Environmental Assessment of Suncor Energy's Eastern Newfoundland Offshore Area 2D/3D/4D Seismic Program, 2014–2024

Prepared by



for



December 2013
Project No. SA1233

Environmental Assessment of Suncor Energy's Eastern Newfoundland Offshore Area 2D/3D/4D Seismic Program, 2014–2024

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Table of Contents

Page

Table of Contents ii
List of Figures v
List of Tables vii
1.0 Introduction 1
1.1 Relevant Legislation and Regulatory Approvals 2
1.2 The Proponent: Suncor Energy 2
1.3 Canada-Newfoundland and Labrador Benefits 3
1.4 Contacts 3
2.0 Proposed Project 5
2.1 Name and Location 5
2.2 Spatial and Temporal Boundaries 5
2.3 Project Overview 5
2.3.1 Objectives and Rationale 6
2.3.2 Alternatives to the Project and within the Project 6
2.3.3 Project Scheduling 7
2.3.4 Site Plans 7
2.3.5 Personnel 7
2.3.6 Seismic Vessel 7
2.3.7 Seismic Energy Source Parameters 7
2.3.8 Seismic Streamers 8
2.3.9 Logistics and Support 8
2.3.10 Waste Management 9
2.3.11 Air Emissions 9
2.3.12 Accidental Events 9
2.4 Mitigations 9
2.5 Project Site Information 9
2.5.1 Environmental Features 10
2.5.2 Physical Environment and Effects on the Project 10
2.5.3 Fish and Fish Habitat 10
2.5.4 Species at Risk 10
2.6 Other Users 10
2.6.1 Fisheries 10
2.6.2 Navigable Waters 11
2.6.3 Consultations 11
2.6.4 Effects of the Project on the Environment 11
2.6.5 Spatial and Temporal Boundaries 11
2.6.6 Valued Ecosystem Components 11
2.6.7 Environmental Mitigation and Monitoring 12
3.0 Physical Environment 13
3.1 Bathymetry and Geology 13
3.2 Climatology 13
3.2.1 Weather Systems 13
3.2.2 Extreme Analysis 14
3.3 Physical Oceanography 20
3.3.1 Major Currents in the Study Area 20
3.3.2 Temperature 21
3.3.3 Visibility 22

3.4 Sea Ice and Icebergs 23
3.4.1 Sea Ice 23
3.4.2 Icebergs 23
4.0 Biological Environment 28
4.1 Ecosystem 28
4.2 Fish and Fish Habitat 28
4.2.1 Fish Habitat 28
4.2.2 Plankton 28
4.2.3 Benthos 29
4.2.4 Fishes 32
4.3 Fisheries 51
4.3.1 Information Sources 51
4.3.2 Regional NAFO Fisheries 53
4.3.3 Domestic Fisheries 54
4.3.4 Principal Species 62
4.3.5 Macroinvertebrates and Fishes Collected during DFO RV Surveys 77
4.3.6 Aboriginal and Recreational Fisheries 87
4.3.7 Industry and DFO Science Surveys 87
4.4 Seabirds 88
4.4.1 Information Sources 88
4.4.2 Summary of Seabirds in the Study Area 88
4.4.3 Breeding Seabirds in Eastern Newfoundland 89
4.4.4 Seasonal Occurrence and Abundance 92
4.4.5 Prey and Foraging Habits 98
4.5 Marine Mammals and Sea Turtles 101
4.5.1 Marine Mammals 101
4.5.2 Sea Turtles 114
4.6 Species at Risk 115
4.6.1 Profiles of *SARA*-Listed Species 118
4.7 Sensitive Areas 124
4.7.1 Integrated Management Areas 124
4.7.2 Bonavista Cod Box 126
4.7.3 Coral and Sponge Areas 126
5.0 Effects Assessment 127
5.1 Scoping 127
5.1.1 Consultations 127
5.2 Valued Environmental Components 131
5.3 Boundaries 132
5.4 Effects Assessment Procedures 133
5.4.1 Identification and Evaluation of Effects 133
5.4.2 Classifying Anticipated Environmental Effects 133
5.4.3 Mitigation 134
5.4.4 Evaluation Criteria for Assessing Environmental Effects 134
5.4.5 Cumulative Effects 137
5.4.6 Integrated Residual Environmental Effects 137
5.5 Effects of the Environment on the Project 138
5.6 Effects of the Project Routine Activities on the Environment 139
5.6.1 Fish and Fish Habitat VEC 140
5.6.2 Fisheries VEC 152
5.6.3 Seabird VEC 161
5.6.4 Marine Mammal and Sea Turtle VEC 164

5.6.5 Species at Risk (SAR) VEC 180
5.6.6 Sensitive Areas VEC..... 184
5.7 Cumulative Effects 184
5.8 Mitigations and Follow-up..... 186
5.9 Assessment Summary 188
6.0 Literature Cited..... 190
Appendix A. Seabird Summary Tables…….... A-1
Appendix B. Persons Consulted……...B-1
Appendix C. SPOC (and FLO) Protocols, Procedures and Reporting Forms…….. C-1
Appendix D. Review of Potential Effects of Airgun Sound on Marine Invertebrates……... D-1
Appendix E. Review of Potential Effects of Airgun Sound on Fishes……..... E-1
Appendix F. Review of Potential Effects of Airgun Sound on Marine Mammals…….. F-1
Appendix G. Review of Potential Effects of Airgun Sound on Sea Turtles……G-1

List of Figures

Page

Figure 1.1. Locations of the Project Area and Study Area for Suncor's Proposed 2D/3D/4D Seismic Program, 2014 to 2024. 1
Figure 3.1. Location of the Grid Points (14845, 13912, and 11423) and Regions used in the Physical Environment Analyses. 15
Figure 3.2. The Major Circulation Features Around the Flemish Cap and Sackville Spur. 21
Figure 3.3. Iceberg Sightings within the Project Area 24
Figure 3.4. Iceberg Sightings in Region 1 of the Project Area from 1974-2009. Study and Project Areas outlined in red (outer and inner dashed lines, respectively). 24
Figure 3.5. Iceberg Size by Month within Region 1 of the Project Area. 25
Figure 3.6. Iceberg Sightings in Region 2 of the Project Area from 1974-2009. Study and Project Areas outlined in red (outer and inner dashed lines, respectively). 26
Figure 3.7. Iceberg Size by Month within Region 2 of the Project Area. 27
Figure 3.8. Iceberg Sightings in Region 3 of the Project Area from 1974-2009. Study and Project Areas outlined in red (outer and inner dashed lines, respectively). 27
Figure 3.9. Iceberg Size by Month within Region 3 of the Project Area. 27
Figure 4.1. Study Area Location Relative to NAFO Unit Areas. 52
Figure 4.2. Annual Catch Weight within Study Area UAs, 1986-2010, Groundfish. 54
Figure 4.3. Annual Catch Weight within Study Area UAs, 1987-2010, Shrimp and Snow Crab. 55
Figure 4.4. Annual Catch Weight within Study Area UAs, 1986-2010, All Species Combined. 55
Figure 4.5. Annual Total Catch Weight of Newfoundland-landed Harvests within the Study Area, All Species Combined, 2005 to 2010. 57
Figure 4.6. Harvesting Locations of All Species Combined, 2005-2010. 58
Figure 4.7. Harvest Location Coverage of all Species Combined within the Study Area, 2011 (top) and 2012 (bottom). 59
Figure 4.8. Fixed (top) and Mobile (bottom) Harvesting Locations, 2005 to 2010 Combined. 61
Figure 4.9. Average Monthly Catch Weight of all Species in the Study Area, 2005 to 2010 Combined. 62
Figure 4.10. Northern Shrimp Fishing Areas. 63
Figure 4.11. Proportional (top) and Non-proportional (bottom) Northern Shrimp Harvesting Locations in the Study Area, 2005 to 2010. 64
Figure 4.12. Northern Shrimp Harvesting Locations by Landed Catch Weight Quartile Ranges, 2011. 65
Figure 4.13. Northern Shrimp Harvesting Locations by Landed Catch Weight Quartile Ranges, 2012. 65
Figure 4.14. Annual Northern Shrimp Catch Weight in the Study Area, 2005 to 2010. 66
Figure 4.15. Average Monthly Northern Shrimp Catch Weight in the Study Area, 2005 to 2010. 66
Figure 4.16. Newfoundland Snow Crab Fishing Areas. 67
Figure 4.17. Proportional (top) and Non-proportional (bottom) Snow Crab Harvesting Locations in the Study Area, 2005 to 2010. 68
Figure 4.18. Snow Crab Harvesting Locations by Landed Catch Weight Quartile Ranges, 2011. 69
Figure 4.19. Snow Crab Harvesting Locations by Landed Catch Weight Quartile Ranges, 2012. 69

Figure 4.20. Annual Snow Crab Catch Weight in the Study Area, 2005 to 2010. 70
Figure 4.21. Average Monthly Snow Crab Catch Weight in the Study Area, 2005 to 2010..... 70
Figure 4.22. Proportional (top) and Non-proportional (bottom) Stimpson's Surf Clam Harvesting Locations in the Study Area, 2005 to 2010. 72
Figure 4.23. Stimpson's Surf Clam Harvesting Locations by Landed Catch Weight Quartile Ranges, 2011..... 73
Figure 4.24. Proportional (top) and Non-proportional (bottom) Greenland Halibut Harvesting Locations in the Study Area, 2005 to 2010. 74
Figure 4.25. Greenland Halibut Harvesting Locations by Landed Catch Weight Quartile Ranges, 2011. 75
Figure 4.26. Greenland Halibut Harvesting Locations by Landed Catch Weight Quartile Ranges, 2012. 75
Figure 4.27. Annual Greenland Halibut Catch Weight in the Study Area, 2005 to 2010. 76
Figure 4.28. Average Monthly Greenland Halibut Catch Weight in the Study Area, 2005 to 2010. 76
Figure 4.29. DFO RV Survey Catch Locations within the Study Area, 2007 to 2011 Combined. 79
Figure 4.30. DFO RV Survey Proportional Northern Shrimp Catch Locations within the Study Area, 2007 to 2011 Combined. 82
Figure 4.31. DFO RV Survey Proportional Snow Crab Catch Locations within the Study Area, 2007 to 2011 Combined. 82
Figure 4.32. DFO RV Survey Proportional Greenland Halibut Catch Locations within the Study Area, 2007 to 2011 Combined. 83
Figure 4.33. DFO RV Survey Proportional Roughhead Grenadier Catch Locations within the Study Area, 2007 to 2011 Combined. 83
Figure 4.34. DFO RV Survey Proportional Deepwater Redfish Catch Locations within the Study Area, 2007 to 2011 Combined 84
Figure 4.35. DFO RV Survey Proportional American Plaice Catch Locations within the Study Area, 2007 to 2011 Combined. 84
Figure 4.36. DFO RV Survey Proportional Atlantic Cod Catch Locations within the Study Area, 2007 to 2011 Combined. 85
Figure 4.37. DFO RV Survey Proportional Atlantic, Northern and Spotted Wolffish Catch Locations within the Study Area, 2007 to 2011 Combined. 86
Figure 4.38. Joint DFO-Industry Post-season Crab Survey Locations, 2013. 87
Figure 4.39. Locations of Seabird Nesting Colonies at Important Bird Areas (IBAs) relative to the Study Area. 90
Figure 4.40. Baleen Whale Sightings in the Study Area. 105
Figure 4.41. Large Toothed Whale Sightings in the Study Area. 105
Figure 4.42. Dolphin and Porpoise Sightings in the Study Area. 106
Figure 4.43. Locations of the NL Shelves EBSAs, PBGB LOMA EBSAs, Bonavista Cod Box, and NAFO Coral/Sponge Closure Areas Relative to the Suncor Project Area. 125

List of Tables

Page

Table 3.1. Number of Storms Providing Best Fit for Extreme Value Analysis of Winds and Waves. 15
Table 3.2. 1-Hour Extreme Wind Speed Estimates (m/s) for Return Periods of 1, 10, 25, 50 and 100 Years. 16
Table 3.3. 10-Minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years. 17
Table 3.4. 1-Minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years. 17
Table 3.5. Extreme Significant Wave Height Estimates (m) for Return Periods of 1, 10, 25, 50 and 100 Years. 18
Table 3.6. Extreme Maximum Wave Height Estimates (m) for Return Periods of 1, 10, 25, 50 and 100 Years. 19
Table 3.7. Extreme Associated Peak Period Estimates (m) for Return Periods of 1, 10, 25, 50 and 100 Years. 19
Table 4.1. Reproduction Specifics of Macroinvertebrate and Fish Species likely to Reproduce within or near the Study Area. 50
Table 4.2. Average Annual Study Area Catch Weight by Species, 2005 to 2010. 56
Table 4.3. Average Annual Study Area Catch Weight by Gear Type, 2005 to 2010. 60
Table 4.4. Catch Weights and Numbers of Macroinvertebrate and Fish Species Collected during 2007 to 2011 DFO RV Surveys within the Study Area. 78
Table 4.5. Percentage Catch and Mean Catch Depth by Survey Season for Macroinvertebrates and Fishes Caught during DFO RV Surveys within the Study Area, 2007 to 2011 Combined. 80
Table 4.6. Total Catch Weights and Predominant Species Caught at various Mean Catch Depth Ranges, 2007 to 2011 DFO RV Surveys Combined. 81
Table 4.7. Predicted Monthly Abundances of Seabird Species Occurring in the Study Area. 89
Table 4.8. Numbers of Pairs of Marine Birds Nesting at Marine Bird Colonies in Eastern Newfoundland. 91
Table 4.9. Foraging Strategy and Prey of Seabirds in the Study Area. 99
Table 4.10. Marine Mammals Known or Expected to Occur in the Study Area. 103
Table 4.11. Cetacean Sightings within the Study Area, 1961 to 2009. 104
Table 4.12. Sea Turtles Potentially Occurring in the Study Area. 114
Table 4.13. *SARA*- and COSEWIC-Listed Marine Species that Potentially Occur in the Study Area. 116
Table 5.1. Potential Interactions of the Project Activities and the Fish and Fish Habitat VEC. 141
Table 5.2. Assessment of Effects on the Fish and Fish Habitat VEC. 149
Table 5.3. Significance of Potential Residual Environmental Effects of Project Activities on the Fish and Fish Habitat VEC. 150
Table 5.4. Potential Interactions of Project Activities and the Fisheries VEC. 153
Table 5.5. Assessment of Effects on the Fisheries VEC. 157
Table 5.6. Significance of Potential Residual Environmental Effects on the Fishery VEC. 158
Table 5.7. Potential Interactions between the Project and Seabird VEC. 161
Table 5.8. Assessment of Effects on the Seabird VEC. 165

Table 5.9. Significance of Potential Residual Environmental Effects of the Project on the Seabird VEC. 166
Table 5.10. Potential Interactions between the Project and the Marine Mammal and Sea Turtle VECs. 167
Table 5.11. Assessment of Effects on the Marine Mammal VEC. 172
Table 5.12. Significance of Potential Residual Environmental Effects of the Proposed Geophysical Program on the Marine Mammal VEC. 173
Table 5.13. Assessment of Effects on the Sea Turtle VEC. 176
Table 5.14. Significance of Potential Residual Environmental Effects of the Proposed Geophysical Program on the Sea Turtle VEC. 178
Table 5.15. Potential Interactions between the Project and Species at Risk VEC. 181
Table 5.16. Assessment of Effects on the Species at Risk VEC. 182
Table 5.17. Significance of Potential Residual Environmental Effects of the Proposed Geophysical Program on the Species at Risk VEC. 183
Table 5.18. Summary of Mitigations Measures. 187
Table 5.19. Significance of Potential Residual Environmental Effects of the Proposed Geophysical Program on VECs in the Study Area. 189

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1.0 Introduction

Suncor Energy (Suncor) is proposing to conduct 2D/3D/4D seismic survey program(s) in offshore Newfoundland and Labrador (the Project) in an area that includes portions of the Jeanne d'Arc Basin, the Flemish Pass and Orphan Basin (Figure 1.1). The Project will also include wellsite surveys (i.e., geohazard surveys) and Vertical Seismic Profiling (VSP). The Project is proposed for an eleven-year period 2014-2024. It is currently uncertain whether Suncor will conduct seismic surveys in 2014.

This document is an environmental assessment (EA) prepared to allow the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) to fulfill its responsibilities under Section 138 (1) (b) of the *Canada-Newfoundland Atlantic Accord Implementation Act* and Section 134 (1) (b) of the *Canada-Newfoundland and Labrador Act* (Accord Acts). This EA has been guided by the Scoping Document prepared by the C-NLOPB (C-NLOPB 2013), as well as by advice and information received and issues identified by other federal agencies and stakeholder groups.

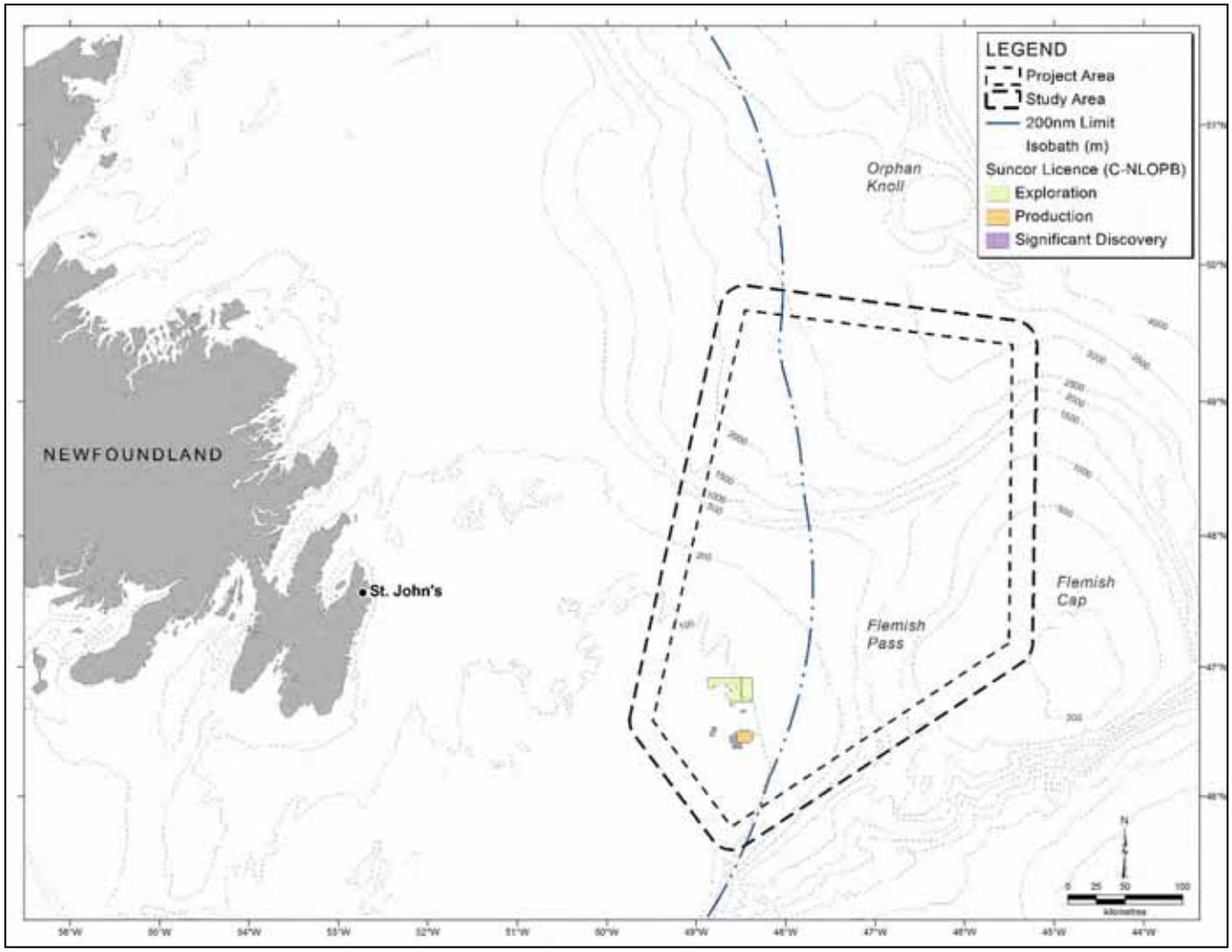


Figure 1.1. Locations of the Project Area and Study Area for Suncor's Proposed 2D/3D/4D Seismic Program, 2014 to 2024.

1.1 Relevant Legislation and Regulatory Approvals

An *Authorization to Conduct a Geophysical Program* will be required from the C-NLOPB. The C-NLOPB is mandated as a regulator by the *Canada-Newfoundland Atlantic Accord Implementation Act* and the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act*. Pursuant to the Accord Acts, the C-NLOPB 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 seabirds, marine mammals, sea turtles, and fish and fisheries, Fisheries and Oceans Canada (DFO) and Environment Canada (EC) are the agencies that will have the most involvement in the EA process.

Legislation that is relevant to the environmental aspects of the Project includes:

- *Canada-Newfoundland Atlantic Accord Implementation Act*
- *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act*
- *Oceans Act*
- *Fisheries Act*
- *Navigable Waters Act*
- *Canada Shipping Act*
- *Migratory Bird Convention Act*
- *Species at Risk Act (SARA)*

Suncor will follow guidelines issued by the C-NLOPB, the *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2012). The Project will also be guided by DFO's *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment* that forms part of the above-noted guidelines, and other advice received during the consultations for this Project.

The Board has formally delegated the responsibility for the preparation of an acceptable environmental assessment report and any supporting documents to Suncor Energy, the Project Proponent.

1.2 The Proponent: Suncor Energy

Suncor Energy, the Operator, is one of the largest integrated oil and gas companies in Canada. Headquartered in Calgary, Alberta, Suncor is a Canadian-based integrated energy company serving global customers and committed to conducting its offshore oil and gas operations in an environmentally responsible manner.

Suncor is the management and operating company for ten Significant Discovery Licences, three Production Licences, and two Exploration Licences on the northern Grand Banks. The Terra Nova Field, the largest of the Operator's Significant Discovery Areas, is estimated to contain approximately 500 million barrels of recoverable reserves. Suncor is also a major partner in the Hibernia, White Rose and Hebron developments.

1.3 Canada-Newfoundland and Labrador Benefits

An important aspect of the C-NLOPB's mandate is the administration of provisions in the Accord Acts relating to industrial and employment benefits from the development of oil and gas resources in the Newfoundland and Labrador Offshore Area for Canada in general, and for Newfoundland and Labrador in particular.

The Accord Acts require that before any work or activity is authorized in the offshore area, a Canada-Newfoundland and Labrador Benefits Plan must be approved by the Board. In general, a benefits plan must describe the Proponent's plan for the employment of Canadians and, in particular, members of the labour force of the province. The Terra Nova Development Application Canada-Newfoundland Benefits Plan also contains plans for providing manufacturers, consultants, contractors and service companies in the province and other parts of Canada with a full and fair opportunity to participate on a competitive basis in the supply of goods and services.

Suncor manages East Coast operations from its St. John's office. Canadian, and in particular, Newfoundland and Labrador individuals and organizations are provided with full and fair opportunity to participate in Suncor's activities on the East Coast. Suncor also supports the principle that first consideration be given to personnel, support and other services that can be provided by Newfoundland and Labrador, and to goods manufactured in Newfoundland and Labrador where such goods and services are competitive in terms of fair market price, quality and delivery. Contractors and subcontractors working for Suncor on its East Coast operations must also subscribe to and apply these principles in their own operations.

Suncor is committed to bringing maximum benefits associated with East Coast operations to Canada, especially Newfoundland and Labrador, where commercially achievable in accordance to their operating philosophy and legislative requirements. In the spirit of the Atlantic Accord, Suncor actively seeks to enhance the participation of Canadian and Newfoundland and Labrador individuals and organizations in offshore oil and gas activity on the East Coast.

1.4 Contacts

Relevant contacts at Suncor for the proposed Project include:

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2.0 Proposed Project

2.1 Name and Location

The official name of the Project is "*Suncor Energy's Eastern Newfoundland Offshore Area 2D/3D/4D Seismic Program, 2014-2024*." Suncor is proposing to conduct 2D/3D/4D seismic, VSP and wellsite surveys in an area of the eastern Newfoundland offshore area that includes portions of the Jeanne d'Arc Basin, the Flemish Pass and Orphan Basin (see Figure 1.1).

2.2 Spatial and Temporal Boundaries

The ***spatial boundaries*** of the Project Area are shown in Figure 1.1. The Study Area includes the Project Area plus a 25 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). The corner coordinates of the Study Area are as follows:

- North: 49.850°N;
- East: 45.196°W;
- South: 45.579°N; and
- West: 49.748°W

The areas of the Study Area and Project Area are 117,899 and 92,268 km^2, respectively.

The ***temporal scope*** of the proposed 2D/3D/4D surveys is typically between 1 May and 31 December, 2014-2024. As indicated above, it is uncertain whether Suncor will conduct seismic surveys in 2014. The duration of a 2D/3D/4D survey is estimated at 30 to 120 days in any given year.

The ***temporal scope*** of proposed wellsite surveys is typically between 1 March and 31 December, 2014-2024. The duration of a typical wellsite survey is estimated at 7 to 14 days in any given year.

The ***temporal scope*** of proposed VSP is any time of the year, 2014-2024. The duration of a typical VSP survey is estimated at a few days in any given year.

2.3 Project Overview

The objective of the Project is to determine the presence and likely locations of geological structures that might contain hydrocarbon deposits. This is typically done in a stepwise fashion. In general, 2D surveys are used to determine areas where precise and detailed 3D surveys should be done. The 3D data provide higher resolution and quality images than are available from 2D surveys which use more widely spaced seismic lines. Results of 3D surveys are then used to find potential locations for exploration drilling. The 4D surveys (i.e., 3D seismic surveys over an area previously imaged by 3D) would be used to monitor fluid and pressure changes in the reservoirs and also to aid in optimization of future development well locations. The 4D data would become part of a reservoir management plan.

Wellsite surveys may be conducted after potential drill sites have been identified. Wellsite surveys involve the acquisition of high resolution seismic, sub-bottom profile, side scan sonar and bathymetric data over a proposed drill site. Seismic data collected during wellsite surveys are typically acquired

over survey lines spaced closer together (e.g., 250 m spacing), and data are acquired using smaller equipment with lower source levels and over a shorter time period (several days vs. months) relative to 2D and 3D seismic surveys. Surficial data are collected using a broadband boomer or sparker (500 Hz to 6 kHz) as a sound source which provides information on the shallow sediments of the seabed. A single or multibeam echo sounder (~100 to 400 kHz) provides bathymetric data and a side scan sonar (dual frequency, ~100/500 kHz) is used to obtain seabed imagery. Seabed video and/or grab samples permit ground-truthing of the characteristics of the seabed and sediments.

Vertical Seismic Profiling is normally conducted after some drilling has been completed. These programs use hydrophones suspended in the well at intervals which receive signals from external sound sources, usually airgun(s) suspended from the drill rig or a nearby supply vessel. Data are used to aid in determining the structure of a particular petroleum-bearing zone.

The seismic survey vessel(s) used during the proposed program will be approved for operation in Canadian waters and will be typical of the worldwide survey fleet. Specific vessels have not yet been selected as Suncor currently does not have a seismic program planned.

The C-NLOPB's *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2012) will be used as the basis for the marine mammal monitoring and mitigation program for the seismic surveys. Dedicated Marine Mammal Observers (MMOs) will monitor for marine mammals (and sea turtles if present) and implement mitigation measures as appropriate. In addition, the MMOs will conduct seabird observations [as per the guidelines (C-NLOPB 2012)] and a release program for seabirds which may strand on board the seismic vessel. As required, a fisheries liaison officer (FLO) will be on board to ensure implementation of communication procedures intended to minimize conflict with the commercial fishery.

2.3.1 Objectives and Rationale

The primary objective of the Project is to acquire data to assess the presence of geological structures suitable for the containment and accumulation of hydrocarbons and to determine the hydrocarbon characteristics.

2.3.2 Alternatives to the Project and within the Project

Suncor has made commitments to pursue exploration activities on its exploration licenses in the Study Area. The 2D/3D seismic surveys are standard precursors to offshore exploratory drilling. The 3D surveying better defines the target subsurface geological formations believed to contain hydrocarbon resources, lessens the chances of expending resources "drilling dry holes" and increases the overall safety of the drilling activity. Accordingly, there is no alternative to the proposed 3D survey program other than to incur the financial penalties attendant on not fulfilling Suncor's exploration commitments and to explore for oil and gas elsewhere.

Viable alternatives within the program's surveys are essentially the choices between different contractor's ships and survey equipment which will be evaluated through the bid evaluation process.

2.3.3 Project Scheduling

The proposed 2D/3D/4D surveys will normally be conducted between 1 May and 31 December, 2014-2024. The duration of a 2D/3D/4D survey is estimated at 30 to 120 days in any given year.

Proposed wellsite surveys will normally be conducted between 1 March and 31 December, 2014-2024. The duration of a typical wellsite survey is estimated at 7 to 14 days in any given year.

Proposed VSP will be conducted at any time of the year, 2014-2024. The duration of a typical VSP survey is estimated at a few days in any given year.

2.3.4 Site Plans

The survey line orientations for the proposed 2D/3D/4D seismic surveys have not yet been determined. The Project Area proposed for the 2014-2024 geophysical surveys is shown in Figure 1.1. Water depths in the Project Area range from <100 m to >3,000 m.

2.3.5 Personnel

A typical seismic vessel can accommodate approximately 50-100 personnel. Personnel on a seismic vessel include ship's officers and marine crew as well as technical and scientific personnel. The seismic vessel used for 2D/3D/4D surveys will also have at least one MMO and FLO on board. Wellsite surveying and VSP will also include at least one MMO. All project personnel will have all of the required certifications as specified by the relevant Canadian legislation and the C-NLOPB.

2.3.6 Seismic Vessel

Specifics of seismic vessels will be provided in subsequent document submissions once the vessels have been identified. The selected ships will be fully equipped and suited to the environment and task, and will meet applicable legal certification and requirements.

2.3.7 Seismic Energy Source Parameters

The proposed 2D/3D/4D survey sound sources will likely consist of one or two airgun arrays, 3,000 to 6,000 in^3 in total volume, which will operate at towed depths between 6 and 15 m. The airguns will be operated with compressed air at pressures of 2,000 to 2,500 psi, and produce approximate peak-to-peak pressures of 100 to 200 bar-m.

The proposed wellsite surveys will likely be conducted with one array consisting of up to four airguns, up to 160 in^3 in total volume (with each airgun 40 in^3). Operating pressure of the airguns will be a maximum of 2,000 psi, and produce an approximate peak-to-peak pressure of 100 bar-m.

Detailed specifications of the airgun arrays will be provided once the survey designs are completed and parameters are selected.

2.3.8 Seismic Streamers

The 2D/3D/4D seismic surveys will use towed streamers with an approximate length of 8,000 m and deployed at depths ranging from 5 to 80 m. Typically 10 to 14 streamers (strings of hydrophone sound receivers), are towed behind the seismic vessel to record the airgun pulses during 3D seismic surveys. [Individual stand alone 2D profiles might be acquired by the 3D vessel without any change of configuration or by a different vessel towing only one streamer.] The streamers are typically separated by 100 m.

The wellsite surveys will use a single towed streamer approximately 600 m in length, likely deployed at a depth of 3 m.

Streamer equipment specifications will be provided when survey designs are complete. Depending on the survey design, streamer equipment specifications will vary. Streamer flotation could potentially include, but is not limited to, solid or liquid-filled streamers.

2.3.9 Logistics and Support

Details of logistical operations to support the Project will largely depend on the contracted seismic acquisition company. Offshore seismic operations will be supported by a picket and/or supply vessel and potentially a helicopter.

2.3.9.1 Vessels

The seismic survey vessel(s) used during the proposed program will be approved for operation in Canadian waters and will be typical of the worldwide fleet. Specific vessels have not yet been selected. The 2D seismic survey vessel will tow one or two sound sources (airgun arrays) and a single streamer with receiving hydrophones. The 3D seismic survey vessel will tow two sound sources and multiple streamers. The streamers will be up to several kilometres in length. The 4D seismic survey will involve one or two vessels which will also tow two sound sources and multiple streamers.

In order to mitigate any potentially adverse effects on marine animals, the commercial fisheries, and other vessel traffic, a mitigation plan will be developed as part of the Project. A standby or picket vessel may be required as a mitigation measure for any 2D/3D/4D seismic surveying. This vessel would be used as an additional method to obtain information on commercial fishing activity in the area and to warn other vessels in order to avoid gear losses for all parties involved. It would also be used to scout ahead of the seismic vessel for hazards such as ice and floating debris.

Offshore supply vessels will re-supply the seismic vessel with water, food, equipment parts, fuel, etc. throughout the duration of the Project. The supply vessels will be typical of those that regularly service the Newfoundland offshore.

2.3.9.2 Helicopter

The seismic vessel may be equipment with a helicopter deck and helicopters are often used for crew changes and light re-supply. It is not known at this time whether helicopters will be used for crew changes during the proposed seismic program(s). Once the final extents of the 2D/3D/4D seismic

surveys are determined, the necessity for and feasibility of helicopter support for crew changes will be determined.

2.3.9.3 Shore Base, Support and Staging

Suncor will maintain operational offices and use existing shore facilities in St. John's. No new shore base facilities will be established as part of the Project.

2.3.10 Waste Management

Waste management will be consistent with industry best practices in offshore Newfoundland and Labrador. Wastes produced from the seismic, supply and picket vessels, including grey and black water, bilge water, deck drainage, discharges from machinery spaces and hazardous and non-hazardous waste material will be managed in accordance with applicable legislation and with Suncor's East Coast Waste Management Plan (OD-PE-EVO3-X00-001). The contracted vessels' policies and procedures will be reviewed against the Suncor Plan. Suncor's East Coast Waste Management Plan is currently on file with the C-NLOPB.

2.3.11 Air Emissions

Air emissions will be those associated with standard operations for marine vessels, including the seismic vessel and any potential picket and/or supply vessel. There are no anticipated implications for the health and safety of workers on these vessels.

2.3.12 Accidental Events

In the unlikely event of an emergency, including the accidental release of hydrocarbons during the Project, the Operator and its seismic contractor will implement the measures outlined in Suncor's various emergency response plans which are on file with the C-NLOPB.

2.4 Mitigations

Project mitigations will follow the guidance provided in the *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2012), and the associated *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment*. Mitigation procedures will include, but are not limited to, the planning of seismic surveys, safety zone and airgun ramp-up requirements, implementation of ramp-up delays and airgun array shutdowns for designated marine mammal and sea turtle species, line change and maintenance shut-down requirements, operations in low visibility, use of dedicated MMOs and a FLO (as required), and a fisheries compensation program. The Operator recognizes that the fisheries have a long tradition off Newfoundland and Labrador and that both industries are important users of the sea and seabed.

2.5 Project Site Information

Project location is in the eastern Newfoundland offshore area (see Figure 1.1).

2.5.1 Environmental Features

The physical and biological environments of the general area have been described in recent EAs for the northern Grand Banks and Flemish Pass (e.g., LGL 2011a,b, 2012a,b, 2013a,b). Summaries of the physical and biological environments, based on the previous EAs plus any new information, are provided below (Sections 3.0 and 4.0).

2.5.2 Physical Environment and Effects on the Project

A description of the general physical environment of the area is contained in recent EAs for the northern Grand Banks and Flemish Pass (e.g., LGL 2011a,b, 2012a,b, 2013a,b) and is summarized in Section 3.0. The survey will be conducted in water depths ranging from <100 m to >3,000 m. The scheduling of 2D/3D/4D seismic, wellsite and VSP surveys during a period (e.g., May to December) when NW Atlantic operating conditions (e.g., temperatures, wind, wave and ice conditions) are generally better than the January to April period should lessen any effects of the environment on the Project.

A summary of expected effects of the physical environment on the Project, based on information in the SEA for the Orphan Basin (LGL 2003) and previous EAs, as well as any new information, is provided in Section 5.5.

2.5.3 Fish and Fish Habitat

Fish and fish habitat, including marine invertebrates and physical attributes, have been discussed in detail in previous EAs for the Jeanne d'Arc Basin and the Flemish Pass. These components of the ecosystem are summarized in Section 4.2, based on previous EAs and other relevant documents, and any new information.

2.5.4 Species at Risk

The Project Area is not known to contain any sensitive areas or critical habitats for species listed on Schedule 1 of the *Species at Risk Act* (*SARA*). Several species listed as *endangered*, *threatened*, or of *special concern* on Schedule 1 of *SARA*, including the blue whale, North Atlantic right whale, fin whale, Sowerby's beaked whale, leatherback sea turtle, Ivory gull, white shark and three wolffish species, may occur in the Project Area. The potential effects on these species and those currently considered *endangered*, *threatened*, or of *special concern* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) which may occur in the Study Area are discussed in Section 5.5.5.

2.6 Other Users

2.6.1 Fisheries

The Project Area supports a variety of fisheries as described in Section 4.3 based on the latest available DFO catch landings data. Some of the most important fisheries in and adjacent to the Project Area include those for northern shrimp, snow crab, and Greenland halibut.

Plans will be developed to avoid or lessen any potential effects on the fisheries. These plans will include mitigations such as good communications (e.g., fishery broadcast notifications), the presence of a FLO on the vessel for 2D/3D/4D seismic surveys, and a fishing gear damage compensation program. Consultations with the fishing industry (e.g., Fish, Food and Allied Workers [FFAW], Association of Seafood Producers [ASP], etc.) will be undertaken through the established One Ocean mechanism and directly with relevant fishing interests as necessary.

2.6.2 Navigable Waters

In addition to fishery vessels, potential users of the navigable waters in the offshore North Grand Banks regional area may include cargo and passenger vessels, other oil industry-related vessels, transport and military vessels, or other commercial ships.

2.6.3 Consultations

During the course of the assessment, Suncor will consult with stakeholders with an interest in the Project through the established One Ocean mechanism and FFAW/ASP, and directly with other relevant fishing interests as necessary. Those consulted and the results of those consultations are presented in Section 5.1.1.

2.6.4 Effects of the Project on the Environment

The proposed Project will be similar to many other programs routinely conducted offshore Newfoundland and elsewhere in eastern Canada, and is not expected to produce any adverse significant environmental effects on the marine environment in or adjacent to the Project Area. Nonetheless, potential environmental effects are examined in detail with focus on the fishery, *SARA* species, marine mammals, and cumulative effects from interactions with other users of the area, particularly any other potential seismic programs. Malfunctions and accidental events (such as an unplanned hydrocarbon release) associated with Project activities are also assessed in this EA (Section 5.6).

2.6.5 Spatial and Temporal Boundaries

The spatial boundaries for the Project are shown in Figure 1.1. Consideration was given to the Regional Area (i.e., the Grand Banks and Orphan Basin) when analyzing cumulative effects, including the information compiled in recent seismic EAs and the SEA (LGL 2003). The temporal boundaries for the proposed Project are 2014 to 2024 inclusive, as defined in Section 2.2 above.

2.6.6 Valued Ecosystem Components

As is common practice on the East Coast and as recommended in the Scoping Document (C-NLOPB 2013), a valued ecosystem component (VEC) approach was used in this EA. The VECs include:

- Fish and fish habitat;
- Fisheries;
- Seabirds;

- Marine mammals and sea turtles;
- Species at Risk; and
- Sensitive areas.

2.6.7 Environmental Mitigation and Monitoring

As noted previously, MMO(s) will be on board the vessel(s) to provide proper identification of marine mammals and species at risk for mitigation purposes, and to collect opportunistic data of marine mammal behaviour and distribution both during and outside of airgun operations. Information on marine bird occurrence and distribution will also be collected during the seismic surveys.

3.0 Physical Environment

The Scoping Document required that the EA include a review of the meteorological and oceanographic characteristics, including extreme conditions, in order to provide the basis for assessing the effects of the environment on the Project. A detailed description of met-ocean conditions in the Study and Project areas, and methodologies used, is contained in Oceans (2012). Summaries of the relevant sections of that report are provided below.

3.1 Bathymetry and Geology

As indicated in the Orphan Basin SEA (LGL 2003) and the White Rose Comprehensive Study (Husky 2000), the topography of the Study Area is highly diverse and includes at least four distinct types as characterized by depth, location, and physiography: (1) Jeanne d'Arc Basin (depths ≤200 m) in the southwestern portion of the Study Area; (2) northeast Newfoundland Shelf Slope and Flemish Cap Shelf (depths >200 to 2,000 m); (3) Orphan Basin (depths 2,000 to >3,000 m) in the northern portion of the Study Area; and (4) the Flemish Pass (depths >1,000 m). The characterization of surficial sediment in the Study Area ranges from fine (mud and clay) to extremely coarse (boulders and bedrock).

3.2 Climatology

Every marine seismic survey program is influenced by weather conditions both from routine operational and environmental safety perspectives. During routine activities, data quality and hence, survey time on site can be affected by weather, particularly wind and wave conditions. This section, based primarily on Oceans (2012), provides a general overview of climatic conditions in the Study Area with a more detailed description of extreme events. The reader is referred to Section 2.0 of Oceans (2012) for more details.

3.2.1 Weather Systems

The Study Area including the Northeast Grand Banks, Flemish Pass, and the southern Orphan Basin experiences weather conditions typical of a marine environment which moderates air temperatures. In general, marine climates experience cooler summers and milder winters than continental climates and have a much smaller annual temperature range. Furthermore, a marine climate tends to be fairly humid, resulting in reduced visibilities, low cloud heights, and significant amounts of precipitation.

The climate of the Study Area is very dynamic, being largely governed by the passage of high and low pressure circulation systems. These circulation systems are embedded in, and steered by, the prevailing westerly flow that arises because of the normal tropical to polar temperature gradient and typifies the upper levels of the atmosphere in the mid-latitudes. The mean strength of the westerly flow is a function of the intensity of this gradient, and as a consequence is considerably stronger in the winter months than during the summer months, due to an increase in the south to north temperature gradient. [Meteorological convention defines seasons by quarters; e.g., winter is December, January, February, etc.]

At any given time, the upper level flow is a wave-like pattern of large and small amplitude ridges and troughs. These ridges and troughs tend to act as a steering mechanism for surface features and therefore their positions in the upper atmosphere determine the weather at the earth's surface. Upper ridges tend to support areas of high pressure at the surface, while upper troughs lend support to low pressure developments. The amplitude of the upper flow pattern tends to be greater in winter than summer, which is conducive to the development of more intense storm systems.

During the winter months, an upper level trough tends to lie over Central Canada and an upper ridge over the North Atlantic resulting in three main storm tracks affecting the region: one from the Great Lakes Basin, one from Cape Hatteras, North Carolina, and one from the Gulf of Mexico. These storm tracks, on average, bring eight low pressure systems per month over the area. The intensity of these systems ranges from relatively weak features to major winter storms.

Frequently, intense low pressure systems become 'captured' and slow down or stall off the coast of Newfoundland and Labrador. This may result in an extended period of little change in conditions that may range, depending on the position, overall intensity and size of the system, from the relatively benign to heavy weather conditions.

Rapidly deepening storms are a problem south of Newfoundland in the vicinity of the warm water of the Gulf Stream. Sometimes these explosively deepening oceanic cyclones develop into a "weather bomb"; defined as a storm that undergoes central pressure decreases greater than 24 mb over 24 hours. Hurricane force winds near the center, the outbreak of convective clouds to the north and east of the center during the explosive stage, and the presence of a clear area near the center in its mature stage (Rogers and Bosart 1986) are typical of weather bombs. After development, these systems will either move across Newfoundland or near the southeast coast producing gale to storm force winds from the southwest to south over the area.

With increasing solar radiation during spring, there is a general warming of the atmosphere that is relatively greater at higher latitudes. This spring warming results in a decrease in the north-south temperature gradient. By summer, the main storm tracks have moved further north than in winter, and storms are less frequent and much weaker. With the low pressure systems passing to the north of the region, the prevailing wind direction during the summer months is from the southwest to south. As a result, the incidences of gale or storm force winds are relatively infrequent during summer.

3.2.2 Extreme Analysis

An analysis of extreme wind and waves was performed by Oceans (2012) using the MSC50 data set. This data set was determined to be the most representative of the available data sets, as it provides a continuous 52-year period of hourly data for the Project Area. The extreme values for wind speeds and waves were calculated using the peak-over-threshold method. After considering four different distributions, the Gumbel distribution was chosen to be the most representative as it provided the best fit to the data. Since extreme values can vary, depending on how well the data fits the distribution, a sensitivity analysis was carried out to determine how many storms to use in the analysis. The number of storms determined to provide the best fit annually and monthly for each of three grid points used in the analyses are presented in Table 3.1 and Figure 3.1.

Table 3.1. Number of Storms Providing Best Fit for Extreme Value Analysis of Winds and Waves.

Grid Point No.	Parameter	Annually	Monthly
14845	Wind	265	66
	Wave	181	58
13912	Wind	314	84
	Wave	192	79
11423	Wind	259	107
	Wave	251	76

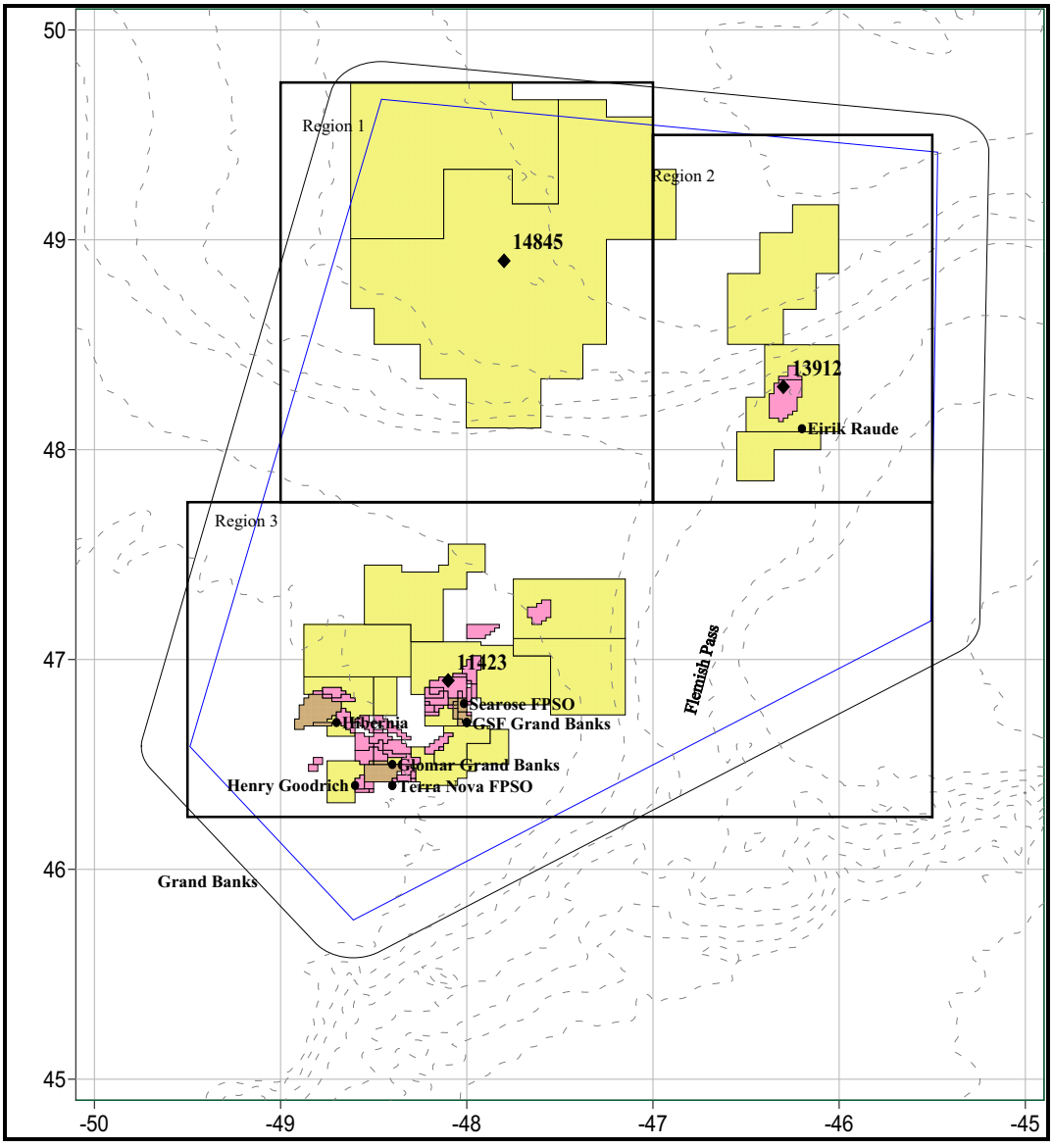


Figure 3.1. Location of the Grid Points (14845, 13912, and 11423) and Regions used in the Physical Environment Analyses.

3.2.2.1 Extreme Value Estimates for Winds from the Gumbel Distribution

The extreme value estimates for wind were calculated by Oceans (2012) using Oceanweather's Osmosis software for the return periods of 1-year, 10-years, 25-years, 50-years and 100-years. The analysis used hourly mean wind values for the reference height of 10 m above sea level. These values were converted to 10-minute and 1-minute wind values using a constant ratio of 1.06 and 1.22, respectively (U.S. Geological Survey 1979).

The calculated annual and monthly wind values for 1-hour, 10-minutes and 1-minute are presented in Tables 3.2 to 3.4. The annual 100-year extreme 1-hour wind speed was determined to be 32.8 m/s for grid point 14845, 33.1 m/s for grid point 13912, and 32.3 m/s for grid point 11423. Monthly, the highest 100-year extreme winds occurred during the month of February. From May to December, the highest 100-year extreme 1-hour wind speeds occur in December, while the lowest occur in July.

Table 3.2. 1-Hour Extreme Wind Speed Estimates (m/s) for Return Periods of 1, 10, 25, 50 and 100 Years.

	Grid Point #14845					Grid Point #13912					Grid Point #11423				
Month	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	23.3	26.8	27.8	28.6	29.3	23.3	27.1	28.4	29.3	30.3	22.8	26.5	27.8	28.8	29.7
February	22.5	28.1	29.8	31.1	32.4	23.0	28.0	29.6	30.9	32.1	22.4	27.2	28.9	30.2	31.5
March	20.9	25.9	27.4	28.6	29.7	20.8	20.6	27.2	28.4	29.6	20.5	24.9	26.5	27.7	28.8
April	18.6	22.4	23.6	24.4	25.3	18.7	22.5	23.8	24.8	25.7	18.2	22.5	24.0	25.2	26.3
May	16.1	21.0	22.5	23.6	24.7	16.5	20.9	22.4	23.5	24.6	15.7	19.7	21.1	22.1	23.2
June	14.8	19.0	20.2	21.2	22.1	15.1	18.8	20.1	21.0	21.9	14.7	18.4	19.8	20.8	21.8
July	13.5	16.6	17.6	18.3	19.0	13.6	16.8	17.8	18.6	19.4	13.5	16.7	17.9	18.7	19.6
August	14.2	19.4	21.0	22.1	23.3	14.4	20.7	22.9	24.5	26.0	14.7	21.1	23.3	25.0	26.7
September	17.3	23.3	25.1	26.5	27.9	17.7	24.0	26.2	27.8	29.4	17.2	22.6	24.6	26.0	27.4
October	18.3	25.0	27.0	28.5	30.0	19.0	24.4	26.3	27.7	29.0	18.6	23.5	25.3	26.6	27.9
November	20.3	25.0	26.4	27.8	28.5	20.5	24.8	26.3	27.3	28.4	20.0	24.4	25.9	27.1	28.2
December	22.2	27.6	29.2	30.4	31.6	22.4	27.6	29.3	30.6	31.8	22.0	26.5	28.1	29.3	30.4
Annual	26.0	29.5	30.8	31.8	32.8	25.9	29.6	31.0	32.1	33.1	25.3	28.9	30.2	31.2	32.3

Table 3.3. 10-Minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years.

	Grid Point #14845					Grid Point #13912					Grid Point #11423				
Month	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	24.7	28.4	29.5	30.3	31.1	24.7	28.7	30.1	31.1	32.1	24.1	28.0	29.4	30.5	31.5
February	23.9	29.8	31.6	33.0	34.3	24.4	29.6	31.4	32.7	34.0	23.8	28.9	30.7	32.0	33.4
March	22.1	27.4	29.1	30.3	31.5	22.1	21.8	28.8	30.1	31.4	21.7	26.4	28.1	29.3	30.5
April	19.8	23.8	25.0	25.9	26.8	19.8	23.9	25.2	26.3	27.3	19.2	23.8	25.5	26.7	27.9
May	17.1	22.3	23.8	25.0	26.2	17.5	22.1	23.7	24.9	26.1	16.6	20.8	22.3	23.5	24.6
June	15.7	20.1	21.4	22.4	23.4	16.0	19.9	21.3	22.3	23.2	15.5	19.5	21.0	22.0	23.1
July	14.3	17.6	18.6	19.4	20.1	14.4	17.8	18.9	19.8	20.6	14.3	17.7	18.9	19.9	20.8
August	15.0	20.5	22.2	23.5	24.7	15.2	22.0	24.2	25.9	27.6	15.6	22.3	24.7	26.5	28.3
September	18.3	24.7	26.6	28.1	29.5	18.7	25.5	27.8	29.5	31.2	18.2	24.0	26.0	27.5	29.1
October	19.4	26.4	28.6	30.2	31.8	20.1	25.9	27.9	29.3	30.8	19.7	24.9	26.8	28.2	29.6
November	21.5	26.5	28.0	29.4	30.3	21.8	26.3	27.8	29.0	30.1	21.2	25.8	27.5	28.7	29.9
December	23.6	29.2	30.9	32.2	33.5	23.8	29.2	31.0	32.4	33.8	23.3	28.0	29.7	31.0	32.3
Annual	27.5	31.2	32.6	33.7	34.8	27.5	31.4	32.8	34.0	35.1	26.8	30.6	32.0	33.1	34.2

Table 3.4. 1-Minute Extreme Wind Speed (m/s) Estimates for Return Periods of 1, 10, 25, 50 and 100 Years.

	Grid Point #14845					Grid Point #13912					Grid Point #11423				
Month	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	28.5	32.6	33.9	34.9	35.8	28.4	33.1	34.6	35.8	37.0	27.8	32.3	33.9	35.1	36.3
February	27.5	34.3	36.4	37.9	39.5	28.1	34.1	36.2	37.7	39.2	27.3	33.2	35.3	36.9	38.4
March	25.4	31.6	33.4	34.8	36.2	25.4	25.1	33.2	34.6	36.1	25.0	30.4	32.3	33.7	35.2
April	22.7	27.3	28.7	29.8	30.8	22.8	27.5	29.0	30.2	31.4	22.2	27.4	29.3	30.7	32.1
May	19.7	25.6	27.4	28.8	30.1	20.1	25.5	27.3	28.7	30.0	19.1	24.0	25.7	27.0	28.3
June	18.1	23.1	24.7	25.8	27.0	18.4	23.0	24.5	25.6	26.8	17.9	22.5	24.1	25.4	26.6
July	16.5	20.3	21.4	22.3	23.2	16.6	20.5	21.8	22.7	23.7	16.5	20.4	21.8	22.9	23.9
August	17.3	23.6	25.6	27.0	28.4	17.5	25.3	27.9	29.8	31.8	17.9	25.7	28.4	30.5	32.5
September	21.1	28.4	30.7	32.3	34.0	21.6	29.3	32.0	33.9	35.9	21.0	27.6	30.0	31.7	33.5
October	22.3	30.4	32.9	34.8	36.6	23.1	29.8	32.1	33.7	35.4	22.7	28.7	30.9	32.5	34.1
November	24.8	30.5	32.2	33.9	34.8	25.0	30.3	32.0	33.4	34.7	24.4	29.7	31.6	33.0	34.4
December	27.1	33.6	35.6	37.1	38.6	27.4	33.6	35.7	37.3	38.8	26.8	32.3	34.2	35.7	37.1
Annual	31.7	35.9	37.6	38.8	40.0	31.6	36.1	37.8	39.1	40.4	30.9	35.2	36.9	38.1	39.4

3.2.2.2 Extreme Value Estimates for Waves from a Gumbel Distribution

The annual and monthly extreme value estimates for significant wave height for return periods of 1-year, 10-years, 25-years, 50-years and 100-years are given in Table 3.5. The annual 100-year extreme significant wave height was 14.9 m at grid point 14845, 16.0 m at grid point 13912, and 15.0 m at grid point 11423. A storm with a return period of 100 years means that the calculated significant wave height will occur once every 100 years, averaged over a long period of time.

The maximum individual wave heights and extreme associated peak periods are presented in Table 3.6 and Table 3.7. Maximum individual wave heights and the extreme associated peak periods peak during the month of December at grid point 14845, and the month of February at grid points 13912 and 11423.

Table 3.5. Extreme Significant Wave Height Estimates (m) for Return Periods of 1, 10, 25, 50 and 100 Years.

	Grid Point #14845					Grid Point #13912					Grid Point #11423				
Month	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	9.2	12.1	12.9	13.5	14.0	10.1	12.8	13.7	14.4	15.0	9.2	12.0	12.9	13.5	14.2
February	8.5	12.1	13.0	13.7	14.4	9.4	13.0	14.2	15.0	15.9	8.5	12.2	13.4	14.3	15.2
March	6.8	10.1	10.9	11.6	12.2	7.8	10.5	11.4	12.1	12.8	7.1	10.0	11.0	11.7	12.4
April	5.7	9.0	9.9	10.5	11.1	6.4	9.2	10.0	10.7	11.4	5.7	8.6	9.6	10.3	11.0
May	4.2	8.1	9.1	9.9	10.6	5.1	8.1	9.1	9.9	10.6	4.6	7.2	8.1	8.7	9.4
June	3.4	6.5	7.3	7.9	8.5	4.1	6.5	7.3	7.9	8.5	3.8	6.1	6.9	7.4	8.0
July	3.1	5.2	5.8	6.2	6.6	3.3	5.4	6.0	6.4	6.8	3.4	5.3	5.9	6.3	6.8
August	3.5	6.2	6.9	7.4	7.9	4.1	6.5	7.2	7.8	8.4	3.8	6.7	7.7	8.4	9.1
September	4.5	10.1	11.5	12.6	13.6	5.8	10.3	11.7	12.8	13.9	5.3	9.3	10.6	11.6	12.5
October	5.7	10.8	12.2	13.1	14.1	6.7	11.1	12.5	13.6	14.6	6.3	10.0	11.2	12.1	13.0
November	7.2	11.3	12.4	13.1	13.9	8.1	11.5	12.6	13.4	14.2	7.4	10.5	11.5	12.3	13.0
December	9.0	12.5	13.5	14.2	14.9	9.7	12.9	14.0	14.8	15.6	8.9	11.7	12.7	13.4	14.1
Annual	11.3	13.2	13.9	14.4	14.9	11.8	14.0	14.8	15.4	16.0	10.8	13.0	13.8	14.4	15.0

Table 3.6. Extreme Maximum Wave Height Estimates (m) for Return Periods of 1, 10, 25, 50 and 100 Years.

	Grid Point #14845					Grid Point #13912					Grid Point #11423				
Month	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	16.9	22.6	24.1	25.3	26.4	18.8	24.0	25.7	27.0	28.3	17.0	22.0	23.6	24.8	26.0
February	15.8	22.4	24.2	25.4	26.7	17.5	24.1	26.2	27.9	29.5	15.8	22.6	24.8	26.5	28.1
March	12.5	19.1	20.8	22.1	23.4	14.5	19.7	21.4	22.7	24.0	13.4	18.7	20.4	21.7	23.0
April	10.6	16.5	18.0	19.2	20.3	12.1	17.1	18.7	20.0	21.2	10.7	15.9	17.7	18.9	20.2
May	7.5	15.6	17.7	19.2	20.7	9.9	15.7	17.7	19.1	20.5	8.7	14.0	15.7	17.0	18.3
June	6.6	12.0	13.4	14.4	15.4	7.9	12.1	13.5	14.5	15.6	7.4	11.6	13.0	14.0	15.0
July	5.9	9.9	10.9	11.7	12.4	7.0	10.0	11.1	11.8	12.6	6.5	9.9	11.0	11.8	12.6
August	6.7	11.5	12.7	13.6	14.5	7.8	12.2	13.7	14.7	15.8	7.2	12.3	14.0	15.3	16.6
September	8.7	18.4	20.9	22.8	24.6	10.9	18.6	21.2	23.1	25.0	10.0	17.0	19.2	20.9	22.6
October	10.5	20.0	22.5	24.3	26.1	12.8	20.5	23.1	25.0	26.9	11.8	18.5	20.7	22.4	24.0
November	13.5	21.0	22.9	24.3	25.7	15.0	21.2	23.2	24.7	26.2	13.8	19.5	21.3	22.7	24.0
December	16.6	23.1	24.9	26.3	27.6	18.0	23.9	25.8	27.3	28.7	16.3	21.7	23.5	24.8	26.1
Annual	20.9	24.4	25.7	26.6	27.6	21.8	25.7	27.2	28.3	29.4	20.0	23.9	25.3	26.5	27.6

Table 3.7. Extreme Associated Peak Period Estimates (m) for Return Periods of 1, 10, 25, 50 and 100 Years.

	Grid Point #14845					Grid Point #13912					Grid Point #11423				
Month	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**	**1**	**10**	**25**	**50**	**100**
January	12.8	14.5	14.9	15.2	15.5	13.4	14.9	15.3	15.7	16.0	12.8	14.4	14.9	15.3	15.6
February	11.9	14.6	15.3	15.7	16.2	12.7	14.9	15.6	16.1	16.5	12.4	14.3	14.9	15.3	15.7
March	11.7	13.1	13.5	13.7	13.9	12.1	13.3	13.7	14.0	14.2	11.8	13.2	13.6	13.9	14.2
April	10.6	13.1	13.6	14.0	14.4	11.4	12.9	13.3	13.6	13.9	10.7	12.3	12.8	13.1	13.4
May	9.3	12.3	12.9	13.4	13.8	10.2	12.3	12.9	13.3	13.7	9.9	12.0	12.6	13.0	13.4
June	8.6	11.1	11.6	11.9	12.3	9.2	11.2	11.7	12.1	12.5	8.8	10.9	11.5	11.9	12.3
July	7.9	10.4	10.9	11.3	11.7	8.3	10.6	11.2	11.6	12.0	8.5	10.6	11.2	11.6	12.1
August	9.1	10.9	11.3	11.6	11.8	9.4	11.3	11.9	12.3	12.6	9.0	11.8	12.6	13.2	13.7
September	9.9	13.6	14.3	14.8	15.3	11.1	13.8	14.6	15.1	15.6	10.9	13.2	13.9	14.3	14.7
October	11.3	13.6	14.1	14.4	14.7	11.8	14.0	14.5	15.0	15.3	11.4	13.4	14.0	14.4	14.8
November	11.6	13.8	14.3	14.6	15.0	12.3	13.9	14.4	14.7	15.1	12.1	13.4	13.8	14.0	14.3
December	12.6	14.5	14.9	15.3	15.6	13.2	14.9	15.4	15.7	16.1	12.8	14.3	14.7	15.1	15.4
Annual	13.9	15.0	15.3	15.6	15.9	14.3	15.5	15.9	16.3	16.6	13.7	14.9	15.3	15.6	15.9

3.3 Physical Oceanography

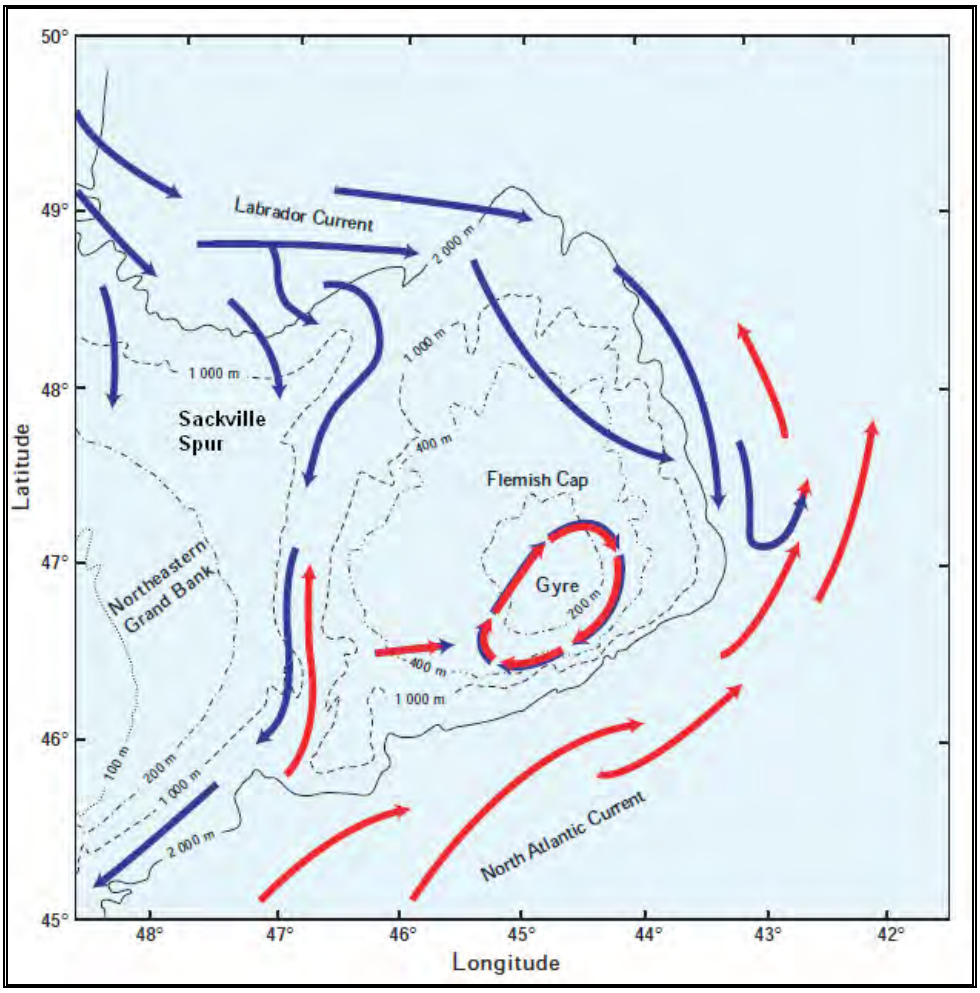
A detailed review of current physical oceanographic information for the Study Area is provided in Oceans (2012). Current velocities and water mass properties (temperature and salinity) at various water depths are provided in Section 4.0 of Oceans (2012). A summary of the major currents in the Study Area is provided below.

3.3.1 Major Currents in the Study Area

The Study Area overlaps the southern part of Orphan Basin, the Sackville Spur, the Northeast Newfoundland Slope, northern Flemish Pass, and the Jeanne d'Arc Basin. The large scale circulation off the coast of Newfoundland and Labrador is dominated by well-established currents that flow along the margins of the Continental Shelf. The two major current systems in the area are the Labrador Current and the North Atlantic Current (Colbourne and Foote 2000). The Labrador Current is the main current in the Study Area, and it transports sub-polar water to lower latitudes along the Continental Shelf of eastern Canada. Oceanographic studies show that this strong western boundary current follows the shelf break with relatively low variability compared to the mean flow. Over the Grand Banks a weaker current system is observed where the variability often exceeds that of the mean flow (see Figure 4.1 in Oceans 2012).

The Labrador Current consists of two major branches. The inshore branch of the Labrador Current is ~100 km wide (Stein 2007) and is steered by the local underwater topography through the Avalon Channel. The stronger offshore branch flows along the shelf break over the upper portion of the Continental Slope. The offshore branch passes between the 400 m and 1,200 m isobaths (Lazier and Wright 1993). This branch of the Labrador Current divides east of 48°W, resulting in part of the branch flowing to the east around Flemish Cap and the other flowing south around the eastern edge of the Grand Banks and through Flemish Pass. Within Flemish Pass, the width of the Labrador Current is reduced to 50 km with speeds of about 30 cm/s (Stein 2007). This flow transports cold, relatively low salinity Labrador Slope water into the region. To the southeast of the Flemish Cap the North Atlantic Current transports warmer, high salinity water to the northeast along the southeast slope of the Grand Banks and the Flemish Cap (Figure 3.2).

The outer branch of the Labrador Current exhibits a distinct seasonal variation in flow speeds (Lazier and Wright 1993), in which mean flows are a maximum in October and a minimum in March and April. This annual cycle is reported to be the result of the large annual variation in the steric height over the continental shelf in relation to the much less variable internal density characteristic of the adjoining deep waters. The additional freshwater in spring and summer is largely confined to the waters over the shelf. In summer, the difference in sea level between the shelf and open ocean is 0.09 m greater than in winter (Lazier and Wright 1993). This difference produces a greater horizontal surface pressure gradient and hence, stronger mean flows.



Source: Modified from Colbourne and Foote 2000.

Figure 3.2. The Major Circulation Features Around the Flemish Cap and Sackville Spur.

3.3.2 Temperature

The moderating influence of the ocean serves to limit both the diurnal and the annual temperature variation on the Grand Banks. Diurnal temperature variations due to the day/night cycles are very small. Short-term, random temperature changes are due mainly to a change of air mass following a warm or cold frontal passage. In general, air mass temperature contrasts across frontal zones are greater during the winter than during the summer months. Air and sea surface temperatures for the each region were extracted from the ICOADS data set (Oceans 2012).

In Region 1 (grid point 14845), the atmosphere is coldest in March with a mean monthly air temperature of 4.5°C, and warmest in August with a mean monthly air temperature of 10.8°C. Similarly, sea surface temperature is warmest in August with a mean monthly temperature of 11.3°C, and coldest in March with a mean monthly temperature of 3.7°C. The mean sea surface temperature is cooler than the mean air temperature from October to June, with the greatest difference occurring in the month of January. From July to September, sea surface temperatures are warmer than the mean air temperature.

In Region 2 (grid point 13912), the atmosphere is coldest in February with a mean monthly air temperature of 3.1°C, and warmest in August with a mean monthly air temperature of 11.5°C. Similarly, sea surface temperature is warmest in August with a mean monthly temperature of 11.8°C, and coldest in February with a mean monthly temperature of 3.1°C. The mean sea surface temperature is cooler than the mean air temperature from October to June, with the greatest difference occurring in the month of May. From July to September, sea surface temperatures are warmer than the mean air temperature.

In Region 3 (grid point 11423), the atmosphere is also coldest in February with a mean monthly air temperature of -0.3°C, and warmest in August with a mean monthly air temperature of 14.2°C. Similarly, sea surface temperature is warmest in August with a mean monthly temperature of 13.6°C, and coldest in February with a mean monthly temperature of 0.8°C. The mean sea surface temperature is cooler than the mean air temperature from October to June, with the greatest difference occurring in the month of January. From July to September, sea surface temperatures are warmer than the mean air temperature.

3.3.3 Visibility

Visibility is defined as the greatest distance at which objects of suitable dimensions can be seen and identified. Horizontal visibility may be reduced by any of the following phenomena, either alone or in combination:

- Fog
- Mist
- Haze
- Smoke
- Liquid Precipitation (e.g., drizzle)
- Freezing Precipitation (e.g., freezing rain)
- Frozen Precipitation (e.g., snow)
- Blowing Snow

During the winter months, the main obstruction is snow, although mist and fog may also reduce visibilities at times. As spring approaches, the visibility reduction attributed to snow decreases. As air temperature increases, the occurrence of advection fog also increases. Advection fog forms when warm moist air moves over cooler waters. By April, the sea surface temperature south of Newfoundland is cooler than the surrounding air, and the presence of advection fog increases from April through July. The month of July has the highest percentage of obscuration to visibility, most of which is in the form of advection fog, although frontal fog can also contribute to the reduction in visibility. In August, the temperature difference between the air and the sea begins to narrow and by September, the air temperature begins to fall below the sea surface temperature and the occurrence of fog decreases. September and October have the lowest occurrence of reduced visibility since the air temperature has, on average, decreased below the sea surface temperature, but it is not cold enough for snow. Reduction in visibility during autumn and winter is relatively low and is mainly attributed to the passage of low-pressure systems.

3.4 Sea Ice and Icebergs

The analysis of sea ice and icebergs in the Study Area was divided into three regions (see Figure 3.1). Table 5.1 in Oceans (2012) provides definitions of the various ice types.

3.4.1 Sea Ice

The 30-year median concentration of sea ice reaches its maximum during the week of 5 March (see Figure 5.1 in Oceans 2012). The median of ice concentration does not extend into any of the three Regions that compose the Project Area. The maximum median sea ice extent reaches to approximately 48°N, 49°W.

A weekly analysis of the Canadian Ice Service's 30-Year Frequency of Presence of Sea Ice in Region 1 shows that the area is affected by sea ice beginning the week of 15 January and lasting until the week beginning 28 May. The week of 12 March is the period when the frequency of presence of sea ice is the greatest (see Figure 5.2 in Oceans 2012). The frequency of presence of sea ice over the majority of Region 1 is 1–15%. The frequency of presence of sea ice is greatest in the southwest corner of Region 1 with the highest frequency between 34–50%. The predominant ice type within the area from 15 January to the week of 5 February is a mixture of grey and grey-white. By 19 February, thin first-year ice begins to form in the northern part of Region 1 and new ice forms to the northwest. Thin first-year ice is the predominant ice type from 19 February until the week of 2 April, with a small amount of medium and thick first-year ice also present. Thick first-year and some old ice are predominant for the remainder of the season.

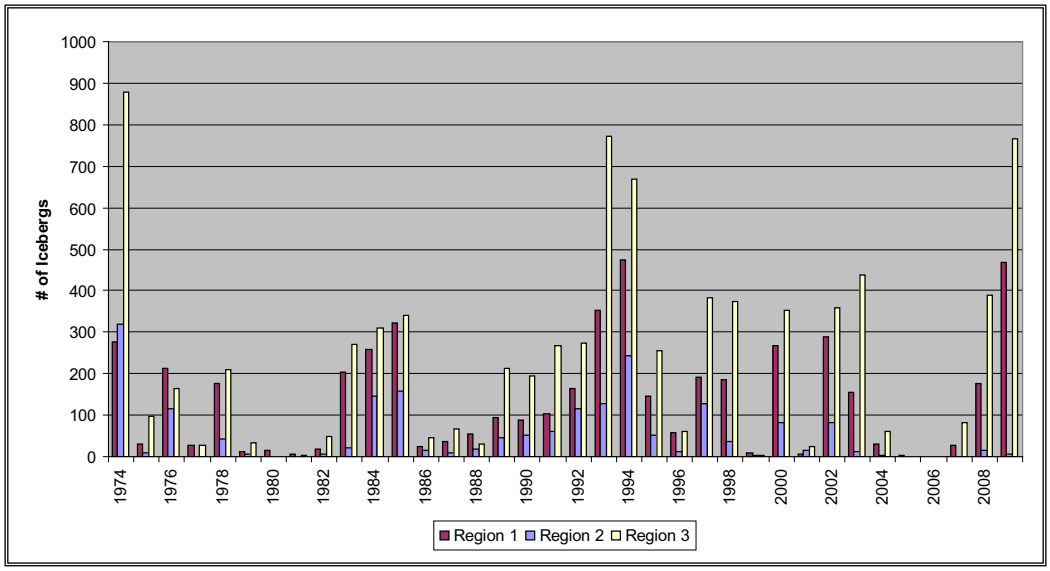
In Region 2, the area is affected by sea ice beginning the week of 29 January and lasting until the week beginning April. The week of 12 March is the period when the frequency of presence of sea ice is the greatest over the area (see Figure 5.2 in Oceans 2012). The frequency of presence of sea ice over the majority of the southern half of Region 2 is 1–15%, while the northern half is mostly ice free.

In Region 3, the area is affected by sea ice beginning the week of 15 January and lasting until the week beginning 21 May. The week of 19 March is the period when the frequency of presence of sea ice is the greatest over the area (see Figure 5.3 in Oceans 2012). The frequency of presence of sea ice over the majority of southern half of Region 3 is 1–15% while the frequency of presence of sea ice in the northern half is highest at 16–33%. There is a small sector in the southeast corner that is ice free. The predominant ice type within the area from 15 January to the week of 12 February is a mixture of grey and grey-white. By 19 February, thin first-year ice begins to form in the eastern part of Region 3. Thin first-year ice is the predominant ice type from 19 February until the week of 2 April, with a small amount of grey-white, medium first-year and thick first-year ice also present. Medium and thick first-year ice is predominant for the remainder of the season.

3.4.2 Icebergs

An analysis was performed to determine the threat posed by icebergs in the Project Area; more specifically in Regions 1, 2, and 3 (see Figure 3.1). The International Ice Patrol Iceberg Sightings Database from 1974-2009 was used as the primary data source in this analysis (NSIDC 2009). Overall there is a good distribution of iceberg sightings ranging from a total of 1,474 in all three regions for 1974 to only one over all three regions in 2006 (Figure 3.3). Only iceberg sightings that occurred within the

Project Area were considered in this analysis. Duplicate sightings of the same iceberg were also eliminated from the data set so that only the initial sighting was counted.



Source: IIP.

Figure 3.3. Iceberg Sightings within the Project Area.

The positions of all icebergs within Region 1 from 1974-2009 are shown in Figure 3.4. Icebergs are concentrated towards the southern portion of the region. Over the 35 years studied, 3,546 icebergs have been sighted inside Region 1. Environmental factors such as iceberg concentration, ocean currents, and wind determine how icebergs drift through the area.

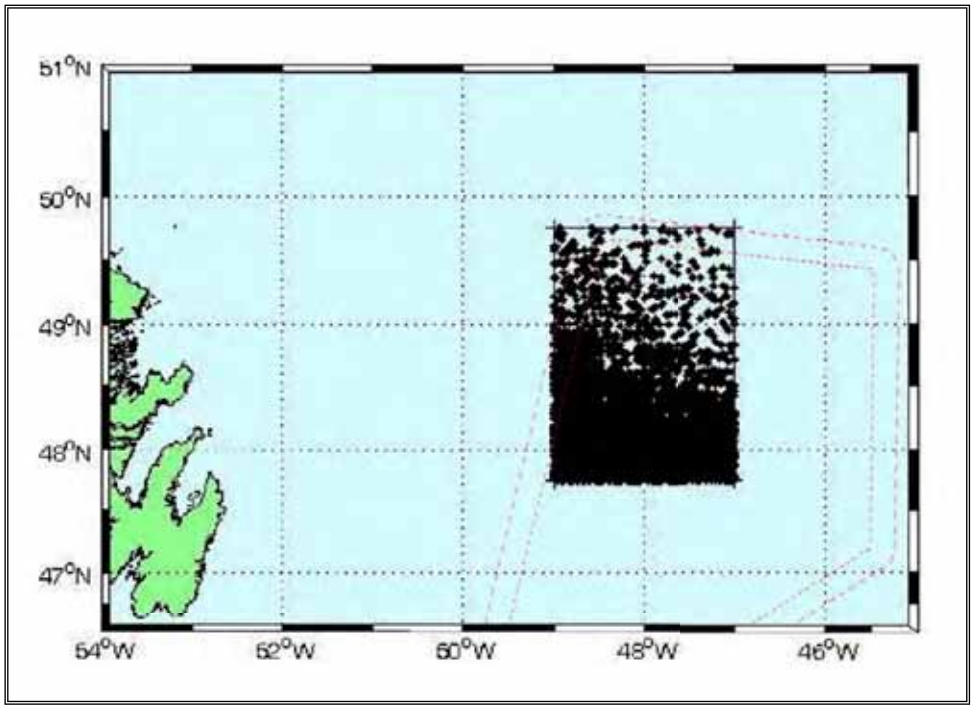
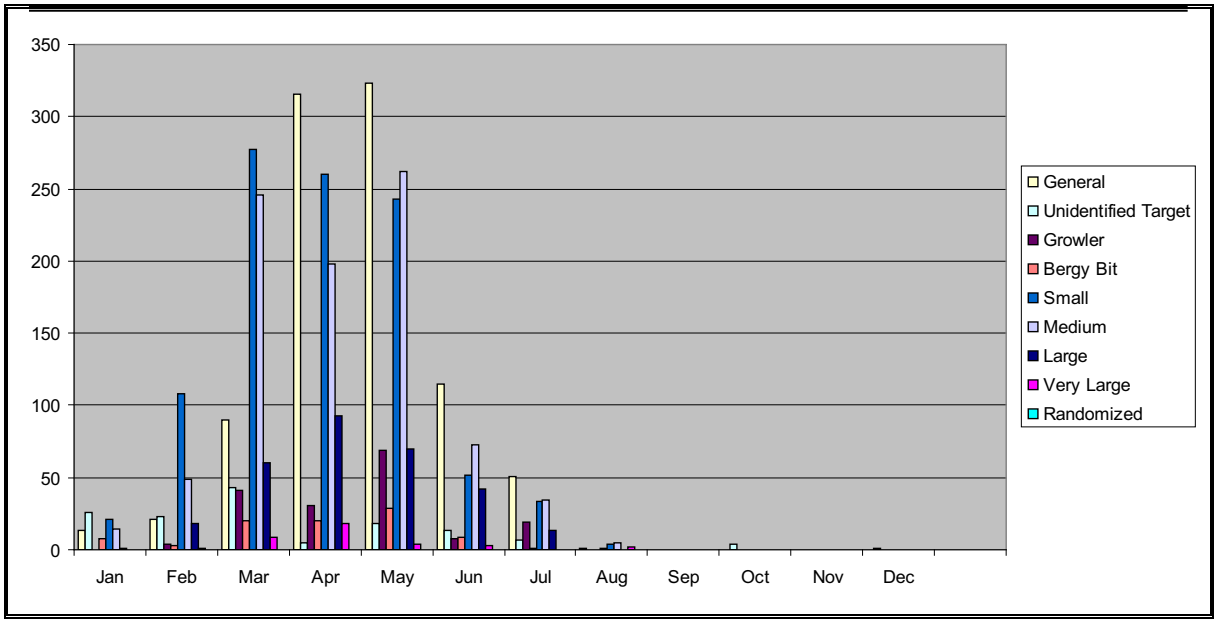


Figure 3.4. Iceberg Sightings in Region 1 of the Project Area from 1974-2009. Study and Project Areas outlined in red (outer and inner dashed lines, respectively).

A monthly analysis shows that icebergs have been spotted within Region 1 in all months except September and November. Icebergs are most prominent during the months of April and May (Figure 3.5). With respect to size, the most prominent icebergs are small, accounting for 28.1% of observed icebergs within the region. Large icebergs occur 8.4% of the time.



Source: IIP.

Figure 3.5. Iceberg Size by Month within Region 1 of the Project Area.

In Region 2, icebergs are concentrated towards the southern portion of the region for 1974-2009 (Figure 3.6). Over the 35 years studied, 1,002 icebergs have been sighted inside Region 2. Environmental factors such as iceberg concentration, ocean currents, and wind determine how icebergs drift through the area.

A monthly analysis shows that icebergs have been spotted within Region 2 from January through August and they are most prominent during the month of March (Figure 3.7). With respect to size, the most prominent icebergs are medium, accounting for 25.4% of observed icebergs within the region. Large icebergs occur 8.5% of the time.

The greatest overall distribution of icebergs of all three sectors occurs within Region 3, with icebergs having been spotted over nearly the entire region (Figure 3.8). Over the 35 years studied, 9,527 icebergs have been sighted inside the region. Environmental factors such as iceberg concentration, ocean currents, and wind determine how icebergs drift through the area.

A monthly analysis shows that icebergs have been spotted within Region 3 in all months except September and November. They are most prominent during April (Figure 3.9). With respect to size, the most prominent icebergs are medium, accounting for 27.6% of observed icebergs within the region. Large icebergs occur 9.7% of the time.

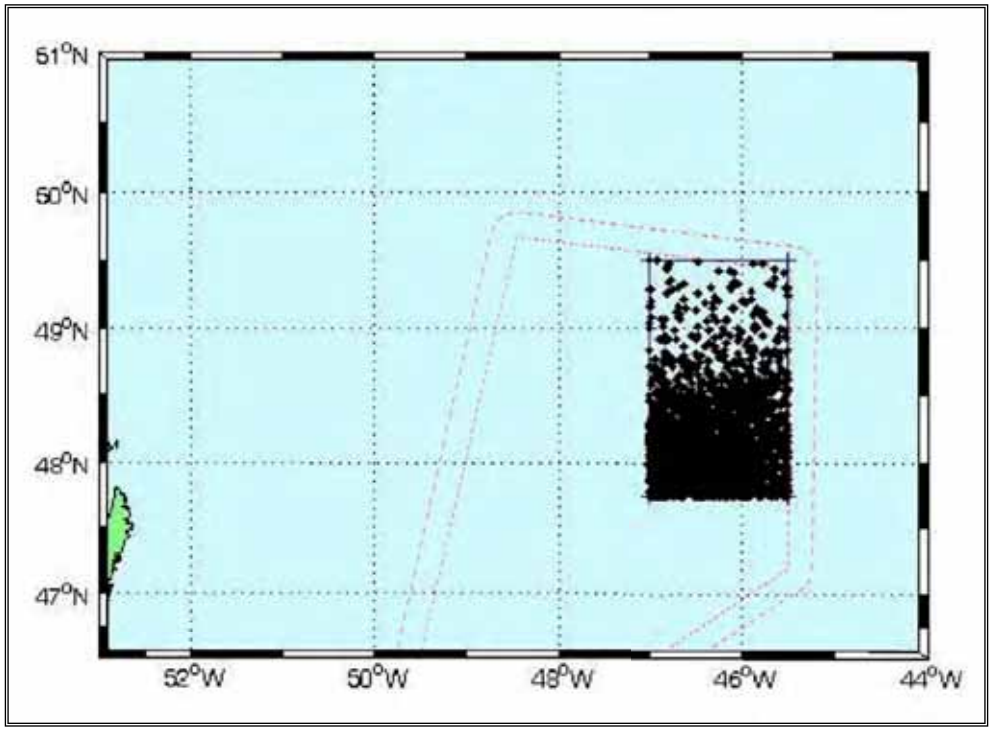
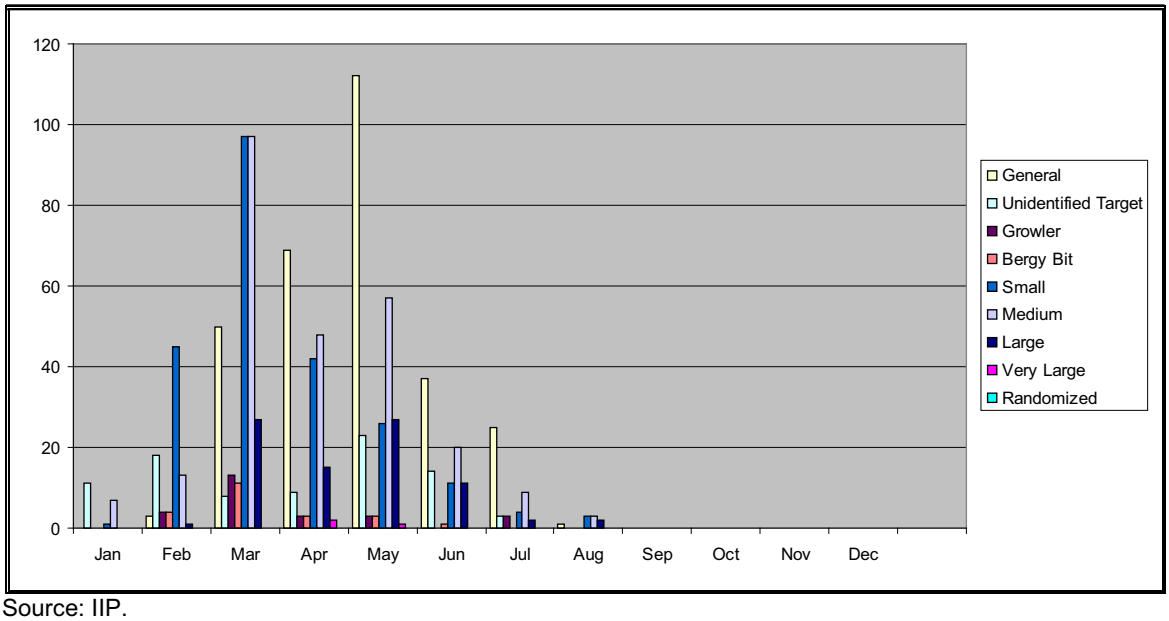


Figure 3.6. Iceberg Sightings in Region 2 of the Project Area from 1974-2009. Study and Project Areas outlined in red (outer and inner dashed lines, respectively).



