceans.

In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans near the airguns at the time of startup (if the sounds are aversive) to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array (see above). Thus, most baleen whales likely will not be exposed to high levels of airgun sounds provided the ramp-up procedure is applied. Likewise, many odontocetes close to the trackline are likely to move away before the sounds from an approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for low-frequency cetaceans (baleen whales) or mid-frequency cetaceans (odontocetes) that show avoidance of ships or airguns to be close enough to an airgun array to experience TTS. The potential to incur TTS for high-frequency cetaceans, even if they avoid the airguns, is likely higher. In the event that a few individual cetaceans did incur TTS through exposure to strong airgun sounds, this is a temporary and reversible phenomenon unless the exposure exceeds the TTS-onset threshold by a sufficient amount for PTS to be incurred (see below). If TTS but not PTS were incurred, it would most likely be mild, in which case recovery is expected to be quick (probably within minutes).

1.6.2 Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges (Kryter 1985). Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times. (Rise time is the interval required for sound pressure to increase from the baseline pressure to peak pressure.)

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the strong possibility that some mammals close to an airgun array might incur at least mild TTS (see above), there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS (e.g., Richardson et al. 1995, p. 372*ff*; Gedamke et al. 2011). In terrestrial animals, exposure to sounds sufficiently strong to elicit a large TTS induces physiological and structural changes in the inner ear, and at some high level of sound exposure, these phenomena become non-recoverable (Le Prell 2012). At this level of sound exposure, TTS grades into PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but

repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS (e.g., Kastak and Reichmuth 2007; Kastak et al. 2008; Reichmuth et al. 2019).

Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals (Southall et al. 2007). Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is at least 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB higher (Southall et al. 2007). The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002, 2005; Nachtigall et al. 2003, 2004). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). When a harbour seal was exposed to an underwater pure tone at 4.1 kHz for 60 s (SEL of 202 dB re 1 µPa^2), an initial threshold shift in excess of 50 dB was reported upon the second exposure to the sound; a possible permanent threshold shift of 7–10 dB was still evident two months after the exposure (Kastak et al. 2008). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995; Southall et al. 2007). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times (e.g., from explosions) can result in PTS even though their peak levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not as fast as that of an explosion.

Some factors that contribute to onset of PTS, at least in terrestrial mammals, are as follows:

- exposure to single very intense sound,
- fast rise time from baseline to peak pressure,
- repetitive exposure to intense sounds that individually cause TTS but not PTS, and
- recurrent ear infections or (in captive animals) exposure to certain drugs.

Cavanagh (2000) reviewed the thresholds used to define TTS and PTS. Based on this review and SACLANT (1998), it is reasonable to assume that PTS might occur at a received sound level 20 dB or more above that inducing mild TTS. However, for PTS to occur at a received level only 20 dB above the TTS threshold, the animal probably would have to be exposed to a strong sound for an extended period, or to a strong sound with rather rapid rise time. Kastelein et al. (2013a) suggested that for a harbour seal exposed to octave-band white noise centred at 4 kHz for 60 min with mean SPLs of 124–148 re 1 µPa, the onset of PTS would require a level of at least 22 dB above the TTS onset. Southall et al. (2007, 2019) and NMFS (2024) estimated that received levels would need to exceed the TTS threshold by at least 15 dB, on an SEL basis, for there to be risk of PTS.

The PTS onset dual-criteria used by NMFS (2024) are shown in Table 1. However, these criteria are based on limited underlying data and numerous assumptions. Also, data have been published indicating that, at least for non-pulse sounds, the "equal energy" model is not be entirely correct—TTS and presumably PTS thresholds may depend somewhat on the duration over which sound energy is accumulated, the frequency of the sound, whether or not there are gaps, and probably other factors (Ketten 1994, 2012). PTS effects may also be influenced strongly by the health of the receiver's ear.

As described above for TTS, in estimating the amount of sound energy required to elicit the onset of TTS (and PTS), it is assumed that the auditory effect of a given cumulative SEL from a series of pulses is the same as if that amount of sound energy were received as a single strong sound. There are no data from marine mammals concerning the occurrence or magnitude of a potential partial recovery effect between pulses. In deriving the estimates of PTS (and TTS) thresholds, NMFS (2024) made the precautionary assumption that no recovery would occur between pulses.

However, the levels of successive pulses that will be received by a marine mammal that is below the surface as a seismic vessel approaches, passes and moves away will tend to increase gradually and then decrease gradually, with periodic decreases superimposed on this pattern when the animal comes to the surface to breathe. To estimate how close a marine mammal's CPA distance would have to be for the cumulative SEL to exceed the relevant criterion, one would (as a minimum) need to allow for the sequence of distances at which airgun pulses would occur, and for the dependence of received SEL on distance in the region of the seismic operation (e.g., Erbe and King 2009).

It is unlikely that an odontocete (in particular, mid-frequency odontocetes) would remain close enough to a large airgun array for sufficiently long to incur PTS. There is some concern about bowriding odontocetes, but for animals at or near the surface, auditory effects are reduced by Lloyd's mirror and surface release effects. The presence of the vessel between the airgun array and bow-riding odontocetes could also, in some but probably not all cases, reduce the levels received by bow-riding animals (e.g., Gabriele and Kipple 2009). The TTS (and thus PTS) thresholds of low-frequency cetaceans is expected to be lower than for other marine mammals. If so, TTS and potentially PTS, may extend to a somewhat greater distance for those animals. Again, Lloyd's mirror and surface release effects will ameliorate the effects for animals at or near the surface.

Although pinnipeds are also likely to avoid an operating airgun source to some extent, there may be an increased potential of phocids to incur TTS (or PTS), as the extent of avoidance may not be as great as for other marine mammals, such as mid- and low-frequency cetaceans. Hermannsen et al. (2015) concluded that there is little risk of hearing damage to pinnipeds and porpoise when using a single airgun in shallow water.

The TTS (and thus PTS) thresholds of baleen whales are unknown but, as an interim measure, assumed to be no lower than those of mid-frequency cetaceans (odontocetes). Also, baleen

whales generally avoid the immediate area around operating seismic vessels, so it is unlikely that a baleen whale could incur PTS from exposure to airgun pulses.

