DEFINING CRITICAL HABITAT FOR LARGE WHALES IN NEWFOUNDLAND AND LABRADOR WATERS - DESIGN AND ASSESSMENT OF A STEP-BY-STEP PROTOCOL

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Defining Critical Habitat for Large Whales in Newfoundland and Labrador Waters – Design and Assessment of a Step-by-Step Protocol

by

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Abstract

The aim of this study was to develop a procedure to define critical habitat for species at risk under the *Species at Risk Act* and apply it to blue, fin, and sei whales in an effort to increase our understanding of their habitat use and preference around Newfoundland and Labrador. To achieve this goal, a step-by-step protocol was developed to help scientists and decision makers achieve habitat protection goals for species at risk: Step 1 – natural history description; Step 2 – population concentrations as habitat ranking markers ("Candidate" Critical Habitats); Step 3 – assessing limiting resources and limiting factors ("Protected" Critical Habitats); and Step 4 – active monitoring.

Areas of high population concentrations, including seasonal peaks, for blue, fin, and sei whales were identified through historical shore-based whaling records and the Department of Fisheries and Oceans' cetacean sightings database. These areas were labelled as initial candidate critical habitats and include: the south coast of Newfoundland during spring and summer and the Strait of Belle Isle/Gulf of St. Lawrence during spring for blue whales; coastal Labrador and northeast Newfoundland during summer for fin whales; and the south coast of Newfoundland during summer and coastal Labrador during summer and autumn for sei whales. These regions were demonstrated to have served historically as feeding habitats for all of these species.

An Ecological Niche Factor Analysis (ENFA), using ecogeographical variables (water depth, seabed slope, sea-surface temperature, and chlorophyll concentrations), provided more precise models of habitat suitability and candidate critical habitats. Results of the ENFA indicated that blue whale distribution around Newfoundland and Labrador was found to be mainly correlated with areas of deep water and steep seabed slope, and particularly off the south coast of Newfoundland, with the steepness of the seabed slope. Fin whale and sei whale distribution were correlated mainly with deeper than average waters and colder surface waters. Season-specific critical habitat models were also generated, but were generally low in their predictive accuracy. When the models were challenged with a limited set of aerial survey sighting records that were not used in the ENFA, 64% of blue whale sightings (n = 11) and 60% of fin whale sightings (n = 10) were located within *core* habitat as defined by ENFA. Finally, potential limiting factors were summarized and conditions were highlighted under which these "candidate" critical habitats should become "protected" critical habitats.

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List of Acronyms

CI	Confidence interval
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Department of Fisheries and Oceans
EGV	Ecogeographical variable
ENFA	Ecological Niche Factor Analysis
EPBC Act	Environment Protection and Biodiversity Conservation Act
ESA	Endangered Species Act
EU	European Union
HS	Habitat suitability
IWC	International Whaling Commission
SARA	*Species at Risk Act*
SST	Sea-surface temperature
TNASS	Trans North Atlantic Sightings Survey

Chapter 1: General Introduction

The Canadian *Species at Risk Act* (*SARA*) requires that a recovery plan be developed for those species listed as "endangered" or "threatened". Included in the recovery plan is the requirement to identify and protect the species' critical habitat from current or future anthropogenic activities that could hinder the survival or recovery of the species. The need for such identification of critical habitat is particularly urgent for species at risk that have recently experienced a severe population decline such as the blue whale (*Balaenoptera musculus*). The blue whale is currently listed as "endangered" in the north Atlantic and on Schedule 1 of the *SARA*.

Critical habitat is defined by the Canadian *Species at Risk Act* (*SARA*-Bill C-5) as "the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in a recovery strategy or in an action plan for the species". Unfortunately, while a legal definition of critical habitat is provided under the *SARA*, no guidelines exist to help scientists and managers identify critical habitat. This lack of operational guidance could, in part, explain the slow progress of critical habitat designation in Canada. As of March 2009, only nine Critical Habitat Statements have been added to the federal public registry (http://www.sararegistry.gc.ca). Of the nine Critical Habitat Statements described in Canada, one is for a marine mammal species: northern and southern resident killer whales (*Orcinus orca*) in the Pacific Ocean (added 10 September 2008).

Similar in goal to the *SARA*, the Endangered Species Act (ESA) of 1973 (http://www.fws.gov/endangered/esa/content.html) was enacted in the United States to achieve the dual goals of species conservation and species recovery. The ESA was amended in 1978 to include critical habitat. In January 2002, 152 out of 1,256 listed species had critical habitat designations (Scarpello 2003). This proportion became 152 out of 1,846 by May 2002 (Scarpello 2003). Critical habitat designation did not vary with the degree of threat faced by species and recovery potential (Hoekstra *et al.* 2002). While operational guidance is also absent from the ESA critical habitat designation process, larger institutional, financial, and legal constraints may be the main reasons to explain the slow progress of critical habitat designation in the U.S. As of October 2008, the FWS (Fish and Wildlife Service) and NMFS (National Marine Fisheries Service) had designated critical habitat for 526 species listed as threatened or endangered under the ESA (http://ecos.fws.gov/tess_public/CriticalHabitat.do?nmfs=1).

The European Union also provides habitat protection for its natural wildlife. The Habitats Directive (http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm), which was enacted in 1992, can designate "Special Area of Conservation" for those species whose habitat requires special measures of protection (Annex II). In February 2007, the EU elaborated a "Guidance document on the strict protection of animal species of Community interest under the Habitats Directive 92/43/EEC" (http://ec.europa.eu/environment/nature/conservation/species/guidance/index_en.htm). However, this document is mainly aimed at clarifying confusion in the legal interpretation of the Habitat Directive and lacks operational guidance.

The Australian government passed the Environment Protection and Biodiversity Conservation Act (EPBC Act) in 1999 (http://www.deh.gov.au). Similarly to the Canadian *SARA* regulation, the EPBC Act is responsible for identifying and listing threatened species and threatened ecological communities, and developing a recovery plan. The EPBC Act also allows for the development of a Register of Critical Habitat, five of which existed as of October 2008 (http://www.environment.gov.au/cgi-bin/sprat/public/publicregisterofcriticalhabitat.pl). A list of matters to consider when identifying critical habitats exists, but no formal protocol is provided.

Hence, Canadian guidelines for defining critical habitat are on par with other international legislative guidelines. However, the limited number of critical habitats defined for species at risk in Canada, and internationally, suggests that available guidelines are currently inadequate to assist scientists and managers in the inclusion of critical habitat protection to the overall goal of species at risk conservation.

1.1 Study Objectives

Killer whale populations off the west coast of Canada are among the most comprehensively studied marine mammal populations in Canada, yet the process to identify critical habitat for this species has been long and controversial. How are critical habitat identification challenges going to be met in the case of marine mammal species and population for which more limited knowledge exists? Scientists and managers need comprehensive and transparent guidance to assess the important components related to the critical habitat definition process and achieve robust critical habitat models that can withstand scientific and legal challenges. Without such guidance, scientific, managerial, and fiscal objectives and deadlines cannot be achieved.

The recent listing of the blue whale as endangered under the *SARA* and the critical habitat identification requirements associated with this listing highlight the urgent need for a better understanding of habitat use and preference of this species in Newfoundland and Labrador (Figure 1.1). The absence of resources to address the current habitat use and preference of these whales and the urgency of addressing critical habitat requirements for blue whales require the use of opportunistic data sources. Historical whaling records and various sighting databases can be used to develop habitat suitability models and address these needs. The creation of a critical habitat definition operational guideline under the new *SARA* would facilitate the process of critical habitat definition for blue whales in Newfoundland and Labrador waters, as well as for other marine mammals in this and other regions.

Fin whales (*Balaenoptera physalus*) and sei whales (*Balaenoptera borealis*) are not listed as "endangered" or "threatened" in the north Atlantic under the *SARA* at this time. They are nonetheless considered in this study as the process of information gathering and analysis for these two species of large rorquals follows that of the blue whale. This would simplify the critical habitat identification process for fin and sei whales should their status change under the *SARA* in the future.

Given these needs, this thesis has three main objectives:

I. *Define critical habitat in general and the various components linked to its definition (Chapter 2).*

II. *Devise a step-by-step protocol to assess critical habitat (Chapter 2).*

III. *Execute the step-by-step protocol to assess critical habitat for blue, fin, and sei whales in the Newfoundland and Labrador study area (Chapters 3 – 5).*

   a) *Describe natural history (Step 1), and identify historic and current distribution patterns and areas of high population concentration (Step 2) of blue, fin, and sei whales in the Newfoundland and Labrador study area (Chapter 3).*

   b) *Identify limiting resources and factors (Step 3) for blue, fin, and sei whales in the Newfoundland and Labrador study area (Chapter 4).*

   c) *Challenge the critical habitat model through active monitoring (Step 4) of blue, fin, and sei whales in the Newfoundland and Labrador study area (Chapter 5).*

1.2 General Methods

I. *Define critical habitat in general and the various components linked to its definition (Chapter 2).*

Despite the existing legal definitions, no operational guidelines exist in Canadian (or international) law to identify or describe habitat critical for any species. A transparent approach to describe and assess critical habitat must be developed. This should integrate existing data with elements of risk management and recommendations for further science to address data gaps. A description of the components that are essential to the assessment of critical habitats is included in this approach. These components will then be used as tools to guide scientists studying species at risk in their assessment of knowledge gaps and the critical habitat definition process.

II. Devise a step-by-step protocol to assess critical habitat (Chapter 2).

Managers need to know where critical habitats are located and when they are occupied in order to assess the potential risks that could be associated with proposed human activities within or near these areas, and to provide adequate protection. The process of identifying these critical habitats can be difficult, especially in the absence of a protocol to guide managers and scientists. By developing a step-by-step protocol to assess and define the critical habitat of a species, managers can know which data they will require from science, and how to integrate it within a risk management framework to simplify the assessment process.

The critical habitat protocol should be generalized and applicable to the critical habitat definition process of all species. However, the protocol should also be flexible enough to allow for consideration of species- or regionally-specific traits. Using the components of critical habitats established in the first objective (Chapter 2) facilitates the establishment of a protocol framework needed to properly define a species' critical habitat. The third objective examines the components of critical habitat for blue, fin, and sei whales off Newfoundland and Labrador in accordance with this newly created step-by-step protocol.

III. a) Describe natural history (Step 1), and identify historic and current distribution patterns and areas of high population concentration (Step 2) of blue, fin, and sei whales in the Newfoundland and Labrador study area (Chapter 3).

Historic patterns of large rorqual habitat use are assessed by examining whaling records from Newfoundland and Labrador shore-based whaling stations. This will help managers identify areas of high population concentration and address issues of critical habitat for large whales in Newfoundland and Labrador waters in general terms in the absence of distribution and abundance data for the study area, particularly for the endangered blue whale. Most of these records originated from past Newfoundland Annual Fisheries Reports (1898–1915) and the International Whaling Commission (IWC, 1927–1972).

The historic habitat use patterns and areas of high population concentration derived from whaling records were complemented with recent sighting records from a large database of marine mammal sightings maintained at the Department of Fisheries and Oceans (DFO) in St. John's, Newfoundland and Labrador. This sightings database is derived through merging and error-checking of multiple marine mammal sightings databases which originated from a variety of sources within DFO, Memorial University's

Whale Research Group, the aerial surveillance unit of Provincial Airlines (under contract to DFO), and many reports contributed by the public and industry.

III. b) Identify limiting resources and factors (Step 3) for blue, fin, and sei whales in the Newfoundland and Labrador study area (Chapter 4).

Once historic and current habitat use patterns, and areas of high population concentration of blue, fin, and sei whales are derived for the study area, limiting resources also need to be assessed within this geographic and temporal context. The main limiting resource likely to impact large rorquals in Newfoundland and Labrador waters is prey availability as this region, for the most part, represents important feeding grounds. Stomach contents originating from shore-based whaling records were used to differentiate between historic feeding areas for these large rorquals and potential migration routes. Habitat preference was then assessed through habitat suitability models using environmental features that have been shown to influence large rorqual distribution in other regions.

In addition to limiting resources, the limiting factors that could impact the survival or recovery of the blue, fin, and sei whales were also assessed. Potential limiting factors are identified and their potential scope of impact in Newfoundland and Labrador is described.

III. c) Challenge the critical habitat model through active monitoring (Step 4) of blue, fin, and sei whales in the Newfoundland and Labrador study area (Chapter 5).

No critical habitat should be considered permanent. Population dynamics and environmental features change over time. Our perception and ability to accurately describe a species' habitat also changes over time. New sources of data will become available and modelling techniques will improve in their predictive accuracy. In order to test the robustness of the habitat suitability models described in this study, sightings that have recently become available to the sightings database (these were not available when the habitat suitability models were developed) were used to challenge the models.

Finally, additional research aims are suggested to complement the current study and address outstanding knowledge gaps.

1.3 Background

1.3.1 Blue Whales

The blue whale is the largest animal known to have existed and is found in all of the world's oceans, ranging from tropical waters to pack ice in both hemispheres (Rice 1998). Once abundant in both hemispheres, the blue whale population declined dramatically during intense whaling from the start of the 20th century until the mid-1960s. Starting in 1904, an estimated 360,000 blue whales were taken in the Southern hemisphere alone (Clapham and Baker 2002). At least 11,000 blue whales were killed in the north Atlantic before the IWC banned whaling in this region in 1955, and gave the blue whale protected status in 1966 (Sears and Calambokidis 2002).

The blue whale is separated into three populations: the north Atlantic, north Pacific, and southern hemisphere populations (Rice 1998). The northwest Atlantic population of blue whales occupies waters from the Caribbean, Eastern U.S. and Canada. Estimates suggest the population numbers between 600 and 1,500 individuals - although obtaining accurate counts has been difficult (Sears *et al.* 1987; Sigurjónsson and Gunnlaugsson 1990; Christensen *et al.* 1992b). More recent estimates suggest this number could be lower than 300 (Sears and Calambokidis 2002). The blue whale was classified as "endangered" in 2002 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in both the Atlantic and Pacific oceans (COSEWIC 2002). The blue whale is currently listed on Schedule 1 of the *Species at Risk Act*.

Mating and calving occur from late fall to mid-winter (Yochem and Leatherwood 1985). Individuals reach sexual maturity between 5-15 years, or when whales have a body length of 20-24 m depending on sex and location. Following an 11 month gestation period, females give birth to a 6-7 m calf which is weaned after 7-9 months (Yochem and Leatherwood 1985). Calving intervals are 2-3 years and individuals are believed to live 70-80 years or more (Yochem and Leatherwood 1985).

Blue whales feed almost exclusively on shrimp-like euphausiids (Yochem and Leatherwood 1985). They tend to swim at speeds of 2-8 km/hr while feeding, but are capable of speeds of up to 36 km/hr (Yochem and Leatherwood 1985). Some of the most concentrated krill aggregations of the northwest Atlantic are in the St. Lawrence estuary, where blue whales come to feed every year (Simard and Lavoie 1999). Local environmental factors such as tidal currents and topography, as well as the negative phototactism behaviour of krill have recently been linked to the formation of local krill aggregation in this productive area (Cotté and Simard 2005).

1.3.2 Fin Whales

Fin whales were also hunted in all of the world's oceans and only recently received full protection from commercial whaling. In the southern hemisphere, 723,000 fin whales were taken from 1904 to 1976 (Clapham and Baker 2002), when the IWC protected fin whales in the Antarctic and Pacific oceans. Fin whales in the Atlantic Ocean only gained protection from whaling by the IWC in 1986. The Atlantic fin whale population was listed as "special concern" by COSEWIC in 2005. The Pacific population, however, was designated as "threatened" (COSEWIC 2005b).

Geographically, fin whales are found mainly in temperate waters, but migrate seasonally to higher latitude feeding grounds in the summer and lower latitude mating grounds in the winter. Mating and calving occur in winter (Haug 1981). Calves are born after a gestation period of a little less than a year and are nursed for 6-7 months (Haug 1981; Gambell 1985a). Females give birth at a mean interval of 2.7 years according to photo-identification studies (Agler *et al.* 1990) and an estimated two-year interval based on whaling records (Christensen *et al.* 1992a). Sexual maturity is reached in females from the age of 10 or older, but can be as early as the age of six for exploited populations (Gambell 1985a).

Fin whales prey primarily on crustaceans such as euphausiids and schooling fish such as capelin (*Mallotus villosus*), herring (*Clupea harengus*), and sand lance (*Ammodytes* spp.) (Jonsgård 1966; Sergeant 1977; Overholtz and Nicolas 1979; Christensen *et al.* 1992a; Borobia *et al.* 1995). From whaling records around Newfoundland, krill appear to be the preferred prey early in the season, changing over to capelin in late June to late July (Sergeant 1966). Other studies have supported the importance of capelin for fin whales off Newfoundland (Mitchell 1975b; Brodie *et al.* 1978; Whitehead and Carscadden 1985). Fin whales appear to feed preferentially on euphausiids in the Bay of Fundy (Gaskin 1983). Both euphausiids and the capelin associated with its aggregation are likely the food of choice of fin whales in the St. Lawrence estuary (Simard and Lavoie 1999). Rare occurrences of squid and lantern fish in fin whale stomachs have been reported (Sergeant 1966).

1.3.3 Sei Whales

Sei whales were not hunted as commonly as blue and fin whales because they were less common (or less easily sighted), and/or because of the greater difficulty in catching them. Nonetheless, 208,000 sei whales, the third largest number of baleen whales killed following blue and fin whales, were taken in southern waters starting in 1904 (Clapham and Baker 2002). No protection was given to sei whales until 1970, when quotas were introduced for north Pacific whaling. Quotas were introduced for north Atlantic whaling in 1977. Full protection from commercial whaling by the IWC was not introduced until 1976 for the north Pacific and 1986 for the north Atlantic. The latter also coincided with a moratorium on commercial whaling in the northern hemisphere. Sei whales are listed as "data deficient" in the Atlantic and "endangered" in the Pacific (COSEWIC 2003). Over 4,000 sei whales were hunted off the coast of British Columbia from 1908 to 1967 and they are no longer observed off this coast today.

Sei whales are found mostly in mid-temperate latitudes. In the northern hemisphere, they undergo a north-south migration spending winters in southern latitudes and summer at higher latitudes (Gambell 1985b). Their distribution might also be partly linked to oceanic fronts that created physical oceanographic processes leading to an enhanced productivity (COSEWIC 2003). Sei whales may have a temperature limitation (Kawamura 1974; Horwood 1987). Thus, they may follow warmer, poleward moving currents towards higher latitude feeding grounds.

Mating and calving occurs in the winter for sei whales (Lockyer and Martin 1983). After an 11-month gestation period, the calves are nursed for 6-9 months before being weaned (Lockyer and Martin 1983). Sexual maturity is reached between the ages of 8-10 years. Calving interval appears to be about two years (Lockyer and Martin 1983).

Sei whales are diversified feeders and use both skimming and gulping feeding strategies (Nemoto 1959). The preferred prey items of sei whales are calanoid copepods and euphausiids (Mitchell 1975b; Christensen *et al.* 1992a). However, their diet seems to vary geographically based on prey availability in the north Pacific and the Antarctic, and sei whales feeding in more coastal waters also appear to have a more diverse diet (Nemoto and Kawamura 1977; Flinn *et al.* 2002). The geographic difference in stomach contents was hypothesized to result from differences in the trophic structures of both regions (Nemoto and Kawamura 1977).

Chapter 2: Defining Critical Habitat for Marine Mammals in the Context of Canada's *Species at Risk Act* - A Step-by-step Protocol

2.1 Introduction

One mandate of the Canadian *Species at Risk Act* (*SARA* – Bill C-5) of 2003 is to assess "critical habitat" for those Canadian species listed as "at risk"[1]. Critical habitat is defined under *SARA* as "the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species". This implies that the entire known range or all habitat of a listed species will not be designated as "critical" and that only habitat of sufficient size and quality to ensure the survival or recovery of the *SARA*-listed species would be designated as such. Habitat defined as "critical" must be included in a Federal recovery strategy or management plan. As of October 2008, only seven Critical Habitat Statements have been added to the federal public registry (http://www.sararegistry.gc.ca).

One reason for the low number of critical habitat listings under *SARA* may be the difficulty in defining such areas given the many ecological and operational considerations underlying this concept. Hall *et al.* (1997) provided a simplified ecological definition of critical habitat as "an area's ability to provide resources for population persistence".

[1] "*SARA*-listed" species are those whose status has been first assessed and recommended as being "extirpated", "endangered", "threatened", or "special concern" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and later accepted as such by the responsible Federal minister.

Whether a legal or ecological construct is used to delineate critical habitat, a number of common key attributes remain.

Returning an ecosystem or hunted species to a pre-harvest state may be impossible as the current state of the ecosystem that previously supported such a population has likely changed and natural food chain configurations will likely be different. Instead, a stable or detectably increasing population level for a *SARA*-listed species of concern may be a more realistic goal. Once a population recovery goal is set, different strategies are available to help attain this goal; one is to reduce mortality or enhance reproductive success through designation of certain habitat that is deemed to be "critical" to the species of concern.

The process of defining critical habitat is potentially complex and such decisions are often made in the absence of detailed knowledge of the species of interest and its relationships with its ecosystem. Creating a summary list of habitat attributes to be addressed by decision-makers, using precautionary advice from scientists, would be a valuable means to simplify the process of critical habitat designation and ensure that important issues are not overlooked. Some means to assess the risk to the species must also be included in the process. A critical habitat definition process is described here in a step-by-step protocol. While this chapter uses marine mammals as its genera of interest, the approach could be applied to other species as well.

2.2 Components of Critical Habitat

2.2.1 Natural History

Jax *et al.* (1998) described critical habitat for a particular species as the "ecological unit" whose existence is essential for that species' persistence. Consequently, ecological units can be identified as providing habitat for a particular population if changes in the units' characteristics affect survival, fecundity, or movement rates resulting in a change in the size of that population (Harwood 2001). This could be caused by food limitation (leading to decreased reproductive output through a delay in age of sexual maturity or an increase in birthing interval), increased predation on calves or pups due to an increase in the number of predators, or a decrease in the adequate quality and amount of refugia.

Harwood and Rohani (1996) reviewed factors that affect marine mammal abundance and concluded that the most important was the availability of safe areas for breeding and foraging. Harwood (2001) concluded that critical habitats for marine mammals can be defined in terms of the ecological units that provide one or both of these resources. These authors state that breeding and foraging grounds should be the main targets of critical habitat designation. Limiting resources and limiting factors within these breeding and foraging grounds could then be used as indicators of areas needing to be designated as critical habitat.

Some *SARA*-listed whale species are highly migratory, so there is a need to consider their migratory routes as critical habitat when designing recovery plans (Gregr and Trites

2001). The need to have an unimpeded passage from one habitat to another is of vital importance. Therefore, areas included within a species' migratory routes should also be considered for critical habitat designation, in the same manner as breeding and foraging areas are, to ensure safe passage.

2.2.2 Population Concentrations

Spatial aggregation of a species' population is also an important component of critical habitat. Species that concentrate in one or more areas of their habitat may equally benefit from a smaller proportion of their overall habitat defined and protected as "critical" than would species with a more general distribution across their habitat. The *SARA* defines habitat as "the area or type of site where an individual or wildlife species naturally occurs or depends on directly or indirectly in order to carry out its life processes or formerly occurred and has the potential to be reintroduced". This definition is further specified for aquatic species as "spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced".

Unlike many of the classically-defined critical habitats in terrestrial environments, the scale and four-dimensional (three-dimensional space plus time) nature of marine mammal critical habitat requires that decision-makers account for the integrated nature of many habitats. Identifying habitat "hot spots" can provide a critical habitat ranking order, with areas predicted to have the highest concentrations of species of interest being afforded further study first. The final decision as to whether such areas will be designated critical habitat would be based on the impact of the other components, such as limiting resources and limiting factors, on each habitat.

Some feature might set a particular portion of a species' habitat apart from others such that it favours the presence of a *SARA*-listed species and could be a defining component of the critical habitat for that species. One example is the deep ocean canyons in the Sable Gully, off Nova Scotia, designated as a Marine Protected Area under Canada's Oceans Act based on their presumed importance for the northern bottlenose whale (*Hyperoodon ampullatus*). Environmental features are sometimes used as proxies for marine mammals' habitat preferences or for suspected areas of marine mammal concentration where such information is poor or lacking for a species. Numerous studies have established links between marine mammal occurrence and environmental features such as fronts, eddies and areas of upwelling, bathymetry, sea-surface temperature, primary productivity (often inferred using measures of physical oceanography), and prey abundance (see Appendix A). Other studies have used a combination of environmental features to predict areas of highest marine mammal concentration (Moses and Finn 1997; Gregr and Trites 2001; Guinet *et al.* 2001; Hamazaki 2002; Littaye *et al.* 2004).

2.2.3 Limiting Resources

Resources such as access to prey in feeding areas or mates in breeding areas can be concentrated in restricted portions of the species' total area of distribution due to oceanographic and/or behavioural factors. In these cases, areas containing concentrated resources could be considered critical habitat if such resources might not be accessed in an energetically feasible way in other parts of the home range or make completion of other life history processes difficult. If feeding patches can be identified and are areas of concentrated feeding effort for a population, these patches could be designated critical habitat for this population, especially if they were spatially predictable. Spatial and temporal changes in these feeding patches would have to be monitored as they could lead to corresponding shifts in the associated critical habitat.

Krill aggregation in the St. Lawrence Estuary, a preferred location for many whale species, is an example of such feeding patches that vary in concentration with tidal periods (Cotté and Simard 2005). Inshore whale abundance off the coast of Newfoundland has been linked to capelin (Whitehead and Carscadden 1985), and could represent another example of prey-linked shifting of critical habitat. Limited resources for marine mammals could also include sheltered waters. Humpback whales (*Megaptera novaeangliae*) favour an inshore distribution on breeding grounds (Herman and Antinoja 1977; Whitehead and Moore 1982; Mattila 1984; Glockner-Ferrari and Ferrari 1985; Mattila and Clapham 1989; Ersts and Rosenbaum 2003). Grey whales (*Eschrichtius robustus*) also use sheltered, shallow lagoons for calving during winter months (Rice *et* *al.* 1981). This preference may be due to the protection that inshore waters and lagoons provide from rougher waters (Whitehead and Moore 1982; Mattila and Clapham 1989; Smultea 1994) or reduced predation, mainly from killer whales (Whitehead and Glass 1985; Flórez-González *et al.* 1994; Smultea 1994; Corkeron and Connor 1999). If such sheltered habitat is in limited supply and has the potential to limit the marine mammal's ability to survive or recover from perturbation, or prevent successful mating on breeding grounds, it could be considered critical habitat as are prey aggregations on feeding grounds.

2.2.4 Limiting Factors

Limiting factors affecting a species' distribution and abundance include natural mortality and anthropogenic threats. Anthropogenic threats represent most limiting factors and are human activities that could impact a marine mammal species' ability to access resources or cause direct physical harm.

While anthropogenic threats can occur on feeding and breeding grounds, and thus, disrupt these essential activities, they could also affect another important natural history parameter of many marine mammals, such as migration. Some *SARA*-listed whale species are highly migratory and need to travel from one habitat to another. Specific anthropogenic threats along these migratory routes may need to be mitigated and designating habitat along the route as critical may facilitate this. For example, the Bering-Chukchi-Beaufort population of bowhead whales (*Balaena mysticetus*) travels a well-defined route in the spring and fall that can be considered critical as it travels to and from summer feeding areas in the Canadian Beaufort Sea prior to freeze over (COSEWIC 2005a). Seismic geophysical exploration projects have been conducted within this migration corridor and have been the subject of intensive monitoring and mitigation programs.

Some anthropogenic threats will not impact a species' population level, but others might. If an impact has the potential to decrease a population level beyond a level set in the species' recovery strategy, then mitigation measures, including critical habitat designation, need to be considered.

2.2.5 Vulnerability and Resilience

An important component of critical habitat relates to the vulnerability of the species used to define it. The level of threat facing a species could influence the home range proportion needing to be protected and designated as critical habitat. No formulae exist to determine the proportion of the critical habitat relative to total habitat for any marine mammal species – especially as a number of other natural history parameters specific to each species will also impact the amount of habitat that might need to be protected for each particular species. In general, the proportion of a species' home range that should be classified as "critical habitat" and/or the degree of protection afforded should increase with the level of threat facing this species or its ability to cope with perturbation.

Not only is a species' vulnerability in a system an essential element of critical habitat determination, but understanding and favouring that system's resilience to perturbation must also be considered. A system with low resilience is more sensitive to disturbances and may have a greater impact on a species' survival or recovery.

Because of the dynamic nature of ecological systems, an adaptive management approach needs to be employed and critical habitat borders need to be flexible. The total area of a species' home range defined as critical habitat and its location should be adjusted according to any change in that species' vulnerability (reflected through its COSEWIC status) or other critical habitat components described in this protocol in order to add resilience to the system through adaptive management.

Polar marine mammal species are highly vulnerable to habitat changes and may require a more cautious critical habitat definition. Polar bears (*Ursus maritimus*) rely on the sea ice for hunting phocid seals. A reduction in access to the sea ice could reduce the nutritional condition of females. This could in turn affect offspring survival. Activities leading to a reduction in sea ice in general could also affect the seal populations that rely on the ice for pupping and resting. This could lead to a reduction in the polar bear's primary prey, or in the polar bear's access to it, notably the bearded (*Erignathus barbatus*) and ringed (*Phoca hispida*) seals (Stirling and Archibald 1977; Smith 1980). This could, in turn, lead to impacts such as declining body condition, lowered reproductive rates, reduced survival of cubs, and increased polar bear-human interactions (Stirling and Derocher 1993). As the northern territories are likely to become more open to human exploitation, polar bear denning could also potentially suffer through disturbance or habitat loss. The dependence of these polar species on specific habitat requirements and the limitations of its availability both influence the species vulnerability and the extent of its habitat that may need to be defined as critical habitat.

2.2.6 Recent Population Trends

Population trends should also be an important consideration when assessing the size or type of habitat that is defined as critical for a particular marine mammal and are taken into account during the process of COSEWIC status designation. An unstable population would require a greater proportion of its habitat to be classified as critical in an effort to stabilize its population size and enable survival and recovery goals to be reached.

Marine mammals, especially cetaceans, have long life spans and calving intervals. The bowhead whale is thought to attain sexual maturation around the age of 25 and live more than 100 years (George *et al.* 1999). Blue whales reach sexual maturity in 5-15 years and can live 70 – 80 years or more (Yochem and Leatherwood 1985). Right whales (Eu*balaena glacialis*) calving intervals averaged close to 6 years in the 1990s (Kraus *et al.* 2001). Such features need to be considered when defining a marine mammal's critical habitat. Changes in population trends will not be observed for many years. Marine mammal critical habitat definition and monitoring must account, not only for the observed recent population trends of a species, but also for the timeframe over which changes in population trends can be observed.

2.2.7 Other Considerations

In addition to the preceding habitat attributes to be addressed by decision-makers, there are other features of any species' natural history or habitat that must be considered when deciding which habitat to designate as critical.

Marine mammals require a link with the non-aquatic world to survive because they are air breathers and, in the case of pinnipeds, to haul-out on land to give birth. Therefore, when considering habitat designation we may need to expand beyond marine areas and include shoreline areas, such as haul-out sites, for pinnipeds. It is also possible that foraging or breeding areas important for marine mammals may be governed by terrestrial processes. For example, productive feeding areas for killer whales relate to the fish entering and leaving rivers, whose outflow volume and productivity is somewhat independent of oceanic processes.

The quality of the data used to describe a particular habitat must also be taken into consideration when deciding whether to list it as "critical" for a marine mammal species. In the event that the natural history, distribution, and population trends of a resident species are not well understood, a precautionary approach is needed when deciding if habitat protection is warranted as a conservation tool for that species. The scope of the critical habitat designation could be refined if data gaps are filled or improved data are obtained.

Where current data are poor or incomplete for a species of interest, and opportunities for new research are limited, the use of historic and current commercial activities related to the species of interest could be of use. For example, old whaling records and whale watching excursions can provide useful indicators of marine mammal occurrence and habitat use patterns. Whaling records have been employed to postulate the original range of some hunted whale species such as right whales (*Eubalaena japonica*) in the north Pacific (Clapham *et al.* 2004; Shelden *et al.* 2005; Josephson *et al.* 2008) and humpback and blue whales in the north Atlantic (Reeves *et al.* 2004b). Studies have also used Yankee whaling records to link sperm whale (*Physeter macrocephalus*) distribution to areas of high productivity (Jaquet *et al.* 1996). Access to these whaling records can prove difficult, suffer from limitations in quantified search effort, and may not provide an accurate model for the whales' current distribution. Managers must be aware that current distribution patterns for whale populations might reflect areas that for some reason were inaccessible to whalers. Additionally, and given the depleted state of many large whale populations, "critical" habitats might also include areas that are not currently occupied, but that might represent important habitat for the long-term survival or recovery of a species. With sufficiently precautious interpretation, pre-harvest distribution information from historic records could provide useful insight for potential critical habitats.

It is difficult to compare past biological oceanographic characteristics of the habitat to present ocean conditions when in many places regime shifts of a major scale have occurred. Recent work using Continuous Plankton Recorder data for the north Atlantic demonstrated a 600 km biogeographical shift in some planktonic assemblages over the last 30 years (Beaugrand *et al.* 2002). Natural variations in climate conditions affecting food availability through oceanographic conditions, and, indirectly, reproductive rates, such as the North Atlantic Oscillation, could also impact critical habitat of certain endangered marine mammal species, such as the north Atlantic right whale (Greene and Pershing 2004). These natural variations, and the manner in which they might be influenced by anthropogenic activities, should, if possible, be considered when determining critical habitat requirements for depleted species.

Wildlife watching activities are subject to economic and logistical constraints, but they can still provide general indications of whale concentrations in certain areas. As has been done with fishing effort and fish habitat, the historic and seasonal patterns in whale watching effort could provide an additional method (beyond directed research surveys and autonomous acoustic monitoring) of habitat ranking during the evaluation process. The effort per location would have to be measured in a comparative form accounting for the inflow of tourism and human population size of the surrounding area. A major limitation is that the area "surveyed" by whale watching vessels will be, in most cases, focused in the nearshore area; much of the vast offshore areas will not be assessed without directed study. An alternative source of information covering offshore areas would be the use of opportunistic platforms such as commercial shipping and ferry routes.

2.3 Adaptive Management and Critical Habitat Definition

Given how little we usually know about the natural history of aquatic species, can we define critical habitats using attributes or factors other than the areas of highest animal concentration? While areas of high animal concentration play an important role in defining a species' critical habitat, this chapter has emphasized how other definable (and in many cases, quantifiable) components must also be considered during critical habitat definition as they can potentially affect the proportion of a species' home range that will be designated as critical habitat (Table 2.1).

In addition to areas of local marine mammal abundance, critical habitats can be defined by the types of anthropogenic pressures acting upon them, the rate of change of these pressures, and their magnitude. Abiotic and biotic factors may be used to assess the habitat preference of a species and determine the range over which anthropogenic impacts should be measured. According to the *SARA* legislation, critical habitat is the "habitat that is necessary for the survival or recovery of a listed wildlife species". Therefore, by definition, critical habitats are not legally constrained to the anthropogenic impacts potentially affecting them. By not limiting critical habitat definition to a scale that would only address anthropogenic threats, *SARA* provides protection to critical habitats not currently affected by anthropogenic impacts, but that could be in the future.

Harwood (2001) stated that critical habitat must be a functioning ecological unit, that accounts for all species and their interactions within the unit, or else it will not persist through time. Ecological units and anthropogenic impacts change over time. Critical habitats must be designed and implemented in a manner that accounts for these temporal and spatial changes in their defining components. A flexible, adaptive management approach such as the one presented here would be able to respond to threats adaptively.

For instance, if prey availability in an area falls below the designated species' ability to compensate by increasing foraging effort, it is assumed that changes in other natural history parameters, such as increased emigration rate, reduced growth rate or reproductive effort, occur and are detectable using research methods employed to monitor the population. Therefore, if a high concentration of the population remains in an area despite changes in prey availability, this area should be considered critical to that species or population based on other components of the habitat that might be important to it. Concurrently, if spatial changes in prey distribution or abundance are observed to be a feature of the habitat (and marine mammals' responses to them), the designated critical habitat cannot be a static area, but rather a "floating" critical habitat that can change in delineation according to temporal and/or spatial changes in the marine mammal population's ecological unit. It is useless to define critical habitat and mitigate against negative impacts in the same way as a static habitat as these measures would likely not provide the intended protection to a shifting, variable marine mammal and/or prey population.

The same approach would apply if new, potentially harmful, anthropogenic activities are introduced that might impact a species or population in a previously unprotected habitat. The precautionary approach, which recognizes that the absence of full scientific certainty shall not be used as a reason to postpone decisions where there is a risk of serious or irreversible harm (www.ec.gc.ca), requires that the population and its habitat be afforded protection until it is proven that these new activities do not cause an impact.

Additional habitat protection through critical habitat designation should not require detectable changes in the habitat or population before being provided. The absence of impact from a new activity needs to be proven before removing a habitat's critical status rather than adding the critical status to a habitat once an impact is detected. If baseline biological data on the species or habitat in question are missing to properly assess the potential impact of a new activity, the responsibility to fill the gaps and monitor the initial impacts rests within the hands of the party proposing the new activity.

Areas of high natural mortality do not fit within the strict *SARA* definition of critical habitat as the "removal" of such areas would not "negatively impact the survival or recovery of listed species". But from a management point of view these areas can be of great relevance to a *SARA*-listed species, even if not protected through more traditionally-defined critical habitats. Appropriate mitigation measures may be directed towards these areas to potentially reduce natural mortalities of the *SARA*-listed species.

Natural ice entrapments of marine mammals off the southwest coast of Newfoundland have in the past been an important cause of natural mortality for blue whales in Canadian waters (Lien *et al.* 1989). These events resulted in the death of 25 blue whales between 1974 and 1992 (Seton and Lien, Unpubl. MS), and for a population consisting of fewer than 250 mature individuals (Sears and Calambokidis 2002), this removal could hinder this populations' survival or recovery. Such areas can therefore be considered critical habitat, and mitigation measures put in place to reduce or eliminate this source of natural mortality. For example, in the event that ice and meteorological conditions occur that would increase the risk of cetacean entrapments, these areas could be surveyed for the presence of blue whales. If animals are found in such hazardous circumstances acoustic harassment methods could be employed in an effort to displace them to safer open waters. Other areas of mortality, such as areas of high predation, might not be afforded similar safeguards as the protection of one species would come at the expense of the predator.

2.4 Step-by-step Critical Habitat Designation Protocol

Based on discussions of the components of critical habitat described above, a flexible step-by-step protocol can be proposed to assist managers in the designation process. Four steps are essential in the definition process (Table 2.2); the first of which is natural history description for the species of concern. This needs to be done for each population of a species at risk and is usually addressed in the relevant COSEWIC status report. Specific information regarding habitat requirements should be provided including the identification of feeding, mating, and birthing grounds. Migratory routes should also be provided for migratory species. If any gaps exist in the available data, these must be identified and their contribution to the risks of negative impacts on the population must be assessed. In cases of risk of significant impact or where crucial data are lacking, immediate research efforts should be focused in filling these gaps.

The second step focuses on describing the population concentrations, if any exist, for the targeted species. The areas of high concentrations within each habitat (e.g., within a feeding ground, or within a mating ground) should be considered "candidate" critical habitats and used as ranking markers for further assessment. The areas having the largest concentrations of a species within a habitat will rank highest, as they will likely be more at risk of potentially affecting population levels if disturbed. These ranking markers can then be used to provide an order in which "candidate" critical habitats should be investigated in Step 3.

The third step is to describe the limiting resources and limiting factors existing in each "candidate" critical habitat; these should be assessed and listed for each *SARA*-listed species as part of a recovery strategy. As each area of concentration is being assessed in the order or priority based on the ranking order of Step 2, the list of limiting resources and limiting factors affecting each specific area should be noted. If any of these are known to potentially affect the species' recovery goal, the area being assessed can then be considered "protected" critical habitat, as opposed to "candidate" critical habitat as defined in Step 2. The impacts of the activities affecting the species directly (physically) or indirectly (behaviourally, or through their access to limiting resources) need to be mitigated within this "protected" critical habitat to reach a level that no longer counters the species' recovery goal objectives. This could involve spatial or temporal (seasonal) cessation or reduction of anthropogenic activities, creation of fishery or human occupation exclusion zones, or potentially the permanent elimination of a specific activity within the entire area defined as critical habitat.

By describing limiting factors in this step, rather than only anthropogenic factors, areas of high natural mortality that require a certain level of protection and monitoring will be awarded this protection even if not directly accounted for under the *SARA*. This was highlighted above in the case of blue whale ice entrapments off the southwest coast of Newfoundland. The risk to a species of not providing a "candidate" critical habitat the status of "protected" critical habitat should increase with the ranking order given to the area in Step 2 (highest risk for areas of high population concentration), and with the existence of other considerations relating to the species' natural history (unique components of a species, presence of data gaps, or sensitivity of the habitat and species to climate change).

The final step, Step 4, is development of a proactive monitoring program. A regular assessment of the marine mammal population of interest should be done in a time frame determined to be small enough that the risk of adverse effects going undetected or being irreversible, is acceptable to scientists and managers. Monitoring of the components that have the potential to influence the previous steps (natural history, population concentration, limiting resources, and limiting factors) will allow managers to determine whether the critical habitat characteristics (biological, spatial, or temporal boundaries) need to be adjusted. These adjustments could include an increase or decrease in size of a specific area, or an increase or decrease in the number of areas to be protected. Changes in population vulnerability, ecosystem resilience, or abundance trends would likely trigger an adjustment of the critical habitat parameters.

2.5 Summary

The definition of critical habitat will vary for a particular species of interest as it relates to that species' ecological needs. Our ability to define a critical habitat for that species is constrained by our perception of the species' natural history and biological requirements, our impacts upon them, our ability to detect and monitor these impacts, and ultimately the level of acceptable risk that management decisions invoke for the fate of the marine mammal population. Managers must account for the components of critical habitat affecting a species (natural history, population concentration, limiting resources, limiting factors, vulnerability and resilience, and population trend), and how these shift over space and time. Such dynamic descriptions of habitat are difficult to summarize, and particularly so when biological understanding for marine mammals which spend so little time within our view is limited or non-existent. Within this context, decision makers must act in a highly precautionary manner and utilize adaptive management so as to minimize the risks to *SARA*-listed marine mammal species.

A step-by-step protocol (Table 2.2) is provided to help decision makers achieve these goals by supplying a guideline by which critical habitat determination studies and timetables can be developed and more concise, specific adaptive management objectives can be outlined: Step 1 – natural history description; Step 2 – population concentrations as habitat ranking markers ("Candidate" Critical Habitats); Step 3 – assessing limiting resources and limiting factors ("Protected" Critical Habitats); and Step 4 – active monitoring.

Chapter 3: Steps 1 & 2 - Natural History Description and Identification of Areas of High Concentration of Large Rorqual Whales in Newfoundland and Labrador Waters

The first step in the Critical Habitat Designation Protocol requires a natural history description of the species of interest. This study considers three large rorqual whale species. Chapter 1 provided a general overview of the species' natural histories. The first part of this chapter (Step 1) will review our existing knowledge of the natural histories of blue, fin, and sei whales in the north Atlantic, more specifically, in waters off Newfoundland and Labrador. The second part of this chapter (Step 2) will use existing sources of data to highlight historic and current areas of high population concentration for the three species.

3.1 Step 1 - Natural History Description of Large Rorqual Whales in Newfoundland and Labrador Water

3.1.1 Blue Whales

The blue whales found in Newfoundland and Labrador waters are believed to be from a north Atlantic population divided into two populations (Gambell 1979). The western population ranges from New England waters to eastern Canada, including the Scotian Shelf, Grand Banks, St. Lawrence Gulf and Estuary, and Labrador Sea. The eastern population is thought to range from western Icelandic waters and north to Jan Mayen and Spitsbergen.