Source: IIP.

Figure 3.7. Iceberg Size by Month within Region 2 of the Project Area.

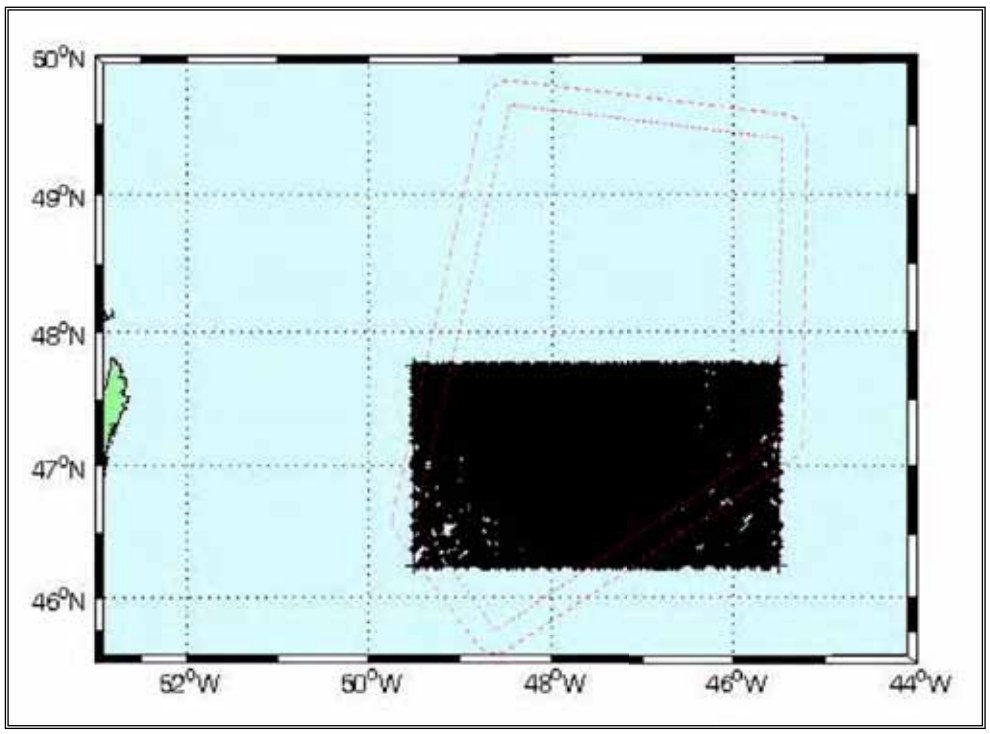
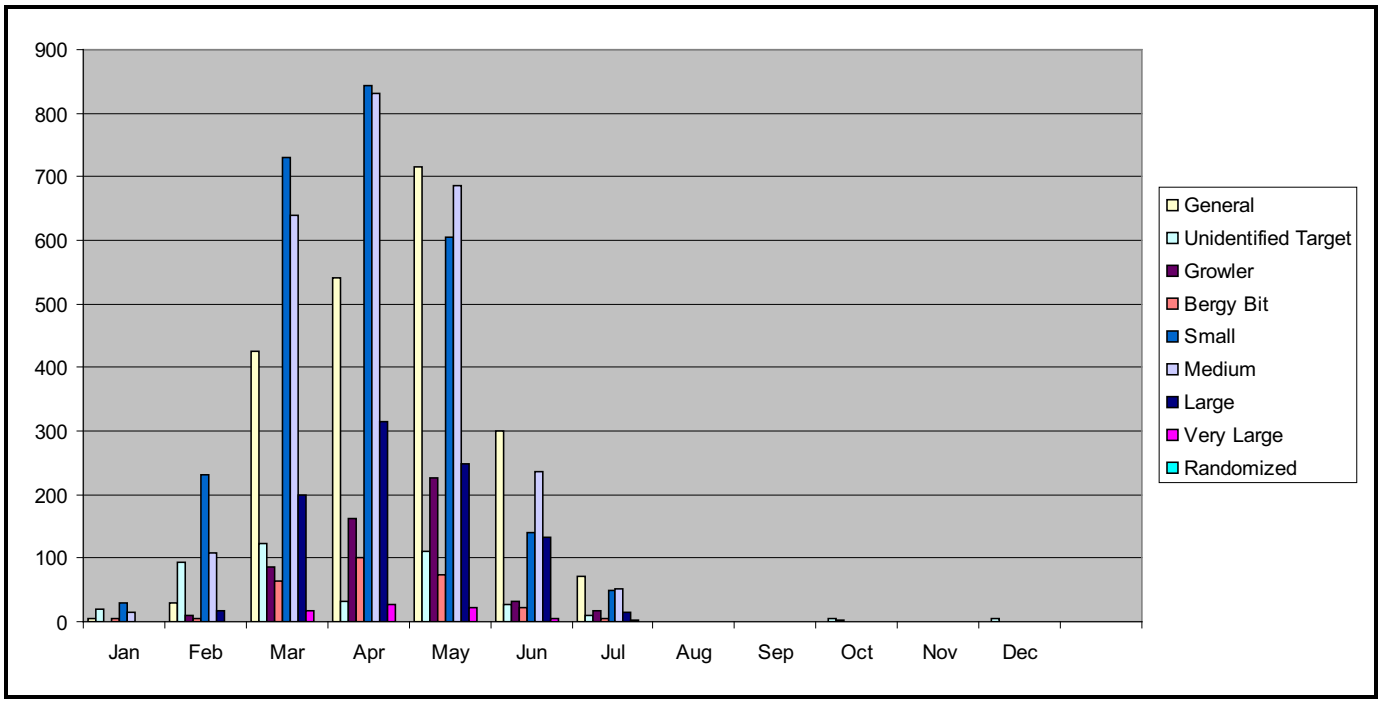


Figure 3.8. Iceberg Sightings in Region 3 of the Project Area from 1974-2009. Study and Project Areas outlined in red (outer and inner dashed lines, respectively).



Source: IIP.

Figure 3.9. Iceberg Size by Month within Region 3 of the Project Area.

4.0 Biological Environment

The biological and socio-economic environments in and near the Study Area have been described in the Orphan Basin SEA (LGL 2003; Buchanan et al. 2004) and more recently, in exploration and drilling EAs and their amendments for Orphan Basin (Moulton et al. 2005a,b; LGL 2005, 2006a, 2009), Jeanne d'Arc Basin (Christian 2008; LGL 2006b, 2007a,b, 2008a,b, 2011a, 2012a) and Flemish Pass (LGL 2011b). In addition to updated information, summaries of relevant information from these documents are presented in the following subsections for fish and fish habitat, fisheries, seabirds, marine mammals and sea turtles, species at risk, and potentially sensitive areas.

4.1 Ecosystem

An ecosystem is an inter-related complex of physical, chemical, geological, and biological components that can be defined at scales ranging from a relatively small area (that may only contain one habitat type (e.g., a shelf) to a relatively large regional area ecosystem which is topographically and oceanographically complex (e.g., the Northwest Atlantic). This EA focuses on components of the ecosystem such as selected species and life stages of fish, seabirds and marine mammals that are important ecologically, economically, and/or socially, and have potential to interact with the Project. This is the VEC approach to the EA which is detailed in Section 5.0. The VECs are discussed in the following subsections.

4.2 Fish and Fish Habitat

This subsection provides a description of the existing fish and fish habitat in the Study Area. Fish habitat in the Study Area is considered first, followed by a discussion of fish (macroinvertebrates and fishes) in the Study Area.

4.2.1 Fish Habitat

For the purposes of this EA, fish habitat is considered to include physical, chemical, and biological aspects of the marine environment used by macroinvertebrate and fish species in the Study Area. The physical and chemical nature of the water column and bottom substrate is a critical factor affecting the characterization of associated marine biological communities. 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).

4.2.2 Plankton

Plankton is composed of free-floating organisms that form the basis of the pelagic ecosystem. Members include bacteria, fungi, phytoplankton, and zooplankton (mostly invertebrates, but may also include eggs and larvae of fishes, known as ichthyoplankton). In simplest terms, phytoplankton (e.g., diatoms) produce carbon compounds through the utilization of sunlight, carbon dioxide, and nutrients (e.g., nitrogen, phosphorus, silicon); this process is called primary production. Herbaceous zooplankton (e.g., calanoid copepods, the dominant component of Northwest Atlantic zooplankton) feed on phytoplankton, a growth process known as secondary production. The herbivores in turn are ingested by predators (i.e., tertiary production) such as predacious zooplankton (e.g., chaetognaths,

jellyfish, etc.), all of which may be grazed by higher predators such as fish, seabirds, and marine mammals. This food web also links to the benthic ecosystem through bacterial degradation processes, dissolved and particulate carbon, and direct predation. An understanding of plankton production is important because areas of enhanced production and (or) biomass are areas where fish, seabirds, and marine mammals congregate to feed (LGL 2003).

Phytoplankton distribution, productivity, and growth regulation in high-latitude ecosystems constitute a complex system with light, nutrients, and herbivore grazing being the principal factors limiting phytoplankton populations (Harrison and Li 2008). In the Northwest Atlantic, there is usually a spring plankton bloom (May/June) which is often followed by a smaller bloom in the fall (September/October). This general pattern likely applies to the Study Area. There may be areas of enhanced production in the Study Area, similar to other slope areas that have been studied. For example, chlorophyll 'a' concentration images collected by Moderate Resolution Imaging Spectroradiometer (MODIS) from October 2011 to 2013 (http://www.bio.gc.ca/science/newtech-technouvelles/sensing-teledetection/composites-eng.php#images) indicate that the highest chlorophyll 'a' concentrations occurred in the Study Area between March and May. The spring peak was followed by a second peak between September and October. Typically, the spring bloom of phytoplankton is the driving force of high-latitude marine ecosystem dynamics. Sunlight has been considered the limiting factor for development of the spring bloom; however, factors such as nutrients, latitude, and water column stratification are also important (Wu et al. 2008).

Zooplankton reproduction is tied to the phytoplankton bloom, which either coincides with or immediately follows the brief but intense phytoplankton blooms in high latitudes (Huntley et al. 1983; Head et al. 2000; Head and Pepin 2008). Zooplankton is the foremost link between primary production and higher-level organisms in the marine ecosystem. They transfer organic carbon from phytoplankton to higher trophic levels including fishes, birds, and marine mammals. Zooplankton is a food source for a broad spectrum of species, and they contribute carbon via faecal matter and dead zooplankton to the benthic food chains. Pepin et al. (2011) noted that plankton distribution in the Study Area is primarily influenced by local advective transport and mixing processes, and that several species of *Calanus* copepods act as key contributors to the regional secondary production. More information on phytoplankton in and around the Study Area is available in Section 3.2.1 of the Orphan Basin SEA (LGL 2003) and the Husky New Drill Centre Construction and Operations Program EA (Section 5.4 *in* LGL 2006b).

Planktonic organisms are so ubiquitous and abundant in the world's oceans, and many have such rapid generation times it logically follows that there will be essentially no or 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 in this EA. However, planktonic stages of commercial invertebrates (e.g., shrimp, snow crab) and fishes (e.g., cod) are described in following sections because of their VEC status.

4.2.3 Benthos

Benthic invertebrates are bottom-dwelling organisms that can be classified into three categories: infaunal organisms, sessile organisms, and 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 mysids, amphipods, and decapods.

Benthic invertebrate communities can be spatially variable due to 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 latitudes 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.

As indicated in the Orphan Basin SEA (LGL 2003) and the Husky New Drill Centre Construction and Operations Program EA (Subsection 5.4 *in* LGL 2006b), there are large gaps in the current knowledge of benthic ecosystems of the offshore waters of Newfoundland and Labrador. The existing literature, although extensive in appearance, tends to be spatially restricted and often species specific. Subsection 3.2.2 of LGL (2003) and Subsection 5.5.1.1 of LGL (2006b) include more general information on benthos in the vicinity of the Study Area. Deepwater corals and sponges have gained more focus in recent years. Some information on corals and sponges occurring within the Study Area is presented in the following subsection.

4.2.3.1 Deepwater Corals and Sponges

A variety of coral groups occur in Newfoundland and Labrador waters and include scleractinians (solitary stony corals), antipatharians (black wire corals), alcyonaceans (large and small gorgonians, and soft corals), and pennatulaceans (sea pens) (Wareham and Edinger 2007; Wareham 2009). Corals are largely distributed along the edge of the continental shelf and slope off Newfoundland and Labrador (Edinger et al. 2007; Wareham and Edinger 2007). Typically, they are found in canyons and along the edges of channels (Breeze et al. 1997), deeper than 200 m. Soft corals are distributed in both shallow and deep waters, while horny and stony corals (hard corals) are typically restricted to deep water areas. Most grow on hard substrate (Gass 2003), such as large gorgonian corals (Breeze et al. 1997). Others, such as small gorgonians, cup corals, and sea pens prefer sand or mud substrates (Edinger et al. 2007). In total, 30 species of corals were documented and included two antipatharians (black wire corals), 13 alcyonaceans (large gorgonians, small gorgonians, and soft corals), four scleractinians (solitary stony corals), and 11 pennatulaceans (sea pens) for offshore Newfoundland and Labrador.

Several recently published reports present knowledge on the ecology of deep cold-water corals of Newfoundland and Labrador waters, including information on biogeography, life history, biochemistry, and relation to fishes (e.g., Gilkinson and Edinger 2009; Kenchington et al. 2010a,b; Baillon et al. 2012; Baker et al. 2012). Wareham (2009) updated deep-sea coral distribution data for the Newfoundland and Labrador and Arctic regions to partially fill information gaps previously identified by Wareham and Edinger (2007). A DFO Science Advisory Report (DFO 2010a) also discusses the occurrence and ecological function of corals in Canadian waters.

According to distribution maps provided by Wareham (2009), there are ~22 species of corals occurring within the Study Area. The species identified include antipatharians (*Stauropathes arctica* and *Bathypathes* spp.), large gorgonians (*Keratoisis ornata*, *Paragorgia arborea*, and *Paramuricea* spp.),

small gorgonians (*Acanella arbuscula*, *Acanthogorgia armata*, *Anthothela grandiflora*, and *Radicipes gracilis*), and soft corals (*Anthomastus grandiflorus*, *Duva florida*, *Gersemia rubiformis*, and *Nephtheid spp.*). One scleractinian species (*Flabellum alabastrum*) and eight pennatulacean species (*Anthoptilum grandiflorum*, *Distichoptilum gracile*, *Halipteris finmarchica*, *Pennatula grandis*, *Pennatula phosphorea*, *Umbellula lindahli*, *Funiculinia quadrangularis*, and *Pennatulacea* sp.) are also noted to occur there. According to Murillo et al. (2011), antipatharian species (*Leiopathes* sp.), one scleractinian species (*Desmophyllum dianthus*), and one pennatulacean species (*Pennatula aculeata*) also occur in the Flemish Pass region of the Study Area. The majority of coral species was observed to occur both on the continental slope and within Flemish Pass, with the exception of several soft corals (e.g., *Gersemia rubiformis* and *Duva florida*) found on the shelf of Jeanne d'Arc Basin. Based on DFO Research Vessel (RV) survey data collected in the Study Area from 2007 to 2011, most of the corals were caught at mean water depths of ~300 and ~675 m in the spring and fall surveys, respectively.

The patterns of association between deep-sea corals, fish, and invertebrate species, based on DFO scientific surveys and remotely operated vehicle (ROV) surveys are discussed by Edinger et al. (2009). Although there were no dramatic relationships between corals and abundance of the 10 groundfish species studied, there was a weak but statistically significant positive correlation between coral species richness and fish species richness. For various sample segment lengths and depth ranges in the southern Grand Banks, Baker et al. (2012) found significant positive relationships between the presence and/or abundance of roundnose grenadier (*Coryphaenoides rupestris*) with that of large skeletal corals and cup corals, of roughhead grenadier (*Macrourus berglax*) with large gorgonians/antipatharians and soft corals, and of marlin-spike grenadier (*Nezumia bairdii*) with small gorgonians. Baillon et al. (2012) determined that several types of coral, particularly sea pens (e.g., *Anthoptilum grandiflorum*) were hosts to eggs and/or larvae of two redfish species (*Sebastes fasciatus* and *S. mentella*), lantern fish (*Benthosema glaciale*) and greater eelpout (*Lycodes esmarkii*) in the Laurentian Channel and southern Grand Banks. This suggests that habitats that support diverse corals may also support diverse assemblages of fishes. Although relationships between corals and groundfish or invertebrates are not obligate and may result from coincidence, conservation areas established for corals may effectively protect populations of groundfish, including some commercial species (Edinger et al. 2009). By increasing the spatial and hydrodynamic complexity of habitats, deep-sea corals may provide important, but probably not critical, habitat for a wide variety of fishes. Effects of deep-sea corals on fish habitat and communities may include higher prey abundance, greater water turbulence, and resting places for a wide variety of fish size classes (Auster et al. 2005; Costello et al. 2005 *in* Edinger et al. 2009).

Sponges also provide significant deep-sea habitat, enhance species richness and diversity, and exert clear ecological effects on other local fauna. Sponge grounds and reefs support increased biodiversity compared to structurally-complex abiotic habitats or habitats that do not contain these organisms (DFO 2010a). Kenchington et al. (2013) noted the association of several demersal fish taxa with *Geodia*-dominated sponge grounds on the Grand Banks and Flemish Cap, although the precise nature of this association is unknown. According to the DFO RV survey data collected in the Study Area from 2007 to 2011, most of the sponges were collected in approximately 340 and 500 m depth in spring and fall, respectively.

Morphological forms such as thick encrustations, mounds, and branched, barrel- or fan-like shapes influence near-bottom currents and sedimentation patterns. They provide substrate for other species and offer shelter for associated fauna through the provision of holes, crevices, and spaces. Siliceous hexactinelid sponges can form reefs as their glass spicules fuse together; when the sponge dies, the

skeleton remains. This skeleton provides settlement surfaces for other sponges, which in turn form a network that is subsequently filled with sediment (DFO 2010a).

Although some of the siliceous spicules of non-reef-forming species dissolve quickly, there is some accumulation of shed spicules forming a thick sediment-stabilizing mat, which constitutes a special bottom type supporting a rich diversity of species. Organisms commonly associated with sponges and sponge grounds include species of marine worms and bryozoans, as well as higher fauna. Live glass sponge reefs have been shown to provide nursery habitat for juvenile rockfish, and high-complexity reefs are associated with higher species richness and abundance (DFO 2010a).

In 2008 and 2009, the North Atlantic Fisheries Organization (NAFO) Scientific Council identified areas of significant coral and sponge concentrations within the NAFO Regulatory Area. NAFO Coral/Sponge Closure Area Five was updated in 2012. These areas that have been deemed closed to fishing with bottom gear are shown in Section 4.7.3 (see "Potentially Sensitive Areas" DFO 2010a).

4.2.4 Fishes

For the purposes of this EA, the fishery VEC includes commercial fishery-targeted macroinvertebrate and fish species, incidental commercial fishery bycatch species, and macroinvertebrates and fishes captured during DFO RV surveys in the Study Area.

4.2.4.1 Macroinvertebrates and Fishes Primarily Targeted in Commercial Fisheries

The total commercial fisheries catch weight within the Study Area from 2005 to 2010 was 115,362 mt (DFO Landings Data 2005–2010). Two macroinvertebrate species, northern shrimp (*Pandalus borealis*) and snow crab (*Chionoecetes opilio*), dominated the reported landings of commercial catches within the Study Area during 2005 to 2010 (combined average annual catch weight over 99% of total). Other species that account for at least 0.7% of the 2005 to 2010 average annual total catch weight include Stimpson's surf clam (*Mactromeris polynyma*; 0.4%), and Greenland halibut (0.3%). Thirteen other species/groups accounted for <1% each of the average annual catch weight. These species are profiled below, with major commercial species presented first.

Northern Shrimp

The primary cold-water shrimp resource in the North Atlantic, the northern shrimp is distributed from Davis Strait to the Gulf of Maine. It usually occupies soft muddy substrates from depths of 150 to 600 m in temperatures of 1°C to 6°C (DFO 2013a). Large individuals generally occur in deeper waters than small ones (DFO 2006a). A diel vertical migration is undertaken with shrimp feeding on various prey, such as annelids, small crustacea and detritus, during the day and then migrating up the water column at night to feed on pelagic copepods and krill (DFO 2006a). After insemination, gravid female shrimp may migrate to shallower areas where the water temperatures are most appropriate for embryonic development and subsequent larval hatch (http://www.dfo-mpo.gc.ca/science/publications/article/2009/08-31-09-eng.html).

Northern shrimp are protandric hermaphrodites (Orr et al. 2009). They first mature as males, mate as males for one to several years, and then change to females for the remainder of their lives (DFO 2013a). Eggs are typically extruded in the summer and remain attached to the female until the

following spring, when the female migrates to shallow coastal waters to spawn (Nicolajsen 1994 *in* Ollerhead et al. 2004). The hatched larvae float to the surface and commence feeding on planktonic organisms (DFO 2006a). Northern shrimp are known to live for more than eight years in some areas and are large enough for recruitment to the fishery as early as three years of age (DFO 2013a).

As with most crustaceans, northern shrimp grow by moulting their shells. During this period, the new shell is soft, causing them to be highly vulnerable to predators such as Greenland halibut, Atlantic cod, skates, wolfish, snow crab, and harp seals (DFO 2013a).

Georeferenced commercial catch location data for 2005–2010 and commercial catch data for 2011-2012 indicate that most northern shrimp catches within the Study Area occurred on the northeastern Newfoundland Slope in areas with water depths between 200 and 500 m. Scattered shrimp catches were also reported on the slopes of the Jeanne d'Arc Basin and Flemish Pass. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, the greatest proportion of northern shrimp was caught between the 200 and 500 m isobaths on the northeastern slope of Jeanne d'Arc Basin in the west-central portion of the Study Area.

Snow Crab

The snow crab, a decapod crustacean, occurs over a broad depth range in the Northwest Atlantic from Greenland to the Gulf of Maine (DFO 2013b). Snow crab distribution is widespread and continuous in waters off Newfoundland and southern Labrador. Large males are most common on mud or mud/sand, while smaller crabs are common on harder substrates.

After spring hatching, snow crab undergo a multi-stage life cycle featuring a 12 to 15 week planktonic larval period, before settlement. Benthic juveniles of both sexes moult frequently and at ~40 mm carapace width (CW; ~4 years of age) they become sexually mature. Female crabs carry the fertilized eggs for about two years (DFO 2013b).

Snow crab typically feed on fish, clams, benthic worms, brittle stars, shrimps and crustaceans, including smaller snow crabs. Their predators include various groundfish, other snow crabs, and seals (DFO 2013b).

Georeferenced commercial catch location data for 2005–2010 and commercial catch data for 2011-2012 indicate a wider distribution of catch locations for snow crab than for northern shrimp. Most snow crab catches were made between the 100 and 200 m isobaths of the Jeanne d'Arc Basin located in the western, central, and south-central portions of the Study Area. Scattered harvest locations were also reported for the shallower regions of the Jeanne d'Arc Basin and on the Flemish Pass in the western and central portions of the Study Area, respectively. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, the greatest proportion of snow crab were caught between the 100 and 500 m isobaths on the northeastern slope of Jeanne d'Arc Basin in the southwestern portion of the Study Area.

Stimpson's Surf Clam

This bivalve mollusc is a circumboreal species, inhabiting both the Atlantic and Pacific Oceans. It is the largest clam in the Northwestern Atlantic and occurs from Labrador to Rhode Island, often on medium to coarse sand substrate (Abbott 1974 *in* Christian et al. 2010). In the Canadian part of its

range, this species occurs in commercial quantities in the offshore areas of the Scotian Shelf and Eastern Grand Banks, and inshore areas off southwest Nova Scotia and in the Gulf of St. Lawrence (DFO 1989a, 1999, 2004a *in* Christian et al. 2010). The Stimpson's surf clam appears to prefer medium to coarse sand substrate in which it burrows (DFO 2009 *in* Christian et al. 2010).

Surf clam spawning in the offshore areas typically occurs during the fall (DFO 2009 *in* Christian et al. 2010). Davis and Shumway (1996 *in* Christian et al. 2010) report that larval hatch occurs within days of spawning, and that larvae remain planktonic for one to two months before settlement to the bottom substrate. Stimpson's surf clams are filter feeders with a microalgal diet (e.g., dinoflagellates; Smith and Wikfors 1992 *in* Christian et al. 2010). Predators of the surf clam include sea stars, whelk, crabs, and large groundfish (Himmelman and Hamel 1993; Rochette et al.1995; Morissette and Himmelman 2000 *in* Christian et al. 2010).

Georeferenced commercial catch location data for 2005–2010 and commercial catch data for 2011-2012 indicate that Stimpson's surf clams were caught in the south-western portion of the Study Area, between January and March of 2006 and in November of 2011, at locations with water depths <100 m.

Greenland Halibut

The Greenland halibut is distributed throughout cold, deep waters of the Labrador-eastern Newfoundland area, inhabiting the continental shelf and slope at depths of 200 to 2,200 m (Morgan et al 2013). The majority of the adult population is distributed in the deep and warm North Atlantic waters (e.g., Davis Strait, between Greenland and Baffin Island) where spawning occurs in winter or early spring (Templeman 1973; Bowering 1983; Bowering and Brodie 1995; Bowering and Nedreaas 2000). Larvae and juveniles are transported south by oceanic currents where they colonize the deep channels (Bowering 1983; Bowering and Brodie 1995). Greenland halibut are highly mobile and capable of travelling long distances (Boje 2002); they typically move progressively offshore to the deep edges of the continental slope with increasing age and size (Bowering and Brodie 1995; Bowering and Nedreaas 2000). With increasing maturity most Greenland halibut presumably migrate northward to areas such as Davis Strait to spawn (Templeman 1973; Chumakov 1975; Bowering and Brodie 1995). Movements and changes in distribution of Greenland halibut may also be due to fluctuations in oceanic temperatures (Morgan et al 2013). Small scale localized spawning may also occur along the deep slopes of the continental shelf throughout its range (Bowering and Brodie 1995).

In addition to shrimp, Greenland halibut feed on a variety of species, including small pelagic crustaceans, small fish (e.g., Arctic cod, capelin), larger fish (e.g., redfish, grenadier), and squid (DFO 2008a).

Georeferenced commercial catch location data for 2005–2010 and commercial catch data for 2011-2012 indicate Greenland halibut catch locations predominantly in the west-central portion of the Study Area, in water depths ranging between 200 and 1,500 m. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, the greatest proportion of Greenland halibut was caught between the 200 and 1,000 m isobaths on the northeastern slope of Jeanne d'Arc Basin in the central portion of the Study Area.

Cockle

This bottom-dwelling bivalve occurs submerged just under the sediment surface in a variety of substrate types, ranging from soft mud to stony gravel (Franklin 1972). A non-selective filter-feeder, the cockle slightly projects two fleshy siphons through the sediment surface into the water, and directs a continuous flow of water through its body for respiration and feeding (Franklin 1972). Cockles fall prey to a variety of predators, such as various fish (including flounders and plaice), crabs, starfish, and even seabirds in shallower waters (Franklin 1972).

Cockles generally spawn in the spring, but spawning may extend into summer and fall (Franklin 1972). Eggs and sperm are shed freely into the water, and larvae are thought to remain planktonic for approximately three weeks before they settle on the sea bed.

Several species of cockle are known to occur in Northwest Atlantic waters. Of these, the Greenland cockle (*Serripes groenlandicus*) occurs in and around the Study Area and is a common bycatch species in the Arctic surf clam (*Mactromeris polynyma*) commercial fishery (DFO 2011a). As such, it is likely the cockle species in question in the georeferenced and ranged DFO commercial catch location data for 2005 to 2010 and 2011 to 2012, respectively, in the Study Area.

The Greenland cockle is widely distributed throughout the Arctic Ocean and southward in varying degrees (Golikov and Scarlato 1973 *in* Christian et al. 2010). In the Northwest Atlantic Ocean, this bivalve is found from Greenland to Cape Cod at subtidal depths >9 m. Barrie (1979 *in* Christian et al. 2010) found this cockle species on sandy substrates within a depth range of 6 to 18 m at various Labrador locations. It is ~100 mm in diameter at full growth (Gosner 1979 *in* Christian et al. 2010). The life history of the Greenland Cockle is poorly understood.

The Greenland cockle displays intense escape behaviour towards the sea stars *Leptasterias polaris* and *Asterias rubens,* two of its primary predators (Legault and Himmelman 1993 *in* Christian et al. 2010). Other predators of the Greenland cockle include demersal fish (e.g., cod, haddock; Dolgov and Yaragina 1990 *in* Christian et al. 2010) and marine mammals (Fisher and Stewart 1997 and Born et al. 2003 *in* Christian et al. 2010).

Georeferenced commercial catch location data for 2005–2010 and commercial catch data for 2011-2012 indicate that most cockle catches occurred in the southwestern portion of the Study Area at locations with water depths <100 m.

Atlantic Herring

Atlantic herring (*Clupea harengus*) occurs on both sides of the North Atlantic, ranging from western Greenland to Cape Hatteras in the Northwest Atlantic (Scott and Scott 1988). Typically a pelagic species, Atlantic herring generally inhabit relatively shallow waters, in depths <200 m. Immature fish and/or mature fish prior to spawning may form particularly large schools (Scott and Scott 1988). Atlantic herring stocks have been shown to undertake extensive annual migrations between spawning grounds, overwintering areas, and feeding areas (Scott and Scott 1988).

Spawning time and location varies with each herring stock. In Canadian waters, Atlantic herring spawning can occur between April and November, with the offshore stocks typically spawning in the fall (Scott and Scott 1988). Atlantic herring eggs remain on the seabed until the time of hatching. Upon

hatching, the larvae are slender and light-sensitive and tend to seek deeper water on bright days (Graham and Sampson 1982 *in* Scott and Scott 1988). Egg and larval mortality is high, with relatively few fertilized eggs surviving to adult age (Scott and Scott 1988).

Atlantic herring are visual feeders (Blaxter 1966 *in* Scott and Scott 1988) and consume a variety of small organisms, including phytoplankton (the primary diet of young herring), euphausiids, copepods, fish eggs, pteropods, mollusc larvae, and the larvae of small fishes. Atlantic herring off Newfoundland have been known to eat very little during the winter months, instead surviving on accumulated fat (Hodder 1972 *in* Scott and Scott 1988). Atlantic herring make up the basic food source for numerous organisms, including many fish, marine bird, and marine mammal species.

Georeferenced commercial catch location data for 2005–2010 and commercial catch data for 2011-2012 indicate a few Atlantic herring catch locations in the central and northwestern portion of the Study Area, primarily in water depths <500 m. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, most of the Atlantic herring were caught at a mean water depth of ~245 m during spring and fall surveys.

Roughhead Grenadier

The roughhead grenadier occurs in deep water along coasts in subarctic to temperate waters on both sides of the North Atlantic. In the Northwest Atlantic, this species of grenadier is abundant and widespread, and occurs from Davis Strait along the continental slope off Newfoundland, off Nova Scotia on Banquereau, Sable Island and Browns Bank, and on Georges Bank (Scott and Scott 1988). The roughhead grenadier is predominant at depths ranging from 800 to 1,500 m, although it may inhabit depths between 200 and 2,000 m (Murua and De Cardenas 2005 *in* González-Costas 2013) and has been found as deep as 2,700 m. Catches tend to be highest at water temperatures ranging between 2.0 and 3.5ºC (Scott and Scott 1988).

Spawning is thought to occur during the winter and early spring. Little is known about the spawning grounds of this fish off Newfoundland although it is believed that some spawning does occur on the southern and southeastern slopes of the Grand Banks (Scott and Scott 1988; COSEWIC 2007). Food for the roughhead grenadier consists of a variety of benthic invertebrates including bivalve molluscs, shrimp, sea stars, polychaetes, and some fish. Roughhead grenadier has been found in the stomachs of Atlantic cod. This grenadier species is quickly becoming an important commercial fish in the Northwest Atlantic. Presently its fishery is unregulated since it is usually taken as bycatch in the Greenland halibut fishery (González-Costas 2012).

Georeferenced commercial catch location data for 2005–2010 and commercial catch data for 2011-2012 indicate most roughhead grenadier catches in the central portion of the Study Area with water depths <1,000 m. Catches were generally deeper in 2011 and 2012, between 500 and 2,000 m, and ranged from the west-central to northwest portions of the Study Area. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, the greatest proportion of roughhead grenadier was caught between the 200 and 1,000 m isobaths in the central and south-central portions of the Study Area.

Roughhead grenadier is currently designated as *special concern* under COSEWIC.

Redfish

The Northwest Atlantic redfish consists of a complex of three species identified as Acadian redfish (*Sebastes fasciatus*), golden redfish (*S. marinus*), and deepwater redfish (*S. mentella*) (DFO 2008b). The deepwater redfish is the dominant species in northern areas, including the Study Area. The redfish distribution in the Northwest Atlantic ranges from the Gulf of Maine, northwards off Nova Scotia and southern Newfoundland banks, in the Gulf of St. Lawrence, and along the continental slope and deep channels from the southwestern Grand Banks to areas as far north as Baffin Island. Redfish are also present in the area of Flemish Cap and west of Greenland.

These species inhabit cool waters (3 to 8°C) along the slopes of banks and deep channels in depths of 100 to 700 m (Scott and Scott 1988; DFO 2010b). Redfish are generally slow growing and long lived fishes (DFO 2010b).

The reproductive cycle of redfish differs from that of other fish species. Unlike many other species, fertilization in redfish is internal and females bear live young. Mating takes place in the fall most likely between September and December, and females carry the developing embryos until they are extruded as free swimming larvae in spring. Larval extrusion takes place from April to July depending on the areas and species. Mating and larval extrusion do not necessarily occur in the same locations.

Generally found near the bottom, redfish have been observed to undertake diel vertical migrations, moving off the bottom at night to follow the migration of their prey (DFO 2010b). Redfish are pelagic or bathypelagic feeders, feeding primarily on zooplankton such as copepods, amphipods, and euphausiids. Fishes and crustaceans become more important in the diet of larger redfish (Scott and Scott 1988).

Georeferenced commercial catch location data for 2005–2010 and commercial catch data for 2011-2012 indicate a concentration of redfish catch locations in the central and west-central portions of the Study Area with water depths between the 200 and 500 m isobaths. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, most of the redfish caught were deepwater redfish. The highest catches of deepwater redfish occurred at a mean water depth of 400 m during both spring and fall surveys. In terms of total catch weight, the greatest proportion of deepwater redfish was caught between the 200 and 500 m isobaths in the central and south-central portions of the Study Area.

Deepwater redfish and the Atlantic population of Acadian redfish are currently designated as *threatened* under COSEWIC.

Skate

Skates are bottom-living fishes that can be found in temperate, arctic, or tropical waters worldwide (Scott and Scott 1988). At least 14 species have been found to occur in Canadian Atlantic waters (BIO and NAFC 2007), with thorny skates (*Amblyraja radiata*) and spinytail skates (*Raja spinicauda*) typically dominating those caught during research surveys in and around the Study Area (e.g., DFO 1998, 2009a; DFO RV survey data 2007–2011).

Skates lay eggs in rectangular, horny capsules known as ‘sea- or mermaids’ purses,’ usually with one egg per capsule (Scott and Scott 1988). Eggs are presumed to be laid on the sea-bottom.

Skates are carnivorous, generalists, and typically opportunistic feeders (BIO and NAFC 2007). They consume a wide variety of organisms, which may include crabs, shrimps, lobsters, amphipods, isopods, mysids, polychaetes, bivalve molluscs, small fish, and occasionally cephalopods (Scott and Scott 1988). Energy-rich skate eggs are preyed upon by gastropods and marine mammals such as seals and sea lions, while hatched skates are consumed by numerous predators including sharks, other skates and rays, and grey seals (BIO and NAFC 2007).

A common bycatch species in offshore trawler catches, skate was traditionally discarded and often not reported in catch statistics (Kulka and Miri 2007). However, with the decline in the groundfish resources in waters around Newfoundland, interest in skate began to increase in the early 1990s (Kulka and Miri 2003). Commercial catches of skates consist of several skate species; however, thorny skate dominates the catch composition. In Canadian commercial catches, about 95% of the skate catch is thorny skate (Kulka and Miri 2007; Kulka and Mowbray 1999 *in* Simpson and Miri 2012). Thus, the skate fishery on the Grand Banks can be considered a directed fishery for thorny skate, and this is likely the species in question in the georeferenced and ranged DFO commercial catch location data for 2005 to 2010 and 2011 to 2012, respectively, in the Study Area.

Thorny skate is a widely distributed species in temperate and arctic waters of the North Atlantic. In the western Atlantic, this skate is distributed from Greenland to South Carolina, with the center of distribution on the Grand Banks in NAFO Divisions 3LNO (Simpson and Miri 2012). Thorny skate occur on both hard and soft substrates (Kulka et al. 1996 *in* JW 2007) but are primarily associated with muddy, sandy and pebble substrates typical of Grand Banks sediment (Kulka and Miri 2003a *in* JW 2007).

The migration patterns of the thorny skate are not fully understood, but evidence suggests a seasonal migration between the continental shelf edge during December to June, and the top of the banks during the remainder of the year (Kulka and Mowbray 1998 *in* JW 2007). All available evidence suggests that thorny skates in Divisions 3LNOPs comprise a single population (Kulka and Miri 2007). Males mature at smaller sizes than females with size at maturity increasing from north to south. Ovaries of sexually mature females hold 10 to 12 pairs of eggs in various developmental stages (Kulka and Miri 2003a *in* JW 2007), and females deposit 6 to 40 egg cases per year (Templeman 1982, 1987). Larger thorny skate produce larger egg cases; it is not known if egg case size is related to survival rates (Kulka and Miri 2003a *in* JW 2007).

Georeferenced commercial catch location data for 2005–2010 indicate a skate catch distribution in the west-central, south-central, and northeast portions of the Study Area in areas in water depths between 200 and 1,500 m, with the majority of catches ~500 m depth. No skate catches were reported in the commercial catch data for 2011-2012. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, most of the thorny skate catches were at mean water depths of ~300 m during both spring and fall surveys.

Capelin

Capelin is a small pelagic species that has a circumpolar distribution in the northern hemisphere (DFO 2013c). Capelin are often found along the coasts during the spawning season and occur pre-dominantly in offshore waters (e.g., Grand Banks) while immature and maturing. Migration towards the coast precedes spawning on beaches or in deeper waters (Nakashima and Wheeler 2002; DFO 2013c). The preferred spawning substrate is usually fine to coarse gravels. Capelin beach

spawning is more prevalent at night and typically occurs at a water temperature range of 5 to 8.5°C, but they have been observed to spawn at 4 to 10°C. On the bottom, spawning temperatures can be as low as 2°C as observed on the Southeast Shoal, located far south of the Study Area. Capelin are able to spawn at the age of two; males and most females usually die following spawning. Spawning commences in early June and may continue through July or August depending on tides, winds, and water temperatures (Scott and Scott 1988; Nakashima and Wheeler 2002; DFO 2013c). Incubation varies with ambient temperature and lasts ~15 days at 10°C (Scott and Scott 1988). Once hatched, larval capelin can be found at the surface to depths >40 m (Frank et al. 1993).

Capelin prey consists of planktonic organisms comprised primarily of euphausiids and copepods. Capelin feeding is seasonal with intense feeding in late winter and early spring leading up to the spawning cycle, when feeding ceases. Feeding recommences several weeks after cessation of spawning (Scott and Scott 1988).

Capelin is a major component in marine ecosystem dynamics as they are a key forage species that facilitate the transfer of energy between trophic levels, principally between primary and secondary producers to higher trophic levels (DFO 2013c). Capelin predators comprise most major fish species including Atlantic cod, haddock, herring, flatfish species, dogfish, and others. Several marine mammal species including minke whales, fin whales, harp and ringed seals, as well as a variety of seabirds also prey on capelin.

Other than the fishery the primary cause of capelin mortality is predation, therefore variations in capelin abundances are directly linked to natural causes (DFO 2013c). Capelin have a short life span (usually five years or less), and abundances are linked to a few age classes. Management of capelin fisheries tends to be conservative as a result of the prominent role of capelin in the marine ecosystem.

Commercial fishery capelin catches during 2005–2010 were primarily concentrated in the west-central portion of the Study Area, at locations with water depths ranging from 200 to 500 m. A single capelin catch location was reported in the commercial catch data in July of 2011 at ~500 m depth; no catch locations were reported in 2012. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, most of the capelin was caught during springtime surveys at a mean water depth of 160 m. The fall survey mean catch depth was 200 m.

Mackerel

Mackerel (*Scomber scombrus*) is a fast swimming, pelagic, schooling species (NOAA 1999) distributed in both Northeast and Northwest Atlantic waters (DFO 2009b). In the Northwest Atlantic, it ranges from Newfoundland to North Carolina, occurring in coastal waters in spring and summer and deeper waters along the continental shelf edge in fall and winter (DFO 2009b). Mackerel is unique among most other pelagic species, such as capelin, in that it does not possess a swim bladder and must swim continuously or it will sink (DFO 2013d). Mackerel prefer water temperatures between 7 and 15ºC; in the past several years a trend of migration to northerly regions has been observed in response to increased water temperature from climate change, with some mackerel ranging as far as the vicinity of the Arctic Circle at depths of around 20 m (DFO 2013d).

Most mackerel reach sexual maturity by two years of age (Sette 1943), with each female able to spawn repeatedly via batch spawning (Sette 1943; DFO 2009b). In Canadian waters, spawning occurs near the surface, day or night, primarily between June and July in the southern Gulf of St. Lawrence when

sea surface temperatures reach 7 to 9ºC and peaks between 10 to 13ºC (Ware and Lambert 1985; DFO 2009b). Eggs, larvae, and juveniles are pelagic, ranging from near surface to 15 to 25 m depth (Sette 1943). Mackerel is an opportunistic feeder, preying on zooplankton (e.g., copepods, euphausiids, amphipods, and chaetognaths), crustaceans (including northern shrimp), molluscs, and fish (including capelin, yellowtail flounder, and other mackerel) (NOAA 1999; DFO 2009b). Mackerel, a muscular and fatty fish, falls prey to numerous cetaceans, pelagic and demersal fish, seals, and seabirds (Savenkoff et al. 2005; DFO 2009b).

Mackerel has traditionally been used as bait in lobster and crab traps, but has become popular commercially within the past several years due to the decline in traditionally harvested groundfish species (DFO 2013d). However, there are concerns regarding management of the mackerel fishery, owing to unreported catch (bait or recreational fishing), and to potentially unreliable biomass estimates from traditional egg surveys due to the climate-induced migrational trends seen in recent years (DFO 2009b, 2013d). As such, the fishery is being managed cautiously by DFO, with freezes put in place for new mobile gear as of 2007, and the potential implementation of marine recreational fishing licences (DFO 2009b).

Georeferenced commercial catch location data for 2005–2010 indicate a single mackerel catch in the northwestern portion of the Study Area, where water depths range from 2,000 to 2,500 m. No mackerel catches were reported in the commercial catch data for 2011-2012.

Atlantic Halibut

Atlantic halibut, the largest of the flatfishes, is typically found along the slopes of the continental shelf. Atlantic halibut move seasonally between deep and shallow waters, apparently avoiding temperatures below 2.5ºC (Scott and Scott 1988), and prefer sandy soft bottoms that they can bury themselves in (DFO 2013e). Fish tagging studies in the Gulf of St. Lawrence have shown that Atlantic halibut can migrate long distances (up to 1,000 km), but often prefer to remain in the area that they were born. Atlantic halibut migrate horizontally as well as vertically, hunting for their prey by swimming up in the water column at sunset and returning to the bottom at dawn (DFO 2013e).

The spawning grounds of the Atlantic halibut are not clearly defined; however in the Gulf of St. Lawrence the Magdalen Shallows is thought to be a region favourable to the reproduction of Atlantic halibut (DFO 2013e). The fertilized eggs are slightly positively buoyant so that they naturally disperse and only gradually float toward the ocean's surface. Once hatched, the developing larvae live off their yolk for the next six to eight weeks while their digestive system develops so they can begin feeding on natural zooplankton. After a few weeks of feeding, they metamorphose from a bilaterally symmetrical larva to an asymmetrical flatfish, and are ready to assume a bottom-living habit. At this point they are ~20 mm long. As juveniles, Atlantic halibut feed mainly on invertebrates, including annelid worms, crabs, shrimps, and euphausiids. Young adults (between 30 to 80 cm in length) consume both invertebrates and small fish, while mature adults (>80 cm) feed entirely on larger fish such as redfish, cod, haddock, small halibut and lumpfish (Scott and Scott 1988; DFO 2013e). Juveniles are preyed upon mostly by cod and other large fish, while full size adults are preyed on by sharks, killer whales, and seals (DFO 2013e).

Few commercial catches of Atlantic halibut were reported in the Study Area during 2005–2010. Most of the reported catches were located in the south-central portion of the Study Area at locations with depths ~500 m. Two commercial catches were also reported in the west-central portion of the

Study Area at depths of ~1,000 m. Commercial catch data for 2011-2012 indicate the majority of Atlantic halibut catches in the west-central portion of the Study Area at ~500 m depth; catches also occurred in water depths between the 1,000 and 3,000 m isobaths in the west- and north-central portions of the Study Area, particularly in 2012. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, the mean catch depths during spring and fall surveys were 360 and 350 m, respectively.

Rock Crab

Rock crab are found from Labrador to South Carolina at various depths, ranging from the intertidal zone to 575 m (DFO 2013f). This bottom-dwelling species prefers sandy or mud bottom, but is also commonly found on other types of substrate (DFO 2013f).

Rock crabs increase in size through moulting, which occurs primarily in April and May (DFO 2000). Males reach a larger maximum size than females. On average, these crabs become sexually mature at a carapace width of ~75 mm and 57 mm for males and females, respectively. Mating can occur while the female carapace is still soft after moulting between July and October depending on location, and egg extrusion is thought to occur around late October (Scarratt and Lowe 1972; DFO 2000, 2013f).

Rock crabs are opportunistic, generalist predators (Salierno et al. 2003). Their prey species vary according to availability, location, and season, and can include polychaetes, mussels, sea stars, sea urchins, molluscs, amphipods, gastropods, and fish, among others (Scarratt and Lowe 1972). These crabs are preyed upon by various fishes, decapods, seabirds, and marine mammals (Donahue et al. 2009).

Rock crabs were traditionally considered pests in the lobster fishery, as they were known to enter lobster traps and steal the bait. However, the commercial fishery for these crabs began in the 1970s in the Atlantic region and has gained more attention with the collapse of traditional groundfish species, such as cod. Only males are taken in the commercial, bait, and bycatch rock crab fisheries and males typically reach commercial size at approximately six years of age (DFO 2013f). The fishery is regulated by DFO to include mandatory licences (limited entry), dockside monitoring and logbook, quotas, minimum legal size (carapace width ≥102 mm), and a ban on catching females or soft-shelled crabs (DFO 2013f).

Georeferenced commercial catch location data indicated a single reported rock crab catch for 2005-2010, which occurred in the southeastern portion of the Study Area in water depths ~1,000 m. No catches were reported in the Study Area in commercial catch data for 2011-2012.

Sea Scallops

Sea scallops (*Placopecten magellanicus*) are found in the Northwest Atlantic, from northern Newfoundland to North Carolina. Their preferred habitat consists of sandy or gravel seabeds, ranging in depth from 10 to 384 m, with large offshore concentrations typically found on banks between 35 and 120 m (DFO 2013g). Sea scallops can reach up to 20 cm in size and can live up to 21 years.

Sea scallops primarily spawn between late summer and fall (August to October), with a given population generally spawning over a period of two to four weeks (DFO 1993). Two spawning periods,

in the spring and fall, have been reported for coastal Newfoundland (Naidu 1970 *in* DFO 1993). The fertilized eggs hatch into planktonic larvae, which metamorphose and settle to the sea bottom within one to two months (DFO 1993).

Sea scallops are suspension filter feeders and feed primarily on plankton (DFO 2013g). Larval scallop mortality is high prior to settling on the seabed, owing to predators, such as zooplankton and fish, and to currents transporting them away from favourable habitats. Adult sea scallops are primarily preyed upon by sea stars, crabs, lobster, and various groundfish (DFO 2013g).

The offshore sea scallop fishery takes place year-round within Canada's 200 nmi Exclusive Economic Zone (EEZ), with some exceptions to avoid interference with the lobster fishery, spawning cod, and yellowtail flounder (DFO 2013g). Individual sea scallops need approximately four to five years to reach commercial size. These bivalves are one of Canada's most important offshore commercial shellfish species, valuing $68.5 million in 2011 (DFO 2013g). The offshore Eastern Canada sea scallop fishery received Marine Stewardship Council (MSC) eco-certification as a sustainable and well-managed fishery on 25 March 2010. This is the first scallop fishery in North America to receive an MASC eco-certification. DFO maintains that the offshore sea scallop populations are healthy and sustainably managed (DFO 2013g).

A single sea scallop catch was reported in the georeferenced commercial fishery data during 2005-2010, located in the central portion of the Study Area in ~500 m water depth. Commercial catch data for 2011-2012 indicated a single catch location in 2012 in the central portion of the Study Area in ~500 m depth.

Witch Flounder

Witch flounder range from the Hamilton Inlet Bank to North Carolina in the Northwest Atlantic (DFO 2013h). They preferentially inhabit deep holes and channels located between and along coastal banks (DFO 2013h), and gullies with clay, muddy sand or pure mud bottoms, and usually move from shallower, soft mud bottoms in the summer to deeper gullies in the winter, with bottom temperatures ranging from -1 to +11ºC (DFO 2013h). Evidence suggests that witch flounder are most abundant within a bottom temperature range of 2 to 6ºC. A deepwater species, witch flounder is most abundant at depths of 185 to 400 m, although some have been caught at depths >1,500 m (DFO 2013h). Witch flounder do not embark on long distance migrations and are considered more or less sedentary, concentrating in areas favourable for spawning and moving in surrounding areas to feed (DFO 2013h).

Witch flounder form dense prespawning concentrations between winter and spring, and spawning occurs in shallow water and on the slopes of the Grand Banks area, in late spring to late summer or early fall (DFO 2013h). Eggs and larvae of witch flounder are pelagic, while juveniles can be either pelagic or deepwater fishes.

Witch flounder have a very small mouth, and their diet consists mainly of polychaetes, small crustaceans and shellfish (DFO 2013h). Although a considerable portion of witch flounder catch occurs as bycatch of other fisheries, it has been a component of the Canadian Atlantic groundfisheries since the early 1940s (DFO 2013h).

There were few georeferenced commercial catch location data for witch flounder in the Study Area during 2005–2010. These were located in the west-central portion of the Study Area in water depths ~500 m. The majority of witch flounder catch was also located in the west-central portion of the Study Area at ~500 m depth in commercial catch data for 2011-2012, however catches also occurred in water up to <2,500 m depth in the western/northwestern portions of the Study Area, and between 200 and 1,000 m depth on the Flemish Cap (catches on the Flemish Cap occurred in 2011). Based on DFO RV survey data collected in the Study Area from 2007 to 2011, most witch flounder were caught at mean water depths of 400 and 500 m during spring and fall surveys, respectively.

American Plaice

American plaice is a bottom-dwelling flatfish that resides on both sides of the Atlantic (COSEWIC 2009; DFO 2011b). American plaice that reside in the West Atlantic region range from the deep waters off Baffin Bay and Davis Strait, south to Labrador, the Grand Banks, and the Flemish Cap, and southwards to the Gulf of Maine and Rhode Island (DFO 2011b). In Newfoundland waters, plaice occurs both inshore and offshore over a wide variety of bottom types (Morgan 2000) but seem to prefer fine sand and gravel substrates (DFO 2011b). Adult and juvenile plaice typically inhabit the same areas over depths ranging from 20 to 700 m, but prefer depths from 100 to 300 m (DFO 2011b). It is tolerant of a wide range of salinities and has been observed in estuaries (Scott and Scott 1988; Jury et al. 1994). It is a coldwater species, preferring water temperatures of -1.5°C to 13°C, but is most abundant at temperatures ranging from just below zero to -1.5°C (DFO 2011b). Tagging studies in Newfoundland waters suggest that, once settled, juveniles and adults are rather sedentary and do not undertake large scale migrations (DFO 2008c). However, older plaice have been known to move up to 160 km (Powles 1965). Migrations have been observed in Canadian waters to deeper offshore waters in the winter, returning to shallower water in the spring (Hebert and Wearing-Wilde 2002 *in* Johnson 2004).

In Newfoundland waters, American plaice spawn during the spring (Scott and Scott 1988). Within the Study Area, there are limited data with respect to the actual spawning times. American plaice in the Newfoundland Region have no specific spawning areas; rather spawning occurs over the entire area occupied (DFO 2008c) with the most intense spawning coincident with areas where the higher abundance of adults are found (Busby et al. 2007; DFO 2011b). American plaice are group synchronous, batch spawners that generally release and fertilize large quantities of eggs on the seabed over a period of days (Johnson 2004; DFO 2011b). Eggs are buoyant and drift into the upper water column where they are widely dispersed, allowing for some intermingling of stocks. Intermingling of adults is minimal. Hatching time is temperature dependent, occurring in 11 to 14 days at temperatures of 5°C (Scott and Scott 1988). Larvae are 4 to 6 mm in length when they hatch; they begin to settle to the seabed when they reach 18 to 34 mm in length and their body flattens (Fahay 1983).

Georeferenced commercial catch location data for 2005 to 2010 and commercial catch data for 2011-2012 indicate a concentration of American plaice catch locations in the west-central portion of the Study Area, in water depths ranging between 200 and 500 m. Catches also occurred between the 500 and 2,000 m isobaths in the west-central portion of the Study Area in 2011 and 2012, and between 200 and 500 m water depth on the Flemish Cap in 2011. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, the greatest proportion of American plaice were caught at ~500 m depth in the west- and south-central regions of the Study Area.

The Newfoundland and Labrador population of American plaice is currently designated as *threatened* under COSEWIC.

Atlantic Cod

The Atlantic cod is a demersal fish that inhabits cold (10 to 15°C) and very cold (<0 to 5°C) waters in coastal areas and in offshore waters overlying the continental shelf throughout the Northwest and Northeast Atlantic Ocean (COSEWIC 2010a). The species is found contiguously along the east coast of Canada from Baffin Island to Georges Bank. Outside Canadian waters in the Northwest Atlantic, cod can be found on the northeast and southeast tips of the Grand Banks and on the Flemish Cap. During the first few weeks of life, cod eggs and larvae are found in the upper 50 m of the water column. As juveniles, cod are settled on the bottom and tend to occur in nearshore habitats with vertical structure such as eelgrass (*Zostera marina*) and macroalgae. As adults, the habitat requirements of cod are increasingly diverse.

Atlantic cod typically spawn over a period of less than three months in water that may vary in depth from tens to hundreds of metres (COSEWIC 2010a). Cod are described as batch spawners because only a small percentage (5 to 25%) of the female's egg total is released at any given time during a three to six week period. After hatching, larvae obtain nourishment from a yolk sac until they have reached a length of 1.5 to 2.0 mm. During the larval stage, the young feed on phytoplankton and small zooplankton in the upper 10 to 50 m of the water column. After the larval stage, the juveniles settle to the bottom where they appear to remain for a period of 1 to 4 years. These settlement areas are known to range from very shallow (<10 to 30 m) coastal waters to moderately deep (50 to 150 m) waters on offshore banks. After this settlement period, it is believed that the fish begin to undertake seasonal movements and migrations characteristic of adults (COSEWIC 2010a).

Dispersal in Atlantic cod appears to be limited to the egg and larval phases of life, during which surface and near-surface water currents and turbulence are the primary determinants of horizontal and vertical displacement in the water column (COSEWIC 2010a). For some cod populations, eggs and larvae are capable of dispersing over very long distances. For example, cod eggs spawned off southeastern Labrador (NAFO Division 2J) may possibly disperse as far south as the Grand Banks (Helbig et al. 1992; Pepin and Helbig 1997). By contrast, eggs spawned by cod in inshore, coastal waters, especially at the heads of large bays, may experience dispersal distances of a few kilometres or less (Bradbury et al. 2000, 2002, 2008).

Long-term movements by cod take the form of seasonal migrations (COSEWIC 2010a). These migrations can be attributed to geographical and seasonal differences in water temperature, food supply, and possibly spawning grounds. At one extreme, some inshore populations are suspected to have extremely short migrations, possibly limited to tens of kilometres, or less, in distance. By contrast, cod in other populations are known to traverse hundreds of kilometres during their seasonal migrations.

Two stocks of Atlantic cod occur within the Study Area: 2J3KL cod that occur off Labrador and eastern Newfoundland, and 3M cod that occur in the vicinity of the Flemish Cap and Flemish Pass. Recent DFO fall sampling of the 2J3KL stock indicates that length-at-age and weight-at-age have improved since the low values of the early 1990s, particularly in NAFO Divisions 3K and 3L (DFO 2013i). The condition of cod in 3K and 3L has also improved from that seen in the early 1980s, although it did decline between 2008 and 2009 (DFO 2013i). The NAFO Division 3M cod stock was on fishing

moratorium from 1999 to 2009. Recent assessment results indicate a substantial increase in Spawning Stock Biomass, which should continue only if current post-moratorium fishing level is maintained (Gonzàlez-Troncoso et al. 2013).

Georeferenced commercial catch location data for 2005–2010 and commercial catch data for 2011-2012 indicate the majority of Atlantic cod catches occurred in the west-central portion of the Study Area in water depths between 200 and 500 m. Catches also occurred between 200 and 1,000 m water depth on the Flemish Cap in 2011. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, the greatest proportion of Atlantic cod was caught between the 200 and 500 m isobaths in the central portion of the Study Area.

Atlantic cod as a species is currently designated as *special concern* under Schedule 3 of the *SARA*. The Newfoundland and Labrador population of Atlantic cod is currently designated as *endangered* under COSEWIC.

4.2.4.2 Other Fishes Caught in the Commercial Fishery

Other species that have been caught during commercial fisheries being prosecuted within the Study Area during recent years include the following:

- Squid (*Illex* sp.)
- Wolffishes (*Anarhichas* spp.)
- Bluefin tuna (*Thunnus thynnus*);
- White and blue hakes (*Urophycis tenuis*; *Antimora rostrata*);
- Whelks; and
- Yellowtail flounder (*Limanda ferruginea*).

More fishery-related details for these species are included in Section 4.3 of this EA. These species are briefly profiled in this subsection.

Squid

Two species of squid, the short-finned squid (*Illex illecebrosus*) and the long-finned squid (*Loligo pealiei*), inhabit the Northwest Atlantic. Of these, only the short-finned squid has been of major commercial importance to the Atlantic Canadian fishery (DFO 2013j). Squid were traditionally caught for bait around Newfoundland until the early 1970s, after which an international *Illex* fishery was developed.

Short-finned squid are a short lived species, believed to have life spans no greater than 12 to 18 months. Adults migrate southwest from feeding areas and are thought to spawn in the fall near Cape Hatteras or possibly further south over the Blake Plateau, although the precise spawning locations are unknown (DFO 2013j). Females create large (up to 1 m diameter), clear, almost neutrally-buoyant egg masses, each containing about 100,000 eggs. Larvae hatch after approximately two weeks. Little is known of juvenile growth rates, but adults grow very rapidly, adding ~1.5 mm in mantle length per day (DFO 2013j). Both males and females die after spawning.

Short-finned squid are voracious predators and consume a variety of prey including crustacean and fish (DFO 2013j). Larger individuals are also given to cannibalism. These squid fall prey to numerous fish, marine mammals, and birds, including tunas, swordfish, haddock, cod, Pollock, sharks, pilot whales, dolphins, shearwaters, fulmars, gannets and gulls (DFO 2013j).

The squid fishery takes advantage of the short-finned squid's diel lifestyle; they spend daylight hours near the sea bottom and disperse upward into the water column at night (DFO 2013j). The offshore squid fishery in Atlantic Canada is primarily carried out via traps or jigging from dories in shallower regions and by trawlers offshore (DFO 2013j). The Atlantic Canadian population has declined since a record high catch in 1979 (162,000 mt); it is a difficult species to manage on account of its short life span.

Georeferenced commercial catch location data for 2005–2010 indicate a few incidences of *Illex* squid in the west-central portion of the Study Area at water depths between 200 and 500 m. There were no *Illex* catches reported in commercial catch data for 2011-2012. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, most of the relatively few *Illex* squid caught were taken during the spring surveys at a mean depth of ~260 m; the mean catch depth during the fall surveys was ~300 m.

Spotted and Northern Wolffish

Spotted and northern wolffishes are profiled in Section 4.6 on Species at Risk. In terms of total catch weight, the greatest proportion of catches of these wolffish species in the Study Area occurred between the 100 and 500 m isobaths of the northeastern Newfoundland slope in the central and south-central portions of the Study Area.

Atlantic Wolffish

In Canadian waters, Atlantic wolffish are distributed from the Canadian portion of the Gulf of Maine to offshore of Baffin Island, including the Bay of Fundy, Scotian Shelf, Grand Banks off Newfoundland, Gulf of St. Lawrence, northeastern Newfoundland and the Labrador Sea. Atlantic wolfish are most abundant off northeastern Newfoundland, on the Labrador Shelf, and in the southern Grand Banks (COSEWIC 2012a). Atlantic wolffish are primarily demersal and inhabit shallower areas than the northern and spotted wolffishes. This species has been observed from near shore to a depth of 918 m at water temperatures ranging from -1 to 10°C, but are most common at water depths of 150 to 350 m with water temperatures ranging from 1.5 to 4°C (Kulka et al. 2008). Unlike the northern and spotted wolffishes, Atlantic wolffish are often observed by divers close to shore, and they form dense concentrations offshore. During its feeding period, this wolffish species appears to prefer complex reliefs of rocks without algal growth and sand. Shelters in these rock reliefs are typically situated on 15-30° slopes with good water circulation. There is some indication that Atlantic wolffish form colonial settlements during the feeding period (Kulka et al. 2008).

Prey of Atlantic wolffish are primarily benthic invertebrates (>85%), typically including echinoderms (e.g., sea urchins), crustaceans (e.g., crabs), and molluscs (e.g., scallops) associated with both sandy and hard bottom substrates. Fish also constitutes part (<15%) of the Atlantic wolffish diet (e.g., redfish) (Kulka et al. 2008; COSEWIC 2012a). Little is known of the predators of wolfish; however, juveniles have been found in the stomach contents of a variety of seal species, as well as Atlantic cod, Atlantic halibut, sea raven, spiny dogfish, longhorn sculpin, white hake, and haddock

(COSEWIC 2012a). Migration by Atlantic wolffish is limited, with seasonal inshore movement in the spring when mature fish are found in areas with water depths <15 m. These wolffish seem to prefer stony bottom substrate for spawning in September and October in Newfoundland and Labrador waters. After internal fertilization, cohesive masses of eggs are deposited in crevices on the bottom, remaining unattached to the substrate. The egg mass is guarded and maintained by the male Atlantic wolffish for the 7 to 9 month incubation time, after which pelagic larvae hatch and commence to feed on crustaceans, fish larvae, and fish eggs within a few days of hatching (Kulka et al. 2008).

Georeferenced commercial catch location data for 2005–2010 indicate the majority of Atlantic wolffish catches occurred in the west- and south-central portions of the Study Area at water depths between ~150 and 500 m. No catches were reported in commercial catch data for 2011-2012. During DFO RV surveys conducted in the Study Area during 2007–2011, 1,463 Atlantic wolffish were caught, during both spring and fall survey times. Atlantic wolffish catches were most concentrated in the west- and south-central portions of the Study Area between the 200 and 500 m isobaths.

Atlantic wolffish is currently designated as *special concern* under Schedule 1 of the *SARA* and COSEWIC.

Bluefin Tuna

Atlantic bluefin tuna is a very large species (≥400 kg) inhabiting both sides of the Atlantic, ranging from Newfoundland to the Caribbean and occasionally as far south as coastal Brazil (COSEWIC 2011a). Bluefin tuna are seasonal migrants to Canadian waters and are fished from July through December in and around the Study Area. Bluefin tuna are able to regulate their body temperature, and as such are able to tolerate a wide thermal and depth range during their yearly migrations (COSEWIC 2011a).

The western Atlantic population spawns during the spring in the Gulf of Mexico, and sometimes in the Bahamas and Straits of Florida (COSEWIC 2011a). Bluefin tuna are repeat, broadcast spawners (i.e., eggs and sperm are released into the water), usually at night or early dawn for up to a week at a time. Fertilized eggs float to the surface for several days, after which free-swimming larvae remain planktonic for 10 days before descending into deeper waters (Richards et al. 1989; Rooker et al. 2007; Teo et al. 2007).

Atlantic bluefin tuna are highly active predators, consuming both pelagic and bottom fishes in Canadian waters (COSEWIC 2011a). Adults have few predators, including humans, killer whales, and mako sharks, but natural mortality is presumed to be greater for smaller individuals vulnerable to other pelagic predators and seabirds (COSEWIC 2011a).

Prized for their flesh and often sold either canned or for sushi, Atlantic bluefin tuna are managed by DFO and the International Commission for the Conservation of Atlantic Tunas (ICCAT). There was no georeferenced or commercial catch data for bluefin tuna in the Study Area during 2005–2010 or 2011-2012, respectively.

The Atlantic bluefin tuna is currently designated as *endangered* under COSEWIC.

White and Blue Hakes

White hake inhabit the continental shelf and upper slope of the West Atlantic, ranging from southern Labrador (including the southern slope of the Grand Banks) to North Carolina and occasionally deep waters off Florida (DFO 2013k). This species prefers soft-bottomed areas, with water temperatures ranging from 5 to 11ºC (DFO 2013k). White hake move to shallower waters in warmer months and out into deeper areas during colder periods.

Mature female white hake are among the most fertile of the commercial demersal species in the Northwest Atlantic, producing millions of eggs when they spawn in summer to early fall (DFO 2013k). Eggs are buoyant, while larvae and juveniles are pelagic for up to three months.

Young, demersal juveniles feed primarily on shrimps, polychaetes, and small crustaceans, while older juveniles also consume krill and some fish (DFO 2013k). Adult white hake consume a variety of fish species, including Atlantic herring, Atlantic cod, haddock, longfin hake, redfish, Atlantic mackerel, northern sand lance, and winter flounder (DFO 2013k). White hake are preyed upon by larger cod and hake, Atlantic puffins, Arctic terns, and grey seals (DFO 2013k). White hake are targeted in Canadian fisheries, but are also caught as bycatch in other fisheries. They are caught using gillnets, hooks and lines, bottom trawls, and seines (DFO 2013k). There was no georeferenced or commercial catch data for white hake in the Study Area during 2005–2010 or 2011-2012, respectively. Most of the white hake caught during DFO RV surveys in the Study Area from 2007 to 2011 were captured at a mean depth of about 370 m in both spring and fall surveys.

Blue hake occur globally in all oceans. Although their preferred depth ranges are not known, they have been found at depths up to nearly 3,000 m (DFO 2011c). Relatively little is known about their life cycles, but blue hake are presumed to migrate into deeper waters to spawn (DFO 2011c). Blue hake is not particularly attractive as a commercial fish (DFO 2011c).

There were a few georeferenced commercial catches of blue hake in the northeastern portion of the Study Area during 2005–2010 at around 1,500 m depth. There were no catches of blue hake in commercial catch data for 2011-2012. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, most of the blue hake were caught during the fall at a mean water depth of 900 m. The mean catch depth during the spring surveys was 600 m.

Whelks

Whelks are marine snails that are distributed from Newfoundland and Labrador to New Jersey, including the Gulf of St. Lawrence (DFO 2010c). An abundant and relatively inactive species, whelks are typically found partially buried in muddy or sandy substrates at a variety of depths, from the intertidal zone to >200 m (DFO 2003, 2010c), but occurs in greatest densities on soft bottoms at 15 to 30 m depths (DFO 2011d).

Sexual maturation is relatively slow with maturity being reached between 4 to 7 years of age, varying with gender and location. Whelks are polygamous, with females able to store sperm from several different males (DFO 2011d). Spawning takes place between late spring or summer and late autumn, depending on location (DFO 2003, 2011d). Fertilization occurs internally; females lay their embryos inside capsules which they adhere to hard surfaces such as rocks and boulders. After 3 to 8 months of development, juvenile whelks will emerge from the capsules (DFO 2011d). Whelks have no planktonic

or pelagic stage. Whelks reach up to 120 mm in shell height and can live over 10 years of age (DFO 2011d).

Whelks feed on both live and dead animals, primarily molluscs and other invertebrates such as urchins, polychaetes, bivalves, and crustaceans (DFO 2003). Whelks are able to detect a scent trail and follow it to a particular source, which is why they are commonly found in lobster, crab and cod traps. Feeding activity generally decreases with the onset of spawning (DFO 2003, 2011d). Whelks are preyed upon by lobster, cod, crab, starfish, dogfish, wolffish, rays, and gulls, and their empty shells often serve as habitat for organisms such as hermit crabs (DFO 2003).

Whelks are harvested all year offshore, using various pot designs. This fishery is monitored by DFO; around Newfoundland, fishers are required to have licences and abide by size (minimal shell height of 63 mm) and pot number regulations (DFO 2011d). There was no georeferenced or ranged commercial catch location data for whelk in the Study Area during 2005–2010 or 2011-2012, respectively. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, most of the whelks caught during the survey were taken during the fall at a mean water depth of ~500 m. The mean catch depth for whelk during the spring surveys was ~320 m.

Yellowtail Flounder

Yellowtail flounder inhabit the continental shelf of the Northwest Atlantic from Labrador to Chesapeake Bay at depths ranging from 37 to 91 m (DFO 2013l) in water temperatures exceeding 2ºC (LGL 2006b). The northern limit of commercial concentrations reaches extend to the Grand Banks off the east coast of Newfoundland. Yellowtail spawning on the Grand Banks generally occurs between May and September with peaks during the latter part of June. The eggs, larvae and early juvenile stages of yellowtail are pelagic. Growth rates of flounder are slower in the northern range (Grand Banks and Gulf of St. Lawrence) in comparison to the southern range (Georges Bank) and consequently sexual maturation is slower, with maturity occurring by age 4 to 6 in the northern range and age 2 to 3 in the southern range (DFO 2013l).

Because of its small mouth size, this flounder is restricted in its choice of prey. The most common prey of yellowtail flounder includes polychaetes, amphipods, shrimp, cumaceans, mollusks, isopods, and small fish. The most common predators of yellowtail flounder include cod and spiny dogfish; however, they are also preyed upon by skates, monkfish, bluefish, Atlantic halibut, American fourspot flounder and seals (DFO 2013l).

Juvenile and adult yellowtail are generally concentrated on the southern Grand Banks, on or near the Southeast Shoal where the substrate consists primarily of sand (Unit Area 3Nc, primarily) (Walsh et al. 2001 *in* LGL 2006b). Maddock Parsons and Brodie (2008) discussed the distribution and abundance of yellowtail flounder on the Grand Banks based on spring and fall trawl surveys. They indicated the greatest concentrations of yellowtail flounder southwest of the Project Area near Southeast Shoal.

There was no georeferenced or commercial catch data for yellowtail flounder in the Study Area during 2005–2010 or 2011-2012, respectively. Based on DFO RV survey data collected in the Study Area from 2007 to 2011, most of the yellowtail flounder catch weight was taken at mean water depths of ~70 m during both spring and fall surveys.

4.2.4.3 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 Reproduce 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 to 10 months	12 to 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 to 15 weeks
Stimpson's surf clam	Eastern Grand Banks	Fall	4 to 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
Greenland cockle	Eastern Grand Banks	Uncertain	Uncertain
Yellowtail flounder	Shallower sandy areas – typically <100 m water depth – at bottom	May to 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	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 to 8 weeks
American plaice	Spawning generally occurs throughout the range the	April to May	12 to 16 weeks

Species	Locations of Reproductive Events	Times of Reproductive Events	Duration of Planktonic Stages
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 to June	10 to 12 weeks
Wolffishes	Along bottom in deeper water, typically along continental slope	Summer to early winter (species dependent)	Uncertain
Cusk	Uncertain	May to August Eggs are buoyant	Presumed to be 4 to 16 weeks
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
Sand lance	On sand in shallow water of the Grand Banks	November to January	Several weeks

4.3 Fisheries

This section describes the existing fisheries (i.e., commercial, research survey, aboriginal, and recreational fisheries) in the Study Area for Suncor's proposed geophysical program and provides additional context for the area's foreign commercial fisheries.

4.3.1 Information Sources

Most of the information used to characterize the fisheries is catch weight, either commercial catches landed at Newfoundland and Labrador ports or catches made during DFO research vessel surveys. Landed catch values are also reported for certain scenarios.

4.3.1.1 Data Sets

Commercial fisheries within the Study Area are managed by either DFO or NAFO. The domestic commercial and research vessel fisheries analyses in this subsection are based on DFO Newfoundland and Labrador Region databases. NAFO catch weight data are used to describe both domestic and foreign fisheries beyond the 200 nmi EEZ. More than half of the proposed Study Area is located outside of the 200 nmi limit. The NAFO data are derived from the STATLANT 21A data set for 2005 to 2012. The STATLANT reporting system of questionnaires is a long-standing standardized statistical inquiry for submission of national catch data to international fisheries agencies by national reporting offices. Rather than being georeferenced, these STATLANT data are geographically resolved at the NAFO Division level only. Thus the following analysis quantifies harvesting for portions of NAFO Divisions 3K, 3L, 3M, and 3N (Figure 4.1)[1]. Most of the proposed Study Area overlaps with NAFO Unit Areas 3Le, 3Li and 3Lt.

[1] For an indication of location of effort by Convention nations see maps in NAFO Ad Hoc Working Group report, 2009 at http://archive.nafo.int/open/fc/2009/fcdoc09-02.pdf.

The DFO commercial fishery landings data used in this EA (DFO 2005 to 2012) represent all catches landed within the Newfoundland and Labrador region (whether managed by NAFO or DFO, as described above). The 2005-2010 DFO catch data for the Study Area are georeferenced (typically >95% of the harvest, by quantity) so that harvesting locations can be plotted. The positions provided in the datasets are those recorded in the vessels' fishing logs, and are reported in the database by degree and minute of latitude and longitude. For some gear, such as mobile gear towed over an extensive area, or for extended gear, such as longlines, the reference point does not represent the full distribution of the gear or activity on the water. However, over many data entries, the reported locations create a relatively accurate indication of where fishing activities occur. The DFO catch data for 2011 and 2012 are cumulative catch weight ranges (defined by quartile values) within 6 min x 6 min cells. Figures based on these 2011 and 2012 commercial fishery databases are included in the EA. To provide a historical perspective of catches in the general area of the proposed Study Area, DFO data for Unit Areas 3Kgk, 3Ldehirt, 3Mac, and 3Nab between 1986 and 2010 were also analyzed.

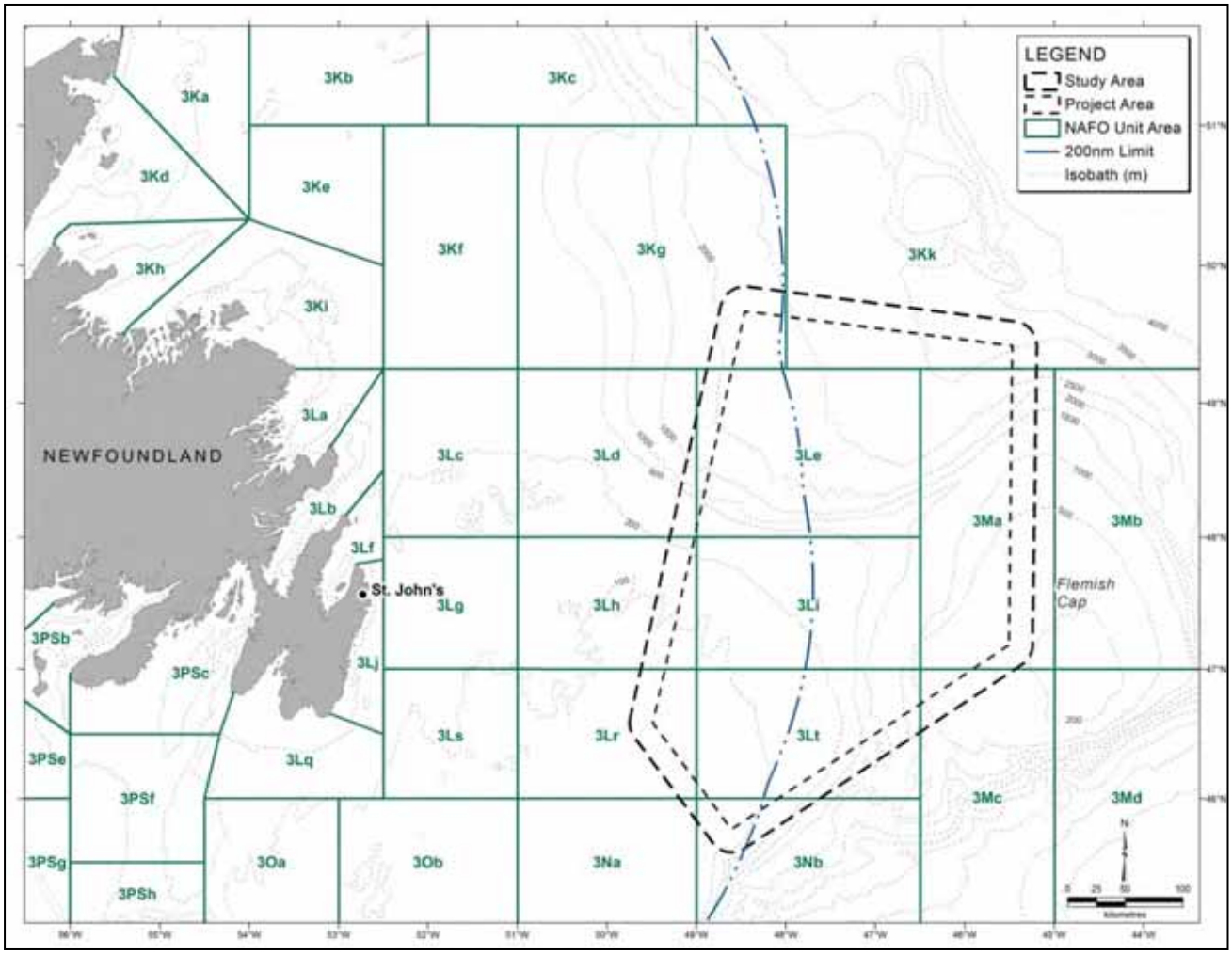


Figure 4.1. Study Area Location Relative to NAFO Unit Areas.

4.3.1.2 Consultations

Consultations for Suncor's proposed 2014–2024 geophysical program were conducted with the following agencies, stakeholders and interest groups:

- Fisheries and Oceans Canada (DFO);
- Environment Canada (EC);
- Nature Newfoundland and Labrador (NNL) (and various member organizations);
- One Ocean;
- Fish, Food and Allied Workers Union (FFAW);
- Association of Seafood Producers (ASP);
- Ocean Choice International (OCI);
- Icewater Seafoods;
- Clearwater Seafoods Limited Partnership;
- Newfound Resources Ltd. (NRL);
- Groundfish Enterprise Allocation Council (GEAC); and
- Canadian Association of Prawn Production (CAPP).

The consultations were conducted to provide information about the proposed Suncor geophysical program, and to gather information about fishing activities and any other issues and concerns. Those consulted are listed in Appendix B. Fisheries-related information provided during the consultation process is reported under the discussions of the fisheries below. Details of the consultations are discussed in Section 5.1.1.

4.3.1.3 Other Sources

Other information sources used for this subsection include fisheries management plans, quota reports, and other DFO documents such as Science Advisory and Stock Status reports.

4.3.2 Regional NAFO Fisheries

As noted previously, more than half of the Study Area occurs outside of Canada's 200 nmi EEZ. The Study Area overlaps portions of NAFO Divisions 3K, 3L, 3M, and 3N (see Figure 4.1). NAFO manages 19 stocks comprised of 11 species: Atlantic cod (3L, 3M, 3NO stocks), redfish (3LN, 3M, 3O, Sub-area 2 and Div. 1F+3K stocks), American plaice (3LNO, 3M stocks), witch flounder (3L, 3NO stocks), yellowtail flounder (3LNO stock), Greenland halibut (3LMNO stock), white hake (3NO stock), skates (3LNO stock), capelin (3NO stock), squid (Subareas 3+4 stock), and shrimp (3L and 3NO stocks). Of the 19 stocks managed by NAFO, 16 straddle the EEZ; only the 3M cod, redfish, and American plaice stocks occur entirely outside of the EEZ. Most fishing for relevant species in the NAFO Convention Regulatory Area is conducted using bottom trawlers.

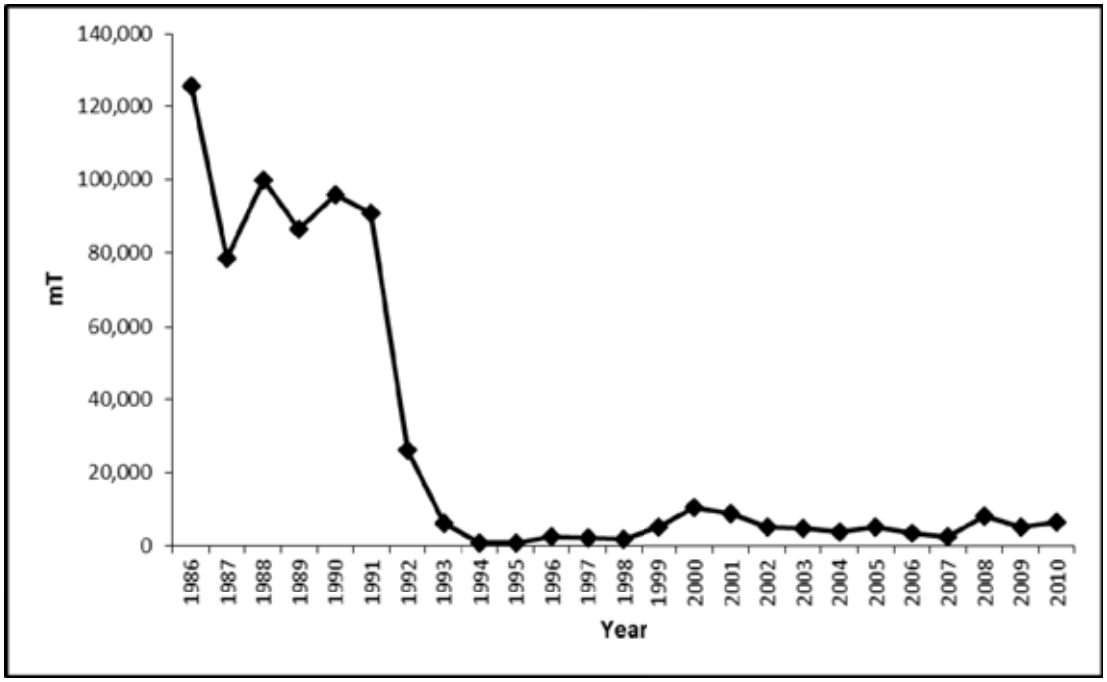
During the 2005–2012 period, commercial harvesting beyond the 200 nmi EEZ, in terms of catch weight, was dominated by northern shrimp (35% of total catch weight) (primarily in NAFO Division 3K), snow crab (20%) (primarily in NAFO Division 3L), and capelin (12%) (primarily in NAFO Divisions 3L and 3K). Greenland halibut and Atlantic mackerel catches each accounted for 6% of the 2005–2012 commercial fishery catch weight outside of the EEZ (primarily in NAFO Divisions 3L and 3K, respectively). The highest catch weights during the eight-year period were taken in NAFO Divisions 3K (40%) and 3L (~38%), followed by 3M and 3N. Canadian vessels accounted for 77% of the commercial

catch weight reported for this area during 2005–2012. Only in Division 3M did the foreign vessels dominate catches (>99% of total catch weight in this Division). Catches in 3M were dominated by northern shrimp, redfish, Atlantic cod, Greenland halibut, and blue shark. Percentage catches by weight in Division 3N were similar for Canadian and foreign vessels (~55 and 45%, respectively).