Although it is unlikely that airgun operations during most seismic surveys would cause PTS in many marine mammals, caution is warranted given

- the limited knowledge about sound-induced hearing damage in marine mammals, particularly baleen whales, pinnipeds, and sea otters;
- the seemingly greater susceptibility of certain species (e.g., harbour porpoise and harbour seal) to TTS and presumably also PTS; and
- the lack of knowledge about TTS and PTS thresholds in many species, including various species closely related to the harbour porpoise and harbour seal.

The avoidance reactions of many marine mammals, along with commonly-applied monitoring and mitigation measures (visual and passive acoustic monitoring, ramp ups, and power downs or shut downs when mammals are detected within or approaching the "safety radii"), would reduce the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

1.6.3 Strandings and Mortality

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). However, explosives are no longer used in marine waters for commercial seismic surveys or (with rare exceptions) for seismic research; they have been replaced by airguns and other non-explosive sources. Airgun pulses are less energetic and have slower rise times, and there is no specific evidence that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of mass strandings of beaked whales with naval exercises and possibly seismic surveys (Malakoff 2002; Cox et al. 2006; Castellote and Llorens 2016), has raised the possibility that beaked whales exposed to strong "pulsed" sounds may be especially susceptible to injury and/or behavioural reactions that can lead to stranding (e.g., Hildebrand 2005; Southall et al. 2007). Hildebrand (2005) reviewed the association of cetacean strandings with high-intensity sound events and found that deep-diving odontocetes, primarily beaked whales, were by far the predominant (95%) cetaceans associated with these events, with 2% mysticete whales (minke). However, as summarized below, there is no definitive evidence that airguns can lead to injury, strandings, or mortality even for marine mammals in close proximity to large airgun arrays.

Specific sound-related processes that lead to strandings and mortality are not well documented, but may include (1) swimming in avoidance of a sound into shallow water; (2) a change in behaviour (such as a change in diving behaviour that might contribute to tissue damage, gas bubble formation, hypoxia, cardiac arrhythmia, hypertensive hemorrhage or other forms of

trauma; (3) a physiological change such as a vestibular response leading to a behavioural change or stress-induced hemorrhagic diathesis, leading in turn to tissue damage; and (4) tissue damage directly from sound exposure, such as through acoustically mediated bubble formation and growth or acoustic resonance of tissues. Some of these mechanisms are unlikely to apply in the case of impulse sounds. However, there are increasing indications that gas-bubble disease (analogous to "the bends"), induced in supersaturated tissue by a behavioural response to acoustic exposure, could be a pathologic mechanism for the strandings and mortality of some deep-diving cetaceans exposed to sonar. The evidence for this remains circumstantial and associated with exposure to naval mid-frequency sonar, not seismic surveys (Cox et al. 2006; Southall et al. 2007; Kvadsheim et al. 2012). Morell et al. (2017) examined the inner ears of long-finned pilot whales after a mass stranding in Scotland and reported damage to the cochlea compatible with over-exposure from underwater noise, but no specific sound-producing activity could be linked to the stranding. Morell et al. (2021) also reported evidence of hearing loss in a harbour porpoise that stranded on the Dutch coast. Morell et al. (2020) described new methodology that visualizes scars in the cochlea to detect hearing loss in stranded marine mammals.

Seismic pulses and mid-frequency sonar signals are quite different, and some mechanisms by which sonar sounds have been hypothesized to affect beaked whales are unlikely to apply to airgun pulses. Sounds produced by airgun arrays are broadband impulses with most of the energy below 1 kHz. Typical military mid-frequency sonars emit non-impulse sounds at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time (though the frequency may change over time). Thus, it is not appropriate to assume that the effects of seismic surveys on beaked whales or other species would be the same as the apparent effects of military sonar. For example, resonance effects (Gentry 2002) and acoustically-mediated bubble-growth (Crum et al. 2005) are implausible in the case of exposure to broadband airgun pulses. Nonetheless, evidence that sonar signals can, in special circumstances, lead (at least indirectly) to physical damage and mortality (e.g., Balcomb and Claridge 2001; NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2004, 2005; Hildebrand 2005; Cox et al. 2006) suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity "pulsed" sound. One of the hypothesized mechanisms by which naval sonars lead to strandings might, in theory, also apply to seismic surveys: If the strong sounds sometimes cause deep-diving species to alter their surfacing–dive cycles in a way that causes bubble formation in tissue, that hypothesized mechanism might apply to seismic surveys as well as mid-frequency naval sonars. However, there is no specific evidence of this upon exposure to airgun pulses.

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys. However, Gray and Van Waerebeek (2011) have suggested a cause-effect relationship between a seismic survey off Liberia in 2009 and the erratic movement, postural instability, and akinesia in a pantropical spotted dolphin based on spatially and temporally close association with the airgun array. Additionally, 10 cases of strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic

surveys and strandings, although there was no conclusive evidence for any of those cases (Castellote and Llorens 2016). The three cases of beaked whale strandings coincident with seismic surveys and strandings near naval exercises involving use of mid-frequency sonar suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales until more is known about effects of seismic surveys on those species (Hildebrand 2005; Castellote and Llorens 2016).

1.6.4 Non-Auditory Physiological Effects

Based on evidence from terrestrial mammals and humans, sound is a potential source of stress for marine mammals (Wright and Kuczaj 2007; Wright et al. 2007a,b, 2009, 2011; Atkinson et al. 2015; Houser et al. 2016; Lyamin et al. 2016; Yang et al. 2023). However, almost no information is available on sound-induced stress in marine mammals, or on its potential (alone or in combination with other stressors) to affect the long-term well-being or reproductive success of marine mammals (Fair and Becker 2000; Hildebrand 2005; Wright et al. 2007a,b). Such long-term effects, if they occur, would be mainly associated with chronic noise exposure, which is characteristic of some seismic surveys and exposure situations (McCauley et al. 2000a:62*ff*; Nieukirk et al. 2012) but not of some others.