The occurrence of blue whales in Newfoundland and Labrador waters has not been studied comprehensively. Information is available from whaling records from the start of the 20th century, when blue whales represented 15-30% of the whale catches (Sergeant 1966). Based on catches from pelagic factories in the Davis Strait between 1929 and 1934, Sergeant (1955) proposed that Newfoundland blue whales migrated northward through the Davis Strait to waters west of Greenland. Kellogg (1929) reports that blue whales have been observed migrating eastward off the coast of Newfoundland as early as February.

Despite their apparent low abundance, blue whales have been observed frequently in Newfoundland and Labrador, often near the southwest coast of Newfoundland. Reports of blue whales on the southwest coast of Newfoundland were included in the IWC Progress Report for 1975 to 1980 (Mitchell 1975a, 1976, 1977, 1978, 1979, 1980). Most of these observations were of carcasses and ice-entrapped whales. Whaling records from Newfoundland stations also corroborate this distribution pattern. No recent distribution or abundance estimates have been made for the Newfoundland and Labrador region. Individual sightings in Newfoundland and Labrador waters are not uncommon in the sightings database maintained by DFO.

A catalogue of photo-identified blue whales observed in the Gulf of St-Lawrence is maintained by the Mingan Island Cetacean Study group in Mingan, Quebec. Few opportunities to photo-identify blue whales have occurred in Newfoundland and Labrador. None of the six individuals photographed off the coast of Newfoundland have been identified in the Gulf of St. Lawrence (Mingan Island Cetacean Study, Pers. Comm.). Thus, it appears that not only are Newfoundland and Labrador waters a habitat for blue whales, but also that some of these whales may not have been included in previous population estimates. Several fishermen off the southwest coast of Newfoundland have reported spotting large blue whale-like animals along the coast. In addition, two blue whales were sighted during a DFO aerial survey in the fall of 2003 off the south coast of Newfoundland. More recently, two sightings of a blue whale were made in the Orphan Basin, over 300 km northeast of St. John's, in the summer of 2007 (Abgrall *et al.* 2008a).

Newfoundland, during periods of extreme North Atlantic Oscillations from the mid-1970s through the 1980s and into early 1990s, may also represent a location of natural mortality of adults from this population (J. Lien, Pers. Comm.). A unique combination of coastal features, ice formation, and wind patterns can result in the entrapment and possible mortality by crushing or drowning animals in the Port aux Port area.

Lien *et al.* (1989) described two mechanisms of blue whale ice entrapment off the southwest coast of Newfoundland. The first results from pack ice movement coming from the northern Gulf of St. Lawrence. As the pack ice accumulates around the Port au Port Peninsula, it creates an area of open water in St. George's Bay. This shore lead can be closed if strong westerly winds push the ice into the bay, causing the entrapment of any whales found in the shore lead. The second mechanism results from southerly winds pushing ice toward the southwest coast when the ice extent reaches the Cabot Strait and curves around Channel-Port-aux-Basques.

Natural ice entrapments off the southwest coast of Newfoundland resulted in the death of 25 blue whales between 1974 and 1992 (Seton and Lien, Unpubl. MS). For such a small population with no scientific evidence of recovery (absence of calf sightings in most years), such natural mortality numbers are of potential significance.

3.1.2 Fin Whales

Fin whales which inhabit the north Atlantic demonstrate variations in mtDNA between the Mediterranean Sea, the eastern north Atlantic (Spain), and the western north Atlantic (Gulf of Maine and Gulf of St. Lawrence) populations (Bérubé *et al.* 1998). However, eastern and western north Atlantic populations appear to mix regularly in waters around Greenland and Iceland (Bérubé *et al.* 1998). Clark (1995) has, however, observed differences between underwater vocalizations recorded in the West Indies and those recorded in the Norwegian Sea which may indicate some degree of segregation within the population.

Fin whales are common off the coast of Newfoundland and Labrador. No systematic photo-identification research has been conducted on fin whales in this region. On the east coast of Canada, fin whale catalogues exist for individual whales seen in the St. Lawrence estuary in Quebec and for individuals sighted off Nova Scotia. In the winter, fin whales off Newfoundland are believed to move south into Nova Scotia waters, while fin whales from Nova Scotia move into more southern waters (Mitchell 1974). It is still unclear, however, to what extent individuals seen around Newfoundland mix with individuals summering off Nova Scotia or in the Gulf of St. Lawrence.

As with blue whales, fin whales were a prime target of whalers in Newfoundland and Labrador. Over 10,000 fin whales were taken by whalers off Newfoundland and Labrador during the first half of the last century (Sergeant 1966). Fin whale strandings around Newfoundland do occur and up to 12 fin whales were found entrapped by ice in St. George's Bay in March 1959 (Sergeant 1966). These strandings were less common for fin whales, compared to blue whales, around Newfoundland, and usually involved a single individual.

3.1.3 Sei Whales

In Atlantic Canada, two populations of sei whales are distinguished based on whaling records (Mitchell and Chapman 1977): one is found on the southeast coast of Newfoundland and extends northward toward Labrador, and a second is found south of Newfoundland toward the Scotian Shelf. An eastern Atlantic population was also proposed for Iceland and Denmark (Donovan 1991).

Whaling for sei whales off Newfoundland was limited due to this whale's low oil yield compared to larger animals such as blue and fin whales. In a given year, most animals caught were usually taken later in the whaling season (Sergeant 1966). This could be caused either by a reduction in the number of larger animals later in the season, or a result of their later migration to northern waters as they tended to be present on the south coast of Newfoundland from August and September. They have been sighted in areas such as the Grand Banks as early as June (Mitchell and Chapman 1977).

Sei whales are assumed to be uncommon in Newfoundland and Labrador, but this may be a function of observers confusing them with fin whales. Photographs of individual sei whales in Newfoundland are rare. No photo-identification catalogue exists in the northwest Atlantic for sei whales. Individual sei whales observed in Newfoundland and Labrador waters can therefore not be matched to other sightings through photo-identification. Nonetheless, regular and frequent sightings of this species are made along the Newfoundland south coast and in offshore waters frequented by offshore supply vessels (J. Lawson, Pers. Comm.).

3.1.4 Knowledge Gaps

Most of the available data on large rorqual occurrence in Newfoundland and Labrador come from historic shore-based whaling records and opportunistic records resulting from whale entrapments or strandings. Few records exist for free-swimming rorquals in this area and even less result from dedicated cetacean surveys with measurement of search effort. Even with the recent results of the large-scale Trans North Atlantic Sightings Survey (TNASS; Lawson and Gosselin 2008), limited abundance and distribution assessments for blue, fin, and sei whales off Newfoundland and Labrador will be the main knowledge gaps related to defining critical habitats for these species in these waters. The spatial and temporal analysis of historical shore-based whaling records, compared with that available through a sightings database, as reviewed in this chapter fills an urgent data gap and makes a significant contribution to the current body of knowledge regarding the habitat use of large rorquals off Newfoundland and Labrador. This information will also enable the identification and ranking of tentative "candidate" critical habitats (Step 2) in the absence of dedicated visual and acoustic cetacean surveys.

Blue, fin, and sei whales migrate through and feed in Newfoundland and Labrador waters. It is not clear, however, where such activities occur specifically, and hence, what limiting resources and limiting factors are or could be acting on the habitats that they use. Analyses described in Chapter 4 will identify historical feeding areas by comparing the stomach contents of whales killed during shore-based whaling in the different regions in which they were hunted. A more detailed analysis of habitat preference is described in Chapter 4 in an attempt to identify environmental features that may have influenced the historical or may influence the current and future distribution of the target species. These analyses can then serve to identify "candidate" critical habitats at a finer scale than what would be possible in the present chapter and build on the knowledge of habitat use of blue, fin, and sei whales gained in the following section.

3.2 Step 2 - Areas of High Concentration of Large Rorquals in Newfoundland and Labrador

3.2.1 Introduction

The absence of complete distribution and abundance data for large rorquals in Newfoundland and Labrador is a knowledge gap when attempting to identify areas of high population concentration of large rorquals. The financial constraints limiting the fulfilment of this knowledge gap, combined with the urgent requirement for critical habitat designation as a means to mitigate the impacts of expanding anthropogenic activities in the habitat of endangered marine mammals, poses a serious problem. This section examines two different data sources (shore-based whaling records and a sightings database) in order to assess their effectiveness in describing general areas of high concentration for blue, fin, and sei whales.

Modern shore-based whaling reduced large whale populations in Newfoundland and Labrador coastal waters. Beginning in 1898 with the first shore-based station built in Notre Dame Bay at Snook's Arm, the Newfoundland and Labrador shore-based whaling industry grew rapidly peaking in 1905 with 17 operational stations (Sanger and Dickinson 2000). In total, 21 shore-based whaling stations were operational at one time or another between 1898 and 1972 when Canada declared a moratorium on whaling (Figure 3.1). During this period, Dickinson & Sanger (2005) identified four main phases of shore-based whaling (Figure 3.2).

Whaling records have been used previously to describe or compare the distribution and movements of cetacean species in other regions (Gregr *et al.* 2000; Clapham *et al.* 2004; Reeves *et al.* 2004a,b; Shelden *et al.* 2005; Josephson *et al.* 2008). Historical distribution patterns of large whales based on whaling records were used in this study to identify areas of high population concentration and, in the process, provide baseline indicators of "candidate" critical habitat for historically-hunted rorquals in Newfoundland and Labrador.

More recent sources of data may also provide valuable insight in assessing areas of high species concentration and complement the historical whaling analysis. One such source is a sightings database managed at the Department of Fisheries and Oceans in St. John's, Newfoundland and Labrador. The database contains over 18,000 cetacean sightings (>121,000 individuals) in waters surrounding Newfoundland and Labrador, with most reported sightings occurring from 1974 to 2006. The temporal limits of this database represent a good complement to historical shore-based whaling records off Newfoundland and Labrador for the identification of areas of high population concentration for blue, fin, and sei whales.

The sightings database is not intended to represent the complete biological distribution of large rorquals off the coast of Newfoundland and Labrador. Most of these sightings are not the result of systematic surveys and in most cases there are no measures of search-effort associated with them. Therefore, areas indicated as having no blue, fin, or sei whale sightings may be a product of little or no observation effort rather than a true absence of these whales.

The main objective of this section is to enable the assessment of areas of high population concentration for blue, fin, and sei whales in the absence of a high-effort systematic survey, using alternative historical and opportunistic data sources. Secondary objectives include the monitoring of temporal (for historical shore-based whaling data only) and seasonal variations in areas of high population concentration of blue, fin, and sei whales over the shore-based whaling and sightings database periods.

The methods used to describe areas of high population concentration in this section represent a crucial starting point in the process of increasing our understanding of large rorqual habitat use off Newfoundland and Labrador. It would, however, require revision once distribution and abundance survey data are available. The absence of dedicated distribution and abundance surveys for the species in question and its implications in regards to the critical habitat definition process would fall under a requirement of Step 4 – Active Monitoring.

3.2.2 Materials and Methods

Shore-based Whaling

Whaling records for blue, fin, and sei whales dating back to 1898 were examined. Whaling records from 1898 to 1915 originated from Newfoundland Annual Fisheries Reports (Table 3.1). Records are complete until 1915 (except for missing documents in

1913). No whaling records were available for 1918 and between 1923 and 1926, when whaling did take place. The total number of whales taken in 1918 and the total number of whales of each species taken from 1923-1926 are published in Dickinson and Sanger (2005). Records from 1927 to 1972 originated from the IWC database (Table 3.1). Only records from 1937 were not available in the IWC database. The number of whales of each species caught for Rose-au-Rue and Hawke Harbour combined in that year are provided in Dickinson and Sanger (2005).

To facilitate mapping, the water around Newfoundland and Labrador was subdivided using Northwest Atlantic Fisheries Organization (NAFO) divisions. These divisions were used with the intent of extrapolating the whaling coverage from the whaling stations to the surrounding waters and thus, serving as large-scale distribution indicators. Five main regions were then described from these NAFO divisions (Figure 3.3): coastal Labrador (2J and 2H), northeast Newfoundland (3K), east Newfoundland (3L), the south coast of Newfoundland (3Pn and 3Ps), and the Strait of Belle Isle/Gulf of St. Lawrence (4R and 4S).

Positions for all whales were assigned to the corresponding NAFO division. The total number of each species of whale caught in each region was compiled and mapped to compare whale occurrence among the five regions (Figure 3.3). Any catch lacking an individual kill position was given a position at the location of the whaling station from which it was processed. Hunted whales lacking confirmed species identification at a station, in years when only the total number of whales caught at that station was reported, were assigned a species label based on the proportion of each species caught at that specific whaling station from two neighbouring whaling years. Whales lacking kill locations (when the total number of catches was given for two or more stations combined) were also assigned an estimated station of origin. The proportion of whales taken at each station was estimated using the catch data from two corresponding neighbouring whaling years for the stations that have combined data. If whales assigned to a station also lacked species identification, the proportion of whales of each species taken was then estimated using the proportions of each species taken in the two neighbouring whaling years at that specific station.

To account for the varying number of whaling stations and whaling years within each of the main regions, an effort-adjusted number of whales caught was calculated and used in this analysis. For this purpose, whale numbers were divided by the number of catcher boats working out of the station from which it was caught in the year during which it was caught. In the event that a station caught whales in more than one region during a whaling year, each additional region from which whales were caught was considered as a having a mirror whaling station. Therefore, the actual whaling station operated within its own region, and mirror stations, with corresponding whaling years, were created in the other regions from which whales were caught and were considered operational stations for the purpose of this effort-adjusted data analysis.

The number of catcher boats used to calculate the number of effort-adjusted whales caught in each region, for the station and its mirror station, were estimated from the total number of catcher boats that operated out of the actual station during the year and the proportion of whales caught in each division. To account for the different number of years during which whaling occurred within each region, the effort-adjusted number of whales (number of whales per catcher boat) was further divided by the number of active whaling years that took place within the region from which the catcher operated (Table 3.2).

Temporal Variation

Temporal variations in effort-adjusted whaling pattern and distribution were assessed. The effort-adjusted number of whales of each individual species in each of the five main regions was assessed for each of the four main whaling phases (1898-1918, 1923-1937, 1939-1951 and 1952-1972). To account for the different number of years during which whaling took place within each region during each whaling phase, the effort-adjusted number of whales (number of whales per catcher boat) was further divided by the number of active whaling years that took place within the region from which the catcher operated during the whaling phase in question.

Seasonal Variation

Seasonal effort-adjusted whale catches for each individual species were also calculated. The effort-adjusted number of whales of each individual species in each main region was calculated for winter (January-March), spring (April-June), summer (July-September), and autumn (October-December). As the whaling records originating from the Newfoundland Annual Fisheries Reports did not include dates for each whale killed, only the IWC records were used for this seasonal mapping (1927 – 1972). To account for the different number of years during which whaling took place within each main region from 1927 to 1972, the effort-adjusted number of whales was further divided by the number of active whaling years during which whales with catch dates were recorded in the region from which the whale was caught during this period (including mirror stations, as described earlier, to account for catcher boats hunting in more than one region in a single year). No additional temporal divisions were used to assess the data. Seasonal variations were assessed when all regions were combined and within each main region.

Statistical Analyses

To assess differences in the number of effort-adjusted whales hunted among regions, across whaling phases (temporal variation), or seasons (seasonal variation) for each individual species, Kruskal-Wallis analyses of variance by ranks were performed on the number of whales/catcher boat taken during each whaling year for the data groups being examined using SPSS 10.1 (SPSS Inc., 1989-2000). When significant differences were observed (α=0.05), nonparametric Tukey-type multiple comparisons with unequal sample sizes (Zar 1999) were performed to determine which of the differences between samples were significant. These statistical analyses enabled a ranking of regions or seasons for the assessment of areas of high population concentration.

In addition, chi-square (χ^2) goodness-of-fit tests were performed to assess the significance of observed differences in the number of whales landed with respect to region or season. Simultaneous Bonferonni-corrected 95% confidence intervals (CIs) were calculated for the observed proportions of whales landed in each region or during each season. An expected proportion (based on the proportion of catcher-boat years within each region or season in respect to the total number of whales landed in all regions or seasons) falling outside the confidence interval for the observed proportion for that region or season was considered significantly different (Manly *et al.* 1993).

The regions, and seasons, that ranked highest following the Kruskal-Wallis analysis of variance by ranks (combined with nonparametric Tukey-type multiple comparisons with unequal sample sizes) or recorded expected proportions of landed whales which fell outside of the confidence interval (CI) for the observed proportion (where CI for observed proportion > expected proportion) were considered areas, and seasons, of high population concentration and "candidate" critical habitat.

Sightings Database

This cetacean sightings database was derived through merging and error-checking of multiple marine mammal sightings databases. These databases originated from a variety of sources within the Department of Fisheries and Oceans, Memorial University's Whale Research Group, the aerial surveillance unit of Provincial Airlines (under contract to DFO), and many reports contributed by the general public and industry. Reported sightings used in this analysis range from 1958-2006 with most coming from 1974-1992 and 1999-2006.

Each reported sighting is assigned a code indicating the probable reliability of the reported species identification. This assignment of a reliability code takes into account both the familiarity of the observer with large whale identification (for instance, the observer's ability and experience in distinguishing between a fin whale and a blue whale) and the quality of the observation conditions (the distance from the whale, the weather conditions, and the amount of time to observe the animal are examples of conditions that could affect the observer's ability to make a positive identification). Based on the information available, the database manager assesses each observation as being either reliable or not. Sightings recorded as fin/blue whale and fin/sei whales were classified as unreliable for the purpose of this study; sightings used in the present analysis represent only the most reliable subset of recorded observations of blue, fin, and sei whales.

The database records include a variety of other information associated with each reported sighting including the date of the sighting and the number of animals sighted. The type of sighting is also recorded: (1) open-water/free swimming; (2) stranded or entrapped. Dead animals observed in open-water were classified as stranded or entrapped for the purpose of this analysis as their sighting location is the result of days or weeks of drifting, and would not be representative of the species habitat preference.

To facilitate the mapping and enable comparison of the results with those obtained from the mapping of historical shore-based whaling records, the water around Newfoundland and Labrador was divided using NAFO divisions. The same five regions used in the shore-based whaling data analysis were described from these NAFO divisions.

However, sightings from the cetacean sightings database ranged beyond that of Newfoundland and Labrador shore-based whaling records. In order to incorporate these sightings in the present analysis of areas of high concentration, additional neighbouring NAFO divisions were thus included, when appropriate, in each of the five regions (Figure 3.4): coastal Labrador (2G, 2J, and 2H), northeast Newfoundland (3K), east Newfoundland (3L, 3N, and 3O), the south coast of Newfoundland (3Pn, 3Ps, 4Vn, and 4Vs), and the Strait of Belle Isle/Gulf of St. Lawrence (4R, 4S, and 4T).

Blue, fin, and sei whales were mapped, individually, and the number of sightings in each of the five main regions was summed. Each region was attributed a ranking order to serve as indicator of area of high concentration, with the region having the most number of sightings ranking highest. Number of sightings, rather than total number of animals from these sightings, were used to rank area of high concentration because the number of animals attributed to each sighting in the database was a less accurate value and often estimated in the case of sightings of large groups of rorquals. In addition, a number of sightings of large groups of rorquals (up to 20 animals per sightings) are reported at the same location on a number of occasions within the span of a 10-20 day period. It is possible that the same group of rorquals was observed repeatedly and the impact of including these sightings in the assessment of area of high concentration was minimized when considering the number of sightings as opposed to the total number of individuals.

Blue, fin, and sei whale sightings used were distinguished as to whether they represent open-water/free swimming individuals, or entrapped/stranded animals.

Similarly, only open-water/free swimming sightings were used to assess areas of high population concentration. Sightings of strandings or entrapments are presented in this section, but were excluded from the analysis of areas of high population concentration.

Seasonal Variation

Seasonal distributions for each species were assessed for sightings with available sighting dates. In all, 221 sightings were excluded for a lack of corresponding sighting dates in the database. The number of sightings of each species in each main region were calculated for winter (January-March), spring (April-June), summer (July-September), and autumn (October-December).

Statistical Analyses

No statistical analyses were performed to assess differences in the number of sightings observed among regions. The absence of an indicator of search effort variables would reduce the utility of hypothesis testing.

3.2.3 Results

Shore-based Whaling

Fin whale comprised the majority of rorqual catches used in the effort-adjusted shore-based whaling analysis (13,801 fin whales), followed by blue whales (1,920), and sei whales (291; Table 3.3). Effort-adjusted whale catches and estimates of whale catches from stations and years with incomplete whaling reports resulted in the inclusion of 775 blue whales, 3,230 fin whales, and 63 sei whales (an increase of 67.7, 30.6, and 27.6%, respectively) that would have otherwise not been available for the current analysis.

Table 3.4 summarizes the habitat ranking of each region for all whaling phases combined and each individual whaling phase (Temporal Variation) for blue, fin, and sei whales. Regions are ranked based on the mean ranks obtained from Kruskal-Wallis analysis of variance by ranks. Tied rankings represent regions that did not significantly vary following Kruskal-Wallis analysis of variance by ranks or nonparametric Tukey-type multiple comparisons. Regions that recorded CIs of the observed proportions of whales landed that were greater than expected are also indicated. Details of the statistical analyses performed to generate Table 3.4 are provided in Appendix B (see Tables B-1 to B-28).

Blue whales

Considering the period from 1898 to 1972, there was a significant difference in the effort-adjusted number of blue whales taken in each region (H=91.74, df=4, p<0.001). Most blue whales were taken off the south coast of Newfoundland, followed by the Strait of Belle Isle/Gulf of St. Lawrence, east Newfoundland, coastal Labrador, and northeast Newfoundland, respectively (Figure 3.5). Nonparametric Tukey-type multiple comparisons indicated significant differences exist in the effort-adjusted number of blue whales taken between each pair of stations except between the third and fourth ranked regions (east Newfoundland and coastal Labrador; Table 3.4). Only the south coast of

Newfoundland recorded a CI of the observed proportion of blue whales landed that was greater than expected (Table 3.4).

Fin whales

There was a significant difference in the effort-adjusted number of fin whales taken in each region (H=63.65, df=4, p<0.001). Most fin whales were taken off northeast Newfoundland and coastal Labrador, followed by the Strait of Belle Isle/Gulf of St. Lawrence, south coast of Newfoundland, and east Newfoundland, respectively (Figure 3.6). Nonparametric Tukey-type multiple comparisons indicated significant differences in the effort-adjusted number of fin whales taken between each pair of stations except between the two highest ranking regions (northeast Newfoundland and coastal Labrador), the third and fourth ranked regions (the Strait of Belle Isle/Gulf of St. Lawrence and south coast of Newfoundland), and fourth and fifth ranked regions (the south coast of Newfoundland and east Newfoundland; Table 3.4). Only northeast Newfoundland and coastal Labrador recorded CIs of the observed proportions of fin whales landed that were greater than expected (Table 3.4).

Sei whales

There was a significant difference in the effort-adjusted number of sei whales taken in each region (H=22.59, df=4, p<0.001). Most sei whales were taken off the south coast of Newfoundland and coastal Labrador, followed by the Strait of Belle Isle/Gulf of St.

Lawrence, northeast Newfoundland, and east Newfoundland, respectively (Figure 3.7). Nonparametric Tukey-type multiple comparisons indicated significant differences in the effort-adjusted number of sei whales taken between each pair of stations except between the two highest ranking regions (south coast of Newfoundland and coastal Labrador), the third and fourth ranked regions (northeast Newfoundland and east Newfoundland), and fourth and fifth ranked regions (east Newfoundland and the Strait of Belle Isle/Gulf of St. Lawrence; Table 3.4). Only the south coast of Newfoundland and coastal Labrador recorded CIs of the observed proportions of sei whales landed that were greater than expected (Table 3.4).

Temporal Variation

Blue whales

The south coast of Newfoundland ranked first or tied for first in the first two whaling phases and recorded CIs of the observed proportions of blue whales landed that were greater than expected in both phases (Table 3.4). The Strait of Belle Isle/Gulf of St. Lawrence ranked first in the third whaling phase and recorded a CI of the observed proportion of blue whales landed that was greater than expected (Table 3.4). The only other region to record a CI of the observed proportion of blue whales landed that was greater than expected was coastal Labrador in the third whaling phase (ranked tied for second; Table 3.4). No blue whales were caught during the fourth whaling phase.

Fin whales

During the first whaling phase, coastal Labrador ranked first, and northeast Newfoundland ranked second (Table 3.4). Both these regions recorded CIs of the observed proportions of fin whales landed that were greater than expected in the first whaling phase (Table 3.4). In the third whaling phase, northeast Newfoundland, coastal Labrador, and the south coast of Newfoundland ranked tied for first, although, only northeast Newfoundland and coastal Labrador recorded CIs of the observed proportions of fin whales landed that were greater than expected (Table 3.4). In the fourth whaling phase, northeast Newfoundland, the Strait of Belle Isle/Gulf of St. Lawrence, and coastal Labrador ranked tied for first, although, only northeast Newfoundland recorded a CI of the observed proportion of fin whales landed that was greater than expected (Table 3.4). There were no significant differences in the effort-adjusted number of fin whales caught in each region during the second whaling phase (Table 3.4).

Sei whales

During the first whaling phase, the south coast of Newfoundland ranked first, and all other regions tied for second (Table 3.4). The south coast of Newfoundland was the only region to exhibit a CI of the observed proportion of sei whales landed that was greater than expected in the first whaling phase (Table 3.4). There were no significant differences in the effort-adjusted number of sei whales caught in each region during the final three whaling phases (Table 3.4).

Seasonal Variation

Table 3.5 summarizes the habitat ranking of each season for all regions combined and for each individual region for blue, fin, and sei whales. Seasons are ranked based on the mean ranks obtained from Kruskal-Wallis analysis of variance by ranks. Tied rankings represent seasons that did not significantly vary between each other following Kruskal-Wallis analysis of variance by ranks or nonparametric Tukey-type multiple comparisons. Seasons that recorded CIs of the observed proportions of whales landed that were greater than expected are also indicated. Details of the statistical analyses performed to generate Table 3.5 are provided in Appendix B (see Tables B-29 to B-56).

Blue whales

Considering all regions combined, there was a significant difference in the effort-adjusted number of blue whales taken in each season (H=25.18, df=2, p<0.001). Most blue whales were taken during spring and summer, followed by autumn (Table 3.5). Nonparametric Tukey-type multiple comparisons indicated significant differences in the effort-adjusted number of blue whales taken between spring and autumn, and between summer and autumn, but not between spring and summer (Table 3.5). Only summer had a CI of the observed proportion of blue whales landed that was greater than expected (Table 3.5).

There were no significant differences in the effort-adjusted number of blue whales caught in each season in any of the main regions that had sufficient data to be compared following Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons (Table 3.5). However, spring had a CI of the observed proportion of blue whales landed that was greater than expected off the south coast of Newfoundland, and summer had a CI of the observed proportion of blue whales landed that was greater than expected off northeast Newfoundland (Table 3.5).

Fin whales

Considering all regions combined, there was a significant difference in the effort-adjusted number of fin whales taken in each season (H=20.04, df=2, p<0.001). Most fin whales were taken during summer, followed by autumn and spring (Table 3.5). Nonparametric Tukey-type multiple comparisons indicated significant differences in the effort-adjusted number of fin whales taken between summer and autumn, and between summer and spring, but not between autumn and spring (Table 3.5). Only summer had a CI of the observed proportion of fin whales landed that was greater than expected (Table 3.5).

When considering each region individually, summer ranked first off coastal Labrador and northeast Newfoundland where CIs of the observed proportions of fin whales landed were greater than expected (Table 3.5). Spring ranked first off the south coast of Newfoundland where the CI of the observed proportions of fin whales landed was greater than expected (Table 3.5). While there were no significant statistical differences in the effort-adjusted number of fin whales caught among seasons off eastern Newfoundland, following Kruskal-Wallis analysis of variance by ranks, summer had a CI of the observed proportions of fin whales landed that were greater than expected (Table 3.5). There were insufficient data to assess statistical seasonal differences in the Strait of Belle Isle/Gulf of St. Lawrence (Table 3.5).

Sei whales

Considering all regions combined, there was a significant difference in the effort-adjusted number of sei whales taken in each season (H=16.90, df=2, p<0.001). Most sei whales were taken during summer and autumn, followed by spring (Table 3.5). Nonparametric Tukey-type multiple comparisons found significant differences in the effort-adjusted number of sei whales taken between summer and spring, and between autumn and spring, but not between summer and autumn (Table 3.5). Only summer had a CI of the observed proportion of sei whales landed that was greater than expected (Table 3.5).

There were no significant differences in the effort-adjusted number of sei whales caught in each season in any of the main regions that had sufficient data to be compared following Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons (Table 3.5). However, summer and autumn exhibited CIs of the observed proportions of sei whales landed that were greater than expected off coastal Labrador and summer had a CI of the observed proportions of sei whales landed that were greater than expected off the south coast of Newfoundland and northeast Newfoundland (Table 3.5).

Sightings Database

The DFO cetacean sightings database contains 1,591 sightings of blue, fin, and sei whales with known position information within the five main regions considered in this study. Of these, 1,392 were considered to be reliably identified to the species level: 111 were blue whales, 1,177 were fin whales, and 104 were sei whales. The remaining 199 sightings could not be identified, with confidence, to the species level and were classified, in this analysis, as unreliable sightings of large rorquals. Only sightings of free-swimming rorquals with confirmed species identification were used to analyse areas of high population concentration. Thus, 20 sightings of stranded blue whales and two sightings of stranded fin whales were also excluded from the analysis.

Blue whales

Blue whales were recorded most frequently off the south coast of Newfoundland, where more than two thirds of the recorded sightings occurred (66 sightings; Figure 3.8). Six times fewer blue whale sightings were recorded in both east Newfoundland and the Strait of Belle Isle/Gulf of St. Lawrence regions (11 sightings in each region; Figure 3.8). Only two and one sightings were recorded in the northeast Newfoundland and coastal Labrador regions, respectively (Figure 3.8). Blue whale strandings were recorded exclusively in the Strait of Belle Isle/Gulf of St. Lawrence (13) and south coast of Newfoundland (7) regions.

Fin whales

Fin whales were observed primarily in the east Newfoundland region, where half of the total fin whale sightings were reported (592 sightings; Figure 3.9). The second highest number of fin whale sightings reported were in the northeast Newfoundland region, accounting for more than a quarter of the open-water fin whale sightings (261 sightings; Figure 3.9). Nearly equal numbers of open-water fin whale sightings were recorded off the south coast of Newfoundland and coastal Labrador (137 and 136 sightings, respectively; Figure 3.9). The fewest number of open-water fin whale sightings were recorded in the Strait of Belle Isle/Gulf of St. Lawrence region (49 sightings; Figure 3.9). Two sightings of stranded fin whales (each of a single dead individual observed drifting at sea) were recorded, one in each of the east Newfoundland and Strait of Belle Isle/Gulf of St. Lawrence regions.

Sei whales

Sei whales were observed primarily off coastal Labrador and east Newfoundland, where 78% of all sei whale sightings were recorded (44 and 37 sightings, respectively; Figure 3.10). A few sei whale sightings were also recorded in the northeast Newfoundland and south coast of Newfoundland regions (16 and 7 sightings, respectively; Figure 3.10). No reliable sightings of sei whales were recorded in the Strait of Belle Isle/Gulf of St. Lawrence region (Figure 3.10).

Seasonal Variation

Blue whales

Blue whales were sighted most frequently during summer (Table 3.6). The number of blue whale sightings recorded during winter and spring were similar (14 and 10 sightings, respectively; Table 3.6). All but one of the winter sightings of blue whales were reported off the south coast of Newfoundland (Table 3.6). Only a single sighting was recorded during autumn, in the Strait of Belle Isle/Gulf of St. Lawrence region (Tables 3.5).

Fin whales

Most open-water fin whale sightings were reported during summer (Tables 3.5). Three times fewer sightings of fin whales were recorded during spring and more than four times fewer sightings were recorded during autumn (Table 3.6). Only 9 of 1,175 fin whale were recorded during winter (Table 3.6). While the number of sightings reported during summer ranked first in all five main regions, spring sightings outnumbered autumn sightings in the three most southerly regions (east Newfoundland, south coast of Newfoundland, and Strait of Belle Isle/Gulf of St. Lawrence; Table 3.6). Conversely, autumn sightings outnumbered spring sightings in the two most northerly regions (coastal

Labrador and northeast Newfoundland; Table 3.6). Winter sightings were only observed off east Newfoundland and the south coast of Newfoundland (Table 3.6).

Sei whales

Sei whales had similar seasonal sighting patterns to fin whales with the exception that no sei whale sightings were reported during winter in any of the five main regions (Table 3.6).

3.2.4 Discussion

The main objective of this chapter was to identify areas of high population concentration ("candidate" critical habitats) for large whales. In the absence of systematic survey data, and when considering the urgent (and legal) need for critical habitat definition, alternative data sources were considered. Two methods were used to provide "candidate" critical habitats; using effort-adjusted historical shore-based whaling data and DFO's cetacean sightings database.

Based on the inherent limitations of the data available, areas indicated as having few or no blue, fin, or sei whale records may be a product of little or no whaling/observation effort rather than an absence of these whales. Many factors can result in the absence of sightings in a certain regions or seasons. The absence of whaling and sightings off coastal Labrador or northeast Labrador during winter is correlated with the presence of pack ice which would preclude the presence of rorquals. Similarly, pack ice also limits access to these regions for whaling vessels and opportunistic platforms of observation. Hence, the distribution from shore-based whaling records and the sightings database is a reflection of potential habitat preference of large rorquals and of areas most surveyed or observed. The areas of high population concentration described through this analysis should be re-assessed and updated when results from dedicated survey effort become available.

Shore-based whaling catches peaked in 1904. In these early whaling years, the whaling stations were distributed on every coastline of Newfoundland and up the coast of Labrador. An observed temporal shift in the distribution of shore-based whaling stations across Newfoundland and Labrador was reflected in the overall shift of whale catches following the first whaling phase and suggested a potential narrowing of large whale distribution through the 75-year shore-based whaling period.

While the potential role of shifting oceanographic properties and socio-economic factors through the surveyed period cannot be assessed, the observed temporal shift in whaling off Newfoundland and Labrador is likely the result of local resource (whale) depletion in areas of high population concentration, most notably in the case of the blue whale for which the effort-adjusted data of catches off the south coast of Newfoundland steadily decreased from the first whaling phase through the second and third whaling phases. This was not as evident in the case of fin and sei whales for which the effort-adjusted catches more than doubled off the south coast of Newfoundland from the first to the second whaling phase. However, the overall shift of whaling station locations and whaling patterns support the premise of a local depletion of numbers off the south coast of Newfoundland, even within the first whaling phase when the rapid expansion of the industry within the first seven years led to an over-exploitation of whale populations.

The shift in resource exploitation from a south coast of Newfoundland-dominated industry to one dominated by coastal Labrador and northeast Newfoundland in the final three whaling phases could suggest the existence of distinct sub-populations. The collapse of a "south coast" blue whale sub-population which represented 49% of the whales taken in this region during the first whaling phase, and 13% and 3% during the second and third whaling phases, respectively, combined with the gradual increase in blue whale hunting off coastal Labrador to surpass catches off the south coast of Newfoundland by the third whaling phase puts into question the amount of population exchange between these two regions. If limited population exchange is indeed occurring between these two regions, it will need to be accounted for by managers when preparing recovery plans.

Gambell (1979) described two populations of blue whales in the north Atlantic. The first ranges from New England waters to eastern Canada, including the Scotian Shelf, Grand Banks, St. Lawrence Gulf and Estuary, and Labrador Sea. The other has most of its sightings from western Icelandic waters, ranging north to Jan Mayen and Spitsbergen. It is possible that the first population is composed of two sub-populations with limited exchange. One ranges from New England waters to eastern Canada, including the Scotian Shelf, the south coast of Newfoundland, and possibly the Grand Banks, while the second ranges from the Gulf of St. Lawrence up to the Labrador Sea, and possibly towards Greenland. This is further supported by limited photo-identification work coming from the south coast of Newfoundland and the Scotian Shelf. Of six blue whale photos taken off Newfoundland and one off Nova Scotia, none could be matched to the primary blue whale photo-identification catalogue of the Gulf of St. Lawrence (Mingan Island Cetacean Study, Pers. Comm.).

The population structure of fin whales in the north Atlantic is not well resolved (Waring *et al.* 2007). While there are no photo-identification results for fin whales off the coast of Newfoundland at this point, it is believed that two, or perhaps three different populations are present in waters of the northwest Atlantic (Mitchell 1974; Donovan 1991). Further, two populations of sei whales can be distinguished based on whaling records (Mitchell and Chapman 1977): one on the southeast coast of Newfoundland extending northward towards Labrador, and a second south of Newfoundland towards the Scotian Shelf.

Shore-based Whaling versus Sightings Database

Notable differences in defined "candidate" critical habitats can be observed when comparing areas of high population concentration derived from the historical shore-based whaling records and DFO cetacean sightings database. Blue whales showed the most similar pattern, with the south coast of Newfoundland ranking first in both cases. Only seasonal preferences between both sources of data differed off the south coast of

Newfoundland with the DFO sightings database recording more sightings during summer, while the historical shore-based whaling records indicated significantly more effort-adjusted catches during spring. The Strait of Belle Isle/Gulf of St. Lawrence region ranked second in the analysis of the sightings database, not because of its open-water sightings, but because of the large number of strandings occurring in the region, along with the western edge of the south coast of Newfoundland.

No seasonal preference differences were observed in the case of fin whales, as whaling catches and sightings from the DFO database were both most frequent during summer off the highest ranking areas of high population concentration. Northeast Newfoundland was suggested as a secondary candidate critical habitat for fin whales following the analysis of both data sets, but the primary "candidate" critical habitat differed with the most northern region, coastal Labrador, ranking first from the analysis of historical shore-based whaling records and east Newfoundland, the region nearest the largest urban centre, ranked first from the analysis of the sightings database. East Newfoundland, however, consistently ranked tied for last in the analysis of areas of high population concentrations from effort-adjusted shore-based whaling data (when considering all whaling phases combined and for each individual whaling phase). The high ranking of the eastern Newfoundland region in the sightings database analysis is thus likely an artefact of its proximity to Newfoundland and Labrador major urban centre and should not be considered a "candidate" critical habitat for fin whales.

Coastal Labrador, during summer and autumn, was proposed as a primary "candidate" critical habitat for sei whales following the analysis of both the historical shore-based whaling records and the DFO cetacean sighting database. However, the south coast of Newfoundland which ranked tied for first in the analysis of areas of high population concentration for sei whales using the historical shore-based whaling records, and which was identified as a primary "candidate" critical habitat, was not identified as such through the analysis of the DFO cetacean sighting database. In fact, only seven sei whale sightings in total were recorded off the south coast of Newfoundland in this database. Sei whales are more difficult to reliably identify than blue or fin whales and could easily be misidentified as small fin whales by an inexperienced observer. Sei whales had the greatest proportion of unreliable identifications (28% of all sei whales vs. 16% and 8% for blue and fin whales, respectively). The difficulty in identifying sei whales could partly be responsible for their absence in certain regions, including the south coast of Newfoundland. This artefact would be prominent in the sightings database than in the whaling database, making the latter a more reliable source of "candidate" critical habitat for the sei whale.

Overall, differences between the two data sets and the proposed candidate critical habitats are likely a function of the manner and the scale at which the different types of data were collected. Historical whaling records are recorded for every station and region from which whaling took place. On the other hand, the cetacean sightings database does not include effort-weighted sightings in all areas off Newfoundland and Labrador.

Therefore, on a large scale, the historical whaling records likely represent better indicators of habitat preference and areas of high population concentration. On a smaller, regional scale, the sightings database may be able to provide more detailed and current insights into areas of high population concentration and local habitat preference.

Technological advances such as GPS and the potential for the rapid and easy electronic reporting of sightings will likely support the expansion and long-term success of the sighting database as an "active monitoring" tool for species at risk and the maintenance of an updated evaluation of habitat use and areas of high population concentration for large rorquals in eastern Canadian waters. The reporting of exact locations of sightings in the DFO cetacean sighting database, which is not always available from historical shore-based whaling records, will also provide invaluable data when attempting to identify environmental features, and potentially limiting resources, responsible for the habitat selection of these large rorquals in waters off Newfoundland and Labrador in Chapter 4.

Conclusion

The current study plays an important role in increasing our limited understanding of large rorqual habitat use off the coast of Newfoundland and Labrador. The use of whaling records to map the distribution of various cetacean species has proved useful for this purpose in other studies (Gregr *et al.* 2000; Clapham *et al.* 2004; Reeves *et al.* 2004a,b; Shelden *et al.* 2005; Josephson *et al.* 2008). Similar studies using fishing boat locations have worked in describing the distribution and movements of the north Atlantic cod (*Gadus morhua*) (Kulka *et al.* 1995; Wroblewski *et al.* 1995). While this study cannot be used to describe areas in which whales are not found, it can serve as an indicator of whale presence (for instance, the limited whaling from shore-based Newfoundland and Labrador stations located within the Strait of Belle Isle/Gulf of St. Lawrence region is not a valid indicator of the absence of whales in that region) and this is what is urgently needed to begin the advancement of our understanding of large rorqual habitat use and facilitate the process of critical habitat designation for these large whales, particularly the endangered blue whale. The effort-adjusted data analysis provided an objective tool for identifying and ranking areas of high population concentrations based on statistical comparisons of regional catches and dedicated whaling effort.

While the use of NAFO divisions limits the resolution at which areas of high population concentrations are being assessed, it does, however, link areas of high concentration to already existing management units used in fisheries. The grouping of two NAFO subdivisions into a main region, such as 3Ps and 3Pn into a "south coast" region, also provides additional flexibility for the whaling analysis in accounting for whales taken in waters of one NAFO division, but processed at a station's plant in the neighbouring division. The limitations in quality of the data available to address areas of high population concentration would likely not benefit from a greater resolution of the analysis area at the current scale.

The data available, nonetheless, enable the description of historical and current important areas for these large whale species. These areas will make useful candidates for further critical habitat designation studies, on a smaller scale, as they may represent the "pristine" areas that could be frequented by the remaining rorquals. Studies employing the most recent sightings and dedicated large cetacean surveys will focus and expand on the main regions highlighted in this study. Along with a better understanding of prey availability and anthropogenic impacts within these areas, the defined "candidate" critical habitats can potentially obtain the listing of "protected" critical habitats.

3.3 Summary

This chapter aimed to fulfil Steps 1 and 2 of the critical habitat definition protocol described in Chapter 2. Step 1 requires a description of the species natural history. A general overview of the natural histories of blue, fin, and sei whales, with a focus on the current knowledge of their natural histories in the North Atlantic, and more specifically, in waters off Newfoundland and Labrador, was provided in Chapter 1. Primary knowledge gaps were identified and included knowledge of habitat use to assess areas of high population concentration and, in the process, identify "candidate" critical habitats (Step 2), and the limiting resources (Step 3) within these candidate critical habitats in order to determine if they should be designated "protected" critical habitats.

Historical shore-based whaling records and the DFO cetacean sighting database were identified as the best available tools to assess the habitat use of blue, fin, and sei whales and identify areas of high population concentration off Newfoundland and Labrador, in the absence of systematic distribution and abundance surveys. The analysis of effort-adjusted shore-based whaling records through a combination of statistical analyses proved to be the most effective and objective of these tools. Table 3.7 describes the "candidate" critical habitats identified from the analyses of areas of high population concentrations using the historical shore-based whaling records and the DFO cetacean sightings database.