4.3.3 Domestic Fisheries

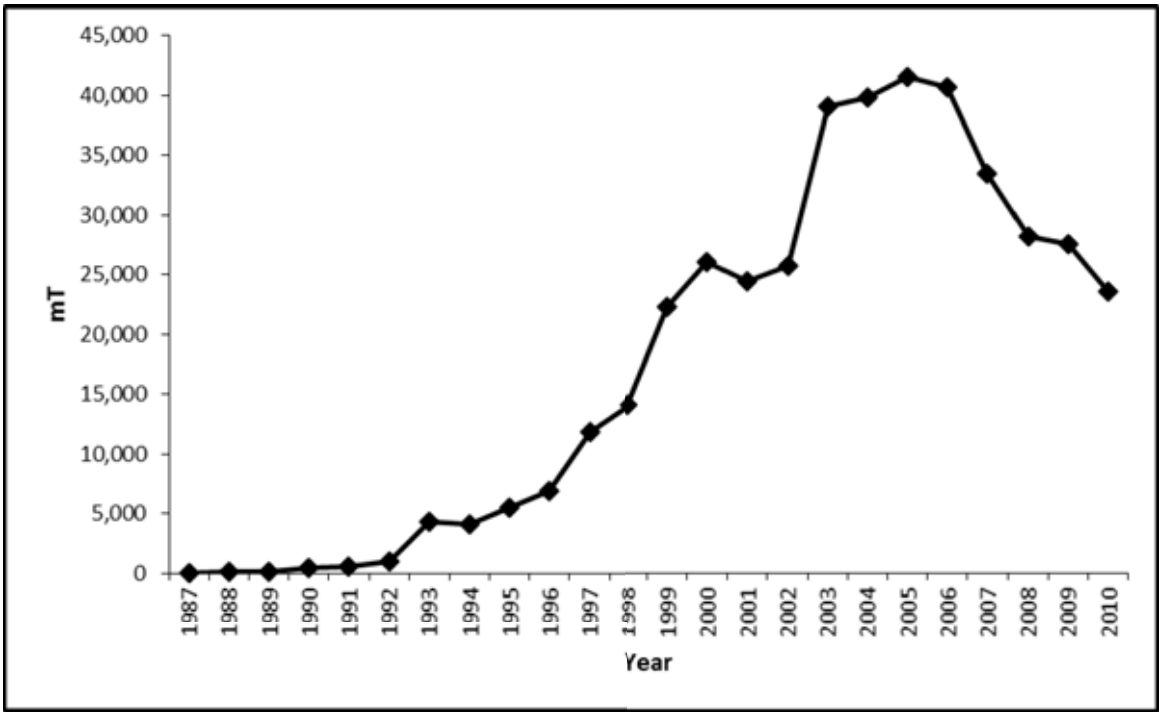
4.3.3.1 1986 to 2010 Catch Trends

From the late 1980s to the early 1990s, the Canadian fisheries in the northern Grand Banks area were dominated by groundfish harvesting using stern otter trawlers which primarily targeted Atlantic cod, American plaice, and a few other groundfish species. Landings of groundfish were quite high during this time. However, these record landings would not continue as groundfish stocks had become severely depleted from the unsustainable levels of fishing effort. With the acknowledgement of the collapse of several groundfish stocks in 1992, a harvesting moratorium was declared and directed fisheries for cod virtually vanished in this area. Since the collapse of these fisheries, formerly underutilized species, specifically snow crab and northern shrimp, have come to replace groundfish as the principal target species on the northern Grand Banks. Based on georeferenced DFO landings data, Figures 4.2 to 4.4 summarize catch weight data for the 12 NAFO Unit Areas (UAs) which overlap the Study Area (Study Area UAs) during the 1986–2010 period (there were no catches recorded in the georeferenced data for snow crab or northern shrimp in 1986; Figure 4.3). These figures illustrate the total groundfish harvest (Figure 4.2), combined snow crab and shrimp harvest (Figure 4.3), and total annual harvest (Figure 4.4). Snow crab harvesting with fixed gear tends to be concentrated in areas along the shelf break and slope. Northern shrimp harvesting with mobile gear tends to extend into deeper water in the Study Area, along the northeastern slope of Jeanne d'Arc Basin. Since the two gear types have a potential to conflict with each other, crab and shrimp harvesting do not typically overlap in time or location.



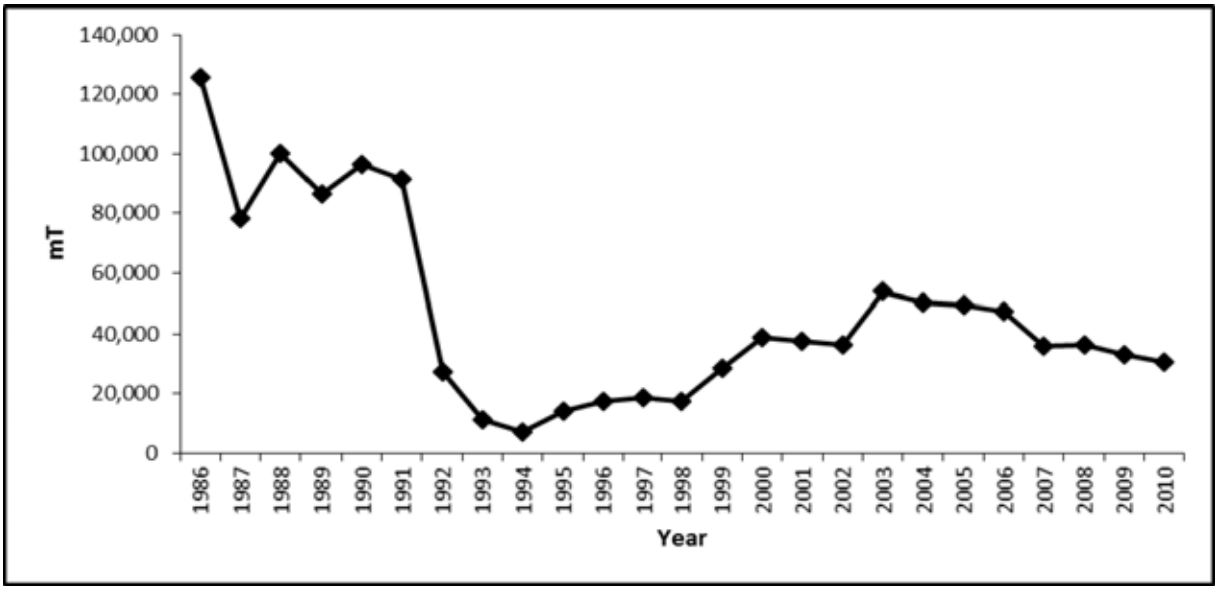
Source: DFO Newfoundland Commercial Fishery Landings Database, 1986-2010.

Figure 4.2. Annual Catch Weight within Study Area UAs, 1986-2010, Groundfish.



Source: DFO Newfoundland Commercial Fishery Landings Database, 1987-2010.

Figure 4.3. Annual Catch Weight within Study Area UAs, 1987-2010, Shrimp and Snow Crab.



Source: DFO Newfoundland Commercial Fishery Landings Database, 1986-2010.

Figure 4.4. Annual Catch Weight within Study Area UAs, 1986-2010, All Species Combined.

4.3.3.2 Study Area 2005-2010 Catch Analysis

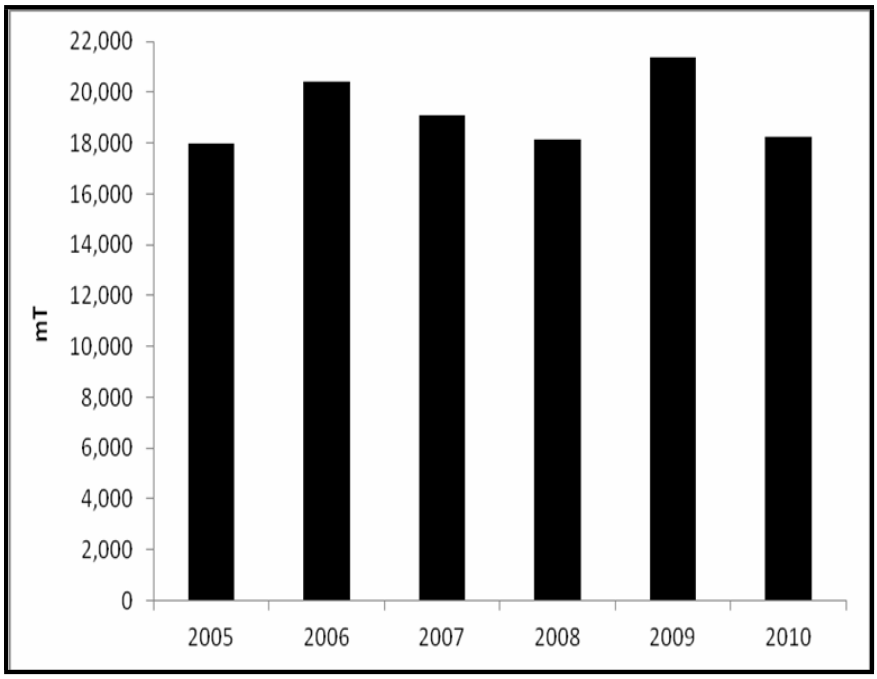
The average annual Newfoundland-landed commercial harvests from the Study Area, 2005 to 2010 are shown in Table 4.2. While the domestic harvest catch weight in the Study Area was dominated by northern shrimp (~64% versus ~35% for snow crab) during this period, the snow crab landed value was slightly higher than that of shrimp (Table 4.2).

Figure 4.5 indicates the variability in annual total catch weight in the Study Area during the 2005 to 2010 period. The annual total catch weight remained relatively steady over this six-year period. Despite the collapse of traditional groundfisheries, the total catch weight was maintained at this level mainly as the result of increasing shrimp catches in the Study Area.

Table 4.2. Average Annual Study Area Catch Weight by Species, 2005 to 2010.

Species	Quantity (mt)	% of Total	Value ($)	% of Total
Northern Shrimp	12,267	63.8	18,049,676	46.3
Snow Crab	6,792	35.3	20,682,192	53.1
Stimpson's Surf Clam	81	0.4	119,983	0.3
Greenland Halibut	54	0.3	103,797	0.3
Cockles	9	<0.1	9,708	<0.1
Herring	6	<0.1	1,164	<0.1
Roughhead Grenadier	6	<0.1	1,711	<0.1
Redfish (spp.)	3	<0.1	1,136	<0.1
Skate	3	<0.1	834	<0.1
Capelin	3	<0.1	443	<0.1
Mackerel	2	<0.1	1,042	<0.1
Atlantic Halibut	<1	<0.1	4,563	<0.1
Rock Crab	<1	<0.1	74	<0.1
Sea Scallops	<1	<0.1	154	<0.1
Witch Flounder	<1	<0.1	27	<0.1
American Plaice	<1	<0.1	10	<0.1
Atlantic cod	<1	<0.1	13	<0.1
Totals	**19,227**	**100.0**	**38,976,525**	**100.0**

Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.



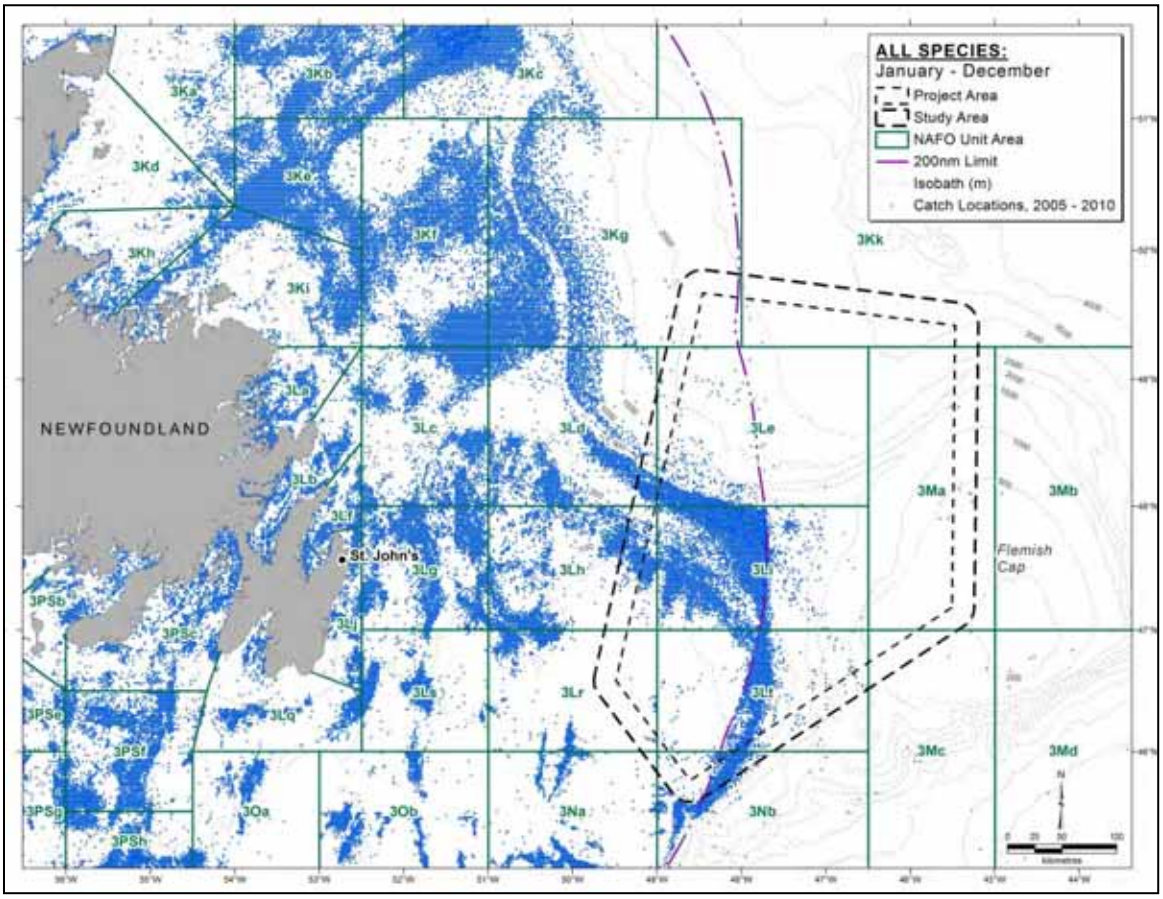
Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.5. Annual Total Catch Weight of Newfoundland-landed Harvests within the Study Area, All Species Combined, 2005 to 2010.

4.3.3.3 Harvesting Locations

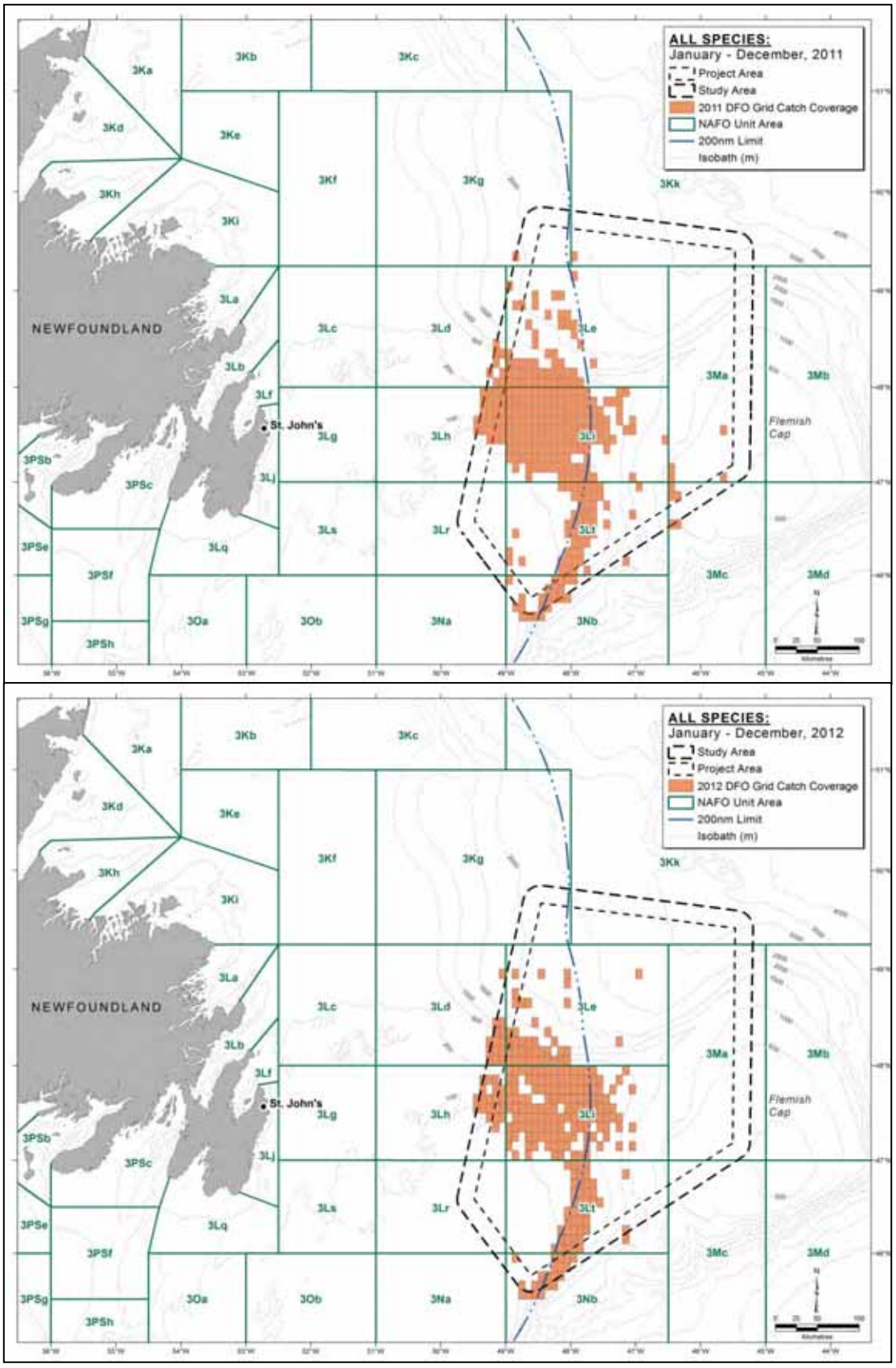
The georeferenced harvest locations in the Study Area for all species during 2005 to 2010 are presented in Figure 4.6. Harvest locations in 6 min x 6 min cells of latitude and longitude in the Study Area for all species in 2011 and 2012 are indicated in Figure 4.7. Most of total catch weight was harvested between May and July (61.4%). As Figures 4.6 and 4.7 illustrate, most of the domestic fish harvesting in the Study Area was concentrated between the 100 and 1,000 m depth contours of UA 3Li, and outside the 200 nmi EEZ in UAs 3Lt and 3Nb. The pattern of harvesting locations tends to be quite consistent from year to year.

In terms of catch weight differences between gear types, mobile gear accounted for approximately twice the catch weight in the Study Area than fixed gear (Table 4.3; Figure 4.8). Northern shrimp accounted for essentially all of the mobile gear catch weight and snow crab accounted for essentially all of the fixed gear catch weight.



Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010

Figure 4.6. Harvesting Locations of All Species Combined, 2005-2010.



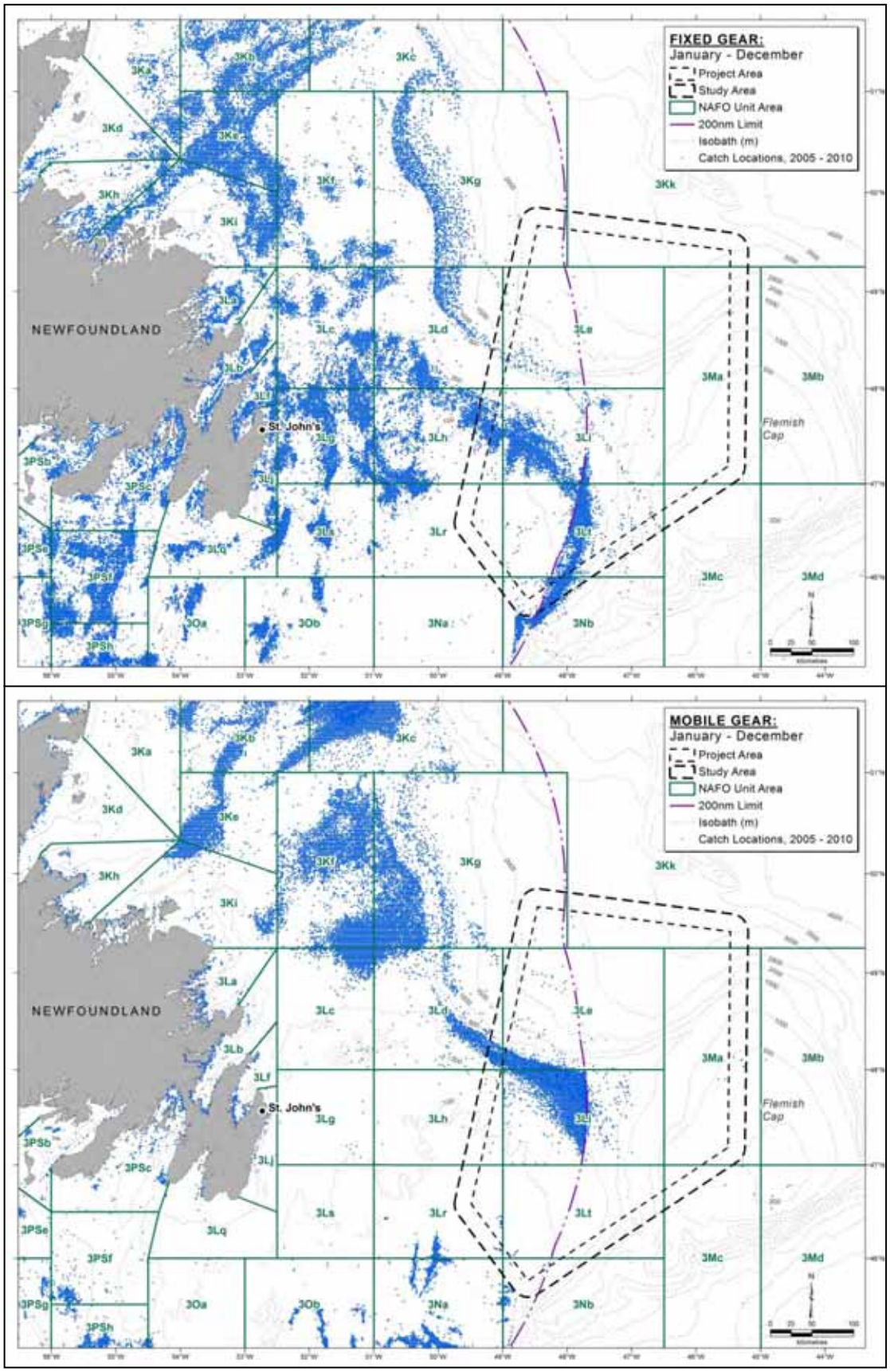
Source: DFO Newfoundland Commercial Fishery Landings Database, 2011 and 2012

Figure 4.7. Harvest Location Coverage of all Species Combined within the Study Area, 2011 (top) and 2012 (bottom). Cells are 6 min x 6 min Latitude and Longitude.

Table 4.3. Average Annual Study Area Catch Weight by Gear Type, 2005 to 2010.

Species	Fixed Gear (mt)	% of Total	Mobile Gear (mt)	% of Total
Northern Shrimp	0	0.0	12,267	99.1
Snow Crab	6,792	99.1	0	<0.1
Stimpson's Surf Clam	0	0.0	81	0.7
Greenland Halibut	52	0.8	1	<0.1
Cockles	0	0.0	9	0.1
Herring	0	0.0	6	<0.1
Roughhead Grenadier	5	0.1	<1	<0.1
Redfish (spp.)	<1	<0.1	3	<0.1
Skate	3	<0.1	<1	<0.1
Capelin	0	0.0	3	<0.1
Mackerel	0	0.0	2	<0.1
Atlantic Halibut	1	<0.1	0	<0.1
Rock Crab	<1	<0.1	0	<0.1
Sea Scallops	0	0.0	<1	<0.1
Witch Flounder	0	0.0	<1	<0.1
American Plaice	0	0.0	<1	<0.1
Atlantic cod	<1	<0.1	<1	<0.1
Totals	**6,854**	**100**	**12,373**	**100**

Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

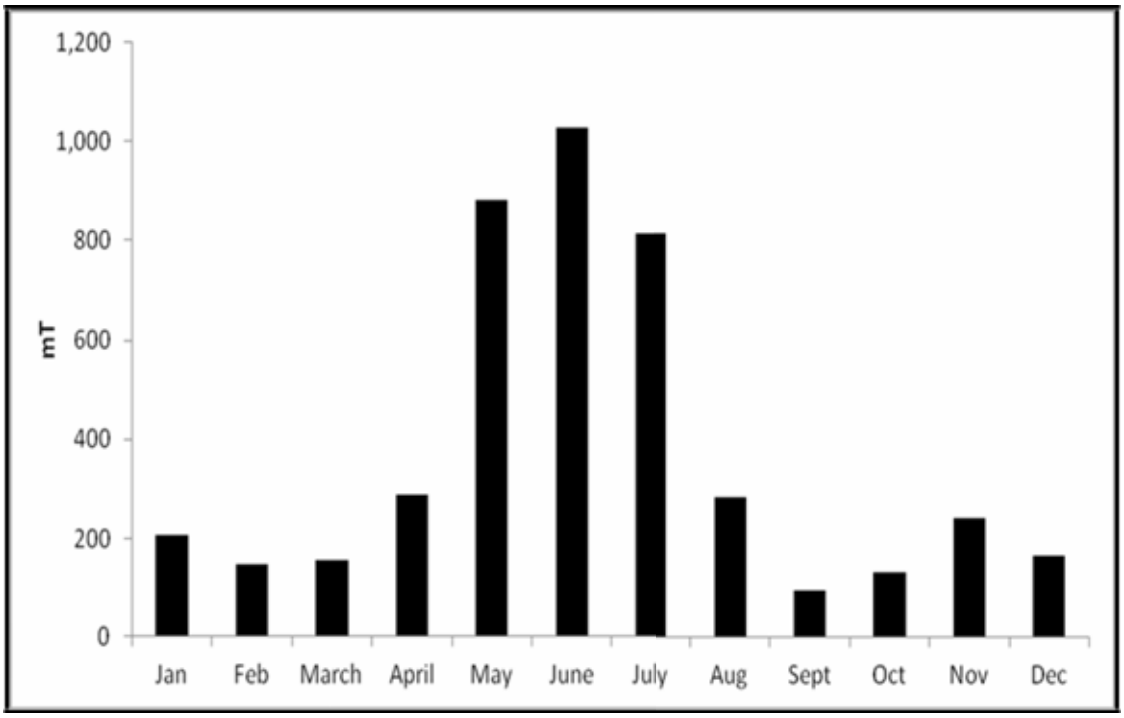


Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.8. Fixed (top) and Mobile (bottom) Harvesting Locations, 2005 to 2010 Combined.

4.3.3.4 Harvest Timing

The timing of commercial harvesting for any particular species varies depending on seasons and regulations set by DFO, the harvesting strategies of fishing enterprises, and the availability of the resource itself. The May to July period during 2005–2010 accounted for about 61% of the total catch weight from the Study Area (Figure 4.9).



Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.9. Average Monthly Catch Weight of all Species in the Study Area, 2005 to 2010 Combined.

4.3.4 Principal Species

As noted above, the recent domestic harvest within the Study Area has been dominated by northern shrimp and snow crab catches, followed by Stimpson's surf clam and Greenland halibut. These four species have typically accounted for more than 99% of the Study Area harvest catch weight in recent years. This subsection describes these four fisheries in more detail.

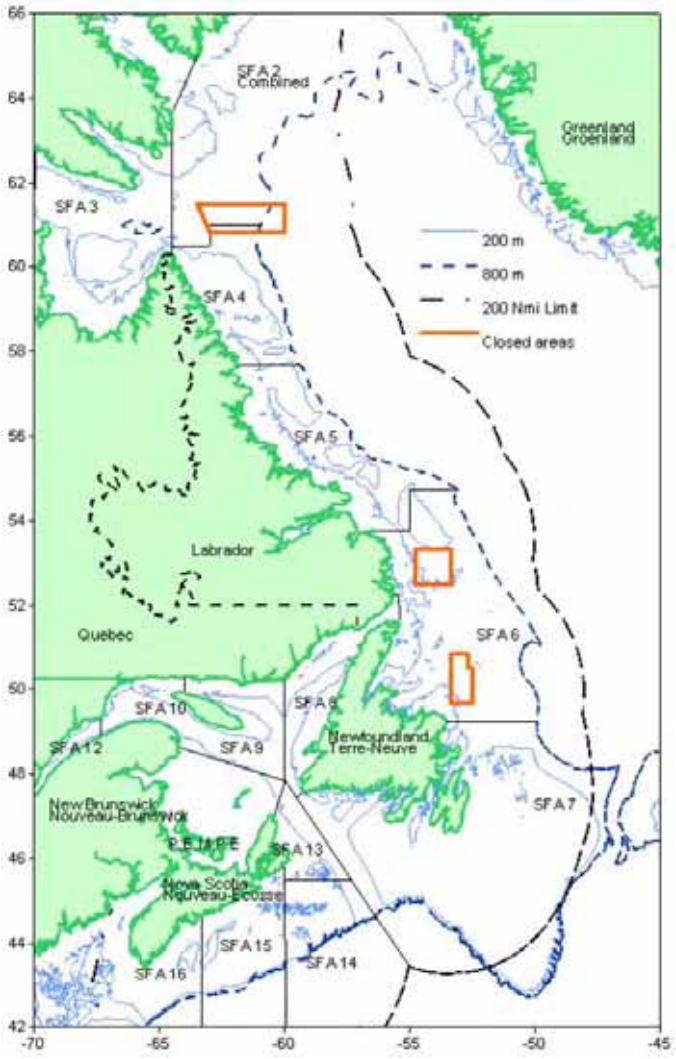
4.3.4.1 Northern Shrimp

Northern shrimp was the most significant species harvested within the Study Area during 2005–2010 in terms of catch weight (63.8% of total) (see Table 4.2), and the second-most significant species harvested within the Study Area during the same period in terms of catch value (46.3% of total) (see Table 4.2). The Study Area overlaps with parts of Shrimp Fishing Area (SFA) 7, and a very small portion of SFA 6 (Figure 4.10). As noted above, SFA 7 (which corresponds to NAFO Division 3L) and Divisions 3MN are managed by NAFO, while SFA 6 (which corresponds to Division 3K) is managed by DFO. Domestic northern shrimp harvest locations in the Study Area during 2005–2010 are indicated in Figure 4.11. Annual domestic catch weight ranges for northern shrimp in 2011 and 2012 are indicated in Figures 4.12 and 4.13. The majority of shrimp harvesting occurs in the central and west-central portions of the Study Area, between 200 and 500 m depths (within SFA 7/NAFO Unit Areas 3Ldei).

Northern shrimp trawls are mobile gear and pose a relatively low potential for physical conflict with seismic gear.

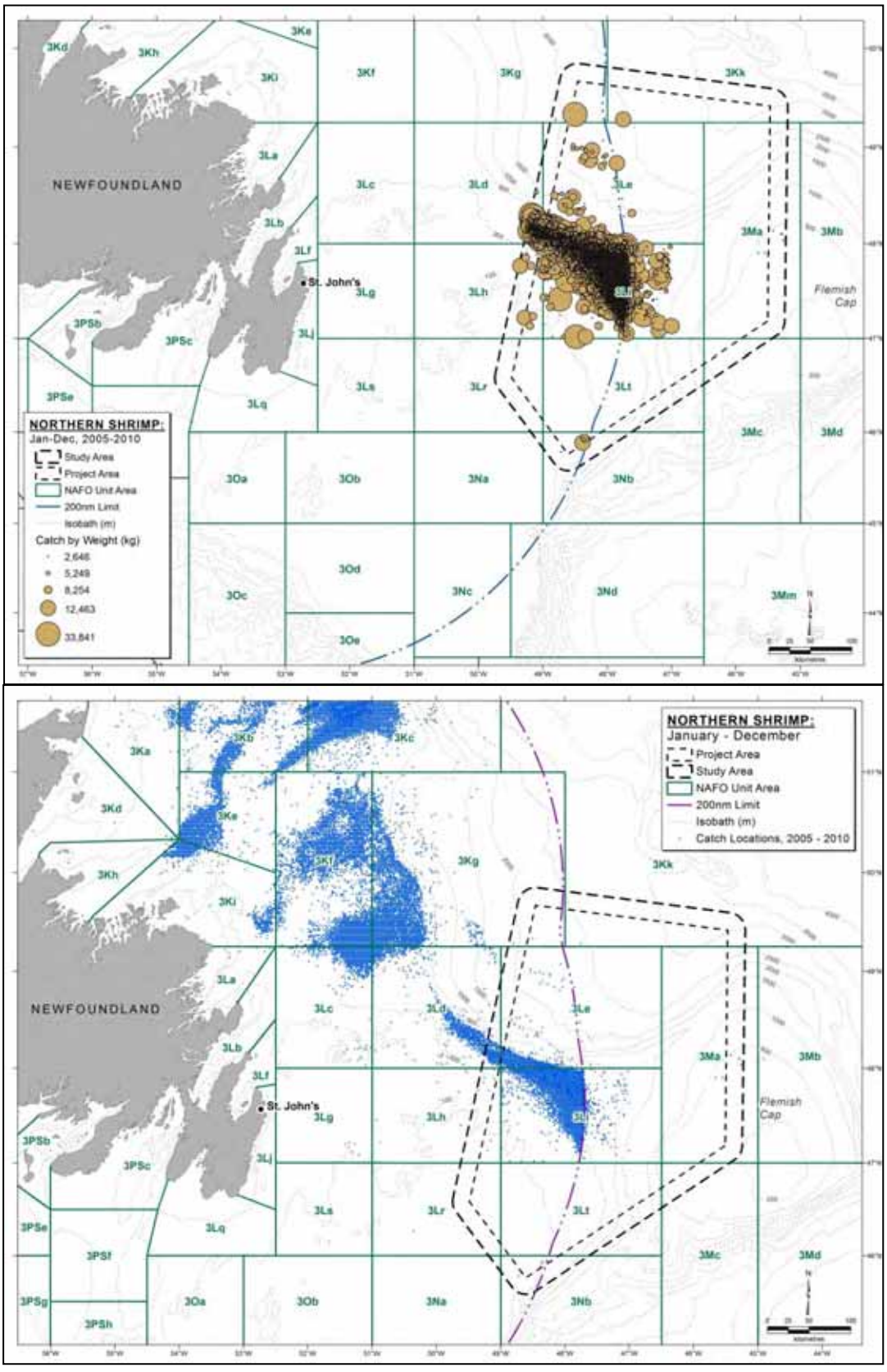
The annual quantity of the northern shrimp caught in the Study Area from 2005 to 2010 is indicated in Figure 4.14. The overall increase prior to 2010 was largely the result of increasing quotas. However, because of increasing scientific concerns about the status of the resource, catch allowances have decreased in this area since 2010. As such, a decrease in catch is expected, potentially for the next several years. The offshore northern shrimp commercial fishery operates on a calendar year until annual quotas are reached, and the inshore fishery (including SFAs 6 and 7/Divisions 3KL) normally operates from the spring to the fall. The inshore fishery opened on 16 May 2013 (FFAW 2013). Based on opening dates from previous years, this fishery will likely continue to open in early to mid-spring in future years in and around the Study Area.

The average monthly quantity of the northern shrimp caught in the Study Area from 2005 to 2010 is indicated in Figure 4.15. The largest average monthly harvests of northern shrimp in the Study Area during the six-year period occurred mainly during the summer, although harvesting did occur throughout the year.



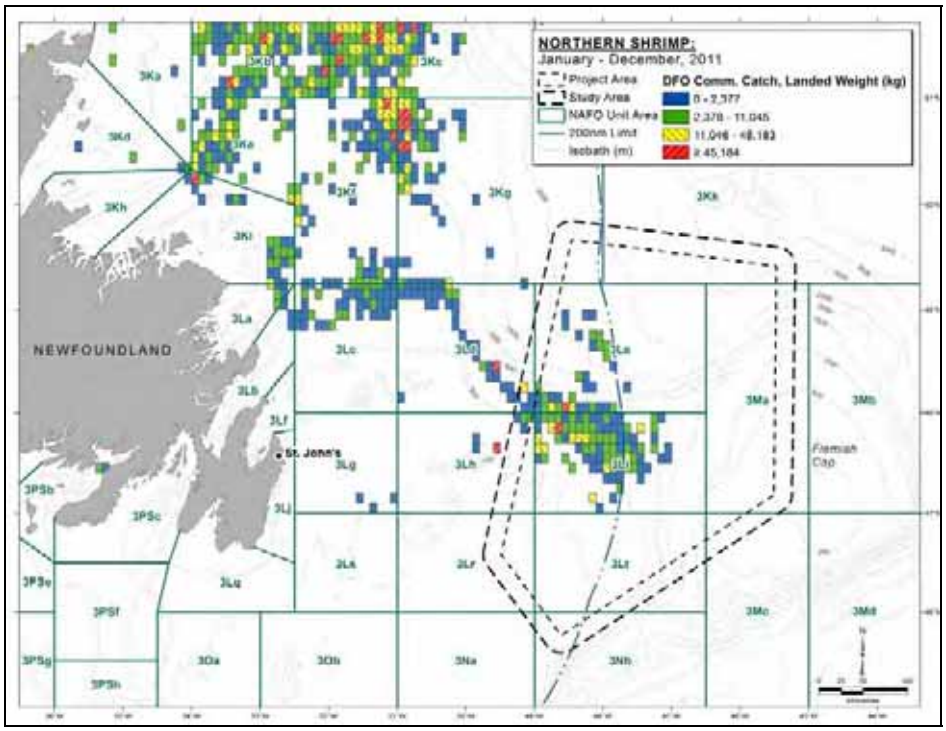
Source: DFO website (2013)

Figure 4.10. Northern Shrimp Fishing Areas.



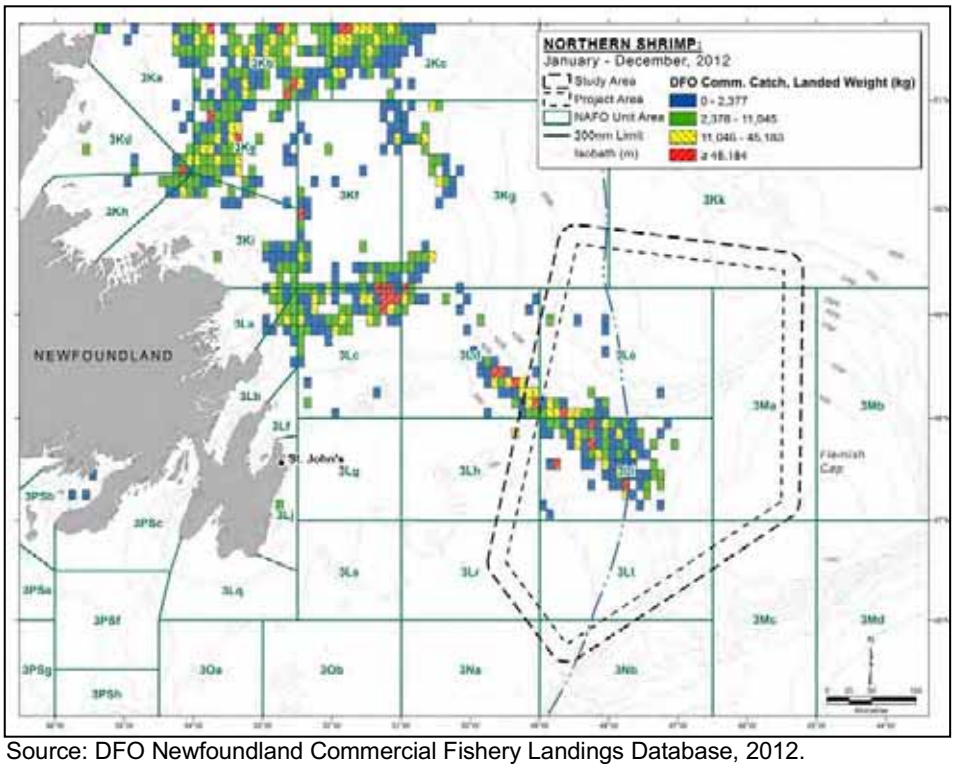
Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.11. Proportional (top) and Non-proportional (bottom) Northern Shrimp Harvesting Locations in the Study Area, 2005 to 2010.



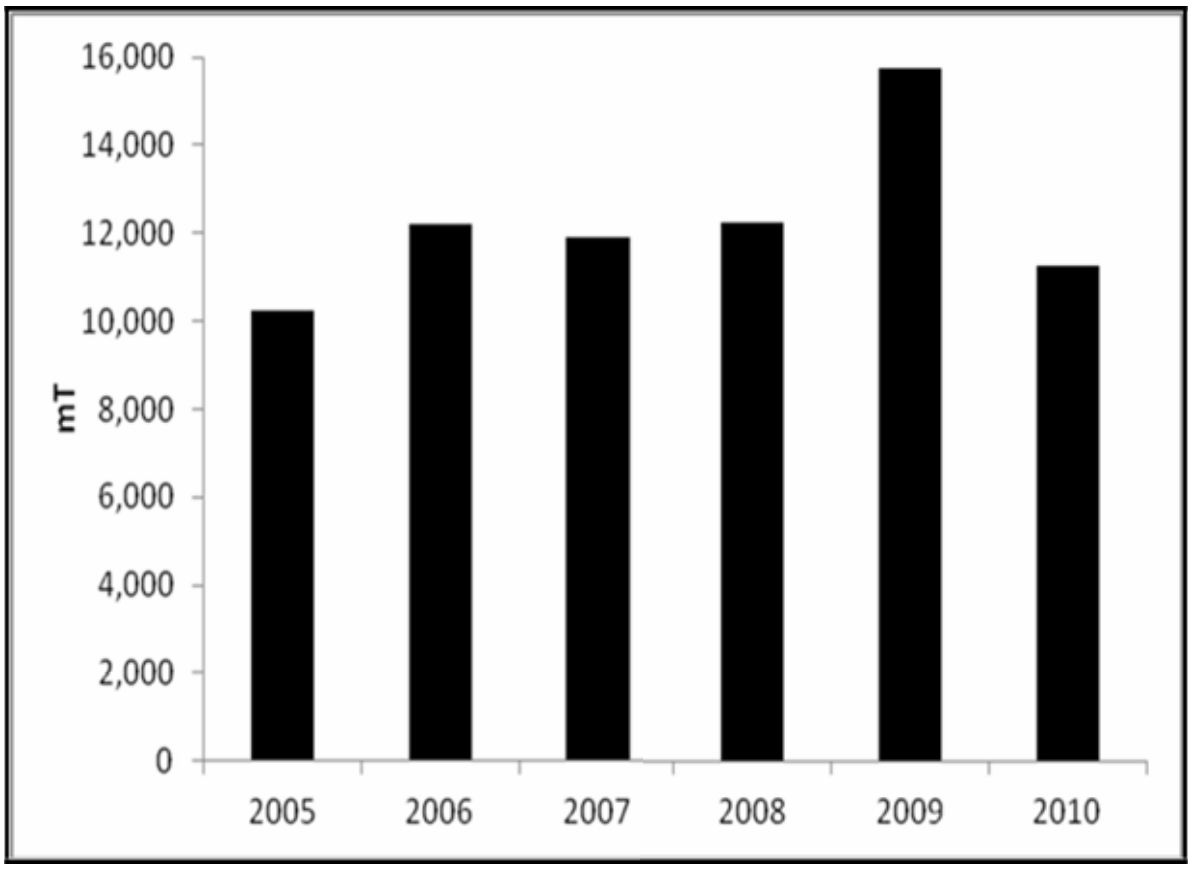
Source: DFO Newfoundland Commercial Fishery Landings Database, 2011.

Figure 4.12. Northern Shrimp Harvesting Locations by Landed Catch Weight Quartile Ranges, 2011. Cells are 6 min x 6 min Latitude and Longitude.



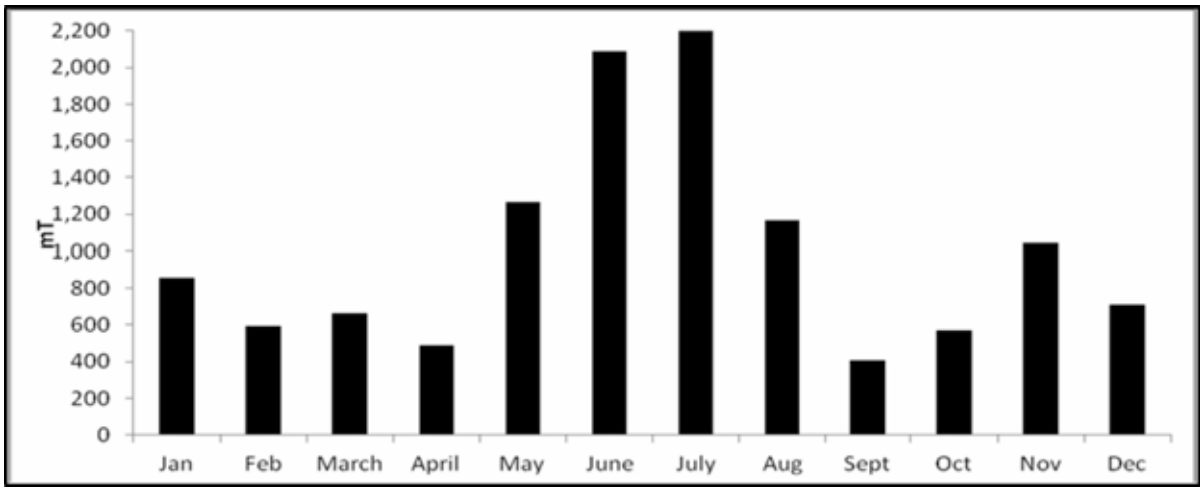
Source: DFO Newfoundland Commercial Fishery Landings Database, 2012.

Figure 4.13. Northern Shrimp Harvesting Locations by Landed Catch Weight Quartile Ranges, 2012. Cells are 6 min x 6 min Latitude and Longitude.



Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.14. Annual Northern Shrimp Catch Weight in the Study Area, 2005 to 2010.



Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.15. Average Monthly Northern Shrimp Catch Weight in the Study Area, 2005 to 2010.

4.3.4.2 Snow Crab

Snow crab was the second-most significant species harvested within the Study Area during 2005 to 2010 in terms of catch weight (35.3% of total), and the most significant in terms of catch value (53.1% of total) (see Table 4.2). The Study Area overlaps with portions of Crab Fishing Areas (CFA) 4

(offshore Division 3K), 8B (southern Avalon, outside of 50 nmi), Msex (mid-shore extended), 3Lex (from 170 miles to 200 nmi from shore) and 3L200 (>200 nmi), which are partly within Divisions 3KLMN (Figure 4.16). The season is defined each year, but typically runs from April to July or August.

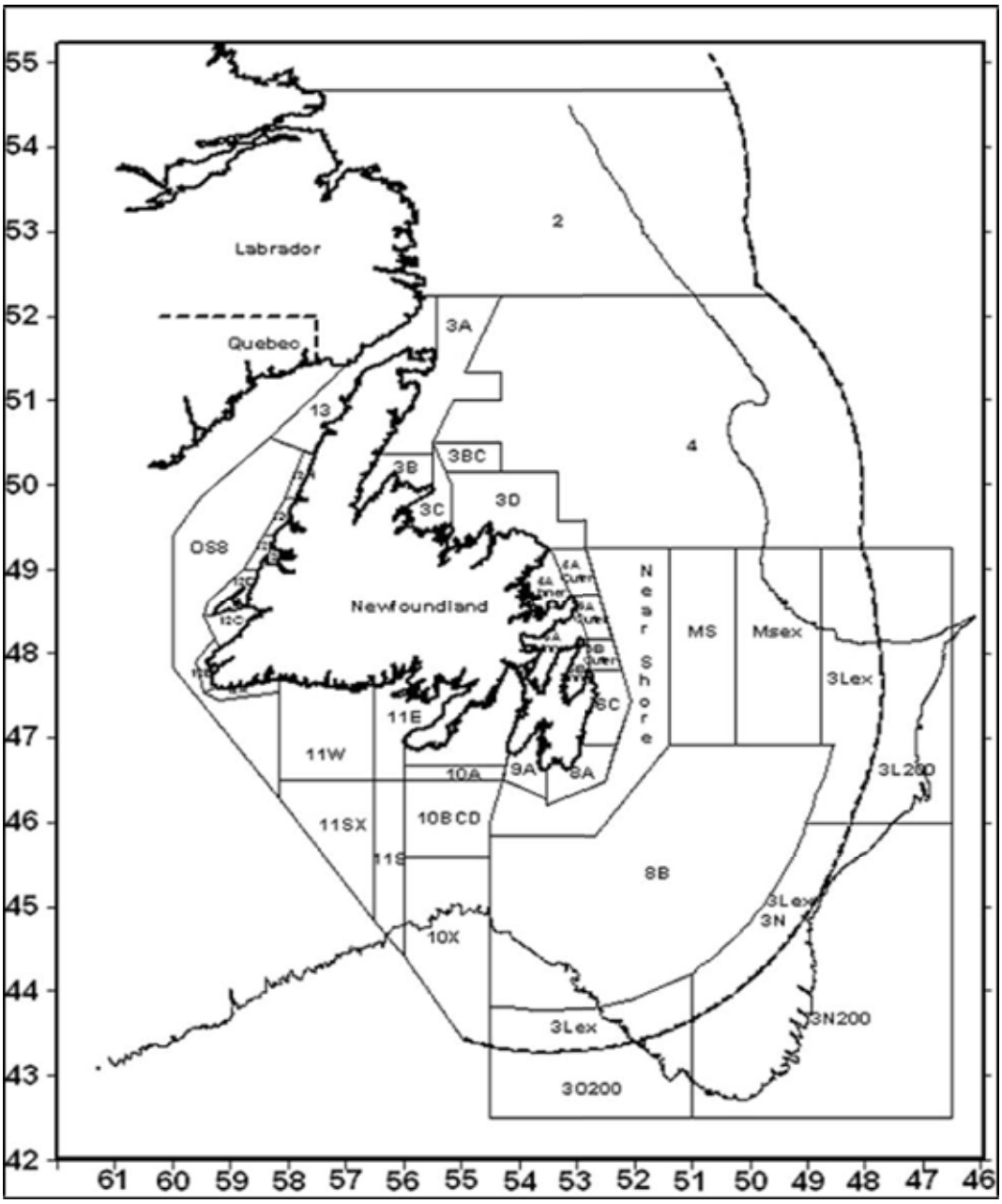
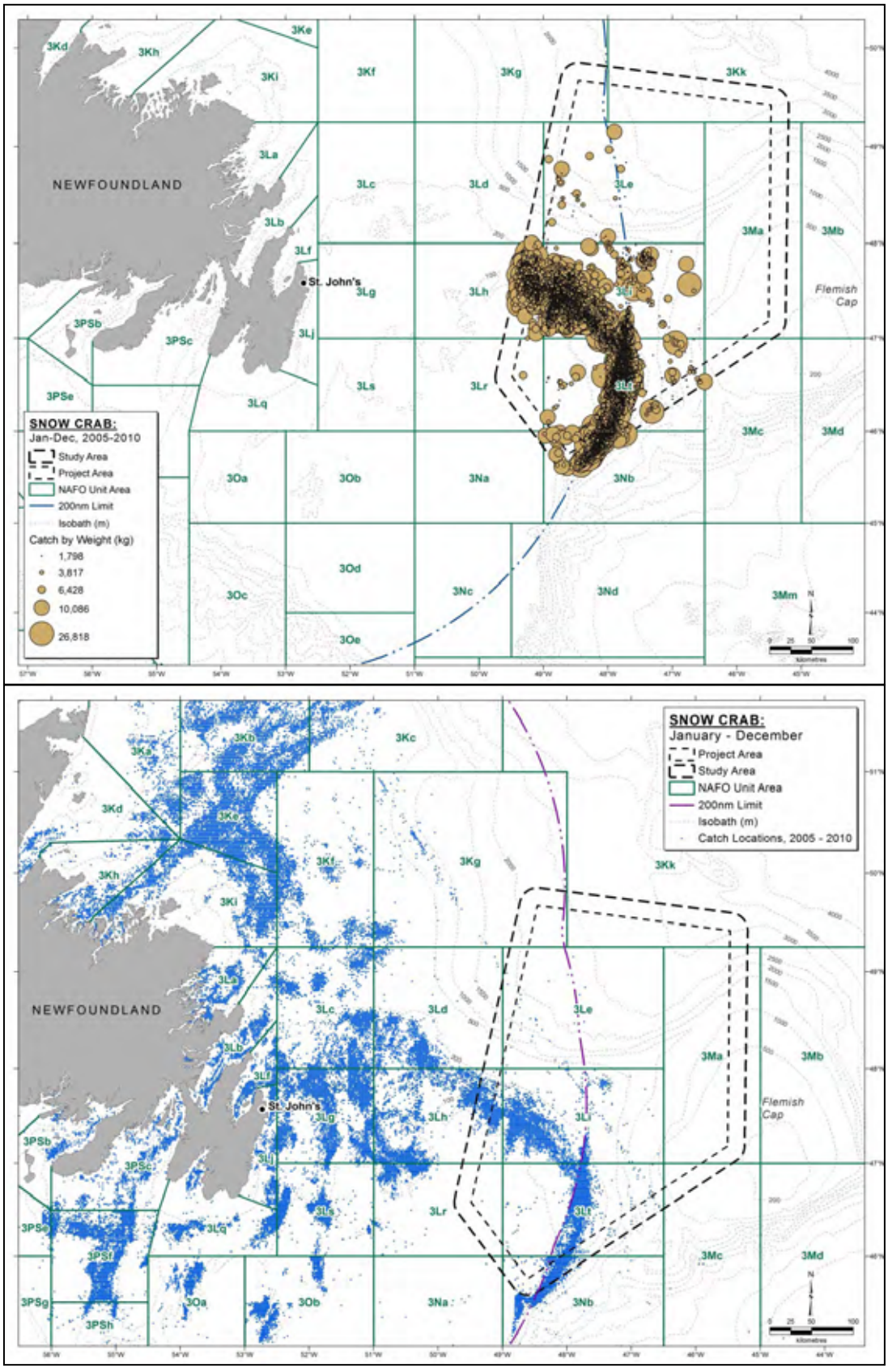


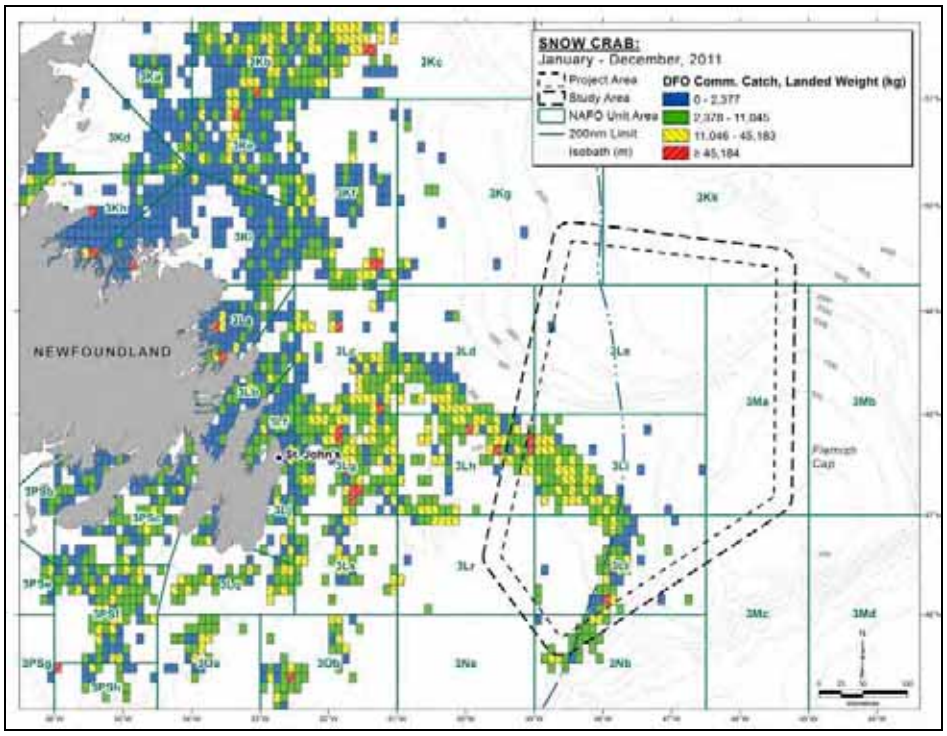
Figure 4.16. Newfoundland Snow Crab Fishing Areas.

Domestic snow crab harvest locations in the Study Area during 2005-2010 are shown in Figure 4.17. Annual domestic catch weight ranges of snow crab in 2011 and 2012 are indicated in Figures 4.18 and 4.19. The fishery is focused along the slope edge of Jeanne d'Arc Basin, beyond the 100 m isobath in the central, west- and south-central portions of the Study Area. The aggregated annual and average monthly snow crab harvest quantities from the Study Area for 2005 to 2010 are indicated in Figures 4.20 and 4.21. The highest average monthly harvests of snow crab in the Study Area during the six-year period occurred during the April to July period.



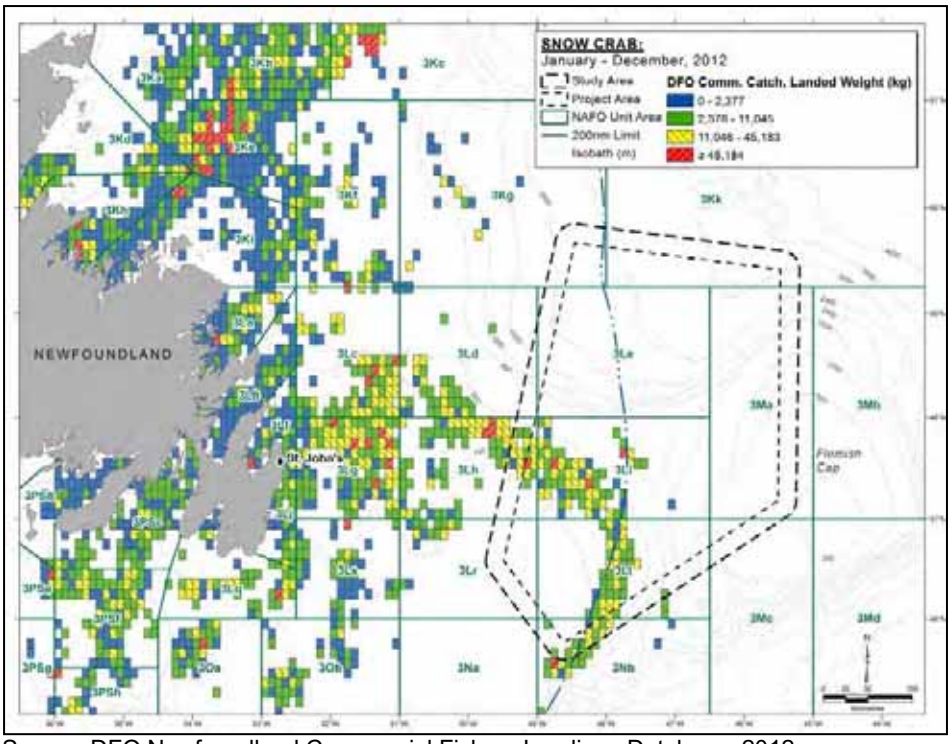
Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.17. Proportional (top) and Non-proportional (bottom) Snow Crab Harvesting Locations in the Study Area, 2005 to 2010.



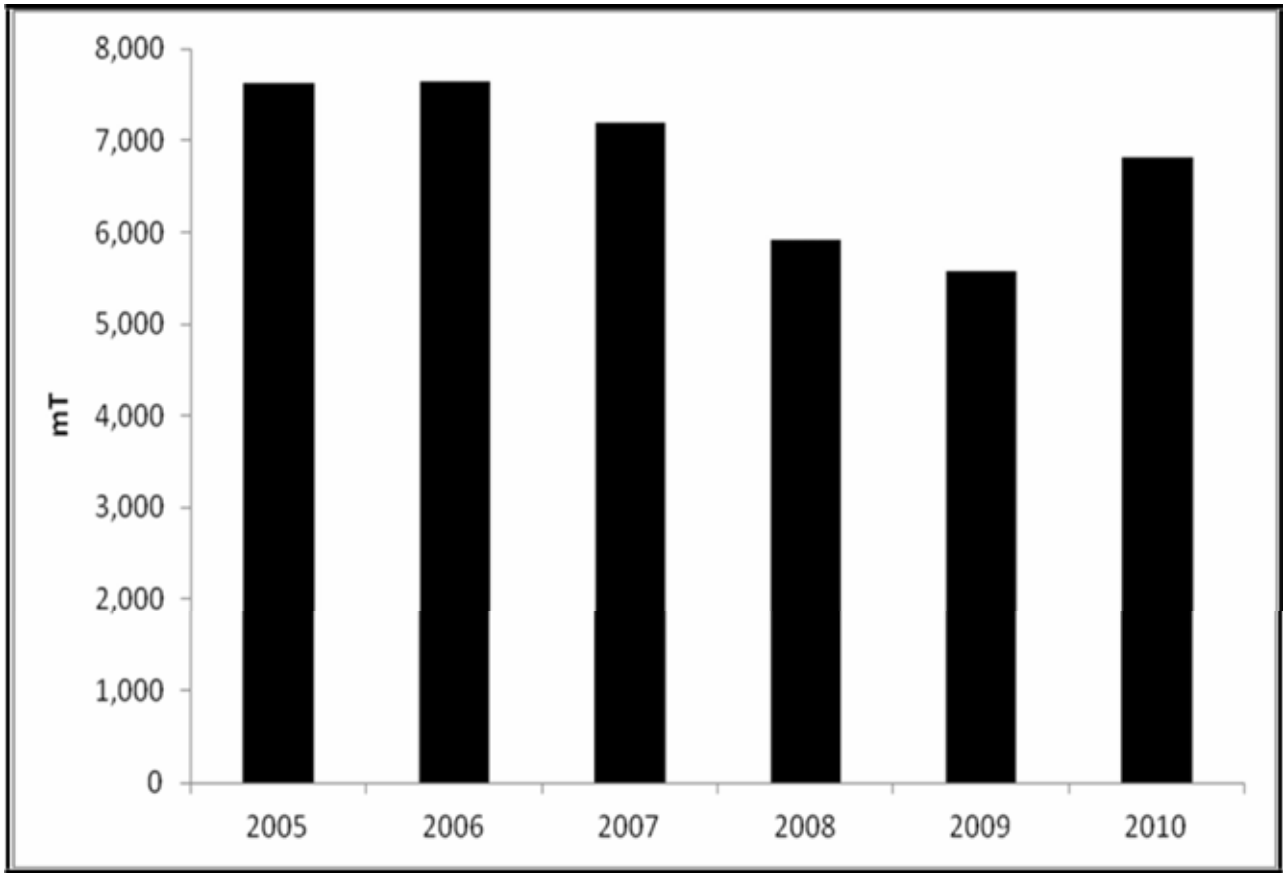
Source: DFO Newfoundland Commercial Fishery Landings Database, 2011.

Figure 4.18. Snow Crab Harvesting Locations by Landed Catch Weight Quartile Ranges, 2011. Cells are 6 min x 6 min Latitude and Longitude.



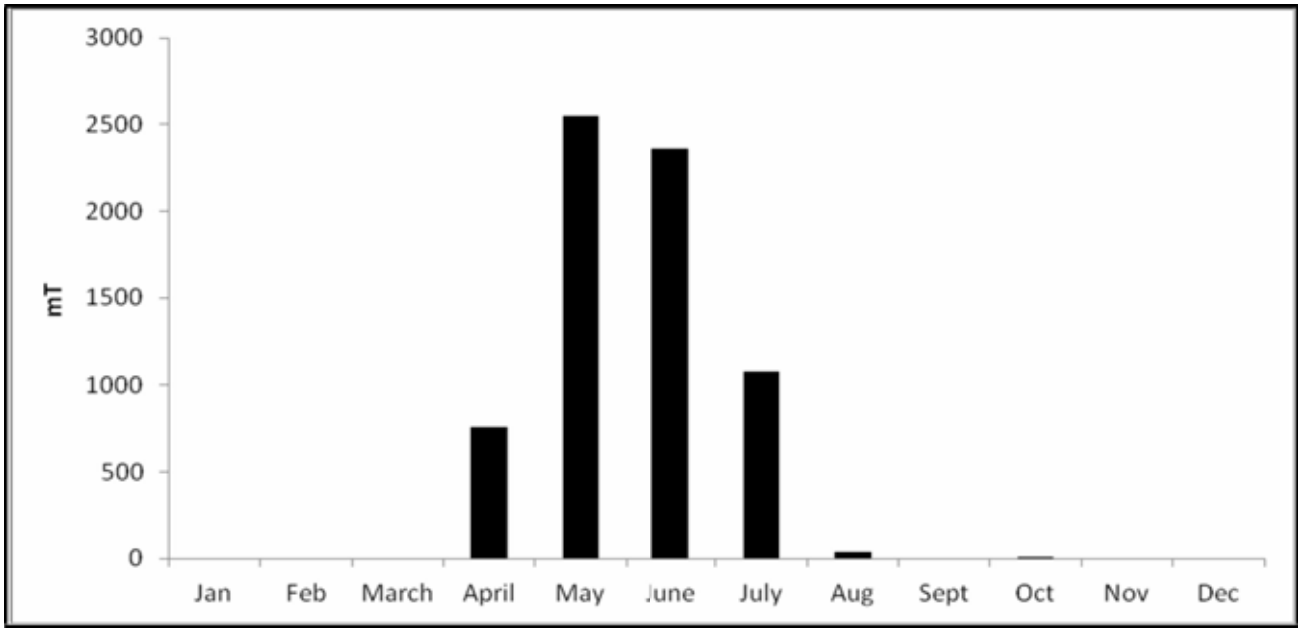
Source: DFO Newfoundland Commercial Fishery Landings Database, 2012.

Figure 4.19. Snow Crab Harvesting Locations by Landed Catch Weight Quartile Ranges, 2012. Cells are 6 min x 6 min Latitude and Longitude.



Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.20. Annual Snow Crab Catch Weight in the Study Area, 2005 to 2010.



Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.21. Average Monthly Snow Crab Catch Weight in the Study Area, 2005 to 2010.

During the snow crab fishery, crab pots are set on the seabed in strings buoyed at the surface. Crab gear generally has a highflyer (radar reflector) at one end and a large buoy at the other. Some fishers use highflyers at both ends. Depending on weather, they may be left unattended several days at a time. Fishers typically try to leave ~20 fathoms (36.5 m or 120 feet) on the seabed between each pot. This allows slack for the anchor ropes on either end of the string to extend upwards at an angle; the distance between the typical highflyer and end-buoy of, for example, a 50 to 60 pot string of crab gear would be 6,000 to 7,500 feet or ~1.8 km to 2.3 km. This fixed gear fishery poses more potential than mobile gear fisheries for seismic/fishing gear conflicts in those areas where the two marine activities might overlap in time and space.

4.3.4.3 Stimpson's Surf Clam

Stimpson's surf clam accounted for an average of 0.4% of the total Study Area catch weight and 0.3% of the total catch value during 2005-2010 (see Table 4.2). The primary gear used for this fishery is dredge. This Study Area fishery is managed by DFO.

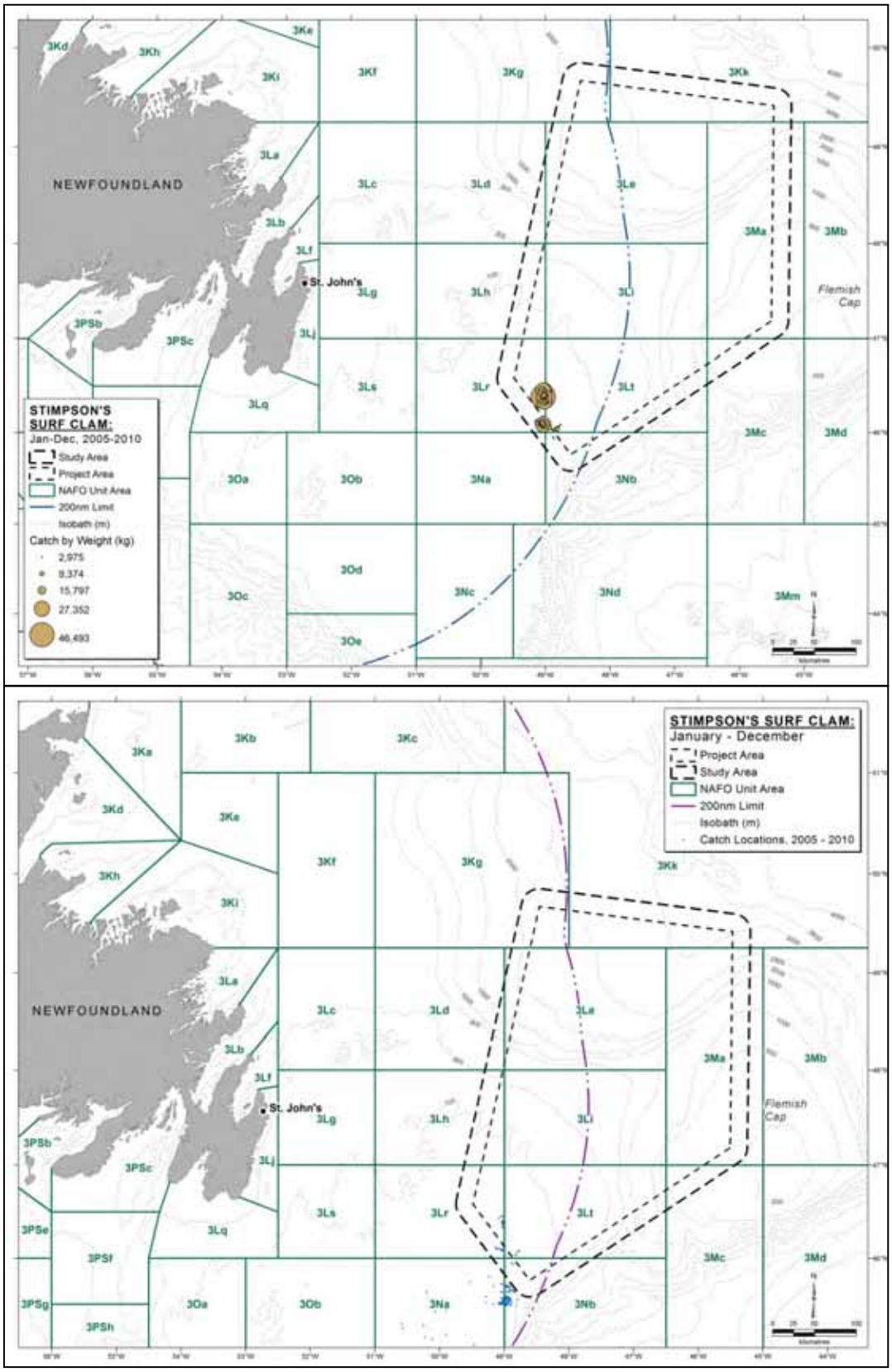
The Study Area domestic harvest of this bivalve in 2006 and 2011 was entirely within the EEZ, in NAFO Divisions 3Lrt and 3Nb (Figures 4.22 and 4.23). This clam harvesting occurred in the southwestern corner of Suncor's Study Area. Harvesting has also occurred outside of the Study Area, in Divisions 3Nab. All harvesting of this clam in 2006 occurred during the January to March period. In 2011, Stimpson's surf clam harvesting within the Study Area occurred in November.

4.3.4.4 Greenland Halibut

Greenland halibut accounted for an average of 0.3% of the total Study Area catch weight and 0.3% of the total catch value during 2005–2010 (see Table 4.2). Most of this harvest in the Study Area is typically taken by gillnets, while the remaining catch weight occurred as bycatch in bottom trawl fisheries. The Greenland halibut fishery in the Study Area is managed by NAFO.

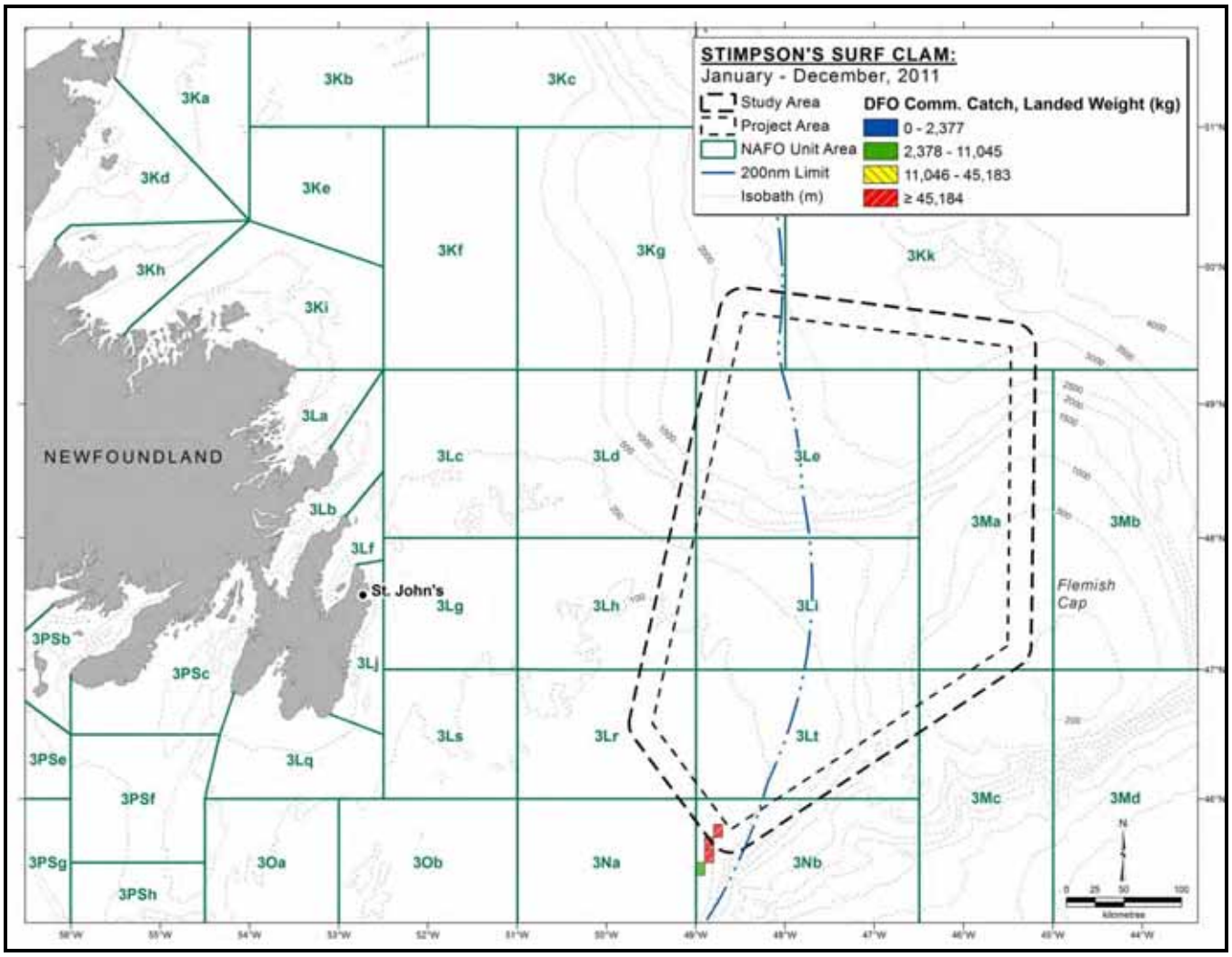
The Study Area domestic harvest of Greenland halibut is almost entirely within the EEZ, primarily in NAFO Divisions 3Kg and 3Ldeit (Figures 4.24 to 4.26). The majority of the harvest occurred in the west-central portion of the Study Area, in Divisions 3Lde.

The annual and average monthly quantities of the Greenland halibut caught in the Study Area from 2005 to 2010 are indicated in Figures 4.27 and 4.28. The largest average monthly harvests of Greenland halibut in the Study Area during the six-year period occurred during the June to September period.



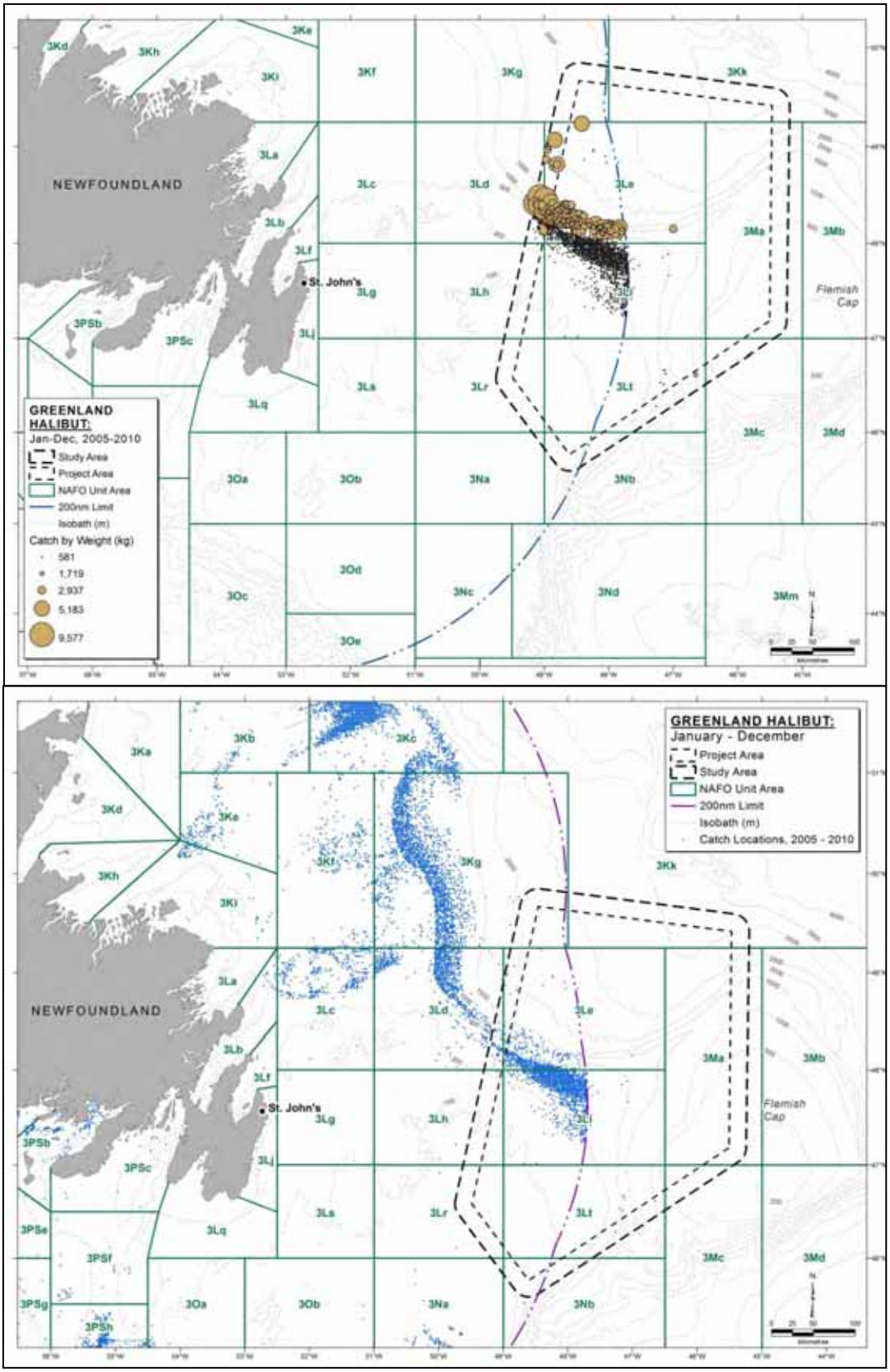
Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.22. Proportional (top) and Non-proportional (bottom) Stimpson's Surf Clam Harvesting Locations in the Study Area, 2005 to 2010.



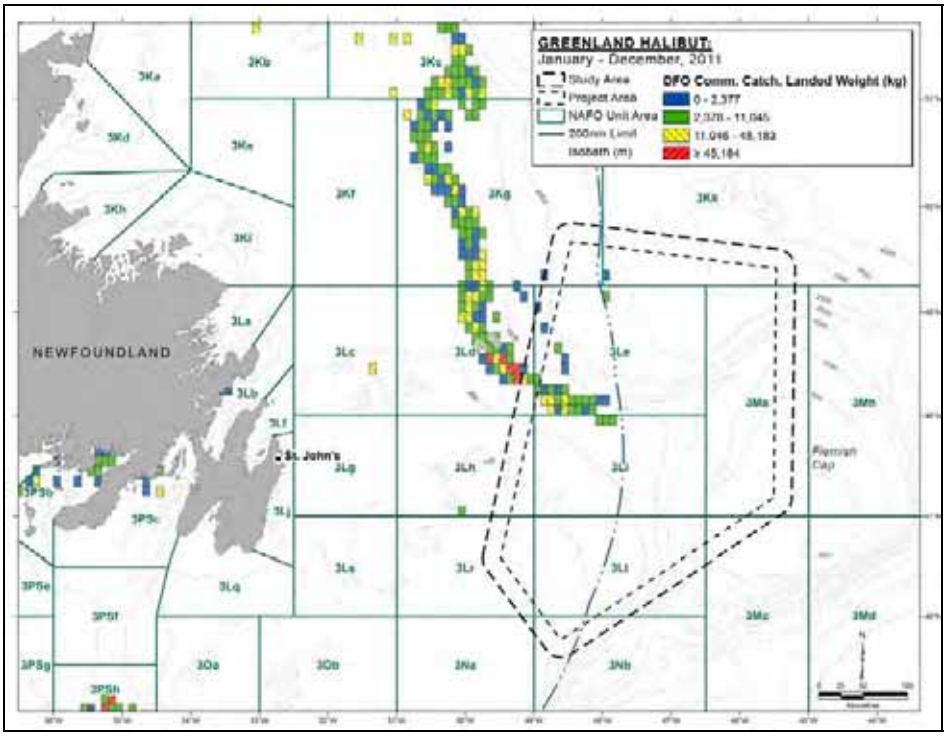
Source: DFO Newfoundland Commercial Fishery Landings Database, 2011.

Figure 4.23. Stimpson's Surf Clam Harvesting Locations by Landed Catch Weight Quartile Ranges, 2011. Cells are 6 min x 6 min Latitude and Longitude.



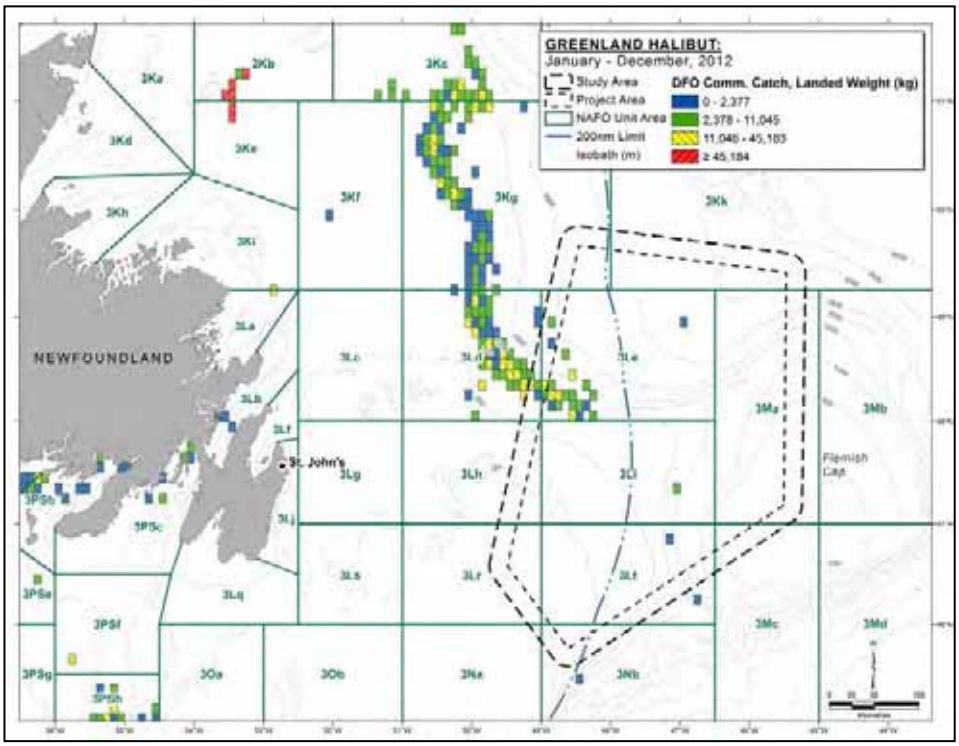
Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.24. Proportional (top) and Non-proportional (bottom) Greenland Halibut Harvesting Locations in the Study Area, 2005 to 2010.