Available data on potential stress-related impacts of anthropogenic noise on marine mammals are quite limited, and additional research on this topic is needed. ***(1)*** Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (source level up to 228 dB re 1 µPa ·m_{p-p}) and single short-duration pure tones (sound pressure level up to 201 dB re 1 µPa) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hr. ***(2)*** During playbacks of recorded drilling noise to four captive beluga whales, Thomas et al. (1990) found no changes in blood levels of stress-related hormones. Long-term effects were not measured, and no short-term effects were detected. ***(3)*** Rolland et al. (2012) suggested that ship noise causes increased stress in right whales; they showed that baseline levels of stress-related faecal hormone metabolites decreased in North Atlantic right whales with a 6 dB decrease in underwater noise from vessels. ***(4)*** Lyamin et al. (2016) suggested that heart rate can be used to measure physiological response or stress in captive belugas and other cetaceans when exposed to anthropogenic noise. Williams et al. (2022) reported an increase in energetic cost of diving by narwhals that were exposed to airgun noise, as they showed marked behavioural, cardiovascular, and respiratory reactions.

Aside from stress, other types of physiological effects that might, in theory, be involved in beaked whale strandings upon exposure to naval sonar (Cox et al. 2006), such as resonance and gas bubble formation, have not been demonstrated and are not expected upon exposure to airgun pulses (see preceding subsection). If seismic surveys disrupt diving patterns of deep-diving species, this might perhaps result in bubble formation and a form of "the bends", as speculated

to occur in beaked whales exposed to sonar. However, there is no specific evidence that exposure to airgun pulses has this effect.

In summary, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physiological effects in marine mammals. Such effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. The available data do not allow identification of a specific exposure level above which non-auditory effects can be expected (Southall et al. 2007), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways.

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Appendix D:
Review of the Effects of Airgun Sounds on Sea Turtles[1]

[1] By **Valerie D. Moulton, W. John Richardson**, and **Meike Holst**, LGL Ltd., environmental research associates (updates to May 2025).

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1.0 Introduction

The following subsections review relevant information concerning the potential effects of airgun sounds on sea turtles. This information is included here as background. Much of this information has been included in varying formats in previous reviews, assessments, and regulatory applications prepared by LGL Limited.

2.0 Sea Turtle Hearing

Although there have been a limited number of studies on sea turtle hearing (see review by Southwood et al. 2008), the available data are not very comprehensive (Willis 2016). However, the data demonstrate that sea turtles appear to be low-frequency specialists (see Table 1). Charrier et al. (2022) also recently recorded the first underwater vocalizations made by green sea turtles (*Chelonia mydas*), which ranged in frequency from ~240 Hz up to 10 kHz.

Sea turtle auditory perception is thought to occur through a combination of both bone and water conduction rather than air conduction (Lenhardt 1982; Lenhardt and Harkins 1983). Detailed descriptions of sea turtle ear anatomy are found in Ridgway et al. (1969), Lenhardt et al. (1985), and Bartol and Musick (2003). Sea turtles do not have external ears, but the middle ear is well adapted as a peripheral component of a bone conduction system. The thick tympanum is disadvantageous as an aerial receptor but enhances low-frequency bone conduction hearing (Lenhardt et al. 1985; Bartol et al. 1999; Bartol and Musick 2003). A layer of subtympanal fat emerging from the middle ear is fused to the tympanum (Ketten et al. 2006; Bartol 2004, 2008). A cartilaginous disk, the extracolumella, is found under the tympanic membrane and is attached to the columella (Bartol 2004, 2008). The columella is a long rod that expands to form the stapes, and fibrous strands connect the stapes to the saccule (Bartol 2004, 2008). When the tympanum is depressed, the vibrations are conveyed via the fibrous stapedo-sacular strands to the sacule (Lenhardt et al. 1985). This arrangement of fat deposits and bone enables sea turtles to hear low-frequency sounds while underwater and makes them relatively insensitive to sound above water. Vibrations can also be conducted through the bones of the carapace to reach the middle ear. Based on studies of semi-aquatic turtles, Christensen-Dalsgaard et al. (2012) speculated that the sea turtle ear may not be specialized for bone conduction, but rather that sound-induced pulsations may drive the tympanic disc if the middle ear cavity is air-filled. Willis et al. (2013) also reported on the importance of the middle ear cavity in underwater sound detection in turtles.

A variety of audiometric methods are available to assess hearing abilities. Electrophysiological measures of hearing (e.g., auditory brainstem response or ABR) provide good information about relative sensitivity to different frequencies. However, this approach may underestimate the frequency range to which the animal is sensitive and may be imprecise at determining absolute hearing thresholds (e.g., Wolski et al. 2003). Nevertheless, when time is critical and only untrained animals are available, this method can provide useful information on sea turtle hearing (e.g., Wolski et al. 2003).

Ridgway et al. (1969) obtained the first direct measurements of sea turtle hearing sensitivity (Table 1). They used an electrophysiological technique (cochlear potentials) to determine the response of green sea turtles (*Chelonia mydas*) to aerial- and vibrational-stimuli consisting of tones with frequencies 30 to 700 Hz. They found that green turtles exhibit maximum hearing sensitivity between 300 and 500Hz and speculated that the turtles had a useful hearing range of 60–1000 Hz. However, there was some response to strong vibrational signals at frequencies down to 30 Hz

Table 1. Hearing capabilities of sea turtles as measured using behavioural and electro-physiological techniques. ABR: auditory brainstem response; AEP: auditory evoked potential; Beh.: behavioural.

Sea Turtle Species	Hearing		Technique	Source
	Range (Hz)	Highest Sensitivity (Hz)		
Green	60-1000	300-500	Cochlear Potentials [a]	Ridgway et al. 1969
	100-800	600-700 (juveniles) 200-400 (subadults)	ABR [w]	Bartol & Ketten 2006; Ketten & Bartol 2006
	N.A.	300	ABR [a]	Yudhana et al. 2010a
	50-1600	50-400	AEP [a,w]	Piniak et al. 2012a, 2016
Loggerhead	250-1000 50-1131	250 100-400	ABR [a] AEP [w], Beh.[w]	Bartol et al. 1999; Martin et al. 2012; Lavender et al. 2014
Kemp's ridley	100-500	100-200	ABR [w]	Bartol & Ketten 2006; Ketten & Bartol 2006
Leatherback	50-1600	100-400	AEP [a,w]	Piniak et al. 2012b
Hawksbill	N.A.	50-508	ABR [a]	Yudhana et al. 2010b

N.A. = not available. [a] measured in air; [w] measured underwater.
Note that there are no empirical data available for olive ridley or flatback sea turtles.