Chapter 4: Step 3 - Limiting Resources and Limiting Factors for Large Rorquals in Marine Waters of Newfoundland and Labrador

Chapter 3 fulfilled Steps 1 and 2 of the critical habitat definition protocol described in Chapter 2. Step 1 described what is known about the natural history of blue, fin, and sei whales, with emphasis on waters off Newfoundland and Labrador, and identified knowledge gaps. Step 2 used the best-available data to describe areas of high population concentration of blue, fin, and sei whales off Newfoundland and Labrador. Historical shore-based whaling records and the DFO cetacean sighting database were used to assess habitat use and identify "candidate" critical habitats for these species. This chapter will build on the "candidate" critical habitats identified and identify limiting resources and limiting factors for blue, fin, and sei whales in marine waters of Newfoundland and Labrador (Step 3).

4.1 Limiting Resources for Blue, Fin, and Sei Whales in Marine Waters of Newfoundland and Labrador

The limiting resource for blue, fin, and sei whales in marine waters of Newfoundland and Labrador is primarily prey availability. Rorqual species migrate to colder, more productive waters to feed (Sergeant 1963, 1977; Mitchell 1973, 1974; Whitehead and Carscadden 1985; Yochem and Leatherwood 1985; COSEWIC 2002, 2003, 2005b). However, little is known about their actual habitat use in this area, and within the different main regions described in Chapter 3. The first part of this section will spatially describe potentially limiting prey resources affecting the habitat use of blue, fin, and sei whales in these waters using stomach contents from historical shore-based whaling records. The identification of areas where whales fed in previous years may indicate areas of high population concentration that serve as potential current feeding habitat.

Resources such as prey can be concentrated in restricted portions of the species' total range due to oceanographic factors. In these cases, areas containing concentrated resources could be considered critical habitat if such resources are less accessible in an energetically feasible way in other parts of the species' range or if searching for these other resources interferes with life history processes. If feeding patches can be identified and are areas of concentrated feeding effort for a population, these patches should be designated critical habitat for this population and protected from potential anthropogenic disturbances. Spatial and temporal changes in these feeding patches would have to be monitored as they could lead to corresponding shifts in the associated critical habitat. Krill aggregation in the St. Lawrence Estuary and Gulf of St. Lawrence, an area of aggregation of several whale species, is an example of such feeding patches that vary in concentration with tidal periods and are influenced by regional circulation patterns (Simard and Lavoie 1999; Cotté and Simard 2005; Sourisseau *et al.* 2006).

The apparent periodic nature of inshore whale abundance off the coasts of Newfoundland and Labrador has been linked to seasonal capelin aggregation (Whitehead and Carscadden 1985), and could represent another example of prey-linked shift of critical habitat. However, the limited knowledge of marine mammal distributions and oceanographic features influencing feeding patterns of large rorquals in these waters necessitates a more general description of habitat preference.

The second part of this chapter describes the habitat preference of blue, fin, and sei whales off Newfoundland and Labrador by focusing on identifying the oceanographic features that potentially influence their habitat use. Then, using these features, along with data from historical shore-based whaling records and the DFO cetacean sightings database, the habitat preference of these whale species in waters off Newfoundland and Labrador was modelled. Specifically, the whales' apparent habitat preference within areas of higher density and "candidate" critical habitats identified in Step 2 of the protocol was modelled. A more detailed analysis of prey distribution shift within the modelled habitat preferences would provide some additional insight and be required as a component of active monitoring of critical habitats, as will be discussed in Step 4 of the protocol (see Chapter 5).

4.1.1 Using Stomach Contents of Hunted Whales to Assess the Habitat Use of Large Rorquals in Waters around Newfoundland and Labrador

4.1.1.1 Introduction

It is accepted that large rorquals migrate north to waters off Newfoundland and Labrador to feed in its highly productive waters (Sergeant 1963, 1977; Mitchell 1973, 1974; Whitehead and Carscadden 1985; Yochem and Leatherwood 1985; COSEWIC

2002, 2003, 2005b). What is unknown, however, is whether large rorquals utilize all waters of Newfoundland and Labrador as feeding areas or whether some regions are used mainly as migration routes to and from such feeding areas, and therefore serve only as opportunistic feeding areas. While migration routes can be just as important to whales attempting to reach feeding grounds and warrant consideration for critical habitat designation, the potential impact of anthropogenic activities and the mitigation measures required for these routes could differ relative to feeding areas. It is therefore crucial to know whether large rorquals utilize some areas preferably as primary feeding areas or for migration (and possibly as opportunistic feeding areas), especially in areas of high population concentration.

Blue whales feed almost exclusively on krill, a shrimp-like euphausiid (Yochem and Leatherwood 1985). Fin whales prey primarily on crustaceans such as euphausiids, and schooling fish such as capelin, herring, and sand lance (Jonsgård 1966; Sergeant 1977; Overholtz and Nicolas 1979; Christensen *et al.* 1992a; Borobia *et al.* 1995). From a previous analysis of whaling records around Newfoundland and Labrador, krill appeared to be the food of choice early in the season, changing to capelin in late June to late July (Sergeant 1966). Other studies have corroborated the importance of capelin for fin whales off Newfoundland and Labrador (Mitchell 1975b; Brodie *et al.* 1978; Whitehead and Carscadden 1985). Sei whales appear to have a more diversified diet, but feed primarily on calanoid copepods and euphausiids (Mitchell 1975b; Christensen *et al.* 1992a).

Some studies rely on direct observations of cetaceans and their spatial and temporal relationships with prey (Croll *et al.* 1998; Gill 2002). Blue whales have been associated with surface krill off the southern coast of Australia (Gill 2002) and off southern California (Croll *et al.* 1998). However, gathering sufficient field observations of blue, fin, and sei whales to assess the proportion of individuals feeding in all of their potential habitats would be logistically difficult within the current large study area. Cetacean feeding habits have historically been studied through stomach content analyses of whales killed during commercial hunts (Sergeant 1963; Okutani and Nemoto 1964; Roe 1969; Kawamura 1980; Martin and Clarke 1986; Clapham *et al.* 1997; Ichii and Kato 2001; Olsen and Holst 2001; Flinn *et al.* 2002). More recently, stomach contents of stranded whales (Clarke *et al.* 1980; Pascoe *et al.* 1990; González *et al.* 1994; Lick *et al.* 1995; Clarke 1997; Clarke and Pascoe 1997; Fertl *et al.* 1997; Gannon *et al.* 1997; Santos *et al.* 1999, 2001a,b; Das *et al.* 2003), faecal sample analyses (Papastavrou *et al.* 1989; Whitehead *et al.* 1989; Smith and Whitehead 1993, 2000; Whitehead 1996; Jarman *et al.* 2002; Croll *et al.* 2005), and fatty acid and stable isotope ratio studies from biopsy samples (Ostrom *et al.* 1993; Hooker *et al.* 2001; Das *et al.* 2003; Olsen and Grahl-Nielsen 2003) have also contributed to the study of cetacean feeding behaviour. Historical shore-based whaling records off Newfoundland and Labrador provide one means to differentiate between feeding grounds and migration routes in the study area.

The objective of this section is to identify historical feeding areas for blue, fin, and sei whales in waters off Newfoundland and Labrador. Secondary objectives are to compare feeding behaviour of these whales among the different main regions, including during seasons and areas of peak abundance, and to link feeding grounds with prey preferences. These results will enable the differentiation among natural history activities occurring in rorqual species' habitat and provide a link between historical feeding grounds and potential current feeding grounds through regional variations in prey preference distribution.

4.1.1.2 Materials and Methods

Records of stomach contents for hunted whales were available from 1927-1972 through the IWC's records of Newfoundland and Labrador shore-based whaling. The IWC's database included records of the type of prey found in the stomachs and an estimate of quantity. Only records from the IWC database with actual catch locations (latitude and longitude) of animals were used in the current analysis, resulting in the exclusion of 2,388 of the 10,573 records in the IWC database.

To identify historical feeding grounds for blue, fin, and sei whales, hunted animals with food in their stomach (and those with empty stomachs) were mapped. To facilitate this, waters around Newfoundland and Labrador were divided using NAFO divisions. These divisions were used for regional comparisons and to relate the results to the areas of high population concentration described in Chapter 3. Five regions were described from these NAFO divisions (see Figure 3.3): coastal Labrador (2J and 2H), northeast

Newfoundland (3K), east Newfoundland (3L), the south coast of Newfoundland (3Pn and 3Ps), and the Strait of Belle Isle/Gulf of St. Lawrence (4R and 4S).

To compare feeding behaviour of blue, fin, and sei whales among the main regions and enable a possible regional ranking of feeding habitat quality, differences in the proportions of animals caught with food in their stomach were compared. For this study, regions with the highest proportion of whales with food in their stomach were considered preferred feeding grounds, while regions with the lowest proportion of whales with food in their stomach were considered secondary feeding grounds. These differences were assessed for blue, fin, and sei whales, individually, across the five regions using chi-square analyses (α=0.05) and for seasons of peak abundance in areas of high population concentration as described in Chapter 3 (see Table 3.7).

The quality of the data recorded in the IWC database, in terms of stomach quantity, prevented analyses of differences in stomach contents quantity and potential food availability in different regions, and hence, limited the regional ranking of feeding habitat quality. The data available only enabled the differentiation between stomachs containing food versus empty stomachs, and to some degree, a description of stomach contents. Stomach contents were described in the following broad categories: capelin, fish, krill, shrimp, squid, other, empty, and unknown.

4.1.1.3 Results

A total of 8,185 large rorquals were caught from shore-based whaling off Newfoundland and Labrador, with associated stomach content records. Of these, 5,905 had prey-type records in their stomach; 781 were recorded as having empty stomachs and 1,499 were recorded as having an unknown stomach content status (Table 4.1). Large rorquals, in general, were caught with food in their stomach in all five main regions (Figure 4.1). However, only 12 of 703 large rorquals caught off the south coast of Newfoundland were recorded as having either food in their stomach or empty stomachs; the remaining 691 had unknown stomach content records (Table 4.1).

Blue whales

Records of blue whales with corresponding stomach contents were only available for three of the five main regions: coastal Labrador, northeast Newfoundland, and the Strait of Belle Isle/Gulf of St. Lawrence. Stomach contents were not recorded for the 90 blue whales caught off the south coast of Newfoundland (coded as "unknown") and blue whales were not caught off east Newfoundland during the period used in this analysis (Table 4.1).

Overall, 92.6% (189 of 204) of all blue whales with stomach content records were caught with food in their stomach (Table 4.1). The lowest percentage of blue whales caught with food in their stomach occurred off coastal Labrador (91.1%). This was also the region for which most blue whales stomach content records were available (146 blue whales recorded as having food in their stomach or empty stomachs). All of the blue whales records off northeast Newfoundland (16 records) were coded as "with food" (Table 4.1). There were, however, no statistically significant difference in the number of blue whales caught with food in their stomach in each of the main regions with records available (χ^2=0.16, *df*=2, *p*>0.90; Table 4.1).

When considering differences in the number of blue whales caught with food in their stomach in each of the main regions during peak seasonal abundance of areas of high population concentration described in Chapter 3, no statistically significant differences were observed among the main regions with records available when considering stomach contents of whales taken during spring (χ^2=0.01, *df*=2, *p*>0.95) or summer (χ^2=0.13, *df*=2, *p*>0.90; Table 4.2).

Most blue whales taken off Newfoundland and Labrador with an identified prey-type in their stomach, when considering all regions combined, had recently fed on krill/shrimp (84.7% or 160 of 189 blue whales; Table 4.3). Fish were only seldom found in blue whale stomachs (Table 4.3). Fifteen blue whales were caught with empty stomachs. An additional 121 blue whales were caught during the study period, but did not have the details of their stomach contents recorded.

Fin whales

Fin whales were found with food in their stomach in all five main regions. Overall, 88.4% (5,612 of 6,351) of all fin whales with stomach content records were caught with food in their stomach (Table 4.1). The lowest percentage of fin whales caught with food in their stomach occurred off the south coast of Newfoundland (63.4%). This was also the region for which the fewest number of fin whales with stomach content records were available (11 fin whales recorded as having food in their stomach or empty stomachs). The highest percentage of fin whales caught with food in their stomach occurred off coastal Labrador (95.1%; Table 4.1). The number of fin whales caught with food in their stomach statistically differed among each of the main regions (χ^2=28.66, df=4, p<0.001; Table 4.1).

When considering differences in the number of fin whales caught with food in their stomach in each of the main regions during peak seasonal abundance in areas of high population concentration described in Chapter 3, statistical differences were observed among each of the main regions during summer (χ^2=15.51, df=4, p<0.01; Table 4.2). The highest percentage of fin whales caught with food in their stomach occurred off coastal Labrador (96.0%; Table 4.2).

Most fin whales taken off Newfoundland and Labrador with an identified prey-type in their stomach, when considering all regions combined, had recently fed on fish (76.3% or 4,292 of 5,622 fin whales; Table 4.3 including "fish" and "capelin" combined). Of the fin whales that fed on fish, 25.0% (1,072 of 4,292 fin whales) had recently fed on capelin. Krill/shrimp were also commonly found in fin whale stomach (23.3% or 1,312 of 5,622 fin whales; Table 4.3). The remaining prey-types found in fin whale stomachs were categorized as squid (0.1%) or other (0.2%; Table 4.3). Seven hundred and twenty-nine fin whales were caught with empty stomachs. An additional 1,326 fin whales were caught during the study period, but did not have the details of their stomach contents recorded.

Sei whales

Sei whales were found with food in their stomach in all five regions. Overall, 79.4% (104 of 131) of all sei whales with stomach content records were caught with food in their stomach (Table 4.1). The lowest percentage of sei whales caught with food in their stomach occurred off eastern Newfoundland (70.0%); only 10 sei whales were recorded as having food in their stomach or empty stomachs in this region. All sei whales caught off the south coast of Newfoundland and in the Strait of Belle Isle/Gulf of St. Lawrence regions had food in their stomachs (Table 4.1). However, only one and three sei whales, respectively, were recorded as having food in their stomach or empty stomachs in these two regions. The number of sei whales caught with food in their stomach did not statistically differ among each of the main regions (χ^2=0.43, *df*=4, p>0.95; Table 4.1).

When considering differences in the number of sei whales caught with food in their stomach in each of the main regions during peak seasonal abundance of areas of high population concentration described in Chapter 3, no statistically significant differences were observed among the main regions with records available when considering stomach contents of whales taken during summer (χ^2=0.21, *df*=3, p>0.95) or autumn (χ^2=0.62, *df*=3, p>0.80; Table 4.2).

Most sei whales taken off Newfoundland and Labrador with an identified prey-type in their stomach, when considering all regions combined, had recently fed on fish (88.5% or 92 of 104 sei whales; Table 4.3 including "fish" and "capelin" combined). Of the sei whales that fed on fish, only 2.2% (2 of 92 sei whales) had recently fed on capelin, specifically. Krill/shrimp were also found in sei whale stomach, although less commonly (11.5% or 12 of 104 sei whales; Table 4.3). Twenty-seven sei whales were caught with empty stomachs. An additional 52 sei whales were caught during the study period, but did not have the details of their stomach contents recorded.

4.1.1.4 Discussion

The main objective of this section was to identify historical feeding areas for blue, fin, and sei whales in waters off Newfoundland and Labrador. The results of stomach content analyses indicate that most blue, fin, and sei whales had recently fed prior to when they were captured in all main regions off Newfoundland and Labrador. A secondary objective was to compare feeding behaviour among the different main regions and assess whether some regions could be considered preferred or potentially higher quality feeding grounds. Blue and sei whales did not differ in the number of whales found with food in their stomach across the five regions (only three regions could be used in the blue whale analysis) and thus, all regions could be considered as equally probable feeding grounds. It should be noted that while blue whales were caught off the south coast of Newfoundland during the study period, all of the stomach content records for blue whales caught in this region were coded as "unknown". This is an important data limitation as the south coast of Newfoundland was identified as an historic area of high population concentration for blue whales and a "candidate" critical habitat in Chapter 3.

The number of fin whales caught with food in their stomach, unlike blue and sei whales, did vary significantly across the five main regions. The highest proportion of fin whales caught with food in their stomach was found off coastal Labrador (95.1%). However, large proportions fin whales were also found feeding in the other regions. In fact, the lowest proportion of fin whales caught with food in their stomach was 63.6% off the south coast of Newfoundland. This number was generated from the analysis of only 11 stomach records (an addition 563 records taken off the south coast of Newfoundland had stomach contents coded as "unknown"). When considering all regions, fin whales were caught with food in their stomach 88.4% of the time. So, while coastal Labrador may have been the region of greatest feeding intensity, fin whales did feed in all waters of the study area.

These results for these whale species support the accepted belief that large rorquals utilize Canadian waters around Newfoundland and Labrador for feeding. In addition, when considering only the records for peak seasonal abundance identified in Chapter 3, the results mimicked the general tendency described above. Proportionally, large rorquals are likely to feed in all regions, including during seasonal peaks. Therefore, areas of high population concentration and the "candidate" critical habitats described in Chapter 3 are possibly not a direct result of the type of natural history activity being carried out by these whales in each region. It is possible that other feeding parameters are influencing large rorquals' habitat selection and use off Newfoundland and Labrador. Such feeding parameters could include the type and density of prey available in the different regions (and hence the catch per unit hunting effort for the whales), the energetic quality of the prey available, other habitat features not measured in this study, or other rorqual social mechanisms.

A secondary goal of the current study was to use these descriptive data to associate regional feeding grounds with prey types. Combined with updated fisheries analyses and more detailed prey distribution studies, such baseline information can be updated frequently during active monitoring and adaptive management steps of the protocol (Step 4 – see Chapter 5). Unfortunately, the quality of the whaling data limited opportunities to assess the prey preference of different rorqual species in the different regions of Newfoundland and Labrador. Notably, records off the south coast of Newfoundland lacked stomach content details and, concurrently, details on prey species consumed. Thus, there are no feeding data to corroborate identification of the south coast of Newfoundland as a "candidate" critical habitat for blue and sei whales in Chapter 3 using estimates of spatial density.

Records estimating the quantity of food in the stomachs (e.g., proxy measures for fullness or meal size) and additional details on the degree of digestion are also not available for the study period. Therefore, the information available adds little to the body of knowledge on prey preferences of blue, fin, and sei whales. Further work dedicated to this question, using current prey distribution and abundance data, plus non-invasive diet assessment techniques such as stable isotope and fatty acid studies of field biopsy samples (Ostrom *et al.* 1993; Hooker *et al.* 2001; Das *et al.* 2003; Olsen and Grahl-Nielsen 2003), is required as a component of the active monitoring step of the critical habitat definition protocol to limit the disturbance of potentially important limiting resources to these species and ensure optimal management.

Studies assessing limiting resources using current data are crucial. Even with complete historical data, the question of "how reliable, or relevant, is historic information in the current ecosystem which is significantly perturbed by human activities" would remain. To what degree have marine systems changed since these whaling-based data were collected? It has been proposed that the depletion of great whale populations may have lead to a shift in the feeding habits of other marine mammals such as killer whales (Mizroch and Rice 2006). With the past and present anthropogenic pressures being applied to all ecosystems and possibly resulting in the decline of certain marine mammal populations (Bearzi *et al.* 2006), additional, more subtle behavioural modifications could be occurring in both marine mammals and their prey. Large rorquals that have been the target of intense commercial whaling pressure also likely modified their feeding habits (including the proportion of different prey-types being consumed, or available for consumption, and preferred feeding grounds) if their feeding strategies are density-dependent.

Despite the limitations of the historical shore-based whaling data available, it does assist with building a model of a whale species' critical habitat by identifying areas used for feeding that could potentially represent limiting resources. Although, for rorqual species at risk in Newfoundland and Labrador, these limiting resources may not be simply feeding areas, but instead relative prey abundance, distribution, and availability. Indeed, large rorqual stomach content records off Newfoundland and Labrador indicated that blue, fin, and sei whales fed in every region where they were captured. However, data gaps remain. For instance, stomach content records were not recorded in the area of highest population concentration for blue whales, the south coast of Newfoundland. Records of stomach fullness, as an indicator of feeding habitat quality, were also unavailable. Further studies focussing on the environmental features that play a role in influencing prey abundance, distribution, and availability will help describe and narrow "candidate" critical habitats for blue whales, as well as fin and sei whales.

4.1.2 Fine-scale Analysis of Large Rorqual Habitat Preference Based on Environmental Features in Newfoundland and Labrador

4.1.2.1 Introduction

Blue, fin, and sei whales are known to have historically fed in all waters around Newfoundland and Labrador (see Section 4.1.1). Certain environmental features can create conditions that lead to favourable feeding conditions through increased production of prey or aggregation of prey (Selzer and Payne 1988), and could serve as indicators of habitat preference for large whales in the absence of direct data on prey abundance and distribution. Therefore, modelling a species' habitat, using environmental features, could identify both habitat that has been historically associated with the occurrence of a species, as well as potentially suitable habitats lacking survey effort directed towards those species. Such a process, termed a "habitat suitability model", would enable a more detailed assessment of a species' habitat use and, in the process, its critical habitat by taking into account potentially limiting resources.

Habitat suitability (HS) models can be generated using two methods: presence-only and presence/absence data. The ecological niche factor analysis (ENFA) is a frequently used method to compute a habitat suitability model when absence data are lacking (Hirzel *et al.* 2002). On the other hand, when reliable absence data are available, presence/absence methods such generalised linear models (GLM) can and, in most cases, should be used to increase the predictive accuracy of the model (Brotons *et al.* 2004). This is particularly true when species use available habitat proportionally to their suitability (Brotons *et al.* 2004). Hirzel *et al.* (2001) compared both methods using a virtual species and concluded that the ENFA was very robust to the quality and quantity of the data. The authors examined three population scenarios: spreading, at equilibrium, and overabundant species. The GLM produced slightly better results than the ENFA when the species was overabundant, but was badly affected in the case of the spreading species. In scenarios when the species was at equilibrium, both methods produced equivalent results (Hirzel *et al.* 2001).

When dealing with heavily hunted large rorquals, scenarios of overabundance that favour the use of presence/absence modelling techniques are unlikely. In addition, given the cryptic behaviour of cetaceans, presence-only data analysis avoids the potential bias associated with absence data ("true" absences when the whales are actually absent from the survey area versus "false" absences when the whales are present, but not detected during the study) and can result in more accurate HS predictions.

The ENFA compares, in the multidimensional space of ecogeographical variables (EGVs), the distribution of the localities where the focal species was observed to a reference set describing the whole study area (Hirzel *et al.* 2002). A number of studies have examined the link between various environmental features and marine mammal distribution (see Appendix A for a review of these studies). Some studies have modelled marine mammal habitat using combinations of environmental features (Moses and Finn 1997; Gregr and Trites 2001; Guinet *et al.* 2001; Hamazaki 2002; Compton 2004; Littaye *et al.* 2004; Ferguson *et al.* 2006; Wheeler and Gilbert 2007; Laran and Gannier 2008), and in some case, habitat suitability of marine mammals using the proposed ENFA approach (Compton 2004; Wheeler and Gilbert 2007; Praca and Gannier 2008; Skov *et al.* 2008). Based on evidence from these previous efforts, with special considerations for blue, fin, and sei whales, four environmental features were selected in the current analysis: water depth, seabed slope, sea-surface temperature (SST), and chlorophyll – a proxy measure for productivity (Eppley *et al.* 1985).

The objective of this section is to define and model specific suitable habitats that have been used and could potentially be used by blue, fin, and sei whales around Newfoundland and Labrador using available data sources. The effectiveness of mitigation measures developed by policy makers for a critical habitat will result from both the quality of the data used to define that habitat and the scale over which it is applied. Habitat suitability models were defined for each species a) in the overall area, including all waters of Newfoundland and Labrador; b) exclusively in areas of high population concentration, as described in Chapter 3; and c) accounting for seasonal peaks in whale abundance within areas of high population concentrations as described in Chapter 3.

4.1.2.2 Materials and Methods

Records of blue, fin, and sei whales originated from shore-based whaling records and a compilation of sighting records. Shore-based whaling off the coasts of Newfoundland and Labrador spanned the period of 1898 to 1972 (see Section 3.2). However, records of exact kill positions for hunted whales that could be used in the current analysis were only available as of 1945 for certain whaling companies, through the International Whaling Commission's records of Newfoundland and Labrador shore-based whaling. Sighting records originated from the DFO cetacean sightings database (see Section 3.2 for details on this database). Only records of open water/free swimming whales with confirmed species identification and sighting location were included in the current analysis.

The study area was identical to the one used in Section 3.2. The five regions were, as in Chapter 3, described using NAFO divisions (see Figure 3.4): coastal Labrador (2G, 2J, and 2H), northeast Newfoundland (3K), east Newfoundland (3L, 3N, and 3O), the south coast of Newfoundland (3Pn, 3Ps, 4Vn, and 4Vs), and the Strait of Belle Isle/Gulf of St. Lawrence (4R, 4S, and 4T).

SST (degrees Celsius) and chlorophyll (mg/m^3) data were acquired from the MODIS Level 3, 4-km binned product offered from the "Ocean Color Web" (http://oceancolor.gsfc.nasa.gov/cgi/climatologies.pl?TYP=masst and http://oceancolor.gsfc.nasa.gov/cgi/climatologies.pl?TYP=machl, respectively). Because the sighting records covered a large temporal scale (from 1945 to 2006), and SST and chlorophyll satellite imagery is not available for the entire analysis period, 6-year averages (2002-2007) of SST and chlorophyll satellite imagery were used for cumulative and seasonal data, as provided from Ocean Color Web. The use of recent multi-year averages to assess historical marine mammal data, including historical whaling data, has been used in other cetacean habitat use studies (Jaquet *et al.* 1996; Wheeler and Gilbert 2007). Bathymetry data (depth and slope) were obtained from the 2-Minute Gridded Global Relief Data (ETOPO2v2), provided by the World Data Centre for marine Geology & Geophysics. EGVs were transformed into grids that could be imported into BioMapper 3.2 (Hirzel *et al.* 2004) as documented in Section 3.2 of Wheeler and Gilbert (2007). Once imported into BioMapper, the ecogeographical maps were normalised through Box-Cox transformation (Hirzel *et al.* 2002).

BioMapper is a kit of GIS and statistical tools designed to build habitat suitability models and maps. It is centred on the ENFA, which allows it to compute HS models without the need for absence data (Hirzel *et al.* 2002). The ENFA results in a score matrix summarizing factors that explain part of the species' ecological distribution and its correlation with the selected EGVs. The extracted factors are uncorrelated, but have a biological significance. The first factor is the marginality factor, which describes the distance between the species' optimum habitat and the "mean" habitat in the study area (based on mean values for selected environmental features within the study area). A low marginality value (close to 0) indicates that the species tends to use parts of the study area with average conditions. A high marginality value (close to 1) indicates a tendency for "extreme" habitats. The +/- sign associated with the value indicates whether the species prefers habitat conditions above or below average conditions. The other factors are specialization factors and describe how specialized the species is by reference to the available range of habitat in the study area. It is defined as the ratio of the standard deviation of the global distribution of EGVs to that of the species' distribution.

Once the ENFA completed, HS models were computed using the distance geometric mean algorithm provided in BioMapper. This algorithm was used because it provided good generalization power and made no *a priori* assumptions about the species' distribution and is described in Hirzel and Arlettaz (2003). The number of factors derived from the ENFA analysis and used in the HS computation was selected after comparison to the distribution of MacArthur's broken-stick.

Following the HS computation, the model was validated using a jack-knife cross-validation procedure (Hirzel *et al.* 2006). This cross-validation provided a confidence interval around the predictive accuracy of the model and enables the evaluation of the HS map produced from the ENFA through the computation of a Boyce index that varies from -1 to 1. A positive value, near 1, indicates a model whose predictions are consistent with the presences distribution in the evaluation of the dataset, whereas values close to zero indicate a model that does not differ from a chance model. Negative values indicate an incorrect model that predicts poor quality areas where presences are more frequent (Hirzel *et al.* 2006). However, there is no suitable single measure of performance (or statistic) available to compare and contrast models (Pearce and Boyce 2006). The HS model cross-validation also enabled the evaluation of the number of habitat bins needed in order to best describe habitat types. Three habitat suitability bins were defined and used throughout the HS mapping analyses: *core*, *marginal*, and *unsuitable* habitats types.

These analyses were performed for blue, fin, and sei whales individually a) in the overall area, including the study area around Newfoundland and Labrador; b) exclusively in areas of high population concentration as described in Chapter 3; and c) accounting for seasonal peaks within areas of high population concentrations as described in Chapter 3.

4.1.2.3 Results

Blue Whale Habitat Characterization

a) Overall

A total of 148 blue whale records (59 from the IWC database and 89 from the DFO sightings database) were available to use in the ENFA when considering all regions of the study area during all seasons combined (Figure 4.2). The ENFA score matrix (Table 4.4), when considering the marginality factor, suggested that blue whale distribution around Newfoundland and Labrador was best characterized by deeper than average waters, steeper than average seabed slope, and higher than average chlorophyll densities. Blue whale distribution was not correlated with SST. The resulting HS map indicated that the most suitable habitat for blue whales around Newfoundland and Labrador is mainly found in the Gulf of St. Lawrence and off the southern coast of Newfoundland with other *core* habitat also being identified along the coastlines of northeast Newfoundland and coastal Labrador, and farther offshore, following the steep continental slope (Figure 4.3). The model cross validation resulted in a Boyce index of 0.95±0.15, indicating that the model is a good predictor of HS for blue whales in the overall waters of Newfoundland and Labrador.

b) Areas of high population concentration

In the region of highest population concentration for blue whales, the south coast of Newfoundland, 64 blue whale records (all from the DFO sightings database) were available to use in the ENFA when considering all seasons. The ENFA score matrix (Table 4.5), when considering the marginality factor, suggested that blue whale distribution off the south coast of Newfoundland was best characterized by a steeper than average seabed slope, higher than average chlorophyll densities, and lower than average SST. Blue whale distribution was not correlated with water depth. The resulting HS map indicated that the most suitable habitat for blue whales off the south coast of Newfoundland is mainly found along steep slope gradients with other *core* habitat also being identified along the southern coastline of Newfoundland (Figure 4.4). The model cross validation resulted in a Boyce index of 0.537±0.5586, indicating that the model is not a good predictor of HS for blue whales off the south coast of Newfoundland.

In the second area of population concentration identified for blue whales, the Strait of Belle Isle/Gulf of St. Lawrence region, 53 blue whale records (42 from the IWC database and 11 from the DFO sightings database) were available to use in the ENFA when considering all seasons. The ENFA score matrix (Table 4.6), when considering the marginality factor, suggested that blue whale distribution in the Strait of Belle Isle/Gulf of St. Lawrence was best characterized by lower than average SST and, to a lesser extent, a steeper than average seabed slope. Blue whale distribution was not correlated with water depth or chlorophyll densities. The resulting HS map indicated that the most suitable habitat for blue whales in the Strait of Belle Isle/Gulf of St. Lawrence is mainly found along the northern Quebec coastline and around Anticosti Island with other *core* habitat also being identified along steep slopes and off the southwest corner of Newfoundland (Figure 4.5). The model cross validation resulted in a Boyce index of 0.6±0.4359, indicating that the model is not a good predictor of HS for blue whales in the Strait of Belle Isle/Gulf of St. Lawrence.

c) Areas of high population concentration and seasonal peaks

In the region of highest population concentration for blue whales, the south coast of Newfoundland region, blue whales were most commonly observed during spring and summer (see Table 3.7). While there were too few records of blue whales available for use in an ENFA during spring off the south coast of Newfoundland, 52 blue whale records (all from the DFO sightings database) were available to use in the ENFA during summer. The ENFA score matrix (Table 4.7), when considering the marginality factor, suggested that blue whale distribution off the south coast of Newfoundland during summer was best characterized by a steeper than average seabed slope and lower than average SST. Blue whale distribution was less correlated with water depth and was not correlated with chlorophyll densities. The resulting HS map indicated that suitable habitat for blue whales off the south coast of Newfoundland during summer is almost exclusively found along the offshore steep slope gradients (Figure 4.6). The model cross validation resulted in a Boyce index of 0.9±0.2, indicating that the model is a good predictor of HS for blue whales off the south coast of Newfoundland during summer.

In the second area of population concentration identified for blue whales, the Strait of Belle Isle/Gulf of St. Lawrence, blue whales were most commonly observed during spring (see Table 3.7) and 41 blue whale records (35 from the IWC database and six from the DFO sightings database) were available to use in the ENFA. The ENFA score matrix (Table 4.8), when considering the marginality factor, suggested that blue whale distribution in the Strait of Belle Isle/Gulf of St. Lawrence during spring was best characterized by lower than average SST and a steeper than average seabed slope. Blue whale distribution was not correlated with water depth or chlorophyll densities. The resulting HS map indicated that the most suitable habitat for blue whales in the Strait of Belle Isle/Gulf of St. Lawrence region is mainly found along the northern Quebec coastline and around Anticosti Island with other *marginal* habitat also being identified along steep slope regions and off the southwest corner of Newfoundland (Figure 4.7). The model cross validation resulted in a Boyce index of 0.25±0.7159, indicating that the model is not a good predictor of HS for blue whales in the Strait of Belle Isle/Gulf of St. Lawrence during spring.

Fin Whale Habitat Characterization

a) Overall

A total of 5,515 fin whale records (4,331 from the IWC database and 1,184 from the DFO sightings database) were available to use in the ENFA when considering all regions of the study area during all seasons combined (Figure 4.8). The ENFA score matrix (Table 4.9), when considering the marginality factor, suggested that fin whale distribution around Newfoundland and Labrador was best characterized by deeper than average waters, and lower than average SST. Fin whale distribution was not correlated with seabed slope and chlorophyll densities. The resulting HS map indicated that the most *core* suitable habitat for fin whales around Newfoundland and Labrador is found in northeast waters, off Newfoundland (Figure 4.9). The model cross validation resulted in a Boyce index of 0.9±0.2, indicating that the model is a good predictor of HS for fin whales in the overall waters of Newfoundland and Labrador.

b) Areas of high population concentration

In the region of highest population concentration for fin whales, coastal Labrador, 606 fin whale records (461 from the IWC database and 145 from the DFO sightings database) were available to use in the ENFA when considering all seasons. The ENFA score matrix (Table 4.10), when considering the marginality factor, suggested that fin whale distribution off coastal Labrador was best characterized by deeper than average waters and, to a lesser extent, lower than average SST and chlorophyll densities. Fin whale distribution did not seem highly correlated with seabed slope. The resulting HS map indicated that the most suitable habitat for fin whales off coastal Labrador is mainly found near the southern edge of Labrador, in areas of deeper water (Figure 4.10). The model cross validation resulted in a Boyce index of 0.85±0.2291, indicating that the model is a good predictor of HS for fin whales off coastal Labrador.

In the second area of population concentration identified for fin whales, northeast Newfoundland, 3,597 fin whale records (3,341 from the IWC database and 256 from the DFO sightings database) were available to use in the ENFA when considering all seasons. The ENFA score matrix (Table 4.11), when considering the marginality factor, suggested that fin whale distribution off northeast Newfoundland was best characterized by deeper than average waters, lower than average SST and, to a lesser extent, a flatter than average seabed slope and lower than average chlorophyll densities. The resulting HS map indicated that the most suitable habitat for fin whales off northeast Newfoundland cover nearly the entire region on the continental shelf (Figure 4.11). The model cross validation resulted in a Boyce index of 0.8±0.4583, indicating that the model is a fairly good predictor of HS for fin whales off northeast Newfoundland.

c) Areas of high population concentration and seasonal peaks

In the region of highest population concentration for fin whales, coastal Labrador, fin whales were most commonly observed during summer (see Table 3.7) and 443 fin whale records (386 from the IWC database and 57 from the DFO sightings database) were available to use in the ENFA. The ENFA score matrix (Table 4.12), when considering the marginality factor, suggested that fin whale distribution off coastal Labrador during summer was best characterized by lower than average chlorophyll densities and deeper than average waters. Fin whale distribution was not correlated with seabed slope or SST. The resulting HS map indicated that suitable habitat for fin whales off coastal Labrador during summer is less dispersed than during all seasons combined (see Figure 4.10), and *core* habitat can also found further north along the Labrador coastline during summer (Figure 4.12). The model cross validation resulted in a Boyce index of 0.8±0.2291, indicating that the model is a good predictor of HS for fin whales off coastal Labrador during summer.

In the second area of population concentration identified for fin whales, northeast Newfoundland, fin whales were most commonly observed during summer (see Table 3.7) and 2,709 fin whales records (2,521 from the IWC database and 188 from the DFO sightings database) were available to use in the ENFA. The ENFA score matrix (Table 4.13), when considering the marginality factor, suggested that fin whale distribution off northeast Newfoundland during summer was best characterized by deeper than average waters, a steeper than average seabed slope and, to a lesser extent, lower than average chlorophyll densities. Fin whales distribution did not seem highly correlated with SST. The resulting HS map indicated that the most suitable habitat for fin whales off northeast Newfoundland during summer was nearly identical to that when considering all seasons combined (see Figure 4.11), with *core* habitat extending slightly farther offshore during summer (Figure 4.13). The model cross validation resulted in a Boyce index of 0.5±0.6707, indicating that the model is not a good predictor of HS for fin whales off northeast Newfoundland during summer.

Sei Whale Habitat Characterization

a) Overall

A total of 193 sei whale records (97 from the IWC database and 96 from the DFO sightings database) were available to use in the ENFA when considering all regions of the study area during all seasons combined (Figure 4.14). The ENFA score matrix (Table 4.14), when considering the marginality factor, suggested that sei whale distribution around Newfoundland and Labrador was best characterized by lower than average SST and deeper than average water. Sei whale distribution was not correlated with chlorophyll densities and seabed slope. The resulting HS map indicated that the majority of *core* habitat for sei whales around Newfoundland and Labrador is found in northeast waters, off Newfoundland, and northward, along the coast of Labrador (Figure 4.15). The model cross validation resulted in a Boyce index of 0.65±0.45, indicating that the model is not a good predictor of HS for sei whales in the overall waters of Newfoundland and Labrador.

b) Areas of high population concentration

Two areas of high population concentration were identified for sei whales around Newfoundland and Labrador, the south coast of Newfoundland and coastal Labrador. While there were too few records of sei whales available for use in an ENFA off the south coast of Newfoundland, 92 sei whale records (51 from the IWC database and 41 from the DFO sightings database) were available to use in the ENFA off coastal Labrador when considering all seasons. The ENFA score matrix (Table 4.15), when considering the marginality factor, suggested that sei whale distribution off coastal Labrador was best characterized by deeper than average waters and lower than average SST. Sei whale distribution was not correlated with seabed slope and chlorophyll densities. The resulting HS map indicated that the most suitable habitat for sei whales off coastal Labrador is mainly found near the southern edge of Labrador, near the coastline (Figure 4.16). The model cross validation resulted in a Boyce index of 0.7±0.4583, indicating that the model is not a good predictor of HS for sei whales off coastal Labrador.

c) Areas of high population concentration and seasonal peaks

In the only area of high population concentration for sei whales with sufficient records to enable ENFA, coastal Labrador, sei whales were most commonly observed during summer and autumn (see Table 3.7). During summer, 42 sei whale records (17 from the IWC database and 25 from the DFO sightings database) were available to use in the ENFA. The ENFA score matrix (Table 4.16), when considering the marginality factor, suggested that sei whale distribution off coastal Labrador during summer was best characterized by lower than average chlorophyll densities and deeper than average waters. Sei whale distribution was not correlated with seabed slope or SST. The resulting HS map indicated that suitable habitat for sei whales off coastal Labrador during summer is similar to that observed during all seasons combined (see Figure 4.16), but *core* habitat extents farther north along the Labrador coastline during summer (Figure 4.17). The model cross validation resulted in a Boyce index of 0.25±0.6423, indicating that the model is not a good predictor of HS for sei whales off coastal Labrador during summer.

During autumn, 50 sei whale records from the coastal Labrador region (34 from the IWC database and 16 from the DFO sightings database) were available to use in the ENFA. The ENFA score matrix (Table 4.17), when considering the marginality factor, suggested that sei whale distribution off coastal Labrador during autumn was best characterized by deeper than average waters, higher than average chlorophyll densities and lower than average SST. Sei whale distribution was not correlated with seabed slope. The resulting HS map indicated that suitable habitat for sei whales off coastal Labrador during autumn was limited and concentrated just north of the Strait of Belle Isle (Figure 4.18). The model cross validation resulted in a Boyce index of 0.413±0.6357, indicating that the model is not a good predictor of HS for sei whales off coastal Labrador during autumn.

4.1.2.4 Discussion

The objective of this section was to model suitable habitats for blue, fin, and sei whales and, in the process, identify *core* habitats that could potentially serve as indicators of critical habitat. The BioMapper GIS and statistical program was effective in modelling habitat suitability for these species, and more importantly, providing an indicator of HS predictive accuracy through the cross-validation process and Boyce index. Overall, BioMapper enabled good prediction of HS for blue and fin whales in all waters around Newfoundland and Labrador, but not for sei whales. The limited prediction power of the HS model for sei whales is not surprising considering the limited information available for this species; COSEWIC listed this population as *data deficient* (COSEWIC 2003).

Restricting the HS model to areas of high population concentration identified in Chapter 3 resulted in similar HS maps as those produced in the overall study area. The main difference was that HS models for areas of high population concentration were often more narrow in their description of *core* habitat, and thus more useful to the impact assessment process of anthropogenic activities within the *core*, or critical, habitat of species at risk. Conflicts, however, occur when models for regions identified as areas of high population concentration have a low predictive power compared to the HS models of the overall area. Such a case was evident for the blue whale where the overall HS model was determined to be a good predictor of HS, but where both HS models for areas of high population concentration, the south coast of Newfoundland and the Strait of Belle Isle/Gulf of St. Lawrence, had low Boyce index values with high error margins. Fin whale models, perhaps benefiting from a greater number of sighting records in areas of high population concentration, did not suffer the same problem.

In cases such as those of the blue whale, HS models need to be compared carefully. The use of a large spatial scale and greater range of potential habitats may not be representative of a species' actual habitat options. When considering the potential impact of an anthropogenic activity, or potentially limiting factor, is it best practice to assess whether this activity overlaps with a species' critical habitat based on a model that considers available habitat hundreds of kilometres away? Is it reasonable to assess critical versus non-critical habitat off the south coast of Newfoundland for the endangered blue whale based on available habitat off the coast of Labrador?

Species at risk that would benefit the most from having their critical habitat described and protected are often those with the smallest remaining populations, and hence fewer corresponding sighting records. A habitat suitability model based on few sightings is also less likely to be an accurate predictor of critical habitat. The problem is thus obvious. What should habitat managers do when attempting to model a species' critical habitat within a narrow area of population concentration? Are managers better served by a good predictive model on a larger scale (generated from a greater number of overall sightings) than a poor predictive model in a smaller area of interest (generated from few local sightings)? Unfortunately, there is no simple answer to such a question. Models based on different areas should not be directly compared and the extrapolations of results from one area to another are less valid.

The precautionary approach would dictate that a combination of models should be used in such cases, rather than limiting the process of critical habitat definition to a single analysis of a single model. If a HS model with good predictive power is available for an area of interest, such as an area of high population concentration, then this model should be the one used when assessing critical habitat for this area. However, if the HS model has poor predictive power, then both this model and the HS model obtained from the analysis of a larger area should both be used and any *core* habitat described in either model for the area in question should be considered for critical habitat designation. In time, as additional sighting records become available, notably in areas of high population concentration (perhaps obtained using directed surveys – this modelling approach could provide a means for managers to allocate survey effort for most applicable results), HS models should be re-assessed as part of the active monitoring step of the critical habitat definition protocol (see Chapter 5). In addition, as more sightings records become available, managers may choose to run HS models on only the most recent subset of the overall database. EGVs used, such as SST and chlorophyll density, are based on multi-year averages (within the last 6 years) while sighting records date as far back as 1945. Ideally, the time frame of EGVs and sightings used in the ENFA should overlap.