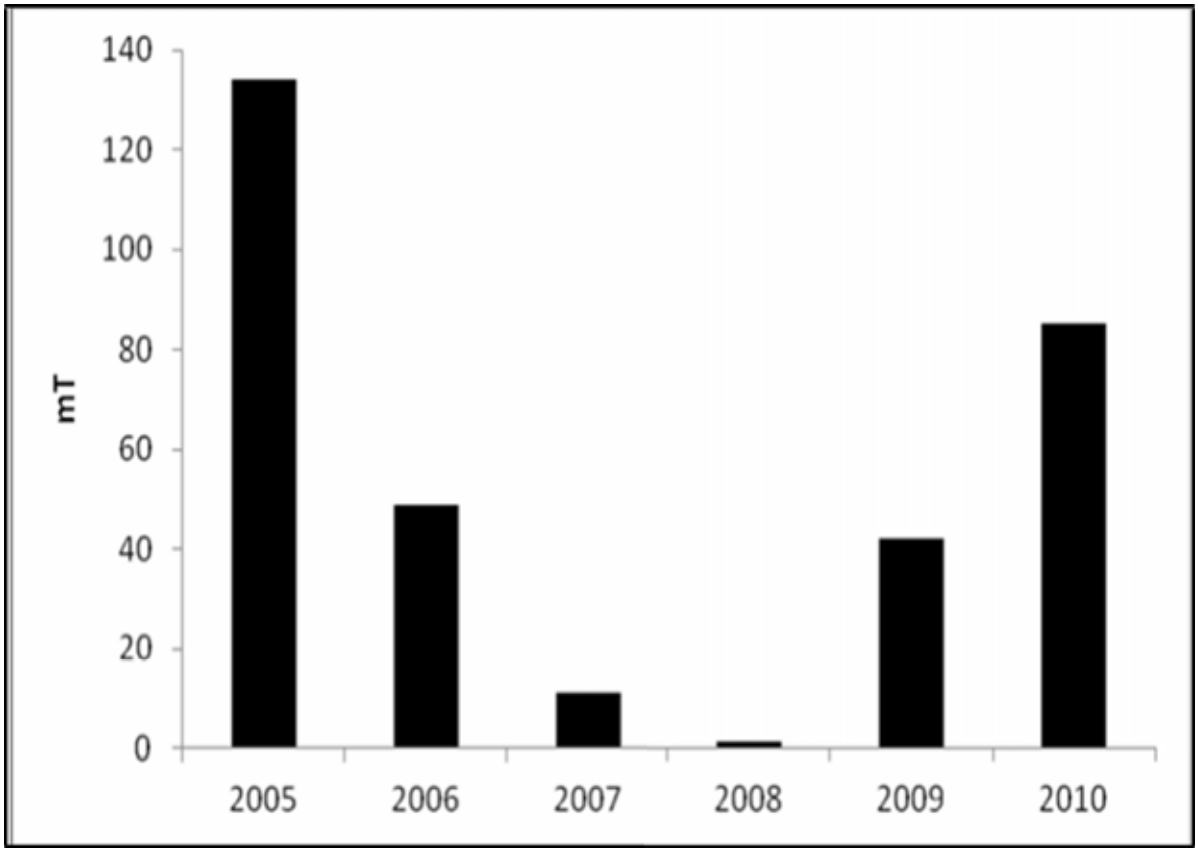
Source: DFO Newfoundland Commercial Fishery Landings Database, 2011.

Figure 4.25. Greenland Halibut Harvesting Locations by Landed Catch Weight Quartile Ranges, 2011. Cells are 6 min x 6 min Latitude and Longitude.



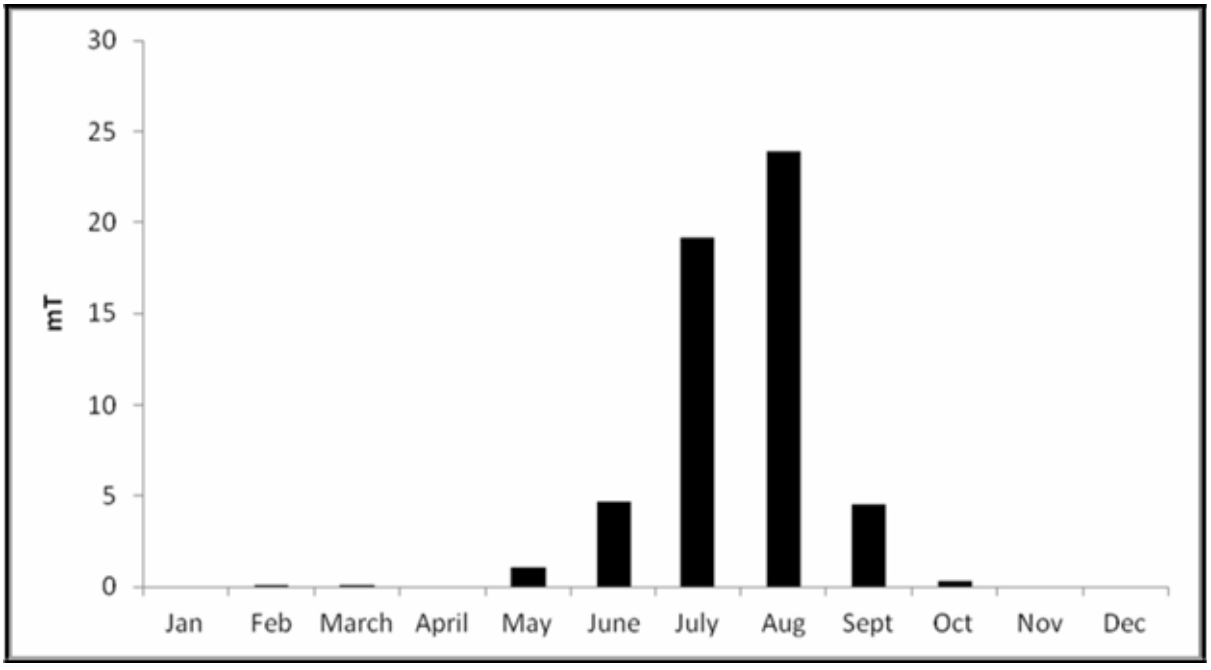
Source: DFO Newfoundland Commercial Fishery Landings Database, 2012.

Figure 4.26. Greenland Halibut Harvesting Locations by Landed Catch Weight Quartile Ranges, 2012. Cells are 6 min x 6 min Latitude and Longitude.



Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.27. Annual Greenland Halibut Catch Weight in the Study Area, 2005 to 2010.



Source: DFO Newfoundland Commercial Fishery Landings Database, 2005-2010.

Figure 4.28. Average Monthly Greenland Halibut Catch Weight in the Study Area, 2005 to 2010.

4.3.5 Macroinvertebrates and Fishes Collected during DFO RV Surveys

Data collected during 2007 to 2011 spring and fall DFO RV surveys in the Study Area were analyzed, and catch weights and catch numbers of species/groups with combined annual catch weights of at least 100 kg are presented in Table 4.4.

Deepwater redfish accounted for 35.8% of the total 2007-2011 catch weight, followed by northern shrimp (10.1%), shrimp (Natantia) (7.4%), sand lance (5.4%), thorny skate (4.4%), capelin (4.3%), sponges (4.2%), American plaice (4.1%), roughhead grenadier (3.1%), Greenland halibut (2.8%), sea anemones (2.0%), yellowtail flounder (1.5%), Greenland shark (1.4%), Atlantic cod (1.2%), blue hake (1.1%), and snow crab (1.1%). All remaining species/groups in Table 4.4 represent ≤1% of the RV survey total catch weight. The distribution of georeferenced catch locations reported during the 2007 to 2011 DFO RV surveys within the Study Area are shown in Figure 4.29.

Across all species caught during the 2007 to 2011 DFO RV surveys in the Study Area, total catch weights were greatest in 2007 (47,360 kg) and 2010 (32,811 kg), and lowest in 2011 (15,199 kg). Catches were consistent between years for species type, with an average contribution to annual total catch weight of 71.7, 28.2, and 0.2% for fish, invertebrates, and corals, respectively. An exception occurred in 2010, when fish recorded in the Study Area accounted for 84.2% of the total catch weight and invertebrates only 15.7%. This exception was driven by catches of deepwater redfish, which accounted for 50.6% of the total catch weight in 2010.

The total catch weight of the 2007 to 2011 DFO RV surveys in the Study Area is divided into spring (May, June, July) and fall (October, November, December). Spring surveys accounted for 46.5% of the total catch weight, and fall surveys accounted for 53.5%. The average mean depths of catch during spring and fall surveys from 2007 to 2011 were 267 m (minimum = 12 m; maximum = 720 m) and 456 m (minimum = 56 m; maximum = 1,436 m), respectively.

The top five species/groups in terms of catch weight during the spring surveys were deepwater redfish, northern shrimp, capelin, shrimp (Natantia), and sand lance. The top five species/groups in terms of catch weight during the fall surveys were deepwater redfish, northern shrimp, shrimp (Natantia), sponges, and sand lance.

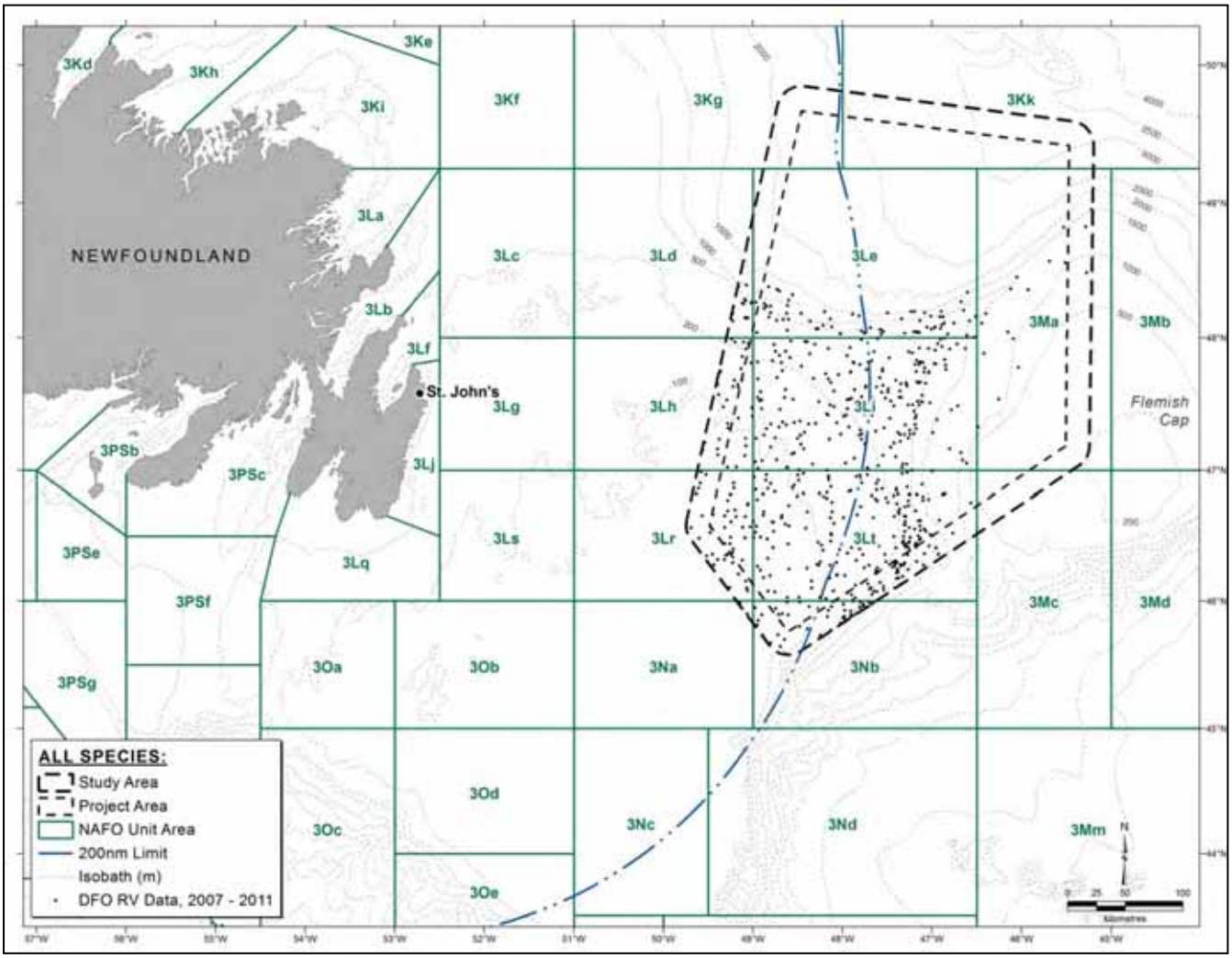
Species/groups that were caught predominantly during the spring surveys included shrimp (*Sergestes arcticus*), capelin, and sand dollars (*Echinarachinus parma* and Clypeasteroida). Species/groups that were caught predominantly during the fall surveys included basket star, eelpouts (*Lycodes* sp.), moustache sculpin, roundnose grenadier, sponges, black dogfish, blue hake, threebeard rockling, longnose eel, corals, large scale tapirfish, lanternfishes, roughhead grenadier, jellyfishes, brittle stars, marlin spike, and comb jellies. The survey depth differences between spring and fall surveys likely account for some of the seasonal differences in species/groups caught (Table 4.5).

DFO RV survey catch weights in the Study Area from 2007 to 2011 were analyzed for 11 mean catch depth ranges and results are presented in Table 4.6.

Table 4.4. Catch Weights and Numbers of Macroinvertebrate and Fish Species Collected during 2007 to 2011 DFO RV Surveys within the Study Area.

Species	Catch Weight (kg)	Catch Number
Deepwater redfish (*Sebastes mentella*)	52,971	248,110
Northern shrimp (*Pandalus borealis*)	14,876	2,816,576
Shrimp (Natantia)	10,963	n/d
Sand lance (*Ammodytes dubius*)	7,974	646,673
Thorny skate (*Raja radiata*)	6,465	3,914
Capelin (*Mallotus villosus*)	6,354	382,442
Sponges	6,243	n/d
American plaice (*Hippoglossoides platessoides*)	6,126	29,108
Roughhead grenadier (*Macrourus berglax*)	4,557	10,676
Greenland halibut (*Reinhardtius hippoglossoides*)	4,186	9,372
Sea anemones	2,885	6,802
Yellowtail flounder (*Limanda ferruginea*)	2,164	6,537
Greenland shark (*Somniosus microcephalus*)	2,000	2
Atlantic cod (*Gadus morhua*)	1,738	3,038
Blue hake (*Antimora rostrata*)	1,673	10,902
Snow crab (*Chionoecets opilio*)	1,537	7,768
Jellyfishes (Scyphozoa)	1,122	28
Longnose eel (*Synaphobranchus kaupi*)	943	8,541
Atlantic wolffish (*Anarhichas lupus*)	793	1,468
Roundnose grenadier (*Coryphaenoides rupestris*)	782	5,279
Black dogfish (*Centroscyllium fabricii*)	749	610
Sea urchins (Echinoidea)	711	37,952
Marlin spike (*Nezumia bairdi*)	631	7,819
Northern wolffish (*Anarhichas denticulatus*)	590	216
Spotted wolffish (*Anarhichas minor*)	586	210
Witch flounder (*Glyptocephalus cynoglossus*)	565	1,685
Vahl's eelpout (*Lycodes vahlii*)	537	5,230
Mailed sculpins (*Triglops* sp.)	450	35,958
Comb jellies (Ctenophora)	345	n/d
Lanternfishes (Myctophidae)	331	58,490
Unspecified invertebrates	314	4
Arctic eelpout (*Lycodes reticulatus*)	298	1,263
Longfin hake (*Urophycis chesteri*)	278	2,139
Shrimp (*Sergestes arcticus*)	265	253,728
Eelpout (*Lycodes* sp.)	239	2,056
Spinytail skate (*Raja* [*Bathraja*] *spinicauda*)	238	21
Sand dollar (*Echinarachinus parma*)	233	8,873
Large scale tapirfish (*Notacanthus nasus*)	225	382
Moustache sculpin (*Triglops murrayi*)	217	17,739
Corals	192	n/d
Brittle star (Ophiuroidea)	166	560
Striped shrimp (*Pandalus montagui*)	160	39,941
Sea star (*Leptasterias polaris*)	148	1,285
Eelpouts (Zoarcidae)	133	2,526
Basket star (Gorgonocephalidae)	132	58
Sand dollar (Clypeasteroida)	112	6,161
Threebeard rockling (*Gaidropsarus* sp.)	106	423

Source: DFO RV Survey Data 2007-2011. n/d denotes data unavailable.



Source: DFO RV Survey Data, 2007-2011.

Figure 4.29. DFO RV Survey Catch Locations within the Study Area, 2007 to 2011 Combined.

Table 4.5. Percentage Catch and Mean Catch Depth by Survey Season for Macroinvertebrates and Fishes Caught during DFO RV Surveys within the Study Area, 2007 to 2011 Combined.

Species	% Catch in Spring Surveys	Spring Survey Mean Catch Depth (m)	% Catch in Fall Surveys	Fall Survey Mean Catch Depth (m)
Deepwater redfish (*Sebastes mentella*)	51	383	49	418
Northern shrimp (*Pandalus borealis*)	65	278	35	231
Shrimp (Natantia)	45	231	55	492
Sand lance (*Ammodytes dubius*)	45	104	55	101
Thorny skate (*Raja radiata*)	45	291	55	276
Capelin (*Mallotus villosus*)	96	165	4	211
Sponges	4	338	96	503
American plaice (*Hippoglossoides platessoides*)	44	207	56	266
Roughhead grenadier (*Macrourus berglax*)	26	456	74	675
Greenland halibut (*Reinhardtius hippoglossoides*)	45	377	55	533
Sea anemones	36	337	64	409
Yellowtail flounder (*Limanda ferruginea*)	48	71	52	68
Greenland shark (*Somniosus microcephalus*)	50	458	50	389
Atlantic cod (*Gadus morhua*)	32	241	68	229
Blue hake (*Antimora rostrata*)	7	607	93	895
Snow crab (*Chionoecets opilio*)	44	165	56	190
Jellyfishes (Scyphozoa)	26	478	74	767
Longnose eel (*Synaphobranchus kaupi*)	10	567	90	862
Atlantic wolffish (*Anarhichas lupus*)	52	265	48	261
Roundnose grenadier (*Coryphaenoides rupestris*)	3	642	97	957
Black dogfish (*Centroscyllium fabricii*)	5	660	95	1,038
Sea urchins (Echinoidea)	46	117	54	361
Marlin spike (*Nezumia bairdi*)	28	489	72	711
Northern wolffish (*Anarhichas denticulatus*)	50	496	50	642
Spotted wolffish (*Anarhichas minor*)	39	318	61	274
Witch flounder (*Glyptocephalus cynoglossus*)	36	400	64	490
Vahl's eelpout (*Lycodes vahlii*)	31	399	69	355
Mailed sculpins (*Triglops* sp.)	46	140	54	161
Comb jellies (Ctenophora)	28	73	72	68
Lanternfishes (Myctophidae)	21	497	79	768
Unspecified invertebrates	42	263	58	486
Arctic eelpout (*Lycodes reticulatus*)	41	187	59	172
Longfin hake (*Urophycis chesteri*)	51	443	49	550
Shrimp (*Sergestes arcticus*)	97	527	3	832
Eelpout (*Lycodes* sp.)	<1	264	>99	404
Spinytail skate (*Raja* [*Bathraja*] *spinicauda*)	57	538	43	547
Sand dollar (*Echinarachinus parma*)	88	147	12	222
Large scale tapirfish (*Notacanthus nasus*)	18	616	82	874
Moustache sculpin (*Triglops murrayi*)	2	153	98	150
Corals	17	296	83	673
Brittle star (Ophiuroidea)	27	195	73	265
Striped shrimp (*Pandalus montagui*)	40	112	60	109
Sea star (*Leptasterias polaris*)	39	85	61	104
Eelpouts (Zoarcidae)	39	271	61	429
Basket star (Gorgonocephalidae)	<1	231	>99	311
Sand dollar (Clypeasteroida)	78	195	22	179
Threebeard rockling (*Gaidropsarus* sp.)	9	507	91	859

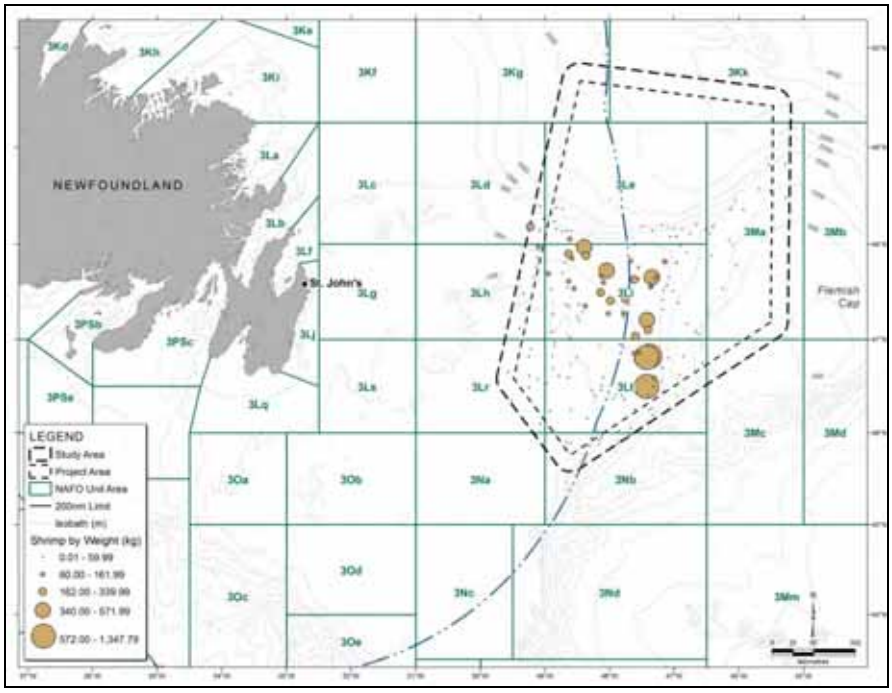
Source: DFO RV Survey Data 2007-2011.

Table 4.6. Total Catch Weights and Predominant Species Caught at various Mean Catch Depth Ranges, 2007 to 2011 DFO RV Surveys Combined.

Mean Catch Depth Range	Total Catch Weight (kg)	Predominant Species
<100 m	12,200	Sand lance (46%) Yellowtail flounder (18%) Capelin (9%) American plaice (7%)
≥100 m to <200 m	16,326	Northern shrimp (21%) Shrimp (Natantia; 21%) Sand lance (13%) Capelin (9%) American plaice (8%) Thorny skate (6%) Snow crab (5%)
≥200 m to <300 m	38,029	Deepwater redfish (31%) Northern shrimp (26%) Shrimp (Natantia; 16%) Capelin (8%) Thorny skate (4%)
≥300 m to <400 m	41,015	Deepwater redfish (69%) Thorny skate (7%) Shrimp (Natantia; 3%)
≥400 m to <500 m	14,840	Deepwater redfish (57%) Sea anemones (11%) Greenland shark (7%) Thorny skate (5%)
≥500 m to <600 m	3,234	Deepwater redfish (58%) Roughhead grenadier (9%) Sand lance (8%) American plaice (6%) Greenland halibut (5%)
≥600 m to <700 m	7,992	Deepwater redfish (31%) Roughhead grenadier (15%) American plaice (9%) Greenland halibut (9%) Sea anemones (6%)
≥700 m to <800 m	1,360	Roughhead grenadier (25%) Greenland halibut (24%) Blue hake (8%) Black dogfish (6%) Marlin spike (4%) Deepwater redfish (4%)
≥800 m to <900 m	3,434	Sponges (65%) Roughhead grenadier (7%) Blue hake (5%) Greenland halibut (5%)
≥900 m to < 1,000 m	1,019	Roughhead grenadier (22%) Black dogfish (14%) Blue hake (13%) Greenland halibut (10%) Longnose eel (9%) Roundnose grenadier (6%) Jellyfish (Scyphozoa: 5%)
≥1,000 m	8,940	Sponges (37%) Roughhead grenadier (11%) Blue hake (11%) Greenland halibut (8%) Roundnose grenadier (7%) Longnose eel (6%) Jellyfish (Scyphozoa: 5%)

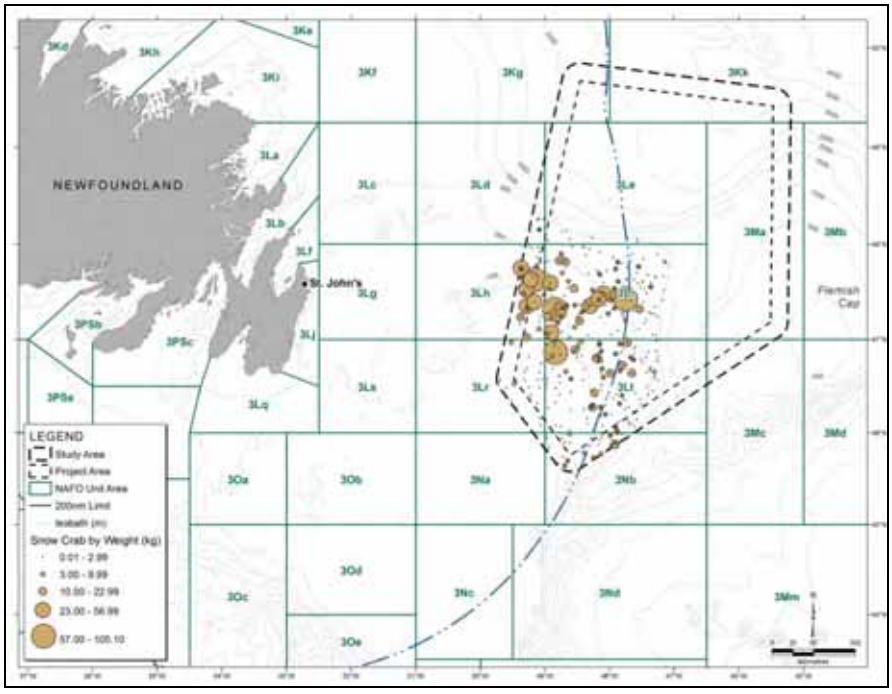
Source: DFO RV Survey Data 2007-2011.

The locations of proportional catches of notable macroinvertebrates and fishes during the DFO RV survey, 2007–2011 combined, are indicated in Figures 4.30 to 4.37.



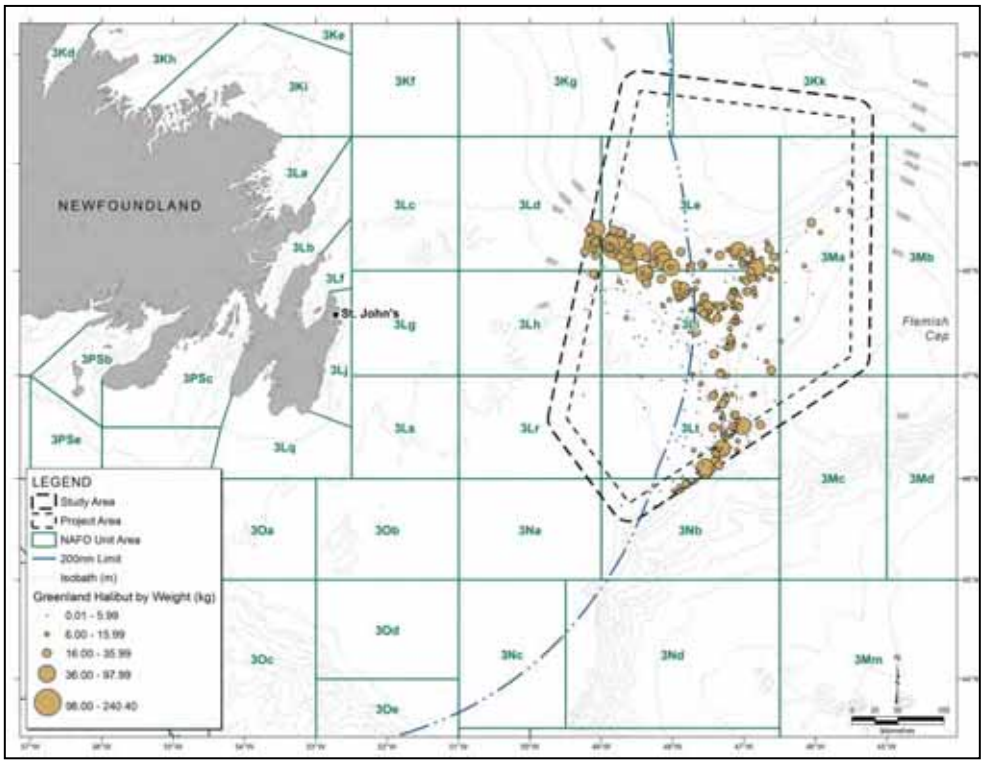
Source: DFO RV Survey Data, 2007-2011.

Figure 4.30. DFO RV Survey Proportional Northern Shrimp Catch Locations within the Study Area, 2007 to 2011 Combined.



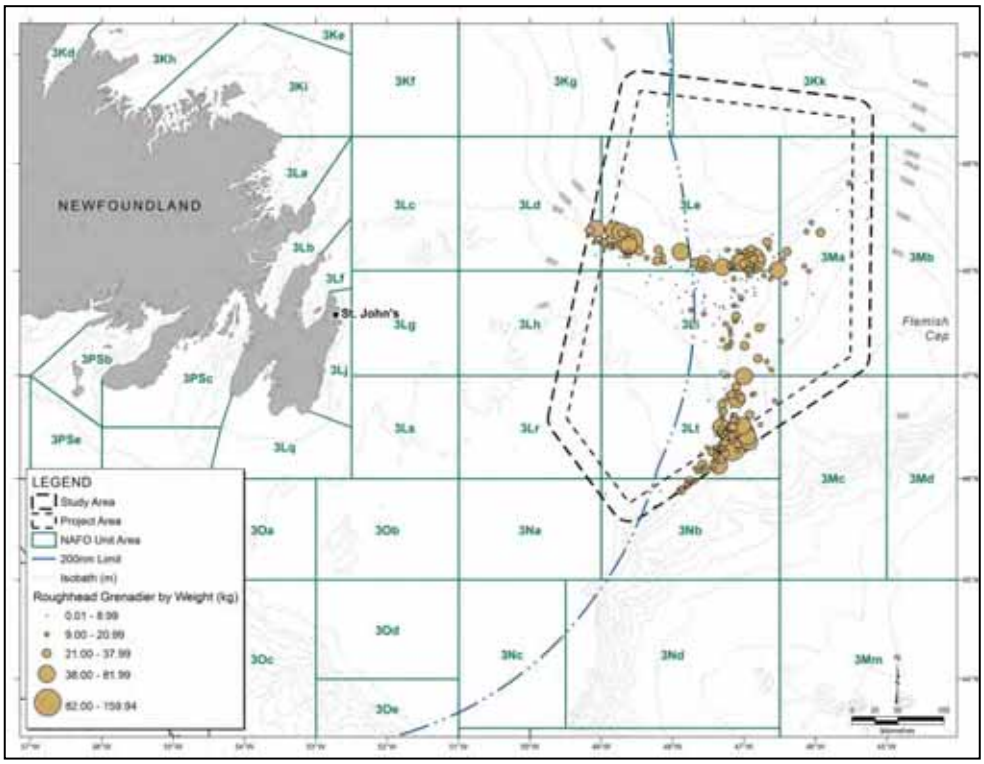
Source: DFO RV Survey Data, 2007-2011.

Figure 4.31. DFO RV Survey Proportional Snow Crab Catch Locations within the Study Area, 2007 to 2011 Combined.



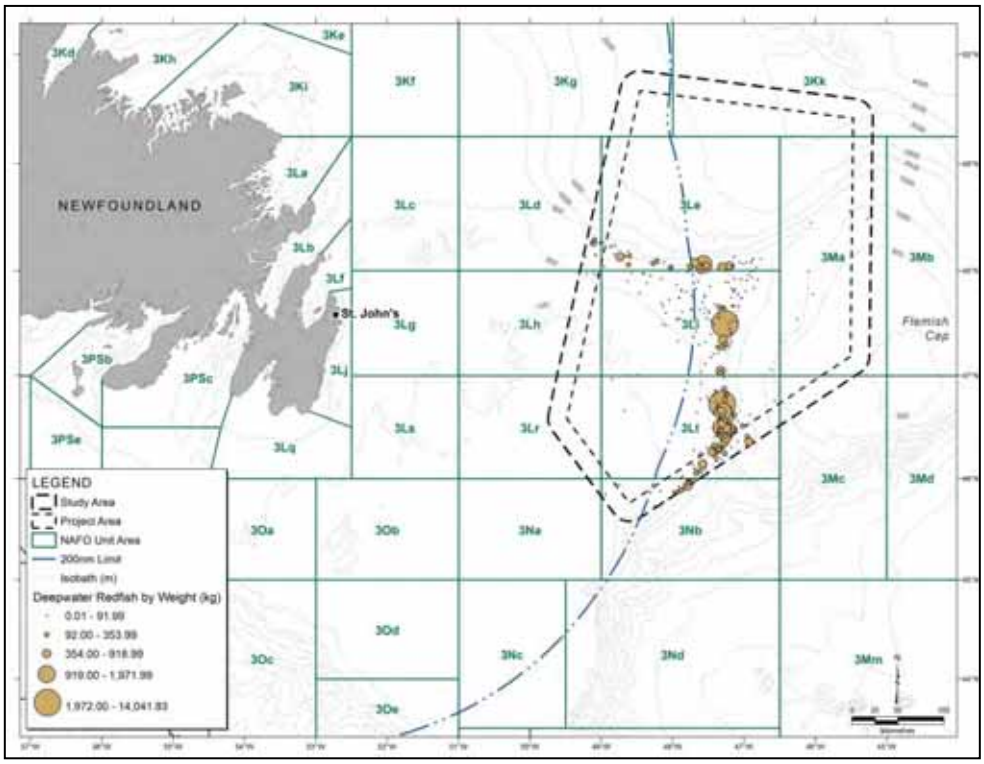
Source: DFO RV Survey Data, 2007-2011.

Figure 4.32. DFO RV Survey Proportional Greenland Halibut Catch Locations within the Study Area, 2007 to 2011 Combined.



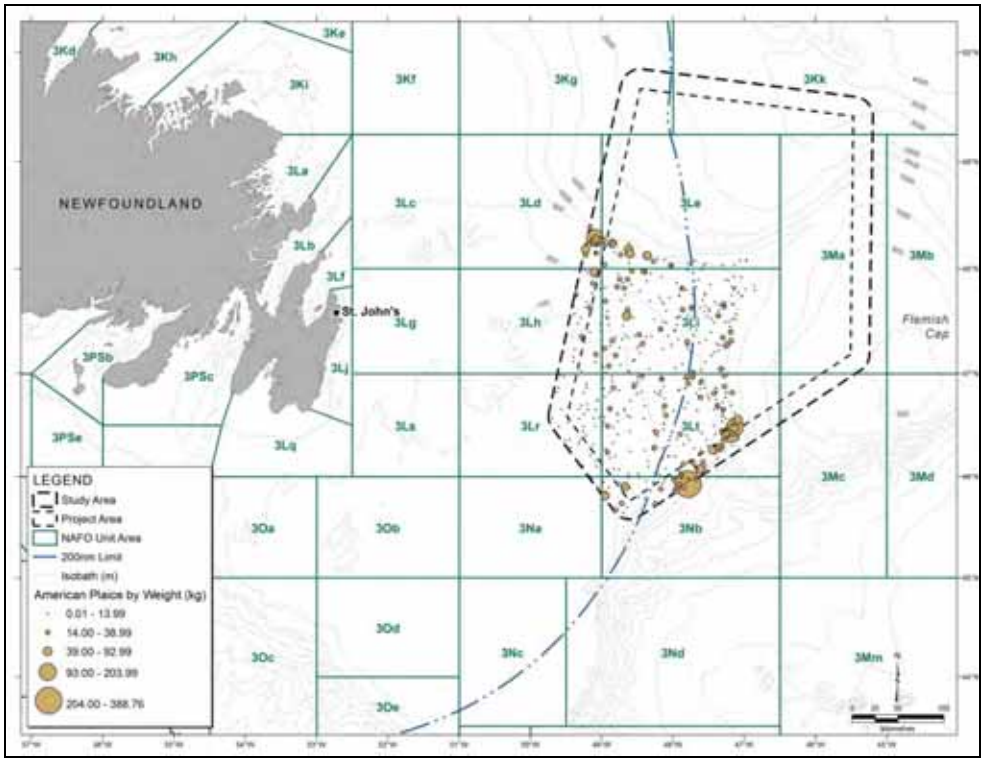
Source: DFO RV Survey Data, 2007-2011.

Figure 4.33. DFO RV Survey Proportional Roughhead Grenadier Catch Locations within the Study Area, 2007 to 2011 Combined.



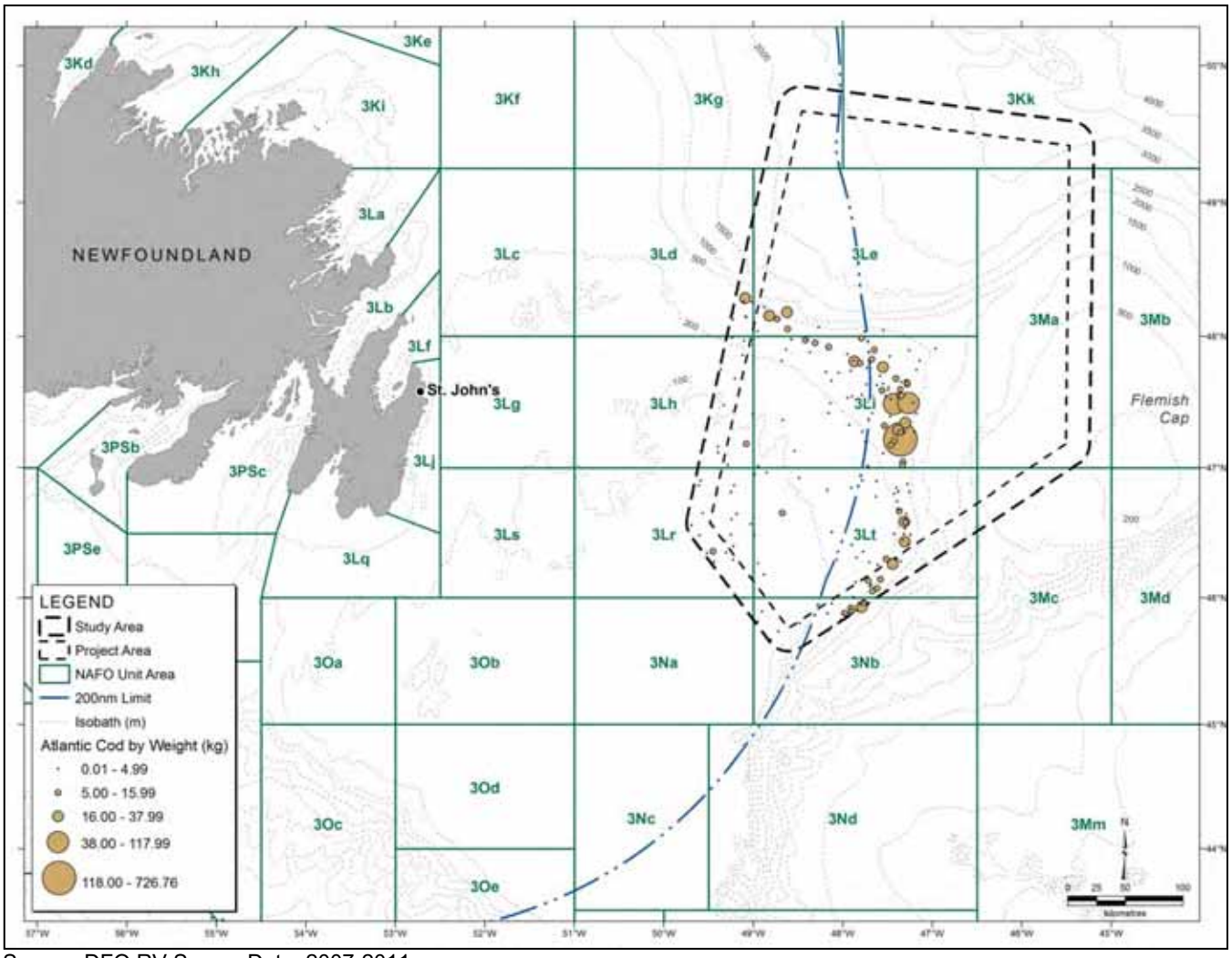
Source: DFO RV Survey Data, 2007-2011.

Figure 4.34. DFO RV Survey Proportional Deepwater Redfish Catch Locations within the Study Area, 2007 to 2011 Combined



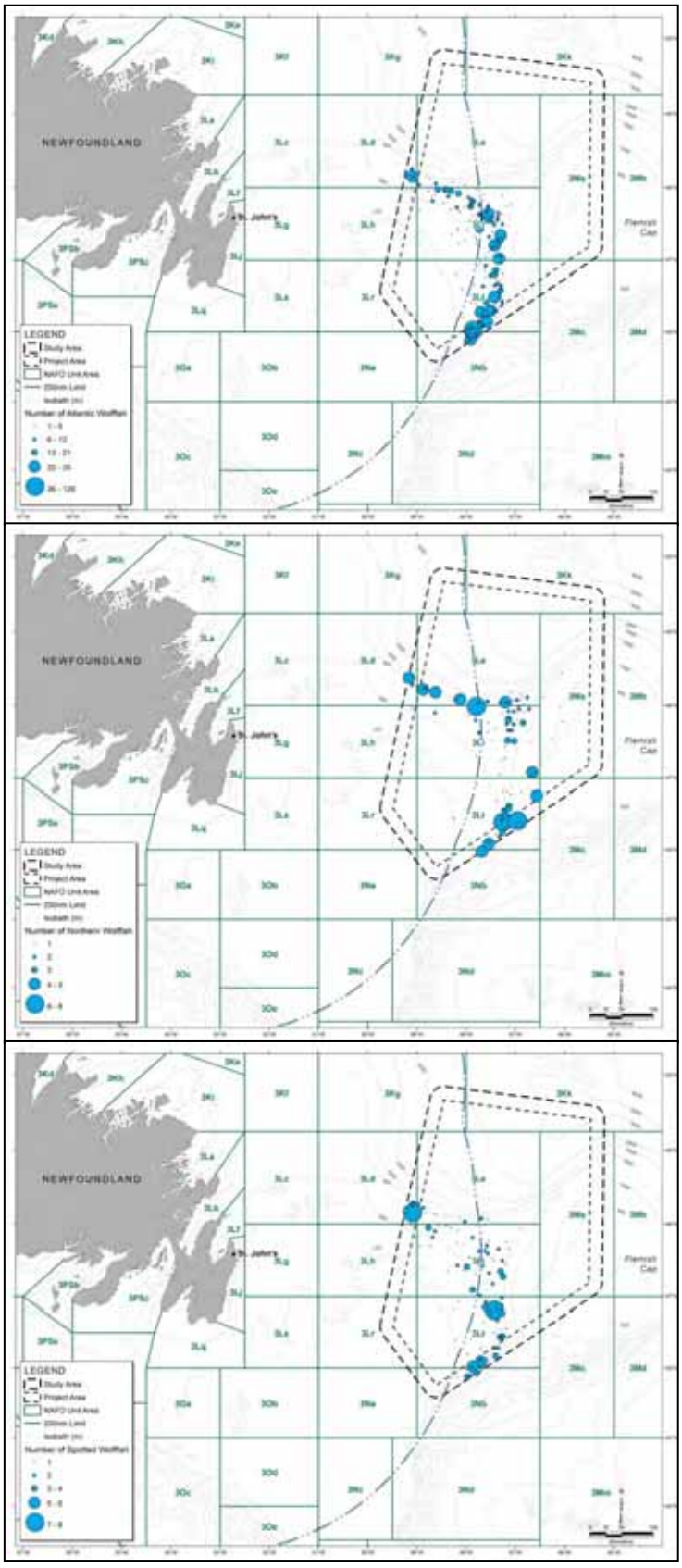
Source: DFO RV Survey Data, 2007-2011.

Figure 4.35. DFO RV Survey Proportional American Plaice Catch Locations within the Study Area, 2007 to 2011 Combined.



Source: DFO RV Survey Data, 2007-2011.

Figure 4.36. DFO RV Survey Proportional Atlantic Cod Catch Locations within the Study Area, 2007 to 2011 Combined.



Source: DFO RV Survey Data, 2007-2011.

Figure 4.37. DFO RV Survey Proportional Atlantic, Northern and Spotted Wolffish Catch Locations within the Study Area, 2007 to 2011 Combined.

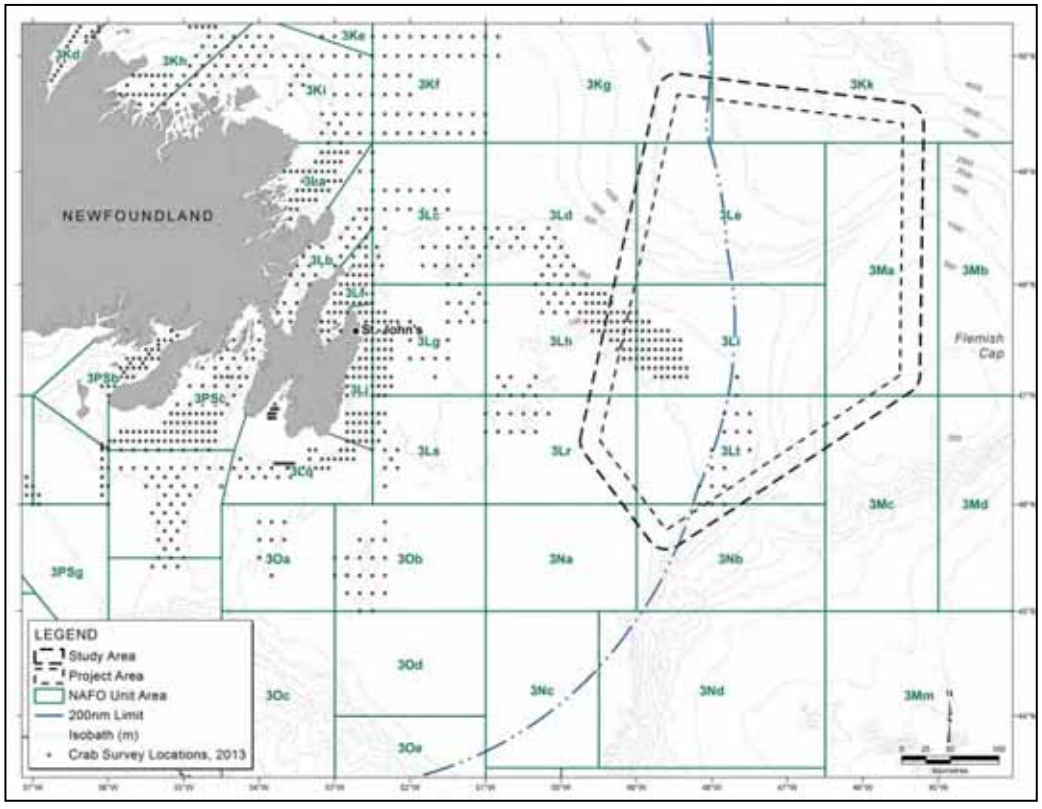
4.3.6 Aboriginal and Recreational Fisheries

There are no aboriginal or recreational fisheries in the Study Area.

4.3.7 Industry and DFO Science Surveys

Fisheries research surveys conducted by DFO, and sometimes by the fishing industry, are important to the commercial fisheries to determine stock status, as well as for scientific investigation. In any year, there may be overlap between the Study Area and DFO research surveys in NAFO 3LM, depending on the timing in a particular year. Typically, DFO conducts a spring survey in sections of 3LNOPs (April to July), and a fall survey of 2HJ3KLMNO (September or October to December). The fall survey may employ two vessels. The deeper waters of 3L (slope areas) are typically surveyed in October, and the shallower areas in November or December. There is also an annual spring acoustic survey for capelin in NAFO Division 3L. In 2013, DFO multispecies research science surveys were conducted from March to December; fall survey vessels included the Coast Guard Vessels *Alfred Needler* and *Teleost*. The 2014 survey schedule is currently in draft form (G. Sheppard, December 2013, pers. comm.).

Members of the FFAW have been involved in the snow crab DFO-industry collaborative post-season trap survey in various offshore harvesting locations over the past few years. This survey is conducted every year. It starts around September 1 and may continue until November before it is completed. The set locations are determined by DFO and do not change from year to year (Figure 4.38).



Source: DFO 2013

Figure 4.38. Joint DFO-Industry Post-season Crab Survey Locations, 2013.

4.4 Seabirds

The highly productive Grand Banks support large numbers of seabirds in all seasons (Lock et al. 1994; Fifield et al. 2009). Seabirds are not spread evenly over the ocean but tend to be concentrated over oceanographic features such as shelf edges, and along current interfaces. In such areas, mixing in the water column creates a productive environment for plankton. The combination of shelf edges and the Labrador Current flowing through the Study Area create prime conditions for enhanced productivity of plankton, the basis of oceanic food chains.

4.4.1 Information Sources

Seabird surveys in the Study Area and surrounding areas have been conducted by the Canadian Wildlife Service (CWS) and through oil industry related seabird monitoring. Prior to 2000, seabird surveys were sparse on the Orphan Basin, northern Grand Banks and Flemish Cap. Original baseline information has been collected by the CWS through PIROP (Programme intégré de recherches sur les oiseaux pélagiques). These data have been published for 1969-1983 (Brown 1986) and 1984-1992 (Lock et al. 1994). Since the late 1990s additional seabird observations have been collected on the northeast Grand Banks by the offshore oil and gas industry from drill platforms and supply vessels (Baillie et al. 2005; Burke et al. 2005; Fifield et al. 2009). Seabird surveys were also conducted from vessels conducting seismic surveys or control source electromagnetic surveys within the Study Area from 2004-2008 as part of marine bird monitoring programs required by the C-NLOPB (Moulton et al. 2005a, 2006; Lang et al. 2006; Lang 2007; Lang and Moulton 2008; Abgrall et al. 2008a,b, 2009). In addition, the CWS initiated a program called Eastern Canadian Seabirds at Sea (ECSAS). The Environmental Studies Research Funds (ESRF) combined with CWS to fund a 3.5 year project focused on improving the knowledge of seabirds at sea on the northern Grand Banks and other areas of oil industry activity in eastern Canada (Fifield et al. 2009). A total of 76 surveys conducted in this time span include many from the Grand Banks and Orphan Basin. Monthly surveys were conducted to the northeast Grand Banks production area from 2006 to 2009.

The results from all of the above surveys have been used here to describe the abundance, diversity and spatial distribution of seabirds in the Study Area. The predicted monthly relative abundance for each species expected to occur regularly in the Study Area are provided in Table 4.7.

4.4.2 Summary of Seabirds in the Study Area

During the ECSAS surveys of Newfoundland and Nova Scotia waters the Sackville Spur, Orphan Basin and Flemish Pass all emerged as important to one or more species/groups in one or more seasons (Fifield et al. 2009). Northern Fulmar and gulls were found in the highest concentrations in the Newfoundland and Labrador shelves region on the Sackville Spur during spring. Significant numbers of these birds were also present in winter. Northern Fulmars, Leach's Storm-petrels and shearwaters were found in summer along the southern edge of the Orphan Basin. ECSAS surveys in the Flemish Pass and Flemish Cap showed local hotspots during winter and spring for Northern Fulmar, Black-legged Kittiwake, Dovekie, gulls (spring only) and murres. Shearwaters were in high densities in summer.

Table 4.7. Predicted Monthly Abundances of Seabird Species Occurring in the Study Area.

Common Name	Scientific Name	Monthly Abundance											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Procellariidae													
Northern Fulmar	*Fulmarus glacialis*	C	C	C	C	C	C	C	C	C	C	C	C
Great Shearwater	*Puffinus gravis*					U	C	C	C	C	C	S	
Sooty Shearwater	*Puffinus griseus*					S	S-U	S-U	S-U	S-U	S-U	S	
Manx Shearwater	*Puffinus puffinus*					S	S	S	S	S	S		
Hydrobatidae													
Leach's Storm-Petrel	*Oceanodroma*				U-C	C	C	C	C	C	C	S	
Wilson's Storm-Petrel	*Oceanites oceanicus*						S	S	S	S			
Sulidae													
Northern Gannet	*Morus bassanus*				S	S	S	S	S	S	S		
Phalaropodinae (Scolopacidae)													
Red Phalarope	*Phalaropus fulicarius*					S	S	S	S	S	S		
Red-necked Phalarope	*Phalaropus lobatus*					S	S	S	S	S			
Laridae													
Herring Gull	*Larus argentatus*	U	U	U	U	U	S	S	S	S	S	S	S
Iceland Gull	*Larus glaucoides*	S	S	S	S						S	S	S
Lesser Black-backed Gull	*Larus fuscus*					VS	VS	VS	VS	VS	VS	VS	VS
Glaucous Gull	*Larus hyperboreus*	S	S	S	S						S	S	S
Great Black-backed Gull	*Larus marinus*	U	U	U	U	U	S	S	U	U	U	U	U
Ivory Gull	*Pagophila eburnea*	VS?	VS?	VS?	VS?								
Black-legged Kittiwake	*Rissa tridactyla*	C	C	C	C	C	S	S	S	U	C	C	C
Arctic Tern	*Sterna paradisaea*					S	S	S	S	S			
Stercorariidae													
Great Skua	*Stercorarius skua*					S	S	S	S	S	S		
South Polar Skua	*Stercorarius*					S	S	S	S	S	S		
Pomarine Jaeger	*Stercorarius pomarinus*				S	S	S	S	S	S	S		
Parasitic Jaeger	*Stercorarius parasiticus*					S	S	S	S	S	S		
Long-tailed Jaeger	*Stercorarius*					S	S	S	S	S			
Alcidae													
Dovekie	*Alle alle*	C	C	C	C	U	VS	VS	VS	S	C	C	C
Common Murre	*Uria aalge*	S-U	S-U	S-U	S-U	S	S	S	S	S	S-U	S-U	S-U
Thick-billed Murre	*Uria lomvia*	U-C	U-C	U-C	U-C	S-U	S-U	S-U	S-U	U-C	U-C	U-C	U-C
Razorbill	*Alca torda*				S	S	S	S	S	S	S	S	
Atlantic Puffin	*Fratercula arctica*				S	S	S	S	S	S-U	S-U	S-U	

Notes: C = Common, present daily in moderate to high numbers; U = Uncommon, present daily in small numbers; S = Scarce, present, regular in very small numbers; VS = Very Scarce, very few individuals or absent. 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 and Jeanne d'Arc Basin and extrapolation of marine bird distribution at sea in eastern Canada in Brown (1986); Lock et al. (1994) and Fifield et al. (2009). **Sources:** Brown (1986); Lock et al. (1994); Baillie et al. (2005); Moulton et al. (2005a, 2006); Lang et al. (2006); Lang (2007); Lang and Moulton (2008); Abgrall et al. (2008a,b, 2009.)

4.4.3 Breeding Seabirds in Eastern Newfoundland

Hundreds of thousands of pairs of seabirds nesting on the Avalon Peninsula reflect the richness of the offshore regions off southeastern Newfoundland. The seabird breeding colonies on Baccalieu Island, the Witless Bay Islands, and Cape St. Mary's are among the largest in Atlantic Canada. More than 4.6 million pairs nest at these three locations alone (Figure 4.39; Table 4.8). This includes the largest Atlantic Canada colonies of Leach's Storm-petrel (3,336,000 pairs on Baccalieu Island), Black-legged Kittiwake (23,606 pairs on Witless Bay Islands), Thick-billed Murre (1,000 pairs at Cape St. Mary's), and Atlantic Puffin (216,000 pairs on Witless Bay Islands). These birds, along with non-breeding seabirds, feed on the Grand Banks during the nesting season from May to September. In addition, Funk Island, 150 km northwest of the Grand Banks supports the largest colony of Common Murre (412,524 pairs) in Atlantic Canada (Chardine et al. 2003). Many of these birds could reach the Study Area in the non-breeding season.

There are nine significant seabird nesting sites on the southeast coast of Newfoundland from Cape Freels to the Burin Peninsula. Each meets the criteria for an Important Bird Area (IBA) (Figure 4.39; Table 4.8). An IBA is defined as a site that provides essential habitat for one or more species of breeding or non-breeding birds. These sites may contain threatened species, endemic species, species representative of a biome, or highly exceptional concentrations of birds (www.ibacanada.com).

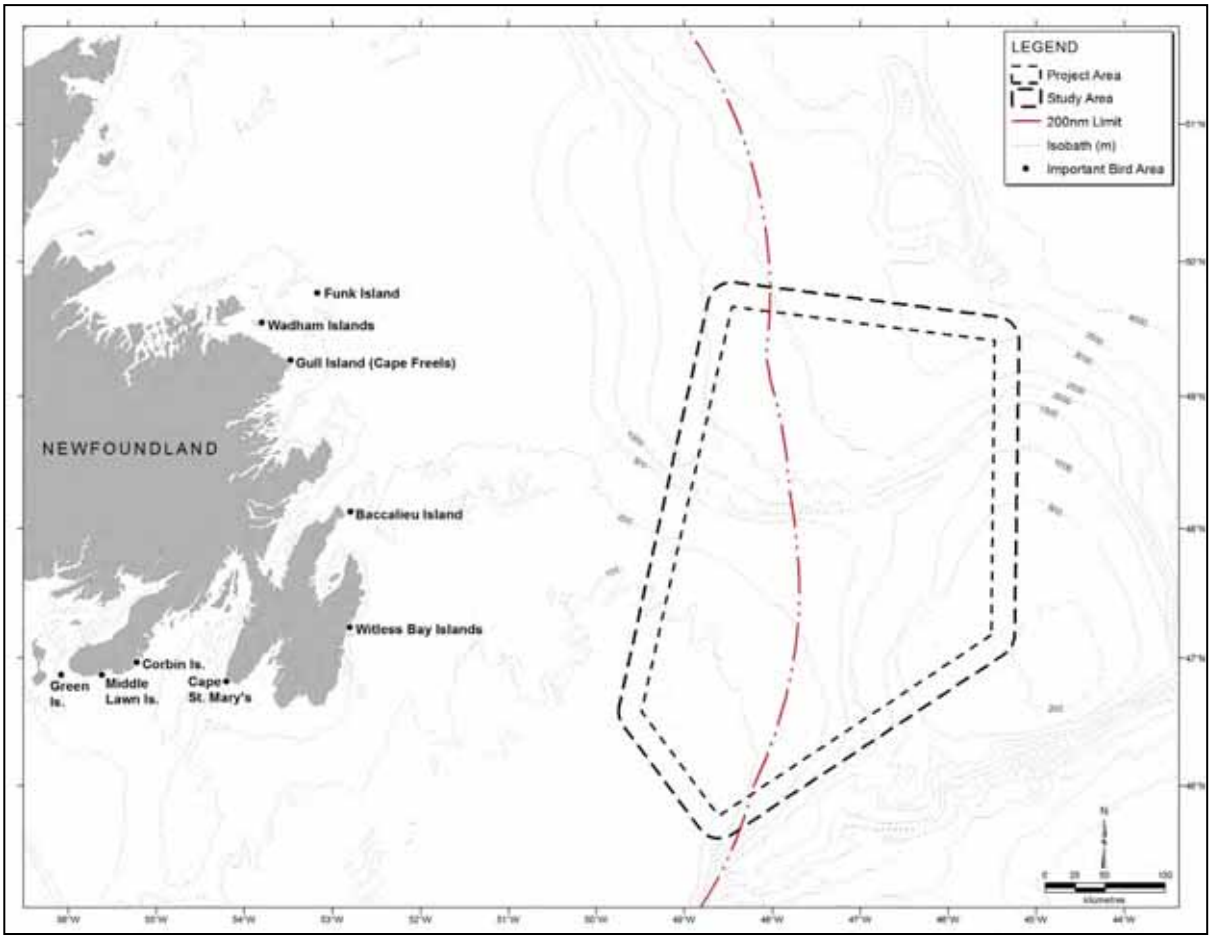


Figure 4.39. Locations of Seabird Nesting Colonies at Important Bird Areas (IBAs) relative to the Study Area.

Table 4.8. Numbers of Pairs of Marine Birds Nesting at Marine Bird Colonies in Eastern Newfoundland.

Species	Wadham Islands	Funk Island	Cape Freels and Cabot Island	Baccalieu Island	Witless Bay Islands	Cape St. Mary's	Middle Lawn Island	Corbin Island	Green Island
Northern Fulmar	-	6[N]	-	12[A]	22[A,F]	Present[A]	-	-	-
Manx Shearwater	-	-	-	-	-	-	13[K, O]	-	-
Leach's Storm-Petrel	1,038[D]	-	250[J]	3,336,000[J]	667,086[H,I,J]	-	13,879[H]	100,000[J]	103,833[M]
Northern Gannet		9,203[N]		2,564[N]	-	14,789[L]	-	-	-
Herring Gull	-	500[J]	-	120[N]	4,638[E,J]	Present[J]	20[J]	5,000[J]	Present[M]
Great Black-backed Gull	Present[D]	100[J]	-	6[N]	166[E,J]	Present[J]	6[J]	25[J]	-
Black-legged Kittiwake	-	95[N]	-	5,100[N]	23,606[F,J]	10,000[J]	-	50[J]	-
Arctic and Common Terns	376[J]	-	250[J]	-	-	-	-	-	-
Common Murre	-	412,524[C]	2,600[J]	1,500[N]	83,001[F,J]	15,484[J]	-	-	-
Thick-billed Murre		250[J]	-	75[N]	600[J]	1,000[J]	-	-	-
Razorbill	273[D]	200[J]	25[J]	500[N]	676[F,J]	100[J]	-	-	-
Black Guillemot	25[J]	1[J]	-	150[N]	20+[J]	Present[J]	-	-	-
Atlantic Puffin	6,190[D]	2,000[J]	20[J]	30,000[J]	272,729[F,G,J]	-	-	-	-
TOTALS	**7,902**	**424,879**	**3,145**	**3,376,027**	**1,052,546**	**41,373**	**13,918**	**105,075**	**103,833**

Sources: [A] Stenhouse and Montevecchi (1999); [B] Chardine (2000); [C] Chardine *et al.* (2003); [D] Robertson and Elliot (2002); [E] Robertson *et al.* (2001); [F] Robertson *et al.* (2004); [G] Rodway *et al.* (2003); [H] Robertson *et al.* (2002); [I] Stenhouse *et al.* (2000); [J] Cairns *et al.* (1989); [K] Robertson (2002); [L] CWS (unpubl. data); [M] Russell (2008); [N] CWS 2012 (unpubl. data); [O] Fraser et al. 2013.

In addition to local breeding birds, there are many non-breeding seabirds on the Grand Banks during the summer months. A significant portion of the world's population of Great Shearwater is thought to migrate to the Grand Banks and eastern Newfoundland to moult and feed during the summer months after completion of nesting in the Southern Hemisphere (Lock et al. 1994). Depending on the species, seabirds require two to four years to become sexually mature. Many non-breeding sub-adult seabirds, notably Northern Fulmars and Black-legged Kittiwakes are present on the Grand Banks and Flemish Cap year-round. During the non-breeding season large numbers of Arctic-breeding Thick-billed Murre, Dovekie, Northern Fulmar, and Black-legged Kittiwake migrate to eastern Newfoundland, including the Grand Banks and Flemish Cap to spend the winter.

The Ivory Gull was designated as an *endangered* species by COSEWIC in April 2006 and is listed as *endangered* under *SARA* Schedule 1. Ivory Gull is likely of less than annual occurrence in the Project Area. See Section 4.6 for more detail.

4.4.4 Seasonal Occurrence and Abundance

The world range and seasonal occurrence and abundance of seabirds occurring regularly in the Project Area are described below. Table 4.7 summarizes the predicted abundance status for each species monthly. The table uses four categories to define a relative abundance of seabirds species observed:

1. *Common* = occurring daily in moderate to high numbers;
2. *Uncommon* = occurring regularly in small numbers;
3. *Scarce* = a few individuals occurring; and
4. *Very Scarce* = very few individuals.

A species world population estimate is taken into consideration when assessing relative abundance; for example, Great Shearwater is far more numerous on a worldwide scale compared to a predator like the great skua. Information was derived from Brown (1986), Lock et al. (1994), Baillie et al. (2005), Lang et al. (2006), Moulton et al. (2006), Lang (2007), Abgrall (2008a,b), and Fifield et al. (2009).

4.4.4.1 Procellariidae (Fulmars and Shearwaters)

Northern Fulmar

Northern Fulmar is common in the Study Area year-round. The Northern Fulmar breeds in the North Atlantic, North Pacific, and Arctic oceans. In the Atlantic, it winters south to North Carolina and southern Europe (Brown 1986; Lock et al. 1994). Through band recoveries, it is known that most individuals in Newfoundland waters are from Arctic breeding colonies. Adults and sub-adult birds are present in the winter with sub-adults remaining through the summer. About 80 pairs breed in eastern Newfoundland (Stenhouse and Montevecchi 1999; Robertson et al. 2004). During the period 1999 to 2002 on the northeast Grand Banks, fulmars were found to be most numerous during spring and autumn (Baillie et al. 2005).

Results from monitoring programs on the Orphan Basin 2004–2007 show Northern Fulmar as being among the top four most numerous species from mid-May to September (Table A.1 to A.3 in Appendix A). Monthly average densities during June, July and August ranged from 1.7 birds/km^2 to 4.8 birds/km^2. Higher densities were recorded in May and September with 30.1 birds/km^2 in May 2005 and 16.1 birds/km^2 in September 2005, and 5.8 birds/km^2 in September 2006. Results from the Jeanne d'Arc Basin show an average of 5.1 birds/km^2 for July and August 2006, 1.2 birds/km^2 in late May to September 2008, and 14.7 birds/km^2 in October and early November in 2005 (Table A.4 to A6 in Appendix A).

The ECSAS survey data from 2006–2009 in the Study Area show that Northern Fulmar was present during all seasons (spring, summer and winter) surveyed (Fifield et al. 2009). Densities within the Study Area (considering 1º survey blocks) ranged from 1.0 to 22.4 birds/km^2 in spring to 0 to 10.7 birds/km^2 in summer, and 0 to 33.7 birds/km^2 in winter. High densities were observed along the southern edge of Orphan Basin at the Sackville Spur in winter (Fifield et al. 2009).

Great Shearwater

Great Shearwater migrates north from breeding islands in the South Atlantic and arrives in the Northern Hemisphere during summer. A large percentage of the world population of Great Shearwaters is

thought to moult their flight feathers during the summer months while in Newfoundland waters (Brown 1986; Lock et al 1994). Great Shearwater was among the top four most numerous species observed on the Orphan Basin during seismic monitoring 2004–2007 from June to September (Table A.4 to A.6 in Appendix A). Monthly density averages ranged from 2.4 to 35.4 birds/km^2. Highest densities were in July and August 2005 with averages of 35.4 birds/km^2 and 21.2 birds/km^2 respectively. Great Shearwater can still be numerous in September on the Orphan Basin where an average density of 9.2 birds/km^2 was recorded during September 2005. Seismic monitoring on the Jeanne d'Arc Basin showed Great Shearwater was common in summer with a mean weekly density of 5.1 birds/km^2 from 9 July to 16 August 2006 (Table A.5 in Appendix A) and 11.9 birds/km^2 from 21 May to 29 September 2008 (Table A.6 in Appendix A). The ECSAS survey data from 2006–2009 lumps all shearwater species within the Study Area and shows densities per 1º survey blocks ranging from 0 to 14.1 birds/ km^2 during the summer period May to August (Fifield et al. 2009).

Other Shearwaters

Sooty Shearwater follows movements similar to Great Shearwater but is scarce to uncommon during May to early November in the Study Area. Hedd et al. (2012) tracked Sooty Shearwaters from the nesting colony on the Falkland Is (south Atlantic) to waters offshore eastern Newfoundland, including the Study Area. Manx Shearwater breeds in the North Atlantic in relatively small worldwide numbers compared to Great Shearwater. It is expected to be scarce in the Study Area during May to October.

4.4.4.2 Hydrobatidae (Storm-petrels)

Leach's Storm-Petrel

Leach's Storm-petrel is common in offshore waters of Newfoundland from April to early November. Very large numbers nest in eastern Newfoundland with more than 3,300,000 pairs breeding on Baccalieu Island (Table 4.8). Adults range far from nesting sites on multi-day foraging trips during the breeding season. Non-breeding sub-adults stay at sea during the breeding season. Leach's Storm-petrel is widespread in Newfoundland waters. It was among the top four most numerous species observed on the Orphan Basin during seismic monitoring 2004–2007 from May to September (Table A.1 to A.3 in Appendix A). The average density for the period May to September 2005 was 7.43 birds/km^2 (Table A.1 in Appendix A; from Moulton et al. 2006). The average monthly densities during August and September 2006 were 6.1 birds/km^2 (Table A.2 in Appendix A). And the average density per survey in the period 23 July to 6 September 2007 was 4.3 birds/km^2 (Table A.3 in Appendix A). Densities of Leach's Storm-petrels were lower on seismic surveys on the Jeanne d'Arc Basin with an average of 0.6 birds/km^2 during the survey period 9 July to 16 August 2006 (Tables A.5 in Appendix A) and 0.9 birds/km^2 during the period 21 May to 29 September 2008 (Tables A.6 in Appendix A). The ECSAS survey data from 2006–2009 for storm-petrels within the Study Area shows densities per 1º survey blocks ranging from 0 to 4.2 birds/km^2 during the summer period May to August (Fifield et al. 2009).

Wilson's Storm-Petrel

The Wilson's Storm-petrel migrates north from breeding islands in the South Atlantic to the North Atlantic in the summer months. Newfoundland is at the northern edge of its range. It is expected to be scarce in the Study Area from June to September.

4.4.4.3 Sulidae (Gannets)

Northern Gannet

More than 26,000 pairs of Northern Gannet nest on three colonies in eastern Newfoundland (Table 4.8). Gannets are common near shore and scarce beyond 100 km from shore. The Study Area is beyond the range of most Northern Gannets. Very few were observed during seabird monitoring on the Orphan and Jeanne d'Arc basins in 2004–2007 (Tables A.1 to A.6 in Appendix A). This species is expected to be a scarce visitor from April to October within the Study Area.

4.4.4.4 Phalaropodinae (Phalaropes)

Red and Red-necked Phalarope

The Red Phalarope and Red-necked Phalarope both breed in the Arctic to sub-Arctic regions of North America and Eurasia. They winter at sea mostly in the Southern Hemisphere. They migrate and feed offshore, including Newfoundland waters during their spring and autumn migrations. Phalaropes seek out areas of upwelling and convergence where rich sources of zooplankton are found. Very small numbers of migrant Red Phalaropes and Red-necked Phalaropes have been observed in the Orphan Basin and northern Grand Banks during monitoring surveys in 2005–2008 (Abgrall et al. 2008a, 2009). Phalaropes are expected to be scarce in the Study Area during May to October.

4.4.4.5 Laridae (Gulls and Terns)

Great Black-backed, Herring, Glaucous, Iceland and Lesser Black-backed Gull

Great Black-backed, Herring, Iceland, Glaucous, and Lesser Black-backed Gulls occur in the Study Area. Great Black-backed Gull and Herring Gull are widespread nesters on the North Atlantic including Newfoundland and Labrador. Glaucous and Iceland Gulls breed in Subarctic and Arctic latitudes. They are winter visitors to Newfoundland. Lesser black-backed Gull is a European gull increasing in numbers as a migrant and wintering species in eastern North America.

Great black-backed Gull is usually the most numerous of the large gulls found in the offshore regions of Newfoundland. The Sackville Spur has been identified as an area with a high concentration of large gulls, particularly in late winter and early spring (Fifield et al. 2009). On drilling platforms on the northeast Grand Banks during 1999 to 2002, Great Black-backed Gull was common from September to February and nearly absent from March to August (Baillie et al. 2005). A similar pattern was observed by environmental observers on offshore installations on the Terra Nova oil field from 1999 to 2009 (Suncor, unpubl. data). Herring Gulls were present in consistent numbers throughout the year but in lower numbers than Great Black-backed Gulls. Results from seismic monitoring programs in Jeanne d'Arc Basin indicate that large gulls were most numerous from mid-August to October (Tables A.4 to A.6 in Appendix A). In the Orphan Basin, highest densities of Great Black-backed Gull occurred in September (Tables A.1 to A.3 in Appendix A).

The ECSAS survey data from 2006–2009 in the Study Area shows 'large gulls' were present during all seasons (spring, summer, fall and winter) surveyed (Fifield et al. 2009). Densities within the Study Area (considering 1º survey blocks) were highest during the non-breeding season ranging from

0 to 7.1 birds/km^2 in spring and 0 to 3.8 birds/km^2 in winter. Herring Gulls were present in consistent numbers throughout the year but in lower numbers than Great Black-backed Gulls. Results from seismic monitoring programs in Jeanne d'Arc Basin between May and October showed that large gulls were most numerous from mid-August to October (Tables A.4 to A.6 in Appendix A).

Black-legged Kittiwake

Black-legged Kittiwake is an abundant species in the North Atlantic. It is a pelagic gull that goes to land only during the nesting season. Non-breeding sub-adults remain at sea for the first year of life. Black-legged Kittiwake is expected to be present within the Study Area year-round and most numerous during the non-breeding season (August to May). Black-legged Kittiwake is present in all months of the year on the Grand Banks. Observations from the drilling platforms on the northeast Grand Banks during 1999 to 2002 showed Black-legged Kittiwakes were present in October to May, but were most prevalent during November to December (Baillie et al. 2005). It was among the most numerous species observed by environmental observers on offshore installations on the Terra Nova oil field during the winter months (Suncor, unpubl. data).

Results from monitoring programs on the Orphan Basin 2004–2007 show Black-legged Kittiwake as being uncommon from mid-May to September (Table A.1 to A.3 in Appendix A). The monthly average density during surveys from 14 May to 24 September 2005 was 0.3 birds/km^2 (Table A.1 in Appendix A). Higher densities were recorded in August and September 2006 with an average of 3.9 birds/km^2 (Table A.3 in Appendix A). The average density during the survey period of 23 July to 6 September 2007 was 0.01 birds/km^2 (Table A.3 in Appendix A). Results from monitoring programs in the Jeanne d'Arc Basin show an average of 0.01 birds/km^2 for July and August 2006, 0.02 birds/km^2 for late May to September 2008, and 6.6 birds/km2 in October and early November 2005 (Table A.4 to A.6 in Appendix A). Based on ECSAS survey data collected within the Study Area from 2006–2009, densities of Black-legged Kittiwakes ranged from 0 to 10.2 birds/km^2 during the winter period (November to February), 0 to 5.8 birds/km^2 during the spring period (March and April), and 0 to 2.1 birds/km^2 during the summer period (May to August; Fifield et al. 2009).

Ivory Gull

Concerns over reduced numbers of Ivory Gulls at known breeding colonies in the Canadian Arctic have resulted in COSEWIC listing it as *endangered* (COSEWIC 2013); this species is reviewed in Section 4.6.

Arctic Tern

Arctic Tern is the only species of tern expected in offshore waters of Newfoundland. It breeds in sub-Arctic to Arctic regions of North America and Eurasia. It winters at sea in the Southern Hemisphere. It migrates in small numbers through the Study Area from May to September. The species is present in such low densities that it is rarely recorded during systematic surveys (Appendix A).

4.4.4.6 Stercorariidae (Skuas and Jaegers)

Great Skua and South Polar Skua

These two skua species occur regularly but in very low densities in offshore waters of Newfoundland during the May to October period. The Great Skua breeds in the Northern Hemisphere, in Iceland and northwestern Europe. The South Polar Skua breeds in the Southern Hemisphere from November to March and migrates to the Northern Hemisphere where it is present from May to October. Identifying skuas to species is very difficult at sea. They usually occur where other marine birds are numerous, particularly along shelf edges. Skuas occurred in such low densities that they were infrequently recorded during systematic surveys during monitoring programs on the Orphan Basin and Jeanne d'Arc Basin in 2004–2007 (Tables A.1 to A.6 in Appendix A). Skuas are expected to be scarce in the Study Area from May to October, or early November.

Pomarine Jaeger, Parasitic Jaeger and Long-tailed Jaeger

All three species of jaeger nest in the Subarctic and Arctic in North America and Eurasia. They winter at sea in the Pacific and Atlantic oceans. Pomarine and Parasitic Jaegers winter mainly south of 35°N, and Long-tailed Jaegers winter mainly south of the equator. Adults migrate through Newfoundland waters in spring, late summer and fall, while sub-adults migrate only part-way to the breeding grounds and are present in Newfoundland waters all summer. Because of the low densities of jaegers, they are infrequently recorded during systematic surveys. All three jaeger species were observed in low densities during monitoring programs on the Orphan Basin (Tables A.1 to A.3 in Appendix A) and Jeanne d'Arc Basin (Tables A.4 to A.6 in Appendix A). Jaegers are expected to be scarce in the Study Area from May to October or early November.

4.4.4.7 Alcidae (Dovekie, Murres, Black Guillemot, Razorbill and Atlantic Puffin)

There are six species of alcids breeding in the North Atlantic. All of these except for Dovekie nest in large numbers in eastern Newfoundland (Table 4.8). Dovekies nest mainly in Greenland. Dovekie, Common Murre, Thick-billed Murre, and Atlantic Puffin occur in the Study Area during part of the year. Black Guillemot and Razorbills are more coastal and are expected to be rare within the Study Area.

Dovekie

Dovekie breeds in the North Atlantic, primarily in Greenland and eastern Nova Zemlya, Jan Mayen and Franz Josef Land in northern Russia. This species winters at sea south to 35°N. The Dovekie is a very abundant bird, with a world population estimated at 30 million (Brown 1986). A large percentage of the Greenland-breeding Dovekies winter in the Northwest Atlantic, mainly off Newfoundland (Brown 1986). The predicted status in the Study Area is common from October to April, uncommon during the end of spring migration in May and at the beginning of fall migration in September, and very scarce during the summer months (June to August). The low numbers of Dovekies observed from the drill platforms on the northeast Grand Banks 1999 to 2002 was attributed to the difficulty in seeing the small birds from the observation posts (Baillie et al. 2005).

Fort et al. (2013) tracked Dovekies from large breeding colonies along northwestern and east Greenland to wintering areas offshore Newfoundland, where the birds spent the period from early

December through April. Some of these birds likely passed through and/or over-wintered in the Study Area.

During seismic monitoring programs on the Orphan Basin in 2005 there was a density of 1.3 birds/km^2 during the last two weeks of May (Table A.1 Appendix A). These were mostly birds flying north in late spring migration. Sightings were rare on the Orphan Basin monitoring programs between mid-June and mid-September (Table A.1 to A.3 in Appendix A).

During seismic monitoring programs on the Jeanne d'Arc Basin in 2005, 2006 and 2008, Dovekies were most numerous in October with an average density of 6.6 birds/km^2 during the period of 1 October to 8 November 2005 (Table A.4 in Appendix A). Incidental observations of Dovekies during these monitoring programs suggest larger numbers were present than the systematic surveys showed. For example, approximate daily totals from incidental observations were 500 on 3 October, 2,000 on 13 October, and 2,500 on 4 November (Abgrall et al. 2008a).

The ECSAS survey data from 2006–2009 for Dovekie within the Study Area shows densities per 1º survey blocks ranging from 0 to 22.59 birds/km^2 during the spring period (March and April), 0 to 5.17 birds/km^2 during the summer (May to August) and 0 to 11.41 birds/km^2 during winter (November to February; Fifield et al. 2009).

Murres

The two species of murre, Common and Thick-billed, are often difficult to tell apart with certainty at sea so are often lumped as "murres" during offshore seabird surveys. Common Murre is an abundant breeding species in eastern Newfoundland with just over a half million pairs nesting. Most of these occur at two colonies, Funk Island (412,524 pairs) (Chardine et al. 2003) and the Witless Bay Islands (83,001 pairs) (Robertson et al. 2004) (Table 4.8). They spend the winter from eastern Newfoundland south to Massachusetts. Thick-billed Murre is an uncommon breeder in eastern Newfoundland with about 2,000 pairs (Table 4.8); most nest much farther north. But Newfoundland waters are an important wintering area for many of the two million pairs breeding in Arctic Canada and Greenland.

The ECSAS survey data from 2006–2009 for murres within the Study Area shows densities per 1º survey blocks ranging from 0 to 6.65 birds/km^2 during the spring period (March and April), 0 to 6.39 birds/km^2 during summer (May to August) and 0 to 9.98 birds/km^2 during winter (November to February; Fifield et al. 2009).

During monitoring surveys on the Orphan Basin in 2005, 2006 and 2007 murres were present in low densities May to September (Table A.1 to A.3 in Appendix A). For example during the 14 May to 24 September 2005 surveys, average monthly densities for Thick-billed Murre were 0.6 birds/km^2 in May and 0.7 birds/km^2 in June, but there were none in July to September (Moulton et al. 2006). During the same survey, Common Murre densities were recorded as 0.05 birds/km^2 in May, 0.06 birds/km$_2$ in June, 0.14 birds/km^2 in July, and none were recorded during surveys in August and September.

On the Jeanne d'Arc Basin, murres were present in moderate densities during seismic monitoring from 1 October to 8 November 2005 with average densities for the period of 4.11 birds/km^2 for Thick-billed Murre and 0.81 birds/km^2 for Common Murre (Table A.4 to A.6 in Appendix A).

Recent tracking studies of Common and Thick-billed Murres have revealed connections between the Study Area and several murre nesting colonies along the northern and eastern coasts of Canada, from the high arctic to Newfoundland: Prince Leopold I (central high arctic), Coats I and East Digges I (northern Hudson Bay), the Minarets (Baffin I), Gannet Is (Labrador), and Funk I and the Witless Bay Is (Newfoundland) (McFarlane Tranquilla et al. 2013). In particular, Common Murres spent most of the non-breeding season in or near the Study Area (Hedd et al. 2011; Montevecchi et al. 2012), although both species used the Study Area. Some Funk Island parental male Common Murres with fledglings swam through the Orphan Basin during August and September en route to the Southeast Shoal of the Grand Bank (Montevecchi et al. 2012).

Other Alcids (Atlantic Puffin, Razorbill and Black Guillemot)

There are more than 310,000 pairs of Atlantic Puffin nesting in eastern Newfoundland (see Table 4.8). Atlantic Puffins winter off southern Newfoundland and Nova Scotia and they occur in low densities as far offshore as the Study Area. Non-breeding sub-adults occur throughout the summer whereas adults and juveniles can occur in late summer and fall. Seabird surveys during monitoring seismic operations in 2004-2008 conducted within the period mid-May to late September on the Orphan Basin and Jeanne d'Arc Basin recorded very low densities of Atlantic Puffins (Table A.1 to A.6 in Appendix A). During monitoring of the seismic survey of Jeanne d'Arc Basin 1 October to 8 November 2005 there was an average density of 1.46 birds/km^2 (Table A.4 in Appendix A). Within the Study Area, Atlantic Puffin is expected to be scarce during the breeding season (April to August) and scarce to uncommon during the post-breeding season (September to November).

About 38,000 pairs of Razorbills nest in eastern Canada (Chapdelaine et al. 2001). Fewer than 2,000 pairs nest in eastern Newfoundland (see Table 4.8). Razorbills tend to occur closer to shore than the murres. Very few were recorded during monitoring programs on the Orphan Basin and Jeanne d'Arc Basin 2004–2008 between mid-May and early November (Table A.1 to A6 in Appendix A). Razorbill is expected to be very scarce in the Study Area from April to November and absent from December to March (see Table 4.7).

Black Guillemot is common nearshore in Newfoundland and Labrador but would not be expected as far offshore as the Study Area.

4.4.5 Prey and Foraging Habits

Seabirds in the Study Area consume a variety of prey ranging from small fish to zooplankton. Different foraging methods include plunge diving from a height of 30 m into the water, feeding on the surface, and sitting on the water then diving. Table 4.9 summarizes the feeding habits of birds expected to occur in the Study Area.

Table 4.9. Foraging Strategy and Prey of Seabirds in the Study Area.

Species	Prey	Foraging Strategy	Time with Head Under Water	Depth (m)
Procellariidae				
Northern Fulmar	Fish, cephalopods, crustaceans, zooplankton, offal	Surface feeding	Brief	1-2
Great Shearwater	Fish, cephalopods, crustaceans, zooplankton, offal	Shallow plunging, surface feeding	Brief	Usually <2, recorded maximum of 18.
Sooty Shearwater	Fish, cephalopods, crustaceans, zooplankton, offal	Shallow plunging, surface feeding	Brief	Usually <10, maximum recorded 60.
Manx Shearwater	Fish, cephalopods, crustaceans, zooplankton, offal	Shallow plunging, surface feeding	Brief	1-10
Hydrobatidae				
Wilson's Storm-Petrel	Crustaceans, zooplankton	Surface feeding	Brief	<0.5
Leach's Storm-Petrel	Crustaceans, zooplankton	Surface feeding	Brief	<0.5
Phalaropodinae				
Red Phalarope	Zooplankton, crustaceans	Surface feeding	Brief	0
Red-necked Phalarope	Zooplankton, crustaceans	Surface feeding	Brief	0
Laridae				
Herring Gull	Fish, crustaceans, offal	Surface feeding, shallow plunging, scavenging	Brief	<0.5
Iceland Gull	Fish, crustaceans, offal	Surface feeding, shallow plunging	Brief	<0.5
Glaucous Gull	Fish, crustaceans, offal	Surface feeding, shallow plunging, scavenging	Brief	<0.5
Great Black-backed Gull	Fish, crustaceans, offal	Surface feeding, shallow plunging, scavenging	Brief	<0.5
Ivory Gull	Fish, crustaceans, offal	Surface feeding, shallow plunging, scavenging	Brief	<0.5
Black-legged Kittiwake	Fish, crustaceans, offal	Surface feeding, shallow plunging	Brief	<0.5
Arctic Tern	Fish, crustaceans, zooplankton	Surface feeding, shallow plunging	Brief	<0.5
Stercorariidae				
Great Skua	Fish, cephalopods, offal	Kleptoparasitism	Brief	<0.5
Pomarine Jaeger	Fish	Kleptoparasitism	Brief	<0.5
Parasitic Jaeger	Fish	Kleptoparasitism	Brief	<0.5
Long-tailed Jaeger	Fish, crustaceans	Kleptoparasitism, surface feeding	Brief	<0.5
Alcidae				
Dovekie	Crustaceans, zooplankton, fish	Pursuit diving	Prolonged	Max 30, average is <30
Common Murre	Fish, crustaceans, zooplankton	Pursuit diving	Prolonged	Max 100, average 20-50
Thick-billed Murre	Fish, crustaceans, zooplankton	Pursuit diving	Prolonged	Max 100, average 20-60
Razorbill	Fish, crustaceans, zooplankton	Pursuit diving	Prolonged	Max 120, average 25
Atlantic Puffin	Fish, crustaceans, zooplankton	Pursuit diving	Prolonged	Max 60, average <60

Sources: Cramp and Simmons (1983); Nettleship and Birkhead (1985); Lock et al. (1994); Gaston and Jones (1998); Ronconi (2010a,b).