ABR techniques have been used to determine the underwater hearing capabilities of six subadult green turtles, two juvenile green turtles, and two juvenile Kemp's ridley (*Lepidochelys kempii*) turtles (Ketten and Bartol 2006; Bartol and Ketten 2006; Table 1). The turtles were physically restrained in a small box tank with their ears below the water surface and the top of the head exposed above the surface. Pure-tone acoustic stimuli were presented to the animals, though the exact frequencies of these tones were not indicated. The six subadult green turtles detected sound at frequencies 100–500 Hz, with the most sensitive hearing at 200–400 Hz. In contrast, the two juvenile green turtles exhibited a slightly expanded overall hearing range of 100–800 Hz, with their most sensitive hearing occurring at 600–700 Hz. Piniak et al. (2016) tested the hearing sensitivity of juvenile green turtles in water using AEP and found that turtles responded to frequencies of 50 to 1600 Hz, with a maximum sensitivity between 200 and 400 Hz. Yudhana et al. (2010a) tested three turtles aged 2, 5, and 9 years, and concluded that the oldest one had the biggest hearing range. The most restricted range of sensitive hearing (100–200 Hz) was found in the two juvenile Kemp's ridley turtles, whose overall frequency range was 100–500 Hz (Ketten and Bartol 2006; Bartol and Ketten 2006).

Bartol et al. (1999) tested the in-air hearing of juvenile loggerhead turtles (*Caretta caretta*) (see Table 1). The authors used ABR to determine the response of the sea turtle ear to two types of vibrational stimuli: (1) brief, low-frequency broadband clicks, and (2) brief tone bursts at four frequencies from 250–1000 Hz. They demonstrated that loggerhead sea turtles hear well between 250 and 1000 Hz; within that frequency range the turtles were most sensitive at 250 Hz. The authors did not measure hearing sensitivity below 250 Hz or above 1000 Hz. The signals used in this study were very brief — 0.6 ms for the clicks and 0.8–5.5 ms for the tone bursts. In other animals, auditory thresholds decrease with increasing signal duration up to ~100–200 ms. Thus, sea turtles probably could hear weaker signals than demonstrated in the study if the signal duration were longer.

Lavender et al. (2014) used ABR and behavioural audiogram analyses to examine the hearing of post-hatchling and juvenile loggerhead turtles; they found that the turtles responded to sounds with frequencies of 50–1100 Hz. Martin et al. (2012) used both behavioural and auditory evoked potential (AEP) methods to derive an underwater audiogram of an adult loggerhead turtle. Both testing methods confirmed that the loggerhead turtle has low-frequency hearing and that best sensitivity occurred from 100–400 Hz (Martin et al. 2012; Lavender 2014).

Lenhardt (2002) exposed loggerhead turtles while they were near the bottom of holding tanks at a depth of 1 m to tones from 35 to 1000 Hz. The turtles exhibited startle responses (neck contractions) to these tones. The lowest thresholds, based on sound pressure levels (SPLs), were in the 400–500 Hz range (106 dB re 1 µPa), and thresholds in the 100–200 Hz range were ~124 dB (Lenhardt 2002). Thresholds at 735 and 100 Hz were 117 and 156 dB, respectively (Lenhardt 2002). Diving behaviour occurred at 30 Hz and 164 dB.

The hearing sensitivity of leatherback (*Dermochelys coriacea*) hatchlings was tested in water and in air using AEP (Piniak et al. 2012b). Hatchlings were exposed to 50 ms pulsed tones between 50 and 1600 Hz. The hatchlings responded to sound stimuli between 50 and 1200 Hz in water and 50 and 1600 Hz in air, with best hearing between 100 and 400 Hz in water (84 dB re 1 μPa_{rms} at 300 Hz) and 50 to 400 Hz in air (62 dB re 20 µParms at 300 Hz). Yudhana et al. (2010b) used ABR to determine that hawksbill turtles (*Eretmochelys imbricata*) responded to frequencies of 50–508 Hz.

In summary, the limited available data indicate that the frequency range of best hearing sensitivity of sea turtles extends from ~100 to 700 Hz. Sensitivity deteriorates as one moves away from this range to either lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz (Ridgway et al. 1969). Thus, there is substantial overlap in the frequencies that sea turtles detect and the dominant frequencies produced by airgun pulses. Given that, plus the high energy levels of airgun pulses, we can conclude that sea turtles hear airgun sounds. However, we are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. Given the high source levels of airgun pulses and the substantial received levels even at distances

many km away from the source, it is probable that sea turtles can also hear the sound source output from distant seismic vessels. However, in the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible to a sea turtle.

3.0 Effects of Airgun Pulses on Behaviour and Movement

The effects of exposure to airgun pulses on the behaviour and distribution of various marine animals have been studied over the past three decades. Most such studies have concerned marine mammals (e.g., see reviews by Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007), but also fish (e.g., reviewed by Thomson et al. 2001; Herata 2007; Payne et al. 2008; Popper et al. 2009a,b; Carroll et al. 2016). There have been far fewer studies on the effects of airgun sound (or indeed any type of sound) on sea turtles, and little is known about the sound levels that will or will not elicit various types of behavioural reactions (Nelms et al. 2016). There have been four directed studies that focused on short-term behavioural responses of sea turtles in enclosures to single airguns. However, comparisons of results among studies are difficult because experimental designs and reporting procedures have varied greatly, and few studies provided specific information about the levels of the airgun pulses received by the turtles. Although monitoring studies are now providing some information on responses (or lack of responses) of free-ranging sea turtles to seismic surveys, we are not aware of any directed studies on responses of free-ranging sea turtles to seismic sounds or on the long-term effects of seismic or other sounds on sea turtles.

3.1 Directed Studies

The most recent of the studies of caged sea turtles exposed to airgun pulses was a study by McCauley et al. (2000a,b) off Western Australia. The authors exposed caged green and loggerhead sea turtles (one of each) to pulses from an approaching and then receding 20 in^3 airgun operating at 1500 psi and a 5-m airgun depth. The single airgun was activated every 10 s. There were two trials separated by two days; the first trial involved ~2 h of airgun exposure and the second ~1 h. The results from the two trials showed that, above a received level of 166 dB re 1 µPa (rms) [2], the turtles noticeably increased their swim speed relative to periods when no airguns were operating. The behaviour of the sea turtles became more erratic when received levels exceeded 175 dB re 1 µPa (rms). The authors suggested that the erratic behaviour exhibited by the caged sea turtles would likely, in unrestrained turtles, be expressed as an avoidance response (McCauley et al. 2000a,b).