Seasonal variations, also, cannot be ignored, especially when assessing the impact of a specific activity in a limited area. Previous sections have demonstrated that blue, fin, and sei whales are observed more frequently in Newfoundland and Labrador waters during certain seasons (see Section 3.2.3). This is also true when considering certain

NAFO regions. The ENFAs and HS models did highlight variations in the distributional range of *core* habitats for some species in areas of high population concentration, notably fin and sei whales off the coast of Labrador. Therefore, when assessing whether an anthropogenic activity will conflict with a species at risk's critical habitat, it is important to consider the seasonal range over which this activity will occur and consider seasonal variations in the EGVs being used in the ENFA.

Earlier in this chapter, blue, fin, and sei whales were shown to have historically fed in all regions surrounding Newfoundland and Labrador based on stomach contents from shore-based whaling records. The characterizations of oceanographic features affecting prey abundance are thus important components of cetacean feeding distribution studies (Selzer and Payne 1988). Spatial distribution of fish can, in part, be influenced by a number of abiotic factors, in particular, bathymetry, temperature, salinity, currents, and sea-bed sediment type (Gray 1974; Lough *et al.* 1989; Gray and Otway 1994; Perry *et al.* 1994). For instance, changes in depth have been shown to concentrate prey (Sutcliffe and Brodie 1977) and areas of high sea floor relief often result in greater nutrient mixing due to topographically-induced upwelling (Svedrup *et al.* 1942). This can lead to enhanced feeding opportunities for cetaceans (Hui 1979, 1985; Payne *et al.* 1986).

Following ENFA, blue whales distribution in the overall area around Newfoundland and Labrador was found to be best characterized by areas of deep water and steep seabed slope. In its area of highest population concentration, the south coast of Newfoundland, blue whales distribution was highly influenced by the steepness of the seabed slope. Fin whales distribution, on the other hand, was mainly driven by water depth (with a preference for deeper than average waters) and colder surface waters, in the overall area and both areas of highest population concentration (coastal Labrador and northeast Newfoundland). While HS models for sei whales did not have good predictive accuracy, the only models available warrant consideration until more information becomes available. The cautious use of the ENFA to describe sei whale distribution suggests that the main factors dictating their distribution around Newfoundland and Labrador, and more specifically off coastal Labrador, are water depth (with a preference for deeper than average waters) and colder surface waters.

Given that most large rorquals taken from shore-based whaling activities off Newfoundland and Labrador had fed recently (based on their stomach contents), *core* habitats described through the ENFA and HS models likely refer to *core* feeding habitat for blue, fin, and sei whales. Whales observed in these *core* habitats could be assumed to be feeding while whale outside of these habitats would be more likely to be travelling between feeding areas or opportunistically feeding while in transit. Therefore, potential limiting factors (see Section 4.2) acting on *core* versus *non-core* habitats of blue, fin, and sei whales would require different levels of mitigation measures. Factors with the potential to impact a species at risk during an important natural history activity, such as feeding, within the *core* habitat of an identified "candidate" critical habitat (area of high population concentration – as described in Chapter 3) would likely trigger a change in critical habitat classification from "candidate" to "protected" and necessitate that restrictive mitigation measures be applied if the impact of these factors has the potential to compromise the recovery goals of this species.

4.2 Limiting Factors for Blue, Fin, and Sei Whales in Newfoundland and Labrador

The identification and use of areas of high population concentration and potentially limiting resources to model critical habitat for species at risk represent only part of the critical habitat designation process. Limiting factors whose impact can affect species at risk directly (physically) or indirectly (behaviourally, or through their access to limiting resources) also need to be identified in order to assist managers in the establishment of appropriate mitigation measures to protect, when required, the identified critical habitats. Potential limiting factors can take the form of either sources of natural mortality (predation and ice entrapments) or anthropogenic threats (offshore oil and gas exploration and development, vessel traffic, and fisheries interactions). This section briefly summarizes the potential limiting factors that could impact marine mammal species at risk and their critical habitat, and emphasizes their potential threat to blue, fin, and sei whales in Newfoundland and Labrador. Each section is not intended to be presented as a complete literature review of each of these limiting factors.

4.2.1 Causes of natural mortality

4.2.1.1 Predation

Predation, mainly by killer whales, may be one of the leading sources of natural mortality for rorqual populations (Steiger *et al.* 2008). Killer whales occur in Newfoundland and Labrador (Lawson *et al.* 2007), although no report of attacks on blue or sei whales have been reported in this region. Fin whales taken during whaling operations did occasionally exhibit scars resulting from killer whale attacks. Sears and Calambokidis (2002) reported that very few blue whales in the St. Lawrence carried the rake-like markings thought to be associated with killer whale attacks. In contrast, in the Sea of Cortez, at least 25% of blue whale sightings carried marks associated with killer whale attacks (Sears and Calambokidis 2002). The size and distribution of the killer whale populations on the western Atlantic coast and the eastern Pacific coastline, as well as differences in feeding preferences and prey availability in both oceans, could be partly responsible for these differences.

Killer whale predation is aimed mainly at young calves (George and Suydam 1998) and it remains unclear to what extent female rorquals with young calves utilize waters around Newfoundland and Labrador, and if so, in which regions. Very few mother-calf pairs have been sighted in this region despite much aerial survey coverage (J. Lawson, Pers. Comm.). In addition, while killer whale occurrence have been documented in areas of high population concentration for blue, fin, and sei whales, and has the potential to overlap with identified core habitat (Figure 4.19), large rorquals off Newfoundland and Labrador may not be a preferred prey option for killer whales in these waters when considered against the large pinniped and small cetacean populations also inhabiting these waters.

4.2.1.2 Ice entrapments

Natural ice entrapments of marine mammals off the southwest coast of Newfoundland have in the past been a source of natural mortality for blue whales in Canadian waters (Lien *et al.* 1989). Lien et al. (1989) described two mechanisms of blue whale ice entrapment off the southwest coast of Newfoundland. The first results from pack ice movement coming from the northern Gulf of St. Lawrence. As the pack ice accumulates around the Port au Port Peninsula, it creates an area of open water in St. George's Bay. This shorelead can be closed if strong westerly wind should push the ice into the bay, causing the entrapment of any whales found in the shorelead. The second mechanism results from southerly winds pushing ice toward the southwest coast when the ice extent reaches the Cabot Strait and curves around Channel-Port-aux-Basques.

These events resulted in the death of at least 34 blue whales between 1974 and 1992, and for a population currently numbering fewer than 250 mature individuals (Sears and Calambokidis 2002), this level of removal may hinder this populations' survival or recovery. Such areas can therefore be considered critical habitat, and mitigation measures put in place to reduce or eliminate this source of natural mortality, if possible. For example, in the event that ice and meteorological conditions occur that would favour cetacean entrapments, these areas could be surveyed for the presence of blue whales. If animals are found in such hazardous circumstances acoustic harassment methods could be employed in an effort to displace them to safer open waters.

4.2.2 Anthropogenic threats.

4.2.2.1 Offshore oil and gas exploration and development

There are three main phases to the offshore oil and gas industry with the potential to impact rorquals in Newfoundland and Labrador waters: exploration, exploitation, and transport. Oil and gas exploration begins with the location of potential hydrocarbon yielding geological structures, generally through the firing of airgun arrays from a seismic vessel. The emitted acoustic signal is bounced back from the sea-floor and received by towed hyrdrophone arrays. The presence of hydrocarbon in a promising geological structure is then confirmed and spatially delimited through rock drilling. The second phase, exploitation, is a much more localized phase extracting the newly-discovered resource and is followed by the transportation of these resources. The effect of resource transportation will be reviewed in the overall effect of vessel traffic (see Section 4.2.2.2).

During the exploitation phase, a physical effect to rorquals might occur from the discharge of contaminants in the environment (oil spills, drill mud, etc.). However, such an effect would be expected to be localized and of minimal impact. The main effect of drilling operations on rorquals would result from the noise being produced, both by the platform itself and its supply vessels. Negative impacts from the effect of noise on blue, fin, and sei whales are expected to be behavioural through local avoidance and result in some habitat loss (Abgrall *et al.* 2008b). This loss of habitat could be significant if it were to occur within the species' defined critical habitat. Mitigations to prevent the loss of critical habitat could include aerial and marine population surveys in the proposed exploitation area and neighbouring waters a year or two before the start of exploitation to assess up-to-date habitat use, including the availability of alternative suitable habitat for the population in the event of a spatial conflict with the species' defined critical habitat.

A number of reviews of the impact of seismic exploration, mainly the effects of seismic sound, exist (Richardson *et al.* 1995; Gordon *et al.* 2004; Stone and Tasker 2006; Nowacek *et al.* 2007; Southall *et al.* 2007; Abgrall *et al.* 2008b). The objective of this section is not to provide another review, but to emphasize how the impacts of oil and gas exploration can affect the critical habitat designation and protection process.

Reviews of the effects of seismic noise have indicated that the potential impact of noise on cetaceans likely varies depending on the type of behaviour being performed (the exposure context). Studies of bowhead whales have shown that responsiveness to seismic surveys can be quite variable depending on the activity of the whales (e.g., migrating versus feeding). Feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales before showing an overt change in behaviour (Richardson *et al.* 1986, 1995; Ljungblad *et al.* 1988; Miller *et al.* 2005). Feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away. Blue, fin, and sei whales using Newfoundland and Labrador waters feed in all regions and could, possibly, also tolerate higher received sound levels than those expected to normally cause behavioural or avoidance reactions.

Many factors likely influence the tolerance of an individual to anthropogenic sound. These include individual sensitivity, social context, quality of the feeding ground, availability/awareness and distance of other feeding grounds of equal or similar quality, received sound levels, environmental features impacting sound propagation, and availability/awareness of quieter habitat within individual tolerance limits. It is often difficult to identify behavioural effects of anthropogenic noise and assess their short- and long-term impact on individuals and populations, let alone predicting and mitigating them.

Recently, a group of experts in acoustic research have proposed a set of initial scientific recommendations in regards to marine mammal noise exposure criteria for both injury and behavioural disturbance (Southall *et al.* 2007). This could require the acoustic modelling of the habitat subject to a proposed seismic exploration project and the creation of specific safety radii for each particular habitat, based on its sound propagation properties. Based on this acoustic modelling, the spatial overlap with a species' critical habitat and the type of behaviour being undertaken by that species a risk, managers can more accurately assess the acceptable sound exposure threshold that an individual marine mammal should be limited to, as well as the spatial and temporal ranges over which monitoring should occur. At the current time, oil and gas seismic exploration projects undertaken in Newfoundland and Labrador are subject to mitigation measures set by the Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment (www.dfo-mpo.gc.ca/oceans-habitat/oceans/im-gi/seismic-sismique/index_e.asp), which are broad and neither context- or species-specific. Based on the location of current Exploration and Production Licences off Newfoundland and Labrador (Figure 4.20), oil and gas exploration and production activities have the greatest potential to overlap with identified blue whale core habitat off the south coast of Newfoundland and the Strait of Belle Isle/Gulf of St. Lawrence regions, and fin and sei whale core habitat off coastal Labrador.

4.2.2.2 Vessel traffic

Vessel traffic has the potential to impact large whales in two ways: physically through vessel collisions and behaviourally, through the presence of vessels (mainly the influence of vessel noise). Physical effects could range from fatal to a non-fatal injury that would not affect the animal's ability to fulfil its normal activities. Behavioural effects resulting from vessel noise could be more subtle and difficult to assess, and could involve the displacement of individuals or masking of acoustic communication, both of which could potentially interfere with migration, feeding, or mating activities.

Vessel collisions

Evidence suggests that a greater rate of mortality and serious injury is correlated with a greater vessel speed at the time of a ship strike (Laist *et al.* 2001; Vanderlaan and Taggart 2007). Most lethal and severe injuries to large whales resulting from documented ship strikes have occurred when vessels were travelling at 14 knots or greater (Laist *et al.* 2001). Vanderlaan and Taggart (2007), using a logistic regression modelling approach based upon vessel strike records, found that for vessel speeds greater than 15 knots, the probability of a lethal injury (mortality or severely injured) approaches 1.0. The probability of lethal injury declined to approximately 0.2 at speeds of 8.6 knots (Vanderlaan and Taggart 2007). In a review of 58 large whale ship strikes in which the vessel speed was known, the average speed of vessels involved in ship strikes that resulted in mortality or serious injuries to the whale was found to be 18.6 knots (Jensen and Silber 2003). The frequency of incidents of ship strikes more than doubled when vessel speeds were 13-15 knots as opposed to 10 knots or less (Jensen and Silber 2003). Most lethal or severe injuries are caused by vessels >80 m in length (Laist *et al.* 2001).

Fin whales are the most commonly reported whale to be struck by vessels, followed by humpback whales and north Atlantic right whales (Jensen and Silber 2003; Vanderlaan and Taggart 2007). Blue whales, fin whales, and humpback whales were all struck in similar proportions, but to a lesser degree than north Atlantic right whales (Vanderlaan and Taggart 2007). Minke whales (*Balaenoptera acutorostrata*), sei whales, and sperm whales were not as frequently struck, proportionally, but have been reported (Vanderlaan and Taggart 2007). Published accounts of ship strikes suggest that most whales are not seen beforehand or are seen at the last minute (Laist *et al.* 2001).

While nearly all species of large whale have been victims of collisions with ships (Laist *et al.* 2001; Jensen and Silber 2003; Vanderlaan and Taggart 2007), right whales are especially vulnerable likely because of certain characteristic behaviours during which they may be less aware of their surroundings. In an attempt to reduce mortalities due to vessel strikes, several mitigation measures have been employed or are proposed, including shifting shipping lanes to avoid areas where right whales occur in high numbers (Right Whale News 2007) and imposing vessel speed restrictions in certain coastal U.S. waters during certain times of the year (Federal Register 2006). Similar mitigations could be employed for blue, fin, and sei whale (and other marine mammal species at risk susceptible to vessel collisions) if their critical habitat overlaps with heavy shipping traffic. Most importantly for large rorquals would be the implementation of speed restrictions, especially during periods of peak season abundance. As most recorded vessel collisions occur at speeds greater than 10 knots (Jensen and Silber 2003), this could be a proposed speed limitation for vessel traffic within blue, fin, and sei whale critical habitat. Based on the location of shipping lanes and offshore platform supply vessel routes (Figure 4.21), vessel traffic activities have the greatest potential to overlap with identified blue whale core habitat off the south coast of Newfoundland and should be carefully monitored within this region.

Vessel noise

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. 252-274. More recent studies are summarized in LGL (2007) and Lusseau and Bejder (2007).

Most studies examining the potential impacts of vessel noise (or other sources of anthropogenic noise) are designed to only describe short-term impacts on individuals. In many cases, the long-term or population-level impacts cannot be assessed. Only with continuous and diligent data recording from various research groups and monitoring programs of offshore anthropogenic activities can such potential long-term and population-level effects be properly assessed. However, considering the often short window of opportunity available for large whales to exploit a selected feeding habitat, the displacement of an individual or population from this habitat could prove detrimental to the successful completion of other life history parameters, such as mating or the ability to care for a young calf.

In Newfoundland and Labrador, and in many other coastal locations around the world, vessel noise is not a concern limited to commercial transport traffic. Whale watching is a rapidly growing business world-wide and plays an important role in attracting tourists to Newfoundland and Labrador. Whale watching excursions are often promoted as ecotourism activities that do not disturb the animals being observed. The review of the impact of vessel noise above (see Richardson *et al.* 1995, LGL 2007, and Lusseau and Bejder 2007) indicates that this is not always the case.

Proponents of whale watching argue that whale watching also plays a more general environmental protection role by inducing conservation (Corkeron 2004). However, attitude changes may not necessarily translate into behavioural changes and environmental actions (Leeming *et al.* 1993; Orams 1997). When educational outcomes were examined in Newfoundland and Labrador, it was determined that the amount of basic knowledge regarding the marine mammal species observed did not differ before versus after the whale watching excursion (Abgrall *et al.* 2003). In addition, a study of the effectiveness of a voluntary Code of Conduct introduced in 2001 in Newfoundland and Labrador revealed that compliance was low among tour operators and that passengers were not familiar with the existence of this Code (Corbelli 2006). Self-regulated voluntary codes of conduct for whale watching operations in Australia and the northeast region of the United States were also determined to be ineffective management tools (Allen *et al.* 2007; Wiley *et al.* 2008). It is evident that the knowledge transfer methods need to be re-evaluated and improved, both between scientists and tour operators, and between tour operators and whale watchers/clients, if whale watching excursions are to be considered ecotourism activities with meaningful environmental benefits.

In the meantime, considering the limited success of the voluntary Code of Conduct in Newfoundland and Labrador, government regulations and enforcement measures could be required to minimize and control the impact of this rapidly growing economical activity on local whale population. These measures would likely need to be more restrictive (increased minimal distance of approach, limitation of the number of vessels allowed to interact with an individual or group of whales at any given time, limitation of the total number of vessel interactions allowed over a time period (daily and weekly, etc.)) when the target species are considered at risk.

4.2.2.3 Fisheries interactions

Fisheries interactions could negatively affect marine mammals in two ways: through the physical entanglement of individuals in fishing gear or through competition by limiting prey availability. Entanglements are most common for humpback whales, and to a lesser extend minke whales (Ledwell *et al.* 2001, 2002; Ledwell and Huntington 2003, 2004, 2006, 2007). While entanglements remain a potential threat to large rorquals (Lien 1994; Sears and Calambokidis 2002), the level of concern, as it relates to blue, fin, and sei whales is not as severe as for other potential anthropogenic threats. Active monitoring of large rorqual entanglements in any new or existing fisheries are needed to ensure a minimal impact of this potential threat as fishing practices and whale habitat are both in continuous states of flux.

Large rorquals have been shown to use waters around Newfoundland and Labrador for feeding. Should changes occur in the distribution and abundance of their prey, this would most likely impact their own distribution and, consequently, their identified critical habitat. Therefore, changes in prey distribution, abundance and pressures acting on these factors need to be monitored continually, a situation that is not happening for many prey species such as krill, in order to detect any potential changes in critical habitat for species at risk and adjust both the spatial and temporal locations of critical habitats when appropriate. Pressures acting on prey abundance and distribution are numerous and can range from changes in fishing pressure, climate change, or habitat degradation (including pollution and contamination). It is often difficult, if not impossible, to accurately predict end-results to changes in these pressures which is why continuous active monitoring represents such a crucial final and ongoing step of the critical habitat definition process.

4.3 Summary

This chapter aimed to fulfil Step 3 of the critical habitat definition protocol by identifying areas of potentially limiting resources and the limiting factors that could impact large rorquals within theses areas. The first two sections focused on determining the habitat use and habitat preference of blue, fin, and sei whales off Newfoundland and Labrador and, in the process, modelling the critical habitat of these species. These species are known to migrate to waters off Newfoundland and Labrador to feed. Stomach content analyses from whales taken by shore-based whaling operations indicated that a high proportion of animals used the waters off Newfoundland and Labrador to feed and that this occurred in every region, including areas of high population concentration.

Based on the data sources available, a model-based approach, using BioMapper and centred around the Ecological Niche Factor Analysis, proved an effective tool for the identification of habitat preference through a combination of ecogeographical variables (that could play a role in influencing prey abundance, distribution, and availability) and determining habitat suitability (*core* habitat) for blue, fin, and sei whales in waters around Newfoundland and Labrador, and more precisely, within the "candidate" critical habitats (areas of high population concentration) identified in Step 2 (see Chapter 3). The habitat suitability model did, however, highlight the importance of continued monitoring in order to increase the number of observations and improve model robustness. It also demonstrated the importance of scale and seasonal variation in the model building process.

The final section of this chapter summarized factors that could potentially impact large rorquals in their critical habitats and could require mitigation and protection, depending on the species using the habitat, the habitat features in question, and the potential impact (or cumulative impacts in the case of multiple factors). Potential limiting factors around Newfoundland and Labrador were described as sources of natural mortality (predation and ice entrapments) and anthropogenic threats (offshore oil and gas exploration and development, vessel traffic, and fisheries interactions). Anthropogenic threats such as environmental pollution and contamination (both marine and terrestrial) with the potential to cause habitat loss and degradation are of a more general concern and were not specifically addressed in this summary.

Because of the variations in the natural environment and the manner in which species interact with it, and the continual changes in the anthropogenic pressures acting on the environment and species at risk, continuous monitoring and adaptive management become key components of the critical habitat definition process to support appropriate mitigations measures and critical habitat protection. Step 4 of the protocol summarizes the role and importance of active monitoring and adaptive management in the critical habitat definition process, and how it relates and complements the first three steps of the protocol.

Chapter 5: Step 4 - Active Monitoring

The final step in the critical habitat definition protocol is the development of a proactive monitoring programme by scientists and managers. A regular assessment of the marine mammal population of interest in all available habitats, not just those considered critical habitat in a previous assessment, should be done in a time frame determined to be short enough so that the risk of adverse effects that would result in reductions in abundance going undetected or being irreversible is low enough to be acceptable to scientists and managers. Monitoring components that have the potential to influence the previous steps (natural history, population concentration, limiting resources, and limiting factors) will allow managers to determine whether the critical habitat characteristics (biological, spatial, or temporal boundaries) need to be adjusted and assess the risk of impacting activities if proposed in other habitats or on other *SARA*-listed species. These adjustments could include an increase or decrease in size of a specific area, or an increase or decrease in the number of areas to be protected. Changes in population vulnerability, ecosystem resilience, or abundance trends are examples of parameters that would likely trigger an adjustment of the critical habitat characteristics. Additionally, mitigation measures established within critical habitats to limit the potential threat of specific anthropogenic activities need to be continuously reviewed and assessed in terms of their effectiveness. Changes in the biological parameters of a species at risk or in its habitat characteristics, as well as changes in the anthropogenic pressures could all impact the effectiveness of a specific mitigation and require scientists and managers to adjust them accordingly.

Harwood (2001) stated that critical habitat must be a functioning ecological unit that accounts for all species and their interactions within the unit, or else it will not persist. Ecological units and anthropogenic impacts change over time. Critical habitats must be designed and implemented to account for these temporal and spatial changes. A flexible, adaptive management approach such as this could respond to threats adaptively.

5.1 Challenging the model

This study has emphasized the importance of active monitoring at various stages of the critical habitat assessment process for blue, fin, and sei whales in Newfoundland and Labrador waters. *Core* habitat, as defined through the ENFA (see Section 4.1.2), within areas of high population concentration was identified as candidate critical habitat in Chapter 4. While each model's accuracy was tested through a cross-validation process in Section 4.1.2.3, it is important to continuously challenge these models and their accuracy when new information becomes available (Drinkwater and Myers 1987). The absence of large quantities of recent sighting records and dedicated survey effort for these rorqual species in Newfoundland and Labrador required the use of the best available data at this time, including shore-based whaling records dating back to 1945. Future aerial, marine, and acoustic surveys will provide valuable data to monitor the validity of these candidate critical habitats. The continued maintenance and expansion of the DFO cetacean sightings database will also add up-to-date data crucial to the active monitoring process. Technological improvements in communications (notably e-mail) and digital photography will facilitate the reporting of cetacean sightings and provide an additional tool to increase the quantity and control the quality of sightings reported.

Since the completion of the analyses presented in this thesis, 126 new sightings (12 blue whales, 112 fin whales, and two sei whales) dating from 2005 to 2007 and occurring in the study area have been added to the DFO cetacean sightings database. Most originated from the recent TNASS aerial survey of eastern Canadian waters conducted by DFO from 17 July to 24 August, 2007 (Lawson and Gosselin 2008). These sightings are used to further challenge the accuracy of the habitat suitability models, and, in the process, the candidate critical habitats identified within areas of high population concentration.

Of the 12 new blue whale sightings, 11 were observed in areas of high population concentration (eight off the south coast of Newfoundland and three in the Strait of Belle Isle/Gulf of St. Lawrence). Using the habitat suitability model for the overall study area (adapted from Figure 4.3) and considering only the subset of sightings within areas of high population concentration, seven of the 11 (64%) blue whale sightings that were observed in areas of high population concentration occurred in *core* habitat (candidate critical habitat), three sightings occurred in *marginal* habitat, and the remaining sighting occurred in the middle of the Laurentian Channel (*unsuitable* habitat; Figure 5.1). The only new sighting reported in a region that was not identified as an area of high population concentration for blue whales occurred in the northeast Newfoundland region (Figure 5.1). Given that 15% of the areas of high population concentration was classified as blue whale *core* habitat, four of 11 sightings in *core* habitat would represent a statistically significant validation of the model (α=0.05, binomial probability=0.015; binomial test, e.g., Zar 1999). Thus, the probability of seven of 11 sightings occurring in the *core* habitat is extremely low (p=0.000028).

The situation differed when considering the new fin whale sightings. Of the 112 new fin whale sightings, 10 were observed in areas of high population concentration (three off coastal Labrador and seven off northeast Newfoundland). Using the habitat suitability model for the coastal Labrador and northeast Newfoundland regions (adapted from Figures 4.10 and 4.11, respectively) and considering only the subset of sightings within areas of high population concentration, six of the 10 fin whale sightings that were observed in areas of high population concentration occurred in or near *core* habitat (candidate critical habitat) while two of the remaining sightings occurred in *marginal* habitat (Figure 5.2). Only two fin whale sightings were reported in *unsuitable* habitat (Figure 5.2). Given that 6% of the areas of high population concentration was classified as fin whale *core* habitat, two of 10 sightings in *core* habitat would represent a statistically significant validation of the model (α=0.05, binomial probability=0.019). Thus, as is the case for the blue whale, the probability of six of 10 fin whale sightings occurring in the *core* habitat is extremely low (p=0.00000029). Most (102) of the new fin sightings were reported in regions that were not identified as areas of high population of concentration in this study (Figure 5.2).

While only a limited number of new blue and fin whale sightings occurred in areas of high population concentration to assess the accuracy of the critical habitat models developed, this process is a good example of an active monitoring technique to continually challenge defined critical habitats and appeared to support the proposed habitat suitability models. The fact that a large number of the new fin whale sightings occurred outside of the areas of high population concentration defined in this study emphasises the need for active monitoring at every step of the protocol. New, more recent, data can challenge our current understanding of large whale habitat use and preference, and in the process, critical habitat definition.

The absence of *a priori* knowledge regarding areas of high population concentration and candidate critical habitats could, in part, be responsible for the limited number of fin whale sightings off northeast Newfoundland and coastal Labrador. The majority of these new sightings result from the 2007 TNASS survey. This survey began off the coast of Labrador and surveyed the waters of Newfoundland and Labrador going south. The completion of the survey in Labrador waters appears to have occurred earlier than the arrival of migratory animals which appeared to be a month later than usual (Lawson and Gosselin 2008). The knowledge gained through the analyses presented in this thesis will provide guidance to scientists charged with the design of future survey efforts so they can better apportion survey effort based on expected whale density. Predictive models such as those derived in this thesis may also allow managers to better understand and support changes in survey effort.

5.2 Future Direction

Studies aimed at identifying the current distribution and abundance patterns within areas of high population concentration would enable scientists and managers to more accurately assess the risk to a population from changes to limiting resources or the introduction of anthropogenic activities (limiting factors). This can be accomplished through dedicated aerial and marine surveys. Other studies such as passive acoustic monitoring, satellite tagging, photo-identification, and biopsy sampling can also add to the general body of knowledge regarding the habitat use of these species. Sea-bottom passive acoustic recorders enable long-term monitoring of areas and would increase our knowledge of seasonal habitat use. Satellite tagging studies are difficult to undertake for large rorquals that utilize offshore waters. The data obtained, although limited in number, can contribute to our knowledge of the habitat use of these species, both locally (including records of dive depth and duration) and generally (including some insight into the overall home range of individuals, migration routes, and the potential for population exchange between different regions). Satellite tracking studies could also contribute to the assessment of habitat suitability models for blue, fin, and sei whales (proportion of time spent in designated *core* habitat). Photo-identification and biopsy sampling can both contribute to our understanding of population exchange and habitat use with neighbouring regions. This also will provide critical information that will enable scientists and managers to accurately assess the risk associated with critical habitat protection, or non-protection.

Finally, studies aimed at understanding the availability and fluctuations of feeding resource, both seasonally and annually, will be essential to our risk assessment of critical habitat protection. Without such information, critical habitat identification and protection remains limited in scope and primarily precautionary. The current study provides a preliminary assessment of blue, fin, and sei whale habitat use and preference in Newfoundland and Labrador. This information is crucial to the critical habitat identification process for these species within the study area and provides the initial building blocks from which additional habitat use and preference studies for blue, fin, and sei whales can expand upon.

Chapter 6: Conclusion

The definition of critical habitat will vary for a particular species of interest (such as those under legal listing with the *Species at Risk Act*) as it relates to that species' ecological needs. Our ability to define a critical habitat for that species is constrained by our understanding of the species' natural history traits and biological requirements, our impacts upon them, our ability to detect and monitor these impacts, and ultimately the level of acceptable risk that management decisions invoke for the fate of the population. Managers must account for the components of critical habitat affecting a species (natural history, population concentration, limiting resources, limiting factors, population or prey vulnerability and resilience, and population trend), and how these shift over space and time. Such dynamic descriptions of habitat are extremely difficult to summarize, and particularly so when biological understanding for marine mammals which spend so little time within our view is limited or non-existent. Within this context, decision makers must act in a highly precautionary manner and utilize adaptive management so as to minimize the risks to *SARA*-listed marine mammal species.

While areas of high animal concentration play an important role in defining a species' critical habitat, this study has demonstrated how other definable (and in many cases, quantifiable) components should also be considered during critical habitat definition as they can potentially affect the proportion of a species' home range that will be designated as critical habitat. In addition to areas of local marine mammal abundance, critical habitats can be defined by the types of anthropogenic pressures acting upon them, the rate of change of these pressures, and their magnitude. Abiotic and biotic factors may be used to assess the habitat preference of a species and determine the range over which anthropogenic impacts should be measured, as has been done in this thesis. According to the *SARA* legislation, critical habitat is the "habitat that is necessary for the survival or recovery of a listed wildlife species". Therefore by definition, critical habitats are not legally restrained to the anthropogenic impacts potentially affecting them. By not limiting critical habitat definition to a scale that would only address anthropogenic threats, *SARA* provides protection to critical habitats not currently affected by anthropogenic impacts, but that could be in the future.

The aim of this project was to develop a procedure to define critical habitat for species at risk under *SARA* and apply it to blue, fin, and sei whales in an effort to increase our understanding of their habitat use and preference around Newfoundland and Labrador. To achieve this goal, a step-by-step protocol was developed to help decision-makers achieve habitat protection goals for species at risk. This protocol can serve as a guideline by which critical habitat determination timetables can be created and more concise, specific adaptive management objectives can be outlined. Critical habitat definition for species at risk was described in a four-step protocol: Step 1 – natural history description; Step 2 – population concentrations as habitat ranking markers ("Candidate" Critical Habitats); Step 3 – assessing limiting resources and limiting factors ("Protected" Critical Habitats); and Step 4 – active monitoring.

The protocol was useful in identifying areas of high population concentrations and potentially limiting resources (by identifying habitat use), and thus modelling "candidate" critical habitats for blue, fin, and sei whales. Potential limiting factors were also summarized and conditions were highlighted in which these "candidate" critical habitats should become "protected" critical habitats.

Areas of high population concentrations, including seasonal peaks, for blue, fin, and sei whales were described through historical shore-based whaling records and DFO's cetacean sightings database. These were labelled as initial candidate critical habitats. They include: the south coast of Newfoundland during spring and summer, and the Strait of Belle Isle/Gulf of St. Lawrence during spring for blue whales; coastal Labrador and northeast Newfoundland during summer for fin whales; and the south coast of Newfoundland during summer and coastal Labrador during summer and autumn for sei whales. These regions were demonstrated to have served historically as feeding habitats for all of these species.

An Ecological Niche Factor Analysis, using ecogeographical variables (water depth, seabed slope, sea-surface temperature, and chlorophyll concentrations) provided more precise models of habitat suitability and candidate critical habitat through an increased understanding of large rorqual habitat use. These models varied in their predictive accuracy and are illustrated, for each region described as an area of high population concentration, in Figures 4.4 and 4.5 for blue whales; Figures 4.10 and 4.11 for fin whales; and Figure 4.16 for sei whales. Season-specific critical habitat models were generally low in their predictive accuracy, with the exception of two critical habitat models: blue whales off the south coast of Newfoundland during summer (Figure 4.6) and fin whales off coastal Labrador during summer (Figure 4.12). When challenged with a small set of new sightings records that were not used in the ENFA, the habitat suitability models, and hence candidate critical habitats, proved to be fairly accurate. Sixty-four percent of new blue whale sightings (n = 11) and sixty percent of new fin whale sightings (n = 10) were located in habitat designated as *core*.

Table 2.1 Biological components of critical habitat.

Components	Relevance to Critical Habitat
Natural history description	Predictable changes in natural history parameters such as feeding, breeding, or migratory routes should lead to spatial and/or temporal shifts or expansions in the boundaries of critical habitats.
Population concentrations	Areas of relatively high population concentration will more likely need to be considered critical habitat based on limiting resources and processes acting within it. The presence of habitat features uniquely suited to the species would also favour its definition as critical.
Limiting resources	Prey: A decrease in overall prey abundance may require that additional, smaller, prey patches be protected and considered critical habitat. Spatial and/or temporal shifts in prey patch boundaries would require corresponding shifts in critical habitat boundaries. Shelter: A decrease in available shelter leading to an increase in predation or a decrease in mating success may require an increase in overall proportion of the home range to be considered critical based on its effect on vulnerability and resilience, and recent population trends (see impacts of these components below).
Limiting factors	Includes sources of natural mortality and anthropogenic threats. Direct (physical harm) or indirect (behavioural effects) impacts will impact population levels. If anthropogenic impacts act to decrease the population level beyond what is considered acceptable (based on set recovery goals), they will need to be mitigated and the habitat protected through critical habitat designation.
Vulnerability and resilience	An increase in the vulnerability of a species may require that a larger proportion of its habitat be designated as critical. Favour ecological resilience through adaptive management.
Recent population trends	Species with increasingly rapid declines in population size may require a larger proportion of their home range to be designated as critical.
Other considerations	Unique components of marine mammal natural history, such as the attachment to land for pinnipeds, need to be considered. The quality of biological data or threats to the species of concern, or its absence in certain cases, may require alternate methods to fill in data gaps and determine critical habitats. Historical data such as from whaling records, marine mammal watching operations, commercial shipping, and ferry routes could provide data if treated appropriately. Climate shifts could force spatial shifts in the boundaries or overall locations of critical habitats to follow shifts in limiting resources.

Table 2.2 A step-by-step protocol for critical habitat definition.

Step	Associated Components	Action
1	Natural history description	Describe natural history of the species (by individual population if appropriate), including feeding, mating, and birthing grounds. Migratory routes, in the case of migratory species, should also be considered. Identify knowledge gaps and address them.
2	Population concentrations as habitat ranking markers ("Candidate" Critical Habitats)	Divide population into areas of population concentration. Use these as ranking markers for assessment in Step 3 with areas of greatest concentration ranking highest. Consider these areas of population concentration as "candidate" critical habitats.
3	Assessing limiting resources and limiting factors ("Protected" Critical Habitats)	Assess limiting resources and limiting factors within population concentration areas prioritizing based on the ranking order established in Step 2. If any of these impact the population in a manner that would affect the attainment of the set recovery goal, the "candidate" critical habitats affected should be considered "protected" critical habitats. Assess risk of not protecting habitat based on population concentration and ranking marker established in Step 2, and other considerations relating to natural history (unique components of species, data gaps, and sensitivity to climate change).
4	Active monitoring of all components, including vulnerability, resilience, and recent population trends	Monitor for changes in critical habitat components used in Steps 1-3, in addition to changes in species vulnerability, ecosystem resilience, and recent population trends. Use adaptive management. Use knowledge gained by monitoring to assist in risk assessment of impacting activities in other habitats or on other *SARA*-listed species.

Table 3.1 Newfoundland and Labrador shore-based whaling data sources.

Year	Data Source
1898-1915 (excluding 1913)	Newfoundland Annual Fisheries Reports
1918, 1923-1923, 1937	Dickinson and Sanger (2005)
1927-1972 (excluding 1937)	International Whaling Commission

Table 3.2 Number of years during which whaling occurred at each station (not including mirror stations), within each region, during the four whaling phases.

	Whaling Phase				
Region/ Station	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**	**All Phases**
Coastal Labrador					
Grady		3			**3**
Hawke Harbour	11	10	11	4	**36**
Total	**11**	**13**	**11**	**4**	**39**
Northeast Newfoundland					
Beaverton	8	1			**9**
Snook's Arm	16				**16**
Williamsport			7	6	**13**
Total	**24**	**1**	**7**	**6**	**38**
East Newfoundland					
Aquaforte	7				**7**
Cape Broyle	10				**10**
Dildo			4	20	**24**
Harbour Grace	3				**3**
Safe Harbour	3				**3**
St. Mary's	3				**3**
Trinity	10				**10**
Total	**36**	**0**	**4**	**20**	**60**
South Coast of Nfld					
Balaena	16				**16**
Chaleur Bay	7				**7**
Dublin Cove	11				**11**
Little St. Lawrence	6				**6**
Rose-au-Rue	13	10	4		**27**
Total	**53**	**10**	**4**	**0**	**67**
Strait of Belle Isle/Gulf					
Cape Charles	8				**8**
Hawk's Bay	8				**8**
L'Anse-au-Loup	2				**2**
Total	**18**	**0**	**0**	**0**	**18**
All Regions	**142**	**24**	**26**	**30**	**222**

Table 3.3 Number of blue, fin, and sei whales taken off Newfoundland and Labrador based on shore-based whaling effort-adjusted data (including estimates for catches lacking specific species identification or location) during each whaling phase for the five NAFO regions from 1898-1972.

	Region by NAFO division					
Species/ Phase	**2H/2J**	**3K**	**3L**	**3Pn/3Ps**	**4R/4S**	**All Regions**
Blue whale						
Phase 1	5	9	126	1,350	61	**1,551**
Phase 2	72	0	0	114	0	**186**
Phase 3	117	16	0	8	42	**183**
Phase 4	0	0	0	0	0	**0**
All Phases	**194**	**25**	**126**	**1,472**	**103**	**1,920**
Fin whale						
Phase 1	608	1,170	1,134	1,337	413	**4,662**
Phase 2	1,895	66	0	751	0	**2,712**
Phase 3	2,180	1,469	4	238	37	**3,928**
Phase 4	121	1,872	501	1	4	**2,499**
All Phases	**4,804**	**4,577**	**1,639**	**2,327**	**454**	**13,801**
Sei whale						
Phase 1	0	1	2	90	0	**93**
Phase 2	30	0	0	37	0	**67**
Phase 3	67	24	0	6	3	**100**
Phase 4	11	8	11	1	0	**31**
All Phases	**108**	**33**	**13**	**134**	**3**	**291**

2H/2J=coastal Labrador
3K=northeast Newfoundland
3L=east Newfoundland
3Pn/3Ps=south coast of Newfoundland
4R/4S=Strait of Belle Isle/Gulf of St. Lawrence

Table 3.4 Habitat ranking of each region for all whaling phases combined, and during each whaling phase, for blue, fin, and sei whales (Region 1=coastal Labrador, 2=northeast Newfoundland, 3=east Newfoundland, 4=south coast of Newfoundland, and 5=Strait of Belle Isle/Gulf of St. Lawrence; bold values represent regions that recorded CIs of the observed proportions of whales landed that were greater than expected).

	Ranking of Regions		
Phase/Rank	**Blue Whales**	**Fin Whales**	**Sei Whales**
All Phases			
1	**4**	**2, 1**	**4, 1**
2	5		
3	3, 1	5, 4, 3	2, 3, 5
4			
5	2		
Phase 1			
1	**4**	**1**	**4**
2	5, 3	**2**	3, 2, 1, 5
3		3, 4, 5	
4	1,2		
5			
Phase 2			
1	**4**, 1, 2	1, 2, **4** *	**4**, 1, 2 *
2			
3			
4			
5			
Phase 3			
1	**5**	**2, 1**, 4	4, 2, **1**, 5, 3 *
2	4, **1**, 2		
3			
4		5	
5	3	3	
Phase 4			
1	-	**2**, 5, 1	4, 3, 1, 2, 5 *
2	-		
3	-		
4	-	3, 4	
5	-		

* Non-significant variation (α=0.05) following Kruskal-Wallis analysis of variance by ranks.

Table 3.5 Habitat ranking of seasons for all regions combined, and for each region, for blue, fin, and sei whales (bolded values represent seasons that recorded CIs of the observed proportions of whales landed that were greater than expected).

	Ranking of Seasons		
Region/ Rank	**Blue Whales**	**Fin Whales**	**Sei Whales**
All Regions			
1	Spring, **Summer**	**Summer**	**Summer**, Autumn
2	Autumn	Autumn, Spring	Spring
3			
2H/2J			
1	Summer, Spring, Autumn	**Summer**	**Summer, Autumn**, Spring*
2		Autumn	
3		Spring	
3K			
1	**Summer**, Spring, Autumn	**Summer**	**Summer**, Autumn, Spring *
2		Autumn	
3		Spring	
3L			
1	Insufficient Data	Spring, Autumn, **Summer** *	Autumn, Summer, Spring *
2			
3			
3Pn/3Ps			
1	**Spring**, Summer, Autumn *	**Spring**	**Summer**, Spring, Autumn *
2		Summer, Autumn	
3			
4R/4S			
1	Insufficient Data	Insufficient Data	Insufficient Data
2			
3			

* Non-significant variation (α=0.05) following Kruskal-Wallis analysis of variance by ranks.

2H/2J=coastal Labrador
3K=northeast Newfoundland
3L=east Newfoundland
3Pn/3Ps=south coast of Newfoundland
4R/4S=Strait of Belle Isle/Gulf of St. Lawrence

Table 3.6 Number of blue, fin, and sei whale sightings off Newfoundland and Labrador based on the DFO cetacean sighting database during each season for the five NAFO regions from 1958-2006 (using only open-water sightings).

	Region by NAFO division					
Species/ Season	**2G/2H/2J**	**3K**	**3L/3N/3O**	**3Pn/3Ps/ 4Vn/4Vs**	**4R/4S/4T**	**Total**
Blue whale						
Winter	0	0	0	13	1	**14**
Spring	0	1	2	1	6	**10**
Summer	1	1	9	52	3	**66**
Autumn	0	0	0	0	1	**1**
Total	**1**	**2**	**11**	**66**	**11**	**91**
Fin whale						
Winter	0	0	5	4	0	**9**
Spring	6	17	176	38	17	**254**
Summer	56	189	386	85	28	**744**
Autumn	74	55	25	10	4	**168**
Total	**136**	**261**	**592**	**137**	**49**	**1,175**
Sei whale						
Winter	0	0	0	0	0	**0**
Spring	0	2	12	2	0	**16**
Summer	26	8	25	3	0	**62**
Autumn	18	6	0	2	0	**26**
Total	**44**	**16**	**37**	**7**	**0**	**104**

2G/2H/2J=coastal Labrador
3K=northeast Newfoundland
3L/3N/3O=east Newfoundland
3Pn/3Ps/4Vn/4Vs=south coast of Newfoundland
4R/4S/4T=Strait of Belle Isle/Gulf of St. Lawrence

Table 3.7 "Candidate" critical habitats of blue, fin, and sei whales off Newfoundland and Labrador based on the shore-based whaling data and the DFO cetacean sighting database.

Species	**Region**	**Season**
Blue whale	Southern Newfoundland	Spring and Summer
	Strait of Belle Isle/Gulf of St. Lawrence	Spring
Fin whale	Coastal Labrador & Northeast Newfoundland	Summer
Sei whale	South coast of Newfoundland	Summer
	Coastal Labrador	Summer and Autumn

Table 4.1 Number of blue, fin, and sei whales taken off Newfoundland and Labrador during shore-based whaling with records of food in their stomach, empty stomachs, and unknown stomach contents for the five NAFO regions from 1927-1972.