4.4.5.1 Procellariidae (Fulmars and Shearwaters)

Northern Fulmar and the three species of shearwaters that are expected to occur in the Study Area feed on a variety of invertebrates, fish and zooplankton at or very near the surface. Capelin is an important food source for shearwaters. They secure their prey by swimming on the surface and picking at items on the surface, or dipping their head under the water. Shearwaters are also capable of diving a short distance under the surface, probably no deeper than a metre on average. They may do this flying low over the water and then plunging into the water with enough force to get them below the surface for a few seconds, or dive from a resting position on the surface.

4.4.5.2 Hydrobatidae (Storm-petrels)

Leach's and Wilson's Storm-petrels feed on small crustaceans, various small invertebrates and zooplankton. These storm-petrels usually feed while on the wing, picking small food items from the surface of the water.

4.4.5.3 Sulidae (Northern Gannet)

Northern Gannet feed on cephalopods and small fish such as capelin, mackerel, herring and Atlantic saury. They secure prey in a spectacular fashion by plunging from a height of up to 30 m into the water, reaching depths of 10 m. They pop back to the surface within a few seconds of entering the water.

4.4.5.4 Phalaropodinae (Phalaropes)

Red-necked and Red Phalaropes eat zooplankton at the surface of the water. They secure food by swimming and rapidly picking at the surface of the water. The head probably rarely goes beneath the surface.

4.4.5.5 Laridae (Gulls and Terns)

The large gulls, Herring, Great Black-backed, Glaucous, and Iceland Gull, are opportunists eating a variety of food items from small fish at the surface, to carrion, and refuse and offal from fishing and other ships at sea. They find this food at the surface and may plunge their head under water to grab food just below the surface but the entire body is rarely submerged.

Ivory Gull often feeds from the wing over water, dip feeding for small fish and invertebrates on the surface. It occasionally plunge dives so that the entire body may be submerged momentarily. It also swims and picks at the surface of the water and walks on ice to scavenge animal carcasses.

Black-legged Kittiwake feeds on a variety of invertebrates and small fish. Capelin is an important part of their diet when available. The kittiwake feeds by locating prey from the wing then dropping to the water's surface and plunge-diving. The body may be submerged very briefly. It also swims and picks at small invertebrates near the surface.

Arctic Tern feeds on small fishes and invertebrates that it catches from the wing with a shallow plunge-dive. The entire bird rarely goes beneath the surface. It rarely rests on the water.

4.4.5.6 Stercorariidae (Skuas and Jaegers)

Skuas and jaegers feed by chasing other species of birds until they drop food they are carrying or disgorge the contents of their crops. This method of securing food is called kleptoparasitism. Long Tailed Jaeger, the smallest member of this group, also feeds on small invertebrates and fish, which are caught by dipping to the surface of the water while remaining on the wing.

4.4.5.7 Alcidae (Dovekie, Murres, Razorbill, and Atlantic Puffin)

This group of birds is different than the other seabirds of the Study Area. They spend considerable time resting on the water and dive deep into the water column for food. Dovekie feeds on zooplankton including larval fish. It can dive down to 30 m and remain under water up to 41 seconds, but average dives are somewhat shallower and shorter in duration (Gaston and Jones 1998). Common Murre and Thick-billed Murre have been recorded diving to 100 m but 20-60 m is thought to be average. Dives have been timed up to 202 seconds but 60 seconds is closer to average (Gaston and Jones 1998). Razorbill has been recorded diving to 120 m but 25 m is thought to be more typical, with time under water about 35 seconds (Gaston and Jones 1998). Black Guillemot usually feeds in water <30 m in depth but in deep water has been recorded diving to 50 m spending a maximum of 147 seconds under water. Average depth and duration of dives is expected to be less (Gaston and Jones 1998). Atlantic Puffin dives to 60 m but 10 to 45 m is thought to be typical. Maximum length of time recorded under water is 115 seconds but a more typical dive would be about 30 seconds.

4.5 Marine Mammals and Sea Turtles

4.5.1 Marine Mammals

A total of 20 marine mammals, including 17 cetacean and three seal species are known or expected to occur in the Study Area (Table 4.10). Most marine mammals use the Study Area seasonally, and the region likely represents important foraging areas for many.

4.5.1.1 Information Sources

A large database of cetacean sightings in Newfoundland and Labrador waters has been compiled by DFO in St. John's (J. Lawson, DFO Research Scientist, pers. comm. 2013) and has been made available for the purposes of describing cetacean sightings within the Study Area. These data can be used to indicate what species have occurred in the region, but cannot provide fine-scale descriptions or predictions of abundance, distribution or habitat use.

As noted by DFO, a number of *caveats* should be considered when using the DFO cetacean sighting data, and include:

1. The sighting data have not yet been completely error-checked,
2. The quality of some of the sighting data is unknown,
3. Most data have been gathered from platforms of opportunity that were vessel-based. The inherent problems with negative or positive reactions by cetaceans to the approach of such vessels have not yet been factored into the data,
4. Sighting effort has not been quantified (i.e., the numbers cannot be used to estimate true species density or abundance for an area),

5. Both older and some more recent survey data have yet to be entered into this database. These other data will represent only a very small portion of the total data,
6. Numbers sighted have not been verified (especially in light of the significant differences in detectability among species),
7. For completeness, these data represent an amalgamation of sightings from a variety of years and seasons. Effort (and number of sightings) is not necessarily consistent among months, years, and areas. There are large gaps between years. Thus seasonal, depth, and distribution information should be interpreted with caution, and
8. Many sightings could not be identified to species, but are listed to the smallest taxonomic group possible.

The DFO database includes sightings collected as part of the marine mammal monitoring programs for seismic and controlled source electromagnetic surveys in Orphan and Jeanne d'Arc basins (e.g., Moulton et al. 2005, 2006; Abgrall et al. 2008a,b, 2009). The Orphan Basin SEA (LGL 2003) provides summaries of marine mammal species (see Section 3.2.5) and previously available sighting data for the Study Area and adjacent waters. Exploration and drilling EAs and their amendments for Orphan Basin (Buchanan et al. 2004; Moulton et al. 2005; LGL 2005, 2009, 2012b, 2013a), Jeanne d'Arc Basin (LGL 2008a, 2011a, 2012a, 2013b), and the northern Grand Banks (LGL 2011b) have also provided information on marine mammals. As requested in the Scoping Document, the following "biological background" overview of marine mammal species likely to occur in the Study Area summarizes and updates relevant information with particular focus on spatial and temporal distribution and life history parameters.

4.5.1.2 Overview of Marine Mammals

As noted earlier, a total of 20 marine mammals, including 17 cetacean and three seal species are known or expected to occur in the Study Area (Table 4.10). Several cetaceans are considered *at risk* by COSEWIC and listed under *SARA*. Those species listed under Schedule 1 of *SARA* are described in Section 4.6.

A summary of the prey of marine mammals that occur in the Study Area is provided in LGL (2008a; Table 4.14). For most species of marine mammals there are no reliable population estimates for Atlantic Canada; most estimates are based on data collected in northeastern U.S. waters. Thus, Waring et al. (2013) was reviewed to acquire updated population estimates for cetaceans considered a part of the Western North Atlantic stock.

Table 4.11 summarizes the cetacean sightings from the DFO Cetacean Database for the Study Area. The data sources include historical and new sightings from commercial whaling, fisheries observers, MMOs aboard seismic vessels, and the general public. Within the Study Area, sighting dates ranged from 1961 to 2009 and included baleen whales (Figure 4.40), large toothed whales (Figure 4.41), and dolphins and porpoises (Figure 4.42).

Table 4.10. Marine Mammals Known or Expected to Occur in the Study Area.

Common Name	Study Area		Habitat	SARA Status [a]	COSEWIC Status [b]
	Occurrence	Season			
Baleen Whales (Mysticetes)					
Blue whale (*Balaenoptera musculus*)	Rare	Year-round but mostly spring to summer	Coastal, pelagic	Schedule 1: E	E
North Atlantic right whale (*Eubalaena glacialis*)	Extremely Rare	Summer?	Coastal, shelf	Schedule 1: E	E
Fin whale (*B. physalus*)	Common	Year-round but mostly summer	Pelagic, slope	Schedule 1: SC	SC
Sei whale (*B. borealis*)	Uncommon	May - Sept.	Pelagic, offshore	NS	DD
Humpback whale (*Megaptera novaeangliae*)	Common	Year-round but mostly May - Oct.	Coastal, banks	Schedule 3: SC	NAR
Minke whale (*B. acutorostrata*)	Common	Year-round but mostly May - Oct.	Shelf, banks, coastal	NS	NAR
Toothed Whales (Odontocetes)					
Sperm whale (*Physeter macrocephalus*)	Uncommon to Common	Year-round but mostly summer	Pelagic, slope, canyons	NS	NAR; LPC
Northern bottlenose whale (*Hyperoodon ampullatus*)[c]	Uncommon	Year-round?	Pelagic, slope, canyons	Schedule 1: E	E
Sowerby's beaked whale (*Mesoplodon bidens*)	Rare	Summer?	Pelagic, deep slope, canyons	Schedule 1: SC	SC
Killer whale (*Orcinus orca*)	Uncommon	Year-round but mostly June-Oct.	Widely distributed	NS	SC
Cuvier's Beaked Whale (*Ziphius cavirostris*)	Rare	Year-round?	Slope, offshore	NS	NAR; MPC
Long-finned pilot whale (*Globicephala melas*)	Common	May - Sept.	Mostly pelagic	NS	NAR
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	Common	Year-round but mostly June-Oct.	Shelf, slope	NS	NAR
Short-beaked common dolphin (*Delphinus delphis*)	Common	Summer-fall	Nearshore, pelagic	NS	NAR
White-beaked dolphin (*L. albirostris*)	Uncommon	Year-round but mosty June-Sept.	Shelf	NS	NAR
Common bottlenose dolphin (*Tursiops truncatus*)	Rare	Summer?	Shelf, coastal, pelagic (occasionally)	NS	NAR
Striped dolphin (*Stenella coeruleoalba*)	Uncommon	Summer?	Offshore convergence zones and upwellings	NS	NAR
Harbour porpoise (*Phocoena phocoena*)	Uncommon	Year-round but mostly spring to fall	Shelf, coastal, pelagic (occasionally)	Schedule 2: T	SC
True Seals (Phocids)					
Harp seal (*Pagophilus groenlandicus*)	Common	Year-round	Pack ice and pelagic	NS	NC; MPC
Hooded seal (*Cystophora cristata*)	Common	Year-round	Pack ice and pelagic	NS	NAR; MPC

Notes: E=Endangered, T=Threatened, SC=Special Concern, NAR=Not at Risk, NC=Not Considered, DD=Data Deficient, NS=No Status, LPC=Low Priority Candidate, MPC=Medium Priority Candidate. ? indicates uncertainty.

[a] www.sararegistry.gc.ca/default_e.cfm, accessed November 2011.

[b] www.cosewic.gc.ca/eng/sct5/index_e.cfm, accessed November 2011.

[c] Refers to the Scotian Shelf population, but it is unclear to which population animals in the Project Area belong. The Davis Strait-Baffin Bay-Labrador Sea population has no status under *SARA* but is considered *special concern* under COSEWIC.

Table 4.11. Cetacean Sightings within the Study Area, 1961 to 2009.

Species	Number of Sightings	Minimum Number of	Months Observed
Mysticetes			
North Atlantic Right Whale	1	2	June
Humpback Whale	257	740	Year round
Fin Whale	54	110	May-Oct
Fin/Sei Whale	14	19	Jul-Sep
Sei Whale	25	40	May-Sep
Minke Whale	45	57	Jan; Apr-Dec
Large Odontocetes			
Sperm Whale	106	196	Year round
Killer Whale	15	67	May-Aug; Oct-Nov
Long-finned Pilot Whale	190	3,630	Jan-Mar; May-Dec
False Killer Whale[a]	1	2	Jun
Northern Bottlenose Whale	11	39	May-Sep
Sowerby's Beaked Whale	1	4	Sep
Beluga[b]	1	1	Jul
Delphinids			
Common Bottlenose Dolphin	1	15	Sep
Short-beaked Common Dolphin	17	253	Mar; Jul-Oct
Atlantic White-sided Dolphin	29	351	Feb; May-Oct
White-beaked Dolphin	14	88	Mar; May-Aug
Striped Dolphin	3	15	Aug
Harbour Porpoise	23	177	Mar; May-Oct
Unidentified Cetaceans			
Unidentified Baleen Whale	25	39	May-Sep
Unidentified Toothed Whale	2	13	Jul-Aug
Unidentified Dolphin	141	2325	Jan-Nov
Unidentified Cetacean	260	474	Year round

[a] extralimital record. [b] dead; this species is unlikely to occur in the Study Area.

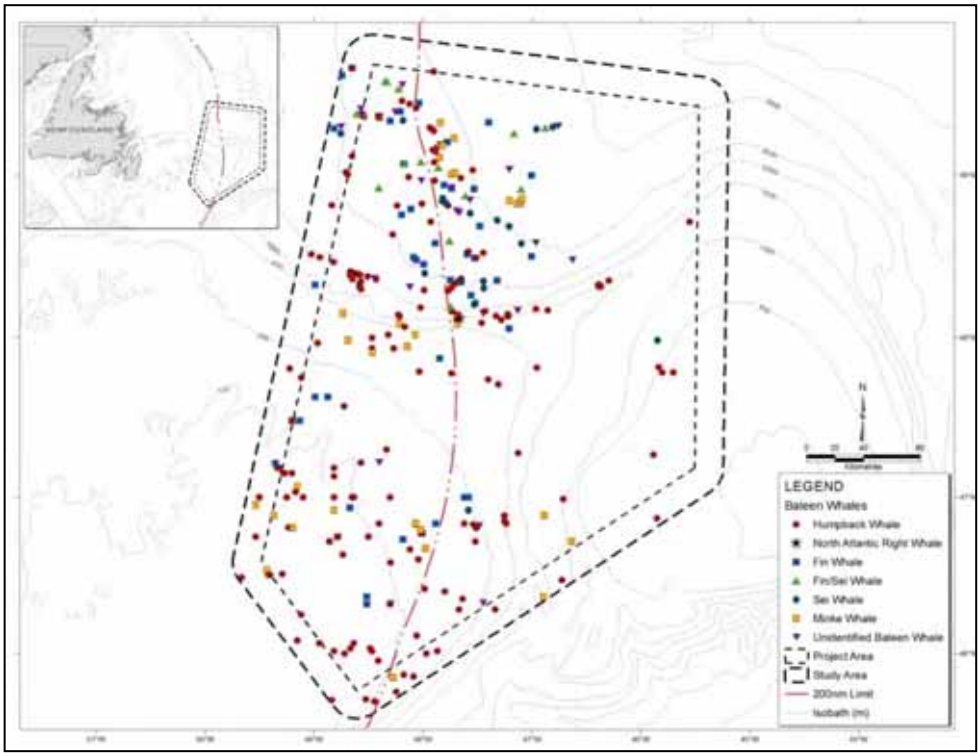


Figure 4.40. Baleen Whale Sightings in the Study Area.

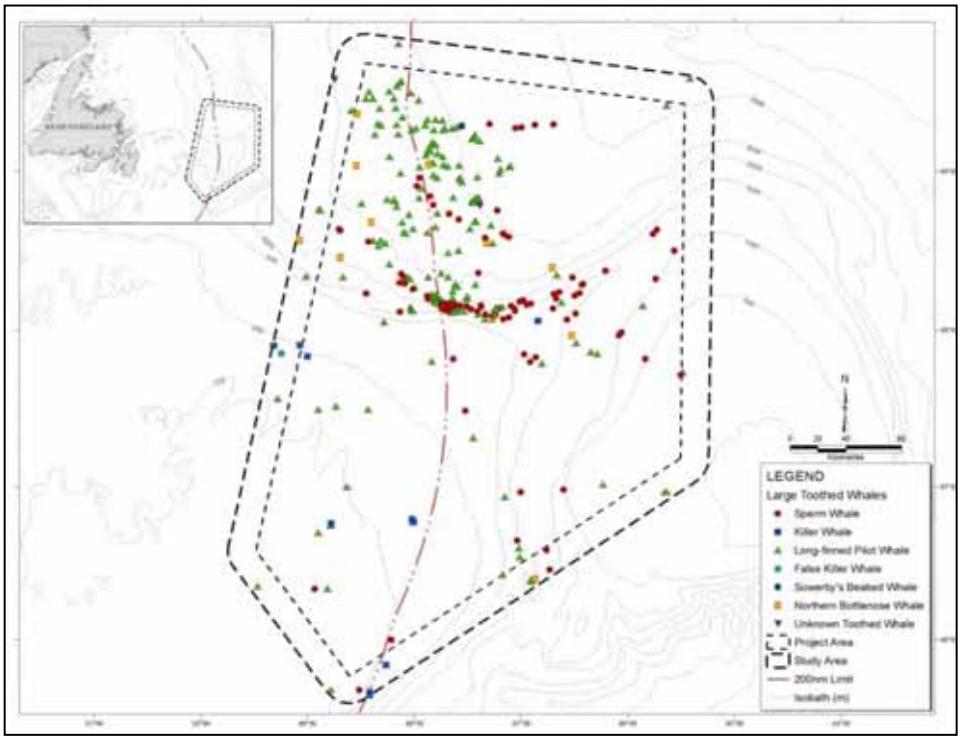


Figure 4.41. Large Toothed Whale Sightings in the Study Area.

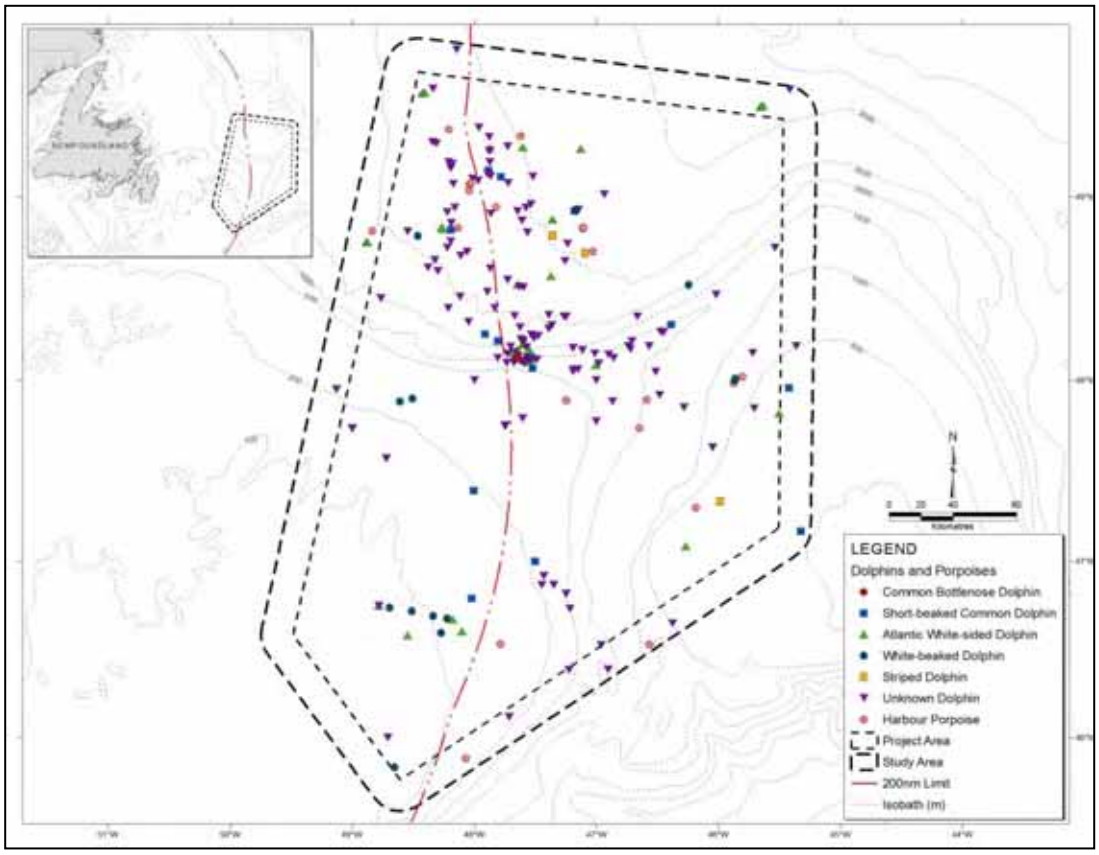


Figure 4.42. Dolphin and Porpoise Sightings in the Study Area.

4.5.1.3 Baleen Whales (Mysticetes)

Six species of baleen whales occur in the Study Area, four of which are considered regular visitors (see Table 4.10). Blue whales are considered rare, and North Atlantic right whales are considered extremely rare in the Study Area; these species are described in the Species at Risk section (Section 4.6). Although some individual baleen whales may be present in offshore waters of Newfoundland and Labrador year-round, most baleen whale species presumably migrate to lower latitudes during winter months.

Fin Whale

Fin whales are distributed throughout the world's oceans, but are most common in temperate and polar regions (Jefferson et al. 2008). The Atlantic fin whale population is currently designated as *special concern* under Schedule 1 of *SARA* and by COSEWIC (see Table 4.10). Fin whales were heavily targeted by commercial whalers in Newfoundland and Labrador, but continue to regularly occur there particularly during summer months. The current estimate for the western North Atlantic stock is 3,522 individuals (CV = 0.27; Waring et al. 2013). Lawson and Gosselin (2009) provided an abundance estimate of 890 fin whales for Newfoundland, based on aerial surveys conducted off the southern and eastern coast; abundance corrected for perception and availability biases was estimated at 1,555 fin whales (Lawson and Gosselin, unpublished data). Based on the DFO cetacean sightings database, fin whales were the second most commonly recorded mysticete in the DFO sightings database, with sightings throughout the western part of the Study Area (see Figure 4.40) from May to October (see Table 4.11). Fin whales were commonly observed in Orphan Basin during the 2004 and 2005

seismic monitoring programs (Moulton et al. 2005, 2006) and were also sighted during the Statoil/Husky seismic monitoring program in Jeanne d'Arc Basin (Abgrall et al. 2009). They feed on small schooling fish and krill and tend to be found in areas where these prey concentrate, such as areas of upwelling, shelf breaks, and banks (COSEWIC 2005). It is likely that fin whales commonly occur in the Study Area at least during late spring to fall.

Humpback Whale

The humpback whale is cosmopolitan in distribution and is most common over the continental shelf and in coastal areas (Jefferson et al. 2008). Humpback whales migrate annually from high-latitude summer foraging areas to Caribbean breeding grounds in the winter. Clapham et al. (1993) noted that not all individuals migrate to the tropics each year; some presumably remain near their foraging grounds in high and mid-latitudes during the winter. Primary feeding areas in the North Atlantic have been described using genetic and individual identification data as the Gulf of Maine, eastern Canada, west Greenland, and the Northeast Atlantic (Stevick et al. 2006). The western North Atlantic population of the humpback whale is considered *special concern* on Schedule 3 of *SARA* and *not at risk* by COSEWIC. There are an estimated 11,570 individuals in the North Atlantic (Stevick et al. 2003). Lawson and Gosselin (2009) provided an abundance estimate of 1,427 humpback whales for Newfoundland, based on aerial surveys conducted off the southern and eastern coast; the abundance corrected for perception and availability biases was estimated at 3,712 whales (Lawson and Gosselin, unpublished data). Most large whale entanglements in Newfoundland and Labrador involve humpback whales (Benjamins et al. 2012).

Humpback whales are common over the banks and nearshore areas of Newfoundland and Labrador from June through September, sometimes forming large aggregations to feed primarily on spawning capelin, sand lance, and krill. Davoren (2013) reported several humpback whale hotspots off northeastern Newfoundland that were associated with capelin spawning. Humpbacks are the most commonly recorded mysticete in the Study Area, with sightings occurring year-round (Figure 4.40; Table 4.11), but predominantly during summer.

Sei Whale

Sei whale distribution is poorly known, but it occurs in all oceans and appears to prefer mid latitude temperate waters (Jefferson et al. 2008). In the Canadian Atlantic, sei whales have no status under *SARA* and are considered *data deficient* by COSEWIC. Two stocks of sei whales are currently considered to occur in eastern Canada, on the Scotian Shelf and in the Labrador Sea, although there is limited evidence supporting the definition of the Labrador Sea stock (COSEWIC 2003a). The best estimate of abundance for the Nova Scotia stock of sei whales is 357 (CV=0.52; Waring et al. 2013). Satellite telemetry data showed that sei whales migrate from the southeast North Atlantic to the Labrador Sea, suggesting a productive feeding ground for sei whales in that area (Olsen et al. 2009; Prieto et al. 2010). One of the tagged individuals spent up to 96 h near the northwest corner of the Study Area en route to the Labrador Sea (Prieto et al. 2010). Sei whales were regularly sighted in the Orphan Basin during the seismic monitoring programs in 2004 and 2005 (6 and 15 sightings, respectively; Moulton et al. 2005, 2006), and one sei whale sighting was recorded in Jeanne d'Arc Basin during the Statoil/Husky seismic monitoring program in 2008 (Abgrall et al. 2009). Based on the DFO cetacean sightings database, at least 25 sei whale sightings have been reported in the Study Area (Figure 4.40; Table 4.11). Sei whales appear to prefer offshore, pelagic, deep areas that are often associated with the shelf edge, and feed primarily on copepods (COSEWIC 2003a).

Minke Whale

The smallest of the baleen whales, the minke whale has a cosmopolitan distribution and uses polar, temperate, and tropical regions (Jefferson et al. 2008). Minke whales have no status under *SARA* and are considered *not at risk* in the Atlantic by COSEWIC. There are four populations recognized in the North Atlantic based on feeding areas, including the Canadian east coast, west Greenland, central North Atlantic, and Northeast Atlantic stocks (Donovan 1991). However, DNA data suggest that there may be as few as two different stocks in the North Atlantic (Anderwald et al. 2011). There are an estimated 20,741 individuals (CV=0.30) in the Canadian east coast stock, which ranges from the continental shelf of the northeastern United States to Davis Strait (Waring et al. 2013). Lawson and Gosselin (2009) provided an abundance estimate of 1,315 minke whales for Newfoundland, based on aerial surveys conducted off the southern and eastern coast; the abundance corrected for perception and availability biases was estimated at 4,691 whales (Lawson and Gosselin, unpublished data). Minke whales are common over the banks and coastal regions of Newfoundland and Labrador from early spring to fall, arriving as early as April and remaining as late as October and November. Within the Study Area, minke whales were the third most commonly recorded mysticete in the DFO sightings database, with sightings predominantly recorded during summer months (see Table 4.11). Thirty-one sightings of minke whales were recorded in Jeanne d'Arc Basin during the Statoil/Husky seismic monitoring program in 2008 (Abgrall et al. 2009). Minke whales tend to forage in continental shelf waters on small schooling fish like capelin and sand lance, making relatively short duration dives (Stewart and Leatherwood 1985).

4.5.1.4 Toothed Whales (Odontocetes)

Twelve species of toothed whales occur in the Project Area (see Table 4.10), ranging from the largest of odontocetes, the sperm whale, to the one of the smallest, the harbour porpoise. Many of these species seem to be present in the Study Area only seasonally, but there is generally little information on the distribution and abundance of these species.

Sperm Whale

The sperm whale is most common in tropical and temperate waters, but is widely distributed and occurs from the edge of the polar pack ice to the equator (Jefferson et al. 2008). Sperm whales have no status under *SARA* and are designated *not at risk* by COSEWIC. They are currently considered a *low priority candidate species* by COSEWIC. Whitehead (2002) estimated a total of 13,190 sperm whales for the Iceland-Faroes area, the area north of it, and the east coast of North America combined. Waring et al. (2013) reported an estimate of 1,593 animals (CV=0.36) for the U.S. North Atlantic. Since males tend to range further north (Whitehead 2003), sperm whales encountered in the Study Area are more likely to be single males. However, mixed groups with females and juveniles have occasionally been observed in higher latitudes, and males can still form large same-sex aggregations (Whitehead and Weilgart 2000; Whitehead 2003). Sperm whales appear to prefer deep waters off the continental shelf, particularly areas with high secondary productivity, steep slopes, and canyons that may concentrate their primary prey of large-bodied squid (Jaquet and Whitehead 1996; Waring et al. 2001). Sperm whales are deep divers, routinely diving to hundreds of metres, sometimes to depths over 1,000 m and remaining submerged up to an hour (Whitehead and Weilgart 2000). Sperm whales were regularly sighted in the deep waters of Orphan Basin during the summers of 2004–2007 (Moulton et al. 2005, 2006; Abgrall et al. 2008b) but were not observed in the shallower waters of Jeanne d'Arc Basin in 2005-2008 (Lang et al. 2006; Lang and Moulton 2008; Abgrall et al. 2008a, 2009). There are 106

sightings of sperm whales reported in the DFO cetacean sightings database that occurred in the Study Area (Table 4.11); these sightings occurred year-round.

Northern Bottlenose Whale

The northern bottlenose whale is profiled in Section 4.6 on Species at Risk.

Sowerby's Beaked Whale

The Sowerby's beaked whale is a small beaked whale found only in the North Atlantic, primarily in deep, offshore temperate to subarctic waters (COSEWIC 2006a). Designated as *special concern* (Schedule 1) under *SARA* and by COSEWIC, it is unclear if Sowerby's beaked whales are rare or poorly surveyed due to their deep-diving behaviour, small size, and offshore habitat. It is the most northerly distributed of the *Mesoplodon* spp., with all but one record occurring in the Northwest Atlantic between New England and Labrador (MacLeod 2000; MacLeod et al. 2006). There are an unknown number of Sowerby's beaked whales in the North Atlantic, but they are occasionally encountered offshore of eastern Newfoundland and Labrador. They are most often observed in deep water, along the shelf edge and slope. Based on analysis of stomach contents, their main prey type appears to be mid to deep-water fish, with squid making up a small portion of the diet (MacLeod et al. 2003; Pereira et al. 2011). Despite the paucity of confirmed sightings, Sowerby's beaked whales may occur in low densities in deep areas in the Study Area. Based on the DFO cetacean sightings database, there has been one sighting of four Sowerby's beaked whales in the Study Area (see Figure 4.41) in September (see Table 4.11).

Killer Whale

Killer whales have a cosmopolitan distribution and occur in all oceans from polar pack ice to the equator, but they appear to be most common in coastal areas of higher latitudes (Jefferson et al. 2008). The northwest Atlantic/eastern Arctic population is categorized as *special concern* by COSEWIC but has no status under *SARA*. The number of killer whales in the northwest Atlantic/eastern Arctic population is unknown (COSEWIC 2008), but at least 67 individuals have been identified in the northwest Atlantic (Lawson and Stevens 2013). Killer whale movements are generally related to the distribution and abundance of their primary prey, which can include fish, other marine mammals, seabirds, and cephalopods (Ford et al. 2000). In Newfoundland and Labrador, killer whales have been observed approaching, attacking, and/or consuming other cetaceans, seals, seabirds and several species of fish; however, it is not known if there is any prey specialization among killer whale groups or individuals (Lawson et al. 2007). Stable isotope analysis of samples from seven killer whales suggests that killer whales off Newfoundland and Labrador mainly feed on fish, although one individual was found to have fed mostly on baleen whales (Matthews and Ferguson 2011). Observed group sizes range from 1 to 30 individuals (rarely more than 15), averaging 5.2 whales (Lawson and Stevens 2013).

Although they occur at relatively low densities, killer whales are considered year-round residents of Newfoundland and Labrador (Lien et al. 1988; Lawson et al. 2007; Lawson and Stevens 2013). Sightings seem to be increasing in recent years, but it is unclear if this is due to increasing abundance or observer effort. There have been 15 killer whale sightings in the Study Area based on the DFO cetacean sightings database (see Figure 4.41); these sightings occurred from May through November (see Table 4.11). Four sightings of killer whales were recorded in Jeanne d'Arc Basin during the

Statoil/Husky seismic monitoring program in 2008 (Abgrall et al. 2009). A killer whale outfitted with a satellite tag at Admiralty Inlet, Baffin Island, on 15 August 2009, was tracked moving into the North Atlantic in mid-November, where it traveled just to the east of Flemish Cap and the proposed Study Area (Matthews et al. 2011). However, it is uncertain whether killer whales from populations in other areas, such as the Canadian Arctic, Greenland, or Iceland mix with whales off Newfoundland and Labrador (Lawson and Stevens 2013).

Cuvier's Beaked Whale

Cuvier's beaked whale is probably the most widespread of the beaked whales, although it is not found in polar waters (Jefferson et al. 2008). It is occasionally observed at sea and is mostly known from strandings. Its inconspicuous blows, deep-diving behavior, and tendency to avoid vessels all help to explain the infrequent sightings (Barlow and Gisiner 2006). Cuvier's beaked whale is not listed under *SARA*, but is considered a mid-priority candidate species by COSEWIC (see Table 4.10). Abundance estimates for this largely offshore species in the NWA are not available.

Cuvier's beaked whale is an offshore, deep-diving species that feeds almost exclusively on large-bodied squid (MacLeod et al. 2003). Deep dives last a median duration of 28.6 min followed by surfacings lasting a median duration of 126 s (MacLeod and D'Amico 2006). Adult males of this species usually travel alone, but these whales can be seen in groups of up to 15, with a mean group size of 2.3 (MacLeod and D'Amico 2006).

In the NWA, Cuvier's beaked whales have stranded and been sighted as far north as the Nova Scotian shelf and occur most commonly from Massachusetts to Florida (MacLeod et al. 2006). Cuvier's beaked whales were not reported within the Study Area in the DFO cetacean sightings database; sightings of Cuvier's beaked whales in the Study Area are not expected.

Long-finned Pilot Whale

The long-finned pilot whale is widespread in the North Atlantic and considered an abundant year-round resident of Newfoundland and Labrador (Nelson and Lien 1996). Long-finned pilot whales have no status under *SARA* and are considered *not at risk* by COSEWIC (see Table 4.10). An estimated 12,619 individuals (CV=0.37) occur in the Northwest Atlantic (Waring et al. 2013). Long-finned pilot whales were the most commonly recorded toothed whale in the DFO cetacean database, occurring most months of the year (see Table 4.11) and primarily in waters >600 m deep in the Study Area (see Figure 4.41). Pilot whales studied near Nova Scotia had an average group size of 20 individuals, but groups ranged in size from 2 to 135 animals (Ottensmeyer and Whitehead 2003). Pilot whale distribution is linked with areas of high relief, the shelf break, or slope, and they often exhibit inshore-offshore movements coinciding with movements of their prey (Jefferson et al. 2008). Short-finned squid have historically been the primary prey item in Newfoundland, but they also consume other cephalopods and fish (Nelson and Lien 1996).

Atlantic White-sided Dolphin

Atlantic white-sided dolphins occur in temperate and sub-Arctic regions of the North Atlantic (Jefferson et al. 2008). This species has no status under *SARA* and is considered *not at risk* by COSEWIC (see Table 4.10). There may be at least three distinct stocks in the North Atlantic, including the Gulf of

Maine, Gulf of St. Lawrence, and Labrador Sea, which combined are estimated to total ~48,819 animals (CV=0.61) in the Northwest Atlantic (Waring et al. 2013). Lawson and Gosselin (2009) provided an abundance estimate of 1,507 white-sided dolphins for Newfoundland, based on aerial surveys conducted off the southern and eastern coast; the abundance corrected for perception and availability biases was estimated at 3,384 dolphins (Lawson and Gosselin, unpublished data). Atlantic white-sided dolphins occur regularly from spring to fall in offshore areas of Newfoundland, but less is known of their winter distribution. Sightings in the North Atlantic seem to coincide with the 100-m depth contour and areas of high relief. There were 29 sightings in the DFO cetacean sightings database (Figure 4.42; Table 4.11). Prey items range from cephalopods to pelagic or benthopelagic fishes like capelin, herring, hake, sand lance, and cod (Selzer and Payne 1988). Atlantic white-sided dolphins tend to occur in large groups ranging from 2 to 2,500 individuals, with an average of 52.4 (Weinrich et al. 2001).

Short-beaked Common Dolphin

The short-beaked common dolphin is an oceanic species that is widely distributed in temperate to tropical waters of the Atlantic (and Pacific) Ocean (Jefferson et al. 2008). This species has no status under *SARA* and is considered *not at risk* by COSEWIC (see Table 4.10). An estimated 67,191 individuals (CV=0.29) occur in the Northwest Atlantic (Waring et al. 2013). Lawson and Gosselin (2009) provided an abundance estimate of 576 common dolphins for Newfoundland, based on aerial surveys conducted off the southern and eastern coast; the abundance corrected for perception and availability biases was estimated at 1,806 dolphins (Lawson and Gosselin, unpublished data). Short-beaked common dolphins form groups ranging in size from several dozens to over 10,000, often moving rapidly and displaying many aerial behaviours such as porpoising and bowriding (Jefferson et al. 2008). They are found in a variety of habitats, ranging from 100 to 2,000 m deep, but appear to prefer areas with high seafloor relief (Selzer and Payne 1988). They are often associated with features of the Gulf Stream (Hamazaki 2002). The abundance and distribution of short-beaked common dolphins also coincides with peaks in abundance of mackerel, butterfish and squid (Selzer and Payne 1988). Gaskin (1992) indicated that common dolphins can be abundant off the coast of Nova Scotia and Newfoundland for a few months during the summer. There were 17 sightings of common dolphins recorded in the Study Area in the DFO database (see Table 4.11); most sightings were in waters >500 m deep (see Figure 4.42).

White-beaked Dolphin

White-beaked dolphins have a more northerly distribution than most dolphin species, occurring in cold temperate and sub-Arctic waters of the North Atlantic (Jefferson et al. 2008). This species has no status under *SARA* and is considered *not at risk* by COSEWIC (see Table 4.10). Waring et al. (2013) reported a total of 2003 individuals (CV=0.94) in the Northwest Atlantic. Lawson and Gosselin (2009) provided an abundance estimate of 1,842 white-beaked dolphins for Newfoundland, based on aerial surveys conducted off the southern and eastern coast; the abundance corrected for perception and availability biases was estimated at 15,625 dolphins (Lawson and Gosselin, unpublished data). Sightings of white-beaked dolphins are considered uncommon in the Study Area. There were 14 sightings recorded in the Study Area (see Table 4.11) in both shelf and slope waters (see Figure 4.42) based on the DFO cetacean database. White-beaked dolphins are thought to remain at high latitudes year-round and are generally observed in continental shelf and slope areas, although they also occur in shallow coastal areas (Lien et al. 1997). They typically occur in groups of less than 30 animals, but group sizes up to the low hundreds have also been reported (Lien et al. 1997). White-beaked dolphins

have a range of prey items, including squid, crustaceans, and a number of small mesopelagic and schooling fishes like herring, haddock, hake, and cod (Jefferson et al. 2008).

Common Bottlenose Dolphin

This species is widely distributed and is found most commonly in coastal and continental shelf waters of tropical and temperate regions (Jefferson et al. 2008). Bottlenose dolphins have no status under *SARA* and are considered *not at risk* by COSEWIC (see Table 4.10). An estimated 81,588 individuals (CV=0.17) occur in offshore waters of the Northwest Atlantic (Waring et al. 2013). Bottlenose dolphins are considered rare in the Study Area; there was only one sighting of bottlenose dolphins (15 individuals) in the DFO cetacean database (see Table 4.11). It was made in September 2005 during Chevron's seismic monitoring program in the Orphan Basin (Moulton et al. 2006).

Striped Dolphin

The striped dolphin preferred habitat seems to be deep water along the edge and seaward of the continental shelf, particularly in areas with warm currents (Baird et al. 1993). This species has no status under *SARA* and is considered *not at risk* by COSEWIC (see Table 4.10). Offshore waters of Newfoundland are thought to be at the northern limit of its range. An estimated 46,882 individuals (CV=0.33) occur in the Northwest Atlantic (Waring et al. 2013). There were only three sightings of this species recorded in the Study Area based on the DFO cetacean database; all sightings occurred in August (see Table 4.11).

Harbour Porpoise

Harbour porpoises occur in continental shelf regions of the northern hemisphere, from Baffin Island to New England in the Northwest Atlantic (Jefferson et al. 2008). There are at least three populations recognized in the Northwest Atlantic: eastern Newfoundland and Labrador, the Gulf of St. Lawrence, and the Gulf of Maine/Bay of Fundy (Palka et al. 1996). Lawson and Gosselin (2009) provided an abundance estimate of 1,195 harbour porpoises for Newfoundland, based on aerial surveys conducted off the southern and eastern coast; the abundance corrected for perception and availability biases was estimated at 3,326 porpoises (Lawson and Gosselin, unpublished data). In the Atlantic, harbour porpoises are considered *threatened* (Schedule 2) by *SARA* and *special concern* by COSEWIC. Limited information is available regarding distribution and movements of harbour porpoises in Newfoundland and Labrador. Data on harbour porpoises incidentally caught in groundfish gillnets suggest that they occur around the entire island of Newfoundland and in southern Labrador (Lawson et al. 2004). Bycatch data also indicate that harbour porpoises occur as far north as Nain, and in deep water (>2000 m) in the Newfoundland Basin and Labrador Sea (Stenson and Reddin 1990 *in* COSEWIC 2006b; Stenson et al. 2011). Harbour porpoises are primarily observed over continental shelves and in areas with coastal fronts or upwelling that concentrate small schooling fish, although sightings also occasionally occur in deeper waters (Read 1999). Bycaught porpoises in Newfoundland appear to primarily consume capelin, Atlantic herring, sand lance, and lantern fish (COSEWIC 2006b). Harbour porpoises typically occur singly or in small groups of up to three individuals, occasionally occurring in larger groups (COSEWIC 2006b). There were 23 harbour porpoise sightings in the Study Area in the DFO cetacean sightings database (Table 4.11; Figure 4.42).

4.5.1.5 True Seals (Phocids)

Three species of seals including harp, hooded, and perhaps grey seals occur in the Project Area (see Table 4.10). None of these species are designated under *SARA* or by COSEWIC.

Harp Seal

Harp seals are widespread in the North Atlantic and Arctic Ocean, ranging from northern Hudson Bay and Baffin Island to the western North Atlantic and the Gulf of St. Lawrence; vagrants have been reported as far south as Virginia (Scheffer 1958; Rice 1998). They are considered the most abundant seal in the Northwest Atlantic. Based on survey data, the population size for eastern Canada was estimated at 8.3 million seals for 2008 (DFO 2012a). Reproductive rates declined after 2008, and the population size for 2012 was estimated at 7.1 million (Hammill et al. 2013a). COSEWIC is considering the harp seal as a *mid-priority candidate* species; it has no status under *SARA.*

Harp seals are common during late winter/early spring off northeast Newfoundland and southern Labrador where they congregate to breed and pup on the pack ice during February and March (DFO 2012a). Large concentrations are found on the sea ice during the moult in April and May (DFO 2012a). The majority of the Northwest Atlantic population uses this region while the small remainder uses the Gulf of St. Lawrence (Lavigne and Kovacs 1988). During the summer, the majority of harp seals migrate to Arctic and Greenland waters, but some harp seals remain in southern waters (DFO 2012a). Offshore areas of southern Labrador and eastern Newfoundland appear to be major wintering areas (Stenson and Sjare 1997; Lacoste and Stenson 2000). Off Newfoundland and Labrador, harp seal diets are composed of capelin, Arctic cod, sand lance, herring, Atlantic cod, redfish, and Greenland halibut (Hammill and Stenson 2000).

Hooded Seal

Hooded seals are found in the North Atlantic, ranging from Nova Scotia to the high Arctic in Canada (Jefferson et al. 2008). Hooded seals have no status under *SARA* and are considered *not at risk* by COSEWIC; however, they are currently a *mid-priority candidate* species. There are an estimated 593,500 individuals in the Canadian Atlantic, the majority of which (~535,800 animals) whelp and breed in the pack ice off northeast Newfoundland/southern Labrador in late winter-early spring (Hammill and Stenson 2006). Four primary pupping and mating areas occur in the North Atlantic and include northeast Newfoundland/southern Labrador, the Gulf of St. Lawrence, Davis Strait, and northeast Greenland (Jefferson et al. 2008). Hooded seals fitted with transmitters in the Gulf of St. Lawrence in March started their migration to Greenland in May by traveling through Cabot Strait or the Strait of Belle Isle (Bajzak et al. 2009). Hooded seals aggregate in eastern Greenland to moult during early summer before dispersing to Davis Strait or the Greenland Sea for late summer and fall (see Hammill and Stenson 2006). Less is known about winter distribution, although there have been winter sightings on the Grand Banks and in the Study Area; recent telemetry data suggest that hooded seals move along the continental shelf edge after leaving Greenland moulting grounds to Davis Strait and Baffin Bay followed by southerly migrations into the Labrador Sea during winter (Andersen et al. 2009). Hooded seals consume benthic invertebrates like shrimp, Greenland halibut, redfish, Arctic cod, and squid (Hammill and Stenson 2000).

Grey Seal

Grey seals inhabit cold temperate to sub-Arctic regions of the North Atlantic, ranging in Canada from Nova Scotia to Labrador (Jefferson et al. 2008). Grey seals have no status under *SARA* and are considered *not at risk* by COSEWIC. Over the last several decades, the Northwest Atlantic population has increased dramatically (Bowen 2011); population estimates in 2010 ranged from 348,900 seals (Thomas et al. 2011) to 402,700 (Hammill and Stenson 2011). The majority breed during the winter on Sable Island, south of Nova Scotia, but pups are also born in the Gulf of St. Lawrence, and along the coast of Nova Scotia (DFO 2010d). An unknown number range into eastern Newfoundland and Labrador. Although generally coastal, grey seals forage over the continental shelf (Lesage and Hammill 2001). Along the east coast of Newfoundland, their diet seems to be dominated by capelin and winter flounder, although other fish species including Atlantic cod, sculpins, and sand lance are also taken (Hammill et al. 2013b). Grey seals are considered rare in the Study Area.

4.5.2 Sea Turtles

Sea turtles regularly occur on the Grand Banks and adjacent waters; three species could potentially occur within the Study Area. Table 4.12 provides a summary of habitat, occurrence and status in the Project Area for leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), and Kemp's Ridley sea turtles (*Lepidochelys kempii*). Of these species, the leatherback sea turtle is designated as *endangered* under COSEWIC and *SARA* (Table 4.12; see Section 4.6 on Species at Risk for profile), and the loggerhead sea turtle is designated as *endangered* under COSEWIC and has no status under the *SARA*. Kemp's Ridley sea turtle has no status under *SARA* and has not been considered by COSEWIC.

Table 4.12. Sea Turtles Potentially Occurring in the Study Area.

Species	Project Area		*SARA* Status[a]	COSEWIC Status[b]	Activities	Habitat
	Occurrence	Timing				
Leatherback sea turtle	Rare	June to Nov	Schedule 1: E	E	Feeding	Open water, bays
Loggerhead sea turtle	Very rare	Summer	NS	E	Feeding	Open water
Kemp's Ridley sea turtle	Very rare	Summer	NS	LPC	Feeding	Open water

[a] Species designation under the *Species at Risk Act*; E = Endangered, NS = No Status.
[b] Species designation by COSEWIC; E = Endangered, LPC = Low Priority Candidate.

4.5.2.1 Loggerhead Sea Turtle

The loggerhead sea turtle has no status under *SARA*, but it is designated as *endangered* by COSEWIC (2010b). The adult female population in the western North Atlantic is estimated at 38,334 individuals (Richards et al. 2011), but there are no current population estimates for loggerhead turtles in Atlantic Canada (DFO 2010e). The loggerhead turtle is the most common sea turtle in North American waters (Spotila 2004). Its distribution is largely constrained by water temperature and it does not generally occur where the water temperature is below 15°C (O'Boyle 2001; Brazner and McMillan 2008), but rather prefers water between 20–25°C (DFO 2010e). There appears to be a seasonal population of juvenile loggerheads in Atlantic Canada (COSEWIC 2010b). Loggerheads can migrate considerable distances between near-equatorial nesting areas and temperate foraging areas, some moving with the Gulf Stream into eastern Canada waters during the summer and fall (Hawkes et al. 2007). Loggerheads

appear to move with the Gulf Stream into eastern Canada waters during summer, especially the Scotian Shelf, Georges Bank and Grand Banks from July through October (Smith 2001, 2002 *in* Brazner and McMillan 2008; Javitech 2002, 2003 *in* Brazner and McMillan 2008). Thousands of mostly immature loggerheads have been bycaught in the Canadian pelagic longline fishery off the east coast since 1999 (Brazner and McMillan 2008; Paul et al. 2010). Loggerheads may be seen in the open seas during migration and foraging (e.g., Mansfield et al. 2009). While foraging at sea, loggerheads likely consume gelatinous zooplankton and squid (Spotila 2004). Although they have not been reported in the Study Area, juvenile loggerhead turtles tagged in U.S. waters were recorded just south of the Study Area (Mansfield et al. 2009). Most loggerhead records offshore Newfoundland have occurred in deeper waters south of the Grand Banks, and sightings have extended as far east as the Flemish Cap (Figures 6 and 7 *in* COSEWIC 2010b).

4.5.2.2 Kemp's Ridley Sea Turtle

Kemp's Ridley sea turtle has no status under *SARA* and is considered a low priority candidate species by COSEWIC. The Kemp's Ridley sea turtle is more restricted in distribution, primarily occurring only in the Gulf of Mexico, but some juveniles sometimes feed along the U.S. east coast and rarely range into eastern Canada waters (Spotila 2004). Movements outside of the Gulf of Mexico likely occur during summer and in coastal areas. There are records of Kemp's Ridley turtle for Nova Scotia, but the presence of this turtle off Newfoundland has not been confirmed (McAlpine et al. 2007).

4.6 Species at Risk

The *Species at Risk Act* (*SARA*) was assented to in December 2002 with certain provisions coming into force in June 2003 (e.g., independent assessments of species by COSEWIC) and June 2004 (e.g., prohibitions against harming or harassing listed *endangered* and *threatened* species or damaging or destroying their critical habitat). Species are listed under *SARA* on Schedules 1 to 3 with only those designated as *endangered* or *threatened* on Schedule 1 having immediate legal implications. Schedule 1 is the official list of wildlife Species at Risk in Canada. Once a species/population is designated, the measures to protect and recover it are implemented. Three cetacean species/populations, one sea turtle species, one seabird species, and three fish species/populations that have potential to occur in the Study Area are legally protected under *SARA* (Table 4.13). In addition, Atlantic wolfish, the Atlantic population of fin whales, and Sowerby's beaked whale are designated as *special concern* on Schedule 1 (Table 4.13). Schedules 2 and 3 of *SARA* identify species that were designated "at risk" by COSEWIC prior to October 1999 and must be reassessed using revised criteria before they can be considered for addition to Schedule 1. Species that potentially occur in the Study Area and are considered at risk but which have not received specific legal protection (i.e., prescribed penalties and legal requirement for recovery strategies and plans) under *SARA* are also listed in Table 4.13, as are *endangered*, *threatened* or species of *special concern* under COSEWIC.

Table 4.13. *SARA*- and COSEWIC-Listed Marine Species that Potentially Occur in the Study Area.

SPECIES		*SARA*[a]			COSEWIC[b]		
Common Name	**Scientific Name**	**Endangered**	**Threatened**	**Special Concern**	**Endangered**	**Threatened**	**Special Concern**
Marine Mammals							
Blue whale (Atlantic population)	*Balaenoptera musculus*	Schedule 1			X		
North Atlantic right whale	*Eubalaena glacialis*	Schedule 1			X		
Northern bottlenose whale (Scotian Shelf population)	*Hyperoodon ampullatus*	Schedule 1			X		
Fin whale (Atlantic population)	*Balaenoptera physalus*			Schedule 1			X
Sowerby's beaked whale	*Mesoplodon bidens*			Schedule 1			X
Harbour porpoise (Northwest Atlantic population)	*Phocoena phocoena*		Schedule 2				X
Humpback whale (Western North Atlantic population)	*Megaptera novaeangliae*			Schedule 3			
Killer whale (Northwest Atlantic/Eastern Arctic population)	*Orcinus orca*						X
Northern bottlenose whale (Davis Strait-Baffin Bay-Labrador Sea population)	*Hyperoodon ampullatus*						X
Sea Turtles							
Leatherback sea turtle	*Dermochelys coriacea*	Schedule 1			X		
Loggerhead sea turtle	*Caretta caretta*				X		
Fishes							
White shark (Atlantic population)	*Carcharodon carcharias*	Schedule 1			X		
Northern wolffish	*Anarhichas denticulatus*		Schedule 1			X	
Spotted wolffish	*Anarhichas minor*		Schedule 1			X	
Atlantic wolffish	*Anarhichas lupus*			Schedule 1			X
Atlantic cod	*Gadus morhua*			Schedule 3			
Bluefin tuna	*Thunnus thynnus*				X		
Atlantic cod (Newfoundland and Labrador population)	*Gadus morhua*				X		
Porbeagle shark	*Lamna nasus*				X		
Roundnose grenadier	*Coryphaenoides rupestris*				X		

SPECIES		*SARA*[a]			COSEWIC[b]		
Common Name	**Scientific Name**	**Endangered**	**Threatened**	**Special Concern**	**Endangered**	**Threatened**	**Special Concern**
Cusk	*Brosme brosme*				X		
American eel	*Anguilla rostrata*					X	
White Hake	*Urophycis tenuis*					X	
Shortfin mako shark (Atlantic population)	*Isurus oxyrinchus*					X	
American plaice (Newfoundland and Labrador population)	*Hippoglossoides platessoides*					X	
Atlantic salmon (South Newfoundland population)	*Salmo salar*					X	
Acadian redfish (Atlantic population)	*Sebastes fasciatus*					X	
Deepwater redfish (Northern population)	*Sebastes mentella*					X	
Blue shark (Atlantic population)	*Prionace glauca*						X
Basking shark (Atlantic population)	*Cetorhinus maximus*						X
Spiny dogfish (Atlantic population)	*Squalus acanthis*						X
Roughead grenadier	*Macrourus berglax*						X
Thorny skate	*Amblyraja radiata*						X
Birds							
Ivory Gull	*Pagophila eburnea*	Schedule 1			X		

Sources: [a] *SARA* website (http://www.sararegistry.gc.ca/default_e.cfm) (as of November 2013); [b] COSEWIC website (http://www.cosewic.gc.ca/index.htm) (as of November 2013); COSEWIC candidate species not included.

Under *SARA*, a 'recovery strategy' and corresponding 'action plan' must be prepared for *endangered*, *threatened*, and *extirpated* species. A 'management plan' must be prepared for species considered as *special concern*. Final recovery strategies have been prepared for six species currently designated as either *endangered* or *threatened* under Schedule 1 and potentially occurring in the Study Area: (1) the leatherback sea turtle (ALTRT 2006); (2) the spotted wolffish (Kulka et al. 2008), (3) the northern wolffish (Kulka et al. 2008), (4) the blue whale (Beauchamp et al. 2009), (5) the North Atlantic right whale (Brown et al. 2009), and (6) the Scotian Shelf population of the northern bottlenose whale (DFO 2010f). A recovery strategy has also been proposed for the Ivory Gull (Environment Canada 2013). A recovery strategy has not yet been prepared for white shark. A management plan has been prepared for the Atlantic wolffish (Kulka et al. 2008), currently designated as *special concern* on Schedule 1. Management plans have not yet been produced for fin or Sowerby's beaked whales.

Suncor will monitor *SARA* issues through the *SARA* and COSEWIC websites, communication with DFO and Environment Canada, Canada Gazette notices and the Canadian Association of Petroleum Producers (CAPP), and will adaptively manage any issues that may arise in the future in the context of the regular updates to this environmental assessment. The company will comply with relevant regulations pertaining to *SARA* Recovery Strategies and Action Plans.

Suncor acknowledges the overall rarity of Species at Risk and will continue to exercise due caution to minimize effects on them during all of its operations. Suncor also acknowledges the possibility of other marine species being designated as *endangered* or *threatened* on Schedule 1 during the course of the Project. Due caution will also be extended to any other species added to Schedule 1 during the life of this Project.

Species profiles of fishes, birds, marine mammals, and sea turtles listed on Schedule 1 as *endangered* or *threatened* and any related special or sensitive habitat in the Study Area are described in the following subsections.

4.6.1 Profiles of SARA-Listed Species

Only those marine species that are listed under Schedule 1 of the *SARA* as either *endangered* or *threatened* are profiled in this subsection.

4.6.1.1 Fishes

Only three fish species are listed under Schedule 1 of the *SARA* as either *endangered* or *threatened*. Profiles of these three species are provided in this subsection. Other fish species/ populations included in Table 4.13 that are routinely taken in commercial fisheries (i.e., Atlantic cod, American plaice, grenadiers, and redfishes) are profiled in Section 4.2.4.1.

White Shark

Worldwide, the white shark is rare but does occur with some predictability in certain areas. The white shark is widely distributed in sub-polar to tropical seas of both hemispheres, but it is most frequently observed and captured in inshore waters over the continental shelves of the Northwest Atlantic, Mediterranean Sea, southern Africa, southern Australia, New Zealand, and the eastern North Pacific. The species is not found in cold polar waters (*SARA* website accessed November 2013).

Off Atlantic Canada, the white shark has been recorded from the northeast Newfoundland Shelf, the Strait of Belle Isle, the St. Pierre Bank, Sable Island Bank, the Forchu Misaine Bank, in St. Margaret's Bay, off Cape La Have, in Passamaquoddy Bay, in the Bay of Fundy, in the Northumberland Strait, and in the Laurentian Channel as far inland as the Portneuf River Estuary. In recent years numerous white sharks have been tagged by OCEARCH, a non-profit organization devoted to global-scale research on white sharks and other large apex predators, providing open source, near-real time data (including satellite tracks) through the Global Shark Tracker (www.ocearch.org/tracker). An adult female, 'Lydia,' originally tagged in March 2013 off Jackson, Florida, was noted in Placentia Bay, NL, and on the Newfoundland Shelf west and southwest of the Study Area from October through early December 2013. The species is highly mobile, and individuals in Atlantic Canada 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 bottom, down to a depth of at least 1,280 m (*SARA* website accessed November 2013).

In reproduction, the female produces eggs which remain in her body until they are ready to hatch. When the young emerge, they are born live. Gestation period is unknown, but may be about 14 months. Litter size varies, with an average of seven pups. Length at birth is assumed to be between 109 and 165 cm. Possible white shark pupping areas on the west and east coasts of North America include off southern California and the Mid-Atlantic Bight, respectively (*SARA* website accessed November 2013).

White sharks are an apex predator with a wide prey base feeding primarily on many types of fish and marine mammals, as well as squid, molluscs, crustaceans, marine birds, and reptiles. There has been one recorded occurrence of a killer whale preying on a white shark (*SARA* website accessed November 2013).

Northern Wolffish

The northern wolffish is a deepwater fish of cold northern seas that has been caught at depths ranging from 38 to 1,504 m, with observed densest concentrations between 500 and 1,000 m at water temperatures of 2 to 5°C. During 1980–1984, this species was most concentrated on the northeast Newfoundland and Labrador shelf and banks, the southwest and southeast slopes of the Grand Banks, and along the Laurentian Channel. Between 1995 and 2003, the area occupied and density within the area was considerably reduced. Northern wolffish are uncommon in the Gulf of St. Lawrence. These wolffish are known to inhabit a wide range of bottom substrate types, including mud, sand, pebbles, small rock and hard bottom, with highest concentrations observed over sand and shell hash in the fall, and coarse sand in the spring. Unlike other wolffish species, both juvenile and adult stages of this species have been found a considerable distance above the bottom, as indicated by their prey species (Kulka et al. 2008; COSEWIC 2012b).

Prey of northern wolffish are primarily bathypelagic (>200 m depth) biota, but also include mesopelagic biota (<200 m depth) and benthic invertebrates. Pelagic fish represent the largest percentage of identifiable stomach contents on the basis of volume. Juvenile wolffish have been found in the stomachs of seals, Atlantic cod, Atlantic halibut, and haddock. Tagging studies have suggested limited migratory behaviour by these wolffish. Sexual maturation in northern wolffish is estimated to be between five to six years of age. Spawning occurs late in the year on rocky bottoms. Fertilization is internal and fecundity is low in comparison to other fish species of a similar size (COSEWIC 2012b). Cohesive masses of fertilized eggs are laid in crevices but are unattached to the substrate. Pelagic

larvae hatch after an undetermined egg incubation time, and typically feed on crustaceans, fish larvae and fish eggs (Kulka et al. 2008; COSEWIC 2012b).

The northern wolfish was first assessed as *threatened* in 2001 by COSEWIC. That status has not changed in the latest assessment which occurred in 2012. The species has been protected under *SARA* since 2003. While the species has no commercial value and there is no directed fishery for northern wolfish, it is still captured as bycatch in some fisheries.

During DFO RV surveys conducted in the Study Area during 2007–2011, 216 northern wolffish were caught, during both spring and fall survey times. Northern wolffish catches were most concentrated in the eastern portion of the Study Area (see Figure 4.37 in Section 4.3.5 of this EA).

Spotted Wolffish

The life history of the spotted wolffish is very similar to that of the northern wolffish except that it seldom inhabits the deepest areas used by the northern wolffish. Although spotted wolffish have been caught at depths ranging from 56 to 1,046 m, the observed densest concentrations occur between 200 and 750 m at water temperatures of 1.5 to 5.0°C. During 1980–1984, spotted wolffish were most concentrated on the northeast Newfoundland and Labrador shelf and banks, the southwest and southeast slopes of the Grand Banks, along the Laurentian Channel, and in the Gulf of St. Lawrence. Between 1995 and 2003, the area occupied and density within the area was considerably reduced. As with northern wolffish, spotted wolffish also inhabit a wide range of bottom substrate types, including mud, sand, pebbles, small rock and hard bottom, with highest concentrations observed over sand and shell hash in the fall, and coarse sand in the spring (Kulka et al. 2008).

Prey of spotted wolffish are primarily benthic (>75%), typically including echinoderms, crustaceans, and molluscs associated with both sandy and hard bottom substrates. Fish also constitutes part of the spotted wolffish diet (<25%) (Kulka et al. 2008). Juvenile spotted wolffish have been found in the stomachs of seals and fish such as Atlantic cod and Atlantic halibut (COSEWIC 2012c). Tagging studies indicate the spotted wolffish migrations are local and limited. Sexual maturation occurs between approximately five to six years of age (COSEWIC 2012c). Spotted wolfish reproduction includes internal fertilization; in Newfoundland and Labrador waters, this typically occurs in July and August on stony bottom. Cohesive masses of eggs are deposited in crevices, remaining unattached to the substrate. After an undetermined incubation time, pelagic larvae hatch and start to feed on crustaceans, fish larvae and fish eggs within a few days of hatching (Kulka et al. 2008; COSEWIC 2012c).

The spotted wolfish was first assessed as *threatened* in 2001 by COSEWIC. That status has not changed in the latest assessment which occurred in 2012. The species has been protected under *SARA* since 2003. While the species has no commercial value and there is no directed fishery for spotted wolfish, it is still captured as bycatch in some fisheries.

During DFO RV surveys conducted in the Study Area during 2007–2011, 210 spotted wolffish were caught, during both spring and fall survey times. Spotted wolffish catches were most concentrated in the central and northwestern portions of the Study Area where water depths were less than at the primary catch locations of northern wolffish (see Figure 4.37 in Section 4.3.5 of this EA).

4.6.1.2 Seabirds

Ivory Gull

The Ivory Gull nests in the central and eastern Canadian arctic, northern Greenland, Svalbard, and some archipelagos in the northwestern Russian Federation (Mallory et al. 2008). During the winter, however, its range is nearly circumpolar and often associated with drifting pack ice. Off eastern Canada, the Ivory Gull regularly winters along the ice edge from Davis Strait, south off the Labrador coast, to north-eastern Newfoundland (Mallory et al. 2008). The Ivory Gull is designated as *endangered* by COSEWIC (COSEWIC 2013), and listed as *endangered* on Schedule 1 of *SARA*. It is also considered near threatened on the Red List of Threatened Species, with a declining population (IUCN 2013).

In comparison to most gulls, Ivory Gulls have reduced reproductive output, in that they usually only lay one to two eggs (Mallory et al. 2008). They depart from colonies immediately following breeding for offshore foraging areas associated with the ice edge of permanent, multi-year pack ice. At sea, the Ivory Gull is a surface-feeder where its main prey includes ice-associated small fish and macro-zooplankton. It is also an opportunistic scavenger of carrion (e.g., seals killed by hunters or polar bears; Mallory et al. 2008).

Currently, the Canadian breeding population is estimated at 400 pairs (Mallory et al. 2008). Surveys conducted during 2002 to 2005 indicate a total decline of 80% and an annual decline of 8.4% over the last 18 years. If this decline continues at a steady rate, the breeding population will decrease by a further 62% over the next decade, to approximately 190 individuals. A March 2004 survey conducted within the pack ice off the coast of Newfoundland and Labrador recorded a decrease in Ivory Gull observations as compared to 1978 results. Numbers of Ivory Gulls observed per 10-minute watch period were 0.69 and 0.02 individuals for 1978 and 2004, respectively (COSEWIC 2006c). Considering that changes to the breeding environment have been insignificant, causes for the observed decline are likely related to factors occurring during migration or on the wintering grounds (Stenhouse 2004).

During heavy ice winters, the Ivory Gull may occasionally reach the northern Grand Banks in the Study Area, late in the winter or early spring when sea ice reaches the maximum southern extremity. The 30-year median of ice concentration shows ice extending into the northern edge of the Grand Banks east to 48°W during late February to late March. A total of 21 Ivory Gulls reported from drill platforms on the northeast Grand Banks during 1999 to 2002 seems improbable, especially considering that most sightings were reported during ice-free periods (Baillie et al. 2005). Ivory Gull is reported regularly along the coast of Labrador and the tip of the Great Northern Peninsula of Newfoundland in winter (Stenhouse 2004). There are occasional sightings of Ivory Gulls south along the east coast of Newfoundland. It is expected to be very rare in the Study Area.

4.6.1.3 Marine Mammals

North Atlantic Right Whale

The North Atlantic right whale is currently listed as *endangered* on Schedule 1 of *SARA* and by COSEWIC (see Table 4.13; COSEWIC 2003b). Research suggests the existence of six major habitats or congregation areas for North Atlantic right whales: the coastal waters of the southeastern United States; the Great South Channel; Georges Bank/Gulf of Maine; Cape Cod and Massachusetts Bays; the Bay of Fundy; and the

Scotian Shelf (COSEWIC 2003b; Waring et al. 2013). Roseway Basin, on the Scotian Shelf, and Grand Manan Basin, in the Bay of Fundy, have been designated as critical habitat for right whales pursuant to *SARA* (Brown et al. 2009). Based on a census of individual whales identified using photo-identification, the western North Atlantic population size is estimated to be comprised of at least 510 individuals (NARWC 2013). This species is considered extremely rare in the Study Area. However, there have been some relatively recent sightings of small numbers of right whales off Iceland and Greenland (Mellinger et al. 2011), and it is possible (although highly unlikely) that this species may occur in the Study Area. Right whales were recorded once in the Study Area (Figure 4.40) on 27 June 2003 during a Provincial Airlines (PAL) reconnaissance survey (J. Lawson, DFO Research Scientist, pers. comm.).

Blue Whale

The blue whale has a cosmopolitan distribution, but tends to be more frequently observed in deep water than in coastal environments (Jefferson et al. 2008). Blue whales became severely depleted during industrial whaling and still occur at relatively low densities in the North Atlantic. The Atlantic population of blue whales is considered *endangered* on *SARA* Schedule 1 and by COSEWIC. The recovery strategy for blue whales in the Northwest Atlantic notes a long-term recovery goal of reaching a total of 1,000 mature individuals through the achievement of three 5-year objectives (Beauchamp et al. 2009). No critical habitat was identified. Blue whales likely number in the low hundreds in the Northwest Atlantic and have been sighted only sporadically off the northeast coast of Newfoundland (COSEWIC 2002). There were no sightings of blue whales in the Study Area in the DFO cetacean sightings database. During a monitoring program in 2007 for a controlled source electromagnetic (CSEM) survey in Orphan Basin, there were two sightings of blues whales in the Study Area; they occurred in August-September in water depths of 2,366 m and 2,551 m (Abgrall et al. 2008b). Blue whales feed primarily on krill, and their distribution is often associated with areas of upwelling or shelf edges where their prey may concentrate. Blue whales are considered rare in the Study Area.

Northern Bottlenose Whale

The distribution of northern bottlenose whales is restricted to the North Atlantic, primarily in deep, offshore areas with two regions of concentration: the Gully and adjacent submarine canyons on the eastern Scotian Shelf, and Davis Strait off northern Labrador (Reeves et al. 1993). Throughout their range, northern bottlenose whales were harvested extensively during industrial whaling, which likely greatly reduced total numbers (COSEWIC 2011b; DFO 2011e). The total abundance of northern bottlenose whales in the North Atlantic is unknown. However, the current estimate for the Scotian Shelf population is 143 individuals (O'Brien and Whitehead 2013). The size of the Davis Strait-Baffin Bay-Labrador Sea population is uncertain (COSEWIC 2011b; Whitehead and Hooker 2012), and few sightings were made during recent surveys (DFO 2011e). No northern bottlenose whales were observed during a recent survey conducted by DFO and Canadian Wildlife Service (CWS) off Labrador (one survey day each in October and November 2013) (J. Lawson, DFO Research Scientist, pers. comm.)

Although the Scotian Shelf population is designated *endangered* under Schedule 1 of *SARA* and by COSEWIC, the Davis Strait population has no status under *SARA* and is considered *special concern* by COSEWIC. The proposed recovery target for the Scotian Shelf population of northern bottlenose whales is to increase population size and maintain the current distribution (DFO 2010f; DFO 2011e). The Gully Marine Protected Area and areas deeper than 500 m in Haldimand and Shortland Canyons have been designated as critical habitat for the Scotian Shelf population (DFO 2010f). Although the

stock origin of northern bottlenose whales off Newfoundland and Labrador is unknown (DFO 2011e; Harris et al. 2013), it seems likely that whales in the Study Area mostly or entirely belong to the Davis Strait population. This population is considered to occur in the area year-round, with mating and births occurring between April and June, with a peak in April (Benjaminsen 1972 *in* COSEWIC 2011b; DFO 2011f). The calving season of the Scotian Shelf population peaks in August (Whitehead et al. 1997). No matches of photo-identified individuals have been made between the Scotian Shelf and the Davis Strait-Labrador populations (COSEWIC 2011b), and nuclear and mitochondrial markers revealed very little interchange between these two populations (Dalebout et al. 2006). The encounter rate during boat surveys was 0.03 encounters/h for the Labrador-Davis Strait population, and 0.50 for the Gully (COSEWIC 2011b *as cited in* Whitehead and Hooker 2012).

Occurring primarily in deep waters over canyons and the shelf edge, northern bottlenose whales routinely dive to depths over 800 m and remain submerged for over an hour (Hooker and Baird 1999). Foraging apparently occurs at depth, primarily on deep-water squid and fish (COSEWIC 2011b; DFO 2011e). Northern bottlenose whales may occur at low densities, but year-round, throughout the deep, offshore waters of the Orphan Basin and the Flemish Pass area. Based on the DFO cetacean sightings database, there have been 11 sightings of northern bottlenose whales in the deeper waters of the Study Area (Figure 4.41) from May to September (see Table 4.11). This species is not expected to occur in the shelf waters of the Study Area.

4.6.1.4 Sea Turtles

Leatherback Turtle

The largest and most widely ranging of sea turtles, the leatherback turtle occurs from sub-polar and cool temperate foraging grounds to tropical and sub-tropical nesting areas in all of the world's oceans (Spotila 2004). Exhibiting wide-ranging oceanic movements, leatherbacks occur in pelagic regions of the North Atlantic to forage on gelatinous zooplankton (Hays et al. 2006). Leatherback turtles forage on jellyfish, such as lion's mane and moon jellyfish, in Atlantic Canadian waters; they consume an average of 330 kg wet mass of jellyfish per day (Heaslip et al. 2012). Three primary habitats, likely used as foraging areas by leatherback turtles in Atlantic Canada, were identified using satellite tracking data: (1) the area near Georges Bank, (2) southeastern Gulf of St. Lawrence and waters east of Cape Breton, and (3) waters south and east of Burin Peninsula, Newfoundland (DFO 2011f). Genetic analysis on leatherback turtles captured off Nova Scotia revealed that most of them had originated from natal beaches in Trinidad, followed by French Guiana, Costa Rica, St. Croix, and Florida (Stewart et al. 2013).

There are an estimated 34,000 to 94,000 leatherback adults in the North Atlantic (TEWG 2007), but there is no current estimate of the number of leatherbacks using eastern Canadian waters (COSEWIC 2012d). Nonetheless, James et al. (2006) suggested that Canadian waters support high densities of leatherbacks during the summer and fall, and that Canadian waters should be considered critical foraging habitat for this species. Even though the species appears to be virtually absent during the winter months (James 2000), leatherback turtles have been sighted off the east coast of Canada, and off Newfoundland, during the winter (McAlpine et al. 2007). The leatherback turtle is designated as *endangered* (Schedule 1) on *SARA* and by COSEWIC, but no critical habitat has been designated by ALTRT (2006). In the recovery strategy for leatherback turtle in the Canadian Atlantic Ocean, the recovery goal is to "achieve the long-term viability of the leatherback turtle populations frequenting Atlantic Canadian waters" via six supporting objectives (ALTRT 2006).

Adult leatherbacks are considered regular summer visitors to eastern Newfoundland, with the northernmost records occurring off Labrador at nearly 54ºN; observations around Newfoundland and Labrador occur from June to November, but are most common in August and September (Goff and Lien 1988). Most sea turtles migrate southward by mid-October (Sherrill-Mix et al. 2008). James et al. (2006) noted that increasing sea surface temperatures in Canadian waters result in a significant increase in turtle sightings. Most leatherbacks that occur in Atlantic Canadian waters are large sub-adults and adults, with a female-biased sex ratio among mature turtles (James et al. 2007). DFO Newfoundland Region has maintained a database of leatherback turtle sightings and entanglements in Newfoundland and Labrador (J. Lawson, DFO Research Scientist, pers. comm.). One leatherback turtle was recorded just south of the Study Area in August 2007. There was also a sighting of a leatherback turtle in Jeanne d'Arc Basin during the Statoil/Husky seismic monitoring program in 2008 (Abgrall et al. 2009). Leatherback turtles outfitted with satellite telemetry have also been tracked near or within the Study Area (TEWG 2007).

4.7 Sensitive Areas

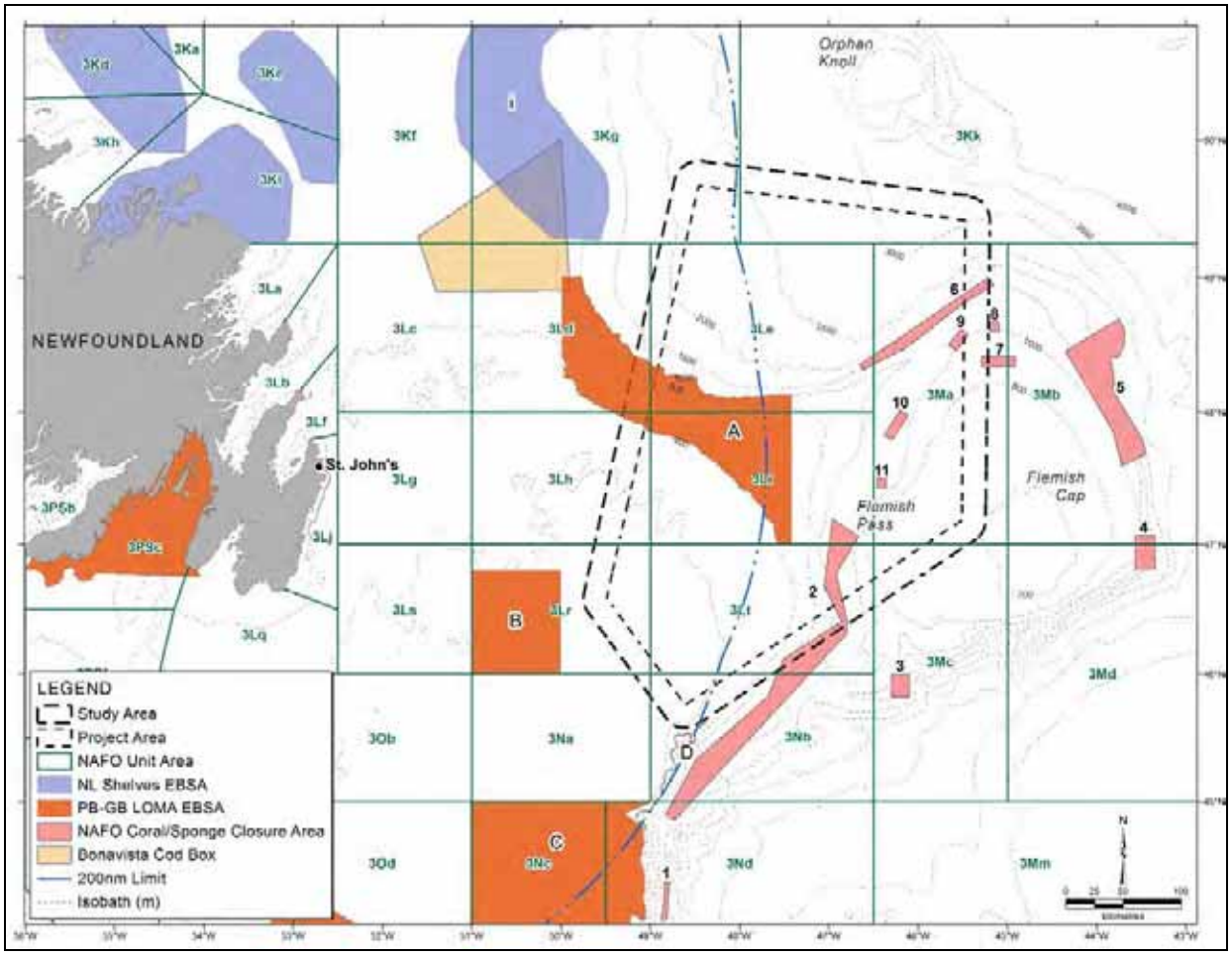
There are a variety of regulatory frameworks that deal directly or indirectly with sensitive areas in Newfoundland and Labrador. Marine fisheries are administered by DFO through the federal *Fisheries Act*. Management of marine mammals, including species at risk, is controlled by DFO under the *Marine Mammals Regulations* of the *Fisheries Act*. All species at risk are administered under the *Species at Risk Act* (2002) which lists the species and provides measures to protect those species. The *Oceans Act* Marine Protected Areas are established by DFO to protect and conserve important fish and marine mammal habitats, *endangered* marine species, unique features and areas of high biological productivity or biodiversity. Migratory birds, including species at risk, are solely or jointly managed (depending on the species) between Canada and the U.S. through the CWS branch of Environment Canada. Current legislation and agreements regarding migratory birds include the Convention for the Protection of Migratory Birds (1916), *Migratory Birds Convention Act*, and the North American Waterfowl Management Plan (CWS and United States Fish and Wildlife Services (USFWS) 1986; CWS, USFWS, and SEMARNAP 1998). Waterfowl are managed according to "flyways" denoting wintering and summering habitat connected by international migration corridors.

4.7.1 Integrated Management Areas

The Study Area includes a portion of the Placentia Bay Grand Banks (PBGB) Large Ocean Management Area (LOMA), one of the marine regions established to form the planning basis for implementation of integrated-management plans by DFO. The LOMAs are typically thousands of square kilometres in size. Their boundaries are determined using a combination of ecological and administrative considerations. For each LOMA, all levels of government, aboriginal groups, industry organizations, environmental and community groups, and academia work together to develop a strategic, long-term plan for sustainable management of resources within its boundaries. This plan is intended to be adaptive, in that strategies and plans may change as new information is obtained through ongoing monitoring and reporting (DFO 2012b). The LOMAs are delineated so that ecosystem health and economic development issues within their boundaries can be addressed and suitably managed. This can best be accomplished using an integrated ocean management approach, an approach based on addressing the socio-economic and cultural needs of humankind while preserving the health of the marine ecosystem (DFO 2012b).

The PBGB LOMA has been recognized by DFO as one of five priority LOMAs in Canada. The PBGB LOMA Committee comprises a group of stakeholders partnering for the sustainable use and

development of coastal and ocean resources within the LOMA. The designation of Ecologically and Biologically Sensitive Areas (EBSAs) is a tool to allow appropriate management of "geographically or oceanographically discrete areas that provide important services to one or more species/populations of an ecosystem or to the ecosystem as a whole, compared to other surrounding areas or areas of similar ecological characteristics" (DFO 2013m). DFO Newfoundland and Labrador Region has identified 11 EBSAs within the PBGB LOMA as potential Areas of Interest (AOIs) for Marine Protected Area (MPA) designation, one of which overlaps the Study Area, namely the Northeast Shelf and Slope EBSA (Figure 4.43). This EBSA overlaps the west-central portion of the Study Area and includes an edge of the Shelf and Slope area down to the 1,000 m isobaths at the Nose of the Grand Bank (DFO 2007a,b). The Study Area also occurs within 20 km of the Virgin Rocks EBSA and ~1 km of the Lilly Canyon-Carson Canyon EBSA.



Source: DFO (2013m).
NL Shelves EBSA: Orphan Spur (i); PBGB LOMA EBSA: Northeast Shelf and Slope (A), Virgin Rocks (B), Southeast Shoal and Tail of the Banks (C), Lilly Canyon-Carson Canyon (D).

Figure 4.43. Locations of the NL Shelves EBSAs, PBGB LOMA EBSAs, Bonavista Cod Box, and NAFO Coral/Sponge Closure Areas Relative to the Suncor Project Area.

The Northeast Shelf and Slope EBSA have an overall 'low priority' rating relative to other EBSAs within the PBGB LOMA. Aspects of this EBSA, relative to other areas within the same LOMA, considered during its assessment include the following (DFO 2007a):

- ***Uniqueness (rarity)*** – the EBSA may be deemed significant to some species, based on function, but has no apparent uniqueness otherwise;
- ***Aggregation (density/concentration)*** – (1) the greatest proportion of spotted wolffish are aggregated in this EBSA in the spring; and (2) the highest concentration of Greenland halibut is aggregated in this EBSA in the spring;
- ***Fitness Consequences (importance to reproduction/survival***) – (1) important to the short- and long-term sustainability of the spotted wolffish; and (2) potentially important feeding area for marine mammals; and
- ***Sensitivity (resilience to disturbance)*** – not particularly sensitive compared to other slope areas in the region.

DFO has also recently identified fifteen EBSAs within the Newfoundland and Labrador Shelves Bioregion (exclusive of the PBGB LOMA), of which 14 are spatially defined. Of these, the Orphan Spur EBSA is nearest the Study Area (~50 km northwest) (DFO 2013m).

The *Oceans Act* provides the Minister of Fisheries and Oceans with a leadership role for coordinating the development and implementation of a federal network of MPAs, which can include areas within and outside of the Integrated Management (IM) area that have yet to be developed within the Region. Therefore, there remains potential for further identification of EBSAs, AOI, MPAs and other sensitive areas within the Study Area.

4.7.2 Bonavista Cod Box

In March 2003, as protection for the Northern cod, the *Fisheries Resource Conservation Council (*FRCC) recommended the establishment of an experimental 'cod box' in the Bonavista Corridor. The Corridor has been identified as an area important for cod spawning and juvenile cod. The FRCC recommended that this area be protected from all forms of commercial fishery (excluding snow crab trapping) and other invasive activity such as seismic exploration (see www.frcc.ccrh.ca). In April 2003, DFO announced that special conservation measures were required for the Bonavista Corridor, including the Bonavista Cod Box, located about 80 km northwest of the Study Area (Figure 4.43).

4.7.3 Coral and Sponge Areas

In 2008 and 2009, the NAFO Scientific Council identified areas of significant coral and sponge concentrations within the NAFO Regulatory Area. Based on these identifications, areas for closure to fishing with bottom contact gear were delineated. Figure 4.43 shows the locations of these 11 areas, six of which occur either entirely or partially within the proposed Suncor Study Area, and one other closure area which is located at the boundary of the Study Area. Implementation date of the closures started on 1 January 2010 (NAFO website). Given the nature of seismic surveys, survey equipment is not expected to come in contact with the corals and sponges.

5.0 Effects Assessment

Two general types of effects are considered in this document:

1. Effects of the environment on the Project; and
2. Effects of the Project on the environment, particularly the biological environment represented by "Valued Environmental Components" (VECs) as described below in Section 5.2.

Methods of effects assessment used here are comparable to those used in recent east coast offshore drilling (e.g., LGL 2005, 2008b) and seismic EAs (e.g., LGL 2008a; LGL 2012a). These documents conform to the *Canadian Environmental Assessment Act* (*CEAA*) and associated Responsible Authority's Guide and the CEA Agency Operational Policy Statement (OPS-EPO/5-2000) (CEA Agency 2000). Cumulative effects are incorporated within the procedures in accordance with *CEAA* (CEA Agency 1994) as adapted from Barnes and Davey (1999) and used in the White Rose EA (Husky 2000).

5.1 Scoping

The C-NLOPB provided a Scoping Document (dated March 4, 2013) for the Project which outlined the factors to be considered in the assessment. In addition, various stakeholders were contacted for input (see below). Scoping for the effects assessment also involved reviewing recent regional EAs including (but not limited to) the Orphan Basin SEA (LGL 2003), the Jeanne d'Arc Basin seismic and geohazard program EA for StatoilHydro (LGL 2008a), exploration and drilling EAs and their amendments for Orphan Basin (LGL 2005, 2006b, 2009), Chevron's Labrador and northern Grand Banks seismic EAs (LGL 2010, 2011b respectively), and Husky's Jeanne d'Arc Basin/Flemish Pass seismic EA (LGL 2012a). A review of current knowledge of the effects of seismic sound on marine organisms is also included (Appendices D to G).

During preparation of this EA, consultations were undertaken with relevant government agencies, representatives of the fishing industry and other interest groups. The objectives of these consultations were to describe the proposed program, identify any issues and concerns, and gather additional information relevant to the EA.

5.1.1 Consultations

A short description of the program and a location map were sent to the various agencies, stakeholders and interest groups listed below.

- Fisheries and Oceans Canada (DFO);
- Environment Canada (EC);
- Nature Newfoundland and Labrador (NNL) (and various member organizations);
- One Ocean;
- Fish, Food and Allied Workers Union (FFAW);
- Association of Seafood Producers (ASP);
- Ocean Choice International (OCI);
- Groundfish Enterprise Allocation Council (GEAC) Ottawa;
- Canadian Association of Prawn Producers;

- Clearwater Seafoods;
- Icewater Fisheries; and
- Newfound Resources Ltd. (NRL)

Appendix B provides a list of agency and industry officials who were consulted during the preparation of the EA.