[2] rms = root mean square. This measure represents the average received sound pressure over the duration of the pulse, with duration being defined in a specific way (from the time when 5% of the pulse energy has been received to the time when 95% of the energy has been received). The rms received level of a seismic pulse is typically about 10 dB less than its peak level, and about 16 dB less than its peak-to-peak level (Greene et al. 1997, 2000; McCauley et al. 1998, 2000a,b).

O'Hara and Wilcox (1990) tested the reactions to airguns by loggerhead sea turtles held in a 300 × 45 m area of a canal in Florida with a bottom depth of 10 m. Nine turtles were tested at different times. The sound source consisted of one 10 in^3 airgun plus two 0.8 in^3 "poppers" operating at 2000 psi[3] and an airgun-depth of 2 m for prolonged periods of 20–36 h. The turtles maintained a standoff range of about 30 m when exposed to airgun pulses every 15 or 7.5 s. Some turtles may have remained on the bottom of the enclosure when exposed to airgun pulses. O'Hara and Wilcox (1990) did not measure the received airgun sound levels. McCauley et al. (2000a,b) estimated that "the level at which O'Hara saw avoidance was around 175–176 dB re 1 µPa rms." The levels received by the turtles in the Florida study probably were actually a few dB less than 175–176 dB because the calculations by McCauley et al. apparently did not allow for the shallow 2-m airgun depth in the Florida study. The effective source level of airguns is less when they are at a depth of 2 m vs. 5 m (Greene et al. 2000).

Moein et al. (1994) investigated the avoidance behaviour and physiological responses of loggerhead turtles exposed to an operating airgun, as well as the effects on their hearing. The turtles were held in a netted enclosure ~18 m by 61 m by 3.6 m deep, with an airgun of unspecified size at each end. Only one airgun was operated at any one time; the firing rate was one pulse every 5–6 s. Ten turtles were tested individually, and seven of these were retested several days later. The airgun was initially discharged when the turtles were near the center of the enclosure and the subsequent movements of the turtles were documented. The turtles exhibited avoidance during the first presentation of airgun sounds at a mean range of 24 m, but the avoidance response waned quickly. Additional trials conducted on the same turtles several days later did not show statistically significant avoidance reactions. However, there was an indication of slight initial avoidance followed by rapid waning of the avoidance response which the authors described as "habituation". Their auditory study indicated that exposure to the airgun pulses may have resulted in temporary threshold shift (TTS; see later section). Reduced hearing sensitivity may also have contributed to the waning response upon continued exposure. Based on physiological measurements, there was some evidence of increased stress in the sea turtles, but this stress could also have resulted from handling of the turtles.

Inconsistencies in reporting procedures and experimental design prevent direct comparison of this study with either McCauley et al. (2000a,b) or O'Hara and Wilcox (1990). Moein et al. (1994) stated, without further details, that "three different decibel levels (175, 177, 179) were utilized" during each test. These figures probably are received levels in dB re 1 µPa, and probably relate to the initial exposure distance (mean 24 m), but these details were not specified. Also, it was not specified whether these values were measured or estimated, or whether they are expressed in SPL (peak-peak, peak, or rms), sound exposure level (SEL, dB re 1 $\mu Pa^2 \cdot s$.), or some other units. Given the shallow water in the enclosure (3.6 m), any estimates based on simple assumptions about propagation would be suspect.

[3] There was no significant reaction by five turtles during an initial series of tests with the airguns operating at the unusually low pressure of 1000 psi. The source and received levels of airgun sounds would have been substantially lower when the air pressure was only 1000 psi than when it was at the more typical operating pressure of 2000 psi.

Lenhardt (2002) exposed captive loggerhead sea turtles while underwater to seismic airgun (Bolt 600) sounds in a large net enclosure. At received levels of 151–161 dB, turtles were found to increase swimming speeds. Similar to the McCauley et al. studies (2000a,b—see above), near a received level of ~175 dB, an avoidance reaction was common in initial trials, but habituation then appeared to occur. Based on ABRs measured pre- and post-airgun exposures, a TTS of over 15 dB was found in one animal, with recovery two weeks later. Lenhardt (2002) suggested that exposure of sea turtles to airguns at water depths >10 m may result in exposure to more energy in the low frequencies with unknown biological effects.

Despite the problems in comparing these studies, they are consistent in showing that, at some received level, sea turtles show avoidance of an operating airgun. McCauley et al. (2000a,b) found evidence of behavioural responses when the received level from a single small airgun was 166 dB re 1 µPa rms and avoidance responses at 175 dB re 1 µPa rms. Based on these data, McCauley et al. estimated that, for a typical airgun array (2678 in^3, 12-elements) operating in 100–120 m water depth, sea turtles may exhibit behavioural changes at ~2 km and avoidance around 1 km. These estimates are subject to great variation, depending on the seismic source and local propagation conditions.

A further potential complication is that sea turtles on or near the bottom may receive sediment-borne "headwave" signals from the airguns (McCauley et al. 2000a,b). As previously discussed, it is believed that sea turtles use bone conduction to hear. It is unknown how sea turtles might respond to the headwave component of an airgun impulse or to bottom vibrations during seismic surveys in shallow waters.

Related studies involving stimuli other than airguns may also be relevant. ***(1)*** Two loggerhead turtles resting on the bottom of shallow tanks responded repeatedly to low-frequency (20–80 Hz) tones by becoming active and swimming to the surface. They remained at the surface or only slightly submerged for the remainder of the 1-min trial (Lenhardt 1994). Although no detailed data on sound levels at the bottom vs. surface were reported, the surfacing response probably reduced the levels of underwater sound to which the turtles were exposed. ***(2)*** In a separate study, a loggerhead and a Kemp's ridley sea turtle responded similarly when vibratory stimuli at 250 or 500 Hz were applied to the head for 1 s (Lenhardt et al. 1983). There appeared to be rapid habituation to these vibratory stimuli. ***(3)*** Sea turtles in tanks showed agitated behaviour when exposed to simulated boat noise and recordings from the U.S. Navy's Low Frequency Active (LFA) sonar (Samuel 2004; Samuel et al. 2006). The tones and vibratory stimuli used in these studies were quite different from airgun pulses. However, it is possible that resting sea turtles may exhibit a similar "alarm" response, possibly including surfacing or alternatively diving, when exposed to any audible sound, regardless of whether it is a pulsed sound or tone. **(4)** A free-swimming green sea turtle fitted with a data logger, camera, and a hydrophone reacted to increasing ship noise when travelling. It exhibited increasing amounts of vigilance (visual scanning, i.e., extending the neck, raising the head and moving it from side to side) (Parra Díaz et al. 2024). However, when at rest on the seabed the turtle did not alter its scanning behaviour in response to increasing noise levels. Their finding suggest that anthropogenic noise has the