	Region by NAFO division					
Species/ Stomach Content	**2H/2J**	**3K**	**3L**	**3Pn/3Ps**	**4R/4S**	**All Regions**
Blue whale						
With Food	133	16	0	0	40	**189**
Empty	13	0	0	0	2	**15**
Unknown	31	0	0	90	0	**121**
Total	**177**	**16**	**0**	**90**	**42**	**325**
Fin whale						
With Food	2,448	2,750	368	7	39	**5,612**
Empty	125	484	124	4	2	**739**
Unknown	643	107	13	563	0	**1,326**
Total	**3,216**	**3,341**	**505**	**574**	**41**	**7,677**
Sei whale						
With Food	67	26	7	1	3	**104**
Empty	19	5	3	0	0	**27**
Unknown	12	1	1	38	0	**52**
Total	**98**	**32**	**11**	**39**	**3**	**183**

2H/2J=coastal Labrador
3K=northeast Newfoundland
3L=east Newfoundland
3Pn/3Ps=south coast of Newfoundland
4R/4S=Strait of Belle Isle/Gulf of St. Lawrence

Table 4.2 Number of blue, fin, and sei whales taken off Newfoundland and Labrador during shore-based whaling with records of food in their stomach/total number of blue, fin, and sei whales (with records of food in their stomach + empty stomachs) during each season for the five NAFO regions from 1927-1972.

	Region by NAFO division					
Species/ Season	**2H/2J**	**3K**	**3L**	**3Pn/3Ps**	**4R/4S**	**All Regions**
Blue whale						
Spring	11/11	5/5	-	-	34/35	**50/51**
Summer	121/134	11/11	-	-	6/7	**138/152**
Autumn	1/1	-	-	-	-	**1/1**
Total	**133/146**	**16/16**	**-**	**-**	**40/42**	**189/204**
Fin whale						
Spring	35/39	168/205	115/163	6/10	29/29	**353/446**
Summer	1,866/1,943	2,110/2,440	189/244	1/1	7/8	**4,173/4,636**
Autumn	547/591	472/589	64/85	-	3/4	**1,086/1,269**
Total	**2,448/2,573**	**2,750/3,234**	**368/492**	**7/11**	**39/41**	**5,612/6,351**
Sei whale						
Spring	-	-	-	-	-	-
Summer	33/38	18/22	5/7	1/1	-	**57/68**
Autumn	34/48	8/9	2/3	-	3/3	**47/63**
Total	**67/86**	**26/31**	**7/10**	**1/1**	**3/3**	**104/131**

2H/2J=coastal Labrador
3K=northeast Newfoundland
3L=east Newfoundland
3Pn/3Ps=south coast of Newfoundland
4R/4S=Strait of Belle Isle/Gulf of St. Lawrence

Table 4.3 Number of blue, fin, and sei whales taken off Newfoundland and Labrador during shore-based whaling with records of different prey-types in their stomach for the five NAFO regions from 1927-1972.

	Region by NAFO division					
Species/ Stomach Content	**2H/2J**	**3K**	**3L**	**3Pn/3Ps**	**4R/4S**	**All Regions**
Blue whale						
Capelin	1	0	0	0	0	**1**
Fish	12	6	0	0	10	**28**
Krill/Shrimp	120	10	0	0	30	**160**
Empty	13	0	0	0	2	**15**
Unknown	31	0	0	90	0	**121**
Total	**177**	**16**	**0**	**90**	**42**	**325**
Fin whale						
Capelin	82	813	171	1	5	**1,072**
Fish	1,893	1,275	20	0	32	**3,220**
Krill/Shrimp	472	661	176	1	2	**1,312**
Squid	1	1	0	5	0	7
Other	1	4	2	4	0	**11**
Empty	124	480	123	0	2	**729**
Unknown	643	107	13	563	0	**1,326**
Total	**3,216**	**3,341**	**505**	**574**	**41**	7,677
Sei whale						
Capelin	0	2	0	0	0	**2**
Fish	61	23	2	1	3	**90**
Krill/Shrimp	6	1	5	0	0	**12**
Empty	19	5	3	0	0	**27**
Unknown	12	1	1	38	0	**52**
Total	**98**	**32**	**11**	**39**	**3**	**183**

2H/2J=coastal Labrador
3K=northeast Newfoundland
3L=east Newfoundland
3Pn/3Ps=south coast of Newfoundland
4R/4S=Strait of Belle Isle/Gulf of St. Lawrence

Table 4.4 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for blue whales around Newfoundland and Labrador during all seasons combined.

EGV	Marginality	Factor 2	Factor 3	Factor 4
	22.4%	52.5%	17.0%	8.1%
Water Depth	-0.637	-0.527	0.021	0.668
Seabed Slope	0.572	0.110	-0.488	0.504
SST	0.111	0.167	0.770	0.525
Chlorophyll	0.505	-0.826	0.410	0.157

Table 4.5 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for blue whales in the south coast of Newfoundland region during all seasons combined.

EGV	Marginality	Factor 2	Factor 3	Factor 4
	66.7%	19.2%	11.2%	2.9%
Water Depth	-0.030	0.329	-0.593	0.439
Seabed Slope	0.689	0.133	0.284	-0.199
SST	-0.466	-0.638	0.720	0.518
Chlorophyll	0.554	-0.683	0.220	0.707

Table 4.6 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for blue whales in the Strait of Belle Isle/Gulf of St. Lawrence region during all seasons combined.

EGV	**Marginality** 43.9%	**Factor 2** 32.1%	**Factor 3** 15.8%	**Factor 4** 8.1%
Water Depth	-0.148	0.054	0.845	-0.094
Seabed Slope	0.539	-0.077	-0.232	-0.841
SST	-0.829	-0.057	-0.303	-0.530
Chlorophyll	-0.003	-0.994	0.375	-0.061

Table 4.7 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for blue whales in the south coast of Newfoundland region during summer.

EGV	**Marginality** 43.1%	**Factor 2** 45.3%	**Factor 3** 9.1%	**Factor 4** 2.5%
Water Depth	0.222	0.246	0.399	0.795
Seabed Slope	0.889	0.018	-0.415	-0.182
SST	-0.399	0.229	-0.724	0.068
Chlorophyll	0.022	0.941	-0.381	0.574

Table 4.8 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for blue whales in the Strait of Belle Isle/Gulf of St. Lawrence region during spring.

EGV	Marginality	Factor 2	Factor 3	Factor 4
	30.4%	46.5%	14.7%	8.5%
Water Depth	-0.177	0.225	0.830	-0.017
Seabed Slope	0.378	0.109	-0.263	-0.898
SST	-0.895	-0.165	-0.196	-0.406
Chlorophyll	0.156	-0.954	0.452	-0.170

Table 4.9 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for fin whales around Newfoundland and Labrador during all seasons combined.

EGV	Marginality	Factor 2	Factor 3	Factor 4
	32.4%	41.8%	19.7%	6.1%
Water Depth	-0.683	-0.480	-0.489	-0.479
Seabed Slope	-0.284	0.148	-0.246	0.816
SST	-0.664	0.299	0.686	0.187
Chlorophyll	0.108	-0.811	0.479	0.264

Table 4.10 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for fin whales in the coastal Labrador region during all seasons combined.

EGV	Marginality 29.7%	Factor 2 52.5%	Factor 3 11.5%	Factor 4 6.3%
Water Depth	-0.831	0.419	0.317	0.455
Seabed Slope	-0.250	-0.023	-0.853	-0.265
SST	-0.356	-0.906	-0.353	-0.043
Chlorophyll	-0.348	-0.058	0.216	-0.849

Table 4.11 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for fin whales in the northeast Newfoundland region during all seasons combined.

EGV	Marginality 78.5%	Factor 2 9.7%	Factor 3 7.1%	Factor 4 4.7%
Water Depth	-0.623	0.524	0.506	0.773
Seabed Slope	-0.360	0.305	-0.521	-0.171
SST	-0.575	-0.794	-0.524	-0.550
Chlorophyll	-0.391	0.053	0.444	-0.265

Table 4.12 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for fin whales in the coastal Labrador region during summer.

EGV	Marginality 39.9%	Factor 2 47.7%	Factor 3 8.3%	Factor 4 4.1%
Water Depth	-0.507	0.033	-0.113	0.768
Seabed Slope	-0.142	-0.039	0.985	-0.064
SST	-0.006	0.998	0.090	-0.457
Chlorophyll	-0.850	-0.020	-0.098	-0.444

Table 4.13 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for fin whales in the northeast Newfoundland region during summer.

EGV	Marginality 82.9%	Factor 2 8.8%	Factor 3 4.4%	Factor 4 3.9%
Water Depth	-0.795	0.402	0.159	0.494
Seabed Slope	-0.467	-0.788	-0.520	-0.131
SST	-0.179	0.456	-0.555	-0.454
Chlorophyll	-0.342	-0.098	0.630	-0.730

Table 4.14 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for sei whales around Newfoundland and Labrador during all seasons combined.

EGV	Marginality 28.8%	Factor 2 42.2%	Factor 3 18.7%	Factor 4 10.3%
Water Depth	-0.575	-0.368	-0.730	-0.398
Seabed Slope	-0.070	0.138	-0.144	0.835
SST	-0.795	0.044	0.606	0.275
Chlorophyll	0.182	-0.918	0.283	0.262

Table 4.15 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for sei whales in the coastal Labrador region during all seasons combined.

EGV	Marginality 56.9%	Factor 2 27.8%	Factor 3 10.9%	Factor 4 4.4%
Water Depth	-0.838	-0.474	0.239	-0.348
Seabed Slope	-0.225	0.114	-0.927	0.277
SST	-0.423	0.873	-0.137	-0.013
Chlorophyll	-0.262	0.007	0.255	0.896

Table 4.16 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for sei whales in the coastal Labrador region during summer.

EGV	**Marginality** 60.7%	**Factor 2** 27.5%	**Factor 3** 9.3%	**Factor 4** 2.5%
Water Depth	-0.666	0.124	0.025	0.685
Seabed Slope	-0.040	0.180	-0.981	-0.061
SST	-0.047	0.959	0.192	-0.433
Chlorophyll	-0.743	-0.181	0.017	-0.583

Table 4.17 Variance explained by marginality and specialization (Factors 2-4) factors, including the amount of specialization accounted for by each factor, for sei whales in the coastal Labrador region during autumn.

EGV	**Marginality** 61.0%	**Factor 2** 31.8%	**Factor 3** 4.9%	**Factor 4** 2.3%
Water Depth	-0.601	0.163	-0.294	0.761
Seabed Slope	-0.284	-0.063	-0.775	-0.199
SST	-0.449	-0.847	0.462	-0.567
Chlorophyll	0.597	-0.502	-0.317	0.246

Figure 1.1 The Newfoundland and Labrador study area.

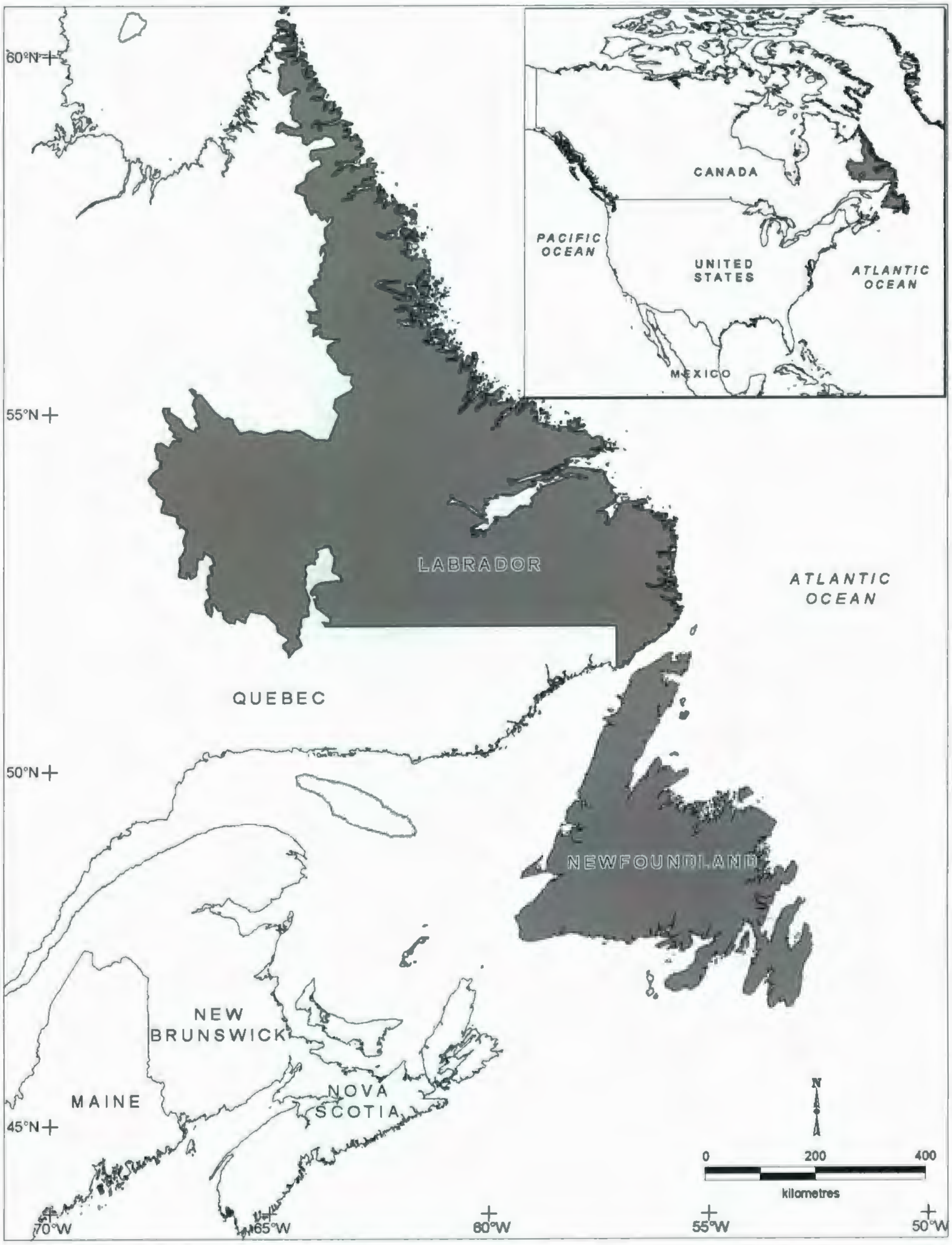


Figure 3.1 Newfoundland and Labrador shore-based whaling stations from 1898 to 1972 (Source: Dickinson and Sanger 2005).

Figure 3.2 Total whale-catch per year for all shore-based whaling stations combined from 1898 to 1972 (adapted from C.W. Sanger).

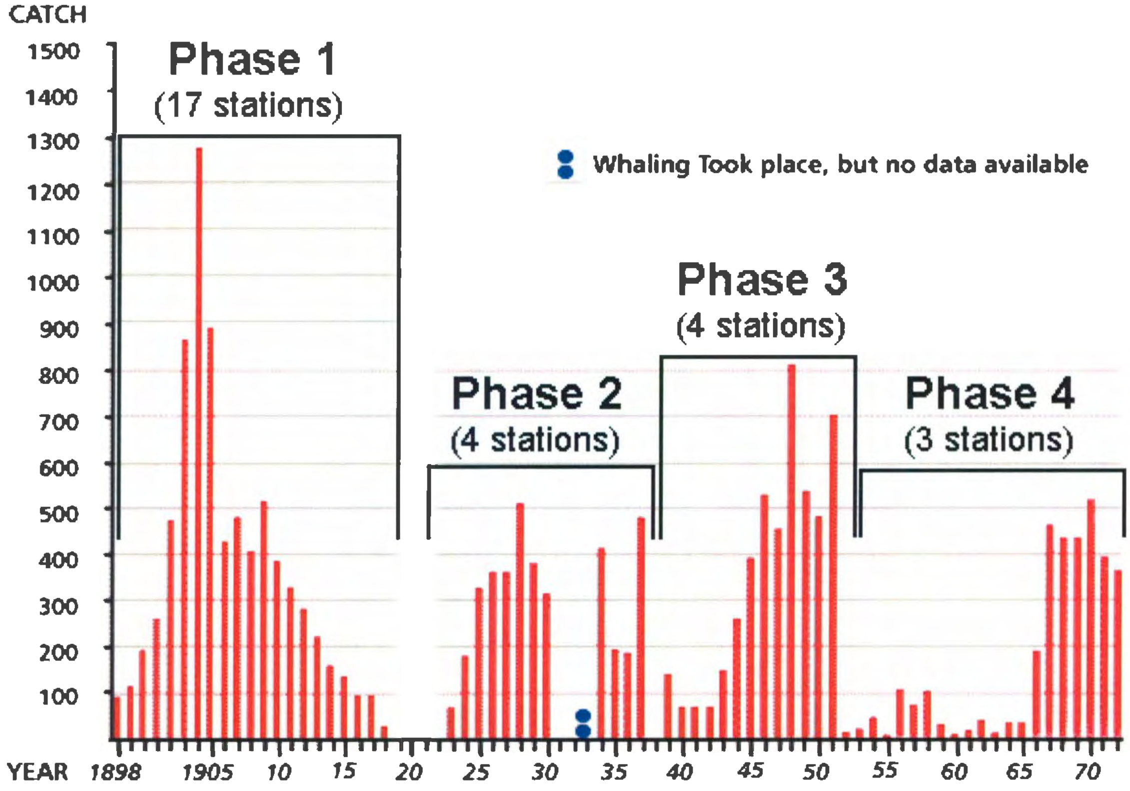


Figure 3.3 Five main regions described using NAFO divisions in waters surrounding Newfoundland and Labrador used in the analysis of shore-based whaling data {darker to lighter: coastal Labrador (2H and 2J), northeast Newfoundland (3K), east Newfoundland (3L), south coast of Newfoundland (3Pn and 3Ps), and Strait of Belle Isle/Gulf of St. Lawrence (4R and 4S)}.

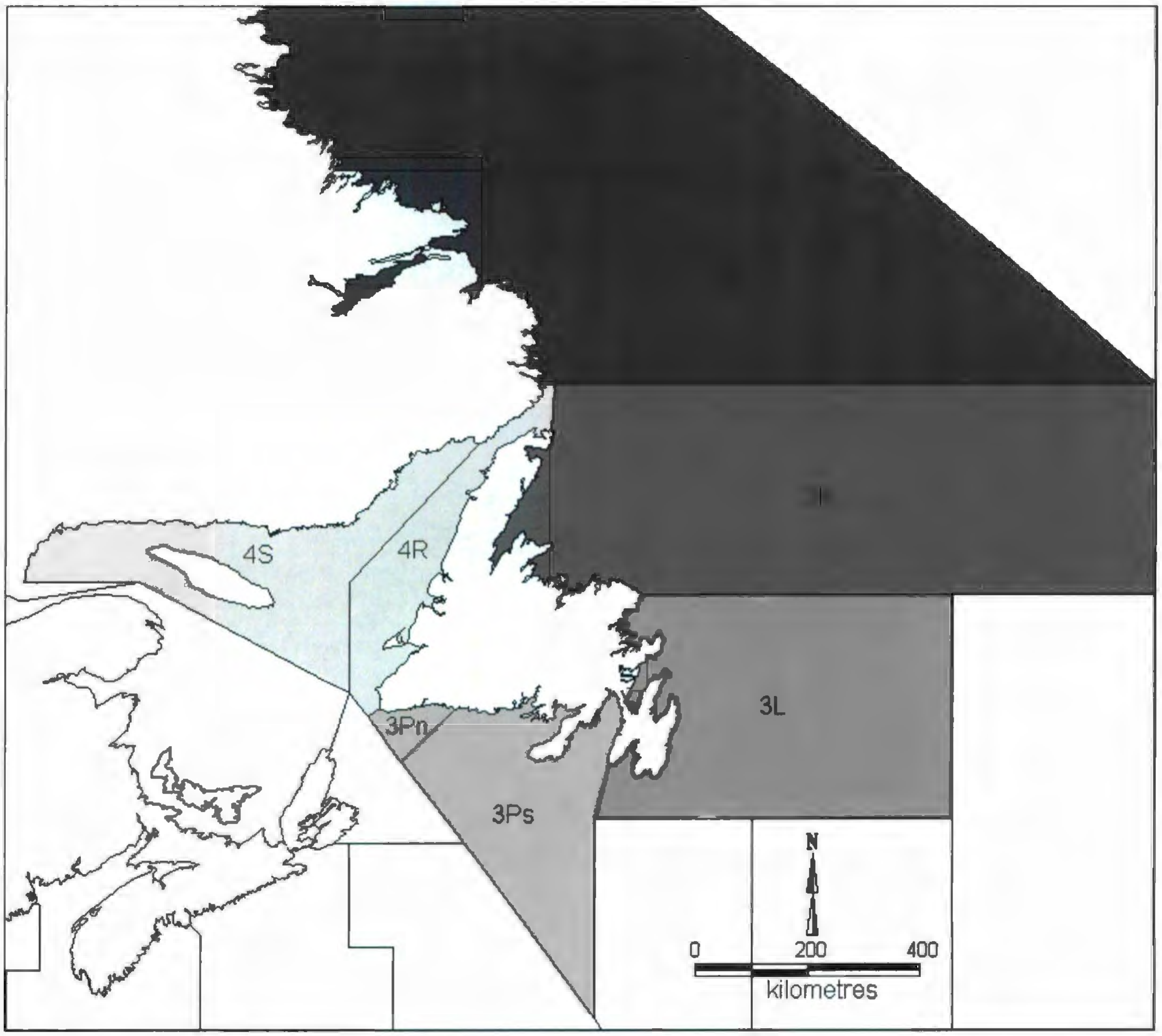


Figure 3.4 Five main regions described using NAFO divisions around Newfoundland and Labrador used in the analysis of the DFO cetacean sightings database {darker to lighter: coastal Labrador (2G, 2H, and 2J), northeast Newfoundland (3K), east Newfoundland (3L, 3N, and 3O), south coast of Newfoundland (3Pn, 3Ps, 4Vn, and 4Vs), and Strait of Belle Isle/Gulf of St. Lawrence (4R, 4S, and 4T)}.

Figure 3.5 Areas of high concentration of blue whales taken off Newfoundland and Labrador based on shore-based whaling effort-adjusted data (number of whales/catcher boat per year of active whaling in region) from 1898-1972.

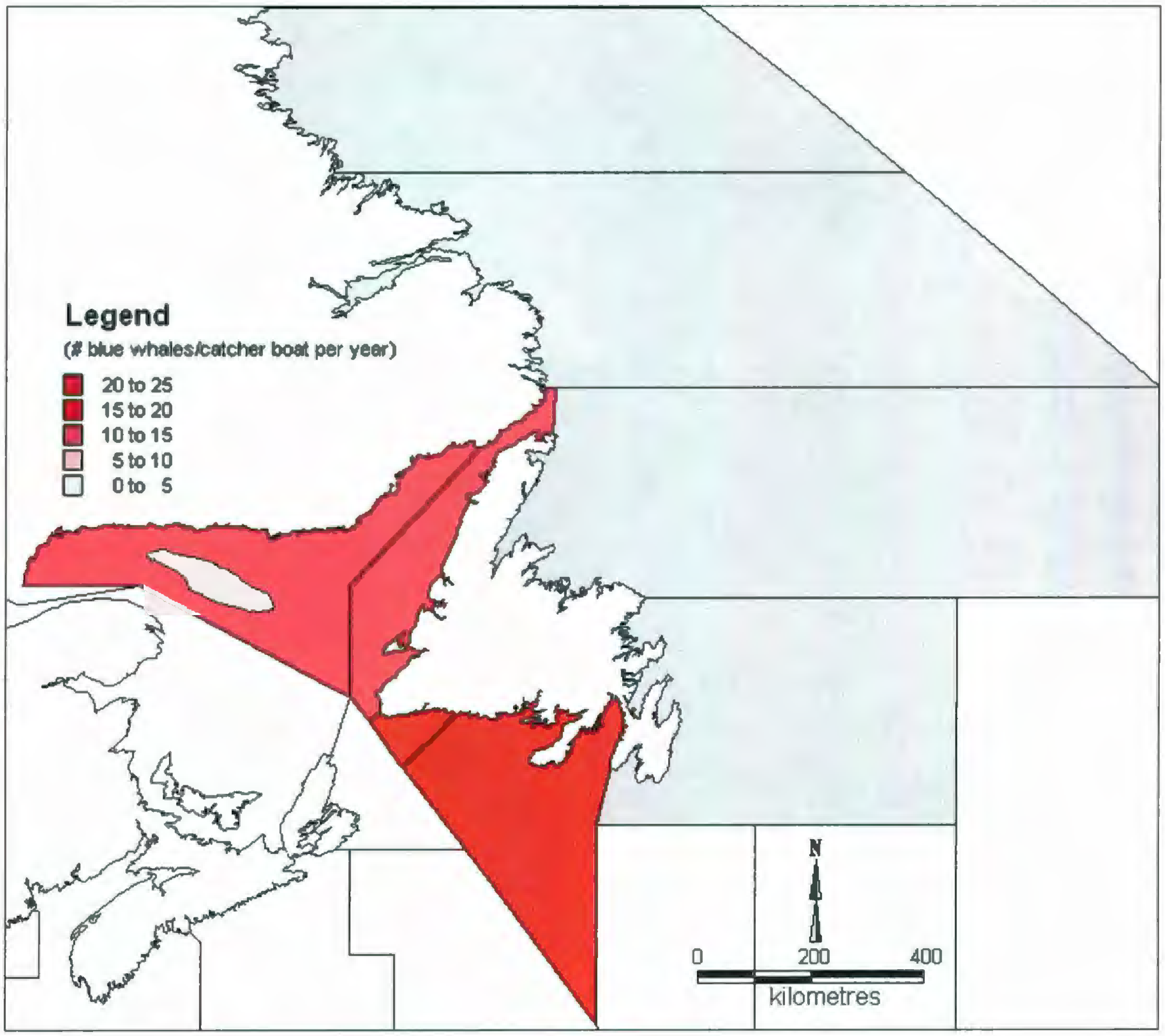


Figure 3.6 Areas of high concentration of fin whales taken off Newfoundland and Labrador based on shore-based whaling effort-adjusted data (number of whales/catcher boat per year of active whaling in region) from 1898-1972.

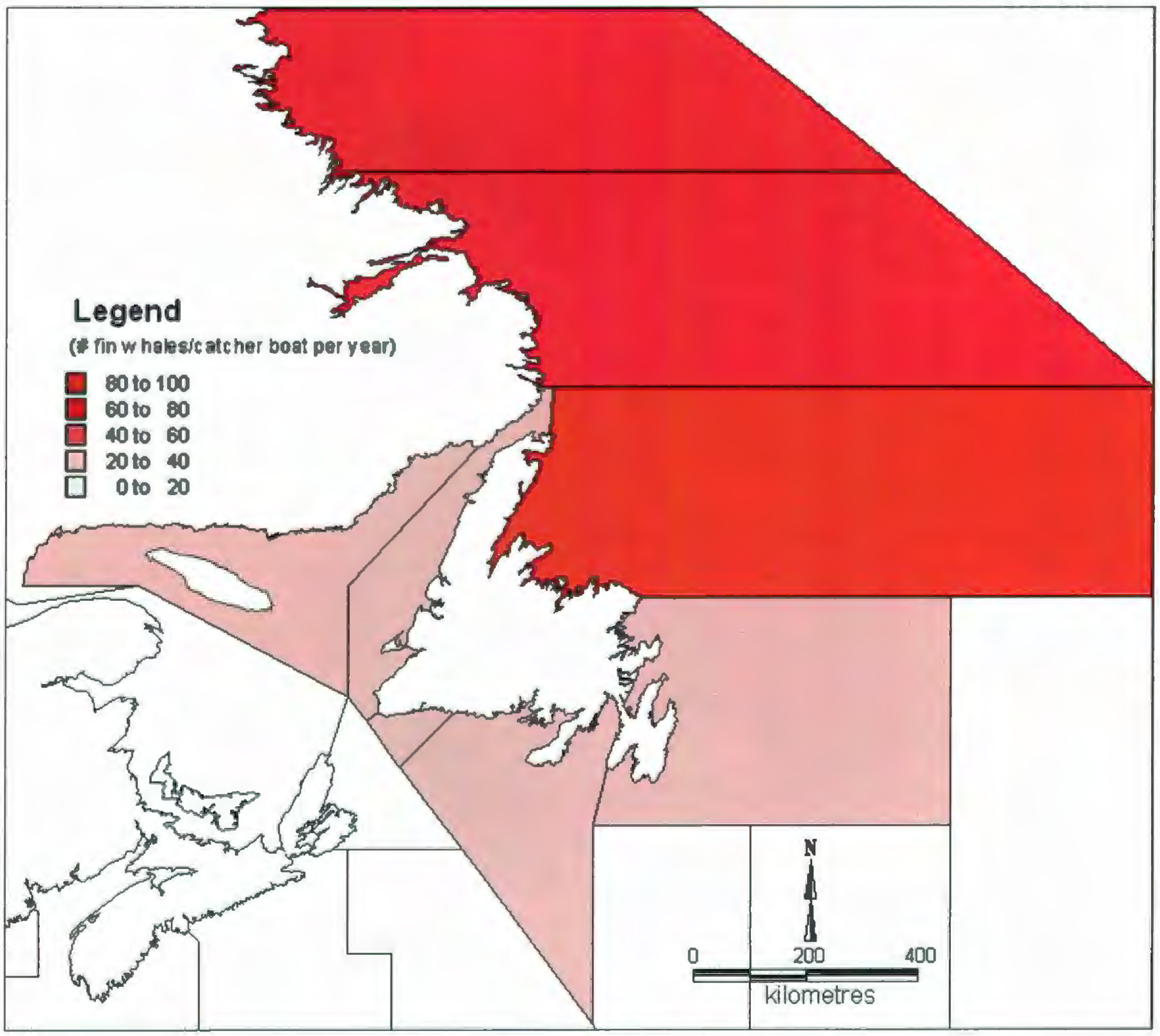


Figure 3.7 Areas of high concentration of sei whales taken off Newfoundland and Labrador based on shore-based whaling effort-adjusted data (number of whales/catcher boat per year of active whaling in region) from 1898-1972.

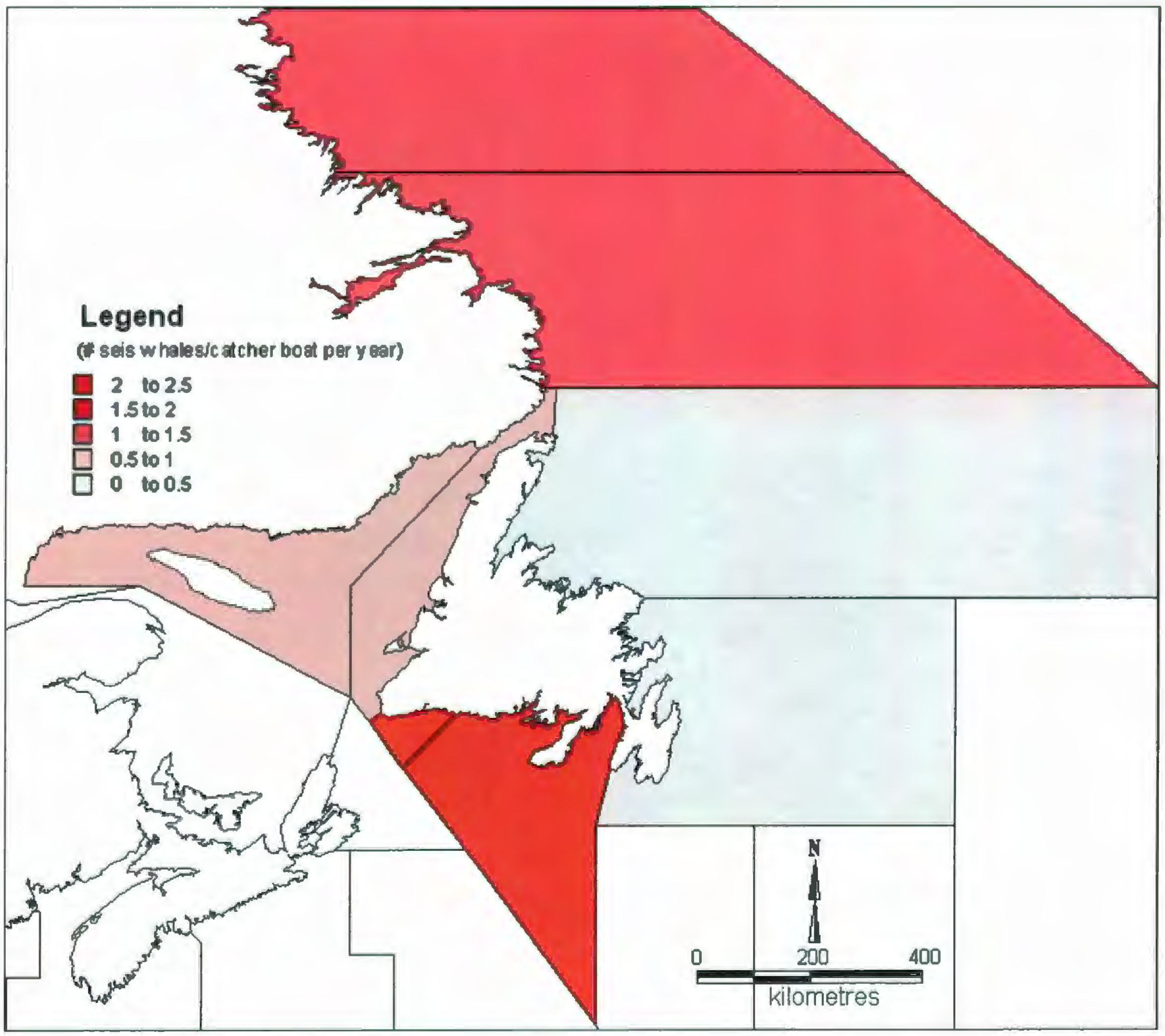


Figure 3.8 Blue whales sightings off Newfoundland and Labrador based on the DFO cetacean sighting database from 1958-2006.

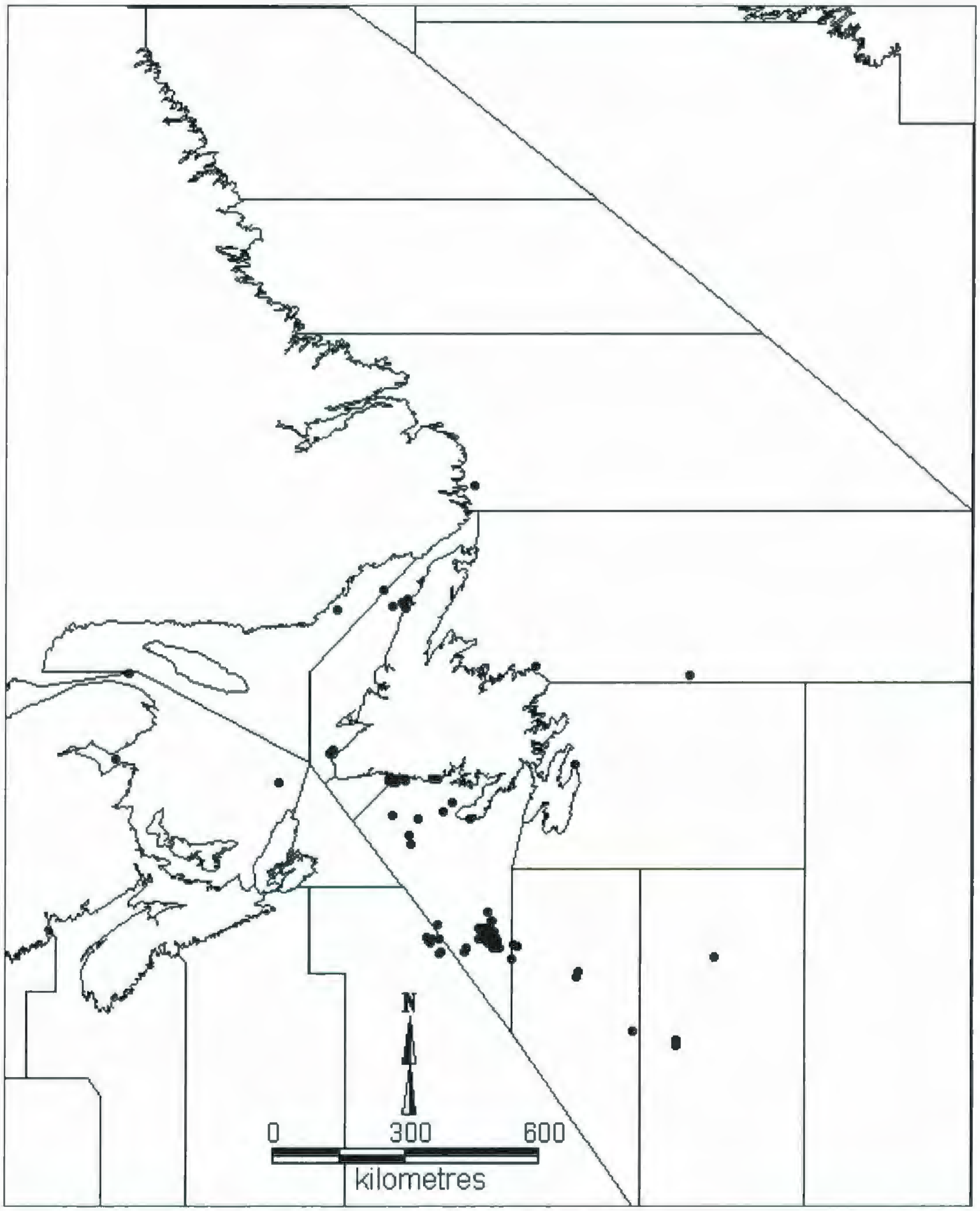


Figure 3.9 Fin whales sightings off Newfoundland and Labrador based on the DFO cetacean sighting database from 1958-2006.

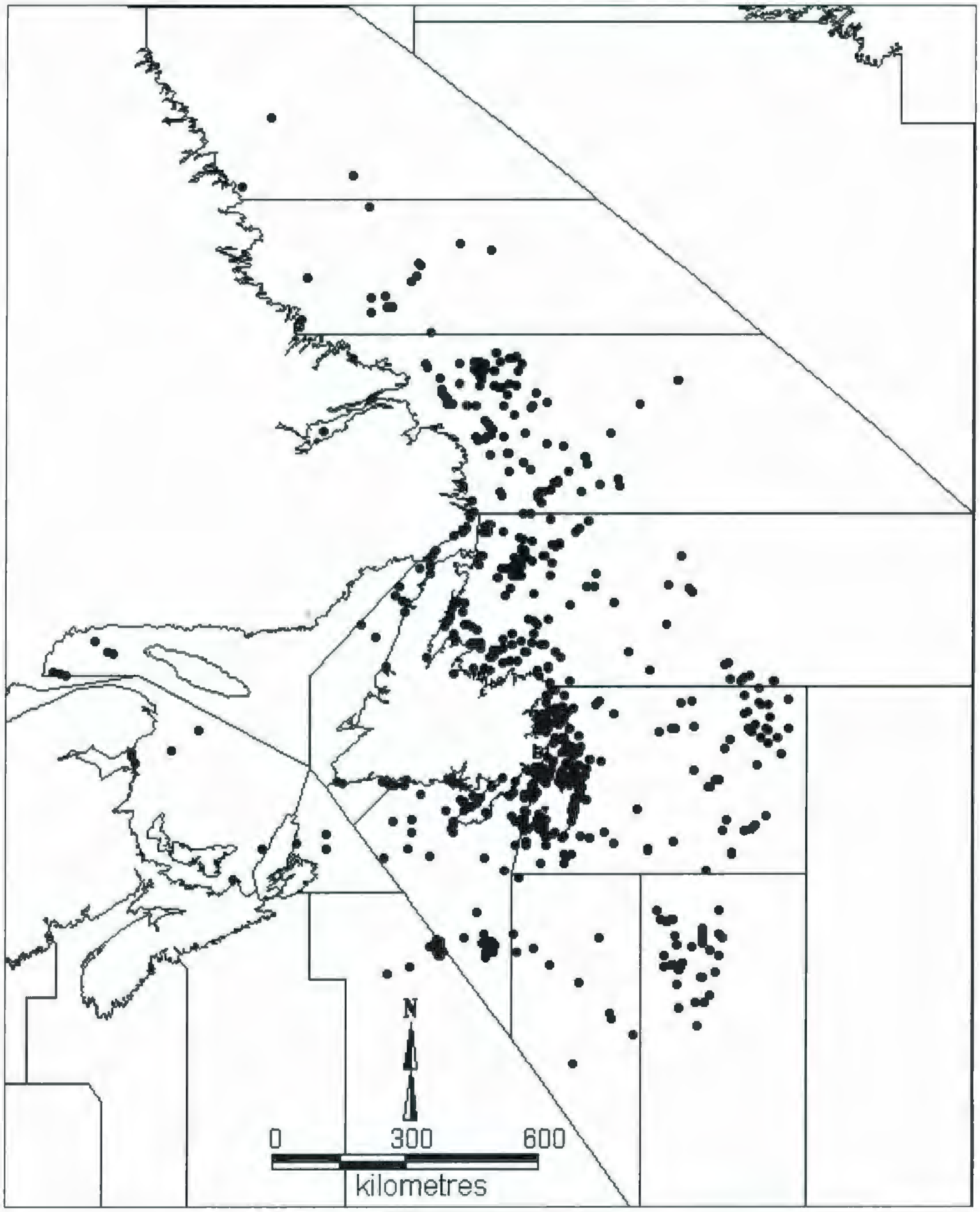


Figure 3.10 Sei whales sightings off Newfoundland and Labrador based on the DFO cetacean sighting database from 1958-2006.

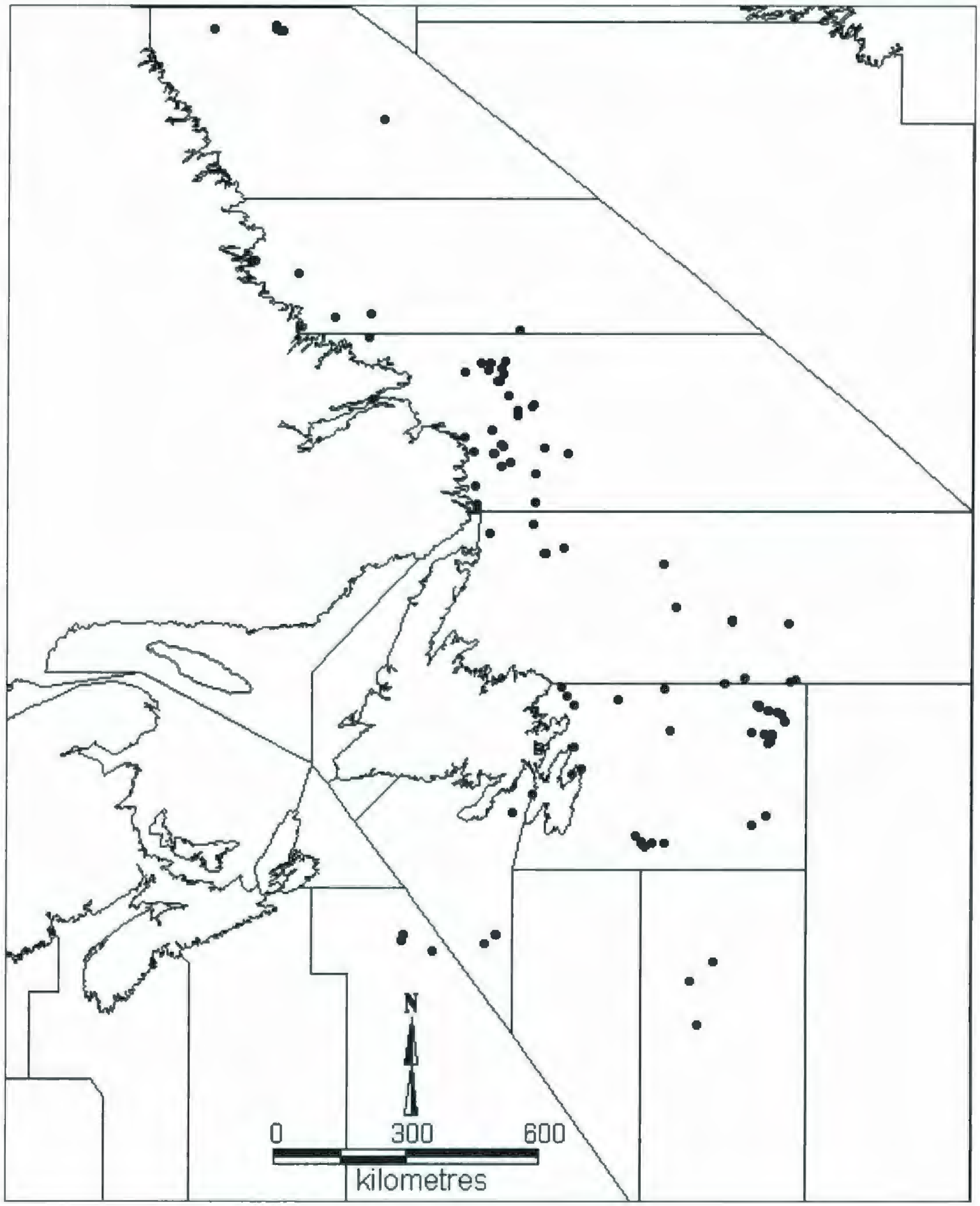


Figure 4.1 Blue, fin, and sei whales taken off Newfoundland and Labrador during shore-based whaling with records of food in their stomach for the five main regions from 1927-1972.