Issues and Concerns

Comments and responses received to date from various stakeholders are provided below.

Fisheries and Oceans Canada

DFO's EA and Major Projects' manager did not have any specific concerns or questions about the proposed seismic program. He noted that DFO would be providing comments on the proposed program and its potential interactions with fish, fisheries, marine mammals and DFO RV surveys through the C-NLOPB's EA review process. He also noted that the department's review is guided in part by the "Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment" (SOCP) which is intended to minimize impacts of seismic surveying on marine life.

Environment Canada

Suncor made a brief PowerPoint presentation that described general aspects and procedures of seismic surveys and provided an overview of the proposed 2014-2024 program. Following this, there was a brief discussion of potential effects of seismic sound on diving birds. Environment Canada managers also asked about the collection of metadata during the survey. In response to this matter, Suncor stated that temperature and salinity factors are usually monitored but that it is difficult to get these metadata after the fact.

Environment Canada managers also asked questions about the typical length of a seismic survey and how crew changes are handled.

Nature Newfoundland and Labrador (NNL)

Following a presentation by Suncor, a number of issues and concerns were raised and discussed, as summarized below.

Nature Newfoundland and Labrador representatives had a general concern about the large temporal and spatial scopes proposed for the EA. They indicated that the 11-year temporal scope was far longer than typically proposed in seismic EAs, and were somewhat surprised by the lack of intended activity in 2014.

Suncor stated that the C-NLOPB has recently been encouraging the "multi-year" approach with annual updates as required.

Nature Newfoundland and Labrador representatives said that they understood the basic rationale but noted that the larger spatial and temporal scopes make it difficult for them to comment effectively and recommend appropriate mitigative measures. They noted, for example, that environmental conditions and issues vary across the different areas within the large Project Area.

Nature Newfoundland and Labrador representatives were also concerned about cumulative impacts, especially with respect to the scenario of two seismic surveys occurring concurrently within the Study Area. Nature Newfoundland and Labrador noted that during the 11-year scope of the EA various aspects could change significantly, such as environmental information and available technologies (e.g., passive acoustic monitoring).

Suncor acknowledged these points of concern but noted that such issues would be addressed in annual updates for the EA and in the authorizations issued by the Board for the specific seismic programs during the 11-year period. Suncor will conduct further consultation for each seismic program.

Suncor noted that the annual updates would serve the same purpose and function as a shorter-term EA. Nature Newfoundland and Labrador representatives generally agreed that an annual update could serve this purpose but, for this to work effectively, the EA update process would need to include more extensive consultation. Nature Newfoundland and Labrador asked if there might be things in the Strategic Environmental Assessment (SEA) currently being prepared for the general area which should be included in Suncor's EA. In response, it was noted that anything new introduced in the SEA, such as new mitigative measures, would be incorporated into Suncor's 2014-2024 EA through the annual update process.

Fish, Food and Allied Workers Union/One Ocean

During a meeting with the FFAW Petroleum Industry Liaison and One Ocean's Director of Operations, a number of general issues and concerns were raised by the FFAW representative. Most of the discussion concerned potential impacts of seismic surveying on the fishing industry's post-season snow crab trap survey that typically occurs every year during September to November. The issues and concerns raised and discussed at the meeting, together with Suncor's response to these points, are summarized below.

The meeting began with a presentation of the proposed program by Suncor. At this point in the planning process, Suncor is not planning to conduct any seismic operations in 2014. He added that when a specific program is being planned, Suncor would consult with the FFAW and One Ocean.

The FFAW's Petroleum Industry Liaison had a number of comments in response to Suncor's presentation. He noted that a large portion of the proposed Project Area is located on established fishing grounds for snow crab and shrimp, and in areas where fishers conduct annual post-season snow crab trap surveys. As such, the FFAW representative requested that Suncor adopt the 'precautionary approach' and not conduct seismic surveys within 20 nmi of any post-season survey stations until those stations have been sampled. The FFAW's preferred/most desirable temporal buffer would be 1 April to the end of the post-season crab survey. He noted that, in 2013, most of the post-season crab survey activities in NAFO Division 3L were completed by the end of September, though sampling in Division 3K usually continues later because fishers are still harvesting shrimp in that area.

In response to the FFAW's position that there should be no seismic surveying within 20 nmi of any research station until it has been sampled, Suncor suggested that it might be useful to draw a 20 nmi radius circle around the relevant post-season crab survey stations to illustrate the size of the area that might have to be avoided if the FFAW recommendation were to be adopted.

LGL's representative pointed out that the FFAW's general concern is that seismic operations may compromise the crab survey data and thereby affect the next year's quotas determined by DFO. Considering this, he said it would be useful to suggest to DFO science managers that they not use any apparently "affected" data in their quota determinations.

FFAW's representative stated that DFO concurs with the Union's position on the 20 nmi spatial buffer. He also noted that current DFO guidelines call for a 2-week temporal buffer between seismic surveying activities and the department's annual Science Branch trawl surveys.

Suncor stated that a temporal buffer lasting several months (i.e., from 1 April to September), or until all stations have been sampled, is not possible. Various scenarios have been discussed but the two industries have yet to agree on the parameters. A common, industry-wide understanding of the FFAW's position on this matter is required. One Ocean's representative agreed with this point and said that it would be very helpful if the FFAW would prepare a formal, written statement indicating its position on spatial/temporal buffers for post-season crab survey activities. Suncor's fisheries consultant asked if this was a matter for One Ocean's Working Group to consider. In response, One Ocean's representative stated that One Ocean's Board would discuss this issue and provide the necessary guidance to its Working Group.

The discussion then focused on what has actually transpired during the past couple of years. It was noted that there have been discussions concerning the possibility of getting the fishers involved to complete their crab survey activities as quickly as possible (i.e., in early September). However, there was a problem attaining this objective given the contractual arrangements between the FFAW and the fishers conducting the survey. The FFAW representative was asked whether there might be more "flexibility" in future arrangements, noting that there should be no economic loss if sampling at particular research stations is completed earlier in the season.

The FFAW's representative noted that DFO established a new management regime for the post-season crab survey in 2013. Participants will no longer receive a monetary payment for their survey activities; instead, they will receive an "extra" amount of crab quota (i.e., a "quota benefit") in the following year. He then went on to explain other aspects of this new regime. These include the provisos that all participating fishers must complete their normal, regular quota before they can harvest any survey crab, and that all participating vessels must have an observer on board. He also noted that the overall crab survey allocation comes "off the top" of the overall crab TAC and the value of the crab that would come off the following year's quota is estimated at about $2 million.

Considering all of these factors and unknowns, and bearing in mind that these are the "early days" of the new management regime, the FFAW's representative noted that it is not yet clear how these changes will influence the way participants in the post-season crab survey conduct their survey-related harvesting activities. Given these "uncertainties", he suggested we need to think very carefully about how to address any problems that post-season crab surveys may pose for offshore seismic operations (and vice versa).

There was further discussion about the best way to proceed. The FFAW representative noted that they were working on a "position paper" that focuses on many of the issues and questions raised during this meeting. This document will include data supporting the FFAW's position on spatial and temporal buffers as well as the approval of fishers for the FFAW's position on these matters. He noted that, as a general guideline, the FFAW recommends that seismic vessels start their surveys in deeper water and then move to shallower areas. This approach would likely minimize potential impacts of seismic surveying on crab survey activities, particularly those located in NAFO Unit Area 3Lt. For example, he noted that if any 2D seismic operations are planned, especially within the northeast corner of 3Lt, the FFAW recommends that the seismic vessel start surveying in the deeper, eastern portion of this area.

One Ocean's representative stressed the need to have more scientific information about the potential impacts of seismic operations on these industry-based surveys. This information will assist both industries to articulate and implement appropriate "operational strategies" to manage any interactions.

Association of Seafood Producers (ASP)

ASP's Executive Director responded that he had no immediate questions about the proposed program, but that he would make contact if questions arose.

Other Fishing Industry Stakeholders

To date, there has not been any response from the other fisheries industry stakeholders contacted for the Suncor EA.

5.2 Valued Environmental Components

The Valued Environmental Component (VEC) approach was used to focus the assessment on those biological resources of most potential concern and value to society and include the following groups:

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

The VECs were identified based on the scoping exercise as described in Section 5.1. The VECs and their associated rationale include:

- **Fish and Fish Habitat** with emphasis on the Study Area's four most important (past and present) commercial species: (1) snow crab, (2) northern shrimp, and (3) Greenland halibut (turbot), and (4) Atlantic cod (a representative fish species that has a swim bladder and hence, may be susceptible to seismic survey sound). It is also recognized that there are many other fish species, important commercial or prey species, that could be considered but it is LGL's professional opinion that this suite of species captures the relevant issues concerning the potential effects of seismic surveys on important invertebrate and fish populations of the Project Area and therefore these species will be the focus.

- **Fisheries** with emphasis on commercial fisheries which is a universally acknowledged important element in the society, culture, economic and aesthetic environment of Newfoundland and Labrador. This VEC is of prime concern from both a public and scientific perspective, at local, national and international scales. Scientific research fishing surveys will also be considered in the EA

- **Seabirds** with emphasis on those species most sensitive to seismic activities (e.g., deep divers such as murres) or vessel stranding (e.g., petrels), and *SARA* species (e.g., Ivory Gull). Newfoundland and Labrador waters support some of the largest seabird colonies in the world and the Study Area hosts large populations during all seasons. They are important socially, culturally, economically, aesthetically, ecologically and scientifically. This VEC is of prime concern from both a public and scientific perspective, at local, national and international scales.

- **Marine Mammals** with emphasis on those species potentially most sensitive to low frequency sound (e.g., baleen whales) and *SARA* species (e.g., blue whale). Whales and seals are key elements in the social and biological environments of Newfoundland and Labrador. The economic and aesthetic importance of whales is evidenced by the large number of tour boats that feature whale watching as part of a growing tourist industry. This VEC is also of prime concern from both a public and scientific perspective, at local, national and international scales.

- **Sea Turtles**, uncommon in the Study Area, are mostly *threatened* and *endangered* on a global scale. The leatherback sea turtle that forages in eastern Canadian waters is considered *endangered* under *SARA*. While they are of little or no economic, social or cultural importance to Newfoundland and Labrador, their *endangered* status warrants their inclusion as a VEC. Also, this VEC is of prime concern from both a public and scientific perspective, at national and international scales.

- **Species at Risk** are those listed as *endangered* or *threatened* on Schedule 1 of *SARA*. All species at risk in Newfoundland and Labrador offshore waters are captured in the VECs listed above. However, due to their special status, they are also discussed separately. Species listed as *special concern* on Schedule 1 of *SARA* and designated as *endangered*, *threatened* and *special concern* by the COSEWIC will also be addressed.

- **Sensitive Areas** are areas considered to be unique due to their ecological and/or conservation sensitivities. Examples of sensitive areas in the study Area include Ecologically and Biologically Significant Areas (EBSAs) and coral conservation areas.

5.3 Boundaries

For the purposes of this EA, the temporal and spatial boundaries are defined in Section 2.2.

5.4 Effects Assessment Procedures

The systematic assessment of the potential effects of the Project involved three major steps:

1. Preparation of interaction matrices (i.e., interactions of Project activities and the environment);
2. Identification and evaluation of potential effects, including description of mitigation measures and residual effects; and
3. Preparation of residual effects summary tables, including evaluation of cumulative effects.

5.4.1 Identification and Evaluation of Effects

Interaction matrices identifying all possible Project activities that could interact with any of the VECs were prepared. The interaction matrices are used to identify potential interactions only and they do not make any assumptions about the potential effects of the interactions.

Interactions were then evaluated for their potential to cause effects. In instances where the potential for an effect of an interaction was deemed impossible or extremely remote, these interactions were not considered further. This approach allows the assessment to focus on key issues and the more substantive environmental effects.

An interaction was considered to be a potential effect if it could change the abundance or distribution of VECs, or change the prey species or habitats used by VECs. The potential for an effect was assessed by considering:

- Location and timing of the interaction;
- Literature on similar interactions and associated effects (seismic EAs for offshore Nova Scotia and Newfoundland and Labrador);
- Consultation with other experts, when necessary; and
- Results of similar effects assessments, especially monitoring studies done in other areas.

If data were insufficient to allow precise effects evaluations, predictions were made based on professional judgement. In such cases, the uncertainty is documented in the EA. Effects were evaluated for the proposed geophysical survey program, and included the consideration of mitigation measures that are either mandatory or have become standard operating procedure in the industry.

5.4.2 Classifying Anticipated Environmental Effects

Classification of environmental effects means determining whether they are negative, positive or neutral. The following are key factors that are considered for determining negative environmental effects, as per the CEA Agency guidelines (CEA Agency 1994):

- Negative effects on the health of biota;
- Loss of rare or *endangered* species;
- Reductions in biological diversity;
- Loss or avoidance of productive habitat, to the extent possible;
- Fragmentation of habitat or interruption of movement corridors and migration routes;
- Transformation of natural landscapes;
- Discharge of persistent and/or toxic chemicals;

- Toxicity effects on human health;
- Either loss of or detrimental change in the current use of lands and resources for traditional purposes;
- Foreclosure of future resource use or production; and
- Negative effects on human health or well-being.

5.4.3 Mitigation

Mitigation measures appropriate for effects predicted in the matrix were identified and the effects of various Project activities were then evaluated assuming the application of appropriate mitigation measures. These effects after application of the mitigation measures are known as 'residual effects'. Residual effects predictions were made taking into consideration both standard and Project-specific mitigations.

Suncor has an Operational Excellence Management System (OEMS), which is an enterprise-wide management system that organizes and links all standards, systems and processes required to manage operational risks, prevent and mitigate environmental impacts and deliver safe, reliable operations. OEMS is based on the Plan-Do-Check-Act continual improvement cycle and follows the internationally recognized management system standards and specifications ISO 14001 and 9001.

The OEMS sets high-level, company-wide mandatory management system requirements with respect to the foundational non-financial risk management processes necessary for a business to achieve operational excellence. However, OEMS does not define specific work processes or provide specifics on how to develop and implement these requirements. To successfully meet the requirements of OEMS each organizational unit will develop appropriate systems, processes and procedures to support its operations.

Suncor's management system includes, but is not limited to:

- An environment, health and safety policy;
- Environmental protection plans;
- Waste management procedures;
- Chemical screening and approval;
- Seabird procedures;
- Fisheries liaison and compensation program;
- Emergency management plans; and
- Oil spill response plans.

5.4.4 Evaluation Criteria for Assessing Environmental Effects

Several criteria were taken into account when evaluating the nature and extent of environmental effects. These criteria include (as per guidance in CEA Agency 1994):

- Magnitude;
- Geographic extent;
- Duration;

- Frequency;
- Reversibility; and
- Ecological, socio-cultural and economic context.

5.4.4.1 Magnitude

Magnitude describes the nature and extent of the residual effect for each activity.

Ratings for this criterion are defined as:

0 *Negligible* - Measureable effect on individuals but less than the 'low' rating.

1 *Low* - Affecting >0 to 10 percent of individuals in the affected area (i.e., Study Area) (e.g., geographic extent). Effects may include acute mortality, sublethal effects or exclusion due to disturbance.

2 *Medium* - Affecting >10 to 25 percent of individuals in the affected area (i.e., Study Area). Effects may include acute mortality, sublethal effects or exclusion due to disturbance.

3 *High* - Affecting >25 percent of individuals in the affected area (i.e., Study Area). Effects may include acute mortality, sublethal effects or exclusion due to disturbance.

Definitions of magnitude used in this EA have been used previously in numerous offshore oil-related environmental assessments under *CEAA*. Some example assessments include the Petro-Canada seismic EA (LGL 2007a), the White Rose Oilfield Comprehensive Study (Husky 2000), the StatoilHydro Jeanne d'Arc Basin area seismic and geohazard program EA (LGL 2008a), the ConocoPhillips Laurentian Sub-Basin exploration drilling EA (Buchanan et al. 2006), the Chevron Labrador and northern Grand Banks seismic EAs (LGL 2010, 2011b), the Hebron Project Comprehensive Study (ExxonMobil 2011), and Husky seismic EA (LGL 2012a).

5.4.4.2 Geographic Extent

Geographic extent refers to the specific area (km^2) of the residual effect caused by the Project activity. Geographic extent will likely vary depending on the activity and the relevant VEC.

Ratings for this criterion are defined as:

1 = <1 km^2
2 = 1-10 km^2
3 = >10-100 km^2
4 = >100-1,000 km^2
5 = >1,000-10,000 km^2
6 = >10,000 km^2

5.4.4.3 Duration

Duration describes how long a residual effect will occur.

Ratings for this criterion are defined as:

1 = <1 month
2 = 1 – 12 months
3 = 13 – 36 months
4 = 37 – 72 months
5 = >72 months

Short duration can be considered 12 months or less, medium duration 13 to 36 months, and long duration >36 months.

5.4.4.4 Frequency

Frequency describes how often a residual effect will occur.

Ratings for this criterion are defined as:

1 = <11 events/yr
2 = 11-50 events/yr
3 = 51-100 events/yr
4 = 101-200 events/yr
5 = >200 events/yr
6 = continuous

5.4.4.5 Reversibility

Reversibility refers to the capability of a VEC population to return to either its pre-Project or an improved condition, after the Project has ended.

Ratings for this criterion are defined as:

R = reversible
I = irreversible

5.4.4.6 Ecological, Socio-cultural and Economic Context

The ecological, socio-cultural and economic context refers to the pre-Project status of the Study Area (i.e., potential affected area) in terms of existing environmental effects. The Study Area is not considered to be strongly affected by human activities.

Ratings for this criterion are defined as:

1 = Environment not negatively affected by human activity (i.e., relatively pristine area)
2 = Evidence of existing negative effects on the environment

5.4.5 Cumulative Effects

Projects and activities considered in the cumulative effects assessment include other human activities in Newfoundland and Labrador offshore waters, with emphasis on the Grand Banks Regional Area.

- Within-Project cumulative impacts. For the most part, and unless otherwise indicated, within-Project cumulative effects are fully integrated within this assessment;
- Existing and *in progress* offshore oil developments in Newfoundland and Labrador: Hibernia (GBS platform), Terra Nova FPSO, White Rose FPSO and associated extension, and the Hebron GBS;
- Other offshore oil exploration activity (particularly seismic surveys and exploratory drilling as outlined on the C-NLOPB website). There is some potential for several 2D/3D/4D, geohazard and VSP surveys in any given year;
- Fisheries (domestic and foreign commercial, recreational, aboriginal/subsistence);
- Marine transportation (tankers, cargo ships, supply vessels, naval vessels, fishing vessel transits, etc.); and
- Hunting activities (marine birds and seals).

5.4.6 Integrated Residual Environmental Effects

Upon completion of the evaluation, the residual environmental effects are assigned a rating of significance for:

- Each project activity;
- Cumulative effects of activities within the Project; and
- Cumulative effects of combined projects in the Regional Area.

As such, this represents an integrated residual environmental effects evaluation.

The analysis and prediction of the significance of residual environmental effects, including cumulative environmental effects, encompasses the following:

- Determination of the significance of residual environmental effects;
- Establishment of the level of confidence for prediction; and
- Evaluation of the scientific certainty and probability of occurrence of the residual impact prediction.

Ratings for level of confidence associated with each prediction are presented in the table of residual environmental effects. In the case of a significant predictive rating, ratings for probability of occurrence and determination of scientific certainty are also included in the table of residual environmental effects. The guidelines used to determine these ratings are discussed in the following sections.

5.4.6.1 Significance Rating

Significant residual environmental effects are those that are considered to be of sufficient magnitude, duration, frequency, geographic extent, and/or reversibility to cause a change in the VEC that will alter its status or integrity beyond an acceptable level. Establishment of the criterion is based on

professional judgment but is transparent and repeatable. In this EA, a significant residual effect is defined as:

> *Having either a high magnitude regardless of duration and geographic extent ratings, or a medium magnitude for more than one year over a geographic extent greater than 100 km^2*

A residual effect can be considered *significant* (S), *not significant* (NS), or *positive* (P).

5.4.6.2 Level of Confidence

The significance of the residual environmental effects is based on a review of relevant literature, consultation with experts, and professional judgement. In some instances, making predictions of potential residual environmental effects are difficult due to the limitations of available data (i.e., technical boundaries). Ratings are therefore provided to qualitatively indicate the level of confidence for each prediction. The level of confidence is considered low (1), medium (2) or high (3).

5.4.6.3 Probability of Occurrence

The probability of occurrence of a *significant* residual effect, based on professional judgement, is considered low (1), medium (2) or high (3).

5.4.6.4 Scientific Certainty

The scientific certainty of a *significant* residual effect, based on scientific information, statistical analysis and/or professional judgement, is considered low (1), medium (2) or high (3).

5.5 Effects of the Environment on the Project

The physical environment is summarized in Section 3.0 and the reader is referred to this section and Section 5.5 in LGL (2012a) to assist in determining the effects of the environment on the Project. Furthermore, safety issues are assessed in detail during the permitting and program application processes established by the C-NLOPB as the regulatory authority in this matter. Nonetheless, effects on the Project are important to consider, at least on a high level, because they may sometimes cause effects on the environment. For example, accidental spills may be more likely to occur during rough weather.

Given the Project time window of May to December for seismic operations and the requirement of a seismic survey to avoid periods and locations of sea ice, sea ice should have little or no effect on the Project. Icebergs in the spring and early summer may cause some survey delays if tracks have to be altered to avoid them. Icebergs may cause some detours in May when iceberg occurrence of any size is on the order of 28% (of total for the year) as opposed to June (9%), July (2%), and August through December (essentially 0%) based on data contained in Table 3.5.3 in LGL (2012a).

Most environmental constraints on seismic surveys on the Grand Banks are those imposed by wind and wave. If the Beaufort wind scale is six or greater, there is generally too much noise for seismic data to be of use. A Beaufort wind scale of six is equivalent to wind speeds of 22-27 knots (11.3-13.9 m/s), and is associated with wave heights ranging from 2.4-4.0 m. In the Study Area, these conditions are typically reached at a consistent level in the late autumn and winter months. Certainly, if the sea state exceeds 3.0 m or winds exceed 40 kt (20.6 m/s), then continuation/termination of seismic surveying will

be evaluated. The absolute operating limits for seismic vessels are 3.5 m combined sea significant wave height and 45 kt (23.2 m/s) winds. Based on multi-year data at a nearby grid point, these wave limits may be approached about 8% of the time in May, 4% in June, 2% in July, 4% in August, 12% in September, 26% in October, 38% in November, and 55% of the time in December (see Figure 3.2.1 in LGL 2012a). Similarly, 23.2 m/s winds might occur 1% or less of the time during the Project time frame based on historical data (see Figure 3.10 in LGL 2012a).

Poor visibility (discussed in Section 3.3.3) can constrain helicopter operations. It also may hinder sightings of other vessels and fishing gear. These constraints are alleviated somewhat by Suncor's seismic contractor's experience in NW Atlantic operations, state of the art forecasting, use of radar and FLOs to detect fishing vessels and gear.

As a prediction of the effects of the environment on the Project, some operators have used an estimate of 25% weather-related down time for the project planning purposes. If 25% is used as a guideline, then conditions in November and December might be considered a significant effect on Project logistics and economics by some proponents although this is likely to be variable depending upon the operator.

The Project scheduling avoids most of the continuous extreme weather conditions and Suncor's contractors will be thoroughly familiar with East Coast operating conditions. 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.

Environmental effects on other Project vessels (e.g., picket and service vessels) are likely less than on the seismic vessel which is constrained by safety of towed gear and data quality issues.

Effects of the biological environment on the Project are unlikely although there are anecdotal accounts of sharks attacking and damaging streamers.

The Department of National Defense (DND) will be contacted in regard to potential unexploded ordnance (UXO) in the area prior to any deployment of OBCs.

Effects of the environment on the Project are predicted to be *not significant* for the reasons discussed above.

5.6 Effects of the Project Routine Activities on the Environment

The main pathway that links the Project and environment is the transmission of sound from the seismic survey sources to the various VECs (or "receivers"). The basics of sound and its propagation in the marine environment are described in Richardson et al. (1995). Of principal concern during seismic programs is the potential effects of sound from air sources on VECs as air sources used during marine seismic operations introduce strong sound impulses into the water (see Appendix C *in* LGL 2007a for a detailed review of the characteristics of air source pulses). The seismic pulses produced by the air sources are intentionally directed downward toward the seafloor, insofar as possible; however, energy will propagate outward from the source through the water. The following sections review the hearing/detection abilities of VECs and the available information on potential effects of sound (as well as other Project activities) from the proposed seismic program on VECs.

5.6.1 Fish and Fish Habitat VEC

Despite the probability of interaction between Project activities and the 'fish habitat' component of the Fish and Fish Habitat VEC (i.e., water and sediment quality, phytoplankton, zooplankton, and benthos) (Table 5.1), residual effects are predicted to be *negligible* and thus *not significant*. The seismic program will not result in any direct physical disturbance of the bottom substrate. Also, the probability of an accidental event (i.e., hydrocarbon release) of sufficient magnitude to cause a significant effect on fish habitat is low. Therefore, other than in Table 5.1, no further reference to the 'fish habitat' component of the Fish and Fish Habitat VEC is made in this assessment subsection. Ichthyoplankton, invertebrate eggs and larvae, and macrobenthos are considered as part of the 'fish' component of the Fish and Fish Habitat VEC.

The following subsections discuss the Project activities that will interact with the Fish and Fish Habitat VEC, and include assessment of the potential effects of these interactions.

5.6.1.1 Underwater Sound

Exposure to anthropogenic underwater sounds has the potential to cause physical, physiological and behavioural effects on marine invertebrates and fishes. Studies that conclude that there are physical and physiological effects typically involve captive subjects that are unable to move away from the sound source and are therefore exposed to higher sound levels than under natural conditions. Comprehensive literature reviews related to auditory capabilities of fishes and marine invertebrates and the potential effects of exposure to seismic airgun noise on them are contained in Appendices D and E. The following sections related to the Fish and Fish Habitat VEC contain summaries of the information contained in the two appendices.

Sound Detection

Sensory systems, like those that allow for hearing, provide information about an animal's physical, biological, and social environments, in both air and water. 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).

Underwater sound has both a pressure component and a particle motion component associated with it. While all marine invertebrates and fishes appear to have the capability of detecting the particle displacement component of underwater sound, only certain fish species appear to be sensitive to the pressure component (Breithaupt 2002; Casper and Mann 2006; Popper and Fay 2010).

Invertebrates

The "hearing" abilities of marine invertebrates are the subject of ongoing debate. Aquatic invertebrates (with the exception of aquatic insects) do not possess the equivalent physical structures present in fish and marine mammals that can be stimulated by the pressure component of sound. It appears that marine invertebrates respond to vibrations rather than pressure (Breithaupt 2002). Statocysts (organs of balance containing mineral grains that stimulate sensory cells as the animal moves) apparently function as a vibration detector for at least some species of marine invertebrates (Popper and Fay 1999). The statocyst is a gravity receptor and allows the swimming animal to maintain a suitable orientation.

Table 5.1. Potential Interactions of the Project Activities and the Fish and Fish Habitat VEC.

Valued Environmental Component: Fish and Fish Habitat							
Project Activities	**Non-Biological Environment**	**Feeding**		**Reproduction**		**Adult Stage**	
	Water or Sediment Quality	**Plankton**	**Benthos**	**Eggs and Larvae**	**Juveniles [a]**	**Pelagic Fish**	**Groundfish**
Sound							
Airguns		X	X	X	X	X	X
Seismic Vessel						X	
Supply Vessel						X	
Picket Vessel						X	
Echo Sounder						X	
Side Scan Sonar						X	
Boomer / Sparker			X	X	X	X	X
Vessel Lights		X				X	
Vessel Presence							
Seismic Vessel							
Supply Vessel							
Picket Vessel							
Helicopter Presence [b]							
Sanitary/Domestic Waste	X	X		X		X	
Atmospheric Emissions	X	X		X		X	
Garbage [c]							
Shore Facilities [d]							
Accidental Releases	X	X		X		X	
Other Projects and Activities							
Oil and Gas Activities on Grand Banks and Orphan Basin	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 have left the plankton and are often found closely associated with substrates.
[b] A crew change may occur via helicopter if the seismic program is longer than 5 to 6 weeks.
[c] Not applicable as garbage will be brought ashore.
[d] There will not be any new onshore facilities; existing infrastructure will be used.

Among the marine invertebrates, decapod crustaceans have been the most intensively studied in this regard. Crustaceans appear to be the most sensitive to low frequency sounds (i.e., <1,000 Hz) (Budelmann 1992; Popper et al. 2001), with some species being particularly sensitive to low-frequency sound (Lovell et al. 2006). Other studies suggest that some species (such as American lobster) may also be more sensitive to high frequencies than has been previously reported (Pye and Watson III 2004).

It is likely that cephalopods also use statocysts to detect low-frequency aquatic vibrations (Budelmann and Williamson 1994). Kaifu et al. (2008) provided evidence that the cephalopod *Octopus ocellatus* detects particle motion with its statocyst. Studies by Packard et al. (1990), Rawizza (1995), Komak et al. (2005) and Mooney et al. (2010) have quantified some of the optimally detected sound frequencies for various octopus (1–100 Hz), squid (1–500 Hz), and cuttlefish (20–8,000 Hz) species. Using the auditory brainstem response approach, Hu et al. (2009) showed that auditory-evoked potentials can be obtained in the frequency ranges 400–1,500 Hz for the squid *Sepiotheutis lessoniana* and 400-1,000 Hz for the octopus *Octopus vulgaris*, higher than frequencies previously observed to be detectable by cephalopods.

A recent study concluded that planktonic coral larvae can detect and respond to sound, the first description of an auditory response in the invertebrate phylum Cnidaria (Vermeij et al. 2010). Eggleston et al. (2013) have presented results of laboratory and field experiments that suggest oyster larvae use underwater sound to optimize settlement.

Fishes

Marine fish are known to vary widely in their ability to hear sounds. Although hearing capability data only exist for fewer than 100 of the 27,000 fish species (Hastings and Popper 2005), current data suggest that most species of fish detect sounds below 1,500 Hz (Popper and Fay 2010). Some marine species, such as shads and menhaden, can detect higher frequency sounds above 180 kHz (Mann et al. 1997, 1998, 2001). Also, at least some species are acutely sensitive to infrasound (very low frequency), down to below 1 Hz (Sand and Karlsen 2000). Reviews of fish-hearing mechanisms and capabilities can be found in Fay and Popper (2000) and Ladich and Popper (2004).

All fish species have hearing (inner ear) and skin-based mechanosensory systems (lateral lines). Amoser and Ladich (2005) hypothesized that, as species within a particular family of fish may live under different ambient sound conditions, the hearing abilities of the individual species are likely to have adapted to the dominant conditions of their specific environments. The ability of fish to hear a range of biotic and abiotic sounds may affect their survival rate, with better adapted fish having an advantage over those that cannot detect prevailing sounds (Amoser and Ladich 2005).

Fish ears are able to respond to changes in pressure and particle motion in the water (van Bergeijk 1964; Schuijf 1981; Kalmijn 1988, 1989; Shellert and Popper 1992; Hawkins 1993; Fay 2005). Two major pathways have been identified for sound transmittance: (1) the otoliths, calcium carbonate masses in the inner ear that act as accelerometers when exposed to the particle motion component of sound, which cause shearing forces that stimulate sensory hair cells; and (2) the swim bladder, which expands and contracts in a sound field, re-radiating the sound's signal within the fish and in turn stimulating the inner ear (Popper and Fay 1993).

Researchers have noted that fish without an air-filled cavity (swim bladder), or with a reduced swim bladder or limited connectivity between the swim bladder and inner ear, are limited to detecting particle motion and not pressure, and therefore have relatively poor hearing abilities (Casper and Mann 2006). These species have commonly been known as 'hearing generalists' (Popper and Fay 1999), although a recent reconsideration suggests that this classification is oversimplified (Popper and Fay 2010). Rather, there is a range of hearing capabilities across species that is more like a continuum, presumably based on the relative contributions of pressure to the overall hearing capabilities of a species (Popper and Fay 2010). Results of direct study of fish sensitivity to particle motion have been

reported in numerous recently published papers (e.g., Horodysky et al. 2008; Wysocki et al. 2009; Kojima et al. 2010).

Sound Production

Many invertebrates and fishes produce sounds. It is believed that these sounds are used for communication in a wide range of behavioural and environmental contexts. The behaviours most often associated with acoustic communication include territorial behaviour, mate finding, courtship and aggression. Sound production provides a means of long distance communication as well as communication when underwater visibility is poor (Zelick et al. 1999).
Invertebrate groups with species capable of producing sound include barnacles, amphipods, shrimps, crabs, and lobsters (Au and Banks 1998; Tolstoganova 2002; Pye and Watson III 2004; Henninger and Watson III 2005; Buscaino et al. 2011). Invertebrates typically produce sound by scraping or rubbing various parts of their bodies, although they also produce sound in other ways.

More than 700 fish species are known to produce sounds (Myrberg 1981, Kaatz 2002 *in* Anderson et al. 2008). Fishes produce sounds mainly by using modified muscles attached to their swim bladders (i.e., drumming) or rubbing body parts together (i.e., stridulating). Examples of 'soniferous' fishes include Atlantic cod (Finstad and Nordeide 2004; Rowe and Hutchings 2004), toadfishes (Locascio and Mann 2008; Vasconcelos and Ladich 2008), and basses (Albers 2008; Johnston et al. 2008).

Effects of Exposure to Airgun Sound

Most airgun sound energy is associated with frequencies <500 Hz, although there is also some energy at higher frequencies. For the purposes of this EA, physical effects include both pathological and physiological effects.

Physical Effects

Invertebrates

To date, experimentation intended to investigate the physical effects of exposure to seismic airgun sound on marine invertebrates has been limited to crustaceans and molluscs. Both egg/larvae and adult stages have been used in the limited number of experiments.

Dungeness crab (*Cancer magister*) larvae and snow crab (*Chionoecetes opilio*) fertilized eggs have both been exposed to airgun sound during studies. In their field study, Pearson et al. (1994) did not find any statistically significant differences in immediate survival, long-term survival, or time to moult between the exposed and unexposed Dungeness crab larvae, even when considering those exposed to the sound within one metre of the seismic source. Christian et al. (2003, 2004) found a significant difference in development rate between exposed and unexposed fertilized eggs containing embryos. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than did the unexposed mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable. In another field study involving snow crab, neither acute nor chronic lethal or sub-lethal injury to crab embryos was apparent after egg-bearing females were exposed to seismic sound emitted during a commercial seismic survey (DFO 2004a,b). In a recent study, wild New Zealand scallop larvae were exposed to recorded seismic sound and results

suggested developmental delays and body abnormalities due to cumulative exposure (de Soto et al. 2013)

Adult American lobster (*Homarus americanus*), snow crab, squid (*Sepioteuthis australis*) and blue mussels (*Mytilus edulis*) have also been used as subjects during the study of the potential effects of exposure to airgun sound on marine biota. Payne et al. (2007) exposed adult lobsters during a laboratory study and observed for both acute and chronic physical effects. No pathological effects were seen but significant differences in levels of serum protein, enzymes and calcium were observed. Payne et al. (2007) also noted during histological analysis four months after exposure the presence of glycogen deposits in the hepatopancreas of some exposed animals, perhaps due to stress or disturbance of cellular processes. Christian et al. (2003, 2004) did not observe any physical effects in adult snow crab exposed to seismic airgun sound. Physical differences between exposed and control female snow crabs were observed during a study in the Gulf of St. Lawrence (DFO 2004a,b) but due to study design, these differences could not be linked to the airgun sound. McCauley et al. (2000a,b) indicated that no squid or cuttlefish mortalities were reported as a result of exposure of the caged animals to airgun sound.

See Appendix D for more details related to experimental study of the physical effects of exposure to airgun sound on marine invertebrates.

Fishes

Review papers on the effects of anthropogenic sources of underwater sound on fishes have been published relatively recently (Payne et al. 2008; Popper 2009; Popper and Hastings 2009a,b). These papers consider various sources of anthropogenic sound, including seismic airguns. As with marine invertebrates, both egg/larvae and adult stages have been used in the study of physical effects of exposure to airgun sound on fishes.

Fertilized capelin (*Mallotus villosus*) eggs and monkfish (*Lophius americanus*) larvae were exposed to seismic airgun sound in the laboratory and subsequently examined and monitored for possible effects of the exposure (Payne et al. 2009). 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 either the capelin eggs or the monkfish larvae. In uncontrolled experiments, Kostyuchenko (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. Eggs, yolk sac larvae, post-yolk sac larvae, post-larvae, and fry of various commercially important fish species (cod, saithe, herring, turbot, and plaice) were exposed to received SPLs ranging from 220 to 242 dB re 1 µPa (unspecified measure type) (Booman et al. 1996). These received levels corresponded to exposure distances ranging from 0.75 to 6 m. The authors reported some cases of injury and mortality but most of these occurred as a result of exposures at very close range.

Evidence for airgun-induced damage to adult fish ears has come from studies using caged pink snapper (*Pagrus auratus*) (McCauley et al. 2000a,b, 2003). 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 hours 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.

Popper et al. (2005) tested the hearing sensitivity of three Mackenzie River fish species after exposure to seismic airgun sound. While the broad whitefish (*Coregonus nasus*) showed no temporary threshold shift (TTS) as a result of the exposure, adult northern pike (*Esox lucius*), and lake chub (*Couesius plumbeus*) did exhibit some TTS from which they recovered after 24 hours. 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.

In uncontrolled experiments using a very small sample of different groups of young salmonids, including Arctic cisco (*Coregonus autumnalis*), fish were caged and exposed to various types of sound, including seismic airgun sound. Swim bladder damage was reported but no mortality was observed when fish were exposed within 1 to 2 m of an airgun source.

See Appendix E for more details related to experimental study of the physical effects of exposure to airgun sound on marine fishes (e.g., received sound pressure levels).

Behavioural Effects

Considering the lack of scientific evidence for physical effects of exposure to airgun sound on unfettered marine invertebrates and fishes, much of the current research is investigating the behavioural effects of exposure to airgun sound on these biota.

Invertebrates

Christian et al. (2003) investigated the behavioural effects of exposure to airgun sound on snow crabs using both telemetry and underwater video. None of the animals tagged with ultrasonic transmitters left the immediate area after exposure to the airgun sound. Underwater video was used to monitor caged animals placed on the ocean bottom at a depth of 50 m and then exposed to airgun sound. They did not exhibit any overt startle response during the exposure period.

Payne et al. (2007), in their study of the effects of exposure to airgun sound on adult American lobsters, noted a trend for increased food consumption by the animals exposed to seismic sound.

McCauley et al. (2000a,b) provided the first evidence of the behavioural response of cephalopods exposed to seismic survey sound. Squid and cuttlefish were exposed to both stationary and mobile airgun sound sources. Some of the squid fired their ink sacs apparently in response to the first shot of one of the trials and then moved quickly away from the airgun. In addition to the startle responses, some squid also increased swimming speed and moved towards the water surface as the airgun approached.

Although not demonstrated in the invertebrate literature, masking can be considered a potential effect of anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005). The functionality and biological relevance of these sounds are not understood (Jeffs et al. 2003, 2005; Lovell et al. 2006; Radford et al. 2007). If some of the sounds are of biological significance to some invertebrates, then

masking of those sounds or sounds produced by predators could potentially have adverse effects on marine invertebrates. However, even if masking does occur in some invertebrates, the intermittent nature of airgun sound is expected to result in less masking effect than would occur with continuous sound.

Invertebrate Fisheries

Christian et al. (2003) investigated the pre- and post-exposure catchability of snow crabs during a commercial fishery. Catch-per-unit-effort did not decrease after the crabs were exposed to seismic survey sound. Note that there was considerable variability in set duration due to poor weather conditions. Anecdotal information from Newfoundland suggested that catch rates of snow crabs showed a reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, pers. comm.). Additional anecdotal information from Newfoundland indicated that a school of shrimp observed via a fishing vessel sounder shifted downwards and away from a nearby seismic airgun sound source (H. Thorne, Newfoundland fisherman, pers. comm.). These observed behaviours were temporary.

Andriguetto-Filho et al. (2005) evaluated the impact of seismic survey sound on artisanal shrimp fisheries off Brazil. Results of that study did not indicate any significant impact on shrimp catches.

Parry and Gason (2006) statistically analyzed data related to rock lobster (*Jasus edwardsii*) commercial catches and seismic surveying in Australian waters from 1978 to 2004. They found no evidence that lobster catch rates were affected by seismic surveys. They also noted that due to natural variability and fishing pressure, a large effect on lobster would be required to make any link to seismic surveys.

See Appendix D for more details related to experimental study of the behavioural effects of exposure to airgun sound on marine invertebrates.

Fishes

Pearson et al. (1992) investigated the behavioural effects of seismic airgun sound on the behaviour of captive rockfishes (*Sebastes* spp.). The authors reported that rockfishes reacted to the airgun sounds by exhibiting varying degrees of startle and alarm responses, depending on the species of rockfish and the received sound pressure level. Skalski et al. (1992) also studied the potential behavioural effects of exposure to seismic airgun sound on the rockfishes. 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 this experimental approach was quite different from an actual seismic survey, in that duration of exposure was much longer.

Caged fish exposed to airgun sound in a study by McCauley et al. (2000a,b) exhibited startle and alarm responses. The occurrence of both startle response (classic C-turn response) and alarm responses (e.g., darting movements, flash school expansion, fast swimming) decreased over time. Other observations included downward distributional shift, increase in swimming speed, and the formation of denser aggregations. Fish behaviour appeared to return to pre-exposure state shortly after the exposures ended.

Other studies of fish behavioural effects of exposure to airgun sound have been conducted (Chapman and Hawkins 1969; Dalen and Knutsen 1986; La Bella et al. 1996; Santulli et al. 1999; Wardle et al.

2001; Thomsen 2002; Hassel et al. 2003, 2004; Slotte et al. 2004; Boeger et al. 2006; Jorgenson and Gyselman 2009). Generally, these studies reported results similar to those described above; temporary startle/alarm responses and distributional shifts.
The next subsection reviews fishery-related studies of fish behavioural effects due to exposure to airgun sound.

Finfish Fisheries

Early experimentation on 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 exposure to seismic airgun sound on distributions, abundances, and catch rates of cod and haddock using acoustic mapping and experimental fishing with trawls and longlines. They concluded that there were indications of distributional change during and immediately following the seismic airgun discharge. 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.

Dalen and Knutsen (1986), Løkkeborg (1991), and Løkkeborg and Soldal (1993) also examined the effects of seismic airgun sound on demersal fish catches. Løkkeborg (1991) examined the effects on cod catches. Catch rate decreases ranging from 55 to 80% within the seismic survey area were observed. This apparent effect persisted for at least 24 hours within about 10 km of the survey area. The effect of exposure to seismic sound on commercial demersal fishes was again studied in 2009 using gillnet and longline fishery methods off the coast of Norway (Løkkeborg et al. 2010). Study results indicated that fishes did react to airgun sound based on observed changes in catch rates during seismic shooting. Gillnet catches increased during the seismic shooting, likely a result of increased fish activity, while longline catches decreased overall.

Turnpenny and Nedwell (1994) reported on the effects of seismic airgun discharge on inshore bass fisheries in shallow U.K. waters (5 to 30 m deep). 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 often more rapid in shallow water, depending on the physical characteristics of the water and substrate in the area.

Skalski et al. (1992) examined the potential effects of airgun sound on the catchability of rockfishes. The catch-per-unit-effort (CPUE) for rockfish declined on average by 52.4% when the airguns were operating. Skalski et al. (1992) believed 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.

See Appendix E for more details related to experimental study of the behavioural effects of exposure to airgun sound on marine fishes.

Effects of Exposure to Marine Vessel Sound

Numerous papers about the behavioural responses of fishes to marine vessel sound have been published in the primary literature. They consider the responses of small pelagic fishes (e.g., Misund et al. 1996; Vabo et al. 2002; Jørgensen et al. 2004; Skaret et al. 2005; Ona et al. 2007; Sand et al. 2008), large pelagic fishes (Sarà et al. 2007), and groundfishes (Engås et al. 1998; Handegard et al. 2003; De Robertis et al. 2008). Generally, most of the papers indicate that fishes typically exhibit some level of reaction to the sound of approaching marine vessels, the degree of reaction being dependent on a variety of factors including the activity of the fish at the time of exposure (e.g., reproduction, feeding, and migration), characteristics of the vessel sound, and water depth.

Sound Exposure Effects Assessment

The assessment in this and subsequent subsections is structured such that the reader should first refer to the interaction table (e.g., Table 5.1) to determine if there are any interactions with Project activities, secondly to the assessment table (e.g., Table 5.2) which contains ratings for magnitude, extent, and duration, and so forth, and thirdly to the significance predictions table (e.g., Table 5.3).

It is impossible to assess in detail the potential effects of every type of sound on every species in the Study Area. The best approach, and common practice in EA, is to provide focus by selecting (1) the strongest sound source, in this case the airgun array, and (2) several species that are locally important and representative of the different types of sensitivities, and (3) species or groups that offer a relevant literature base. Snow crab and Atlantic cod best serve this purpose.

The most notable criteria in the assessment include (1) distance between airgun array and animal under normal conditions (e.g., 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 (e.g., 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 without swimbladder and cod with swimbladder), and (4) reproductive strategy (snow crabs carry fertilized eggs at the bottom until larval hatch, and cod eggs are planktonic).

Potential impacts on other marine invertebrate and fish species are inferred from the assessment using snow crab and Atlantic cod.

As already indicated in this subsection, although research on the effects of exposure to airgun sound on marine invertebrates and fishes is increasing, many data gaps remain. Available experimental data suggest that there may be physical impacts on the fertilized eggs of snow crab and on the egg, larval, juvenile and adult stages of cod at very close range. Considering the typical source levels associated with commercial seismic airgun arrays, close proximity to the source would result in exposure to very high sound levels. While egg and larval stages are not able to actively escape such an exposure scenario, juvenile and adult cod would most likely avoid it. Developing embryos, juvenile and adult snow crab are benthic and generally far enough from the sound source to receive energy levels well below levels that may have effects. In the case of eggs and larvae, it is likely that the numbers negatively affected by exposure to seismic sound would be within the range of those succumbing to natural mortality. Atlantic cod do have swim bladders and are therefore generally more sensitive to underwater sounds than fishes without swim bladders. Spatial and temporal avoidance of critical life history times (e.g., spawning aggregations) to the extent possible as well as ramp-up should mitigate

the effects of exposure to airgun sound. Snow crab, sensitive to the particle displacement component of sound only, will be at least 75-100 m from the airguns and will not likely be affected by any particle displacement resulting from airgun discharge.

Table 5.2. Assessment of Effects on the Fish and Fish Habitat VEC.

Valued Environmental Component: Fish and Fish Habitat									
Project Activity	**Potential Positive (P) or Negative (N) Environmental Effect**	**Mitigation**	**Evaluation Criteria for Assessing Environmental Effects**						
			Magnitude	**Geographic Extent**	**Frequency**	**Duration**	**Reversibility**	**Ecological/ Socio-Cultural and Economic Context**
Sound									
Airguns	Physical effects (N); Disturbance (N)	Ramp-up of array; Spatial & temporal avoidance[a]	1	1-3	6	1-2	R	2
Seismic Vessel	Disturbance (N)	Spatial & temporal avoidance[a]	0-1	1	6	1-2	R	2
Supply Vessel	Disturbance (N)	Spatial & temporal avoidance[a]	0-1	1	6	1	R	2
Picket Vessel	Disturbance (N)	Spatial & temporal avoidance[a]	0-1	1	6	1-2	R	2
Echo Sounder	Disturbance (N)	Spatial & temporal avoidance[a]	0	1	6	1	R	2
Side Scan Sonar	Disturbance (N)	Spatial & temporal avoidance[a]	0	1	6	1	R	2
Boomer / Sparker	Disturbance (N)	Spatial & temporal avoidance[a]	0	1	6	1	R	2
Vessel Lights	Neutral effect	-	-	-	-	-	-	-
Sanitary/ Domestic Waste	Pathological effects (N); Contamination (N)	Treatment	0-1	1	1	1-2	R	2
Atmospheric Emissions	Pathological effects (N); Contamination (N)	Equipment maintenance	0	1	6	1-2	R	2
Accidental Releases	Pathological effects (N); Contamination (N)	Solid streamer[b]; spill response	0-1	1-2	1	1	R	2

Key:

Magnitude:
0 = Negligible, essentially no effect
1 = Low
2 = Medium
3 = High

Frequency:
1 = <11 events/yr
2 = 11-50 events/yr
3 = 51-100 events/yr
4 = 101-200 events/yr
5 = >200 events/yr
6 = continuous

Reversibility:
R = Reversible
I = Irreversible
(refers to population)

Duration:
1 = <1 month
2 = 1-12 months
3 = 13-36 months
4 = 37-72 months
5 = >72 months

Geographic Extent:
1 = <1 km^2
2 = 1-10 km^2
3 = 11-100 km^2
4 = 101-1,000 km^2
5 = 1,001-10,000 km^2
6 = >10,000 km^2

Ecological/Socio-cultural and Economic Context:
1 = Relatively pristine area or area not negatively affected by human activity
2 = Evidence of existing negative effects

[a] Avoidance of sensitive areas and times,to the extent possible.
[b] Solid or isopar filled streamers may be used during surveys, depending on the seismic contractor.

Table 5.3. Significance of Potential Residual Environmental Effects of Project Activities on the Fish and Fish Habitat VEC.

Valued Environmental Component: Fish and Fish Habitat				
Project Activity	**Significance Rating**	**Level of Confidence**	**Likelihood[a]**	
	Significance of Predicted Residual Environmental Effects		**Probability of Occurrence**	**Scientific Certainty**
Sound				
Airguns	NS	2-3	-	-
Seismic Vessel	NS	2-3	-	-
Supply Vessel	NS	2-3	-	-
Picket Vessel	NS	2-3	-	-
Echo Sounder	NS	2-3	-	-
Side Scan Sonar	NS	2-3	-	-
Boomer / Sparker	NS	2-3	-	-
Vessel Lights	NS	3	-	-
Sanitary/Domestic Wastes	NS	3	-	-
Atmospheric Emissions	NS	3	-	-
Accidental Releases	NS	2-3	-	-

Key:

Residual environmental Effect Rating:
S = Significant Negative Environmental Effect
NS = Not-significant Negative Environmental Effect
P = Positive Environmental Effect

Significance is defined as a medium or high magnitude (2 or 3 rating) and duration greater than 1 year (3 or greater rating) and geographic extent >100 km^2 (4 or greater rating).

Level of Confidence: based on professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

Probability of Occurrence: based on professional judgment:
1 = Low Probability of Occurrence
2 = Medium Probability of Occurrence
3 = High Probability of Occurrence

Scientific Certainty: based on scientific information and statistical analysis or professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

[a] Considered only in the case where 'significant negative effect' is predicted.

Limited data regarding physiological impacts on fish and invertebrates indicate that these impacts are both short-term and most obvious after exposure at close range.

The physical effects of exposure to sound with frequencies >500 Hz are *negligible*, based on the available information from the scientific literature. Effects of exposure to >500 Hz sound and marine vessel sound appear to be primarily behavioural and somewhat temporary.

Table 5.2 provides the details of the assessment of the effects of exposure to Project-related sound on the Fish and Fish Habitat VEC. As indicated in Table 5.2, sound produced as a result of the proposed Project (airgun array sound being the worst-case scenario) is predicted to have *negligible* to *low* magnitude residual effects on the various life stages of the Fish and Fish Habitat VEC for a duration of *<1 month* to *1 to 12 months* over an area of *<1 to 11-100 km^2*. Based on these criteria ratings, the

reversible residual effects of *continuous* Project-related sound on the Fish and Fish Habitat VEC are predicted to be *not significant* (see Table 5.3)

5.6.1.2 Other Project Activities

Vessel Lights

There are potential interactions between vessel lights and certain components of the Fish and Fish Habitat VEC (see Table 5.1). However, other than the relatively neutral effect of attraction of certain species/life stages to the upper water column at night, there will be *negligible* effects of vessel lights on this VEC (see Table 5.2). Therefore, the residual effects of vessel lights associated with the proposed Project on the Fish and Fish Habitat VEC are predicted to be *not significant* (see Table 5.3).

Sanitary/Domestic Waste

There are potential interactions between sanitary/domestic waste and certain components of the Fish and Fish Habitat VEC (Table 5.1). After application of mitigation measures, including treatment of the waste, the residual effects of sanitary/domestic waste on the Fish and Fish Habitat VEC are predicted to be *negligible to low* in magnitude for a duration of *<1 to 1-12 months* over an area of *<1 km*^{2} (see Table 5.2). Based on these criteria ratings, the *reversible* residual effects of *infrequen*t exposure to sanitary/domestic waste associated with the proposed Project on the Fish and Fish Habitat VEC are predicted to be *not significant* (see Table 5.3).

Atmospheric Emissions

There are potential interactions between atmospheric emissions and certain components of the Fish and Fish Habitat VEC that occur very near surface (Table 5.1). Considering that the amount of atmospheric emissions produced during the proposed seismic program will rapidly disperse to undetectable levels, the residual effects of exposure to them on the Fish and Fish Habitat VEC are predicted to be *negligible* (see Table 5.2). Therefore, the *reversible* residual effects of *continuous* atmospheric emissions associated with the proposed Project on the Fish and Fish Habitat VEC are predicted to be *not significant* (see Table 5.3).

Accidental Releases

Planktonic invertebrate and fish eggs and larvae are less resistant to effects of contaminants than are adults because they are not physiologically equipped to detoxify them or to actively avoid them. In addition, many eggs and larvae develop at or near the surface where hydrocarbon exposure may be the greatest (Rice 1985). Generally, fish eggs appear to be highly sensitive at certain stages and then become less sensitive just prior to larval hatching (Kühnhold 1978; Rice 1985). Larval sensitivity varies with yolk sac stage and feeding conditions (Rice et al. 1986). Eggs and larvae exposed to high concentrations of hydrocarbons generally exhibit morphological malformations, genetic damage, and reduced growth. Damage to embryos may not be apparent until the larvae hatch. The natural mortality rate in fish eggs and larvae is extremely high and very large numbers would have to be destroyed by anthropogenic sources before effects would be detected in an adult population (Rice 1985).

There is an extensive body of literature regarding the effects of exposure to hydrocarbons on juvenile and adult fish. Although some of the literature describes field observations, most refer to laboratory studies. Reviews of the effects of hydrocarbons on fish have been prepared by Rice et al. (1986), Armstrong et al. (1995), Payne et al. (2003), and numerous other authors. If exposed to hydrocarbons in high enough concentrations, fish may suffer effects ranging from direct physical effects (e.g., coating of gills and suffocation) to more subtle physiological and behavioural effects. Actual effects depend on a variety of factors such as the amount and type of hydrocarbon, environmental conditions, species and life stage, lifestyle, fish condition, degree of confinement of experimental subjects, and others.

As indicated in Table 5.1, there are potential interactions of accidental releases and components of the Fish and Fish Habitat VEC that occur near surface. The effects of hydrocarbon spills on marine invertebrates and fish have been discussed and assessed in numerous recent environmental assessments of proposed offshore drilling programs and assessments have concluded that the residual effects of accidental hydrocarbon releases on the Fish and Fish Habitat VEC are predicted to be *not significant*. With proper mitigations in place, the residual effects of an accidental release associated with Suncor's proposed seismic program on the Fish and Fish habitat VEC would be *negligible* to *low* in magnitude for a duration of *<1 month* over an area of *<1* to *1-10 km*^{2} (see Table 5.2). Based on these criteria ratings and consideration that the probability of accidental hydrocarbon releases during the proposed seismic program are low, the *reversible* residual effects of accidental releases associated with the proposed program on the Fish and Fish Habitat VEC are predicted to be *not significant* (see Table 5.3).

5.6.2 Fisheries VEC

The potential interactions of Project activities and the Fishery VEC are indicated in Table 5.4. DFO and joint DFO/Industry Research Surveys were included in the assessment of the Fishery VEC.

The seismic survey vessel and Project-related support vessel traffic will be present within NAFO Division 3L. Behavioural changes in commercial species in relation to catchability, and conflict with harvesting activities and fishing gear were raised as potential issues during the consultations and issues scoping for recent EAs (see reviewed EAs in Section 5.1). Additionally, concerns related to the annual post-season snow crab trap survey were raised during the consultations for this assessment. Seismic streamers and vessels can conflict with and damage fishing gear, particularly fixed gear (e.g., snow crab pots or gillnets). Such conflicts have occurred in Atlantic Canada in the past when seismic vessels were operating in heavily fished areas. There is also a potential for interference from seismic activities with DFO and DFO/Industry research surveys if both are being conducted in a same general area at the same time. An accidental release of petroleum hydrocarbons may result in tainting (or perceived tainting) thus affecting product quality and marketing.

The chief means of mitigating potential impacts on fishery activities is to avoid active fishing areas, particularly fixed gear zones. For the commercial fisheries, gear damage compensation provides a means of final mitigation of impacts, in case a conflict does occur with fishing gear (i.e., accidental contact of gear with the survey air source array, streamers or seismic vessel).

Table 5.4. Potential Interactions of Project Activities and the Fisheries VEC.

Valued Environmental Component: Fishery			
Project Activities	**Mobile Invertebrates and Fishes (fixed [e.g., gillnet] and mobile gear [e.g., trawls])**	**Sedentary Benthic Invertebrates (fixed gear [e.g., crab pots])**	**Research Surveys (mobile gear-trawls; fixed gear-crab pots)**
Sound			
Airguns	X	X	X
Seismic Vessel	X	X	X
Supply Vessel	X	X	X
Picket Vessel	X	X	X
Echo Sounder	X		
Side Scan Sonar	X		X
Boomer / Sparker	X	X	X
Vessel Lights			
Vessel Presence			
Seismic Vessel	X	X	X
Supply Vessel	X	X	X
Picket Vessel	X	X	X
Helicopter Presence [a]			
Sanitary/Domestic Waste	X	X	X
Atmospheric Emissions			
Garbage [b]			
Shore Facilities [c]			
Accidental Releases	X	X	X
Other Projects and Activities			
Oil and Gas Activities on the Grand Banks and Orphan Basin	X	X	X
Marine Transportation	X	X	X

[a] A crew change may occur via helicopter if the seismic program is longer than 5 to 6 weeks.
[b] Not applicable as garbage will be brought ashore.
[c] There will not be any new onshore facilities. Existing infrastructure will be used.

The document *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2012) provides guidance aimed at minimizing any impacts of petroleum industry surveys on commercial fish harvesters and other marine users. The mitigations described below are also relevant to DFO and joint DFO/Industry research surveys. Development of the guidelines was based on best practices applied during previous surveys in Atlantic Canada, as well as guidelines from other national jurisdictions.

The relevant guidelines state the following (in Appendix 2 of C-NLOPB [2012] - Environmental Planning, Mitigation and Reporting – II. Interaction with Other Ocean Users):

VSP Programs and Wellsite Surveys

a) The operator should implement operational arrangements to ensure that the operator and/or its survey contractor and the local fishing interests are informed of each other's planned activities. Communication throughout survey operations with fishing interests in the area should be maintained.

b) *The operator should publish a Canadian Coast Guard "Notice to Mariners" and a "Notice to Fishers" via the CBC Radio program Fisheries Broadcast.*

c) *Operators should implement a gear and/or vessel damage compensation program, to promptly settle claims for loss and/or damage that may be caused by survey operations. The scope of the compensation program should include replacement costs for lost or damaged gear and any additional financial loss that is demonstrated to be associated with the incident. The operator should report on the details of any compensation awarded under such a program (i.e., to the C-NLOPB).*

d) *Procedures must be in place on the survey vessel(s) to ensure that any incidents of contact with fishing gear are clearly detected and documented (e.g., time, location of contact, loss of contact, and description of any identifying markings observed on affected gear). As per Section 5.2 of these Guidelines, any incident should be reported immediately to the 24-hour answering service at (709) 778-1400 or to the C-NLOPB Duty Officer.*

2D, 3D and 4D Seismic Programs

In addition to the measures indicated above, the following mitigation measures should also be implemented:

a) *Surveys should be scheduled, to the extent possible, to reduce potential for impact or interference with Department of Fisheries and Ocean (DFO) science surveys. Spatial and temporal logistics should be determined with DFO to reduce overlap of seismic operations with research survey areas, and to allow an adequate temporal buffer between seismic survey operations and DFO research activities.*

b) *Seismic activities should be scheduled to avoid heavily fished areas, to the extent possible. The operator should implement operational arrangements to ensure that the operator and/or its survey contractor and local fishing interests are informed of each other's planned activities. Communication throughout survey operations with fishing interests in the area should be maintained. The use of a 'Fisheries Liaison Officer' (FLO) onboard the seismic vessel is considered best practice in this respect.*

c) *Where more than one survey operation is active in a region, the operator(s) should arrange for a 'Single Point of Contact' for marine users that may be used to facilitate communication.*

The following sections assess the potential effects of Project activities on the Fishery VEC.

5.6.2.1 Sound

As indicated in the description of commercial fisheries in Section 4.3, there has been substantial harvesting within NAFO Units 3L, 3Lh, 3Li, 3Lr and 3Lt in the Study Area between 2005 and 2010. Snow crab and northern shrimp accounted for most of the commercial harvest within the Study Area during that period.

The potential for impacts on fish harvesting will, therefore, depend on the location and timing of the surveying activities in relation to these fishing areas, and the type of fishing gear used in any given season. If the survey work is situated away from these fishing areas or occur at different times, the likelihood of any impacts on commercial harvesting will be greatly 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 fish harvesting (i.e., potential effects on catch rates and conflicts with research vessel operations).

Potential effects on marine fish behaviour are assessed in Section 5.6.1. While adult fish could be injured by airgun sound if they are within a few metres of a sound source, this is unlikely since fish are likely to disperse during array ramp-up or vessel approach. Therefore, the most likely type of effect will be behavioural. 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 5.6.1. While some of the behavioural effects studies report decreases in catch rates near the seismic survey area, there is some disagreement on the duration and geographical extent of the effect.

Mitigation

Mitigations are detailed in a previous section. The primary measures intended to minimize the effects of Project activities on the harvesting success component of the Fishery VEC include:

- Avoidance in time and space of concentrated fishing areas to the greatest extent possible;
- Good communications; and
- Deployment of Fisheries Liaison Officers (FLOs), for 2D/3D/4D seismic programs.

The relevant guidelines state the following with respect to planning seismic surveys (in Appendix 2 of C-NLOPB [2012] - Environmental Planning, Mitigation and Reporting – I. Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment):

Mitigation Measures

a) Use the minimum amount of energy necessary to achieve operational objectives;

b) Minimize the proportion of the energy that propagates horizontally; and

c) Minimize the amount of energy at frequencies above those necessary for the purpose of the survey.

Avoidance

The potential effects of seismic sound on fishery catch success can be mitigated by avoiding heavily fished areas when these fisheries are active (specifically the shrimp and snow crab areas) to the greatest extent possible. As described in this report, most of the domestic fishing in the past has been concentrated in well-defined areas within the Study Area. During any seismic survey, the location of current fishing activities will be monitored by the ship and the FLO (see below), and fishing boats will be

contacted by radio as required. Survey personnel (through the Single Point of Contact [SPOC], described below) will also continue to be updated about fisheries near the active survey area. The mapping of fishing activities contained in this EA report will also be an important source of fisheries information for the survey operators.

Communications

During the fisheries consultations for this and other surveys, fisheries representatives noted that good communications is one of the best ways to minimize interference between the seismic operations and fishing activities. Communication will be maintained (both directly at sea and through the survey SPOC) to facilitate information exchange, which includes such groups as DFO managers, independent fishers, representatives of fisheries organizations such as the FFAW, and managers of other key corporate fisheries in the area.

Relevant information about the seismic survey operations will also be transmitted using established communications mechanisms, such as the *Notices to Shipping* (Continuous Marine Broadcast and NavTex), the CBC (Newfoundland) Radio's *Fisheries Broadcast*, by the FFAW in the FFAW *Union Forum* (as suggested during previous consultations), and by direct communication between the seismic survey vessels and fishing vessels via marine radio at sea. This includes seismic survey vessel transit before and after the survey itself.

Fisheries Liaison Officer (FLO)

As a specific means of facilitating at-sea communications, and informing the 2D/3D/4D survey vessel operators about local fisheries, when necessary Suncor will have an on-board fisheries industry liaison officer serving as a "fisheries representative." The FLO will remain on the relevant survey vessel for the entire program. This will provide marine radio contact for all fishing vessels in the vicinity of seismic operations to discuss interactions and resolve any problems that may arise at sea. This person will inform the vessel's bridge personnel about any local fishing activities.

Appendix C contains a description of the FLO responsibilities and qualifications, as agreed in previous discussions with the FFAW.

Assessment of the Effects of Seismic Survey Sound

Since commercial catches are quota-based, the overlap between fishing activity and seismic activity is unknown at the moment, but will be determined prior to the commencement of the seismic surveys. The best way to prevent overlap between the DFO and joint DFO/Industry research surveys is to exchange detailed locational information and establish a mutually-agreed temporal and spatial separation plan, as was implemented with DFO Newfoundland and Labrador in past seasons. With application of the mitigations discussed above, effects of seismic survey sound on the Fishery VEC are predicted to be a *negligible* to *low* magnitude during *<1* to *1-12 months* over an area of *<1* to *11-100 km*^{2} (Table 5.5). Based on these criteria ratings, the *reversible* residual effects of seismic survey sound on the Fishery VEC are predicted to be *not significant* (Tables 5.6).

Table 5.5. Assessment of Effects on the Fisheries VEC.

Valued Environmental Component: Fishery								
Project Activity	**Potential Positive (P) or Negative (N) Environmental Effect**	**Mitigation[a]**	**Evaluation Criteria for Assessing Environmental Effects**					
			Magnitude	**Geographic Extent**	**Frequency**	**Duration**	**Reversibility**	**Ecological/ Socio-Cultural and Economic Context**
Sound								
Airguns	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance[b]; communication	0-1	3	6	1-2	R	2
Seismic Vessel	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance[b]; communication	0	1	6	1-2	R	2
Supply Vessel	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance[b]; communication	0	1	1	1-2	R	2
Picket Vessel	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance[b]; communication	0	1	6	1-2	R	2
Echo Sounder	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance[b]; communication	0	1	6	1	R	2
Side Scan Sonar	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance[b]; communication	0	1	6	1	R	2
Boomer / Sparker	Disturbance (N); Effect on catch rate (N)	Spatial & temporal avoidance[b]; communication	0	1	6	1	R	2
Vessel Presence								
Seismic Vessel	Conflict with gear (N)[c]	FLO; communication	0-1	1-3	6	1-2	R	2
Supply Vessel	Conflict with gear (N)[c]	FLO; communication	0-1	1-3	1	1	R	2
Picket Vessel	Conflict with gear (N)[c]	FLO; communication	0-1	1-3	6	1-2	R	2
Sanitary/Domestic Waste	Taint (N); Perceived taint (N)	Treatment	0-1	1	1	2	R	2
Accidental Releases	Taint (N); Perceived taint (N)	Solid streamer[d]; spill response	0-1	1-2	1	1	R	2

Key:

Magnitude:
0 = Negligible, essentially no effect
1 = Low
2 = Medium
3 = High

Frequency:
1 = < 11 events/yr
2 = 11-50 events/yr
3 = 51-100 events/yr
4 = 101-200 events/yr
5 = > 200 events/yr
6 = continuous

Reversibility:
R = Reversible
I = Irreversible
(refers to population)

Duration:
1 = < 1 month
2 = 1-12 months
3 = 13-36 months
4 = 37-72 months
5 = > 72 months

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

Ecological/Socio-cultural and Economic Context:
1 = Relatively pristine area or area not affected by human activity
2 = Evidence of existing effects

[a] Use of FLO for 2D/3D/4D seismic programs
[b] To the extent possible.
[c] This is considered negligible since, if a conflict occurs, compensation will eliminate any economic impact.
[d] Solid or isopar filled streamers may be used during surveys, depending on the seismic contractor.

Table 5.6. Significance of Potential Residual Environmental Effects on the Fishery VEC.

Valued Environmental Component: Fishery				
Project Activity	**Significance Rating**	**Level of Confidence**	**Likelihood [a]**	
	Significance of Predicted Residual Environmental Effects		**Probability of Occurrence**	**Scientific Certainty**
Sound				
Airgun Array	NS	2-3	-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Echo Sounder	NS	3	-	-
Side Scan Sonar	NS	3	-	-
Boomer / Sparker	NS	3	-	-
Vessel Presence				
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Sanitary/Domestic Wastes	NS	3	-	-
Accidental Releases	NS	2-3	-	-

Key:

Residual environmental Effect Rating:
S = Significant Negative Environmental Effect
NS = Not-significant Negative Environmental Effect
P = Positive Environmental Effect

Significance is defined as a medium or high magnitude (2 or 3 rating) and duration greater than 1 year (3 or greater rating) and geographic extent >100 km^2 (4 or greater rating).

Level of Confidence: based on professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

Probability of Occurrence: based on professional judgment:
1 = Low Probability of Occurrence
2 = Medium Probability of Occurrence
3 = High Probability of Occurrence

Scientific Certainty: based on scientific information and statistical analysis or professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

[a] Considered only in the case where 'significant negative effect' is predicted.

5.6.2.2 Vessel Presence (including towed seismic equipment)

Commercial fish harvesting activities occur throughout the year-round period being assessed. Of these, the fixed gear (e.g., pot fishery for snow crab, and to a lesser extent the Greenland halibut gillnet fishery) poses the highest potential for conflict, particularly if it is deployed concurrently with seismic survey operations. During 2D/3D/4D seismic surveying, operations will be conducted continuously for 30-120 days. Because of the length of the streamers being towed behind it, the maneuverability of a seismic vessel is restricted and other vessels must give way. As already noted in the EA, the turning radius required between each track line extends the assessment area beyond the actual survey project area (but stays within the Project Area). When gear conflict events occur, that damage gear or result in gear loss due to the survey, they will be assessed and compensation will be paid for losses attributable to the seismic survey.

Mitigation

Mitigations measures intended to minimize the conflict effects of Project activities on the fishing gear component of the Fishery VEC include:

- Avoidance to the extent possible;
- Communications;
- Fisheries Liaison Officers for 2D/3D/4D seismic programs;
- Single Point of Contact; and
- Fishing Gear Compensation.

Avoidance

As discussed above, potential impacts on fishing gear will be mitigated by avoiding active fixed gear fishing areas during the seismic survey to the extent possible. If gear is deployed in a survey area, the diligence of the FLO, good at-sea communications and mapping of current fishing locations have usually proven effective at preventing such conflicts.

The principal mitigation will also be avoidance, based on route selection aimed at deviating around fixed gear fishing areas. Since the patterns of fishing vary by month, a final route, taking into account the avoidance of active areas, will be chosen shortly before the survey work begins. As noted above, a route analysis for this purpose will be prepared and discussions with fishing interests undertaken before the transits.

In addition to avoidance based on route analysis and selection, the onshore SPOC and the at-sea FLO will advise the vessel en-route to ensure fishing gear is avoided. In the case the avoidance mitigative measure fails, a gear damage program will be in place to compensate fishers whose gear is damaged or lost.

As with the commercial fishery, those involved in DFO and joint DFO/Industry research surveys will need to exchange detailed locational information with those involved in the seismic surveying. In 2002 when the plan was first implemented in the eastern Newfoundland Region, positional information was exchanged between DFO and the seismic survey company. A temporal and spatial separation plan was then agreed to with DFO and implemented by the seismic vessel to ensure that seismic operations did not interfere with the research survey. This included adequate "quiet time" before the research vessel arrived at its survey location. The avoidance protocol includes a 30 km (16 nmi) spatial separation and a seven day pre-research survey temporal separation.

Communications

During the fisheries consultations for this and other surveys, fisheries representatives noted that good communications is one of the best ways to minimize interference with fishing activities. Communications will be maintained (directly at sea, and through the SPOC) to facilitate information exchange with fisheries participants. This includes such groups as DFO managers, independent fishers, representatives of fisheries organizations such as the FFAW, and managers of other key corporate fisheries in the area.

Relevant information about the survey operations will also be publicized using established communications mechanisms, such as the *Notices to Shipping* (Continuous Marine Broadcast and NavTex), the CBC (Newfoundland) Radio's *Fisheries Broadcast*, by the FFAW in the FFAW *Union Forum* (as suggested during previous consultations), and by direct communication between the survey vessel and fishing vessels via marine radio at sea. This will also include information about transit routes.

Fisheries Liaison Officer (FLO)

As described above, the on-board fisheries industry FLO will provide a dedicated marine radio contact for all fishing vessels near 2D/3D/4D project operations to help identify gear locations, assess potential interactions and provide guidance to those on the bridge, including during transit to and from St. John's.

Single Point of Contact (SPOC)

The SPOC has become a standard and effective mitigation for all seismic surveys operating in this sector. Suncor's Environment Advisor/Lead or designate will serve as the survey's SPOC with the fishing industry, as described in the C-NLOPB Guidelines. The SPOC will endeavor to update vessel personnel (e.g. the FLO) about known fishing activities in the area, and will relay relevant information from DFO and fishing companies.

Fishing Gear Compensation

Suncor has developed a fishing gear damage compensation policy consistent with C-NLOPB guidelines that will be filed with the Board in support of the *Authorization to Conduct a Geophysical Program* application. In case of accidental damage to fishing gear or vessels, Suncor will implement gear damage compensation contingency plans to provide appropriate and timely compensation to any affected fishery participants. The Notices to Shipping, filed by the vessels for surveys and for transits to and from the survey sites, will also inform fishers that they may contact the SPOC if they believe that they have sustained survey-related gear damage. Suncor will follow the protocols outlined by One Ocean (Appendix C) for documenting any incidents.

Assessment of the Effects of Vessel and Seismic Equipment Presence

With application of the mitigations discussed above, effects of vessel presence, including all gear being towed by the seismic vessel, on the Fishery VEC are predicted to be a *negligible* to *low* magnitude during *<1* to *1-12 months* over an area of *<1* to *11-100 km*^{2} (Table 5.5). Based on these criteria ratings, the *reversible* residual effects of vessel presence during the seismic program on the Fishery VEC are predicted to be *not significant* (see Table 5.6).

5.6.2.3 Sanitary/Domestic Wastes

Impacts related to physical effects on fish and invertebrates, including those potentially resulting from releases of sanitary/domestic wastes, are not discussed any further in this section because earlier assessment of the Fish and Fish Habitat VEC predicted that the residual effects of the wastes on that VEC would be *negligible* and hence *not significant*.

5.6.2.4 Accidental Releases

In the event of an accidental release of hydrocarbons (e.g., streamer breakage, fuel spill), there is some possibility of the perception of tainting of invertebrate and fish resources in the proximity of a release, even if there is no actual tainting. Perception alone can have economic effects if the invertebrates and fish lose marketability. Preventative measures/protocols, rapid response plans and good communications are essential mitigations to minimize the effects of any accidental hydrocarbon release. In the event of a release, the length of time that fish are exposed is a determining factor in whether or not their health is substantially affected or if there is actual or perceived tissue tainting. Streamer floatation fluid can be expected to dissipate relatively rapidly. Any effect on access to fishing grounds would be of relatively short duration. In the unlikely event of a substantial hydrocarbon release, the need of compensation for commercial fishers will be determined through the C-NLOPB's guidelines.

With application of the mitigations discussed above, the effect of accidental hydrocarbon releases on the Fishery VEC is predicted have a *negligible* to *low* magnitude during *<1 month* over an area of *<1* to *1-10 km*^{2} (see Table 5.5). Based on these criteria ratings, the *reversible* residual effects of accidental releases on the Fishery VEC during the seismic program are predicted to be *not significant* (see Table 5.6).

5.6.3 Seabird VEC

The potential interactions of Project activities and the Seabird VEC are indicated in Table 5.7. The following subsections discuss the Project activities that will interact with the Seabird VEC, and include assessment of the potential effects of these interactions.

5.6.3.1 Effects of Seismic Sounds

There are few data on the effects of underwater sound on birds. Stemp (1985) made observations on the reactions of birds to seismic exploration programs in southern Davis Strait over three summer periods. No mortality or effects on distribution were detected in 1982, the only year when an airgun-based program was conducted. John Parsons (in Stemp 1985) reported that Shearwaters off Sable Island, Nova Scotia, did not respond to underwater explosive charges 30 m away, even though the birds' heads were underwater. Evans et al. (1993) made observations from operating seismic vessels in the Irish Sea. They noted that when seabirds were near the seismic boats, "there was no observable difference in their behaviour, birds neither being attracted nor repelled by seismic testing." A study on the effects of underwater seismic surveys on moulting Long-tailed Ducks in the Beaufort Sea showed little effect on their movement or diving behaviour (Lacroix et al. 2003). However, the study did not monitor the physical effects on the ducks. The authors suggested caution in interpretation of the data because they were limited in their ability to detect subtle disturbance effects and recommended studies on other species to fully understand the potential effects of seismic testing. This lack of overt response may be at least partly related to the fact that received levels of underwater sound from airguns are greatly reduced at and immediately below the surface as compared with levels deeper in the water (Greene and Richardson 1988).

Table 5.7. Potential Interactions between the Project and Seabird VEC.

Project Activities	Valued Environmental Component: Seabirds
Sound	
Airguns	X
Seismic Vessel	X
Supply Vessel	X
Picket Vessel	X
Echo Sounder	X
Side Scan Sonar	X
Boomer / Sparker	X
Vessel Lights	X
Vessel Presence	
Seismic Vessel	X
Supply Vessel	X
Picket Vessel	X
Helicopter Presence [a]	X
Sanitary/Domestic Waste	X
Atmospheric Emissions	X
Garbage [b]	X
Shore Facilities [c]	X
Accidental Releases	X
Other Projects and Activities	
Oil and Gas Activities on the Grand Banks and Orphan Basin	X
Fisheries	X
Marine Transportation	X

[a] A crew change may occur via helicopter if the seismic program is longer than 5-6 weeks.
[b] Not applicable as garbage will be brought ashore.
[c] There will not be any new onshore facilities. Existing infrastructure will be used.

Some species of seabirds that occur in the Project Area feed at the surface or at less than one metre below the surface of the ocean. This includes Procellariidae (Northern Fulmar), Hydrobatidae (Leach's Storm-petrel, Wilson's Storm-petrel) Phalaropodinae (Red Phalarope and Red-necked Phalarope), Laridae (Great Skua, South Polar Skua, Pomarine Jaeger, Parasitic Jaeger, Long-tailed Jaeger, Herring Gull, Glaucous Gull, Great Black-backed Gull, Black-legged Kittiwake and Arctic Tern). These species are under the surface for a few seconds during each dive so would have minimal opportunity to receive underwater sound.

Diving seabirds are more likely to be affected than are birds that remain at or near the surface of the water. From a resting position on the water they dive under the surface in search of small fish and invertebrates. Diving seabirds that may occur in the area of operations include the Procellariidae (Great Shearwater and Sooty Shearwater) and Alcidae (Thick-billed Murre, Common Murre, Atlantic Puffin, Dovekie). Shearwaters feed mainly at the surface but also chase prey briefly beneath the surface down to a distance of 2-10 m (Brown et al. 1978, 1981; Ronconi 2010a,b). Alcids use their wings to propel their bodies rapidly through the water. All are capable of reaching great depths and spending considerable time under water (Gaston and Jones 1998). An average duration of dive times for typical species of Alcidae is 25-40 seconds reaching an average depth of 20-60 m, but murres are capable of diving to 120 m and have been recorded underwater for up to 202 seconds (Gaston and Jones 1998).

The sound created by airguns is focused downward below the surface of the water. Above the water the airborne sound is reduced to a muffled shot that should have little or no effect on birds that have their heads above water or are in flight. It is possible birds on the water at close range would be startled by the sound; however, the presence of the ship and associated gear dragging in the water should have already warned the bird of unnatural visual and auditory stimuli.

The Alcidae have the most potential to be exposed to the sounds produced by the seismic surveys. The effects of underwater sound are not well known but sound is probably not important to these groups in securing food. On the other hand, Alcids are quite vocal at breeding sites indicating auditory capabilities are important in that part of their life cycle. The 'laughing call' of the Thick-billed Murre is known to cover a frequency range of 1.0-4.0 kHz (Gaston and Jones 1998).

There are no specific data on the levels of low-frequency underwater sound that are harmful to waterbirds, or that cause temporary hearing impairment (temporary threshold shift or TTS). Temporary threshold shift is known to occur in birds exposed to strong, prolonged sounds in air (Saunders and Dooling 1974). Whether TTS could occur in waterbirds that are exposed relatively briefly to intermittent pulses of airgun sound close to an operating airgun array is unknown. Temporary threshold shift is, by definition, only temporary. Indeed, the auditory systems of birds, unlike mammals, have some capability to recover even from exposure to sounds that are strong enough to cause direct auditory injury (Corwin and Cotanche 1988). The presence of the survey vessel and perhaps the ramp-up period for the airguns will displace birds from the immediate program area. Thus, any effects of seismic exploration on birds in the Project Area are expected to be *negligible*. Residual impacts of the proposed program on the seabird VEC would be *not significant*.

5.6.3.2 Effects of Aircraft Overflights

Personnel may be transported to and from the seismic vessel via helicopters with flights occurring at about five to six week intervals. Most sea-associated birds flush or dive in response to low-flying aircraft (e.g. Polar Gas Project 1977; Sharp 1978; Koski et al. 1993). The significance of such disturbance is probably low if the flights are infrequent. In one of the few systematic studies of aircraft disturbance, Ward and Sharp (1974) found that moulting sea ducks in the Beaufort Sea showed no detectable reactions to helicopter overflights at 300 m.

Studies of other species in other situations have shown a variety of responses to overflying aircraft (Davis and Wisely 1974; Gollop et al. 1974a,b; Schweinsburg 1974; Koski 1975; Barry and Spencer 1976; Fyfe and Oldenorff 1976; Platt and Tull 1977; Fletcher and Busnel 1978). In general, those studies support the contention that birds show some type of response to low level flights and the effects of these responses are generally transitory.

Potential effects of helicopters on the marine environment are mainly related to noise (see a review of the effects of noise on seabirds above). The residual effect of helicopters on seabirds is expected to be *negligible* to *low* and *not significant*.

5.6.3.3 Effects of Accidental Releases

Birds are very sensitive to oiling. That is primarily because they lose the insulation value of their feathers. Especially in cold conditions, even very small amounts of oil are enough to break down the feathers' insulation capability and possibly result in death. Birds can also be affected by ingesting oil, which typically occurs when trying to preen the oil off their feathers, and by inadvertently transferring oil

from their plumage to their eggs and/or young at the nest when incubating or brooding. Seabirds often occur at sea in flocks, mostly during the non-breeding season. The potential for a population-level effect is increased when birds are concentrated in flocks and a flock is oiled. However, individual birds are less likely to come in contact with an oil slick when dispersed in a few large flocks versus when evenly scattered across the ocean.

Accidental releases of hydrocarbons during seismic projects have occurred but are historically a rare occurrence. The volume of any accidental release during this project is expected to be small. Even the worst-case scenario of a complete release is limited to the defined volume carried by a ship, which is not large. Marine gas oil, or diesel fuel, is a light oil that persists in the environment for much shorter periods than does crude oil or heavy fuel oils such as Bunker C. In cold water, only about 50% of any spilled diesel fuel would remain on the water surface after 12 hours (Smith and McIntyre 1971).

Standard operating procedures at sea reduce the likelihood, and potential size, of any accidental release of hydrocarbons. Safe bunkering procedures are known and will be employed. Each ship will have an oil response plan, the associated spill response kits, and trained personnel. Suncor operates a Seabird Cleaning Centre in St. John's, NL. The Centre is operated by permits under Environment Canada and the Government of Newfoundland and Labrador.

The effect of accidental hydrocarbon releases on the Seabird VEC is predicted have a low magnitude during *<1 month* over an area of *<1* to *1-10 km*^{2} (Table 5.8). Based on these criteria ratings, the reversible residual effects of accidental releases on the Seabird VEC during the seismic program are predicted to be *not significant* (Table 5.9).

5.6.3.4 Effects Summary

The effects of seismic sounds, aircraft overflights, and accidental releases of hydrocarbons on sea-associated birds were assessed. Diving seabirds are more likely to be affected by underwater seismic sounds than are birds that remain at or near the surface of the water. However, there are no specific data on the levels of low-frequency underwater sound that are adverse to waterbirds, or that cause temporary hearing impairment. The ramp-up period for the airguns will help to displace birds from the immediate program area. Aircraft overflights are expected to be infrequent and potential effects temporary. Accidental releases are of low probability and limited to the volume of material stored onboard the vessels in the worst-case scenario. No significant residual effects on the Seabird VEC are predicted.

5.6.4 Marine Mammal and Sea Turtle VEC

The potential effects of seismic activities on marine mammals and sea turtles have previously been reviewed for several recent seismic projects in the Jeanne d'Arc Basin (e.g., LGL 2007a,b, 2008a, 2011a, 2012a, 2013b), Labrador (LGL 2010), Orphan Basin (LGL 2003, 2005, 2011b, 2013a), Flemish Pass (LGL 2011a,b, 2012a), and several others reviews (e.g., Richardson et al. 1995; Gordon et al. 2004; Stone and Tasker 2006; Southall et al. 2007; Abgrall et al. 2008c). The following review is based largely on these documents with new and relevant literature included. The assessment of impacts is based on the best available information; however, there are data gaps that limit the certainty of these impact predictions. We have discussed potential impacts separately for toothed whales, baleen whales, seals, and sea turtles given their different hearing abilities and sensitivities to sound. Potential interactions between Project activities and marine mammals and sea turtles are shown in Table 5.10.

Table 5.8. Assessment of Effects on the Seabird VEC.