potential to cause changes in time budgets in sea turtles. SELs were not measured. *(5)* Green and hawksbill sea turtles in a pool that were exposed to upsweeps with frequencies 0.2–1 kHz, 100% duty cycle, 0.5-s duration, and SPLs above 151 dB re 1 µPa responded by increasing their swim speed or changing directions, but did not respond when exposed to pure tones, impulsive sounds with SPLs of 120 dB re 1 µPa, helicopter long-range active sonar downsweeps, or killer whale (*Orcinus orca*) calls (Kastelein et al. 2024). The response was dependent on the sound spectrum, frequency modulation and sound temporal pattern, as well as the behavioural state of the sea turtles.

3.2 Monitoring Results

Data on sea turtle behaviour near airgun operations have also been collected during marine mammal and sea turtle monitoring and mitigation programs associated with various seismic operations around the world. Although the primary objectives concerned marine mammals, sea turtle sightings have also been documented in some of monitoring projects. Vessel-based observations indicate that avoidance of approaching seismic vessels is small-scale such that sea turtles are often seen from operating seismic vessels. Also, average distances from the airguns to these sea turtles are usually not greatly increased when the airguns are operating as compared with times when airguns are silent.

For example, during six large-source (10–20 airguns; 3050–8760 in^3) and small-source (up to six airguns or three GI guns; 75–1350 in^3) surveys conducted by L-DEO during 2003–2005, the mean closest point of approach (CPA) for turtles was closer during non-seismic than seismic periods: 139 m vs. 228 m and 120 m vs. 285 m, respectively (Holst et al. 2006). During a large-source L-DEO seismic survey off the Pacific coast of Central America in 2008, the turtle sighting rate during non-seismic periods was seven times greater than that during seismic periods (Holst and Smultea 2008). In addition, distances of turtles seen from the seismic vessel were significantly farther from the airgun array when it was operating (mean 159 m, n = 77) than when the airguns were off (mean 118 m, n = 69; Mann-Whitney U test, P<0.001) (Holst and Smultea 2008). During another L-DEO survey in the Eastern Tropical Pacific in 2008, the turtle sighting rate during non-seismic periods was 1.5 times greater than that during seismic periods; however, turtles tended to be seen closer to the airgun array when it was operating, but this difference was not statistically significant (Hauser et al. 2008).

Weir (2007) reported on the behaviour of sea turtles near seismic exploration operations off Angola, West Africa. A total of 240 sea turtles were seen during 676 h of vessel-based monitoring, mainly for associated marine mammals mitigation measures. Airgun arrays with total volumes of 5085 and 3147 in^3 were used at different times during the seismic program. Sea turtles tended to be seen slightly closer to the seismic source, and at sighting rates twice as high, during non-seismic vs. seismic periods (Weir 2007). However, there was no significant difference in the median distance of turtle sightings from the array during non-seismic vs. seismic periods, with means of 743 m (n = 112) and 779 m (n = 57). DeRuiter and Doukara (2012) observed that small numbers of basking loggerhead sea turtles (n = 6 of 86 turtles of whose behaviour was observed)

exhibited an apparent startle response (sudden raising of the head and splashing of flippers, occasionally accompanied by blowing bubbles from the beak and nostrils, followed by a short dive) immediately following an airgun pulse. Diving turtles (49 of 86 individuals) were observed at distances from the center of the airgun array ranging from 50–839 m. The estimated sound level at the median distance of 130 m was 191 dB re 1 μPa (peak). These observations were made during ~150 h of vessel-based monitoring from a seismic vessel actively operating an airgun array (13 airgun, 2440 in^3) off Algeria—there was no corresponding observation effort during periods when the airgun array was inactive (DeRuiter and Doukara 2012).

Off northeastern Brazil, 46 sea turtles were seen during 2028 h of vessel-based monitoring of seismic exploration using 4–8 GI airguns between June 2002 and August 2003 (Parente et al. 2006). Although slightly more sea turtles were sighted during non-seismic (0.075 turtles per hour) than seismic periods (0.054 turtles per hour), the sighting rates were not statistically significant. Detailed behavioural data during seismic operations were lacking (Parente et al. 2006). De Gurjão et al. (2005) suggested that sea turtles may have shown some avoidance around a seismic survey off Bahia State, Brazil, during January to May 2002.

Behavioural responses of marine mammals and fish to seismic surveys sometimes vary depending on species, time of year, activity of the animal, and other unknown factors. The same species may show different responses at different times of year or even on different days (e.g., Richardson et al. 1995; Thomson et al. 2001). Sea turtles of different ages vary in size, behaviour, feeding habits, and preferred water depths. Nothing specific is known about the ways in which these factors may be related to airgun sound effects in sea turtles. However, it is reasonable to expect lesser effects in young turtles concentrated near the surface (where levels of airgun sounds are attenuated) as compared with older turtles that spend more time at depth where airgun sounds are generally stronger.

4.0 Possible Effects of Airgun Sounds on Distribution

In captive enclosures, sea turtles generally respond to seismic sound by startling, increasing swimming speed, and/or swimming away from the sound source. Animals resting on the bottom often become active and move toward the surface where received sound levels normally will be reduced, although some turtles dive upon exposure. Unfortunately, quantitative data for free-ranging sea turtles exposed to seismic pulses are very limited, and potential long-term behavioural effects of seismic exposure have not been investigated. The paucity of data precludes clear predictions of sea turtle responses to seismic sound. Available evidence suggests that localized behavioural and distributional effects on sea turtles are likely during seismic operations, including responses to the seismic vessel, airguns, and other gear (e.g., McCauley 1994; Pendoley 1997; Weir 2007). Pendoley (1997) summarized potential effects of seismic operations on the behaviour and distribution of sea turtles and identified biological periods and habitats considered most sensitive to potential disturbance. The possible responses of free-ranging sea turtles to seismic pulses could include

- avoiding the entire seismic survey area to the extent that turtles move to less preferred habitat;
- avoiding only the immediate area around the active seismic vessel (i.e., local avoidance of the source vessel but remain in the general area); and
- exhibiting no appreciable avoidance, although short-term behavioural reactions are likely.