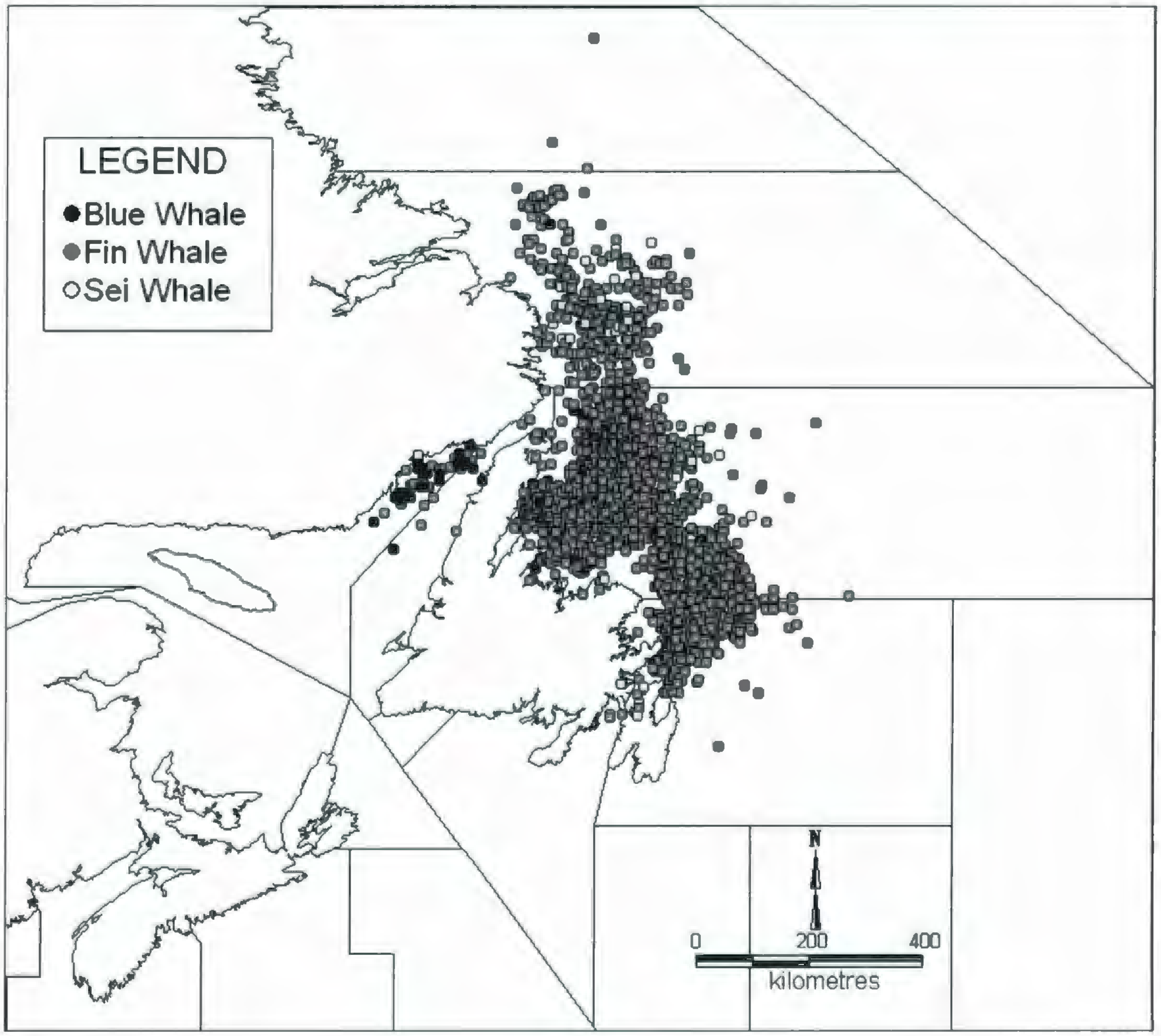


Figure 4.2 Blue whale sighting records off Newfoundland and Labrador from the IWC's shore-based whaling database (59 records) and DFO's cetacean sighting database (89 records) used in the Ecological Niche Factor Analysis.

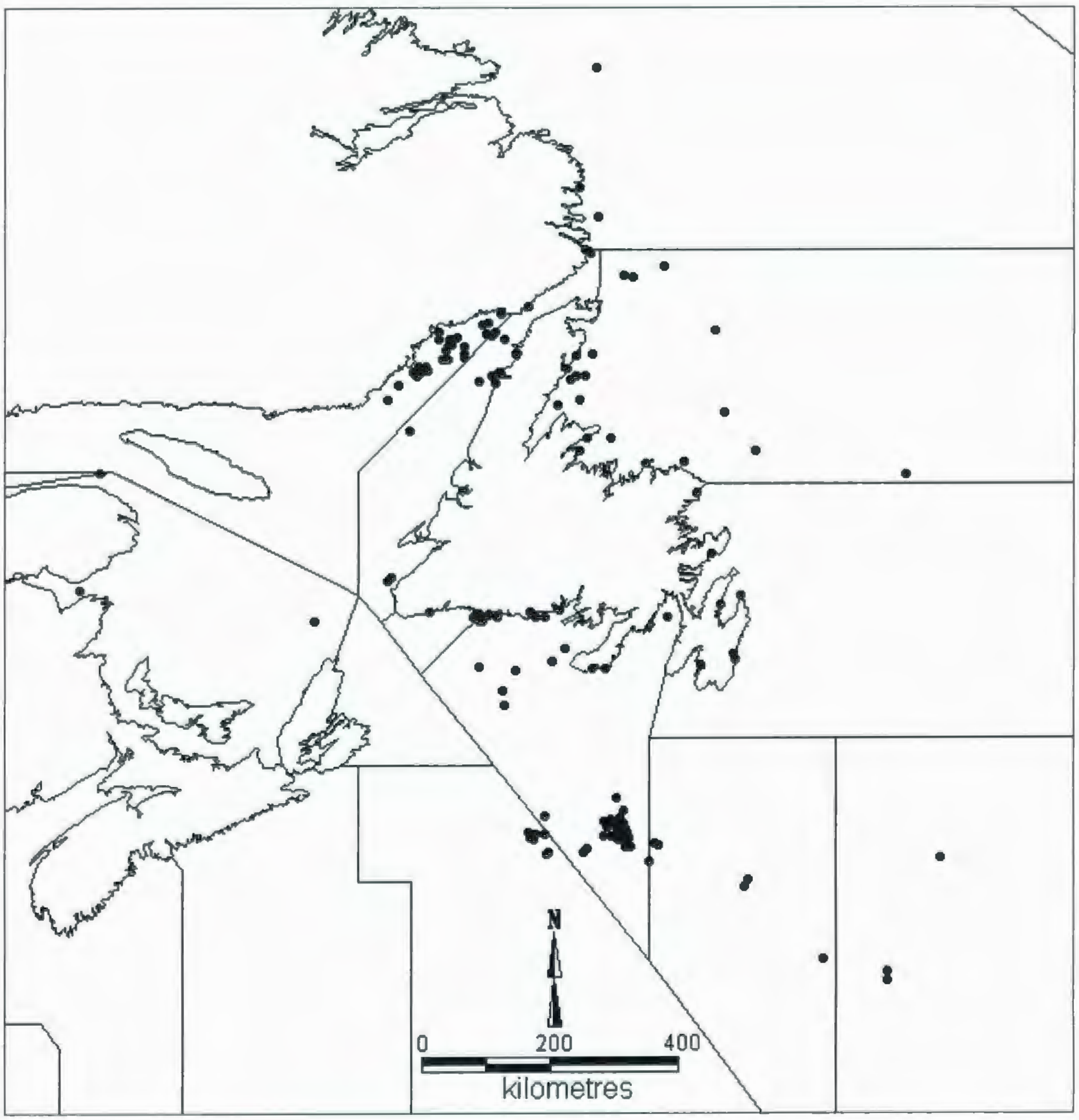


Figure 4.3 Blue whale habitat suitability map generated using BioMapper from blue whale sighting records in all regions around Newfoundland and Labrador during all seasons combined (yellow=*core*; purple=*marginal*; black=*unsuitable*).

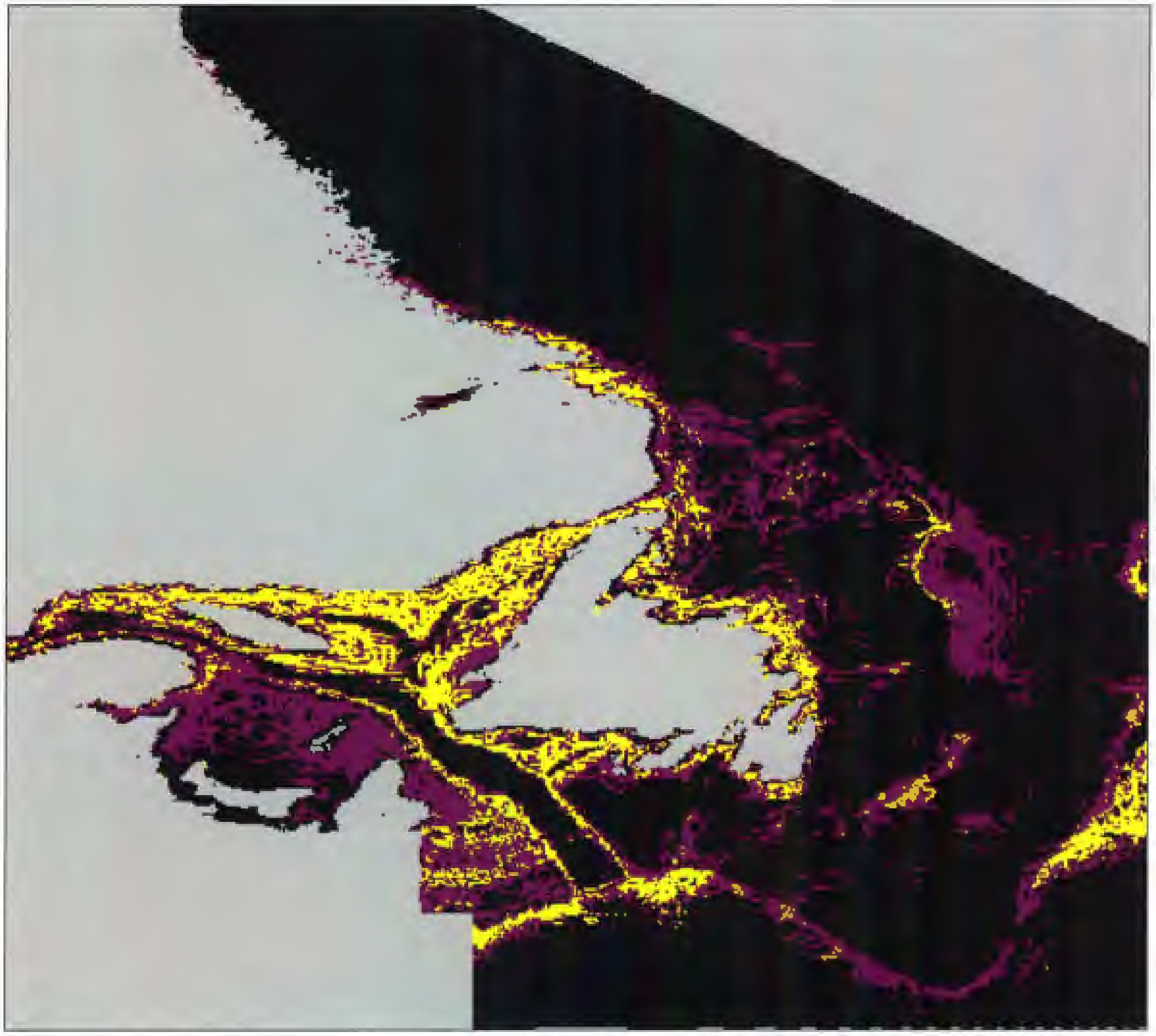


Figure 4.4 Blue whale habitat suitability map generated using BioMapper from blue whale sighting records in the south coast of Newfoundland region during all seasons combined (yellow=*core*; purple=*marginal*; black=*unsuitable*).

Figure 4.5 Blue whale habitat suitability map generated using BioMapper from blue whale sighting records in the Strait of Belle Isle/Gulf of St. Lawrence region during all seasons combined (yellow=*core*; purple=*marginal*; black=*unsuitable*).

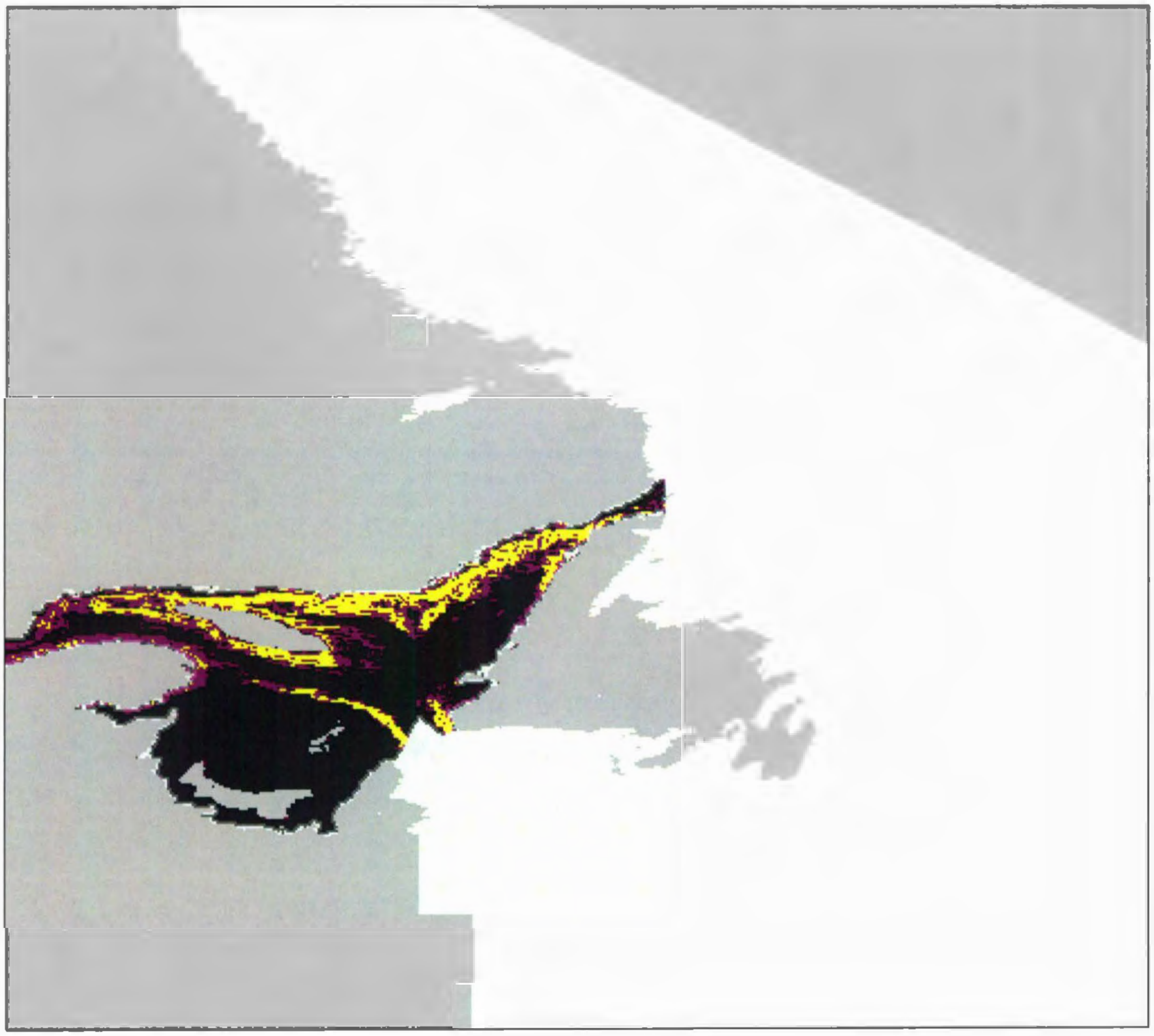


Figure 4.6 Blue whale habitat suitability map generated using BioMapper from blue whale sighting records in the south coast of Newfoundland region during summer (yellow=*core*; purple=*marginal*; black=*unsuitable*).

Figure 4.7 Blue whale habitat suitability map generated using BioMapper from blue whale sighting records in the Strait of Belle Isle/Gulf of St. Lawrence region during spring (yellow=*core*; purple=*marginal*; black=*unsuitable*).

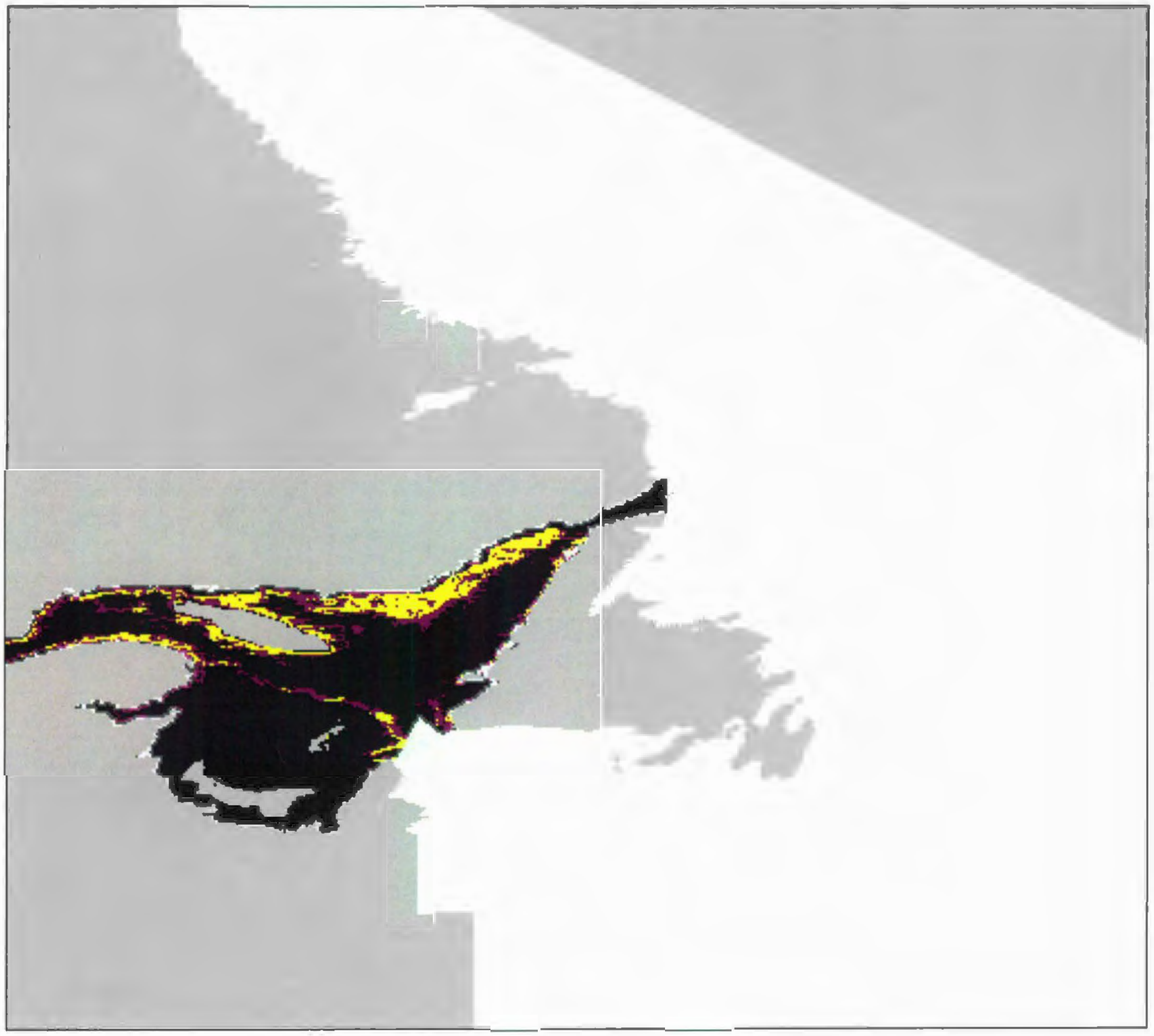


Figure 4.8 Fin whale sighting records off Newfoundland and Labrador from the IWC's shore-based whaling database (4,331 records) and DFO's cetacean sighting database (1,184 records) used in the Ecological Niche Factor Analysis.

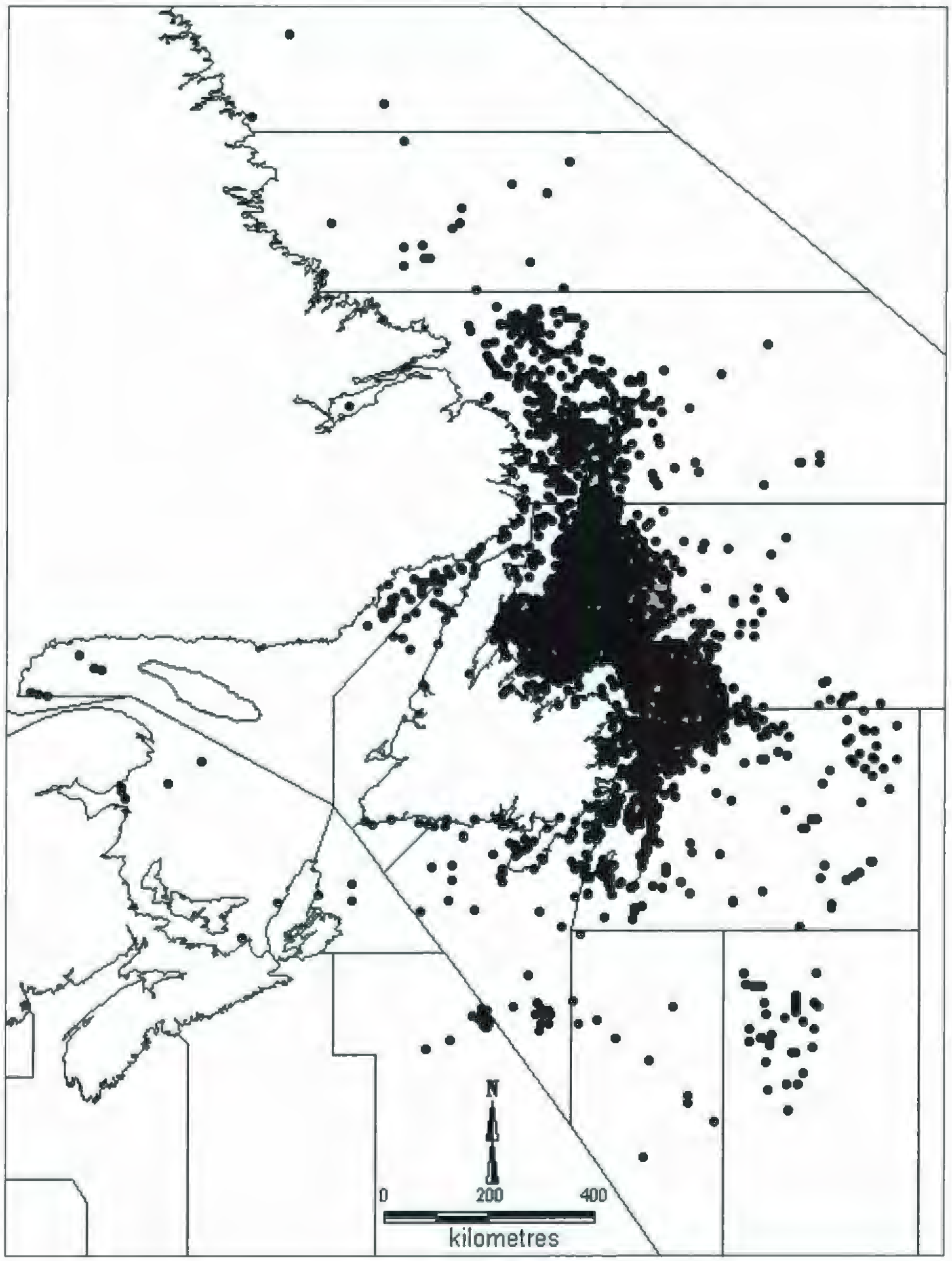


Figure 4.9 Fin whale habitat suitability map generated using BioMapper from fin whale sighting records in all regions around Newfoundland and Labrador during all seasons combined (yellow=*core*; purple=*marginal*; black=*unsuitable*).

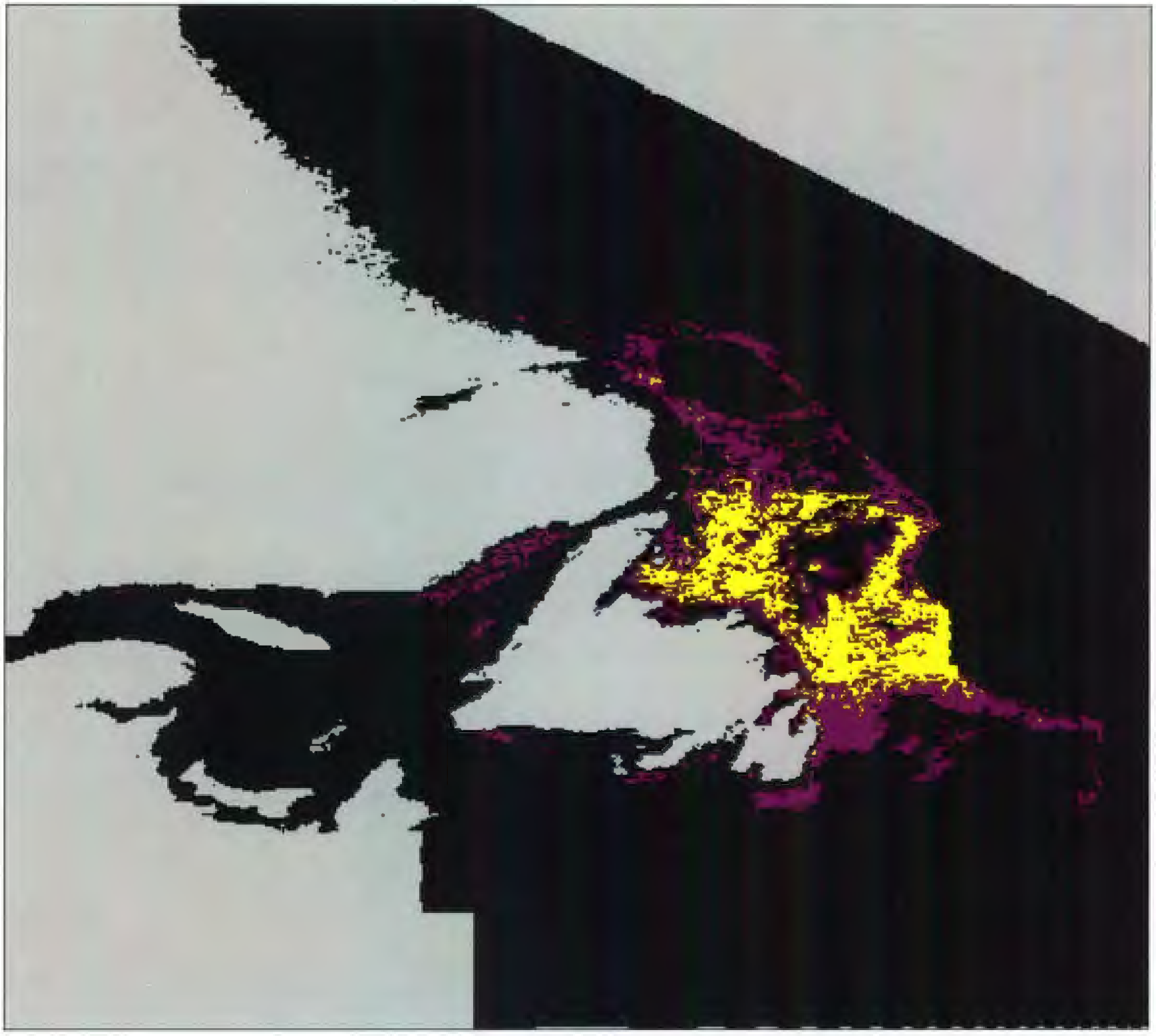


Figure 4.10 Fin whale habitat suitability map generated using BioMapper from fin whale sighting records in the coastal Labrador region during all seasons combined (yellow=*core*; purple=*marginal*; black=*unsuitable*).

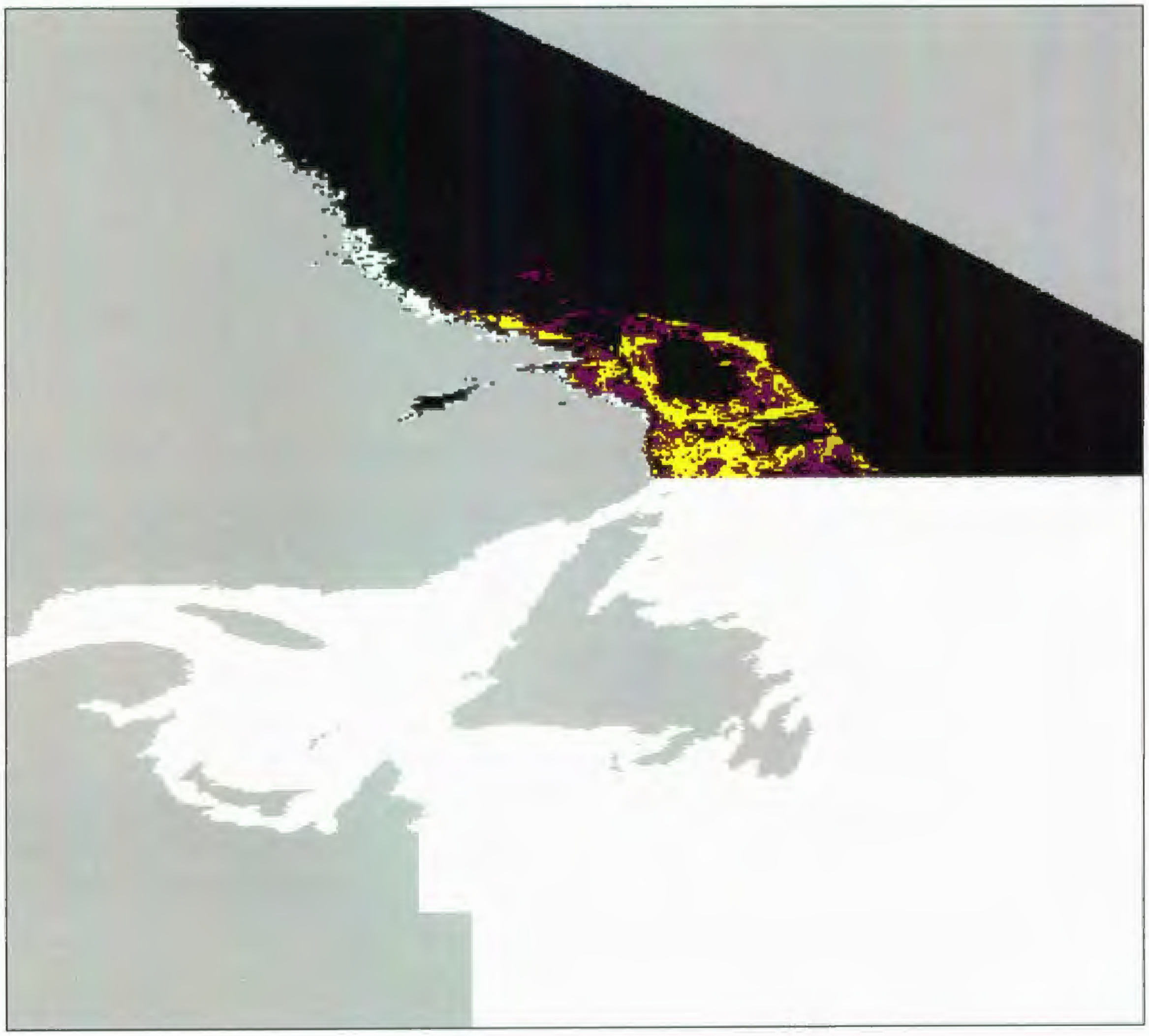


Figure 4.11 Fin whale habitat suitability map generated using BioMapper from fin whale sighting records in the northeast Newfoundland region during all seasons combined (yellow=*core*; purple=*marginal*; black=*unsuitable*).

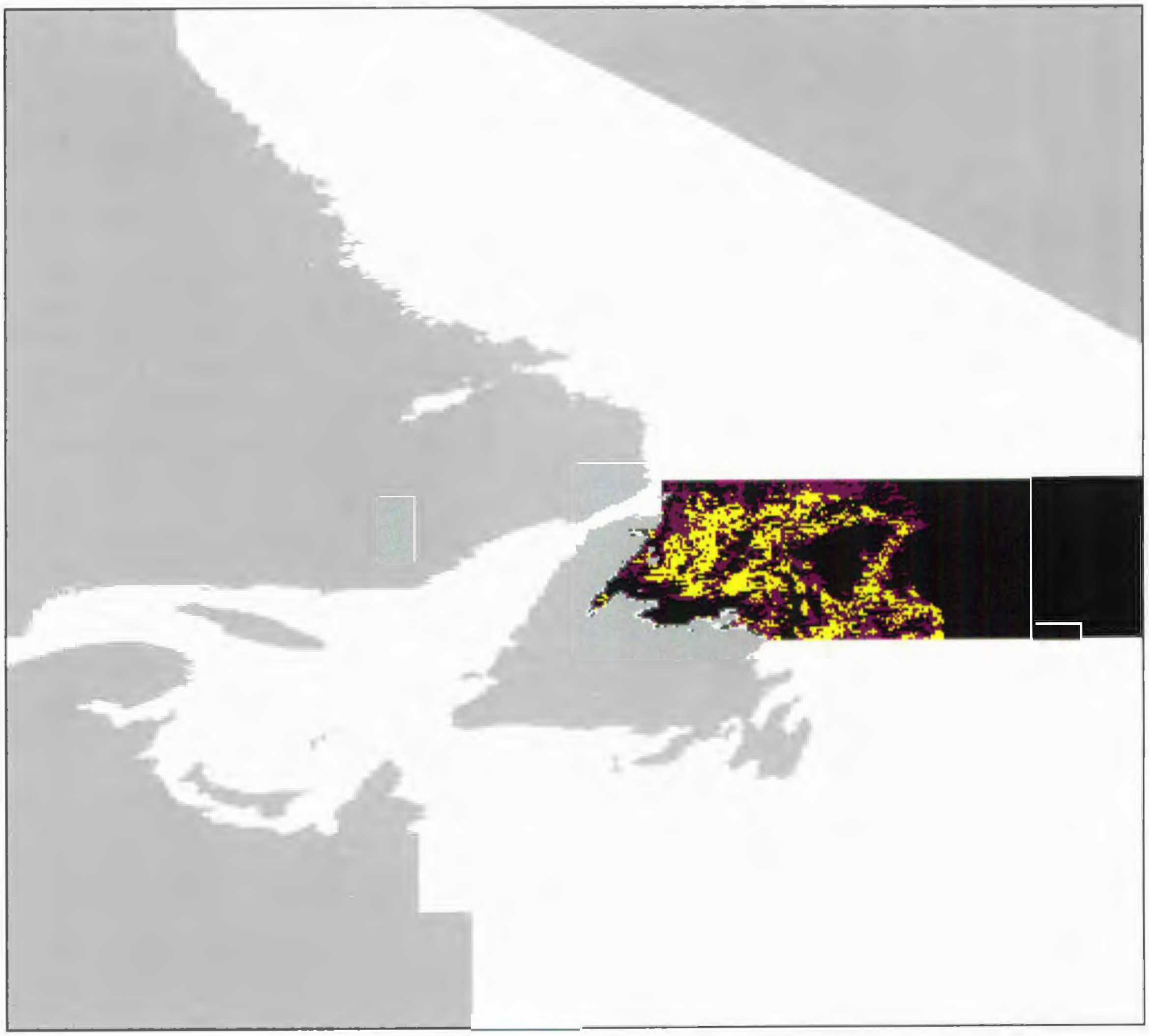


Figure 4.12 Fin whale habitat suitability map generated using BioMapper from fin whale sighting records in the coastal Labrador region during summer (yellow=*core*; purple=*marginal*; black=*unsuitable*).

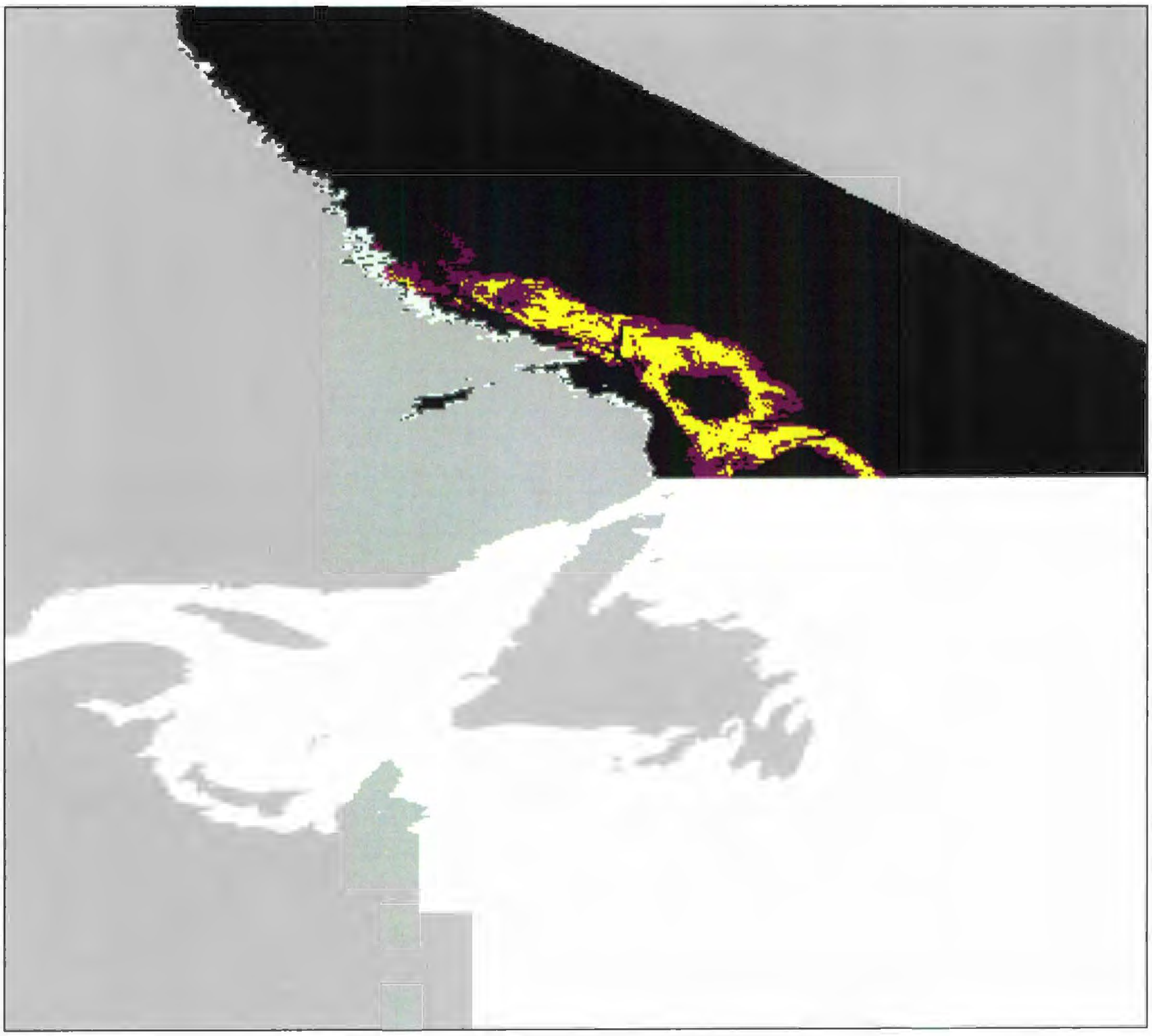


Figure 4.13 Fin whale habitat suitability map generated using BioMapper from fin whale sighting records in the northeast Newfoundland region during summer (yellow=*core*; purple=*marginal*; black=*unsuitable*).