Valued Environmental Component: Seabirds								
Project Activity	**Potential Positive (P) or Negative (N) Environmental Effect**	**Mitigation**	**Evaluation Criteria for Assessing Environmental Effects**					
			Magnitude	**Geographic Extent**	**Frequency**	**Duration**	**Reversibility**	**Ecological/ Socio-Cultural and Economic Context**
Sound								
Airguns	Disturbance (N)		0	2	6	1-2	R	2
Seismic Vessel	Disturbance (N)		0-1	1	6	1-2	R	2
Supply Vessel	Disturbance (N)		0	1	6	1	R	2
Picket Vessel	Disturbance (N)		0	1	6	1-2	R	2
Echo Sounder	Disturbance (N)		0	1	6	1	R	2
Side Scan Sonar	Disturbance (N)		0	1	6	1	R	2
Boomer / Sparker	Disturbance (N)		0	1	6	1	R	2
Vessel Presence								
Seismic Vessel	Disturbance (N)		0	2	6	1-2	R	2
Supply Vessel	Disturbance (N)		0	2	1	1	R	2
Picket Vessel	Disturbance (N)		0	2	6	1-2	R	2
Helicopter Presence	Disturbance (N)	Maintain high altitude	0-1	2	1	1	R	2
Vessel Lights	Attraction (N)	Reduce lighting (if possible)	1-2	2	2-3	1-2	R	2
Sanitary/Domestic Waste	Increased Food (N/P)		0	1	1	1-2	R	2
Atmospheric Emissions	Air Contaminants (N)		0	2	6	1-2	R	2
Accidental Releases	Mortality (N)	Solid streamer[a]; spill response	1	1-2	1	1	R	2

Key:

Magnitude:
0 = Negligible, (essentially no effect)
1 = Low
2 = Medium
3 = High

Frequency:
1 = <11 events/yr
2 = 11-50 events/yr
3 = 51-100 events/yr
4 = 101-200 events/yr
5 = >200 events/yr
6 = continuous

Reversibility:
R = Reversible
I = Irreversible (refers to population)

Duration:
1 = <1 month
2 = 1-12 months
3 = 13-36 months
4 = 37-72 months
5 = >72 months

Geographic Extent:
1 = < 1 km^2
2 = 1-10 km^2
3 = 11-100 km^2
4 = 101-1,000 km^2
5 = 1,001-10,000 km^2
6 = >10,000 km^2

Ecological/Socio-cultural and Economic Context:
1 = Relatively pristine area or area not affected by human activity
2 = Evidence of existing effects

[a] Solid or isopar filled streamers may be used during surveys, depending on seismic contractor.

Table 5.9. Significance of Potential Residual Environmental Effects of the Project on the Seabird VEC.

Valued Environmental Component: Seabirds				
Project Activity	**Significance Rating**	**Level of Confidence**	**Likelihood [a]**	
	Significance of Predicted Residual Environmental Effects		**Probability of Occurrence**	**Scientific Certainty**
Sound				
Airguns	NS	2-3	-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Echo Sounder	NS	3	-	-
Side Scan Sonar	NS	3	-	-
Boomer / Sparker	NS	3	-	-
Vessel Presence			-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Helicopter Presence	NS	3	-	-
Vessel Lights	NS	3	-	-
Sanitary/Domestic Wastes	NS	3	-	-
Atmospheric Emissions	NS	3	-	-
Accidental Releases	NS	2	-	-

Key:

Residual environmental Effect Rating:
S = Significant Negative Environmental Effect
NS = Not-significant Negative Environmental Effect
P = Positive Environmental Effect
Significance is defined as a medium or high magnitude (2 or 3 rating) and duration greater than 1 year (3 or greater rating) and geographic extent >100 km^2 (4 or greater rating).

Probability of Occurrence: based on professional judgment:
1 = Low Probability of Occurrence
2 = Medium Probability of Occurrence
3 = High Probability of Occurrence

Scientific Certainty: based on scientific information and statistical analysis or professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

Level of Confidence: based on professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

[a] Considered only in the case where 'significant negative effect' is predicted.

Table 5.10. Potential Interactions between the Project and the Marine Mammal and Sea Turtle VECs.

Valued Environmental Components: (1) Marine Mammals (2) Sea Turtles				
Project Activities	**Toothed Whales**	**Baleen Whales**	**Seals**	**Sea Turtles**
Sound				
Airguns	X	X	X	X
Seismic Vessel	X	X	X	X
Supply Vessel	X	X	X	X
Picket Vessel	X	X	X	X
Echo Sounder	X	X	X	X
Side Scan Sonar	X	X	X	X
Boomer / Sparker	X	X	X	X
Vessel Lights				
Vessel Presence				
Seismic Vessel	X	X	X	X
Supply Vessel	X	X	X	X
Picket Vessel	X	X	X	X
Helicopter Presence [a]	X	X	X	X
Sanitary/Domestic Waste	X	X	X	X
Atmospheric Emissions	X	X	X	X
Garbage [b]				
Shore Facilities [c]				
Accidental Releases	X	X	X	X
Other Projects and Activities				
Oil and Gas Activities on the Grand Banks and Orphan Basin	X	X	X	X
Fisheries				
Marine Transportation	X	X	X	X

[a] A crew change may occur via helicopter if the seismic program is longer than 5 to 6 weeks.
[b] Not applicable as garbage will be brought ashore.
[c] There will not be any new onshore facilities. Existing infrastructure will be used.

5.6.4.1 Effects of Seismic Sound

The potential effects of sound from airgun arrays on marine mammals and sea turtles are a common concern associated with seismic programs. Airgun arrays used during marine seismic operations introduce strong sound impulses into the water. These sound impulses could have several types of effects on marine mammals and sea turtles 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: species, activity of the animal when exposed to the noise and distance of the animal from the sound source. This section includes a brief summary of the anticipated potential effects (or lack thereof) of airgun sounds on marine mammals and sea turtles. More comprehensive reviews of the relevant background information for marine mammals and sea turtles appear in Appendices F and G, respectively. The characteristics of airgun sounds are also summarized in Appendix F. Descriptions of the hearing abilities of marine mammals and sea turtles are also provided in Appendices F and G, respectively.

The potential effects of airgun sounds considered in this assessment include: masking of natural sounds, behavioural disturbance, non-auditory physical or physiological effects, and at least in theory, temporary or permanent hearing impairment (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007). Permanent hearing impairment or permanent threshold shift (PTS), in the unlikely event that it occurred, would constitute injury, but temporary threshold shift (TTS) is not an

injury (Southall et al. 2007). Although the possibility cannot be entirely excluded, it is unlikely that the program would result in any cases of temporary or permanent hearing impairment, or any significant non-auditory physical or physiological effects. If marine mammals or sea turtles encounter the survey while it is underway, some behavioural disturbance could result, but this would be localized and short-term.

Masking

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies. Masking can occur 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 time (Richardson et al. 1995; Clark et al. 2009). Conversely, masking is not expected if little or no overlap occurs between the introduced sound and the frequencies used by the species or if the introduced sound is infrequent. Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are very few specific data on this. Because of the intermittent nature and low duty cycle of seismic pulses, marine mammals and sea turtles can emit and receive sounds in the relatively quiet intervals between pulses. Some baleen and toothed whales are known to continue calling in the presence of seismic pulses and their calls usually can be heard between the seismic pulses. The sounds important to toothed whales and pinnipeds are predominantly at much higher frequencies than are the dominant components of airgun sounds, thus limiting the potential for masking. Based on reviewed research, the potential for masking of marine mammal calls and/or important environmental cues is considered quite low from the proposed seismic program. Thus, masking is unlikely to be a significant issue for either marine mammals or sea turtles exposed to the sounds from seismic surveys.

Disturbance by Seismic Vessels

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). If a marine mammal or sea turtle 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 or sea turtles from an important feeding or breeding area for a prolonged period, impacts on individuals and populations could be significant (e.g., Lusseau and Bejder 2007; Weilgart 2007).

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the cases of migrating gray and bowhead 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.

Little systematic information is available on reactions of toothed whales to sound pulses. However, there are recent systematic studies on sperm whales, and there is an increasing amount of information

about responses of various odontocetes to seismic surveys based on monitoring studies. 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 vessel. 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. The beluga, however, is a species that (at least at times) shows long-distance (10s of km) avoidance of seismic vessels. 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, but the animals tolerated high received levels of sound before exhibiting aversive behaviours. Odontocete reactions to large arrays of airguns are variable and, at least for delphinids, seem to be confined to a smaller radius than has been observed for the more responsive of the mysticetes and some other odontocetes.

Pinnipeds 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. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behaviour. Based on available data, it is likely that sea turtles would exhibit behavioural changes and/or localized avoidance near a seismic vessel. To the extent that there are any impacts on sea turtles, seismic operations in or near areas where turtles concentrate are likely to have the greatest impact. However, turtles are rare in the Project Area.

Hearing Impairment Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. Temporary threshold shift has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (reviewed in Southall et al. 2007). However, there has been no specific documentation of TTS let alone permanent hearing damage, i.e., PTS, in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions. Current U.S. NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and 190 dB re 1 μPa_{rms}, respectively (NMFS 2000). Those criteria have been used in establishing the safety (=shut-down) radii planned for numerous seismic surveys conducted under U.S. jurisdiction and in some parts of Canada. However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause TTS in marine mammals. The 180 dB criterion for cetaceans is probably quite conservative (i.e., lower than necessary to avoid auditory injury), for at least some species including bottlenose dolphin and beluga.

Recommendations for science-based noise exposure criteria for marine mammals were published by Southall et al. (2007). Those recommendations were never formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys, although some aspects of the recommendations have been taken into account in certain environmental impact statements and small-take authorizations. NMFS is currently moving toward adoption of new procedures taking at least some of the Southall et al. (2007) recommendations into account (Scholik-Schlomer 2012; NMFS 2013). The new noise exposure criteria for marine mammals will account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive (e.g., M-weighting or generalized frequency weightings for various groups of marine mammals, allowing for their functional bandwidths), and other relevant factors.

There is substantial overlap in the frequencies that sea turtles detect vs. the frequencies in airgun pulses. Sounds from an airgun array might cause temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs. However, monitoring studies show that some sea turtles do show localized movement away from approaching airguns. At short distances from the source, received sound levels diminish rapidly with increasing distance. In that situation, even a small-scale avoidance response could result in a significant reduction in sound exposure.

Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals and sea turtles 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 and sea turtles 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.

Non-auditory Physical Effects

Non-auditory physical effects may also occur in marine mammals and sea turtles exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur include stress, 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. Such effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. Marine mammals that show behavioural avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, as well as sea turtles, are especially unlikely to incur non-auditory physical effects. The brief duration of exposure of any given animal and the planned monitoring and mitigation measures would further reduce the probability of exposure of marine mammals and sea turtles to sounds strong enough to induce non-auditory physical effects.

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. The U.S NMFS (1995, 2000) has concluded 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 has been set at 190 dB re 1 μPa_{rms}. These sound levels are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS, one cannot be certain that there will be no injurious effects, auditory or otherwise, to marine mammals. For over a decade, it has been common for marine seismic surveys conducted in some areas of U.S. jurisdiction and in some areas of Canada (Canadian Beaufort Sea and on the Scotian Shelf), to include a “shutdown” requirement for cetaceans based on the distance from the airgun array at which the received level of underwater sounds is expected to diminish below 180 dB re 1 μPa_{rms}. An additional criterion that is often used in predicting “disturbance” impacts is 160 dB re 1 µPa; at this received level, some marine mammals exhibit behavioural effects. There is ongoing debate about the appropriateness of these parameters for impact predictions and mitigation (see Appendix F).

For marine seismic programs in Newfoundland and Labrador, the C-NLOPB (2012) recommends that seismic operators follow the "*Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment*" (hereafter referred to as the *Statement*) issued by the DFO. 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 Mammal VEC

The marine mammal effects assessment is summarized in Table 5.11 and discussed in detail below.

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, 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 whale, Sowerby's beaked whale). Killer whales and harbour porpoises, both with special status by COSEWIC (the harbour porpoise is also listed as *threatened* under Schedule 2 of *SARA*), are not expected to occur in large numbers in the Project Area. The received sound level of 180 dB re 1 μPa_{rms} criterion is accepted as a level that below which there is no physical effect on toothed whales. It is assumed that disturbance effects for toothed whales may occur at received sound levels at or above 160 dB re 1 μPa_{rms}. However, it is noted that there is no good scientific basis for using this 160 dB criterion for odontocetes and that a 170 dB re 1 μPa_{rms} is a more realistic indicator of the area within which disturbance is likely (see Appendix F).

Hearing Impairment and Physical Effects: Given that whales typically avoid at least the immediate area around seismic (and other strong) noise sources, whales in and near the Project Area will likely not be exposed to levels of sound from the airgun array that are high enough to cause non-auditory physical effects or hearing impairment. It is highly unlikely that toothed whales will experience mortality or strand as a result of Project activities. The mitigation measure of ramping-up the airgun array (over a 30 min period) should allow whales close to the airguns to move away before the sounds become sufficiently strong to have potential for hearing impairment. Also, the airgun array will not be started if a toothed whale is sighted within the 500 m safety zone. There is reduced potential for toothed whales being close enough to the array to experience hearing impairment. If some whales did experience TTS, the effects would likely be quite "temporary." As per Table 5.11, Suncor's geophysical program is predicted to have *negligible* to *low* hearing impairment/physical effects on toothed whales, over a duration of *1 to 12 months*, in an area *<1 km^2* to *1–10 km^2*. Therefore, hearing impairment and/or physical effects on toothed whales are judged to be *not significant* (Table 5.12).

Table 5.11. Assessment of Effects on the Marine Mammal VEC.

Valued Environmental Components: Marine Mammals								
Project Activity	**Potential Positive (P) or Negative (N) Environmental Effect**	**Mitigation**	**Evaluation Criteria for Assessing Environmental Effects**					
			Magnitude	**Geographic Extent**	**Frequency**	**Duration**	**Reversibility**	**Ecological/ Socio-Cultural and Economic Context**
Sound								
Airguns	Disturbance (N) Hearing Impairment (N) Physical Effects (N)	Ramp-up; delay start; shutdown [a]	1	3-4	6	1-2	R	2
Seismic Vessel	Disturbance (N)		0-1	1-2	6	1-2	R	2
Supply Vessel	Disturbance (N)		0-1	1-2	6	1	R	2
Picket Vessel	Disturbance (N)		0-1	1-2	6	1-2	R	2
Echo Sounder	Disturbance (N)		0	1	6	1	R	2
Side Scan Sonar	Disturbance (N)		0	1	6	1	R	2
Boomer / Sparker	Disturbance (N)		0	1	6	1	R	2
Presence of Vessels								
Seismic Vessel	Disturbance (N)		0-1	1	6	1-2	R	2
Supply Vessel	Disturbance (N)		0-1	1	1	1	R	2
Picket Vessel	Disturbance (N)		0-1	1	6	1	R	2
Helicopter Presence [b]	Disturbance (N)	Maintain high altitude	0-1	1-2	1	1	R	2
Sanitary/Domestic Waste	Increased Food (N/P)		0-1	1	1	1-2	R	2
Atmospheric Emissions	Surface Contaminants (N)		0	1	6	1-2	R	2
Accidental Releases	Injury/Mortality (N)	Solid streamer [c]; spill response	1	1-2	1	1	R	2

Key:

Magnitude:
0 = Negligible, essentially no effect
1 = Low
2 = Medium
3 = High

Frequency:
1 = <11 events/yr
2 = 11-50 events/yr
3 = 51-100 events/yr
4 = 101-200 events/yr
5 = >200 events/yr
6 = continuous

Reversibility:
R = Reversible
I = Irreversible
(refers to population)

Duration:
1 = <1 month
2 = 1-12 months
3 = 13-36 months
4 = 37-72 months
5 = >72 months

Geographic Extent:
1 = <1 km^2
2 = 1-10 km^2
3 = 11-100 km^2
4 = 101-1,000 km^2
5 = 1,001-10,000 km^2
6 = >10,000 km^2

Ecological/Socio-cultural and Economic Context:
1 = Relatively pristine area or area not negatively affected by human activity
2 = Evidence of existing negative effects

[a] The airgun arrays will be shutdown if an *endangered* (or *threatened*) marine mammal or sea turtle is sighted within 500 m of the array.
[b] A crew change may occur via helicopter if the seismic program is longer than 5 to 6 weeks.
[c] Solid or Isopar filled streamers may be used during surveys, depending on the seismic contractor.

Table 5.12. Significance of Potential Residual Environmental Effects of the Proposed Geophysical Program on the Marine Mammal VEC.

Valued Environmental Component: Marine Mammals				
Project Activity	Significance Rating	Level of Confidence	Likelihood [a]	
	Significance of Predicted Residual Environmental Effects		Probability of Occurrence	Scientific Certainty
Sound				
Airguns	NS	2-3	-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Echo Sounder	NS	3	-	-
Side Scan Sonar	NS	3	-	-
Boomer / Sparker	NS	3	-	-
Presence of Vessels			-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Helicopter Presence	NS	3	-	-
Vessel Lights	NS	3	-	-
Sanitary/Domestic Wastes	NS	3	-	-
Atmospheric Emissions	NS	3	-	-
Accidental Releases	NS	3	-	-

Key:

Residual environmental Effect Rating:
S = Significant Negative Environmental Effect
NS = Not-significant Negative Environmental Effect
P = Positive Environmental Effect
Significance is defined as a medium or high magnitude (2 or 3 rating) and duration greater than 1 year (3 or greater rating) and geographic extent >100 km^2 (4 or greater rating).

Probability of Occurrence: based on professional judgment:
1 = Low Probability of Occurrence
2 = Medium Probability of Occurrence
3 = High Probability of Occurrence

Scientific Certainty: based on scientific information and statistical analysis or professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

Level of Confidence: based on professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

[a] Considered only in the case where 'significant negative effect' is predicted.

Disturbance Effects: Based on our review, there could be behavioural effects on some species of toothed whales within the Project Area. Known effects may range from changes in swimming behaviour to avoidance of the seismic vessel. Based on available literature, a 160 dB re 1 μPa_{rms} sound level is used to assess disturbance effects, more specifically potential displacement from the area around the seismic source. This is likely a conservative criterion since some toothed whale species:

- Have been observed in other areas relatively close to an active seismic source where received sound levels are greater than 160 dB (see Appendix F); and
- Individuals which may be temporarily displaced from an area will not be significantly impacted by this displacement.

It is uncertain how many toothed whales may occur in the Study Area at various times of the year. The Study Area is not known to be an important feeding or breeding area for toothed whales (however, there has been little research to verify this). As per Table 5.11, disturbance effects from Project activity noise on toothed whales would likely be *low*, over *1 to 12 months*, in an area of *11-100* or *101-1,000 km^2*. Therefore, potential effects related to disturbance, are judged to be *not significant* for toothed whales (Table 5.12).

Prey Species: It is unlikely that prey species for toothed whales will be impacted by seismic activities to a degree that inhibits their foraging success. If prey species exhibit avoidance of the seismic ship it will likely be transitory in nature (see Sections 5.6.1 and 5.6.2) and over a small portion of a whale's foraging range within the Project Area. Potential effects of reduced prey availability on toothed whales are predicted to be *negligible*.

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., blue and fin whales). As with toothed whales, the 180 dB re 1 μPa_{rms} criterion is used when estimating the area where hearing impairment and/or physical effects may occur for baleen whales (although there are no data to support this criterion for baleen whales). For all baleen whale species, it is assumed that disturbance effects (avoidance) may occur at sound levels greater than 160 dB re 1 μPa_{rms}.

Hearing Impairment and Physical Effects: Given that baleen whales typically exhibit at least localized avoidance of seismic (and other strong) noise, baleen whales will likely not be exposed to levels of sound from the airgun array high enough to cause non-auditory physical effects or hearing damage. The mitigation measure of ramping-up the airgun array should allow any whales close to the airguns to move away before the sounds become sufficiently strong to have potential for hearing impairment. Also, the airgun array will not be started if a baleen whale is sighted within the 500 m safety zone. Therefore, there is reduced potential for baleen whales being close enough to the array to experience hearing impairment. If some whales did experience TTS, the effects would likely be quite "temporary." As per Table 5.11, Suncor's seismic program is predicted to have *negligible* to *low* hearing impairment effects on baleen whales, over a duration of *1 to 12 months*, in an area *<1 km^2* to *1–10 km^2*. Therefore, hearing impairment and/or physical effects on baleen whales are judged to be not significant (see Table 5.12).

Disturbance Effects: Based on the above review, there could be behavioural effects on some species of baleen whales within and near the Project Area. Reported effects range from changes in swimming behaviour to avoidance of the seismic vessel. The area where displacement would most likely occur would have a predicted scale of impact at *11–100 km^2* to *101–1,000 km^2*. This is likely a conservative estimate given that:

- Some baleen whale species have been observed in areas relatively close to an active seismic source (see Appendix F); and
- It is unlikely that displacement from an area constitutes a significant impact for baleen whales in the Project Area.

It is uncertain how many baleen whales may occur in the Study Area during the period when geophysical activity is most likely to occur (May to December for 2D/3D/4D seismic). The Project Area

is not known to be an important feeding or breeding area for baleen whales. As per Table 5.11, disturbance effects on species of baleen whales would likely be *low*, over a duration of *1 to 12 months*, in an area of *11–100 km²* to *101–1,000 km²*. Therefore, effects related to disturbance, are judged to be *not significant* for baleen whales (see Table 5.12).

Prey Species: It is unlikely that prey species for baleen whales, particularly euphausiids, will be impacted by seismic activities to a degree that inhibits their foraging success. If prey species exhibit avoidance of the seismic ship it will likely be transitory in nature (see Sections 5.6.1 and 5.6.2) and over a small portion of a whale's foraging range within the seismic area. Potential effects of reduced prey availability on baleen whales are judged to be *negligible*.

Seals

Seals are not expected to be abundant within the Study Area, particularly in the time period when seismic operations will likely occur (summer and fall). Harp and hooded seals are expected to have a more northerly distribution during the survey period, although a few could be moving through the Study Area. Grey seals are likely uncommon and would be most common in coastal areas. None of the species of seal that occur within the Study Area are considered at risk by COSEWIC or are designated on a *SARA* schedule, although harp and hooded seals are considered mid-priority candidate species by COSEWIC.

Hearing Impairment and Physical Effects: Given that seals typically avoid the immediate area around a seismic array, seals are unlikely to be exposed to levels of sound from the airgun array (and other noise sources) high enough to cause non-auditory physical effects or hearing impairment. The mitigation measure of ramping-up the airgun array will allow seals close to the airguns to move away before the sounds become sufficiently strong to have potential for hearing impairment. Also, a ramp-up will not be initiated if a seal is sighted within the 500 m safety zone. Therefore, there is reduced potential for seals being close enough to an array to experience hearing impairment. If some seals did experience TTS, the effects would likely be quite "temporary." As per Table 5.11, Suncor's geophysical program is predicted to have *negligible* to *low* hearing impairment and/or physical effects on seals, over a duration of *1 to 12 months*, in an area *<1 km²* to *1–10 km²*. Therefore, hearing impairment and physical effects on seals are judged to be *not significant* (see Table 5.12).

Disturbance Effects: Based on the above review, there could be behavioural effects on seals within and near the Project Area. Known effects include changes in diving behaviour and localized avoidance of the seismic vessel. It is uncertain how many seals may occur in the Project Area during the period when geophysical operations will occur (May to December for 2D/3D/4D seismic). There are no available criteria for assessing the sound level most likely to elicit avoidance reactions in seals. It is noteworthy that seals have been sighted inside the radius thought to cause TTS (190 dB) in other areas. A 160 dB re 1 μPa_{rms} sound level has been conservatively used to assess disturbance effects, more specifically potential displacement from the area around the seismic source. Therefore, the area where displacement may occur would have likely a scale of potential effect at *11–100 km²*. This estimated area around the seismic vessel would be ensonified periodically for a duration of *1 to 12 months*. As per Table 5.11, Suncor's proposed geophysical program is predicted to have *low* disturbance effects on seals. Therefore, effects related to disturbance, are judged to be *not significant* for seals (see Table 5.12).

Prey Species: It is unlikely that prey species for seals will be impacted by seismic activities to a degree that inhibits their foraging success. If prey species exhibit avoidance of the seismic ship it will likely be

transitory in nature (see Sections 5.6.1 and 5.6.2) and over a small portion of the seal's foraging range within the seismic area. Potential effects of reduced prey availability on seals are expected to be *negligible*.

Assessment of Effects of Sound on Sea Turtle VEC

The effects assessment for sea turtles is summarized in Table 5.13.

Hearing Impairment and Physical Effects: Based on available data, it is possible that sea turtles might exhibit temporary hearing loss if the turtles are close to the airguns (Moulton and Richardson 2000). However, there is not enough information on sea turtle temporary hearing loss and no data on permanent hearing loss to reach any definitive conclusions about received sound levels that trigger TTS. Also, it is likely that sea turtles will exhibit behavioural reactions or avoidance within an area of unknown size around a seismic vessel. The mitigation measure of ramping-up the airgun array over a 30 min period should permit sea turtles close to the airguns to move away before the sounds become sufficiently strong to have any potential for hearing impairment. Also, ramp-up will not commence if a sea turtle is sighted within the 500 m safety zone, and the airgun array will be shutdown if a leatherback or loggerhead sea turtle is sighted within the safety zone.

It is very unlikely that many sea turtles will occur in the Study Area. Therefore, there is likely limited potential for sea turtles to be close enough to an array to experience hearing impairment. If some turtles did experience TTS, the effects would likely be quite "temporary." As per Table 5.13, Suncor's seismic program is predicted to have *negligible* to *low* physical effects on sea turtles, over a duration of *1 to 12 months*, in an area *<1* to *1–10 km*^{2}. Therefore, auditory and physical effects on sea turtles are judged to be *not significant* (Table 5.14).

Disturbance Effects: It is possible that sea turtles will occur in the Project Area, although the cooler water temperatures likely preclude some species from occurring there. If sea turtles did occur near the seismic vessel, it is likely that they would exhibit avoidance within a localized area. Based on observations of green and loggerhead sea turtles, behavioural avoidance may occur at received sound levels of 166 dB re 1 μPa_{rms}. Based on available evidence, the area where displacement would most likely occur would have a scale of impact at *11–100 km*^{2}. As per Table 5.13, Suncor's geophysical program is predicted to have *low* disturbance effects on sea turtles, over a duration of *1 to 12 months*, in an area *11-100 km*^{2}. Therefore, effects related to disturbance are judged to be *not significant* for sea turtles (see Table 5.14).

Prey Species: Leatherback sea turtles are expected to feed primarily on jellyfish. It is unknown how jellyfish react to seismic sources, if these invertebrates react at all. Leatherbacks are also known to feed on sea urchins, tunicates, squid, crustaceans, fish, blue-green algae, and floating seaweed. It is possible that some prey species may exhibit localized avoidance of the seismic array but this is unlikely to impact sea turtles, which are also likely to avoid the seismic vessel and are known to search for aggregations of prey. Potential effects of reduced prey availability are predicted to be *negligible*.

Table 5.13. Assessment of Effects on the Sea Turtle VEC.

Valued Environmental Components: Sea Turtles								
Project Activity	**Potential Positive (P) or Negative (N) Environmental Effect**	**Mitigation**	**Evaluation Criteria for Assessing Environmental Effects**					
			Magnitude	**Geographic Extent**	**Frequency**	**Duration**	**Reversibility**	**Ecological/ Socio-Cultural and Economic Context**
Sound								
Airguns	Hearing Impairment (N) Physical Effects (N) Disturbance (N)	Ramp up; delay start; shutdown [a]	1	3	6	1-2	R	2
Seismic Vessel	Disturbance (N)		0-1	1-2	6	1-2	R	2
Supply Vessel	Disturbance (N)		0-1	1-2	6	1	R	2
Picket Vessel	Disturbance (N)		0-1	1-2	6	1-2	R	2
Echo Sounder	Disturbance (N)		0	1	6	1	R	2
Side Scan Sonar	Disturbance (N)		0	1	6	1	R	2
Boomer / Sparker	Disturbance (N)		0	1	6	1	R	2
Vessel Lights								
Vessel Presence								
Seismic Vessel	Disturbance (N)		0-1	1	6	1-2	R	2
Supply Vessel	Disturbance (N)		0-1	1	1	1	R	2
Picket Vessel	Disturbance (N)		0-1	1	6	1-2	R	2
Helicopter Presence [b]	Disturbance (N)	Maintain high altitude	0	1-2	1	1	R	2
Sanitary/Domestic Waste	Increased Food (N/P)		0-1	1	1	1-2	R	2
Atmospheric Emissions	Surface Contaminants (N)		0	1	6	1-2	R	2
Accidental Releases	Injury/Mortality (N)	Solid streamers[c]; Spill Response	1	1-2	1	1	R	2

Key:

Magnitude:
0 = Negligible, essentially no effect
1 = Low
2 = Medium
3 = High

Frequency:
1 = <11 events/yr
2 = 11-50 events/yr
3 = 51-100 events/yr
4 = 101-200 events/yr
5 = >200 events/yr
6 = continuous

Reversibility:
R = Reversible
I = Irreversible
(refers to population)

Duration:
1 = <1 month
2 = 1-12 months
3 = 13-36 months
4 = 37-72 months
5 = >72 months

Geographic Extent:
1 = <1 km^2
2 = 1-10 km^2
3 = 11-100 km^2
4 = 101-1,000 km^2
5 = 1,001-10,000 km^2
6 = >10,000 km^2

Ecological/Socio-cultural and Economic Context:
1 = Relatively pristine area or area not negatively affected by human activity
2 = Evidence of existing negative effects

[a] The airgun arrays will be shutdown if an *endangered* (or *threatened*) sea turtle is sighted within 500 m of the array.
[b] A crew change may occur via helicopter if the seismic program is longer than 5 to 6 weeks.
[c] Solid or Isopar filled streamers may be used during future surveys, depending on the seismic contractor.

Table 5.14. Significance of Potential Residual Environmental Effects of the Proposed Geophysical Program on the Sea Turtle VEC.

Valued Environmental Component: Sea Turtles				
Project Activity	Significance Rating	Level of Confidence	Likelihood [a]	
	Significance of Predicted Residual Environmental Effects		Probability of Occurrence	Scientific Certainty
Sound				
Airguns	NS	2-3	-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Echo Sounder	NS	3	-	-
Side Scan Sonar	NS	3	-	-
Boomer / Sparker	NS	3	-	-
Vessel Presence			-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Helicopter Presence	NS	3	-	-
Vessel Lights	NS	3	-	-
Sanitary/Domestic Wastes	NS	3	-	-
Atmospheric Emissions	NS	3	-	-
Accidental Releases	NS	2	-	-

Key:

Residual environmental Effect Rating:
S = Significant Negative Environmental Effect
NS = Not-significant Negative Environmental Effect
P = Positive Environmental Effect
Significance is defined as a medium or high magnitude (2 or 3 rating) and duration greater than 1 year (3 or greater rating) and geographic extent >100 km^2 (4 or greater rating).

Level of Confidence: based on professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

Probability of Occurrence: based on professional judgment:
1 = Low Probability of Occurrence
2 = Medium Probability of Occurrence
3 = High Probability of Occurrence

Scientific Certainty: based on scientific information and statistical analysis or professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

[a] Considered only in the case where 'significant negative effect' is predicted.

5.6.4.2 Effects of Helicopter Overflights

Available information indicates that single or occasional aircraft overflights will cause no more than brief behavioural responses in baleen whales, toothed whales and seals (summarized in Richardson et al. 1995). As per Table 5.13, disturbance impacts are assessed as *negligible* to *low* impact, over a duration of *<1 month*, in an area *<1km²* to *1–10 km²*. Therefore, effects related to disturbance, are judged to be *not significant* for marine mammals (see Table 5.14).

To the best of our knowledge, there are no systematic data on sea turtle reactions to helicopter overflights. Given the hearing sensitivities of sea turtles, they can likely hear helicopters, at least when the helicopters are at lower altitudes and the turtles are in relatively shallow waters. It is unknown how sea turtles would respond, but single or occasional overflights by helicopters would likely only elicit a brief behavioural response. As per Table 5.13, disturbance impacts are assessed as *negligible*, over a

duration of *<1 month*, in an area *<1 km^2* to *1–10 km^2*. Therefore, impacts related to disturbance, are judged to be *not significant* for sea turtles (see Table 5.14).

5.6.4.3 Effects of Presence of Vessels

During the proposed geophysical program, there will be at least one seismic ship at all times, and possibly a standby or picket vessel and support vessel. There is some risk for collision between marine mammals and vessels, but given the slow surveying speed (typically ~4.5 knots; 8.3 km/h) of the seismic vessel (and its standby/support vessel[s]), this risk is likely to be minimal (e.g., Laist et al. 2001; Vanderlaan and Taggart 2007; Gende et al. 2011; Wiley et al. 2011). Marine mammal responses to ships are presumably responses to noise, but visual or other cues are also likely involved. Marine mammal response (or lack thereof) to ships and boats (pre-1995 studies) are summarized in Richardson et al. (1995), p. 252 to 274. More recent studies are described in Husky (2012). Marine mammal responses to the presence of vessels are variable. Seals often show considerable tolerance to vessels. Toothed whales sometimes show no avoidance reactions and occasionally approach vessels; however, some species are displaced by vessels. Baleen whales often interrupt their normal behaviour and swim rapidly away from vessels that have strong or rapidly changing noise, especially when a vessel heads directly towards a whale. Stationary vessels or slow-moving, “non-aggressive” vessels typically elicit very little response from baleen whales.

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. Hazel et al. (2007) evaluated behavioural responses of green turtles to a research vessel approaching at slow, moderate, or fast speeds (4, 11, and 19 km/h, respectively). Proportionately fewer turtles fled from the approaching vessel as speed increased, and turtles that fled from moderate to fast approaches did so at significantly shorter distances from the vessel than those that fled from slow approaches. The authors concluded that sea turtles cannot be relied on to avoid vessels with speeds greater than 4 km/h. However, studies were conducted in a 6 m aluminum boat powered by an outboard engine, which would presumably be more challenging for a sea turtle to detect than a seismic or support vessel.

Sea turtles may also become entangled with seismic gear (e.g., cables, buoys, streamers, etc.) or collide with the vessel (Pendoley 1997; Ketos Ecology 2007; Hazel et al. 2007; Weir 2007). Entanglement of sea turtles with marine debris, fishing gear, dredging operations, and equipment operations are a documented occurrence and of elevated concern for sea turtles. Turtles can become wrapped around cables, lines, nets, or other objects suspended in the water column and become injured or fatally wounded, drowned, or suffocated (e.g., Lutcavage et al. 1997; NMFS 2007). Seismic 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). With dedicated monitoring by trained biological observers, no incidents of entanglements of sea turtles with this gear have been documented in over 40,000 nmi. (74,000 km) of NSF-funded seismic surveys (e.g., Smultea and Holst 2003; Haley and Koski 2004; Holst 2004; Smultea et al. 2004; Holst et al. 2005a,b; Holst and Smultea 2008). Towing of the hydrophone streamer or other equipment is not expected to significantly interfere with sea turtle movements, including migration, unless they were to become entrapped as indicated above.

However, the eastern Newfoundland offshore area, including the Project Area, is not a breeding area for sea turtles and it is not known or thought to be an important feeding area, and thus it is not expected that high concentrations of sea turtles could potentially be physically affected.

Effects of the presence of vessels on marine mammals or sea turtles, including the risk of collisions, are predicted to be *negligible* to *low*, over a duration of *<1 month* to *1-12 months*, in an area *<1 km²*. Therefore, effects related to the presence of vessels, are judged to be *not significant* for marine mammals and sea turtles (see Tables 5.11 to 5.14).

5.6.4.4 Effects of Accidental Releases

All petroleum hydrocarbon handling and reporting procedures on board will be consistent with Suncor's policy, and handling and reporting procedures. A fuel spill may occur from the seismic ship and/or the standby/support vessel(s). Any spills would likely be small and quickly dispersed by wind, wave, and ship's propeller action. The effects of hydrocarbon spills on marine mammals and sea turtles were reviewed in Section 11.4.3 of Husky (2012) and are not repeated here. Based on multiple studies, whales and seals do not exhibit large behavioural or physiological responses to limited surface oiling, incidental exposure to contaminated food, or ingestion of oil (St. Aubin 1990; Williams et al. 1994). Sea turtles are thought to be more susceptible to the effects of oiling than marine mammals but effects are primarily believed to be sublethal (Husky 2012). Camacho et al. (2013) reported that 88% of loggerhead turtles that stranded due to crude oil in the Canary Islands, Spain, survived; those that died showed signs of ingested oil and internal lesions. Lesions on the skin, carapace, and plastron tend not to be fatal (Camacho et al. 2013). Effects of a small accidental spill on marine mammals or sea turtles would be *low*, over a duration of *<1 month*, in an area *<1 km²* to *1–10 km²* and are judged to be not significant (see Tables 5.11 to 5.14).

5.6.4.5 Effects of Other Project Activities

There is potential for marine mammals and sea turtles to interact with domestic and sanitary wastes, and air emissions from the seismic ship and the standby/support vessel(s). Any effects from these interactions are predicted to be *negligible* (see Tables 5.11 to 5.14).

5.6.5 Species at Risk (SAR) VEC

A biological overview of all species considered at risk under *SARA* and/or by COSEWIC that are likely or may occur in the Study Area was provided in Section 4.6. No critical habitat has been defined for the Study Area. As discussed in previous sections and presented in Table 4.9, *SARA* species of relevance to the Study Area include:

- Northern, spotted and Atlantic wolffish, and white shark;
- Ivory Gull;
- Blue, North Atlantic right, northern bottlenose, fin, and Sowerby's beaked whale; and
- Leatherback sea turtle.

Species not currently designated on Schedule 1 of *SARA* but listed on Schedule 2 or 3 or being considered for addition to Schedule 1 (as per their current COSEWIC listing of *endangered*, *threatened* or *special concern*), are not included in the Species at Risk VEC here but have been assessed in the relevant VEC in Sections 5.6.1 (Fish), 5.6.3 (Marine Birds) and 5.6.4 (Marine Mammals and Sea Turtles) of this EA. If species not currently designated on Schedule 1 of *SARA* do become listed on this legal list during the remainder of the life of the Project (2014–2024), the Proponent will re-assess these species considering the prohibitions of *SARA* 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 Environment Canada. Potential interactions between the Project and SAR are shown in Table 5.15.

As per the detailed effects assessment in Section 5.6.1 and shown again in Tables 5.2 to 5.3, physical effects of the Project on the various life stages of wolffishes and the white shark will range from *negligible* to *low* over a duration of *1–12 months*, within an area of *<1 km²* (Table 5.16). Behavioural effects may extend out to a larger area but are still predicted to be *not significant* (Table 5.17). The mitigation measure of ramping-up the airgun array (over a 30 min period) is expected to minimize the potential for impacts on wolffishes and the white shark.

As per the detailed effects assessment in Section 5.6.3, the predicted effects of the Project on the Ivory Gull is *negligible*, therefore the predicted residual effects of the Project on Ivory Gulls are predicted to be *not significant*. These species are unlikely to occur in the Study Area, particularly during the time when seismic surveys are likely to be conducted. In addition, the foraging behaviour (and location of foraging areas) would not likely expose them to underwater sound from the Project (Tables 5.16 and 5.17). Furthermore, Ivory Gulls are not known to be prone to stranding on vessels. The mitigation measure of monitoring the seismic vessel and releasing stranded birds and ramping-up the airgun array will minimize the potential for impacts on these species. Any injured Ivory Gull would be immediately reported to CWS.

Table 5.15. Potential Interactions between the Project and Species at Risk VEC.

Valued Environmental Components: Species at Risk					
Project Activities	**White Shark**	**Wolffishes**	**Ivory Gull**	**Blue and Right Whales**	**Leatherback Sea Turtle**
Sound					
Airguns	X	X	X	X	X
Seismic Vessel	X	X	X	X	X
Supply Vessel	X	X	X	X	X
Picket Vessel	X	X	X	X	X
Echo Sounder	X	X	X	X	X
Side Scan Sonar	X	X	X	X	X
Boomer / Sparker	X	X	X	X	X
Vessel Lights			X		
Vessel Presence					
Seismic Vessel			X	X	X
Supply Vessel			X	X	X
Picket Vessel			X	X	X
Helicopter Presence [a]			X	X	X
Sanitary/ Domestic Waste	X	X	X	X	X
Atmospheric Emissions	X	X	X	X	X
Garbage [b]					
Shore Facilities [c]					
Accidental Releases	X	X	X	X	X
Other Projects and Activities					
Oil and Gas Activities on Grand Banks and Orphan Basin	X	X	X	X	X
Fisheries	X	X	X	X	X
Marine Transportation	X	X	X	X	X

[a] A crew change may occur via helicopter if the seismic program is longer than 5 to 6 weeks.
[b] Not applicable as garbage will be brought ashore.
[c] There will not be any new onshore facilities. Existing infrastructure will be used.

Table 5.16. Assessment of Effects on the Species at Risk VEC.

Valued Environmental Component: Species At Risk								
Project Activity	**Potential Positive (P) or Negative (N) Environmental Effect**	**Mitigation**	**Evaluation Criteria for Assessing Environmental Effects**					
			Magnitude	**Geographic Extent**	**Frequency**	**Duration**	**Reversibility**	**Ecological/ Socio-Cultural and Economic Context**
Sound								
Airguns	Disturbance (N); Hearing Impairment (N); Physical Effects (N)	Ramp-up; delay start [a]; shutdown [b]	0-1	3-4	6	1-2	R	2
Seismic Vessel	Disturbance (N)		0-1	1-2	6	1-2	R	2
Supply Vessel	Disturbance (N)		0-1	1-2	6	1	R	2
Picket Vessel	Disturbance (N)		0-1	1-2	6	1	R	2
Echo Sounder	Disturbance (N)		0	1	6	1	R	2
Side Scan Sonar	Disturbance (N)		0	1	6	1	R	2
Boomer / Sparker	Disturbance (N)		0	1	6	1	R	2
Vessel Presence								
Seismic Vessel	Disturbance (N)		0-1	1	6	1-2	R	2
Supply Vessel	Disturbance (N)		0-1	1	1	1	R	2
Picket Vessel	Disturbance (N)		0-1	1	6	1	R	2
Helicopter Presence [c]	Disturbance (N)	Maintain high altitude	0	1-2	1	1	R	2
Vessel Lights	Attraction (N); Mortality (N)	Reduce lighting (if safe); release protocols	0-2	1-2	2-3	1-2	R	2
Sanitary/Domestic Waste	Increased food (N/P)		0-1	1	1	1-2	R	2
Atmospheric Emissions	Surface contaminants (N)		0	1	6	1-2	R	2
Accidental Releases	Injury/Mortality (N)	Solid Streamer [d]; Spill Response	1-2	1-3	1	1-2	R	2

Key:

Magnitude:
0 = Negligible, essentially no effect
1 = Low
2 = Medium
3 = High

Frequency:
1 = <11 events/yr
2 = 11-50 events/yr
3 = 51-100 events/yr
4 = 101-200 events/yr
5 = >200 events/yr
6 = continuous

Reversibility:
R = Reversible
I = Irreversible
(refers to population)

Duration:
1 = <1 month
2 = 1-12 months
3 = 13-36 months
4 = 37-72 months
5 = >72 months

Geographic Extent:
1 = <1 km^2
2 = 1-10 km^2
3 = 11-100 km^2
4 = 101-1000 km^2
5 = 1,001-10,000 km^2
6 = >10,000 km^2

Ecological/Socio-cultural and Economic Context:
1 = Relatively pristine area or area not negatively affected by human activity
2 = Evidence of existing negative effects

[a] Ramp up will be delayed if any marine mammal or sea turtle is sighted within the 500 m safety zone.
[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 crew change may occur via helicopter if the seismic program is longer than 5 to 6 weeks.
[d] Solid or Isopar filled streamers may be used during future surveys, depending on the seismic contractor.

Table 5.17. Significance of Potential Residual Environmental Effects of the Proposed Geophysical Program on the Species at Risk VEC.

Valued Environmental Component: Species At Risk				
Project Activity	**Significance Rating**	**Level of Confidence**	**Likelihood [a]**	
	Significance of Predicted Residual Environmental Effects		**Probability of Occurrence**	**Scientific Certainty**
Sound				
Airguns	NS	2-3	-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Echo Sounder	NS	3	-	-
Side Scan Sonar	NS	3	-	-
Boomer / Sparker	NS	3	-	-
Vessel Presence			-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Vessel Lights	NS	3	-	-
Helicopter Presence	NS	3	-	-
Sanitary/Domestic Wastes	NS	3	-	-
Atmospheric Emissions	NS	3	-	-
Accidental Releases	NS	2-3	-	-

Key:

Residual environmental Effect Rating:
S = Significant Negative Environmental Effect
NS = Not-significant Negative Environmental Effect
P = Positive Environmental Effect

Significance is defined as a medium or high magnitude (2 or 3 rating) and duration greater than 1 year (3 or greater rating) and geographic extent >100 km^2 (4 or greater rating).

Level of Confidence: based on professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

Probability of Occurrence: based on professional judgment:
1 = Low Probability of Occurrence
2 = Medium Probability of Occurrence
3 = High Probability of Occurrence

Scientific Certainty: based on scientific information and statistical analysis or professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

[a] Considered only in the case where 'significant negative effect' is predicted.

Based on available information, the blue whale, Sowerby's beaked whale, and leatherback sea turtle are not expected to occur regularly in the Study Area. It is extremely unlikely that a North Atlantic right whale would occur in the Study Area. Northern bottlenose whales, designated as *endangered* (Scotian Shelf population), may occur in the Study Area during summer months and perhaps also at other times of the year. There are finalized recovery strategies for leatherback sea turtles (ALTRT 2006), blue whales in Atlantic Canada (Beauchamp et al. 2009), the Scotian Shelf population of northern bottlenose whales (DFO 2010f), and North Atlantic right whales for which critical habitat has also been designated (Brown et al. 2009). No critical habitat has been designated within the Study Area for any SAR whales or leatherback sea turtles. Mitigation and monitoring designed to minimize potential effects of airgun array noise on *SARA*-listed marine mammals and sea turtles will include:

- Pre-watch of the safety zone before the array is activated;
- Ramp-up of the airgun over a 30-min period;
- Monitoring by MMO(s) during daylight hours that the airgun array is active;

- Shutdown of the airgun array when an *endangered* or *threatened* marine mammal or sea turtle is sighted within the 500-m safety zone; and
- Delay of ramp-up if any marine mammal or sea turtle is sighted within the 500-m safety zone.

With these mitigation measures in place and as per the detailed effects assessment in Section 5.6.4, the Project is predicted to have *no significant effect* (hearing impairment/physical or behavioural) on SAR marine mammals and sea turtles (see Table 5.12 and 5.14, respectively).

In summary, potential effects of Suncor's proposed 2D/3D/4D geophysical program are not expected to contravene the prohibitions of *SARA* (Sections 32(1), 33, 58(1)).

5.6.6 Sensitive Areas VEC

An overview of sensitive areas overlapping the Study Area (Northeast Shelf and Slope EBSA, NAFO coral and sponge closure areas [Figure 4.43]) was provided in Section 4.7. The habitual preferences of biota potentially inhabiting these sensitive areas, including invertebrates, fishes, marine mammals, sea turtles and seabirds, were detailed in Sections 4.2 to 4.5, and species at risk were described in Section 4.6.

Based on the conclusions of Sections 4.6.1 to 4.6.5, the Project is predicted to have *no significant effect* on sensitive habitat or the species therein within the Study Area.

5.7 Cumulative Effects

This EA has assessed cumulative effects within the Project and thus, the residual effects described in preceding sections include any potential cumulative effects from the Suncor geophysical program activities in the Project Area.

It is also necessary to assess cumulative effects from other non-Project activities that are occurring or planned for the Regional Area. These activities may include:

- Commercial and research survey fishing;
- Vessel traffic (e.g., transportation, defense, yachts);
- Hunting (e.g., seabirds, seals); and
- Offshore oil and gas industry.

Fishing has been discussed and assessed in Section 5.6.2. 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 seismic surveys will not cause any mortality to these VECs (with the potential exception of small numbers of petrels) and thus, there will be *no* or *negligible* cumulative effects from mortalities. There is some potential for cumulative effect from disturbance (e.g., fishing vessel noise) but there will be directed attempts by both industries to mitigate effects and to avoid each other's active areas and times. The seismic surveying will also spatially and temporally avoid DFO research vessels during multi-species trawl surveys. Any cumulative effects (i.e., disturbance), if they occur, will be additive (not multiplicative or synergistic) and predicted to be *not significant*.

In the summer, the main North Atlantic shipping lanes between Europe and North America lie to the north of the Grand Banks into the Strait of Belle Isle. In the winter, that traffic shifts to the main shipping lanes along the southern Grand Banks into the Gulf of St. Lawrence. Thus, potential for cumulative effects with other shipping is predicted to be *low* and *not significant*.

The vast majority of hunting of seabirds (mostly murres) in Newfoundland and Labrador waters occurs near shore from small boats. Also, it is predicted that no murres will suffer mortality from the Project's routine activities. Thus, there is little or no potential for cumulative effects on this VEC. Similarly, most, if not all, seal hunting would occur inshore of the Project Area, and the Project will not cause mortality to seals even in the event of an accidental spill of petroleum hydrocarbons.

Potential offshore oil and gas industry activities in the Regional Area (as pre the C-NLOPB public registry, www.cnlopb.nl.ca) include:

- Hibernia Management and Development Company Ltd. (HMDC) 2D/3D/4D seismic surveys in the Jeanne d'Arc Basin, 2013 to the remaining life of the Hibernia oil and gas production field;
- Multi Klient Invest ASA (MKI) 2D seismic program on Northeast Newfoundland Shelf (i.e., Labrador Basin, Orphan Basin, Flemish Pass, Jeanne d'Arc Basin), 2012-2017;
- WesternGeco 2D/3D seismic surveys in the Jeanne d'Arc Basin/Flemish Pass, 2012-2015;
- Statoil 3D/2D geophysical program including geohazard and electromagnetic surveys in Jeanne d'Arc and Central Ridge/Flemish Pass Basins, 2011-2019;
- Husky's seismic and geohazard program in the Jeanne d'Arc Basin/Flemish Pass, 2012-2020;
- Investcan Energy Corporation 2D/3D seismic program including geohazard and VSP surveys on Labrador Shelf, 2010-2017;
- Chevron Canada Resources 3D/2D seismic program including geohazard survey in offshore Labrador, 2010-2017;
- Chevron Canada Resources 3D and/or 2D seismic program including geohazard survey in the North Grand Banks Region, 2011-2017;
- Statoil exploration, appraisal, and delineation drilling program in Jeanne d'Arc Basin area, 2008-2016;
- Suncor exploration drilling in Jeanne d'Arc Basin, 2009-2017;
- Husky White Rose new drill centre construction and operations program, 2008-2015; and
- Husky exploration and delineation drilling program in Jeanne d'Arc Basin, 2008-2017.

While the above list suggests potential for many programs to run concurrently it should be noted that the East Coast operators tend to coordinate their logistics. As a result, based on historical levels of activities, there typically would be no more than two or three drill rigs and two or three seismic programs operating off Newfoundland and Labrador during any one season.

In addition, there are three existing offshore production developments (Hibernia, Terra Nova, and White Rose) on the northeastern part of the Grand Banks. A fourth development (Hebron) began construction in October 2012. Additional production development (White Rose Extension Program, WREP) is anticipated to commence installation in the near future. The existing developments fall inside of the boundaries of Suncor's Study Area but do not create the same levels of underwater noise as seismic, geohazard, or VSP programs. Any cumulative effects (i.e., disturbance), if they occur, will be additive (not multiplicative or synergistic) and predicted to be *not significant*.

There is potential for cumulative effects with other seismic programs proposed for 2014-2024 (e.g., Statoil, Husky, MKI). Different seismic programs could potentially be operating in close proximity. During these periods, marine mammals may be exposed to noise from each of the seismic survey programs. It will be in the interests of the different parties for good coordination between programs in order to provide sufficient buffers and to minimize acoustic interference. Effects on marine mammals (and other VECs) are predicted to be *not significant*. However, there are uncertainties regarding this prediction. The potential for temporal and spatial overlap of future activity of seismic programs (2014-2024) in the area will be assessed in the EA update process. Uncertainty due to the large identified Study Area will be reduced as specific survey designs (covering smaller area) become available.

As discussed in this EA, negative effects on key sensitive VECs 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 start ups, and shutdowns of the airgun arrays. Thus, it seems likely that while some animals may receive sound from one or more geophysical programs, the current scientific prediction is it that *no significant residual effects* will result.

5.8 Mitigations and Follow-up

Project mitigations are summarized in the text provided below and in Table 5.18. Suncor and contractors will adhere to mitigations detailed in Appendix 2 of the *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB) including those in the *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment*.

Fishers who may be operating in the area will be notified of the timing and location of planned activities by means of a CCG “Notice to Mariners” and a “Notice to Fishers” on the CBC Radio Fisheries Broadcast. In addition, if necessary, individual fixed gear fishers will be contacted to arrange mutual avoidance. Any contacts with fishing gear, with any identifiable markings, will be reported to the C-NLOPB within 24 h of the contact (in accordance with the C-NLOPB 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 Conservation and Protection Division of Fisheries and Oceans Canada (NL Region). Suncor will advise the C-NLOPB prior to compensating and settling all valid lost gear/income claims promptly and satisfactorily.

Specific mitigations to minimize potential conflicts and any negative effects with other vessels include:

- Timely and clear communications (VHF, HF Satellite, etc.);
- Utilization of fisheries liaison officers (FLOs) during 2D/3D/4D seismic programs for advice and coordination in regard to avoiding fishing vessels and fishing gear;
- MMO(s) on board;
- Posting of advisories with the Canadian Coast Guard and the CBC Fisheries Broadcast;
- Compensation program in the event any project vessels damage fishing gear; and
- Single Point of Contact (SPOC).

Table 5.18. Summary of Mitigations Measures.

Potential Effects	Primary Mitigations
Interference with fishing vessels	• Upfront planning to avoid high concentrations of fishing vessels to the greatest extent possible • SPOC • Advisories and communications • FLO for 2D/3D/4D programs • Planned transit route to and between Survey Areas (if required)
Fishing gear damage	• Upfront planning to avoid high concentrations of fishing gear to the greatest extent possible • SPOC • Advisories and communications • FLO for 2D/3D/4D programs • Compensation program
Interference with shipping	• SPOC • Advisories and communications • FLO for 2D/3D/4D programs
Interference with DFO/FFAW research vessels	• Communications and scheduling; avoidance to the greatest extent possible
Temporary or permanent hearing damage/disturbance to marine animals	• Delay start-up if marine mammals or sea turtles are within 500 m • Ramp up of airguns over 30 min-period • Shutdown of airgun arrays for *endangered* or *threatened* marine mammals and sea turtles within 500 m • Use of MMO(s) to monitor for marine mammals and sea turtles during daylight seismic operations
Temporary or permanent hearing damage/ disturbance to Species at Risk or other key habitats	• Delay start-up if any marine mammals or sea turtles are within 500 m • Ramp up of airguns • Shutdown of airgun arrays for *endangered* or *threatened* marine mammals and sea turtles • Use of qualified MMO(s) to monitor for marine mammals and sea turtles during daylight seismic operations.
Injury (mortality) to stranded seabirds	• Daily monitoring of vessel • Handling and release protocols • Minimize unnecessary lighting when practical and safe to do so
Exposure to hydrocarbons	• Adherence to International Convention for the Prevention of Pollution from Ships (MARPOL) • Spill contingency plans; bunkering at sea procedures • Use of solid streamer when feasible

Suncor will also coordinate with DFO, St. John's, and the FFAW to avoid any potential conflicts with survey vessels that may be operating in the area. Suncor commits to ongoing communications with other operators with active seismic programs within the general vicinity of its seismic program to minimize the potential for cumulative effects on VECs.

Mitigation measures designed to reduce the likelihood of impacts on marine mammals and sea turtles will include ramp ups, no initiation of airgun array if a marine mammal or sea turtle is sighted 30 min prior to ramp up within 500 m safety zone of the energy source, and shutdown of the energy source if an endangered (or threatened) whale or sea turtle is observed within the 500 m safety zone. Prior to the onset of the seismic survey, the airgun array will be gradually ramped up. One airgun will be activated first and then the volume of the array will be increased gradually over a recommended 30 min period. An observer (MMO) aboard the seismic ship will watch for marine mammals and sea turtles 30 min prior to ramp up. If a marine mammal or sea turtle is sighted within 500 m of the array, then

ramp up will not commence until the animal has moved beyond the 500 m zone or 20 min have elapsed since the last sighting. The observers will watch for marine mammals and sea turtles when the airgun array is active (during daylight periods) and note the location and behaviour of these animals. The seismic array will be shutdown if an endangered (or threatened) marine mammal or sea turtle is sighted within the safety zone. The planned monitoring and mitigation measures, including ramp-ups, visual monitoring, and shutdown of the airguns when endangered or threatened marine mammals or turtles are seen within the "safety radii", will minimize the already-low probability of exposure of marine animals to sounds strong enough to induce hearing impairment. Any dead or distressed marine mammals or sea turtles will be recorded and reported to the C-NLOPB and DFO.

Any seabirds (most likely Leach's Storm-petrel) that become stranded on the vessel will be released using the mitigation methods consistent with *The Leach's Storm-Petrel: General Information and Handling Instructions* by U. Williams (Petro-Canada) and J. Chardine (CWS) (n.d.). Data collection for seabirds at sea will be in accordance with Gjerdrum et al. (2011). It is understood by Suncor that a CWS *Migratory Bird Handling Permit* will be required, and this will be secured as it has been done in the past. Suncor will adhere to the conditions stipulated on the CWS permit. In the unlikely event that marine mammals, turtles or birds are injured or killed by Project equipment or accidental releases of fuel or streamer flotation fluid, a report will immediately be filed with the appropriate agencies (CWS, C-NLOPB) and the need for follow-up monitoring assessed.

Marine mammal and seabird observations will be made during ramp-ups and during data acquisition periods, and at other times on an opportunistic basis. As per the *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2012), monitoring protocols for marine mammals and sea turtles will be consistent with those developed by LGL and outlined in Moulton and Mactavish (2004). Seabird data collection protocols will be consistent with those provided by CWS in Wilhelm et al. (n.d.). Data will be collected and a monitoring report will be submitted to the C-NLOPB within one year after completion of the surveys.

5.9 Assessment Summary

A summary of the Project's residual effects on the environment, in other words those effects that remain after mitigations have been instituted, are shown in Table 5.19. Suncor's geophysical program is predicted to have *no significant* effects on VECs.

Table 5.19. Significance of Potential Residual Environmental Effects of the Proposed Geophysical Program on VECs in the Study Area.

Valued Environmental Component: Fish and Fish Habitat, Fisheries, Birds, Marine Mammals, Turtles, Species at Risk				
Project Activity	**Significance Rating**	**Level of Confidence**	**Likelihood [a]**	
	Significance of Predicted Residual Environmental Effects		**Probability of Occurrence**	**Scientific Certainty**
Sound				
Airguns	NS	2-3	-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Echo Sounder	NS	3	-	-
Side Scan Sonar	NS	3	-	-
Boomer / Sparker	NS	3	-	-
Vessel Presence			-	-
Seismic Vessel	NS	3	-	-
Supply Vessel	NS	3	-	-
Picket Vessel	NS	3	-	-
Vessel Lights	NS	3	-	-
Helicopter Presence	NS	3	-	-
Sanitary/Domestic Wastes	NS	3	-	-
Atmospheric Emissions	NS	3	-	-
Accidental Releases	NS	2-3	-	-

Key:

Residual environmental Effect Rating:
S = Significant Negative Environmental Effect
NS = Not-significant Negative Environmental Effect
P = Positive Environmental Effect

Significance is defined as a medium or high magnitude (2 or 3 rating) and duration greater than 1 year (3 or greater rating) and geographic extent >100 km^2 (4 or greater rating).

Level of Confidence: based on professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

Probability of Occurrence: based on professional judgment:
1 = Low Probability of Occurrence
2 = Medium Probability of Occurrence
3 = High Probability of Occurrence

Scientific Certainty: based on scientific information and statistical analysis or professional judgment:
1 = Low Level of Confidence
2 = Medium Level of Confidence
3 = High Level of Confidence

[a] Considered only in the case where 'significant negative effect' is predicted.

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APPENDICES

A. Seabird Summary Tables
B. Persons Consulted
C. SPOC (and FLO) Protocols, Procedures and Reporting Forms
D. Review of Potential Effects of Airgun Sound on Marine Invertebrates
E. Review of Potential Effects of Airgun Sound on Fishes
F. Review of Potential Effects of Airgun Sound on Marine Mammals
G. Review of Potential Effects of Airgun Sound on Sea Turtles

Appendix A. Seabird Summary Tables

Table A.1 Average densities of seabirds by month recorded during 10-minute seabird counts on the Orphan Basin, 14 May to 24 September 2005.

	Average Densities (number of individuals per km^2) per 10-minute Observation Period					
	May	**Jun**	**Jul**	**Aug**	**Sep**	**All Months Combined**
No. of 10-minute Observation Periods	113	157	45	135	71	521
Total Area Surveyed (km^2)	42.1	63.3	16.1	51.8	30.8	204.1
Species						
Northern Fulmar	30.12	4.75	3.27	4.23	16.14	11.54
Greater Shearwater	1.17	4.23	35.37	21.15	9.18	11.32
Leach's Storm-Petrel	5.14	7.74	5.48	10.23	6.31	7.43
Great Black-backed Gull	0.24	0.08	0.00	4.14	12.07	2.79
Dovekie	1.25	1.21	0.00	0.04	0.00	0.65
Thick-billed Murre	0.61	0.74	0.00	0.00	0.00	0.36
Black-legged Kittiwake	1.07	0.27	0.06	0.06	0.03	0.34
Herring Gull	0.43	0.05	0.00	0.22	0.07	0.18
Sooty Shearwater	0.00	0.12	0.05	0.17	0.38	0.14
Long-tailed Jaeger	0.25	0.06	0.00	0.00	0.00	0.07
Red Phalarope	0.20	0.01	0.00	0.00	0.00	0.05
Unidentified murre	0.03	0.04	0.00	0.10	0.00	0.05
Common Murre	0.05	0.06	0.14	0.00	0.00	0.04
Pomarine Jaeger	0.03	0.00	0.00	0.02	0.04	0.02
Lesser Black-backed Gull	0.00	0.04	0.00	0.00	0.03	0.02
Manx Shearwater	0.00	0.02	0.00	0.00	0.00	0.01
South Polar Skua	0.00	0.00	0.06	0.00	0.03	0.01
Unidentified skua	0.00	0.00	0.00	0.02	0.03	0.01
Parasitic Jaeger	0.03	0.00	0.00	0.00	0.04	0.01
Unidentified jaeger	0.00	0.00	0.00	0.03	0.00	0.01
Glaucous Gull	0.02	0.00	0.00	0.00	0.00	0.01
Sabine's Gull	0.03	0.00	0.00	0.00	0.00	0.01
Arctic Tern	0.00	0.02	0.00	0.00	0.00	0.01
Atlantic Puffin	0.02	0.00	0.06	0.00	0.00	0.01
All Species	**1.27**	**0.61**	**1.39**	**1.27**	**1.39**	**1.10**

Source: Moulton et al. 2006.

Table A.2 **Average densities (± standard deviation) of seabirds by month recorded during 10-minute seabird counts on the Orphan Basin, August (*n* = 53 counts) and September (*n* = 33 counts) 2006.**

Species	Average Densities - number of individuals per km^2 (±SD) - of 10-minute Tasker Counts		
	Aug	**Sep**	**All**
Greater Shearwater	11.78 (±24.67)	2.43 (±5.88)	8.20 (±20.15)
Leach's Storm-Petrel	6.01 (±5.79)	6.26 (±7.13)	6.11 (±6.30)
Black-legged Kittiwake	1.42 (±2.73)	7.81 (±21.89)	3.87 (±13.95)
Northern Fulmar	2.34 (±4.72)	5.75 (±6.09)	3.65 (±5.51)
Great Black-backed Gull	0.25 (±0.95)	2.37 (±6.56)	1.06 (±4.23)
Sooty Shearwater	0.35 (±0.74)	1.06 (±2.21)	0.63 (±1.52)
Pomarine Jaeger	0.07 (±0.28)	0.18 (±0.82)	0.11 (±0.55)
Great Skua	0.11 (±0.31)	0.12 (±0.50)	0.11 (±0.39)
Arctic Tern	0.09 (±0.46)	0.07 (±0.40)	0.08 (±0.43)
Atlantic Puffin	0.15 (±0.91)	0.07 (±0.49)	0.08 (±0.77)
Long-tailed Jaeger	0.12 (±0.38)	0	0.07 (±0.30)
Parasitic Jaeger	0.02 (±0.18)	0.13 (±0.50)	0.07 (±0.34)
Lesser Black-backed Gull	0.04 (±0.21)	0	0.03 (±0.17)
Dovekie	0	0.05 (±0.31)	0.02 (±0.19)
Common Murre	0.03 (±0.22)	0	0.02 (±0.18)
South Polar Skua	0.03 (±0.21)	0	0.02 (±0.16)
skua sp.	0.04 (±0.19)	0	0.02 (±0.15)
Wilson's Storm-Petrel	0.03 (±0.21)	0	0.02 (±0.16)
Herring Gull	0	0.03 (±0.18)	0.01 (±0.11)
Northern Gannet	0.02 (±0.16)	0	0.01 (±0.13)
All Species	**22.89** (±25.15)	**26.35** (±22.89)	**24.22** (±24.23)

Source: Abgrall et al. 2008b.

Table A.3 Average densities (± standard deviation) of seabirds recorded during 10-minute seabird counts during on the Orphan Basin, 23 July to 6 September (*n* = 97 counts) 2007.

Species	Average Densities - number of individuals per km^2 (±SD) - of 10-minute Tasker Counts
Leach's Storm-Petrel	4.34 (±3.23)
Greater Shearwater	2.42 (±3.47)
Northern Fulmar	1.67 (±1.95)
Sooty Shearwater	0.19 (±0.49)
Common Murre	0.09 (±0.46)
Great Black-backed Gull	0.05 (±0.32)
Northern Gannet	0.03 (±0.23)
Long-tailed Jaeger	0.03 (±0.22)
Thick-billed Murre	0.03 (±0.26)
Dovekie	0.02 (±0.20)
Red Phalarope	0.01 (±0.10)
Manx Shearwater	0.01 (±0.01)
unidentified murre	0.01 (±0.10)
Black-legged Kittiwake	0.01 (±0.09)
Lesser Black-backed Gull	0.01 (±0.09)
All Species	**8.87** (±6.38)

Source: Abgrall et al. 2008b.

Table A.4 Average densities of seabirds by week recorded during 10-minute seabird counts in the Jeanne d'Arc Basin and adjacent areas, 1 October to 8 November 2005, arranged in order of decreasing density.

	Average Density (number of individuals per km²) per 10-minute Observation Period						
Species	**1-7 Oct**	**8-14 Oct**	**15-21 Oct**	**22-28 Oct**	**29 Oct - 4 Nov**	**5-8 Nov**	**All weeks combined**
Northern Fulmar	3.07	25.57	4.35	34.17	10.00	10.77	14.72
Dovekie	1.53	5.07	10.14	13.58	7.07	4.16	7.09
Black-legged Kittiwake	1.16	8.38	11.76	8.97	4.29	5.78	6.57
Thick-billed Murre	0	1.86	5.01	4.16	7.41	9.58	4.11
Greater Shearwater	11.82	1.71	0.45	0	0	0	2.87
Atlantic Puffin	0.86	1.73	2.37	1.34	1.65	0.51	1.46
Common Murre	1.05	0.88	1.52	0.83	0.05	0.20	0.81
Great Black-backed Gull	0.25	1.59	0.65	0.67	0.51	0.46	0.68
Leach's Storm-Petrel	1.02	0.39	0.46	0.54	0.04	0	0.47
Sooty Shearwater	0.19	1.03	0.50	0.61	0	0	0.40
Glaucous Gull	0	0	0.06	0.50	0.04	0.48	0.16
Herring Gull	0.04	0.05	0.00	0.06	0.20	0.76	0.13
Pomarine Jaeger	0.21	0	0	0	0	0	0.04
Jaeger sp.	0.08	0	0	0.07	0	0	0.03
Murre sp.	0	0.05	0.04	0.08	0	0	0.03
Northern Gannet	0.07	0	0	0	0.09	0	0.03
Razorbill	0.14	0	0	0	0	0	0.03
Iceland Gull	0	0	0	0	0.05	0.09	0.02
Lesser Black-backed Gull	0	0.12	0	0	0	0	0.02
Parasitic Jaeger	0	0.05	0	0.04	0	0	0.02
Red Phalarope	0.07	0	0	0.04	0	0	0.02
Skua sp.	0	0.05	0.05	0	0	0	0.02
Great Skua	0	0	0.05	0	0	0	0.01
Manx Shearwater	0	0	0	0.04	0	0	0.01
South Polar Skua	0.03	0	0	0	0	0	0.01
All species	**21.70**	**48.55**	**37.40**	**65.71**	**31.39**	**32.79**	**39.76**

Source: Abgrall et al. 2008a.

Table A.5 Average densities of seabirds by week recorded during 10-minute seabird counts in the Jeanne d'Arc Basin, 9 July to 16 August 2006.

Species	Average Density (number of individuals per km²) per 10-minute Observation Period						
	9-16 Jul	17-23 Jul	24-30 Jul	31 Jul - 6 Aug	7-13 Aug	14-16 Aug	All Weeks Combined
Greater Shearwater	2.54	7.04	4.33	8.90	1.57	0.62	5.06
Leach's Storm-Petrel	1.15	0.17	0.24	0.41	0.42	0.10	0.60
Northern Fulmar	0.15	0.05	0.05	0	0	0.05	0.07
Sooty Shearwater	0.07	0	0.05	0.02	0.03	0	0.04
Atlantic Puffin	0.12	0	0	0	0	0	0.03
South Polar Skua	0	0	0.05	0.05	0	0	0.02
Common Murre	0.08	0	0	0	0	0	0.02
Skua sp.	0	0	0.05	0	0	0	0.01
Red Phalarope	0	0	0.10	0	0	0	0.01
Pomarine Jaeger	0	0	0.05	0	0.03	0	0.01
Northern Gannet	0	0	0	0.02	0	0	0.01
Murre sp.	0	0.05	0	0.03	0	0	0.01
Manx Shearwater	0.02	0	0	0.03	0	0	0.01
Great Black-backed Gull	0	0	0	0	0	0.03	0.01
Dovekie	0	0	0	0.03	0	0	0.01
Black-legged Kittiwake	0	0	0	0	0	0.05	0.01
All Species	**4.14**	**7.32**	**4.91**	**9.49**	**2.03**	**0.85**	**5.93**

Source: Abgrall et al. 2008a.

Table A.6 **Average Densities of seabirds bi-monthly recorded during 10-minute seabird counts in the Jeanne d'Arc Basin and adjacent areas, 21 May to 29 September 2008.**

Species	Average Density (number of individuals per km²) per 10-minute Observation Period									
	21-31 May	1-15 Jun	16-20 Jun	1-15 Jul	16-31 Jul	1-15 Aug	16-31 Aug	1-15 Sep	16-29 Sep	Grand Total
Greater Shearwater	0.05	2.11	15.07	26.65	19.93	24.27	9.81	9.04	3.18	11.92
Sooty Shearwater	0	0.33	1.04	0.25	0.1	0.07	0.53	6.06	3.98	1.65
Northern Fulmar	0.08	0.18	3.54	0.15	0.26	0.57	1.02	1.41	3.03	1.24
All murres	1.1	0.25	0.46	0.31	0.29	0.02	0.88	1.61	3.57	1.02
Leach's Storm-Petrel	0.22	0.13	0.21	0.21	0.97	0.57	0.49	1.49	2.92	0.9
Common Murre	0.72	0.09	0.28	0.31	0.24	0	0	1.51	3.42	0.84
Unidentified Murre	0.38	0.12	0.18	0	0.03	0.02	0.88	0.08	0.15	0.18
Great Black-backed Gull	0	0	0	0	0	0	0.03	0.55	0.52	0.15
Atlantic Puffin	0	0.02	0.13	0.14	0.02	0	0	0.02	0.59	0.11
Manx Shearwater	0	0	0.06	0.14	0.21	0.07	0	0	0	0.05
Pomarine Jaeger	0	0	0	0	0	0.02	0.06	0.12	0.14	0.04
South Polar Skua	0	0	0	0.14	0.03	0.03	0.06	0.04	0	0.03
Great Skua	0	0	0	0.03	0	0	0.03	0.06	0.04	0.02
Northern Gannet	0	0	0	0	0	0	0.16	0.03	0	0.02
Dovekie	0.03	0	0.02	0	0	0	0	0	0.07	0.02
Black-legged Kittiwake	0	0.02	0.07	0	0	0	0.03	0.03	0.02	0.02
Thick-billed Murre	0	0.04	0	0	0.03	0	0	0.02	0	0.01
Red Phalarope	0	0	0	0	0	0	0	0.05	0	0.01
Long-tailed Jaeger	0	0	0	0	0	0	0	0.03	0.02	0.01
Unidentified phalarope	0	0	0	0	0	0	0	0.03	0	0.005
Parasitic Jaeger	0	0	0	0	0	0	0	0.005	0.02	0.003
Wilson's Storm-Petrel	0	0	0	0	0	0	0	0.02	0	0.003
Herring Gull	0	0	0	0	0	0	0	0.02	0	0.002
Unidentified Skua	0	0	0	0	0	0	0.03	0	0	0.002
Unidentified Jaeger	0.03	0	0	0	0	0	0	0	0.02	0.002
Lesser Black-backed Gull	0	0	0	0	0	0	0	0	0.02	0.002
Arctic Tern	0	0	0	0	0	0	0	0	0.02	0.002
All Birds	**1.51**	**3.03**	**20.6**	**31.03**	**21.82**	**25.63**	**13.14**	**20.59**	**18.12**	**17.23**

Source: Abgrall et al. 2009.

Appendix B. Persons Consulted

The following agencies, managers and fishing industry participants were consulted for during preparation of Suncor's Environmental Assessment:

Fisheries and Oceans Canada

Jason Kelly, Co-ordinator, Environmental Assessment & Major Projects, Oceans, Habitat & Species at Risk Branch

Environment Canada (Environmental Protection Branch)

Glenn Troke, EA Co-ordinator

Kim Mawhinney (EC)

Natasha Boyd (EC)

Jerry Pulchan (EC)

Brian Drover (EC)

Zena Wright (by phone) (EC)

Nature NL (and member organizations)

Dr. Len Zedel

Dr. Allan Stein

Dr. Rita Anderson

One Ocean

Maureen Murphy, Director of Operations

Fish, Food and Allied Workers Union (FFAW)

Johan Joensen, Petroleum Industry Liaison

Association of Seafood Producers

E. Derek Butler, Executive Director

Ocean Choice International

Rick Ellis, Fleet Manager

Icewater Seafoods

Dennis Slade, Fisheries Consultant

Tom Osbourne, Plant Manager, Arnold's Cove

Clearwater Seafoods Limited Partnership

Catherine Boyd, Manager, Corporate Affairs

Newfound Resources Ltd. (NRL)

Brian MacNamara, President

Groundfish Enterprise Allocation Council (GEAC); Canadian Association of Prawn Producers (CAPP)

Bruce Chapman, Executive Director (GEAC and CAPP)

Appendix C. SPOC (and FLO) Protocols, Procedures and Reporting Forms

One Ocean Protocol for Seismic Survey Programs in Newfoundland and Labrador

ONE OCEAN CORPORATION
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One Ocean

In the province of Newfoundland and Labrador, a unique model has been developed to facilitate effective communication between the offshore fishing and petroleum sectors. In 2002, One Ocean was established as a voluntary, inter-industry liaison organization providing a neutral and practical medium for information exchange. The model promotes mutual awareness and understanding of industry operational activities and its proactive approach to address areas of potential concern is enhanced through its commitment to cooperation and transparency.

One Ocean initiates industry specific activities to meet regional challenges and participates in Research and Development projects relating to potential environmental effects of the fishing and petroleum industries to ensure sustainable and safe practices in the marine environment. Research entities are referenced in Appendix B.

The organization consists of a Chairperson, Secretariat, Industry Board and Working Group. The One Ocean Industry Board is a core component of the organization and is comprised of equal, senior-level representation from the two industry sectors. Fishing industry members are represented by the Fish, Food and Allied Workers (FFAW) union and the Association of Seafood Producers (ASP). Petroleum industry members are affiliates of the Canadian Association of Petroleum Producers (CAPP). The Please see Appendix A for more information on One Ocean member entities.

One Ocean is an industry driven organization not mandated by government. Members identified the value of having industry regulators represented on the Board in the capacity of Official Observers including the Canada-Newfoundland and Labrador Offshore Petroleum Board (C- NLOPB), regulator for the offshore petroleum industry and Fisheries and Oceans Canada (DFO), regulator for the fishing industry. Other Official Observers include the Fisheries and Marine Institute of Memorial University of Newfoundland (Marine Institute) and the Canadian Coast Guard (CCG).

To enhance the functioning of One Ocean, the Industry Board appointed a Working Group in 2009 to provide recommendations and working level support. The Working Group consists of Industry Board entity members from the fishing and petroleum industries.

Please see http://www.oneocean.ca for more information.

EXECUTIVE SUMMARY

In 2011, One Ocean reviewed fishing and petroleum industry practices and processes related to offshore seismic survey programs in Newfoundland and Labrador. The objective was to identify opportunities to better understand and improve operational processes that would mutually benefit both industries.

The results of the review are incorporated in this document, *One Ocean Protocol for Seismic Survey Programs in Newfoundland and Labrador*, (Seismic Protocol) and outline practices and processes to facilitate seismic survey program planning and execution for the provincial fishing and petroleum industries including:

1. A sequential overview of a seismic survey program process;
2. The qualifications, objectives, duties and responsibilities of a Fisheries Liaison Officer (FLO) and Single Point of Contact (SPOC);
3. One Ocean initiatives such as the *Risk Management Matrix Guidelines for the Utilization of Fisheries Liaison Officers and Fisheries Guide Vessels for the Fishing and Petroleum Industries of Newfoundland and Labrador* (Matrix), Vessel Monitoring System (VMS) access and Industry Consultations; and
4. Frequently Asked Questions on seismic survey programs.

TABLE OF CONTENTS

Executive Summary I
Table Of Contents i
List Of Acronyms V
1.0 Introduction 1
2.0 Offshore Seismic Survey Program Overview 2
3.0 One Ocean Seismic Survey Initiatives 5
3.1 Petroleum Industry Liaison Position 5
3.2 One Ocean Matrix 5
3.3 Vessel Monitoring System 5
3.4 Canada-Newfoundland and Labrador Offshore Petroleum Board Map 5
3.5 Canadian Association of Petroleum Producers Fishery Liaison Officer Video 6
3.6 Fact Sheet for Non-One Ocean Petroleum Industry Members 6
3.7 Industry Consultations 6
4.0 Fisheries Liaison Officer Activities 7
4.1 Objectives of the FLO Program 7
4.2 FLO Training and Certification Requirements 7
4.3 FLO Qualifications 8
4.4 FLO Pre-Departure Preparation and Duties 8
4.5 FLO Equipment 8
4.6 FLO Operational Responsibilities, Protocols and Communications 9
4.7 FLO Daily-Weekly Reports 9
4.8 Fishing Gear Observations Recording and Reporting 10
4.9 Fishing Gear Incident Recording and Reporting 10
5.0 Regulatory Requirements for Reporting an Incident 11
6.0 Single Point of Contact (SPOC) 11
7.0 Frequently Asked Questions About Seismic Surveys 13
7.1 How Does Seismic Surveying Work and how is the Information Used? 13
7.2 What Equipment is used for a Seismic Surveys? 13
7.3 Are There Different Types of Seismic Surveys? 14
7.4 Why Do Seismic Survey Programs Occur During Peak Fishing Season? 15
7.5 How is Seismic Data Collected? 15
7.6 Why Do Seismic Vessels Request a Large At-Sea Berth During the Program? 15
7.7 How is the Seismic Survey Information Used? 15
7.8 Why Do Operators Repeat Seismic Surveys in the Same Offshore Area? 16
7.9 Who Authorizes Seismic Survey Programs and what is the Process? 16
7.10 How Do Fish Harvesters Communicate with the C-NLOPB Regarding Proposed Seismic Survey Programs and Mitigation Practices? 16
7.11 What is the Role of DFO in Seismic Survey Programs? 17
Appendix A: One Ocean Fishing And Petroleum Members 18
Appendix B: Research Entities 19
Appendix C: Seismic Survey Program Contact List 20
Appendix D: Seismic Survey Program Check List 21
Appendix E: The Daily Report Spreadsheet 22
Appendix F: Fishing Gear Incident Report Form 23

LIST OF ACRONYMS

2D	Two-Dimensional Seismic Surveys
3D	Three-Dimensional Seismic Surveys
4D	Four-Dimensional Seismic Surveys
Accord Acts	*Canada-Newfoundland Atlantic Accord Implementation Act*, the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act*
ASP	Association of Seafood Producers
CAPP	Canadian Association of Petroleum Producers
CCG	Canadian Coast Guard
CFV	Canadian Fishing Vessel
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board DFO Fisheries and Oceans Canada
FFAW	Fish, Food and Allied Workers
FLO	Fisheries Liaison Officer
GGEG	Geophysical, Geological, Environmental and Geotechnical Program Guidelines
GPS	Global Positioning System
HSE	Health Safety and Environment
HUET	Helicopter Underwater Escape Training
HUEBA	Helicopter Underwater Escape Breathing Apparatus MED Marine Emergency Duties
NL	Newfoundland and Labrador
OCR	Onboard Client Representative
PIL	Petroleum Industry Liaison
ROC-MC	Marine Radio Operator's Certificate
SOCP	*Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment*
SPOC	Single Point of Contact
STCW	Standards of Training, Certification and Watch Keeping
VSP	Vertical Seismic Profiling
WHMIS	Workplace Hazardous Material Information System
WSS	Well Site Survey

1.0 INTRODUCTION

In 2011, One Ocean reviewed fishing and petroleum industry processes and practices for offshore seismic survey programs in Newfoundland and Labrador. The objective was to identify opportunities to better understand and improve operational processes that would mutually benefit both industries.

The results of the review are outlined in this document, *One Ocean Protocol for Seismic Survey Programs in Newfoundland and Labrador*, (Seismic Protocol) and reference streamlined information on suggested operational procedures and processes to facilitate planning and execution of seismic survey programs for the provincial fishing and petroleum industries.

The content of this Seismic Protocol is not meant to influence, form or be adopted by regulatory entities or referenced as a requirement. The Seismic Protocol is a property of One Ocean, strictly for information purposes and as such One Ocean members assume no liability for its use or application. One Ocean reserves the right to make changes to the Seismic Protocol without notice.

2.0 OFFSHORE SEISMIC SURVEY PROGRAM OVERVIEW

For reference purposes, One Ocean has developed a seismic survey program overview, providing insight on sequential processes and practices inclusive of but not exclusive to:

1. Information on proposed offshore seismic programs is frequently shared between fishing and petroleum industry members of One Ocean (Appendix A) in advance of formal and/or regulatory notices;

2. The Canada-Newfoundland and Labrador Offshore Petroleum Board, (C-NLOPB) is the regulator for the provincial offshore petroleum industry (Section 7.10). The C-NLOPB notifies relevant government departments and agencies, One Ocean and fishing industry representatives of proposed seismic survey activities and provides documentation regarding the program for review and comment;

3. The C-NLOPB begins its review process (Sections 7.10) and may consult with federal departments including Fisheries and Oceans Canada, (DFO) regulator for the fishing industry (7.11);

4. The proponent company (Operator) and/or fishing industry representatives: Association of Seafood Producers (ASP); Fish Food and Allied Workers (FFAW) union, may contact One Ocean to discuss planning details of the seismic survey program in preparation for consultation meetings (Section 3.2);

5. The Operator, One Ocean, ASP and the Petroleum Industry Liaison (PIL) at the FFAW (Section 3.1) schedule consultation meetings;

6. The Operator incorporates details of consultation meetings with the fishing industry and One Ocean, including proposed mitigation measures, into its environmental document and submits it to the C-NLOPB;

7. The fishing industry may submit comments to the C-NLOPB pertaining to the proposed seismic program;

8. Seismic survey initiatives developed by members of One Ocean (Section 3.0) are reviewed once the Operator is in a position to communicate timing, space and logistical details of the program to the fishing industry. This may occur at initial consultation or subsequent meetings;

9. The Operator and/or the fishing industry may contact One Ocean to provide assistance with items identified at consultation and/or subsequent meetings;

10. For 2D and 3D seismic programs, (other programs when deemed necessary) the Operator should contract a Fishery Liaison Officer (FLO) to support the program (Section 4.0). The FFAW provides FLO services and maintains an updated list of qualified FLOs and certification requirements;

11. The Operator will arrange for Notice to Shipping, including contact information for the Single Point of Contact (SPOC) [Section 6.0];

12. The Seismic Survey Contact List (Section 4.4; Appendix C) is completed by the Operator and shared with the fishing industry and One Ocean;

13. The PIL prepares a Summary Report on fishing activity for the FLO, including Vessel Monitoring System, (VMS) data (Section 3.4) for pre-departure;

14. The Operator and/or the FFAW will arrange for the provision of VMS data to the FLO while on board the seismic vessel on an as needed basis for the duration of the program;

15. Arrangements are made by the Operator and the FFAW for the FLO to board the seismic vessel;

16. Pre-departure tasks are completed and confirmed by the FLO and onboard Client Representative and reviewed with senior vessel crew (Section 4.4);

17. The FLO participates in pre-departure, Orientation/Safety session(s). The CAPP-FLO video (Section 3.6) is presented at this time;

18. The FLO commences offshore duties (Sections 4.6-4.10).

19. The FLO records activities, observations and communications three times a day in the Daily Report (Section 4.7) and submits it to the onboard Client Representative;

20. In the event of physical contact with fishing gear, (Section 4.9) the FLO will advise the onboard Client Representative and vessel Master, complete a Fishing Gear Incident Report (Appendix F) and submit it to the onboard Client Representative;

21. The onboard Client Representative will notify the Operator of the incident and the Operator will contact the SPOC, if needed and advise the C-NLOPB of the incident (Section 5.0). The Operator will notify the FFAW within 24 hours of the incident.