Complete avoidance of an area, if it occurred, could exclude sea turtles from their preferred foraging area and could displace them to areas where foraging is sub-optimal (Nelms et al. 2016). Avoidance of a preferred foraging area may prevent sea turtles from obtaining preferred prey species and hence could impact their nutritional status. The potential alteration of a migration route might also have negative impacts. However, it is not known whether avoidance by sea turtles would ever be on a sufficient geographic scale, or be sufficiently prolonged, to prevent turtles from reaching an important destination.

Available evidence suggests that the zone of avoidance around seismic sources is not likely to exceed a few kilometers (McCauley et al. 2000a,b). Avoidance reactions on that scale could prevent sea turtles from using an important coastal area or bay if there was a prolonged seismic operation in the area, particularly in shallow waters (e.g., Pendoley 1997). If such avoidance were to occur, it is uncertain how long it would last. Sea turtles might be excluded from the area for the duration of the seismic operation, or they might remain but exhibit abnormal behavioural patterns (e.g., lingering longer than normal at the surface where received sound levels are lower). Whether those that were displaced would return quickly after the seismic operation ended is unknown.

It is unclear whether exclusion from a particular nesting beach by seismic operations, if it occurred, would prevent or decrease reproductive success. It is believed that females migrate to the region of their birth and select a nesting beach (Miller 1997). However, the degree of site fidelity varies between species and also intra-seasonally by individuals. If a sea turtle is excluded from a particular beach, it may select a more distant, undisturbed nesting site in the general area (Miller 1997). For instance, Bjorndal et al. (1983) reported a maximal intra-seasonal distance between nesting sites of 290 km, indicating that turtles use multiple nesting sites spaced up to a few hundred kilometers apart. Also, it is uncertain whether a turtle that failed to go ashore because of seismic survey activity would abandon the area for that full breeding cycle, or would simply delay going ashore until the seismic vessel moved to a different area.

Shallow coastal waters can contain relatively high densities of sea turtles during nesting, hatching, and foraging periods. Thus, seismic operations in these areas could correspondingly impact a relatively higher number of individual turtles during sensitive biological periods. Samuel et al. (2005) noted that anthropogenic noise in vital sea turtle habitats, such as a major coastal foraging area off Long Island, NY, could affect sea turtle behaviour and ecology. There are no specific data that demonstrate the consequences to sea turtles if seismic operations with large or small arrays of airguns occur in important areas at biologically important times of year.

However, a number of mitigation measures can, on a case-by-case basis, be considered for application in areas important to sea turtles (e.g., Pendoley 1997).

5.0 Possible Effects of Airgun Sounds on Hearing

Noise-induced hearing damage can be either temporary or permanent. In general, the received sound must be strong for either to occur and must be especially strong and/or prolonged for permanent impairment to occur.

Few studies have directly investigated hearing or noise-induced hearing loss in sea turtles (Nelms et al. 2016). Moein et al. (1994) used an evoked potential method to test the hearing of loggerhead sea turtles exposed to a few hundred pulses from a single airgun. Turtle hearing was tested before, within 24 h after, and two weeks after exposure to pulses of airgun sound. Levels of airgun sound to which the turtles were exposed were not specifically reported. The authors concluded that five turtles exhibited some change in their hearing when tested within 24 h after exposure relative to pre-exposure hearing, and that hearing had reverted to normal when tested two weeks after exposure. The results are consistent with the occurrence of TTS upon exposure of the turtles to airgun pulses. Unfortunately, the report did not state the size of the airgun used or the received sound levels at various distances. The distances of the turtles from the airgun were also variable during the tests; the turtle was about 30 m from the airgun at the start of each trial, but it could then either approach the airgun or move away to a maximum of about 65 m during subsequent airgun pulses. Thus, the levels of airgun sound that apparently elicited TTS are not known. Nonetheless, it is noteworthy that there was evidence of TTS from exposure to pulses from a single airgun. However, the turtles were confined and unable to move more than about 65 m away. Similarly, Lenhardt (2002) exposed loggerhead turtles in a large net enclosure to airgun pulses. A TTS of >15 dB was evident for one loggerhead turtle, with recovery occurring in two weeks. Turtles in the open sea might have moved away from an airgun operating at a fixed location, and in the more typical case of a towed airgun or airgun array, very few pulses would occur at or around one location. Thus, exposure to underwater sound during net-enclosure experiments was not typical of that expected during an operational seismic survey.

Studies of freshwater turtles have also shown that exposure to underwater sounds can cause TTS in turtles. Using auditory evoked potential methods measured at 400 Hz, Salas et al. (2023) found a TTS in the red-eared slider (*Trachemys scripta elegans*) when exposed to band-limited noise (50-1000 Hz) at SELs varying from 155 to 193 dB re 1 $\mu Pa^2 \cdot s$. Shifts of up to 40 dB were observed. Shift magnitude was positively related to exposure duration, amplitude, and SEL. Recovery rates from TTS varied from less than 1 h to greater than 2 days after exposure and recovery rates were usually greater after TTS of higher magnitude. In a later study on the eastern painted turtle (*Chrysemys picta picta*) they found that this species experienced a TTS when exposed to noise (50-1000 Hz) at SELs ranging from 151 to 171 dB re 1 $\mu Pa^2 \cdot s$ (Salas et al. 2024). TTS occurred in all individuals at both 400 Hz and 600 Hz, with shifts ranging from 6.1 to 41.4 dB. Greater shifts were recorded at 600 Hz than at 400 Hz. When exposed to sound at 600 Hz TTS showed onset at

154 dB re 1 µPa^2·s. At 400 Hz TTS onset occurred at 158 dB re 1 µPa^2·s, which was similar to that found in red-eared slider. The patterns of TTS growth and recovery were also similar to that in red-eared slider.