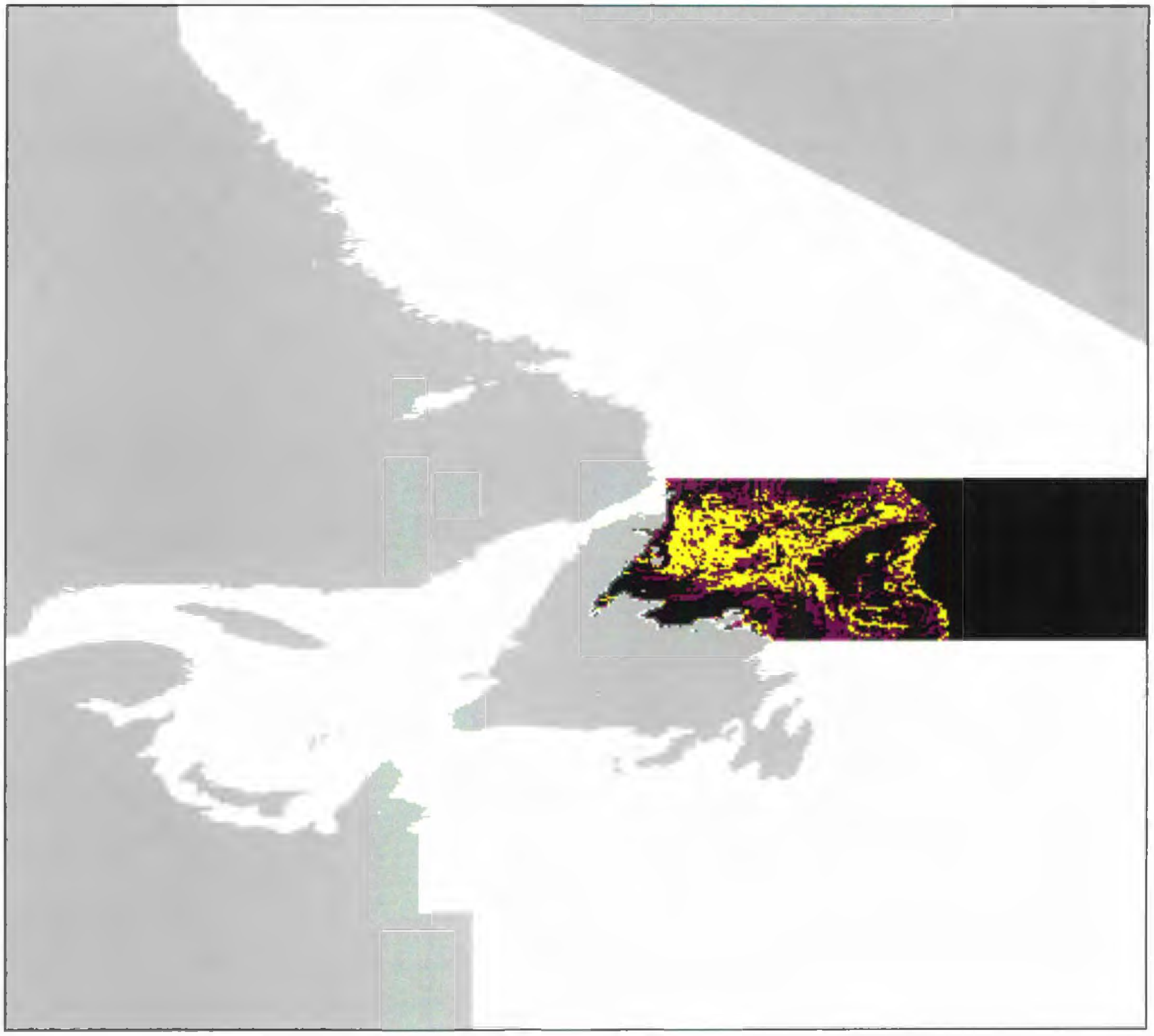


Figure 4.14 Sei whale sighting records off Newfoundland and Labrador from the IWC's shore-based whaling database (97 records) and DFO's cetacean sighting database (96 records) used in the Ecological Niche Factor Analysis.

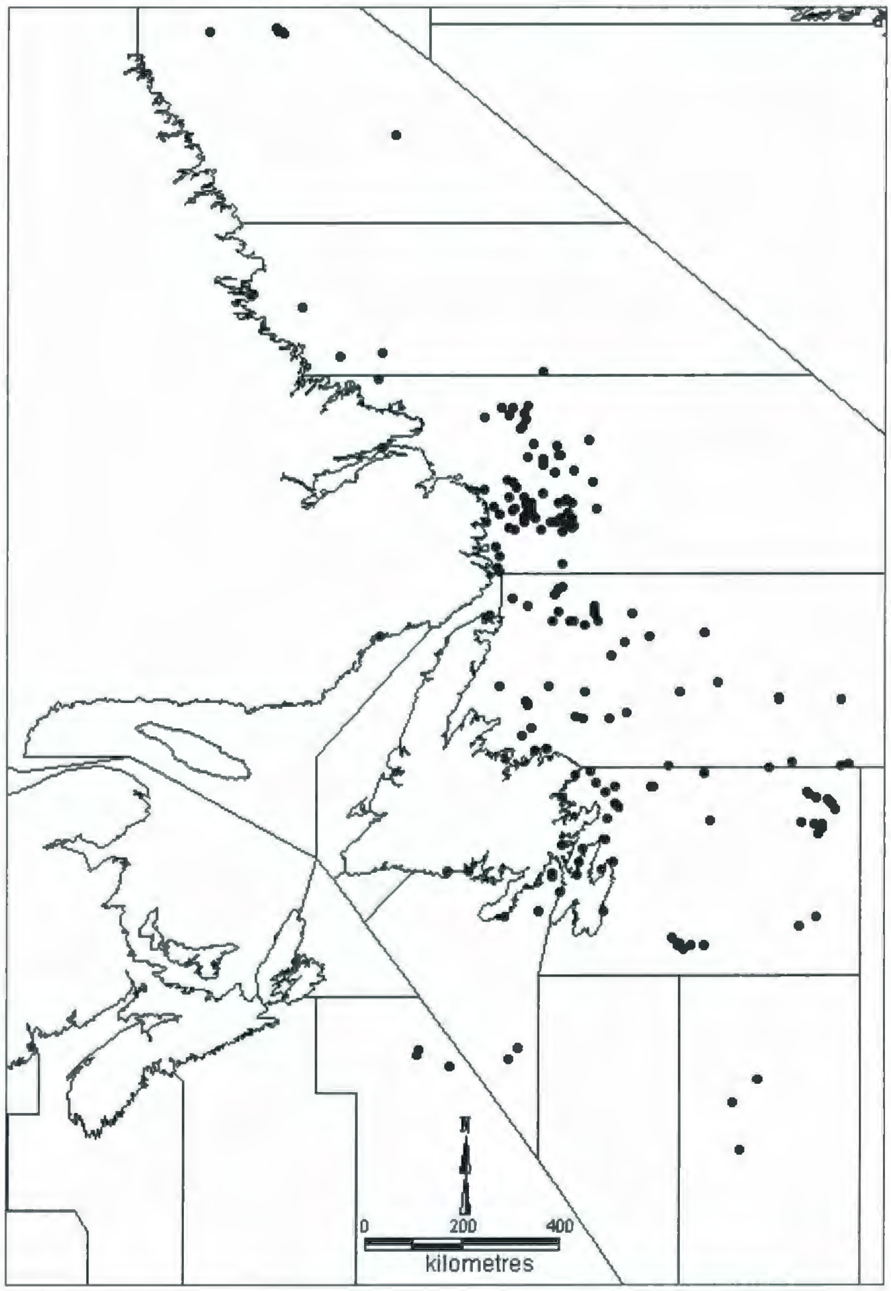


Figure 4.15 Sei whale habitat suitability map generated using BioMapper from sei whale sighting records in all regions around Newfoundland and Labrador during all seasons combined (yellow=*core*; purple=*marginal*; black=*unsuitable*).

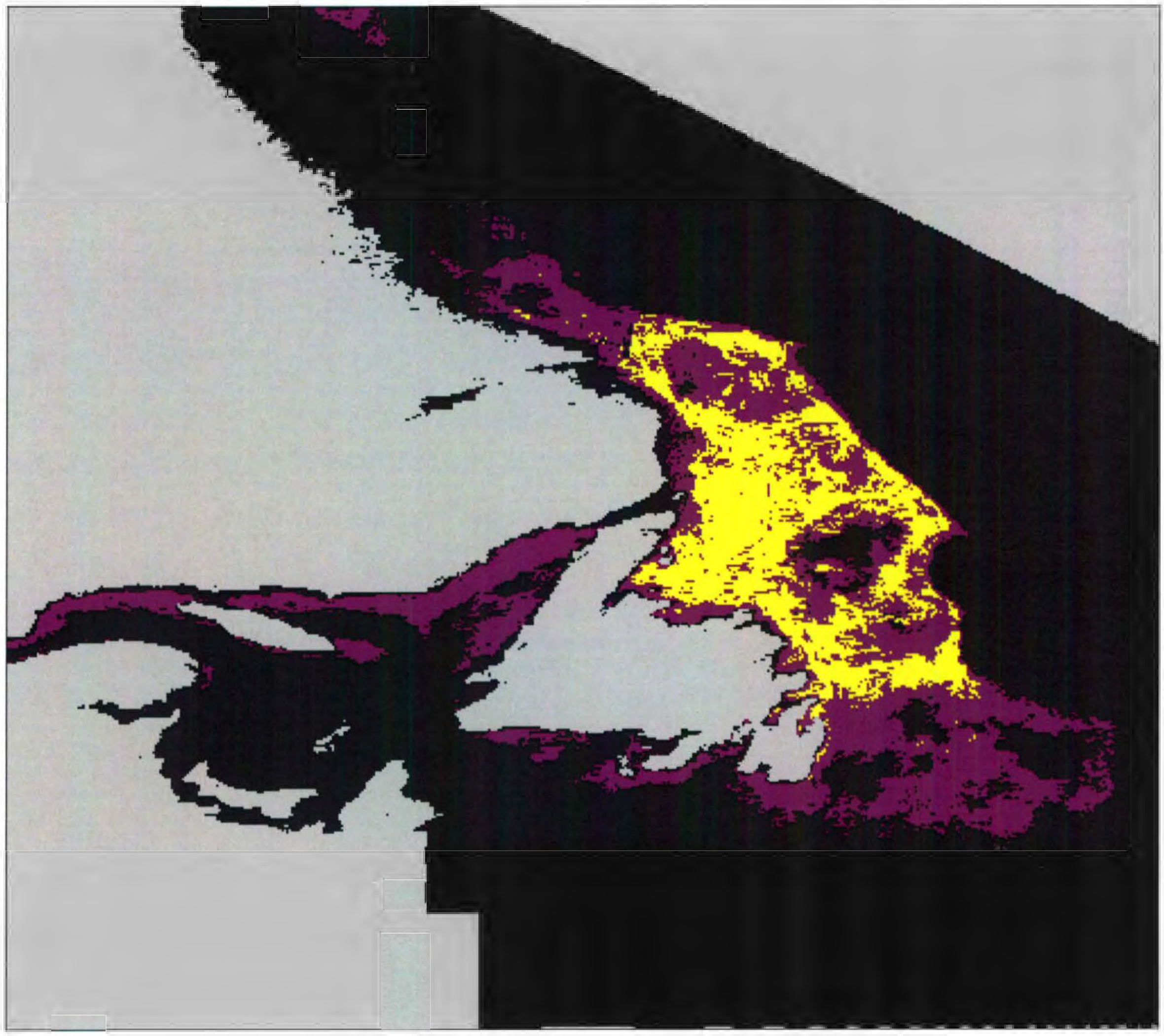


Figure 4.16 Sei whale habitat suitability map generated using BioMapper from sei whale sighting records in the coastal Labrador region during all seasons combined (yellow=*core*; purple=*marginal*; black=*unsuitable*).

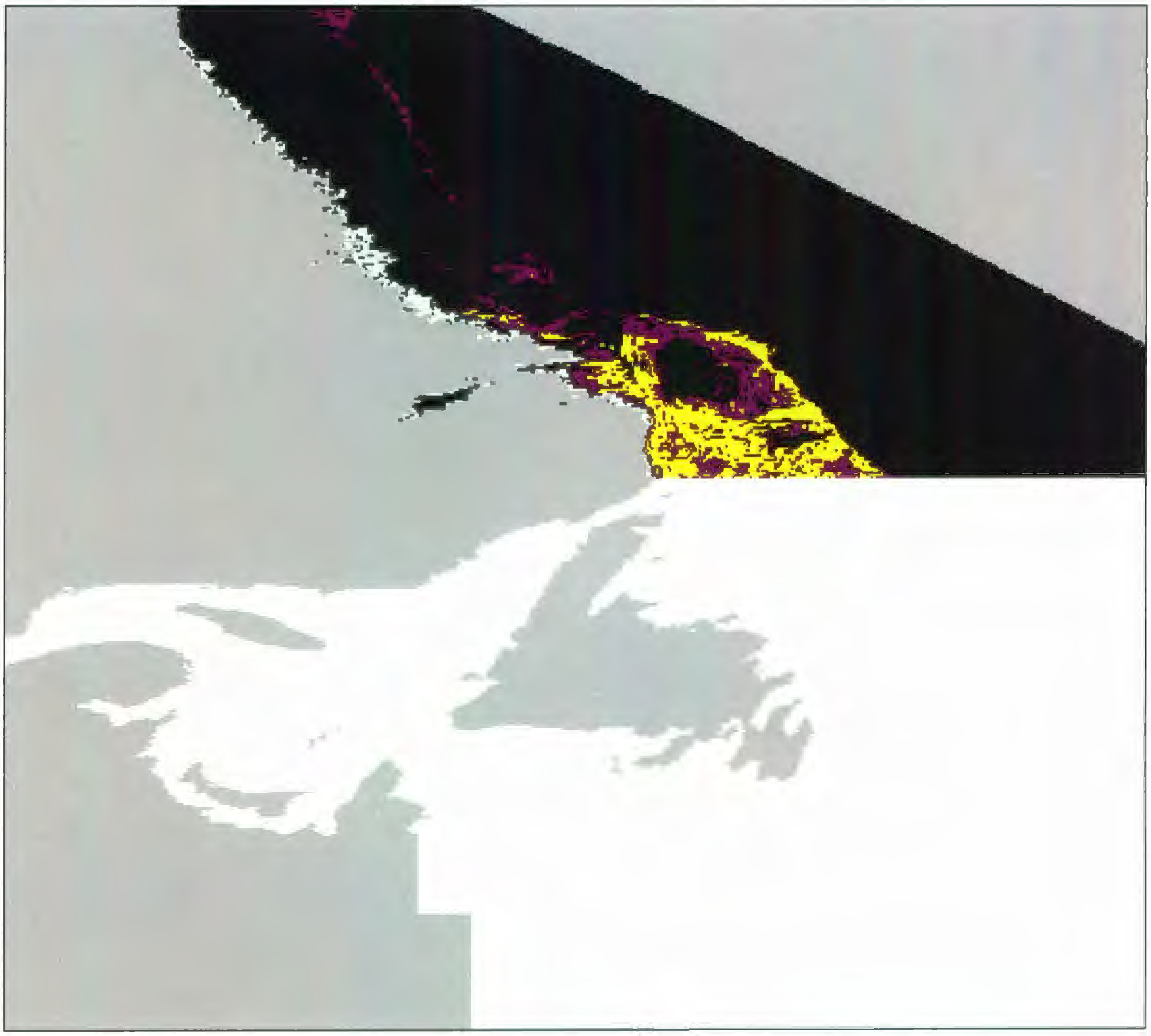


Figure 4.17 Sei whale habitat suitability map generated using BioMapper from sei whale sighting records in the coastal Labrador region during summer (yellow=*core*; purple=*marginal*; black=*unsuitable*).

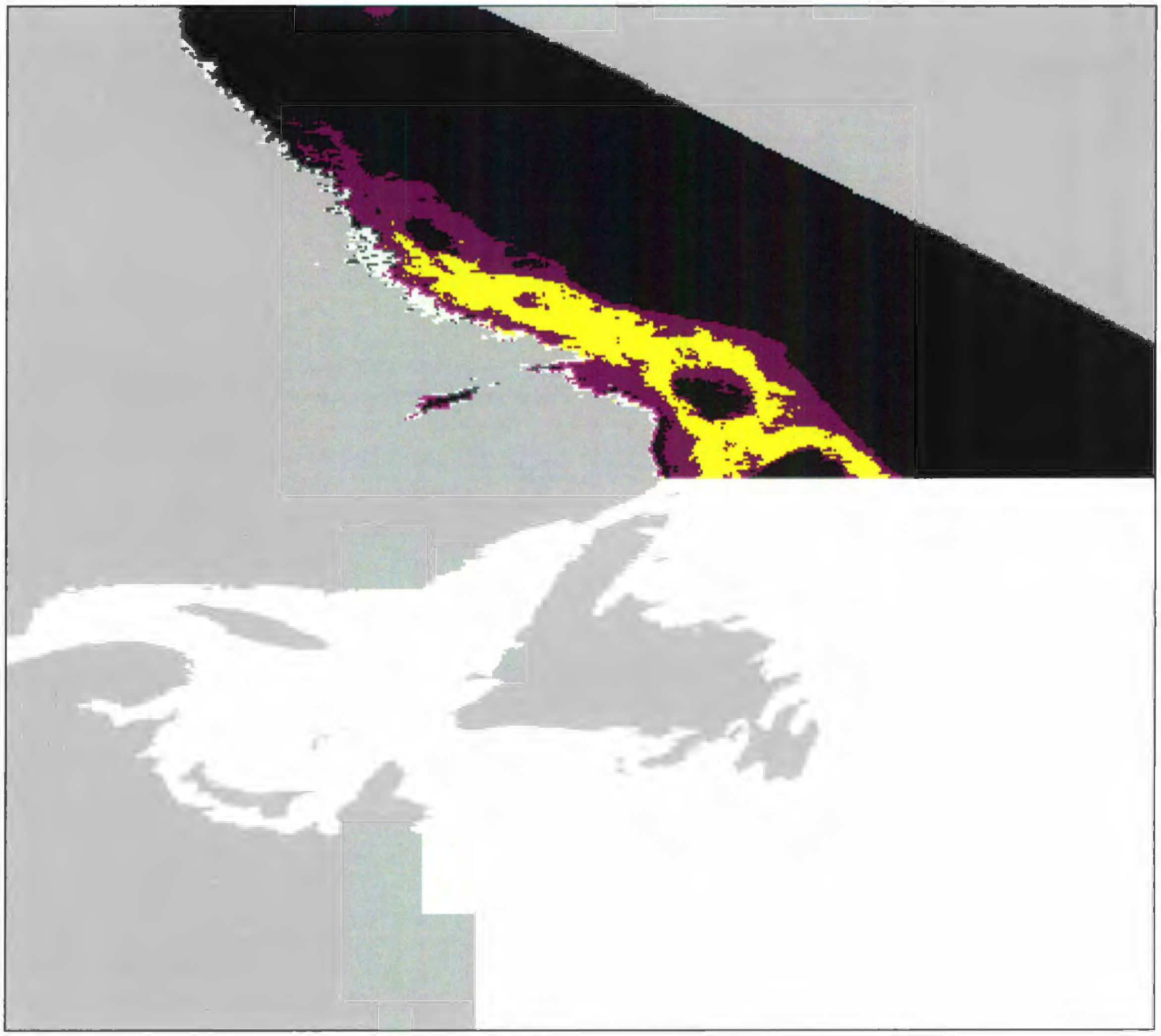


Figure 4.18 Sei whale habitat suitability map generated using BioMapper from sei whale sighting records in the coastal Labrador region during autumn (yellow=*core*; purple=*marginal*; black=*unsuitable*).

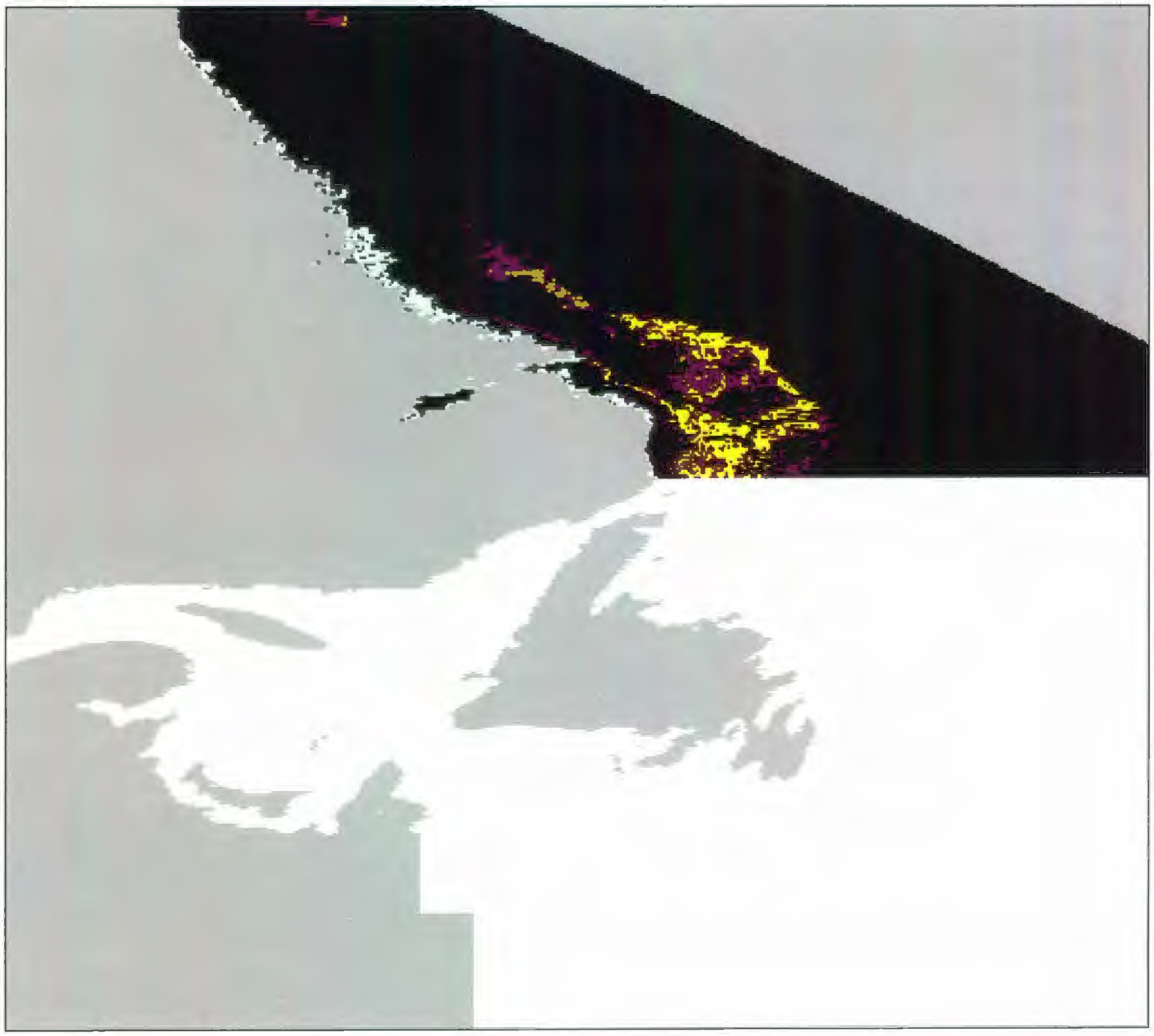


Figure 4.19 Distribution of killer whale sightings off Newfoundland and Labrador from the DFO cetacean sightings database (source: Jack Lawson, DFO).

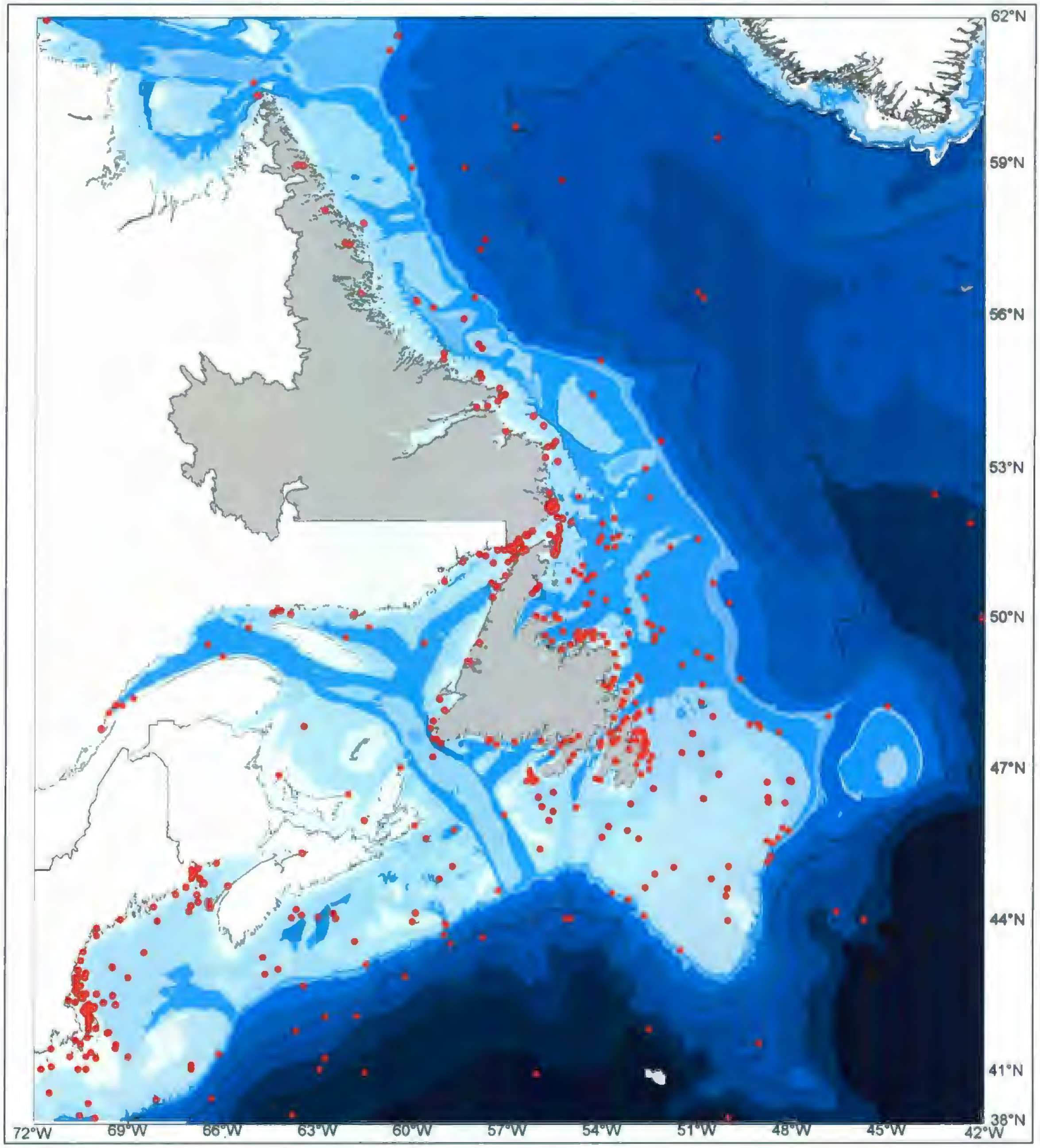


Figure 4.20 Location of current oil and gas Exploration and Production Licences off Newfoundland and Labrador (source: Canada-Newfoundland and Labrador Offshore Petroleum Board).

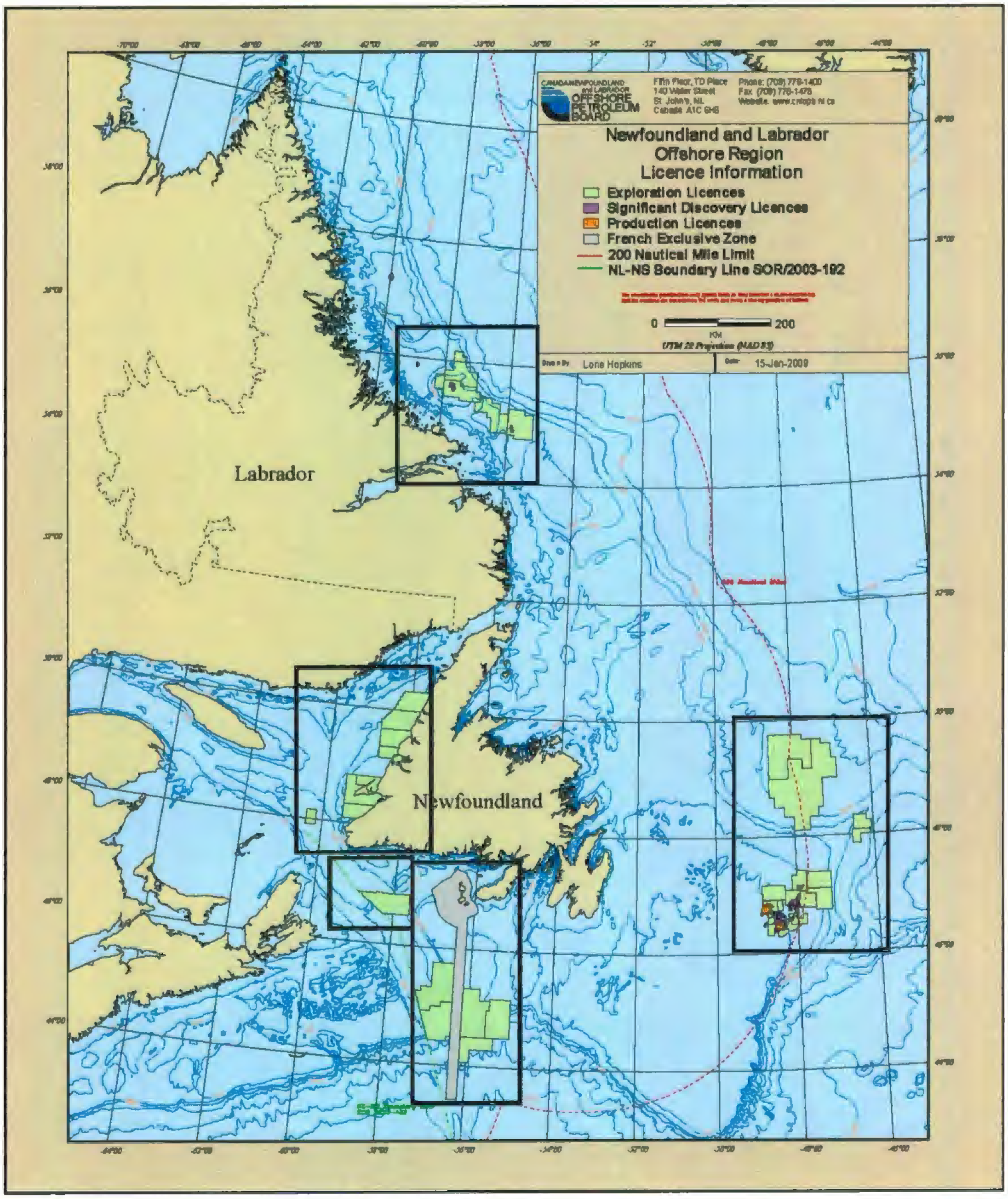


Figure 4.21 Location of typical shipping lanes and offshore platform supply vessel routes off Newfoundland and Labrador (adapted from Transport Canada Coast Guard 1981).

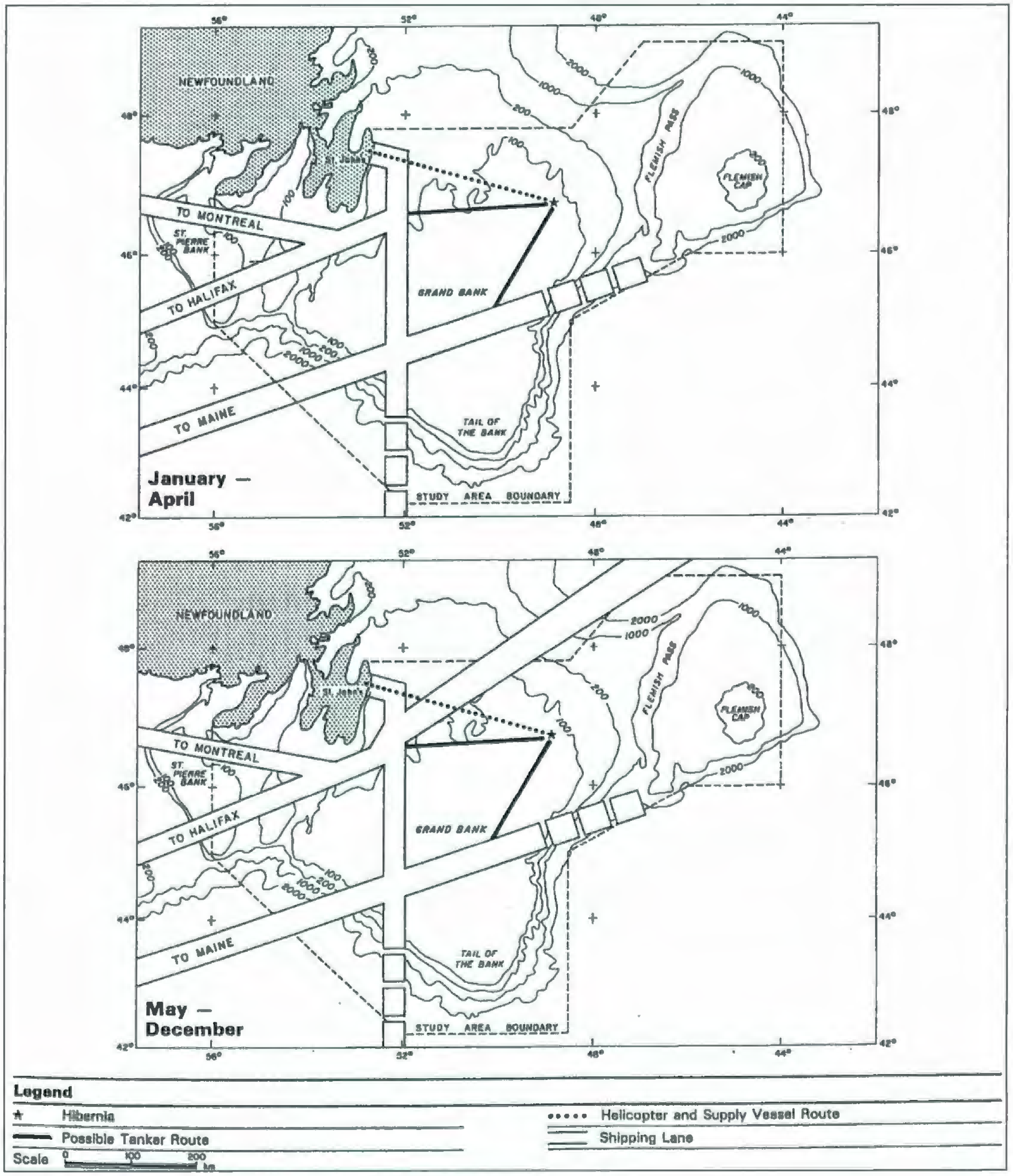


Figure 5.1 New blue whale sightings from the DFO cetacean sightings database overlying the habitat suitability model described in Figure 4.3 (light grey=*core*; dark grey=*marginal*; black=*unsuitable*).

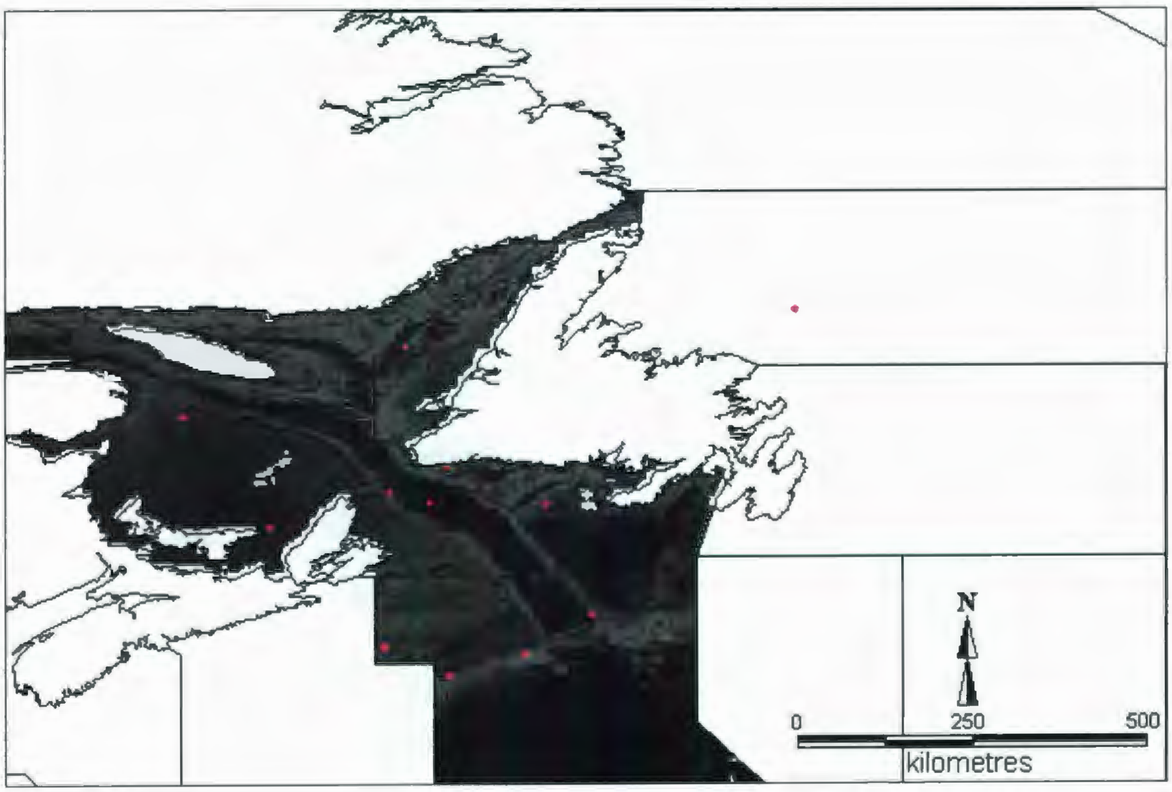
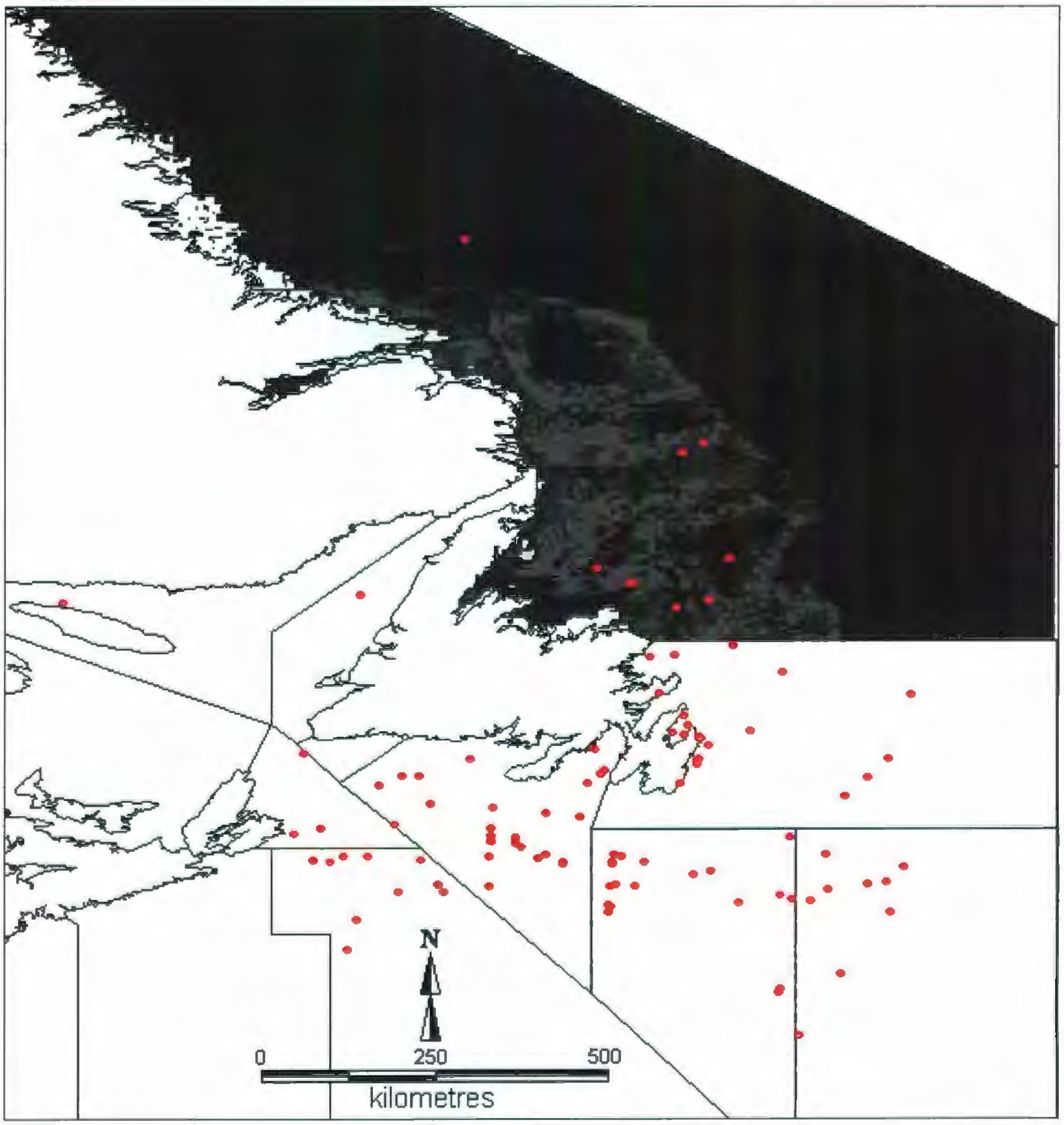


Figure 5.2 New fin whale sightings from the DFO cetacean sightings database overlying the habitat suitability model described in Figure 4.9 (light grey=*core*; dark grey=*marginal*; black=*unsuitable*).



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Appendix A. Review of the Impact of Environmental Features on Marine Mammal Distribution

Bathymetry (depth and slope)

Bottom topography can have a major impact on the creation of upwelling regions. Hui (1979) found dolphins (genus *Delphinus*) to occur more frequently in areas of high relief in the southern California Bight. There was, however, no evidence of an influence of water depth on dolphin distribution (Hui 1979). Hui (1985) later found a non-random distribution of Pacific pilot whales (*Globicephala macrorhynchus*) and common dolphin (*Delphinus delphis*) off the southern Californian coastline. Pilot whales and common dolphins were found to favour areas of high relief topography. This could be the result of their respective feeding habits (Hui 1985).

White-sided (*Lagenorhynchus acutus*) and common dolphins off the northeastern coast of the United States demonstrated preferential bathymetric use (Selzer and Payne 1988). Both species occurred preferentially in areas of maximum sea floor relief (Selzer and Payne 1988). Bottlenose dolphins (*Tursiops truncatus*) preferred areas with the greatest slope and depth in the outer Shannon estuary off the western coast of Ireland (Ingram and Rogan 2002). Harbour porpoise (*Phocoena phocoena*) showed a preferential distribution in deeper waters of the Bay of Fundy (Watts and Gaskin 1985). This could be prey related, as harbour porpoise feed on herring which is locally found in deeper waters (Smith and Gaskin 1974). Harbour porpoise off the coast of Washington were also more frequently observed in waters deeper than 125 m with shallow slopes (Raum-Suryan and Harvey 1998). Water depth was also shown to be important for Indo-Pacific humpback dolphins (*Sousa chinensis*) on the southeastern coast of South Africa where the 25-m isobath seems to be a maximum critical depth (Karczmarski *et al.* 2000).

Woodley and Gaskin (1996) found preferential bathymetric use of the Grand Manan Basin in the lower Bay of Fundy by right and fin whales. Right whales were found mainly in flat bottom topography where the water column was stratified, while fin whales were distributed in shallower water with high topographic variation and a well mixed water column (Woodley and Gaskin 1996). Similarly to Hui (1985), the bottom topography provided the ideal conditions for the prey of choice of both these mysticetes: copepod, *Calanus finmarchicus*, for the right whale (Murison and Gaskin 1989; Mayo and Marx 1990), and herring and euphausiids for fin whales in the Bay of Fundy (Woodley and Gaskin 1996). Baumgartner *et al.* (2003) surveyed right whales in the lower Bay of Fundy and in Roseway Basin off the Scotian Shelf in the summers of 1999 to 2001. Of the 16 environmental variables measured and tested, water depth and depth of the bottom mixed layer were found to be associated with the spatial variability of right whales in these regions (Baumgartner *et al.* 2003).