22. Communication between the Operator, the fishing industry and One Ocean is maintained on an as needed basis throughout the program;

23. At the end of the seismic program, the FLO or contracted Service Provider is responsible for providing the Operator with a complete record of FLO activities, observations and communications;

24. Upon completion of the offshore seismic survey program, the Operator may host a Close- out meeting with One Ocean and fishing industry representatives.

3.0 ONE OCEAN SEISMIC SURVEY INITIATIVES

In an effort to enhance cooperation, information exchange, mitigation measures and safe practices between the fishing and petroleum industries, One Ocean developed several projects that apply to offshore seismic survey programs.

3.1 Petroleum Industry Liaison Position

To provide effective technical capacity to the FFAW regarding the petroleum industry, an arrangement was undertaken by One Ocean in 2006 for the employment of a Petroleum Industry Liaison (PIL) at the FFAW. The principle objective of the PIL is to ensure the views and concerns of fish harvesters are considered by the offshore petroleum industry and regulators during the development, review and execution of exploration, development and production activities. The PIL is the main contact for petroleum related activities at the FFAW.

3.2 One Ocean Matrix

In 2010, One Ocean produced the *Risk Management Matrix Guidelines for the Utilization of Fisheries Liaison Officers and Fisheries Guide Vessels for the Fishing and Petroleum Industries of Newfoundland and Labrador* (Matrix). Fisheries Liaison Officer (FLO) participation in offshore seismic survey programs is outlined in C-NLOPB guidelines and is referenced in the Matrix. The use of Fisheries Guide Vessels (FGV) is offered as a consideration in the Matrix for transit and tow operations; not for seismic programs. The Matrix outlines considerations to advance industry consultations but does not in any way replace them. The Matrix is available on the One Ocean website: http://www.oneocean.ca

3.3 Vessel Monitoring System

One Ocean and Fisheries and Oceans Canada (DFO) have an arrangement to provide Vessel Monitoring System (VMS) information to petroleum company members of One Ocean. The VMS program at DFO Newfoundland Region provides a satellite based, near real time, positional tracking system of fishing vessels within the Canadian Exclusive Economic Zone (EEZ), as well as foreign and domestic vessels in the Northwest Atlantic Fisheries Organization (NAFO) Regulatory Area outside the 200 nautical mile limit. The ability to access current fisheries data (location of activity) is an important component in the development of operational plans for offshore petroleum related activities. The VMS data generated by DFO consists of coordinates only and does not divulge information of a confidential or sensitive nature. Please contact One Ocean for more information.

3.4 Canada-Newfoundland and Labrador Offshore Petroleum Board Map

In 2011, One Ocean requested the C-NLOPB incorporate Northwest Atlantic Fisheries Organization (NAFO) Divisions and Shrimp Fishing Areas (SFA) on its maps illustrating petroleum industry licenses. The map is an important tool to facilitate joint planning and information exchange between the fishing and petroleum industries regarding common offshore

areas of operations. A link to the map is available on the One Ocean website: http://www.oneocean.ca

3.5 Canadian Association of Petroleum Producers Fishery Liaison Officer Video

In 2012, the Canadian Association of Petroleum Producers (CAPP) developed a ten-minute video to communicate the importance of FLO participation in offshore Newfoundland and Labrador exploration activities. The video highlights the role of the FLO and interaction with vessel crew and Client Representatives. The FLO Video is available on the One Ocean and CAPP websites: http://www.oneocean.ca http://www.capp.ca/environmentCommunity/relationshipPartners/Pages/FishingIndustry.aspx

3.6 Fact Sheet for Non-One Ocean Petroleum Industry Members

The *Fact Sheet for Non-One Ocean Petroleum Industry Members* (Fact Sheet) was developed for non-One Ocean petroleum members to provide information on current practices and expectations between the fishing and petroleum industries in Newfoundland and Labrador. The Fact Sheet provides details on One Ocean, its initiatives and member contact information to facilitate effective communication on proposed offshore petroleum exploration activities.

3.7 Industry Consultations

The *One Ocean Protocol for Consultation Meetings: Recommendations for the Fishing and Petroleum Industries in Newfoundland and Labrador,* (Consultation Protocol) outlines recommendations for preparing and holding a consultation meeting as well as follow-up meetings. Its purpose is to streamline the process and expectations for both sectors. Joint industry consultation provides a valuable opportunity to effectively exchange information and facilitate understanding of each other's operational activities; especially time and location details. Information exchange has assisted the two industries in determining best operational time frames and mitigation measures. The Consultation Protocol is available on the One Ocean website: http://www.oneocean.ca

4.0 FISHERIES LIAISON OFFICER ACTIVITIES

Fisheries Liaison Officer (FLO) participation in offshore petroleum industry seismic survey programs is considered a practice of mitigation under the C-NLOPB's *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* for 2D and 3D seismic programs.

A FLO is engaged to monitor fishing and petroleum industry activities during offshore seismic survey programs. The FLO is tasked with identifying issues and offering advice that may prevent potential at-sea conflicts associated with time and space overlap between fishing and petroleum sectors. A FLO is stationed on board the seismic vessel for the duration of the seismic survey program to observe, record and report activities of and interactions between the seismic vessel and commercial fishing vessels to petroleum and fishing industry representatives.

As the liaison, FLOs will initiate and maintain communication with fish harvesters in the project area to gain insight on fishing activity and share details of the seismic survey program. At-sea communication with fish harvesters enables the FLO to collaborate with the onboard Client Representative and senior vessel crew to ensure effective planning and mitigate potential conflict. FLOs must have knowledge of fisheries and fishery operations, demonstrated communication and writing skills and possess valid training and certification to work offshore.

4.1 Objectives of the FLO Program

1. Provide information to identify potential at-sea conflicts with fishing activities during the offshore seismic program;
2. Build and maintain trust between the petroleum and fishing industries;
3. Provide the fishing industry and Operator with feedback on fisheries issues.

4.2 FLO Training and Certification Requirements

1. Marine Radio Operator's Certificate (ROC-MC);
2. Basic First Aid Certificate (or Marine Basic First Aid);
3. Marine Emergency Duties (MED) Certificate that includes:
    a. A1 Basic Safety;
    b. B1 Survival Craft;
    c. B2 Marine Firefighting; or
    d. Standards of Training, Certification and Watch keeping, (STCW) Basic Safety, Survival Craft, and Advanced Firefighting;
4. Seafarer's Medical Certificate;
5. Workplace Hazardous Material Information System (WHMIS) certificate;
6. Helicopter Underwater Escape Training (HUET) and Helicopter Underwater Escape Breathing Apparatus (HUEBA) training (if helicopter transfers are required).

4.3 FLO Qualifications

1. An ability to work independently and in a team environment;
2. Knowledgeable of offshore area fisheries and industry operations;
3. A working knowledge of seismic survey programs including vessels, equipment and operational routes;
4. An ability to initiate and maintain effective communication with fish harvesters, senior vessel crew and the onboard Client Representative during at-sea operations'
5. The capacity to assert authority and control in critical situations;
6. Ability to understand and interpret navigational charts;
7. Proficiency in offshore communication systems (radio, satellite telephones);
8. Ability to produce daily and weekly reports and other correspondence as required in either electronic and/or written format as requested by the Operator;
9. Marine Mammal and Seabird Observation training is an asset;
10. Possess a valid passport.

4.4 FLO Pre-Departure Preparation and Duties

1. The FLO will provide the onboard and/or shore-based Client Representative(s) with a pre-departure Summary Report, prepared by the Petroleum Industry Liaison (PIL), on fishing activity for the deployment and seismic survey program areas identifying approximate number of active fishing vessels, specie(s) actively harvested and gear type(s). Vessel Monitoring System (VMS) information should be included for reference;
2. The FLO will review the Summary Report with onboard and/or shore-based Client Representative(s) and senior vessel crew at pre-departure briefing;
3. The FLO and the onboard and/or shore-based Client Representative(s) will review and confirm information provided by the Operator in the Seismic Survey Program Contact List (Appendix C);
4. The FLO participates in pre-departure Orientation/Safety session(s); the CAPP-FLO video is presented at this time;
5. The FLO and the onboard and/or shore-based Client Representative(s) will review and confirm the Seismic Survey Program Check List provided by the Operator (Appendix D).

4.5 FLO Equipment

The Service Provider is responsible for supplying the FLO with:

1. Binoculars;
2. Laptop;
3. Camera;
4. Contact Information Sheet;
5. Daily/Weekly Report Forms;
6. Fishing Gear Incident Report Forms;
7. Fisheries information (As detailed in the EA and supplemented in Summary Report);

8. Copy of the One Ocean Seismic Protocol;
9. Copy of the One Ocean Matrix.

4.6 FLO Operational Responsibilities, Protocols and Communications

The FLO is the liaison between the commercial fishing industry and the petroleum industry during seismic survey programs. In the role of liaison, the FLO is tasked with identifying potential at-sea conflicts between fishing and petroleum operations. Specific activities include:

1. Stationed on the project seismic vessel, observe activities which may affect the fishing industry and petroleum operations;
2. Initiate and maintain radio contact with fishing boats in the area and ensure all communication with fishing vessels is conducted via the FLO;
3. Inform fishers nearby about the seismic survey program and provide coordinates and relevant spatial and temporal details;
4. Help identify/locate any fishing gear in and near the seismic survey program area so it can be avoided;
5. Determine gear type, layout, fishing plans (when in area, when leaving);
6. Advise bridge about best course of action to avoid gear and/or fishing activities;
7. Serve as initial contact if damaged gear is encountered, verify damage, help identify owners and file an incident report;
8. Regularly discuss/convey fisheries related aspects including changes in relevant fisheries, status of species quotas and closures with the onboard Client Representative;
9. Report to and confer with the onboard Client Representative regarding operational situations;
10. Attend regular operations briefings;
11. Attend safety meetings and participate in all relevant Health Safety and Environment (HSE) initiatives and procedures as requested;
12. Complete and submit a daily report (electronic/hardcopy) including all observations, communications and meetings attended to the onboard Client Representative;
13. Other duties as identified and approved through consultation with the Operator and Service Provider.

4.7 FLO Daily-Weekly Reports

The FFAW provides the FLO with a laptop containing electronically formatted Daily Report spreadsheets (Appendix E). The Daily Report is completed at three specific times per day and compiled for weekly reports. The spreadsheet captures specific information regarding activities, observations and communications for the project and area fisheries and is submitted daily to the onboard Client Representative. In addition to relevant information about the project and area fisheries, the Daily Reports supply relevant details of all fisheries-related gear observations (Section 4.8) and associated radio communication. Fishing gear incidents (Section 4.9) require a separate report but are recorded in the daily log.

4.8 Fishing Gear Observations Recording and Reporting

1. All fishing vessels and gear in the path of the petroleum exploration work should be avoided and clear areas pursued. Fish harvesters are not required to move their vessels or gear from the seismic survey program area and should not be told to do so;
2. If personnel onboard the seismic and/or scout vessel observe fishing gear (abandoned, adrift or active) it should be communicated to the FLO. Gear should not be touched / retrieved by project personnel as it is illegal for anyone but the gear owner to move the gear;
3. If the scout vessel makes the observation, personnel should record exact positions and name or Canadian Fishing Vessel (CFV) number on the gear (buoy/highflyer) and report it to the FLO;
4. The FLO will communicate with fishing vessels in the vicinity in an attempt to identify the gear owner;
5. If the CFV number is known, the FLO may be able to identify and contact the owner;
6. If identification and contact with the gear owner is successful, the FLO will attempt to determine the plans/schedule of the gear owner with respect to the gear and will encourage the owner to communicate with the FLO at sea;
7. If it is not possible to contact the gear owner the exploration vessel should attempt to work in another area and return to the location at a later time;
8. The FLO will record the information in the daily report and submit it to the onboard Client representative.

4.9 Fishing Gear Incident Recording and Reporting

1. Commercial fisheries gear incidents/accidents means a physical interaction versus an observation;
2. If there is any indication a project vessel or its equipment made contact with fishing gear it should be communicated to the FLO immediately;
3. The FLO should contact the onboard Client Representative and vessel Master as soon as possible after discovery of the incident;
4. The FLO will take all reasonable action to prevent any further or continuing damage;
5. If possible, photograph the gear or gear debris in the water and after recovery;
6. If necessary, secure and retain any of the gear debris;
7. Record the incident in the Daily Report;
8. File a Fishing Gear Incident Report (Appendix F) and distribute to the onboard Client Representative.

5.0 Regulatory Requirements for Reporting an Incident

The Canada-Newfoundland Offshore Petroleum Board (C-NLOPB) Guidelines state contact with fishing gear must be reported immediately even if no damage to the gear has occurred. The C- NLOPB maintains a 24-hour answering service at (709) 682-4426 for this purpose and can also be contacted during working hours at (709) 778-1400. Reports on contacts with fishing gear should include the exact time and location of initial contact, loss of contact and a description of any identifying markings on the gear. Incidents will be reported by the onboard Client Representative to the Operator who will report it to the C-NLOPB per the Board's incident reporting guidelines and/or the authorization requirements.

6.0 Single Point of Contact (SPOC)

Single Point of Contact (SPOC) is referenced as a practice of mitigation under the C-NLOPB's *Geophysical, Geological, Environmental and Geotechnical Program Guidelines*:

> "Where more than one survey operation is active in a region, the operator(s) should arrange for a 'Single Point of Contact' for marine users that may be used to facilitate communication."

Operator's may designate a SPOC internally or contract for the service. The Operator will notify relevant entities of the designated SPOC and provide contact information prior to the seismic survey program start-up. Details of the SPOC will also be included in Notices to Shipping.

As the land-based fisheries contact for the Operator, the SPOC provides support to the offshore project as requested by the Operator. The role may include but is not limited to:

1. File Notices to Shipping;
2. For the purpose of determining fishing plans, if the FLO is unable to identify and/or contact a gear owner(s) the SPOC may be asked to assist;
3. In the event of a gear incident and the FLO is the initial contact, the SPOC may be requested to:
    a. Identify and/or contact owner and notify of damage;
    b. Use the FLO's Incident Report Form as a reference to investigate details of the incident (dates, location activities) with the fish harvester, FLO and/or onboard Client Representative and obtain information on other vessels in the area at the time;
    c. Provide fish harvester with relevant form for the claim and follow through on its submission;
    d. Provide a comprehensive report to the Operator.

4. In the event the SPOC is contacted directly by a fish harvester claiming gear loss/damage in relation to the seismic survey program, the SPOC will document information on the fish harvester and incident and contact the Operator. The SPOC may be requested to:
    a. Confirm if the FLO and/or onboard Client Representative are aware of the incident.

5. If the FLO has reported the incident, the SPOC may be asked to:
    a. Use the Incident Report Form as a reference to investigate details of the incident (dates, location activities) with the fish harvester, FLO and/or onboard Client Representative and obtain information on other vessels in the area at the time;
    b. Provide fish harvester with relevant form for the claim and follow through on its submission;
    c. Provide a comprehensive report to the Operator.

6. If the FLO and/or onboard Client Representative are unaware of the incident the SPOC may be asked to:
    a. Coordinate with the FLO and/or onboard Client Representative to obtain information on the seismic vessel location, timing and activity as well as details of other vessels in the area to determine if the incident is related to the seismic survey program;
    b. Provide fish harvester with relevant form for the claim and follow through on its submission;
    c. Provide a comprehensive report to the Operator.

The reporting of all fishing gear incidents to the C-NLOPB will be conducted by the Operator as stated in Section 5.0.

7.0 FREQUENTLY ASKED QUESTIONS ABOUT SEISMIC SURVEYS

7.1 How Does Seismic Surveying Work and how is the Information Used?

Seismic surveys to visualize rock strata below the seabed are a key component of the petroleum exploration industry. Marine seismic surveying applies the science of sound energy and seismology to map geological structures under the seabed. Towed devices produce bursts of acoustic (sound) waves that travel through the water and then bounce back to receivers that measure the strength and return time of each wave. These surveys are the first step in a process of physical exploration for oil and gas which can lead to exploration and delineation drilling and, if economically viable reserves of oil or gas are found, production and transportation of these reserves to market.

Seismic surveys of various types and extent have been taking place in the Newfoundland and Labrador offshore since the 1960's. Close to two million line kilometers of these surveys have been carried out around the island of Newfoundland and along the Labrador coast during that time. As elsewhere in the world, these surveys range from local and specialized surveys within a few kilometers or less of drilling or production platforms to surveys over thousands of square kilometers of seafloor in the search for promising geological formations.

In marine seismic surveys, reflected sound waves, called signals, are combined and interpreted electronically or reproduced on graphic paper recorders. This data gives the company information on the depth, position and shape of underground geological formations that may contain crude oil or natural gas.

To reach the desired depths below the seabed, seismic surveys use high energy, low frequency sound waves that can penetrate more than 6,000 meters (20,000 feet) below the sea floor. The survey results do not show definitely whether oil or gas is present, but they do indicate where hydrocarbons are likely to be found and can help narrow the search area. If the information indicates rock formations or geological structures that could contain hydrocarbons, a company may decide to seek approval to drill an exploratory well.

7.2 What Equipment is used for a Seismic Surveys?

Marine seismic surveys require special ships 75 to 90 meters long (250 to 300 feet) with a crew of between 30 and 65 mariners, survey engineers and technicians. During a survey, the seismic vessel travels approximately 5 knots (9 kilometers) per hour over a predetermined survey pattern and tows:

- One or two sets of underwater equipment immediately behind the ship to generate sound waves;
- One or several long cables or "streamers," each containing several hundred evenly spaced individual listening devices called hydrophones.

The position of the vessel and the signal recording equipment must be closely controlled to ensure geological features can be pinpointed accurately. Modern seismic vessels carry advanced navigation and acoustic systems that permit very accurate positioning. Each streamer can be up to 6000 meters (3.2 miles) long and is towed at a depth of 6 to 12 meters (20 to 40 feet) below the surface to reduce the effect of surface waves. Modern streamers carry multiple global positioning system (GPS) sensors to more accurately establish their position in relation to the earth's surface and the vessel. In the most technically advanced seismic surveys, up to eight streamers are towed at the same time, each about 50 to 120 meters (180 to 400 feet) apart.

7.3 Are There Different Types of Seismic Surveys?

Oil and gas companies routinely carry out two types of seismic programs. Two dimensional (2-D) surveys use one sound source and one set of receivers. These surveys are usually conducted along a grid with parallel lines up to five kilometers apart. The technology provides a general picture of the geological characteristics of an area, including type and size of structures present. Three-dimensional (3-D) surveys use two sound sources and multiple sets of receivers. They are usually carried out over a much smaller grid to get more detailed information about geological features. The pattern of survey lines used by industry is similar to a "racetrack" pattern to ensure the survey is efficient as possible and for control of the steamers towed behind the vessel.

Electromagnetic surveys are a relatively new technique used in deep water (>500m) to discriminate between water and petroleum in known reservoir formations. This involves placing a grid pattern of receivers, in degradable weights, on the seafloor and towing low frequency source of alternating current near the seafloor (~ 50 m) over the area and mapping the induced electrical resistivity.

Exploration for crude oil and natural gas is not the only reason for conducting seismic surveys. For example, natural gas under pressure in shallow geological formations could present a safety hazard during the early stages of drilling before blowout preventers are in place. Therefore, shallow seismic surveys (Well-site/Geo-hazard) are conducted around every proposed well site to find out if any subsurface features could cause problems. Well-site/Geo-hazard surveys use low sound sources and are usually a very short duration.

Four-dimensional (4D) seismic surveys have been conducted over a producing field at various stages of its producing life. The objective is to determine the changes occurring in the reservoir, over time, as a result of hydrocarbon production or injection of water or gas into the reservoir by comparing repeated datasets. 4D data indicates a shift from a purely geophysical interpretation tool to a reservoir management tool, which can be used to assess remaining hydrocarbon volumes and optimize the recovery strategy.

Vertical Seismic Profiling, (VSP) measures acoustic waves between a well bore and the surface. VSP permits calibration of surface seismic data and provides "images" within the vicinity of the well bore that could otherwise not be defined by surface seismic data. VSP consists of an airgun array sound source, typically less powerful than those used during routine seismic surveys, deployed at locations near a drill rig with receivers placed in the well. The purpose of the technique is to tie in or ground-truth the geological data with geophysical information. VSPs vary in type (Zero-offset; Offset, Walkaway) in the positioning of the sound source in proximity of the well bore and its distance from the receivers; zero-offset source is at the drill rig and a walkaway source is 1 or 2km from the drill rig as the survey progresses. VSP Acquisition times are dependent on the type of VSP and acquisition tool but they normally vary between 8-36 hours per well.

7.4 Why Do Seismic Survey Programs Occur During Peak Fishing Season?

The duration of a seismic survey program (2D, 3D) is typically 30 to 60 days. Since rough seas affect the quality of the data collected, programs are usually scheduled from June to September in optimal weather conditions as seismic vessels cannot operate effectively if waves are higher than about 3 meters (10 feet).

7.5 How is Seismic Data Collected?

As the vessel moves along the survey path, computers control the simultaneous discharge of a brief pulse of compressed air from the sound sources, (traditionally called air guns) usually once every 10 seconds. The generated sound waves travel down through rock formations under the sea floor. When they encounter a boundary between different formations, some sound waves are reflected toward the surface where individual hydrophones in each streamer intercept them. Signals from each hydrophone are sent back to high-capacity computers on board the vessel that record, check and store the large volumes of seismic data collected.

7.6 Why Do Seismic Vessels Request a Large At-Sea Berth During the Program?

Operators make every effort to communicate the presence of the seismic survey ship to other vessels in the area before and during the survey. Company representatives communicate the location of the planned seismic program through official radio broadcasts and notices to mariners. A wide berth is often requested as the survey ship cannot change direction quickly when it is towing equipment; deployed streamers can range from 6 to 8km in length and 1 to 2km in width.

7.7 How is the Seismic Survey Information Used?

The collected data go through several processing steps to improve the quality of the signals and filter out background "noise." Geophysicists then interpret the information to develop a detailed picture of the structures and rock formations in the survey area. The results of the survey are interpreted lines and maps showing geological features. Companies look for specific features that

indicate whether oil or gas might be present. These include former sedimentary basins, buried former beaches, faults and ancient reefs that can act as underground traps for crude oil and natural gas.

7.8 Why Do Operators Repeat Seismic Surveys in the Same Offshore Area?

Seismic surveying is an essential part of exploring for oil and gas. 2D surveys are typically the first step in the process and normally cover wide areas with wider line spacing between the streamers. The data collected will help Operators decide if the features found do not warrant further interest or additional surveys may be needed to better define the structures. Usually if more information is needed, Operators will conduct a 3D seismic survey program. A 3D survey is more localized and intense in terms of coverage and is focused on geological areas of interest identified through analysis of 2D data.

7.9 Who Authorizes Seismic Survey Programs and what is the Process? [1]

The Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) is the regulator for the offshore petroleum industry. Oil and Gas companies must obtain authorization from the C-NLOPB before conducting seismic survey work in provincial offshore areas. The regulatory board establishes the conditions for the survey program and the environmental protection conditions that must be followed.

Regulatory authority for seismic surveys (Geophysical Program Operation) in the Newfoundland and Labrador Offshore Area is pursuant to the *Canada-Newfoundland Atlantic Accord Implementation Act*, S.C. 1987, c.3 and the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act,* R.S.N.L. 1990, c. C-2, (Accord Acts). Authorization for seismic survey programs (2-D, 3-D, Vertical Seismic Profiling, Electromagnetic and Well-site/Geo-hazard surveys) under the Accord Acts follow Section 138 (1) (b); Section 134 (1)(b) and Section 139 (4) (b).

7.10 How Do Fish Harvesters Communicate with the C-NLOPB Regarding Proposed Seismic Survey Programs and Mitigation Practices?

Public participation for seismic survey programs is at the discretion of the C-NLOPB. The Geophysical, Geological, Environmental and Geotechnical Program Guidelines, (GGEG) recommend Operators undertake consultation meetings at the early stage of the process with the fishing industry including the FFAW, ASP and One Ocean. The Operator must report on consultations and how issues, if any, were addressed; the C-NLOPB determines adequacy of consultation meetings.

[1] The *Canadian Environmental Assessment Act* does not apply to Seismic Survey Programs. References in this document pertaining to seismic authorization and environmental criteria reflect C-NLOPB legislation at the time this document was written and may require future amendments.

The GGEG lists mitigations to be employed to reduce/eliminate potential impacts to fish and commercial fishery operations. All mitigations a proponent will implement for a seismic survey program are outlined in the environmental document; examples include:

1. Avoidance of heavily fished areas;
2. Timing and spatial avoidance to reduce conflict with DFO Research Vessels surveys;
3. Notice to Mariners;
4. Fisheries Liaison Officer (FLO);
5. Communication with Fishing Industry;
6. Gear Compensation Program;
7. Single Point of Contact (SPOC);
8. Authorization may include additional, warranted mitigations:
    a. The C-NLOPB considers concerns/issues raised by fishers when issuing seismic survey authorization; concerns raised by fishers have resulted in changes to program design (e.g., timing delay to avoid spawning/migration times).

7.11 What is the Role of DFO in Seismic Survey Programs?

The C-NLOPB may request DFO to provide expert advice on environmental criteria related to marine seismic exploration projects. The *Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment* (SOCP) was developed by federal and provincial experts in marine regulatory policy and practice and is based upon a DFO sponsored peer review of seismic surveys by Canadian and international science experts with the objective to develop scientific conclusions and advice on the potential impact of seismic sound on marine life. The SOCP specifies the mitigation requirements that must be met during the planning and conduct of marine seismic surveys to minimize impacts on life in the oceans.

APPENDIX A: ONE OCEAN FISHING AND PETROLEUM MEMBERS

A.1 Association of Seafood Producers

ASP is a not-for-profit corporation representing the interests of seafood producers generally in Newfoundland and Labrador. ASP provides effective input into policy decisions and regulatory matters at all levels of government, engages in media relations on matters of interest to industry, and participates in programs of direct benefit to the fishing industry including research and development. ASP is also the lead processors' representative for collective bargaining negotiations for fish prices under provincial legislation. ASP Members operate processing plants throughout rural Newfoundland and Labrador and source raw material mainly from independent harvesters in the NL inshore fishery, as well as externally. Members are also involved in directed harvesting activities in the offshore fishery. Most NL seafood is sold in international markets including the US, Europe, Africa, and Asia.

A.2 Fish, Food and Allied Workers Union

Fish harvesters and fish plant workers in Newfoundland and most of Labrador are represented by one organization – the FFAW. The fishing industry provides over 22,000 direct employment opportunities in the province and has an annual value of $ 1 billion. There are 40 species of fish harvested in NL; the most lucrative being snow crab and shrimp. Together, these fisheries represent close to 80% of the provincial landed value and are harvested in close proximity to existing petroleum installations and areas of exploration.

A.3 Canadian Association of Petroleum Producers

The Canadian Association of Petroleum Producers (CAPP) represents companies, large and small, that explore for, develop and produce natural gas and crude oil throughout Canada. CAPP's member companies produce more than 90 per cent of Canada's natural gas and crude oil. CAPP's associate members provide a wide range of services that support the upstream crude oil and natural gas industry. Together CAPP's members and associate members are an important part of a national industry with revenues of about $100 billion-a-year. CAPP has offices in St. John's, Newfoundland and Labrador, Halifax, Nova Scotia, Calgary, Alberta and Ottawa, Ontario.

A.4 One Ocean Working Group

To enhance the functioning of the One Ocean organization, a Working Group was formed in 2009. One Ocean Working Group members are representatives of the fishing and petroleum entities on the One Ocean Board and appointed by its Directors. At the direction of the Board, the Working Group reviews joint industry initiatives providing insight and perspective at the working level and brings its considerations and recommendations to the Board. This process optimizes the Board's ability to make informed decisions in a timely and comprehensive manner when it convenes four times a year.

APPENDIX B: RESEARCH ENTITIES

There are several entities which facilitate and fund petroleum related research and development projects. The scope of the research varies from international, national to local initiatives and includes health and safety, security, social responsibility and physical and biological environmental studies. For more information on these organizations and to access reports on seismic research, the following links are provided for reference:

- Petroleum Research Newfoundland and Labrador: http://www.pr-ac.ca
- Environmental Studies Research Funds: http://www.esrfunds.org
- Offshore Energy Environmental Research: http://www.offshoreenergyresearch.ca
- International Association of Oil and Gas Producers: http://www.ogp.org.uk

Appendix C: Seismic Survey Program Contact List

SEISMIC SURVEY PROGRAM CONTACT LIST	
PROGRAM	
Program Name:	
Program Date: (day/month/year) Start:	To:
SEISMIC VESSEL	
Name:	Master:
Bridge Cell:	Master Cell
Fax Cell:	Inmarsat:
SCOUT/CHASE VESSEL	
Name:	Master:
Bridge Cell:	Master Cell
Fax Cell:	Inmarsat:
OTHER VESSEL	
Name:	Master:
Bridge Cell:	Master Cell
Fax Cell:	Inmarsat:
FISHERIES LIAISON OFFICER (FLO)	**ONBOARD CLIENT REPRESENTATIVE**
Name:	Name:
Email:	Email:
Contact Number:	Contact number:
Vessel Aboard:	Vessel Aboard:
SINGLE POINT OF CONTACT (SPOC)	**PETROLEUM INDUSTRY LIAISON**
Name:	Name:
Email:	Email:
Contact Number:	Contact number:
OPERATOR ENVIRONMENTAL LEAD	**OPERATOR REGULATORY ADVISOR**
Name:	Name:
Email:	Email:
Contact Number:	Contact number:
Address:	Address:

Appendix D: Seismic Survey Program Check List

SEISMIC SURVEY PROGRAM CHECK LIST		
PROGRAM		
Program Name:		
Program Date: (day/month/year) Start:	To:	
CHECKLIST: Onboard Client Representative (OCR) and Fisheries Liaison Officer (FLO)		
Contract Agreement for FLO services complete; required certification confirmed	FLO □	OCR □
Confirm FLO Objectives, Operational Responsibilities, Protocols and Communications	FLO □	OCR □
Confirm reporting protocol for fishery gear observations and incidents with Operator and Client Representative		
Confirm FLO has required equipment: Laptop Binoculars Camera Fisheries Summary Report Seismic Survey Contact List Daily and Weekly Report Forms Incident Report Forms One Ocean Seismic Protocol One Ocean Matrix	FLO □	OCR □
Review Summary Report prepared by PIL	FLO □	OCR □
Confirm the provision of daily VMS data to the CR and FLO by the Operator	FLO □	OCR □
Participate in pre-departure orientation/safety meeting	FLO □	OCR □
Confirm Seismic Survey Program Contact List has been received and information verified		
Confirm FLO has been introduced to Vessel Master and CR	FLO □	OCR □
Participate in CAPP, FLO Video presentation at pre-departure	FLO □	OCR □

Appendix E: The Daily Report Spreadsheet

1. Name of FLO
2. Date and time of entry (three specific times 0600, 1200 and 1800)
3. Name of Seismic Vessel
4. Seismic Program
5. Latitude
6. Longitude
7. Activity of Seismic Vessel
8. Fishing Activity
9. Name of Fishing Vessel
10. Number of Fishing Vessel
11. Vessels Contacted
12. Activity of Fishing Vessel
13. Water Depth
14. Gear Type
15. Weather/Wind
16. Visibility
17. Sea State
18. Incidents
19. Comments

Fishing Gear Observations:

20. Time of sighting
21. Gear Type and Quantity (if known)
22. Latitude and Longitude
23. Owner (if known)
24. Condition of gear (active, abandoned or adrift)
25. Type of Communication made (observation, radio, information relayed from a project vessel).

Appendix F: Fishing Gear Incident Report Form

1. Exploration Vessel Name:
2. Did fishing gear appear to be damaged by the contact? Y N
3. Person completing report:
4. Position
5. E-mail/Phone No:
6. How was incident discovered and by whom:
7. Date of incident:
8. Time of incident/discovery:
9. Location of the incident: Lat: Long:
10. Name of fishing vessel (if known):
11. CFV No (on gear/buoy):
12. Vessel Skipper/Owner:
13. Address:
14. Telephone/Fax No:
15. Wind / weather / visibility / sea state at time of incident or discovery:
16. Describe the type and quantity gear recovered (including any identifying marks / numbers, etc.):
17. Describe what the exploration vessel was doing at the time of the incident and retain any data on the ship's positions during the preceding 24 hours:
18. Describe what the fishing vessel was doing at the time of the incident:
19. Draw a sketch/diagram showing the position of the exploration vessel/gear in relation to the gear, fishing vessel:
20. Note if photographs were taken:
21. Describe any measures the exploration vessel took to recover gear, or to stop or limit the damage or loss:
22. Names of any other vessels in the area before/during the time of the incident:
23. Describes steps taken to notify fishing vessel or others:
24. Other pertinent information / remarks (use extra sheets if necessary):

Appendix D. Review of Potential Effects of Airgun Sound on Marine Invertebrates

This review provides a detailed summary of the limited data and literature available on the potential effects of exposure to airgun sounds on marine invertebrates. Specific conditions and results of the studies, including sound exposure levels and sound thresholds of responses, are discussed.

Sound caused by underwater seismic survey equipment results in energy pulses with very high peak pressures (Richardson et al. 1995) and this has the potential to affect the physical condition or behaviour of marine invertebrates. Virtually all underwater seismic surveying conducted today uses airguns which typically have lower peak pressures and longer rise times than chemical explosives. However, Sound levels from underwater airgun discharges might be high enough to potentially injure or kill animals located very close to the source. Less overt than physical effects are potential disturbances to normal behaviours that animals may experience when exposed to sound.

The following sections provide an overview of sound production and detection in marine invertebrates, and information on the effects of exposure to sound on marine invertebrates, with an emphasis on seismic survey sound. The information includes results of studies of varying degrees of scientific veracity as well as anecdotal information. Fisheries and Oceans Canada has published two internal documents that provide a literature review of the effects of seismic and other underwater sound on invertebrates (Moriyasu et al. 2004; Payne et al. 2008).

Acoustic Capabilities

Much of the available information on acoustic abilities of marine invertebrates pertains to crustaceans, specifically lobsters, crabs and shrimps. Other acoustic-related studies have been conducted on cephalopods.

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 that may occur within our Project Area.

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). 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 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 (claws), 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. Measured source sound pressure levels (SPLs) for snapping ship were 183–189 dB re 1 μPa•m_{p-p} and extended over a frequency range of 2–200 kHz.

Sound Detection

There is considerable debate about the hearing capabilities of aquatic invertebrates. Whether they are able to hear or not depends on how underwater sound and underwater hearing are defined. 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. However, vibrations (i.e., mechanical disturbances of the water) are also characteristic of sound waves. Rather than being pressure-sensitive, aquatic invertebrates appear to be most sensitive to the vibrational component of sound (i.e., particle motion) (Breithaupt 2002). Statocyst organs may provide one means of vibration detection for aquatic invertebrates. Laser Doppler vibrometer techniques have recently opened the possibility of measuring whole body vibration as a direct stimulus eliciting statocyst response (André et al. 2013).

More is known about the acoustic detection capabilities in decapod crustaceans than in any other marine invertebrate group although cephalopod capability is now becoming a focus of study. Crustaceans appear to be most sensitive to sounds of low frequencies, i.e., <1000 Hz (Budelmann 1992; Popper et al. 2001). A study by Lovell et al. (2005) suggests greater sensitivity of the prawn (*Palaemon serratus*) to low-frequency sound than previously thought. 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 suggest that these crustaceans are more sensitive to higher frequency sounds than previously realized (Pye and Watson III 2004).

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 motion 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 400 to 1,500 Hz for the squid *Sepiotheutis lessoniana* and 400 to 1,000 Hz for the octopus *Octopus vulgaris*, higher than frequencies previously observed to be detectable by cephalopods.

Recently, Vermeij et al. (2010) studied the movement of coral larvae in the laboratory and concluded that these larvae are able to detect and respond to underwater sound. This is the first description of an auditory response in the invertebrate phylum Cnidaria. The authors speculate 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).

In summary, only a few studies have been conducted on the sensitivity of invertebrate species to underwater sound. Available data suggest that they are capable of detecting vibrations but they do not appear to be capable of detecting pressure fluctuations.

Potential Effects

There are three categories of potential effects of exposure to sound on marine invertebrates: pathological, physiological, and 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.

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). Few studies have assessed the potential for pathological effects on invertebrates from exposure to sound produced from seismic airgun arrays, and these are described below.

The pathological impacts of sound from seismic surveys on marine invertebrates were investigated in a pilot study on snow crabs (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 $\mu Pa^2 \cdot s$). 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 h 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). Proceedings of the workshop did not include any more definitive conclusions regarding the original results.

Payne et al. (2007) recently conducted a pilot study of the effects of exposure to sound from an airgun source on various health endpoints of the American lobster (*Homarus americanus*). Adult lobsters were exposed either 20 to 200 times to 202 dB re 1µPa $_{p\text{-}p}$ or 50 times to 227 dB re 1µPa $_{p\text{-}p}$, and then monitored for changes to survival, food consumption, turnover rate, serum protein level, serum enzyme levels, and serum calcium level. Observations were made over a period of a few days to several months. Results indicated no effects on delayed mortality or damage to the mechanosensory systems associated with animal equilibrium and posture (as assessed by turnover rate).

In a field study, Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab 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 molt, 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.

A recent study involved the exposure of wild New Zealand scallop larvae to recorded seismic pulses. 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 be due to cumulative exposure (de Soto et al. 2013).

In 2001 and 2003, there were two incidents of multiple strandings of the giant squid on the north 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 links 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.

Caged cephalopods (*Sepioteuthis australis*) were exposed to sound from a single 20-in^3 airgun with maximum SPLs of >200 dB re 1 µPa$_{0\text{-}p}$ (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.

Experiments are planned for 2013-2015 in Australia to study the acute and chronic effects of exposure to airgun sound on scallops and lobsters. Both berried and non-berried lobsters will be used in the experiments (McCauley et al. 2013).

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.

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.

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 five days post-exposure, and serum calcium at 12 days post-exposure. During the histological analysis conducted four 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.

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 after 30 minutes of exposure whereas larger mussels responded after 10 minutes of exposure. The larger mussels tended to lower the oxygen uptake rate more than the smaller animals.

Behavioural Effects

The limited study of the effects of exposure to sound on marine invertebrates has not indicated any serious pathological and physiological effects. In light of this, some recent studies have focused on the potential behavioural effects on marine invertebrates.

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 $\mu Pa^2 \cdot s$, 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^2•s, 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.

Parry and Gason (2006) statistically analyzed data related to 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.

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.

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.

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 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 catch rates of snow crabs showed a significant reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, pers. comm.). More 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.

Caged brown shrimp reared under different acoustical conditions exhibited differences in aggressive behaviour and feeding rate (Lagardère 1982). Those exposed to a continuous sound source showed more aggression and less feeding behaviour. It should be noted that behavioural response to stress by caged animals may differ from behavioural responses of animals in the wild.

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 to 15 s. 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 to 161 dB re 1 μPa_{rms} range (McCauley et al. 2000a,b; Fewtrell and McCauley 2012).

Komak et al. (2005) also reported the results of a study of cephalopod behavioural responses to local water movements. In this case, juvenile cuttlefish exhibited various behavioural responses to local sinusoidal water movements of different frequencies between 0.01 and 1000 Hz. These responses included body pattern changing, movement, burrowing, reorientation, and swimming. The behavioural responses of the octopus *Octopus ocellatus* to underwater sound have been investigated by Kaifu et al. (2007). The 120 dB re 1 μPa_{rms} sound stimuli were at various frequencies; 50, 100, 150, 200 and 1,000 Hz. The respiratory activity of the octopus changed when exposed to sound in the 50 to 150 Hz range but not at the 200 to 1,000 Hz range. Respiratory suppression by the octopus perhaps represented a means of escaping detection by a predator.

The behavioural responses of cuttlefish (*Sepia officinalis*) to tone pips ranging from 80 to 1,000 Hz and intensities of 85 to 188 dB re 1 µPa were recently studied. The most dramatic responses (i.e., jetting, inking and startle) were observed at frequencies ranging from 80 to 300 Hz and at intensities exceeding 140 dB re 1 µPa. Subtle skin patterning changes and fin movements were observed at all frequencies and intensities. A decrease in response intensity was also observed, suggesting the potential for habituation to sound in cuttlefish (Samson et al. 2013).

Low-frequency sound (<200 Hz) has also been used as a means of preventing settling/fouling by aquatic invertebrates such as zebra mussels (Donskoy and Ludyanskiy 1995) and balanoid barnacles (Branscomb and Rittschof 1984). Price (2007) observed that blue mussels closed their valves upon exposure to 10 kHz pure tone continuous sound.

Experiments have been conducted under controlled conditions to investigate the sensitivity of unconditioned crustaceans to substrate-borne vibrations of variable frequency and amplitude. Observed behavioural responses varied according to stimulus strength and included withdrawal into the shell and rapid bouts of movement at the onset of the stimuli (Roberts 2013).

Although not yet scientifically investigated, masking can be considered a potential effect of 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), at least the particle displacement component, could potentially have adverse effects on marine invertebrates.

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Appendix E. Review of Potential Effects of Airgun Sound on Fishes[1]

The potential effects of airgun sounds on fishes during seismic surveys has been studied for a variety of taxa including marine, freshwater, and anadromous species (reviewed by Fay and Popper 2000; Ladich and Popper 2004; Hastings and Popper 2005; Popper and Hastings 2009a,b).

It is sometimes difficult to interpret studies on the effects of underwater sound on marine animals because authors often do not provide enough information, including received sound levels, source sound levels, and specific characteristics of the sound. Specific characteristics of the sound include units and references, whether the sound is continuous or impulsive, and its frequency range. 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 can be impossible to directly compare results from two or more independent studies. This is what is available at the moment and study methods are continuously developing to address some of the known shortcomings.

Acoustic Capabilities

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). 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). Fay (2009) and some 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, which often tells of predation risk, prey items, or mating opportunities. Potential negative effects include masking of key environmental sounds or social signals, displacement of fish from their habitat, or interference with sensory orientation and navigation.

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 and cause 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.

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

[1] By **John R. Christian and R.C. Bocking**, LGL Ltd., environmental research associates (rev. September 2012)

transmits this mechanical disturbance directly to the inner ear (discussed below). Such a secondary source 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).

A recent paper by Popper and Fay (2011) discusses the designation of fishes based on sound detection capabilities. They suggest that the designations 'hearing specialist' and 'hearing generalist' no longer be used for fishes because of their vague and sometimes contradictory definitions, and that there is instead a range of hearing capabilities across species that is more like a continuum, presumably based on the relative contributions of pressure to the overall hearing capabilities of a species.

According to Popper and Fay (2011), one end of this continuum is represented by fishes that only detect particle motion because they lack pressure-sensitive gas bubbles (e.g., swim bladder). These species include elasmobranchs (e.g., sharks) and jawless fishes, and some teleosts including flatfishes. 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).

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. These fishes 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 to well over 180 kHz (Mann et al. 1997, 1998, 2001). This may be the widest hearing range of any vertebrate that has been studied to date. While the specific reason for this very high frequency hearing is not totally clear, there is strong evidence that this capability 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 capabilities 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 for the brain to interpret as sound.

A third 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 motion. 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 recent 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 coral reef species tested had significantly more sensitive hearing than the larvae of pelagic species tested. 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 one other pelagic species did not detect frequencies higher than 800 Hz. The larvae of all six species exhibited best hearing at frequencies between 100 and 300 Hz. The results of Wright et al. (2010) suggested that settlement-stage larval reef fishes may be able to detect reef sounds at distances of 100s of metres. Other recent research also indicates that settlement-stage larvae of coral reef fishes may use sound as a cue to locate settlement sites (Leis et al. 2003; Tolimieri et al. 2004; Simpson et al. 2005; Leis and Locket 2005).

Potential Effects on Fishes

Review papers on the effects of anthropogenic sources of underwater sound on fishes have been published recently (Popper 2009; Popper and Hastings 2009a,b; Fay and Popper 2012). 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 fish, and are therefore not representative of the natural scenario of fish being able to move away from the sound source.

There are three categories of potential effects of exposure to air gun sound on marine fishes: pathological, physiological, and 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). For the purpose of this review, pathological and physiological effects are grouped as physical effects. The three categories should not be considered as independent of one another and are likely interrelated in complex ways.

Marine Fishes

Physical Effects

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 of a single moving seismic airgun every 10 s over a period of 1 h and 41 min. The source SPL at 1 m was about 223 dB re 1 µPa • m_{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 to 70 Hz frequency range. The pink snapper 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 sea bass (*Dicentrarchus labrax*) were exposed to multiple discharges from a moving seismic airgun array with a source SPL of about 256 dB re 1 µPa • m_{0-p} (unspecified measure type) (Santulli et al. 1999). The airguns were discharged every 25 s during 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 (Santulli et al. 1999).

Behavioural Effects

Studies described in this subsection suggest that effects on fish behaviour due to exposure to airgun sound seem to be temporary in nature.

The fish exposed to sound from a single airgun in the McCauley et al. studies (i.e., pink snapper and trevally *Pseudocaranx dentex*) also 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 were more likely to display a startle response. Responses were observed above received SPLs of 156 to 161 dB re 1 μPa_{rms}. The occurrence of both startle response (classic C-turn response) and alarm responses (e.g., darting movements, flash school expansion, fast swimming) decreased over time. Other observations included downward distributional shift that was restricted by the 10 m x 6 m x 3 m cages, increase in swimming speed, and the formation of denser aggregations. Fish behavior appeared to return to pre-exposure state 15 to 30 min after cessation of seismic firing.

A study by Pearson et al. (1992) also showed that behavioural effects were temporary in nature. They investigated the effects of seismic airgun sound on the behavior of captive rockfishes (*Sebastes* spp.) exposed to the sound of a single stationary airgun at a variety of distances. The airgun used in the study had a source SPL at 1 m of 223 dB re 1 µPa • m_{0-p}, and measured received SPLs ranged from 137 to 206 dB re 1 μPa_{0-p}. The authors reported that rockfishes reacted to the airgun sounds by exhibiting 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 μPa_{0-p}, and alarm responses occurred at a minimum received SPL of 177 dB re 1 μPa_{0-p}. Other observed behavioral changes included the tightening of schools, downward distributional shift, and random movement and orientation. Some fishes ascended in the water column and commenced to mill (i.e., "eddy") at increased speed, while others descended to the bottom of the enclosure and remained motionless. Pre-exposure behavior was reestablished from 20 to 60 min after cessation of seismic airgun discharge. Pearson et al. (1992) concluded that received SPL thresholds for overt rockfish behavioral response and more subtle rockfish behavioral response are 180 dB re 1 μPa_{0-p} and 161 dB re 1 μPa_{0-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-p}, and the received SPLs at the bases of the rockfish aggregations ranged from 186 to 191 dB re 1 μPa_{0-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 this experimental approach was quite different from an actual seismic survey, in that duration of exposure was much longer.

Activity levels tend to return to normal within hours of exposure to airgun sound. Santulli et al. (1999) also used underwater video cameras to monitor fish response to seismic airgun discharge. Resultant video indicated slight startle responses by some of the sea bass when the seismic airgun array discharged as far as 2.5 km from the cage. The proportion of sea bass that exhibited startle response increased as the airgun sound source approached the cage. Once the seismic array was within 180 m of the cage, the sea bass 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 behavior resumed about 2 h after airgun discharge nearest the fish (Santulli et al. 1999).

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 sound source and a static sound source. Minimum distances between the sound source and the fish cage ranged from 0 to 7 m. Received sound levels were not reported, however neither mortality nor external damage to the fishes was observed in any of the experimental scenarios. Most of the airgun array discharges resulted in startle responses although these behavioral changes lessened with repeated exposures, suggesting habituation.

Chapman and Hawkins (1969) showed that after an hour of exposure to the airgun sound, the whiting appeared to have habituated as indicated by their return to the pre-exposure depth range, despite the continuing airgun discharge. They investigated the reactions of free ranging whiting (silver hake), *Merluccius bilinearis*, to an intermittently discharging stationary airgun with a source SPL of 220 dB re 1 µPa • m_{0-p}. Received SPLs were estimated to be 178 dB re 1 μPa_{0-p}. The whiting were monitored with an echosounder. 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. Airgun discharge ceased for a time and upon its resumption, the fish again descended to greater depths, indicating only temporary habituation.

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun sound on the behavior of captive lesser sandeel, *Ammodytes marinus*, but their commercial fishery catch data were inconclusive with respect to behavioral effects. Depth of the study enclosure used to hold the sandeel 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. No mortality attributable to exposure to the airgun sound was noted. Behavior 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 sandeels 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 seemed to increase as the operating seismic array moved closer to the fish. The sandeels stopped exhibiting the startle response once the airgun discharge ceased. The sandeel tended to remain higher in the water

column during the airgun discharge, and none of them were observed burying themselves in the soft substrate.

Various species of demersal fishes, blue whiting, 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 authors 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 but comparative trawl catches did not support this. 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 seismic array used 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. Horizontal distributions did not appear to change as a result of exposure to seismic discharge, but there was some indication of a downward shift in the vertical distribution. The catch rates during experimental fishing did not differ significantly between pre- and post-seismic fishing periods.

Wardle et al. (2001) used video and telemetry to make behavioral observations 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 behavioral 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 spread over a period of one month used a seismic airgun array with a source SPL of 222.6 dB re 1 µPa • $m_{p\text{-}p}$. 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 of 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 behavior 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 a point 2 km away. The received SEL increased from about 125 to 155 dB re 1 μPa^2 s 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 lack of suddenness of the airgun stimulus, and an increased level of tolerance to the seismic sound.

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 in 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 one to four days post-exposure in any of the exposure trials for either the capelin eggs or 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 μPa_{0-p}.

Eggs, yolk sac larvae, post-yolk sac larvae, post-larvae, and fry of various commercially important fish species (cod, saithe, herring, turbot, and plaice) were exposed to received SPLs ranging from 220 to 242 dB re 1 µPa (unspecified measure type) (Booman et al. 1996). These received levels corresponded to exposure distances ranging from 0.75 to 6 m. 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 caused by 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.

Freshwater Fishes

Popper et al. (2005) tested the hearing sensitivity of three Mackenzie River fish species after exposure to five discharges from a seismic airgun. The mean received peak SPL was 205 to 209 dB re 1 µPa per discharge, and the approximate mean received SEL was 176 to 180 dB re 1 $\mu Pa^2 \cdot s$ per discharge. While the broad whitefish showed no Temporary Threshold Shift (TTS) as a result of the exposure, adult northern pike and lake 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.

In another part of the same Mackenzie River project, Jorgenson and Gyselman (2009) investigated the behavioral responses of arctic riverine fishes to seismic airgun sound. They used hydroacoustic survey techniques to determine whether fish behavior upon exposure to airgun sound can either mitigate or enhance the potential impact of the sound. The study indicated that fish behavioral characteristics were generally unchanged by the exposure to airgun sound. The tracked fish did not exhibit herding

behavior in front of the mobile airgun array and, therefore, were not exposed to sustained high sound levels.

Popper et al. (2013) recently 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 224 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.

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 2,000 to 2,200 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 behavioral 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 behavioral effects were hard to differentiate from normal behavior.

Weinhold and Weaver (1972, cited 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 a recent and 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.

Indirect Effects on Fisheries

The most comprehensive experimentation on 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-p} based on back-calculations from measurements collected via a hydrophone at depth 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 μPa_{0-p} and 178 dB re 1 μPa_{0-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 according to 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 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 times. 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 esonification compared to the fishery areas of the other three species. Acoustic surveys showed that the saithe had partly left the area, 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 • $m_{0\text{-}p}$ 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 $\mu Pa_{0\text{-}p}$. 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 behavior of the fishes. The fish schools descended towards the bottom and their swimming behavior 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 behavior 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 $\mu Pa_{0\text{-}p}$. 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 U.K. waters (5 to 30 m deep). The airgun array used had a source level of 250 dB re 1 μPa • $m_{0\text{-}p}$. Received levels in the fishing areas were estimated to be 163 to 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 sea bass were exposed to sound from seismic airgun arrays 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 discharge 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 (Pickett et al. 1994).

Recent work in Norway suggests that, in the future, particular acoustic-biological models may be used in the design and planning of seismic surveys in order to minimize disturbance to fishing (Hovem et al. 2012).

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Appendix F. Review of Potential Effects of Airgun Sound on Marine Mammals[1]

The following subsections review relevant information concerning the potential effects of 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.

Categories of Noise Effects

The effects of noise on marine mammals are highly variable, and can be categorized as follows (adapted from Richardson et al. 1995):

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;

2. The noise 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 noise 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 reactions;

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 perceives as a threat;

5. Any man-made noise 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 such as surf noise or (at high latitudes) ice noise. Intermittent airgun or sonar pulses would cause strong masking 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] By **W. John Richardson** and **Valerie D. Moulton**, with subsequent updates (to Dec. 2013) by WJR, VDM, **Meike Holst** and others, especially Patrick Abgrall and William E. Cross, all of LGL Ltd., environmental research associates.

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.

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 to 80 kHz. An adult Gervais' beaked whale had a similar upper cutoff frequency (80 to 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 "mid-frequency" (MF) hearing group, and the MF odontocetes (collectively) have functional hearing from about 150 Hz to 160 kHz (Southall et al. 2007). 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. The remaining odontocetes — the porpoises, river dolphins, and members of the genera *Cephalorhynchus* and *Kogia* — are distinguished as the "high frequency" (HF) hearing group. They have functional hearing from about 200 Hz to 180 kHz (Southall et al. 2007).

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 1,000 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).

Belugas hear best at frequencies of ~32 to 100 kHz (e.g., Mooney et al. 2013); the hearing threshold increases progressively (poorer hearing) outside of this range. Belugas 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). There is no evidence that most small odontocetes react to airgun pulses at such long distances. However, beluga whales do seem quite responsive at intermediate distances (10 to 20 km) where sound levels are well above the ambient noise level (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.

Baleen Whales (Mysticetes)

The hearing abilities of baleen whales (mysticetes) have not been studied directly. Behavioural and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Frankel (2005) noted that gray whales reacted to a 21 to 25 kHz whale-finding sonar. 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 humpbacks, with components 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 humpbacks 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 22 kHz or possibly 25 kHz; baleen whales are said to constitute the “low-frequency” (LF) hearing group (Southall et al. 2007; Scholik-Schlomer 2012). 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 freq-uency.

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. 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 seismic (or other source) sounds 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).

Seals and Sea Lions (Pinnipeds)

Underwater audiograms have been obtained using behavioural methods for three species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson

et al. 1995: 211ff; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002, 2009). The functional hearing range for pinnipeds in water is considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although some individual 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 to 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). Recent measurements of underwater hearing for spotted seals (*Phoca largha*) show peak sensitivity of ~51 dB re 1 µPa at 25.6 kHz and good auditory sensitivity extending seven octaves (Sills et al. 2013).

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).

Characteristics of Airgun Sounds

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 firing 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 to 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 to 120 Hz. However, the pulses contain significant energy up to 500 to 1,000 Hz and some energy at higher frequencies (Goold and Fish 1998; Potter et al. 2007). 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 (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 to 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 seismic 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-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 quoted source or received levels. Geophysicists usually quote peak-to-peak (p-p) levels, in bar-metres or (less often) dB re 1 µPa • m. The peak (= zero-to-peak, or 0-p) level for the same pulse is typically ~6 dB less. In the biological 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). A fourth measure that is increasingly used is the energy, or 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 any quoted pulse level. In the past, 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 may travel faster than that in the water, and thus may, in some situations, 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 a seismic pulse is ~10 to 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).

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[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 to 15 dB higher than the SEL value for the same pulse measured in dB re 1 $\mu Pa^2 \cdot s$ (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).

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 (e.g., to SEL) than to the rms values averaged over pulse duration (Southall et al. 2007). However, there is also recent evidence that auditory effect in a given animal is not a simple function of received acoustic energy. Frequency, duration of the exposure, and occurrence of gaps within the exposure can also influence the auditory effect (Mooney et al. 2009a; Finneran and Schlundt 2010, 2011, 2013; Finneran et al. 2010a,b; Finneran 2012; Kastelein et al. 2013a).

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 to 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).

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). 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. 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 in only one situation: 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 are infrequent, in our experience. However, 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, 2013), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree. Guerra et al. (2013) 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 to 2,800 km away. Based on preliminary modelling, Wittekind et al. (2013) reported that airgun sounds may reduce the communication range of blue and fin whales 2,000 km from the seismic source. Klinck et al. (2012) also found reverberation effects between airgun pulses. Nieukirk et al. (2012) and Blackwell et al. (2013) 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; Cerchio et al. 2010). However, some of these studies found evidence of reduced calling (or at least reduced call detection rates) in the presence of seismic pulses. One recent 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, although movement out of the area also contributes to the lower call detection rate (Blackwell et al. 2013). 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 to 450 Hz with a relatively low source level of 193 dB re 1 μPa_{pk-pk}. 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). 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 the airgun pulses and the calls. 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 in the presence of elevated sound levels, shift their peak frequencies in response to strong sound signals, or otherwise modify their vocal behaviour in response to increased noise (Dahlheim 1987; Au 1993; reviewed in Richardson et al. 1995:233ff, 364ff; also Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Scheifele et al. 2005; Parks et al. 2007a, 2009, 2011, 2012; Hanser et al. 2009; Holt et al. 2009; Di Iorio and Clark 2010; McKenna 2011; Castellote et al. 2012; Melcón et al. 2012; Risch et al. 2012). It is not known how often these types of 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 by Seismic Surveys

Disturbance includes a variety of effects, including subtle to conspicuous changes in behaviour, movement, and displacement. In the terminology of the 1994 amendments to the U.S. *Marine Mammal Protection Act* (*MMPA*), seismic noise could cause "Level B" harassment of certain marine mammals. Level B harassment is defined as "...disruption of behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

There has been debate regarding how substantial a change in behaviour or mammal activity is required before the animal should be deemed to be "taken by Level B harassment". NMFS has stated that:

> "…a simple change in a marine mammal's actions does not always rise to the level of disruption of its behavioural patterns. … If the only reaction to the [human] activity on the part of the marine mammal is within the normal repertoire of actions that are required to carry out that behavioural pattern, NMFS considers [the human] activity not to have caused a disruption of the behavioural pattern, provided the animal's reaction is not otherwise significant enough to be considered disruptive due to length or severity. Therefore, for example, a short-term change in breathing rates or a somewhat shortened or lengthened dive sequence that are within the animal's normal range and that do not have any biological significance (i.e., do no disrupt the animal's overall behavioural pattern of breathing under the circumstances), do not rise to a level requiring a small take authorization." (NMFS 2001, p. 9293).

Based on this guidance from NMFS, and on NRC (2005), simple exposure to sound, or brief reactions that do not disrupt behavioural patterns in a potentially significant manner, do not constitute harassment or "taking". In this analysis, we interpret "potentially significant" to mean in a manner that might have deleterious effects on the well-being of individual marine mammals or their populations.

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". 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. 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). 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. 2013). 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 (e.g., Lusseau and Bejder 2007; Weilgart 2007). Also, various authors have noted that some marine mammals that show no obvious avoidance or behavioural changes may still be adversely affected by noise (Brodie 1981; Richardson et al. 1995:317ff; Romano et al. 2004; Weilgart 2007; Wright et al. 2009, 2011). 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. Harwood et al. (2013) emphasized the need for a framework to assess consequences of effects from underwater noise at a population level. 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.

The definitions of “taking” in the U.S. MMPA, and its applicability to various activities, were slightly altered in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to particular groups of mammal species and to particular sound types (Scholik-Schlomer 2012). Southall et al. (2007) made detailed recommendations for new science-based noise exposure criteria. Currently, NMFS is using those proposed levels as a starting point to revise the current acoustic criteria, but they have not yet been finalized (NMFS 2013). Thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

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.

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); and Moulton and Holst (2010). Although baleen whales often show only slight overt responses to operating airgun arrays (Stone and Tasker 2006; Weir 2008a), strong avoidance reactions by several species of mysticetes have been observed at ranges up to 6 to 8 km and occasionally as far as 20 to 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 to 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 to 170 dB re 1 μPa_{rms} 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 to 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 to 170 dB re 1 μPa_{rms}. The largest avoidance radii involved migrating bowhead whales, which avoided an operating seismic vessel by 20 to 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 2,678-in^3 array, and to a single 20 in^3 airgun with a (horizontal) source level of 227 dB re 1 $\mu Pa \cdot m_{p-p}$. 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 to 5 km for traveling pods, with the closest point of approach (CPA) being 3 to 4 km at an estimated received level of 157 to 164 dB re 1 μPa_{rms} (McCauley et al. 1998, 2000a). A greater stand-off range of 7 to 12 km was observed for more sensitive resting pods (cow-calf pairs; McCauley et al. 1998, 2000a). The mean received level 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 level was 143 dB re 1 μPa_{rms}. One startle response was reported at 112 dB re 1 μPa_{rms}. The initial avoidance response generally occurred at distances of 5 to 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 to 400 m, where the maximum received level 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. Studies examining the behavioural response of humpback whales off Eastern Australia to airguns are currently underway (Cato et al. 2011, 2012, 2013).

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 levels of 150 to 169 dB re 1 µPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 µPa on an approximate rms basis. However, 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 (3,147 in^3 or 5,085 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 (3,050 m vs. 2,700 m, respectively). Cerchio et al. (2010) 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 to 99 km and received sound levels of 107 to 158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis, including

shorter surfacings, shorter dives, and decreased number of blows per surfacing (Robertson et al. 2013). Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometres (~3 to 7 km) and when received levels of airgun sounds were 152 to 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 by Miller et al. (2005) and Harris et al. (2007) 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. On the summer feeding grounds, bowhead whales are often seen from the operating seismic ship, though average sighting distances tend to be larger when the airguns are operating. Similarly, preliminary analyses of recent 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 noise pulses from a distant seismic vessel than are 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 to 30 km from a medium-sized airgun source at received sound levels of around 120 to 130 dB re 1 μPa_{rms} (Miller et al. 1999; Richardson et al. 1999; see also Manly et al. 2007). Those results came from 1996–1998, 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 to 24 h after seismic surveying stopped. Preliminary analysis of recent 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).

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; Koski et al. 2009; Blackwell et al. 2013; see also Nations et al. 2009). Blackwell et al. (2013) reported that calling rates in 2007 declined significantly where received levels from airgun sounds were 116 to 129 dB re 1 µPa, and Blackwell et al. (2012) suggested that the cumulative SEL threshold for when bowhead whales cease calling is near 124 dB re 1 μPa^2 • s. This decrease could have resulted from movement of the whales away from the area of the seismic survey or a reduction in calling behaviour, or a combination of the two. Aerial surveys showed that there was strong avoidance of the operating airguns during the 1996–1998 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 1996–1998 study and more dependent on reduced calling behaviour during 2007–2010, but further analysis of the recent data is ongoing.

A recent 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 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 to 2.8 km from an airgun array with a source level of 250 dB re 1 µPa$_{peak}$ in the northern Bering Sea. These findings were generally consistent with the results of studies conducted on larger numbers of gray whales migrating off California (Malme et al. 1984; Malme and Miles 1985) and western Pacific gray whales feeding off Sakhalin, Russia (Würsig et al. 1999; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b), along with a few data on gray whales off British Columbia (Bain and Williams 2006).

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 4,000-in³ airgun array operating off central California. This would occur at an average received sound level of ~170 dB re 1 µPa$_{rms}$. Some slight behavioural changes were noted when approaching gray whales reached the distances where received sound 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 noise were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) and in 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; Weller et al. 2006a; Gailey et al. 2007). 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). The 2001 seismic program, as well as a

subsequent survey in 2010, involved an unusually comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received levels of sound above about 163 dB re 1 μPa_{rms} (Johnson et al. 2007; Nowacek et al. 2012, 2013). The lack of strong avoidance or other strong responses was presumably in part a result of the mitigation measures. Effects probably would have been more significant without such intensive mitigation efforts. Limited data obtained during a monitoring program in 2010 indicated that an increase in vessel traffic and seismic operations may have displaced gray whales from their preferred feeding area (WWF et al. 2010). However, this study also reports that the number of gray whales in the area increased several days after seismic acquisition ceased.

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 ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006), 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). Sightings by observers on seismic vessels during 110 large-source seismic surveys off the U.K. from 1997 to 2000 suggest that, during times of good sightability, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of airguns were active vs. silent (Stone 2003; Stone and Tasker 2006). However, these whales tended to exhibit localized avoidance, remaining significantly further (on average) from the airgun array during seismic operations compared with non-seismic periods ($p = 0.0057$; Stone and Tasker 2006). The average CPA distances for baleen whales sighted when large airgun arrays were operating vs. silent were about 1.6 vs. 1.0 km. Baleen whales, as a group, were more often oriented away from the vessel while a large airgun array was active compared with periods of inactivity ($p < 0.05$; Stone and Tasker 2006). 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 (2003) noted that fin/sei whales were less likely to remain submerged during periods of seismic surveying.

During seismic surveys in the Northwest Atlantic, baleen whales as a group showed localized avoidance of the operating array (Moulton and Holst 2010). Sighting rates were significantly lower during seismic operations compared with non-seismic periods, 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 to 180 dB re 1 µPa.

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 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 sightability 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 to 170 dB re 1 μPa_{rms} range seem to cause obvious avoidance behaviour in a substantial fraction of the animals exposed. In many areas, seismic 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 to 30 km) and lower received sound levels (120 to 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 starts firing 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 strongly suggests that many baleen whales will begin to move away during the initial stages of a 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 seismic 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. In any event, 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.

Toothed Whales

Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales. However, there are recent 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). There is also an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; 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; Barkaszi et al. 2009; Richardson et al. 2009; Moulton and Holst 2010).

Delphinids (Dolphins and similar) and Monodontids (Beluga)

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; Moulton and Miller 2005; Holst et al. 2006; Stone and Tasker 2006;

Weir 2008a; Richardson et al. 2009; Moulton and Holst 2010; see also Barkaszi et al. 2009). 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 3,959 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 to 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. 2010; Moulton and Holst 2010).

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 (Moulton and Holst 2010). 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). 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 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 to 20 km compared with 20 to 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 2,250 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.

Observers stationed on seismic vessels operating off the U.K. from 1997-2000 have provided data on the occurrence and behaviour of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004; Stone and Tasker 2006). Dolphins of various species often showed more evidence

of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods when large-volume[3] airgun arrays were active. Except for the pilot whale and bottlenose dolphin, CPA distances for all of the small odontocete species tested, including killer whales, were significantly farther from large airgun arrays during periods of airgun activity compared with periods of inactivity. Pilot whales were less responsive than other small odontocetes in the presence of seismic surveys (Stone and Tasker 2006). For small odontocetes as a group, and most individual species, orientations differed between times when large airgun arrays were operating vs. silent, with significantly fewer animals traveling towards and/or more traveling away from the vessel during airgun activation (Stone and Tasker 2006). Observers' records suggested that fewer cetaceans were feeding and fewer were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating, and small odontocetes tended to swim faster during periods of airgun activation (Stone and Tasker 2006). For most types of small odontocetes sighted by observers on seismic vessels, the median CPA distance was ≥0.5 km larger during airgun operations (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic surveying in deeper waters.

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 2003–2008 showed that delphinids were generally seen farther from the vessel during seismic than during non-seismic periods (based on Barkaszi et al. 2009, excluding sperm whales). Similarly, during two NSF-funded L-DEO seismic surveys that used a large 20 airgun array (~7,000 in^3), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during seismic than non-seismic periods (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 five 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 (1,698 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 (~6,600 in^3), the results are less easily interpreted (Richardson et al. 2009). During both surveys, the delphinid detection rate was lower during seismic than during non-seismic periods, 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 non-seismic periods; 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.

[3] Large volume means at least 1,300 in^3, with most (79%) at least 3,000 in^3.

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 (3,147 in^3 or 5,085 in^3) (Weir 2008a). Sample sizes were low, but CPA distances of dolphin groups were significantly larger when airguns were on (mean 1,080 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 tend to be less substantial than reactions to large airgun arrays (e.g., Stone 2003; Stone and Tasker 2006). During 91 site surveys off the U.K. in 1997–2000, sighting rates of all small odontocetes combined were significantly lower during periods the low-volume[4] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to three 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 seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non seismic periods 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). 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 noise pulses from underwater explosions (as opposed to airgun pulses) may be indicative of odontocete responses to very strong noise pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas 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 noise 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

[4] For low volume arrays, maximum volume was 820 in^3, with most (87%) ≤180 in^3.

studies that found limited or no effects of noise 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.

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 level of airgun sound (<145 dB re 1 μPa_{rms} at a distance >70 km; Bain and Williams 2006). Similarly, during seismic surveys with large airgun arrays off the U.K. in 1997–2000, there were significant differences in directions of travel by harbour porpoises during periods when the airguns were active vs. silent (Stone 2003; Stone and Tasker 2006). A captive harbour porpoise exposed to single sound pulses from a small airgun showed aversive behaviour upon receipt of a pulse with received level 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 to 10 km (SPLs of 165 to 172 dB re 1 µPa, SELs of 145 to 151 dB $\mu Pa^2 \cdot s$); however, animals returned to the area within a few hours. In contrast, 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 almost no specific 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 vessel noise (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. However, this has not been documented explicitly. Also, 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 recent seismic surveys in the Northwest Atlantic during periods with and without airgun operations (Moulton and Miller 2005; Potter et al. 2007). 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).

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. No conclusive link has been established between seismic surveys and beaked whale strandings. 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).

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). Also, 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).

Recent and 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; 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 (3,147 in^3 or 5,085 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 3,039 m vs. 2,594 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 seismic and non-seismic periods (Moulton and Holst 2010). 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 levels 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).

Sightings of sperm whales by observers on seismic vessels operating in the Gulf of Mexico during 2003–2008 were at very similar average distances regardless of the airgun operating conditions (Barkaszi et al. 2009). For example, the mean sighting distance was 1839 m when the airgun array was in full operation (n = 612) vs. 1,960 m when all airguns were off (n = 66).

A controlled study of the reactions of tagged sperm whales to seismic surveys was done recently 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 sound levels of 111 to 147 dB re 1 μPa_{rms} (131 to 162 dB re 1 μPa_{pk-pk}) at ranges of ~1.4 to 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 seven 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).

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, belugas summering in the Canadian Beaufort Sea showed larger-scale avoidance, tending to avoid waters out to 10 to 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 it is likely that most if not all species show strong 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 belugas 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) would be appropriate. With a medium-to-large airgun array, received levels typically diminish to 170 dB within 1 to 4 km, whereas levels typically remain above 160 dB out to 4 to 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}.

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 seismic 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 seismic 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 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 seismic pulses. 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 orient away whether or not the airguns were firing (Calambokidis and Osmek 1998). Bain and Williams (2006) also stated that their small sample of harbour seals and sea lions tended to orient and/or move away upon exposure to sounds from a large airgun array.

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable information regarding the behaviour of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). Those seismic projects usually involved arrays of 6 to 16 airguns with total volumes 560 to 1,500 in^3. Subsequent monitoring work in the Canadian Beaufort Sea in 2001–2002, with a somewhat larger airgun system (24 airguns, 2,250 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 to 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 non-seismic periods. 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 seismic 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 during all seismic states, including periods without airgun operations. However, seals tended to be seen closer to the vessel during non-seismic than seismic periods. In contrast, during 2002, sighting rates of seals were higher during non-seismic periods than seismic operations, and seals were seen farther from the vessel during non-seismic compared to seismic activity (a marginally significant result). The combined data for both years showed that sighting rates were higher during non-seismic periods compared to seismic periods, and that sighting distances were similar during both seismic states. 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 without nearby seismic than from source vessels at locations with received sound levels (RLs) ≥160 and 159 to 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 to 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.

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. 2010). 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 to 140 dB, but no detections were made at SPLs >140 dB 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).

Hearing Impairmen 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). 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. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and 190 dB re 1 μPa_{rms}, respectively (NMFS 2000). Those criteria have been used in establishing the safety (= shut-down) radii planned for numerous seismic surveys conducted under U.S. jurisdiction. 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. As discussed below,

- The 180-dB criterion for cetaceans is probably precautionary for at least some species including bottlenose dolphin and beluga, i.e., lower than necessary to avoid temporary auditory impairment let alone permanent auditory injury;
- The 180-dB criterion may not be precautionary with regard to TTS in some other cetacean species, including the harbour porpoise. Likewise, the 190-dB criterion for pinnipeds may not be precautionary for all pinnipeds, although for pinnipeds the underlying data are indirect and quite variable among species;
- The likelihood of TTS (and probably also PTS) upon exposure to high-level sound may be better correlated with the amount of acoustic energy received by the animal, measured by the cumulative sound exposure level (SEL) in dB re 1 $\mu Pa^2 \cdot s$, than it is with maximum received RMS pressure level in dB re 1 $\mu Pa_{rms.}$. SEL allows for exposure duration and/or number of exposures; the maximum rms level does not. Thus, the current U.S. criteria may not be expressed in the most appropriate acoustic units;
- Low and moderate degrees of TTS, up to at least 30 dB of elevation of the threshold, are not considered injury and do not constitute "Level A harassment" in U.S. MMPA terminology. Beyond that level, TTS may grade into PTS (Le Prell 2012);
- The minimum sound level necessary to cause permanent hearing impairment ("Level A harassment") is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS; and
- The level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. The actual PTS threshold is likely to be well above the level causing onset of TTS (Southall et al. 2007).

Recommendations for new science-based noise exposure criteria for marine mammals, frequency-weighting procedures, and related matters were published by Southall et al. (2007). Those recommendations were never formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys, although some aspects of the recommendations have been taken into account in certain EISs and small-take authorizations. NMFS is currently moving toward adoption of new procedures taking at least some of the Southall et al. recommendations into account (Scholik-Schlomer 2012; NMFS 2013). The new noise exposure criteria for marine mammals will account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive (e.g., M-weighting or generalized frequency weightings for various groups of marine mammals, allowing for their functional bandwidths), and other relevant factors.

Nowacek et al. (2013) concluded that current scientific data indicate that seismic airguns have a low probability of directly harming marine life, except at close range. 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.

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 noise-induced hearing impairment and non-auditory physical effects.

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. Recent research has shown that sound exposure can cause cochlear neural degeneration, even when threshold shifts and hair cell damage are reversible (Liberman 2013).

The magnitude of TTS depends on the level and duration of noise 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 noise 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).

Toothed Whales

There are empirical data on the sound exposures that elicit onset of TTS in captive bottlenose dolphins, belugas, and finless 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. 2011; Schlundt et al. 2013). A detailed review of all TTS data from marine mammals can be found in Southall et al. (2007). The following summarizes some of the key results from odontocetes.

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 to 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). 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. 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 to 214 dB re 1 $\mu Pa^2 \cdot s$ 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 to 128 kHz at 140 to 160 dB re 1 μPa for 1 to 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. Kastelein et al. (2012a,b; 2013b) also reported that the equal energy model is not valid for predicting TTS in harbour porpoise or harbour seals, and Supin et al. (2013) reported that SEL may not be a valid metric for examining fatiguing sounds on beluga whales.

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). 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 $\mu Pa^2 \cdot s$ or 186 dB SEL (Finneran et al. 2002).[5] The rms level of an airgun pulse (in dB re 1 μPa measured over the duration of the pulse) is typically 10 to 15 dB higher than the SEL for the same pulse when received within a few kilometres of the airguns. Thus, a single airgun pulse might need to have a received level of ~196 to 201 dB re 1 μPa_{rms} in order to produce brief, mild TTS. Exposure to several strong seismic pulses that each has a flat-weighted received level near 190 dB_{rms} (175 to 180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. That 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, recent 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). Schlundt et al. (2013) reported that the potential for seismic surveys using airguns to cause auditory effects on dolphins may be lower than previously thought. Based on behavioural tests, Finneran et al. (2011) and Schlundt et al. (2013) reported no measurable TTS in bottlenose dolphins after exposure to ten impulses from a seismic airgun with a cumulative SEL of ~195 dB re 1 $\mu Pa^2 \cdot s$; results from AEP measurements were more variable (Schlundt et al. 2013).

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 exposed to impulse sound are extremely limited, and the TTS data from the beluga 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

[5] If the low-frequency components of the watergun sound used in the experiments of Finneran et al. (2002) are downweighted as recommended by Southall et al. (2007) using their M_{mf}-weighting curve, the effective exposure level for onset of mild TTS was 183 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007).

above 3 kHz (Finneran and Schlundt 2010, 2011; Finneran 2012). 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. 2013a). Popov et al. (2013b) 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 noise in subsequent sessions (experienced subject state). Similarly, Nachtigall and Supin (2013) reported that false killer whales are able to change their hearing sensation levels when exposed to loud sounds, such as warning signals or echolocation sounds.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. There have been no studies of narwhal hearing impairment attributable to airgun sounds. For a harbour porpoise, the received level of airgun sound that elicited onset of TTS was lower (Lucke et al. 2009). The animal was exposed 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 (Lucke et al. 2009). 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 $\mu Pa^2 \cdot s$. It is inappropriate to assume that onset of TTS occurs at similar received levels in all odontocetes (*cf.* Southall et al. 2007). Some cetaceans may incur TTS at lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin. Tougaard et al. (2013) proposed a TTS criterion of 165 dB re 1 $\mu Pa^2 \cdot s$ for porpoises based on the data from two studies.

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) 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, and harbour 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). From this, it is suspected that received levels causing TTS onset may also be higher in mysticetes (Southall et al. 2007). However, 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 energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from more prolonged (non-pulse and pulse) exposures suggested that some pinnipeds (harbour seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005, 2008; Ketten et al. 2001; Kastelein et al. 2013b). 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 to 12.2 dB, with full recovery within 24 h (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.

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 to impulse sounds has been estimated indirectly as being an SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007). That would be approximately equivalent to a single pulse with received level ~181 to 186 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.

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 the harbour seal than for odontocetes exposed to impulse sound (see above), it is possible that some pinnipeds close to a large airgun array could incur TTS.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels >180 dB re 1 μPa_{rms}. The corresponding limit for pinnipeds has been set by NMFS at 190 dB, although the HESS Team (HESS 1999) recommended a 180-dB limit for pinnipeds in California. The 180 and 190 dB re 1 μPa_{rms} levels have not been 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. As summarized above, data that are now available imply that TTS is unlikely to occur in various odontocetes (and probably mysticetes as well) unless they are exposed to a sequence of several airgun pulses stronger than 190 dB re 1 μPa_{rms}. On the other hand, for the harbour seal, harbour porpoise, and perhaps some other species, TTS may occur upon exposure to one or more airgun pulses whose received level equals the NMFS "do not exceed" value of 190 dB re 1 μPa_{rms}. That criterion corresponds to a single-pulse SEL of 175 to 180 dB re 1 $\mu Pa^2 \cdot s$ in typical conditions, whereas TTS is suspected to be possible in harbour seals and harbour porpoises with a cumulative SEL of ~171 and ~164 dB re 1 $\mu Pa^2 \cdot s$, respectively.

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. 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 baleen whales or odontocetes that show avoidance of ships or airguns to be close enough to an airgun array to experience TTS. 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).

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 likelihood 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).

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 <u>at least</u> 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 to 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. (2013b) suggested that for a harbour seal exposed to octave-band white noise centred at 4 kHz for 60 min with mean SPLs of 124 to 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) 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. Thus, for cetaceans exposed to a sequence of sound pulses, they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of ~198 dB re 1 $\mu Pa^2 \cdot s$ (15 dB higher than the M_{mf}-weighted TTS threshold, in a beluga, for a watergun impulse). Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertained to non-impulse sound (see above). Southall et al. (2007) estimated that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ in the case of a harbour seal exposed to impulse sound. The PTS threshold for the California sea lion and northern elephant seal would probably be higher given the higher TTS thresholds in those species. Southall et al. (2007) also noted that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean or pinniped received one or more pulses with peak pressure exceeding 230 or 218 dB re 1 µPa, respectively. Thus, PTS might be expected upon exposure of cetaceans to <u>either</u> SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ <u>or</u> peak pressure ≥230 dB re 1 µPa. Corresponding proposed dual criteria for pinnipeds (at least harbour seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall et al. 2007).

These estimates are all first approximations, given the limited underlying data, numerous assumptions, and species differences. Also, data have been published subsequent to Southall et al. (2007) 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 quoted here, Southall et al. (2007) made the precautionary assumption that no recovery would occur between pulses.

The TTS section (above) concludes that exposure to several strong seismic pulses that each have flat-weighted received levels near 190 dB re 1 μPa_{rms} (175 to 180 dB re 1 $\mu Pa^2 \cdot s$ SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. Allowing for the assumed 15 dB offset between PTS and TTS thresholds, expressed on an SEL basis, exposure to several strong seismic pulses that each have flat-weighted received levels near 205 dB_{rms} (190 to 195 dB SEL) could result in cumulative exposure of ~198 dB SEL (M_{mf}-weighted), and thus slight PTS in a small odontocete. 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 an odontocete's CPA distance would have to be for the cumulative SEL to exceed 198 dB SEL (M_{mf}-weighted), 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 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 baleen whales are unknown but, as an interim measure, assumed to be no lower than those of 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. The TTS (and thus PTS) thresholds of some pinnipeds (e.g., harbour seal) as well as the harbour porpoise may be lower (Kastak et al. 2005; Southall et al. 2007; Lucke et al. 2009; Kastelein et al. 2012a,b, 2013b). 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 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 noise-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.

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, in one case, a seismic survey (Malakoff 2002; Cox et al. 2006), 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).

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 to 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, a few 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 (e.g., Castellote and Llorens 2013). Suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) were not well founded (IAGC 2004; IWC 2007). In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO seismic vessel R/V *Maurice Ewing* was operating a 20-airgun, 8,490-in^3 airgun array in the general area. The evidence linking the stranding to the seismic survey was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam echosounder at the same time, 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. Nonetheless, the Gulf of California incident plus the beaked whale 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).

Non-Auditory Physiological Effects

Based on evidence from terrestrial mammals and humans, sound is a potential source of stress (Wright and Kuczaj 2007; Wright et al. 2007a,b, 2009, 2011). 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 extremely 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 h. ***(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.

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 G. Review of Potential Effects of Airgun Sound on Sea Turtles[1]

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.

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. However, these data demonstrate that sea turtles appear to be low-frequency specialists (see Table G-1).

Table G-1. Hearing capabilities of sea turtles as measured using behavioural and electro-physiological techniques. ABR: auditory brainstem response; AEP: auditory evoked potential; Beh.: behavioural; NA: no empirical data available.

	Hearing			
Sea Turtle Species	Range (Hz)	Highest Sensitivity (Hz)	Technique	Source
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
	50-1600	50-400	AEP [a,w]	Piniak et al. 2012a
Hawksbill	NA	NA	NA	NA
Loggerhead	250-1000 50-1131	250 100-400	ABR [a] AEP [w], Beh.[w]	Bartol et al. 1999; Martin et al. 2012
Olive ridley	NA	NA	NA	NA
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
Flatback	NA	NA	NA	NA

[a] measured in air; [w] measured underwater.

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.

[1] By **Valerie D. Moulton and W. John Richardson**, with subsequent updates (to Dec. 2013) by Meike Holst, all of LGL Ltd., environmental research associates.

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 G-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 500 Hz, and speculated that the turtles had a useful hearing range of 60 to 1000 Hz. (However, there was some response to strong vibrational signals at frequencies down to the lowest one tested — 30 Hz).

Bartol et al. (1999) tested the in-air hearing of juvenile loggerhead turtles *Caretta caretta* (Table G-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 to 1,000 Hz. They demonstrated that loggerhead sea turtles hear well between 250 and 1,000 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 1,000 Hz. The signals used in this study were very brief — 0.6 ms for the clicks and 0.8 to 5.5 ms for the tone bursts. In other animals, auditory thresholds decrease with increasing signal duration up to ~100 to 200 ms. Thus, sea turtles probably could hear weaker signals than demonstrated in the study if the signal duration were longer.

Lavender et al. (2012) used ABR and behavioural audiogram analyses to examine the hearing of sub-adult loggerhead turtles. They found that the turtles responded to sounds with frequencies of 200 to 700 Hz, and that behavioural response time increased near the hearing threshold. Martin et al. (2012) used both behavioural and auditory evoked potential 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 to 400 Hz.

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 1,000 Hz. The turtles exhibited startle responses (neck contractions) to these tones. The lowest thresholds were in the 400 to 500 Hz range (106 dB SPL re 1 μPa), and thresholds in the 100 to 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.

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 G-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 to 500 Hz, with the most sensitive hearing at 200 to 400 Hz. In contrast, the two juvenile green turtles exhibited a slightly expanded overall hearing range of 100 to 800 Hz, with their most sensitive hearing occurring at 600 to 700 Hz. The most restricted range of sensitive hearing (100 to 200 Hz) was found in the two juvenile Kemp's ridley turtles, whose overall frequency range was 100 to 500 Hz.

Preliminary data from a similar study of a trained, captive green turtle indicate that the animal heard and responded behaviourally to underwater tones ranging in frequency from 100 to 500 Hz. At 200 Hz, the threshold was between 107 and 119 dB, and at 400 Hz the threshold was between 121 and 131 dB [reference units not provided] (Streeter 2003; ONR N.D.).

The hearing sensitivity of leatherback hatchlings was tested in water and in air using auditory evoked potentials (Piniak et al. 2012). Hatchlings were exposed to 50 ms pulsed tones between 50 and 1,600 Hz. The hatchlings responded to sound stimuli between 50 and 1,200 Hz in water and 50 and 1,600 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 μPa_{rms} at 300 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 kilometres 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.

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). 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. 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.

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 1,500 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).

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 2,000 psi[3] and an airgun-depth of 2 m for prolonged periods of 20 to 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 to 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 to 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).

[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).

[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 1,000 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 2,000 psi.

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 to 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 peak-peak, peak, rms, SEL, 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.

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 to 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 (2,678 in^3, 12-elements) operating in 100 to 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.

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 to 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 trtles 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.

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 to 20 airguns; 3,050 to 8,760 in^3) and small-source (up to six airguns or three GI guns; 75 to 1,350 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 5,085 and 3,147 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 to 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, 2,440 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 2,028 h of vessel-based monitoring of seismic exploration using four to eight 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). Moreira 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.

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. 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).

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. 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 sounds 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 with terrestrial reptiles have demonstrated that exposure to airborne impulse noise can cause hearing loss. For example, 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).

Other Physical Effects

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; Hazel et al. 2007; Ketos Ecology 2007; Weir 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).

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 to turtles close to the airguns. However, there are very few data on temporary hearing loss and no data on permanent hearing loss 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 impact is 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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