Studies of exposure to in-air sounds have also demonstrated that noise can cause hearing loss in turtles. Based on TTS elicited by exposure to broadband in-air sound for 24 hours, Mannes et al. (2024) surmised that the red-eared slider would also likely exhibit TTS when exposed to an underwater sound with a SEL of 160 dB re 1 µPa^2·s. Desert tortoises (*Gopherus agassizii*) exhibited TTS after exposure to repeated high-intensity sonic booms (Bowles et al. 1999). Recovery from these temporary hearing losses was usually rapid (<1 h), which suggested that tortoises can tolerate these exposures without permanent injury (Bowles et al. 1999).

The results from captive, restrained sea turtles exposed repeatedly to seismic sounds in enclosed areas indicate that TTS is possible under these artificial conditions. However, there are no data to indicate whether there are any plausible field situations in which exposure to repeated airgun pulses at close range could cause permanent threshold shift (PTS) or hearing impairment in sea turtles. Hearing impairment (whether temporary or permanent) from seismic sounds is considered unlikely to occur at sea; turtles are unlikely to be exposed to more than a few strong pulses close to the sound source, as individuals are mobile and the vessel travels relatively quickly compared to the swimming speed of a sea turtle. However, in the absence of specific information on received levels of impulse sound necessary to elicit TTS and PTS in sea turtles, it is uncertain whether there are circumstances where these effects could occur in the field. If sea turtles exhibit little or no behavioural avoidance, or if they acclimate to seismic sound to the extent that avoidance reactions cease, sea turtles might sustain hearing loss if they are close enough to seismic sources. Similarly, in the absence of quantitative data on behavioural responses, it is unclear whether turtles in the area of seismic operations prior to start-up move out of the area when standard ramp-up (=soft-start) procedures are in effect. It has been proposed that sea turtles require a longer ramp-up period because of their relatively slow swimming speeds (Eckert 2000). However, it is unclear at what distance (if any) from a seismic source sea turtles could sustain hearing impairment, and whether there would ever be a possibility of exposure to sufficiently high levels for a sufficiently long period to cause permanent hearing damage.

In theory, a reduction in hearing sensitivity, either temporary or permanent, may be harmful for sea turtles. However, very little is known about the role of sound perception in the sea turtle's normal activities. While it is not possible to estimate how much of a problem it would be for a turtle to have either temporary or permanent hearing impairment, there is some evidence indicating that hearing plays an important role in sea turtle survival. ***(1)*** It has been suggested (Eckert et al. 1998; Eckert 2000) that sea turtles may use passive reception of acoustic signals to detect the hunting sonar of killer whales (*Orcinus orca*), a known predator of leatherback sea turtles *Dermochelys coriacea* (Fertl and Fulling 2007). Further investigation is needed before this hypothesis can be accepted. Some communication calls of killer whales include components at frequencies low enough to overlap the frequency range where sea turtles hear. However, the echolocation signals of killer whales are at considerably higher frequencies and based on

available evidence, are likely inaudible to sea turtles (e.g., Simon et al. 2007). ***(2)*** Hearing impairment, either temporary or permanent, might inhibit a turtle's ability to avoid injury from vessels. A recent study found that green sea turtles often responded behaviourally to close, oncoming small vessels and that the nature of the response was related to vessel speed, with fewer turtles displaying a flee response as vessel speed increased (Hazel et al. 2007). However, Hazel et al. (2007) suggested that a turtles' ability to detect an approaching vessel was vision-dependent. ***(3)*** Hearing may play a role in navigation. For example, it has been proposed that sea turtles may identify their breeding beaches by their acoustic signature (Lenhardt et al. 1983). However, available evidence suggests that visual, wave, and magnetic cues are the main navigational cues used by sea turtles, at least in the case of hatchlings and juveniles (Lohmann et al. 1997, 2001; Lohmann and Lohmann 1998).

6.0 Other Physical Effects

Although it is possible that exposure to airgun sounds may cause mortality or mortal injuries in sea turtles close to the source, this has not been demonstrated and seems unlikely (Popper et al. 2014), especially since they appear to be highly resistant to explosives (Ketten et al. 2005 *in* Popper et al. 2014). Nonetheless, Popper et al. (2014) proposed mortality/mortal injury criteria for seismic airguns of 210 dB SEL or >207 dB peak. For impulsive sound such as those from airguns, the U.S. Navy (2017) proposed PTS thresholds of 204 dB SEL_{cum} and 232 dB_{peak}.

Other potential direct physical effects to sea turtles during seismic operations include entanglement with seismic gear (e.g., cables, buoys, streamers, etc.) and ship strikes (Pendoley 1997; Ketos Ecology 2007; Weir 2007; Hazel et al. 2007). Entanglement of sea turtles with marine debris, fishing gear, and other equipment has been documented; turtles can become entangled in cables, lines, nets, or other objects suspended in the water column and can become injured or fatally wounded, drowned, or suffocated (e.g., Lutcavage et al. 1997). Seismic-survey personnel have reported that sea turtles (number unspecified) became fatally entrapped between gaps in tail-buoys associated with industrial seismic vessel gear deployed off West Africa in 2003 (Weir 2007). However, no incidents of entanglement of sea turtles have been documented during NSF-funded seismic surveys, which since 2003 have included dedicated ship-based monitoring by trained biological observers, in some cases in areas with many sea turtles (e.g., Holst et al. 2005a,b; Holst and Smultea 2008; Hauser et al. 2008). Turtle guards installed on tail buoys are thought to minimize the risk of entanglement (Ketos Ecology 2007).

7.0 Conclusions

Based on available data concerning sea turtles and other marine animals, it is likely that some sea turtles exhibit behavioural changes and/or avoidance within an area of unknown size near an operating seismic survey vessel. There is also the possibility of temporary hearing impairment or perhaps even permanent hearing damage or other injury to turtles close to the airguns. However, there are very few data on temporary hearing loss and no data on permanent hearing

loss or injury in sea turtles exposed to airgun pulses. Although some information is available about effects of exposure to sounds from a single airgun on captive sea turtles, the long-term acoustic effects (if any) of a full-scale marine seismic operation on free-ranging sea turtles are unknown. Entanglement of turtles in seismic gear and vessel strikes during seismic survey operations are also possible but do not seem to be common. The greatest effects are likely to occur if seismic operations occur in or near areas where turtles concentrate, and at seasons when turtles are concentrated there. However, there are no specific data that demonstrate the consequences of such seismic operations to sea turtles. Until more data become available, it would be prudent to avoid seismic operations near important nesting beaches or in areas of known concentrated feeding during times of year when those areas are in use by many sea turtles.

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