Depth and slope were two variables used in a number of additional studies involving odontocetes (Baumgartner 1997; Hooker *et al.* 1999; Cañadas *et al.* 2002). Sighting of 11 cetaceans in the Gully, off the Scotian Shelf, were compared within this region using depth and slope (Hooker *et al.* 1999). The distribution of these cetaceans in the Gully was correlated with depth, but not slope (Hooker *et al.* 1999), although sperm whales were shown to prefer the edge of the Shelf (Whitehead *et al.* 1992) and steep underwater topography in the South Pacific (Jaquet and Whitehead 1996). Sea-surface temperature was also examined and found to be significantly correlated to the distribution of cetaceans (Hooker *et al.* 1999). Baumgartner (1997) used the same two physiographic variables when comparing the distribution of Risso's dolphin (*Grampus griseus*) in the northern Gulf of Mexico. In this case, Risso's dolphin distribution was found to be non-uniform with respect to both depth and slope, with distribution skewed towards the steeper sloped areas (Baumgartner 1997). Cañadas *et al.* (2002) studied the habitat preference of seven odontocetes in the Alboran Sea, off the southern coast of Spain. Shallow-water odontocetes (common and bottlenose dolphins) preferred habitats from the shore to 400 m depth. Deep-water odontocetes (striped dolphin (*Stenella coeruleoalba*), Risso's dolphin, long-finned pilot whale (*Globicephala melas*), sperm whale, and beaked whale (Ziphiidae family)) preferred waters deeper than 600 m. The effect of slope was more variable by species from these two groups (Cañadas *et al.* 2002).

Early studies emphasized the importance of fronts, eddies, and upwelling to the distribution of marine mammals. Upwelling caused by zones of divergence in the tropics of the eastern Pacific Ocean were also shown to influence sperm whale distribution (Volkov and Moroz 1977). Gaskin (1987) pointed out the potential importance of frontal discontinuities for the right whale in the Bay of Fundy and how they could act as nutrient traps. Brown and Winn (1989) found right whales in the Great South Channel to be positioned non-randomly about thermal front region, while not directly in it. The authors suggested that the physical processes associated with the front play an important role in influencing the whale's distribution in that area. These fronts or other hydrographic features could be the result of topographic upwelling around depths of 100 m as the right whales were also found to be non-randomly distributed in relation to the 100-m isobath.

Woodley and Gaskin (1996) also considered the potential importance of frontal interfaces in the creation of well mixed, highly productive water layers used, notably by fin whales, for feeding. Waring *et* al. (1993) had previously used oceanographic circulation to relate the presence of sperm whales in the Gulf Stream. The Gulf Stream and warm core rings are considered important oceanographic features that contribute to the formation and transport of local prey concentrations (Olson and Backus 1985). Sperm whales sightings in the early 1990s were found to be associated with these features which were determined through daily obtained sea-surface temperature (SST) satellite imagery (Waring *et al.* 1993).

Hydrographic features, including cyclones, anticyclones, and confluence zones, influenced habitat in the northern Gulf of Mexico (Davis *et al.* 2002). A survey of 19 cetacean species identified different levels of potential prey availability, with higher concentrations around cyclonic eddies (Davis *et al.* 2002). These studies all demonstrate that while fronts, eddies and upwelling events all occur at various spatial scales, they can all influence the distribution and behaviour or marine mammals, especially large cetaceans.

More recently, thermal fronts have been used to complement field observations and explain habitat selection of four species of rorqual whales in the Gulf of St. Lawrence (Doniol-Valcroze *et al.* 2007). Blue, fin, humpback, and minke whales were all observed more frequently in the presence of persistent thermal fronts (Doniol-Valcroze *et al.* 2007). A thermal front in the vicinity of a warm-core ring of the Gulf Stream off Georges Bank was also found to lead to an increase in sperm whale sightings (Griffin 1999).

Sea-surface temperature

Sea-surface temperature has been examined to explain distribution patterns of certain whale species (Brown and Winn 1989; Woodley and Gaskin 1996). Right whales in the Great South Channel (Brown and Winn 1989) and in the Bay of Fundy Basin (Woodley and Gaskin 1996) showed no relation between SST and overall distribution. However, in the same study, SST was found to be higher in areas where right whales were observed, compared to areas where they were absent. Gaskin (1987) argued that SST is unlikely to have any direct influence on the distribution of large whales, such as the right whale. The right whale has a blubber layer of over 20 cm and possesses a comparatively small surface to volume ratio because of its squat body shape (Gaskin 1987). Heat loss estimates for the bowhead whales concluded that thermal neutrality maintenance in waters of only a few degrees should not be a problem (Brodie 1981). Right whales and bowhead whales possess a similar morphology and blubber thickness and are thus likely to react in a similar manner. Thus, if not for reasons of increased productivity leading to increased prey availability, SST is likely to have minimal effect on the large cetaceans. The same might not be true for smaller marine mammals, such as porpoise, dolphins, and pinnipeds.

Sea-surface temperature preference was observed for a number of small cetacean species (Gaskin 1968; Smith and Gaskin 1983; Au and Perryman 1985; Watts and Gaskin 1985; Selzer and Payne 1988). Four dolphin species, common, southern right whale (*Lagenorhynchus peronii*), dusky (*Lagenorhynchus obscurus*), and hourglass (*Lagenorhynchus cruciger*) dolphins, found east and south-east of New Zealand, differed in preferential ambient water temperature ranging up to 16°C for southern right whale dolphins to as low at 2°C for hourglass dolphins (Gaskin 1968). In the eastern tropical Pacific, off the coast of Mexico and Central America, four species of dolphins also showed differences in habitat preference in the winter (Au and Perryman 1985). Spotted (*Stenella attenuata*) and spinner (*Stenella longirostris*) dolphins both utilized waters with more stable annual SST, while common and striped dolphins preferred waters with larger seasonal variations (Au and Perryman 1985). A later study by Reilly (1990) also noted differences in seasonal habitat for spotted/spinner dolphins and striped dolphins, but not for common dolphins. While no seasonal differences in common dolphin habitat were observed by Reilly (Reilly 1990), interannual variations in habitat were observed by Reilly and Fiedler (1994), more so than in other school types. The authors observed that this interannual variation appeared related to El Niño-Southern Oscillation variability

(Reilly and Fiedler 1994). The same areas were related to blue whale aggregations (Reilly and Thayer 1990). Although in this last case, no specific environmental feature was linked to these aggregations. The areas were simply referred to as "upwelling-modified" waters referring to their high local productivity.

Sea-surface temperature was also shown to effect harbour porpoise distribution in the Bay of Fundy (Watts and Gaskin 1985). This was less related to body condition factors, but to prey-preferred cooler temperatures resulting from well mixed water columns (Watts and Gaskin 1985). A similar relationship had also previously been observed for harbour porpoise (Smith and Gaskin 1983).

In addition to an identified bathymetric preference, white-sided and common dolphin distribution was also correlated to sea-surface temperature and salinity (Selzer and Payne 1988). White-sided dolphins were found in areas of lower SST and salinity. The authors did recognize that these features may be of secondary importance compared to the effect of bathymetric on the water column and subsequently on these two dolphin species. Overall, salinity is not commonly linked to marine mammal distribution, but might still be of importance to their distribution. One of the ways in which this could be is in the determination of buoyancy of copepod life cycle stages (Gaskin 1987). Another study found salinity to influence the distribution of bowhead whales in the Beaufort Sea (Thomson *et al.* 1986). Bowhead whales were more frequently sighted close to shore when freshwater plumes did not expand far off the coast and coastal salinity increased (Thomson *et al.* 1986).

Chlorophyll concentrations

The productive waters, observed by Fiedler *et al.* (1998) and correlated to blue whale presence, off the Californian coast were measured using surface chlorophyll concentrations. Other studies have also used this method to measure water productivity and correlate it to marine mammal distribution (Smith *et al.* 1986; Jaquet *et al.* 1996). The coast of California was again the site of a study relating marine mammal distribution to sea-surface chlorophyll concentrations in 1979-1980 (Smith *et al.* 1986). Smith *et al.* (1986) found a non-random distribution of marine mammals (nine dolphin species, nine whale species, and one general pinnipeds category) in relation to sea-surface chlorophyll concentrations. The authors also used colour differences from the satellite images to assess coastal thermal fronts. This method was later used in the Gulf of St. Lawrence and discussed earlier as it assessed thermal front association and cetacean distribution directly (Doniol-Valcroze *et al.* 2007). A final study again used averages of satellite imagery over eight years as an indicator of production and related it back to sperm whale catches from 19^{th} century Yankee whaling in the tropical Pacific (Jaquet *et al.* 1996). Sperm whale distribution was correlated to the phytoplankton pigments distribution and this correlation increased with increasing satellite-derived pigmentation scale (Jaquet *et al.* 1996). As expected, some local variations hinted that other factors could be important to sperm whale distribution at the local scale (Jaquet *et al.* 1996).

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Appendix B. Summary of Statistical Analyses

Table B.1 Nonparametric Tukey-type multiple comparisons of effort-adjusted number of blue whales taken off Newfoundland and Labrador between each region from 1898-1972.

Region	Region Code	Mean Rank	*n*
South coast of Newfoundland	4	155.93	68
Strait of Belle Isle/Gulf of St. Lawrence	5	116.65	24
East Newfoundland	3	80.62	42
Coastal Labrador	1	76.97	40
Northeast Newfoundland	2	54.96	34

Tukey-type Multiple Comparisons (Region Codes)	Q^1	*p*-value
4 vs. 2	16.246	<0.001
4 vs. 1	12.652	<0.001
4 vs. 3	12.030	<0.001
4 vs. 5	6.196	<0.001
5 vs. 2	13.702	<0.001
5 vs. 1	8.254	<0.001
5 vs. 3	7.335	<0.001
3 vs. 2	5.037	<0.001
3 vs. 1	0.694	>0.50
1 vs. 2	4.388	<0.001

[1] $Q_{0.05,5}=2.807$

Table B.2 Catches of blue whales in each region versus observed and expected numbers of blue whales landed from 1898-1972.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	65.88	0.262	194	504	0.101	0.083	0.119	<Expected	2.9
2	44.14	0.176	25	338	0.013	0.006	0.020	<Expected	0.6
3	48.00	0.191	126	367	0.066	0.051	0.080	<Expected	2.6
4	74.00	0.295	1472	566	0.767	0.742	0.792	>Expected	19.9
5	18.98	0.076	103	145	0.054	0.040	0.067	<Expected	5.4
Total[3]	**251.00**	**1.00**	**1920**	**1920**	**1.00**				**31.5**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of blue whales landed in all phases vs. region: χ^2=2100.69, *df*=4, *p*<0.001.

Table B.3 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of blue whales taken off Newfoundland and Labrador between each region in Phase 1.

Region	Region Code	Mean Rank	*n*
south coast of Newfoundland	4	109.54	53
strait of Belle Isle/ Gulf of St. Lawrence	5	60.69	18
east Newfoundland	3	57.89	36
Coastal Labrador	1	33.73	11
northeast Newfoundland	2	33.33	24

Kruskal-Wallis *H*	*df*	*p*-value
83.32	4	<0.001

Tukey-type Multiple Comparisons (Region Codes)	Q^1	*p*-value
4 vs. 2	13.845	<0.001
4 vs. 1	12.289	<0.001
4 vs. 3	9.256	<0.001
4 vs. 5	8.676	<0.001
5 vs. 2	7.153	<0.001
5 vs. 1	8.273	<0.001
5 vs. 3	0.617	>0.50
3 vs. 2	5.337	<0.001
3 vs. 1	5.115	<0.001
1 vs. 2	0.107	>0.50

[1] $Q_{0.05,5}=2.807$

Table B.4 Catches of blue whales in each region versus observed and expected numbers of blue whales landed in Phase 1.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence: Lower	Upper	CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
1	11.00	0.077	5	120	0.003	0.000	0.007	<Expected	0.5
2	24.00	0.169	9	262	0.006	0.001	0.011	<Expected	0.4
3	36.00	0.254	126	393	0.081	0.063	0.099	<Expected	3.5
4	53.00	0.373	1350	579	0.870	0.848	0.892	>Expected	25.5
5	18.00	0.127	61	197	0.039	0.027	0.052	<Expected	3.4
Total[3]	**142.00**	**1.00**	**1551**	**1551**	**1.00**				**33.2**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of blue whales landed in Phase 1 vs. region: χ^2=1657.06, df=4, p<0.001.

Table B.5 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of blue whales taken off Newfoundland and Labrador between each region in Phase 2.

Region	**Region Code**	**Mean Rank**	***n***
south coast of Newfoundland	4	16.8	10
Coastal Labrador	1	10	13
northeast Newfoundland	2	2	1

Kruskal-Wallis *H*	***df***	***p*-value**
7.60	2	0.022

Tukey-type Multiple Comparisons (Region Codes)	Q^1	***p*-value**
4 vs. 2	4.255	<0.001
4 vs. 1	2.384	$0.10>p>0.05$
1 vs. 2	1.843	$0.20>p>0.10$

[1] $Q_{0.05,\,3}=2.394$

Table B.6 Catches of blue whales in each region versus observed and expected numbers of blue whales landed in Phase 2.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	24.00	0.600	72	112	0.387	0.302	0.473	<Expected	3.0
2	1.00	0.025	0	5	0.000	0.000	0.000	<Expected	0.0
4	15.00	0.375	114	70	0.613	0.527	0.698	>Expected	7.6
Total[3]	**40.00**	**1.00**	**186**	**186**	**1.00**				**10.6**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of blue whales landed in Phase 2 vs. region: χ^2=46.77, *df*=4, p<0.001.

Table B.7 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of blue whales taken off Newfoundland and Labrador between each region in Phase 3.

Region	Region Code	Mean Rank	*n*
strait of Belle Isle/ Gulf of St. Lawrence	5	36.19	6
south coast of Newfoundland	4	23.63	4
Coastal Labrador	1	17.97	16
northeast Newfoundland	2	16.56	9
east Newfoundland	3	8	4

Kruskal-Wallis H	df	p-value
19.33	4	0.001

Tukey-type Multiple Comparisons (Region Codes)	Q^1	p-value
5 vs. 3	14.424	<0.001
5 vs. 2	8.328	<0.001
5 vs. 1	5.861	<0.001
5 vs. 4	6.427	<0.001
4 vs. 3	9.024	<0.001
4 vs. 2	3.021	$0.05>p>0.02$
4 vs. 1	1.711	>0.50
1 vs. 3	3.015	$0.05>p>0.02$
1 vs. 2	0.460	>0.50
2 vs. 3	3.658	$0.005>p>0.002$

[1] $Q_{0.05,5}=2.807$

Table B.8 Catches of blue whales in each region versus observed and expected numbers of blue whales landed in Phase 3.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	30.88	0.490	117	90	0.639	0.548	0.731	>Expected	3.8
2	19.14	0.304	16	56	0.087	0.034	0.141	<Expected	0.8
3	8.00	0.127	0	23	0.000	0.000	0.000	<Expected	0.0
4	4.00	0.063	8	12	0.044	0.005	0.083	Within	2.0
5	0.98	0.016	42	3	0.230	0.149	0.310	>Expected	42.7
Total[3]	**63.00**	**1.00**	**183**	**183**	**1.00**				**49.3**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of blue whales landed in Phase 3 vs. region: χ^2=596.78, df=4, p<0.001.

Table B.9 Nonparametric Tukey-type multiple comparisons of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each region from 1898-1972.

Region	Region Code	Mean Rank	*n*
Northeast Newfoundland	2	174.67	48
Coastal Labrador	1	174.16	51
Strait of Belle Isle/Gulf of St. Lawrence	5	107.06	27
South coast of Newfoundland	4	104.85	69
East Newfoundland	3	90.25	61

Tukey-type Multiple Comparisons (Region Codes)	Q^1	*p*-value
2 vs. 3	13.842	<0.001
2 vs. 4	10.952	<0.001
2 vs. 5	12.895	<0.001
2 vs. 1	0.088	>0.50
1 vs. 3	13.617	<0.001
1 vs. 4	10.790	<0.001
1 vs. 5	12.441	<0.001
5 vs. 3	2.847	$0.05>p>0.02$
5 vs. 4	0.349	>0.50
4 vs. 3	2.205	$0.50>p>0.20$

[1]$Q_{0.05,5}=2.807$

Table B.10 Catches of fin whales in each region versus observed and expected numbers of fin whales landed from 1898-1972.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	74.22	0.247	4804	3415	0.348	0.338	0.359	>Expected	64.7
2	58.19	0.194	4577	2677	0.332	0.321	0.342	>Expected	78.7
3	74.38	0.248	1639	3422	0.119	0.112	0.126	<Expected	22.0
4	74.11	0.247	2327	3409	0.169	0.160	0.177	<Expected	31.4
5	19.11	0.064	454	879	0.033	0.029	0.037	<Expected	23.8
Total[3]	**300.00**	**1.00**	**13801**	**13801**	**1.00**				**220.6**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed in all phases vs. region: $\chi^2 = 3392.20$, $df=4$, $p<0.001$.

Table B.11 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each region in Phase 1.

Region	**Region Code**	**Mean Rank**	***n***
Coastal Labrador	1	108.32	11
northeast Newfoundland	2	94.23	24
east Newfoundland	3	67.22	36
strait of Belle Isle/ Gulf of St. Lawrence	5	61.5	18
south coast of Newfoundland	4	59.87	53

Kruskal-Wallis *H*	***df***	***p*-value**
21.84	4	<0.001

Tukey-type Multiple Comparisons (Region Codes)	**Q^1**	***p*-value**
1 vs. 4	7.854	<0.001
1 vs. 5	14.368	<0.001
1 vs. 3	8.701	<0.001
1 vs. 2	3.776	$0.002>p>0.001$
2 vs. 4	6.242	<0.001
2 vs. 5	8.556	<0.001
2 vs. 3	5.869	<0.001
3 vs. 4	1.317	>0.50
3 vs. 5	1.260	>0.50
5 vs. 4	0.289	>0.50

[1] $Q_{0.05,5}=2.807$

Table B.12 Catches of fin whales in each region versus observed and expected numbers of fin whales landed in Phase 1.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	11.00	0.077	608	361	0.130	0.118	0.143	>Expected	55.3
2	24.00	0.169	1170	788	0.251	0.235	0.267	>Expected	48.8
3	36.00	0.254	1134	1182	0.243	0.227	0.259	Within	31.5
4	53.00	0.373	1337	1740	0.287	0.270	0.304	<Expected	25.2
5	18.00	0.127	413	591	0.089	0.078	0.099	<Expected	22.9
Total[3]	**142.00**	**1.00**	**4662**	**4662**	**1.00**				**183.7**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed in Phase 1 vs. region: χ^2=502.88, df=4, p<0.001.

Table B.13 Kruskal-Wallis analysis of variance by ranks of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each region in Phase 2.

Region	Region Code	Mean Rank	*n*
Coastal Labrador	1	14.38	13
northeast Newfoundland	2	12	1
south coast of Newfoundland	4	10.1	10

Kruskal-Wallis *H*	*df*	*p*-value
2.08	2	0.353

Table B.14 Catches of fin whales in each region versus observed and expected numbers of fin whales landed in Phase 2.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	24.00	0.600	1895	1627	0.699	0.678	0.720	>Expected	79.0
2	1.00	0.025	66	68	0.024	0.017	0.031	Within	66.0
4	15.00	0.375	751	1017	0.277	0.256	0.297	<Expected	50.1
Total[3]	**40.00**	**1.00**	**2712**	**2712**	**1.00**				**195.0**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed in Phase 2 vs. region: χ^2=113.69, *df*=2, *p*<0.001.

Table B.15 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each region in Phase 3.

Region	Region Code	Mean Rank	*n*
northeast Newfoundland	2	26.89	9
Coastal Labrador	1	24.28	16
south coast of Newfoundland	4	19.88	4
strait of Belle Isle/ Gulf of St. Lawrence	5	9.58	6
east Newfoundland	3	3.13	4

Kruskal-Wallis *H*	*df*	*p*-value
19.33	4	0.001

Tukey-type Multiple Comparisons (Region Codes)	Q^1	*p*-value
2 vs. 3	10.153	<0.001
2 vs. 5	7.344	<0.001
2 vs. 4	2.995	$0.05>p>0.02$
2 vs. 1	0.851	>0.50
1 vs. 3	6.395	<0.001
1 vs. 5	4.729	<0.001
1 vs. 4	1.330	>0.50
4 vs. 3	9.671	<0.001
4 vs. 5	5.270	<0.001
5 vs. 3	3.300	$0.01>p>0.005$

[1] $Q_{0.05,5}=2.807$

Table B.16 Catches of fin whales in each region versus observed and expected numbers of fin whales landed in Phase 3.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	30.88	0.490	2180	1925	0.555	0.535	0.575	>Expected	70.6
2	19.14	0.304	1469	1193	0.374	0.354	0.394	>Expected	76.8
3	8.00	0.127	4	499	0.001	0.000	0.002	<Expected	0.5
4	4.00	0.063	238	249	0.061	0.051	0.070	Within	59.5
5	0.98	0.016	37	61	0.009	0.005	0.013	<Expected	37.6
Total[3]	**63.00**	**1.00**	**3928**	**3928**	**1.00**				**245.0**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed in Phase 3 vs. region: χ^2=598.48, *df*=4, *p*<0.001.

Table B.17 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each region in Phase 4.

Region	Region Code	Mean Rank	*n*
northeast Newfoundland	2	36.93	14
strait of Belle Isle/ Gulf of St. Lawrence	5	35	3
Coastal Labrador	1	31.05	11
east Newfoundland	3	16.6	21
south coast of Newfoundland	4	7	2

Kruskal-Wallis *H*	*df*	*p*-value
21.69	4	<0.001

Tukey-type Multiple Comparisons (Region Codes)	Q^1	*p*-value
2 vs. 4	8.316	<0.001
2 vs. 3	5.750	<0.001
2 vs. 1	1.983	$0.50>p>0.20$
2 vs. 5	0.601	>0.50
5 vs. 4	19.399	<0.001
5 vs. 3	4.216	<0.001
5 vs. 1	1.450	>0.50
1 vs. 4	8.034	<0.001
1 vs. 3	4.139	<0.001
3 vs. 4	1.913	>0.50

[1] $Q_{0.05,\,5}=2.807$

Table B.18 Catches of fin whales in each region versus observed and expected numbers of fin whales landed in Phase 4.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	8.34	0.152	121	379	0.048	0.037	0.059	<Expected	14.5
2	14.05	0.255	1872	638	0.749	0.727	0.771	>Expected	133.3
3	30.38	0.552	501	1380	0.200	0.180	0.221	<Expected	16.5
4	2.11	0.038	1	96	0.000	-0.001	0.001	<Expected	0.5
5	0.12	0.002	4	6	0.002	0.000	0.004	Within	32.3
Total[3]	**55.00**	**1.00**	**2499**	**2499**	**1.00**				**197.0**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed in Phase 4 vs. region: χ^2= 3214.53, df=4, p<0.001.

Table B.19 Nonparametric Tukey-type multiple comparisons of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each region from 1898-1972.

Region	Region Code	Mean Rank	n
South coast of Newfoundland	4	147.09	69
Coastal Labrador	1	143.09	51
Northeast Newfoundland	2	120.27	48
East Newfoundland	3	112.93	61
Strait of Belle Isle/Gulf of St. Lawrence	5	103.26	27

Tukey-type Multiple Comparisons (Region Codes)	Q^1	p-value
4 vs. 5	6.931	<0.001
4 vs. 3	5.160	<0.001
4 vs. 2	4.207	<0.001
4 vs. 1	0.623	>0.50
1 vs. 5	7.385	<0.001
1 vs. 3	4.895	<0.001
1 vs. 2	3.951	<0.001
2 vs. 5	3.244	$0.02>p>0.01$
2 vs. 3	1.204	>0.50
3 vs. 5	1.638	>0.50

$^1Q_{0.05,\,5}=2.807$

Table B.20 Catches of sei whales in each region versus observed and expected numbers of sei whales landed from 1898-1972.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	74.22	0.247	108	72	0.371	0.298	0.444	>Expected	1.5
2	58.19	0.194	33	56	0.113	0.066	0.161	<Expected	0.6
3	74.38	0.248	13	72	0.045	0.013	0.076	<Expected	0.2
4	74.11	0.247	134	72	0.460	0.385	0.536	>Expected	1.8
5	19.11	0.064	3	19	0.010	-0.005	0.026	<Expected	0.2
Total[3]	**300.00**	**1.00**	**291**	**291**	**1.00**				**4.2**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed in all phases vs. region: χ^2=142.93, *df*=4, *p*<0.001.

Table B.21 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each region in Phase 1.

Region	Region Code	Mean Rank	n
south coast of Newfoundland	4	82.93	53
east Newfoundland	3	66.11	36
northeast Newfoundland	2	65.21	24
Coastal Labrador	1	62.5	11
strait of Belle Isle/ Gulf of St. Lawrence	5	62.5	18

Kruskal-Wallis H	df	p-value
19.95	4	0.001

Tukey-type Multiple Comparisons (Region Codes)	Q^1	p-value
4 vs. 5	3.628	$0.005>p>0.002$
4 vs. 1	3.312	$0.01>p>0.005$
4 vs. 2	3.219	$0.02>p>0.01$
4 vs. 3	3.014	$0.05>p>0.02$
3 vs. 5	0.795	>0.50
3 vs. 1	0.764	>0.50
3 vs. 2	0.196	>0.50
2 vs. 5	0.708	>0.50
2 vs. 1	0.726	>0.50
1 vs. 5	0	>0.50

[1] $Q_{0.05, 5}=2.807$

Table B.22 Catches of sei whales in each region versus observed and expected numbers of sei whales landed in Phase 1.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	11.00	0.077	0	7	0.000	0.000	0.000	<Expected	0.0
2	24.00	0.169	1	16	0.011	-0.017	0.038	<Expected	0.0
3	36.00	0.254	2	24	0.022	-0.017	0.060	<Expected	0.1
4	53.00	0.373	90	35	0.968	0.921	1.015	>Expected	1.7
5	18.00	0.127	0	12	0.000	0.000	0.000	<Expected	0.0
Total[3]	**142.00**	**1.00**	**93**	**93**	**1.00**				**1.8**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed in Phase 1 vs. region: $\chi^2 = 140.59$, $df=4$, $p<0.001$.

Table B.23 Kruskal-Wallis analysis of variance by ranks of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each region in Phase 2.

Region	Region Code	Mean Rank	*n*
south coast of Newfoundland	4	14.5	10
Coastal Labrador	1	11.54	13
northeast Newfoundland	2	5	1

Kruskal-Wallis *H*	*df*	*p*-value
2.30	2	0.317

Table B.24 Catches of sei whales in each region versus observed and expected numbers of sei whales landed in Phase 2.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	24.00	0.600	30	40	0.448	0.302	0.593	<Expected	1.3
2	1.00	0.025	0	2	0.000	0.000	0.000	<Expected	0.0
4	15.00	0.375	37	25	0.552	0.407	0.698	>Expected	2.5
Total[3]	**40.00**	**1.00**	**67**	**67**	**1.00**				**3.7**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed in Phase 2 vs. region: χ^2= 9.88, *df*=2, 0.01>*p*>0.001.

Table B.25 Kruskal-Wallis analysis of variance by ranks of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each region in Phase 3.

Region	Region Code	Mean Rank	*n*
south coast of Newfoundland	4	23.13	4
northeast Newfoundland	2	21.89	9
Coastal Labrador	1	21.53	16
strait of Belle Isle/ Gulf of St. Lawrence	5	16.33	6
east Newfoundland	3	12	4

Kruskal-Wallis *H*	*df*	*p*-value
4.31	4	0.365

Table B.26 Catches of sei whales in each region versus observed and expected numbers of sei whales landed in Phase 3.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	30.88	0.490	67	49	0.670	0.549	0.791	>Expected	2.2
2	19.14	0.304	24	30	0.240	0.130	0.350	Within	1.3
3	8.00	0.127	0	13	0.000	0.000	0.000	<Expected	0.0
4	4.00	0.063	6	6	0.060	-0.001	0.121	Within	1.5
5	0.98	0.016	3	2	0.030	-0.014	0.074	Within	3.0
Total[3]	**63.00**	**1.00**	**100**	**100**	**1.00**				**8.0**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed in Phase 3 vs. region: $\chi^2 = 21.98$, $df=4$, $p<0.001$.

Table B.27 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each region in Phase 4.

Region	Region Code	Mean Rank	n
south coast of Newfoundland	4	35.25	2
east Newfoundland	3	26.45	21
Coastal Labrador	1	26.36	11
northeast Newfoundland	2	25.11	14
strait of Belle Isle/ Gulf of St. Lawrence	5	19.5	3

Kruskal-Wallis H	df	p-value
2.43	4	0.657

Table B.28 Catches of sei whales in each region versus observed and expected numbers of sei whales landed in Phase 4.

Region	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
1	8.34	0.152	11	5	0.355	0.133	0.576	Within	1.3
2	14.05	0.255	8	8	0.258	0.056	0.460	Within	0.6
3	30.38	0.552	11	17	0.355	0.133	0.576	Within	0.4
4	2.11	0.038	1	1	0.032	-0.049	0.114	Within	0.5
5	0.12	0.002	0	0	0.000	0.000	0.000	Within	0.0
Total[3]	**55.00**	**1.00**	**31**	**31**	**1.00**				**2.7**

[1]Expected proportion of whales landed=number of catcher-boat years in region/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed in Phase 4 vs. region: $\chi^2 = 10.72$, $df=4$, $0.05>p>0.025$.

Table B.29 Nonparametric Tukey-type multiple comparisons of effort-adjusted number of blue whales taken off Newfoundland and Labrador between each season from 1927-1972.

Season	**Season Code**	**Mean Rank**	***n***
Spring	1	63.46	28
Summer	2	60.48	44
Autumn	3	31.94	32

Tukey-type Multiple Comparisons (Season Codes)	Q^1	***p*-value**
1 vs. 3	6.975	<0.001
1 vs. 2	0.589	>0.50
2 vs. 3	5.563	<0.001

[1] $Q_{0.05,3}$=2.394

Table B.30 Catches of blue whales in each season versus observed and expected numbers of blue whales landed from 1927-1972.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence: Lower	Upper	CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
Spring	45	0.333	124	108	0.382	0.312	0.451	Within	2.8
Summer	45	0.333	194	108	0.597	0.527	0.667	>Expected	4.3
Autumn	45	0.333	7	108	0.022	0.001	0.042	<Expected	0.2
Total[3]	**135.00**	**1.00**	**325**	**325**	**1.00**				**7.2**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of blue whales landed vs. season: $\chi^2 = 164.79$, $df=2$, $p<0.001$.

Table B.31 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of blue whales taken off Newfoundland and Labrador between each season off coastal Labrador.

Season	Season Code	Mean Rank	*n*
Summer	2	32.45	21
Spring	1	24.38	8
Autumn	3	17.42	20

Kruskal-Wallis *H*	*df*	*p*-value
13.96	2	0.001

Tukey-type Multiple Comparisons (Season Codes)	Q^1	*p*-value
2 vs. 3	4.016	<0.001
2 vs. 1	2.281	$0.10>p>0.05$
1 vs. 3	2.023	$0.20>p>0.10$

[1] $Q_{0.05,3}=2.394$

Table B.32 Catches of blue whales in each season versus observed and expected numbers of blue whales landed off coastal Labrador.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence: Lower	Upper	CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
Spring	17	0.333	13	59	0.073	0.023	0.124	<Expected	0.8
Summer	17	0.333	158	59	0.893	0.833	0.953	>Expected	9.3
Autumn	17	0.333	6	59	0.034	-0.001	0.069	<Expected	0.4
Total[3]	**51.00**	**1.00**	**177**	**177**	**1.00**				**10.4**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of blue whales landed vs. season: χ^2= 249.59, *df*=2, *p*<0.001.

Table B.33 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of blue whales taken off Newfoundland and Labrador between each season off northeast Newfoundland.

Season	Season Code	Mean Rank	n
Summer	2	15.11	9
Spring	1	12	6
Autumn	3	8.5	8

Kruskal-Wallis H	df	p-value
6.07	2	0.048

Tukey-type Multiple Comparisons (Season Codes)	Q^1	p-value
2 vs. 3	2.694	$0.05>p>0.02$
2 vs. 1	1.319	>0.50
1 vs. 3	1.549	$0.50>p>0.20$

[1] $Q_{0.05,3}=2.394$

Table B.34 Catches of blue whales in each season versus observed and expected numbers of blue whales landed off northeast Newfoundland.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence: Lower	Upper	CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
Spring	9	0.333	5	5	0.313	0.014	0.611	Within	0.6
Summer	9	0.333	11	5	0.688	0.389	0.986	>Expected	1.2
Autumn	9	0.333	0	5	0.000	0.000	0.000	<Expected	0.0
Total[3]	**27.00**	**1.00**	**16**	**16**	**1.00**				**1.8**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of blue whales landed vs. season: $\chi^2 = 11.38$, $df=2$, $p<0.001$.

Table B.35 Kruskal-Wallis analysis of variance by ranks of effort-adjusted number of blue whales taken off Newfoundland and Labrador between each season off the south coast of Newfoundland.

Season	Season Code	Mean Rank	*n*
Spring	1	15.25	10
Summer	2	10.5	10
Autumn	3	6.17	3

Kruskal-Wallis *H*	*df*	*p*-value
5.27	2	0.072

Table B.36 Catches of blue whales in each season versus observed and expected numbers of blue whales landed off the south coast of Newfoundland.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
Spring	11	0.333	71	30	0.789	0.678	0.900	>Expected	6.5
Summer	11	0.333	18	30	0.200	0.091	0.309	<Expected	1.6
Autumn	11	0.333	1	30	0.011	-0.017	0.040	<Expected	0.1
Total[3]	**33.00**	**1.00**	**90**	**90**	**1.00**				**8.2**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of blue whales landed vs. season: χ^2= 88.87, *df*=2, *p*<0.001.

Table B.37 Nonparametric Tukey-type multiple comparisons of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each season from 1927-1972.

Season	**Season Code**	**Mean Rank**	***n***
Summer	2	113.63	83
Autumn	3	81.65	54
Spring	1	74.76	50

Tukey-type Multiple Comparisons (Season Codes)	Q^1	***p*-value**
2 vs. 1	5.634	<0.001
2 vs. 3	4.608	<0.001
3 vs. 1	1.164	>0.50

[1] $Q_{0.05,3}$=2.394

Table B.38 Catches of fin whales in each season versus observed and expected numbers of fin whales landed from 1927-1972.

						95% Bonferroni Confidence Limits on Proportion of Occurrence			
Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	Lower	Upper	CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
Spring	94	0.333	806	2559	0.105	0.096	0.114	<Expected	8.6
Summer	94	0.333	5375	2559	0.700	0.687	0.714	>Expected	57.2
Autumn	94	0.333	1496	2559	0.195	0.183	0.207	<Expected	15.9
Total[3]	**282.00**	**1.00**	**7677**	**7677**	**1.00**				**81.7**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed vs. season: $\chi^2=4741.24$, $df=2$, $p<0.001$.

Table B.39 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each season off coastal Labrador.

Season	Season Code	Mean Rank	n
Summer	2	41.43	30
Autumn	3	26.22	23
Spring	1	11.89	9

Kruskal-Wallis H	df	p-value
21.70	2	<0.001

Tukey-type Multiple Comparisons (Season Codes)	Q^1	p-value
2 vs. 1	6.817	<0.001
2 vs. 3	3.554	$0.002>p>0.001$
3 vs. 1	3.885	<0.001

$^1Q_{0.05,\,3}=2.394$

Table B.40 Catches of fin whales in each season versus observed and expected numbers of fin whales landed off coastal Labrador.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
Spring	33	0.333	53	1072	0.016	0.011	0.022	<Expected	1.6
Summer	33	0.333	2395	1072	0.745	0.725	0.765	>Expected	72.6
Autumn	33	0.333	768	1072	0.239	0.219	0.258	<Expected	23.3
Total[3]	**99.00**	**1.00**	**3216**	**3216**	**1.00**				**97.5**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed vs. season: $\chi^2 = 2687.60$, *df*=2, $p<0.001$.

Table B.41 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each season off northeast Newfoundland.

Season	Season Code	Mean Rank	*n*
Summer	2	46.14	21
Autumn	3	25.24	21
Spring	1	15.94	17

Kruskal-Wallis *H*	*df*	*p*-value
31.56	2	<0.001

Tukey-type Multiple Comparisons (Season Codes)	Q^1	*p*-value
2 vs. 1	8.329	<0.001
2 vs. 3	5.520	<0.001
3 vs. 1	2.565	$0.05>p>0.02$

$^1Q_{0.05,3}=2.394$

Table B.42 Catches of fin whales in each season versus observed and expected numbers of fin whales landed off northeast Newfoundland.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
Spring	23	0.333	207	1114	0.062	0.051	0.073	<Expected	9.0
Summer	23	0.333	2521	1114	0.755	0.735	0.774	>Expected	109.6
Autumn	23	0.333	613	1114	0.183	0.166	0.201	<Expected	26.7
Total[2]	**69.00**	**1.00**	**3341**	**3341**	**1.00**				**145.3**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed vs. season: χ^2= 2741.66, df=2, p<0.001.

Table B.43 Kruskal-Wallis analysis of variance by ranks of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each season off east Newfoundland.

Season	Season Code	Mean Rank	*n*
Spring	1	16.85	10
Autumn	3	16	6
Summer	2	14.32	14

Kruskal-Wallis *H*	*df*	*p*-value
0.51	2	0.776

Table B.44 Catches of fin whales in each season versus observed and expected numbers of fin whales landed off east Newfoundland.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence: Lower	Upper	CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
Spring	17	0.333	170	168	0.337	0.282	0.391	Within	10.0
Summer	17	0.333	248	168	0.491	0.434	0.548	>Expected	14.6
Autumn	17	0.333	87	168	0.172	0.129	0.216	<Expected	5.1
Total[2]	**51.00**	**1.00**	**505**	**505**	**1.00**				**29.7**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed vs. season: $\chi^2 = 77.02$, $df=2$, $p<0.001$.

Table B.45 Kruskal-Wallis analysis of variance by ranks and nonparametric Tukey-type multiple comparisons of effort-adjusted number of fin whales taken off Newfoundland and Labrador between each season off the south coast of Newfoundland.

Season	Season Code	Mean Rank	*n*
Spring	1	17.85	10
Summer	2	10.63	12
Autumn	3	6.33	3

Kruskal-Wallis *H*	*df*	*p*-value
8.06	2	0.018

Tukey-type Multiple Comparisons (Season Codes)	Q^1	*p*-value
1 vs. 3	4.494	<0.001
1 vs. 2	2.597	$0.05>p>0.02$
2 vs. 3	1.490	$0.50>p>0.20$

$^1Q_{0.05,3}$=2.394

Table B.46 Catches of fin whales in each season versus observed and expected numbers of fin whales landed off the south coast of Newfoundland.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
Spring	12	0.333	347	191	0.605	0.552	0.657	>Expected	28.9
Summer	12	0.333	203	191	0.354	0.302	0.405	Within	16.9
Autumn	12	0.333	24	191	0.042	0.020	0.063	<Expected	2.0
Total[2]	**36.00**	**1.00**	**574**	**574**	**1.00**				**47.8**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of fin whales landed vs. season: $\chi^2 = 273.70$, $df=2$, $p<0.001$.

Table B.47 Nonparametric Tukey-type multiple comparisons of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each season from 1927-1972.

Season	Season Code	Mean Rank	*n*
Summer	2	103.29	83
Autumn	3	98.94	54
Spring	1	73.24	50

Tukey-type Multiple Comparisons (Season Codes)	Q^1	*p*-value
2 vs. 1	4.356	<0.001
2 vs. 3	0.627	>0.50
3 vs. 1	4.341	<0.001

[1] $Q_{0.05,3}=2.394$

Table B.48 Catches of sei whales in each season versus observed and expected numbers of sei whales landed from 1927-1972.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence: Lower	Upper	CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
Spring	94	0.333	6	61	0.033	-0.001	0.067	<Expected	0.1
Summer	94	0.333	111	61	0.607	0.514	0.700	>Expected	1.2
Autumn	94	0.333	66	61	0.361	0.269	0.452	Within	0.7
Total[3]	**282.00**	**1.00**	**183**	**183**	**1.00**				**1.9**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed vs. season: χ^2=90.98, df=2, p<0.001.

Table B.49 Kruskal-Wallis analysis of variance by ranks of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each season off coastal Labrador.

Season	Season Code	Mean Rank	*n*
Summer	2	33.62	30
Autumn	3	33.04	23
Spring	1	20.5	9

Kruskal-Wallis *H*	*df*	*p*-value
5.37	2	0.068

Table B.50 Catches of sei whales in each season versus observed and expected numbers of sei whales landed off coastal Labrador.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
Spring	33	0.333	0	33	0.000	0.000	0.000	<Expected	0.0
Summer	33	0.333	49	33	0.500	0.370	0.630	>Expected	1.5
Autumn	33	0.333	49	33	0.500	0.370	0.630	>Expected	1.5
Total[3]	**99.00**	**1.00**	**98**	**98**	**1.00**				**3.0**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed vs. season: $\chi^2 = 49.00$, $df=2$, $p<0.001$.

Table B.51 Kruskal-Wallis analysis of variance by ranks of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each season off northeast Newfoundland.

Season	Season Code	Mean Rank	*n*
Summer	2	33.1	21
Autumn	3	31.36	21
Spring	1	24.5	17

Kruskal-Wallis *H*	*df*	*p*-value
5.54	2	0.063

Table B.52 Catches of sei whales in each season versus observed and expected numbers of sei whales landed off northeast Newfoundland.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence		CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
						Lower	Upper		
Spring	23	0.333	0	11	0.000	0.000	0.000	<Expected	0.0
Summer	23	0.333	22	11	0.688	0.476	0.899	>Expected	1.0
Autumn	23	0.333	10	11	0.313	0.101	0.524	Within	0.4
Total[3]	**69.00**	**1.00**	**32**	**32**	**1.00**				**1.4**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed vs. season: χ^2= 22.75, *df*=2, p<0.001.

Table B.53 Kruskal-Wallis analysis of variance by ranks of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each season off east Newfoundland.

Season	Season Code	Mean Rank	n
Autumn	3	17.5	6
Summer	2	17.14	14
Spring	1	12	10

Kruskal-Wallis H	df	p-value
4.33	2	0.115

Table B.54 Catches of sei whales in each season versus observed and expected numbers of sei whales landed off east Newfoundland.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence: Lower	Upper	CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
Spring	17	0.33	0	4	0.000	0.000	0.000	<Expected	0.0
Summer	17	0.33	7	4	0.636	0.263	1.010	Within	0.4
Autumn	17	0.33	4	4	0.364	-0.010	0.737	Within	0.2
Total[3]	**51.00**	**1.00**	**11**	**11**	**1.00**				**0.6**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed vs. season: χ^2= 6.73, *df*=2, p<0.001.

Table B.55 Kruskal-Wallis analysis of variance by ranks of effort-adjusted number of sei whales taken off Newfoundland and Labrador between each season off the south coast of Newfoundland.

Season	Season Code	Mean Rank	*n*
Summer	2	15.83	12
Spring	1	10.95	10
Autumn	3	8.5	3

Kruskal-Wallis *H*	*df*	*p*-value
4.98	2	0.083

Table B.56 Catches of sei whales in each season versus observed and expected numbers of sei whales landed off the south coast of Newfoundland.

Season	Catcher-boat Years	Expected Proportion of Whales Landed[1]	Observed No. of Whales Landed	Expected No. of Whales Landed[2]	Observed Proportion of Whales Landed	95% Bonferroni Confidence Limits on Proportion of Occurrence: Lower	Upper	CI of Observed Proportion	Observed No. Whales Landed per Catcher-boat Year
Spring	12	0.333	6	13	0.154	0.005	0.303	<Expected	0.5
Summer	12	0.333	33	13	0.846	0.697	0.995	>Expected	2.8
Autumn	12	0.333	0	13	0.000	0.000	0.000	<Expected	0.0
Total[3]	**36.00**	**1.00**	**39**	**39**	**1.00**				**3.3**

[1]Expected proportion of whales landed=number of catcher-boat years in season/total number of catcher boat years.
[2]Expected number of whales landed=expected proportion of whales landed x total number of observed whales landed.
[3]Observed vs. expected number of sei whales landed vs. season: χ^2= 47.54, *df*=2, *p*<0.001.