Assessing Cetacean Distribution in the Scotian Shelf Bioregion using Habitat Suitability Models

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by
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ABSTRACT

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Prediction and delineation of species' distribution can be used to identify important cetacean habitat, highlighting key areas to consider for conservation. The majority of data on cetacean occurrence in the Scotian Shelf Bioregion has been obtained opportunistically rather than systematically and species distribution has been primarily assessed through the development of qualitative hand-drawn maps. Habitat suitability models (HSMs) have been proposed as an alternative tool to make the most of available information. The potential of using HSMs to investigate cetacean distribution on the Scotian Shelf was explored by conducting a scientific literature review of HSMs used for cetaceans, compiling and evaluating cetacean and environmental data available for the Scotian Shelf, and applying chosen HSMs to selected species. Maximum Entropy (MaxEnt) models were performed for northern bottlenose and Sowerby's beaked whales using five environmental variables: ocean depth, seafloor slope, seafloor aspect, sea surface temperature and Chlorophyll-a concentration. This work highlights the potential effectiveness of HSMs to predict key areas for cetacean conservation within the Scotian Shelf Bioregion; however, further refinement is needed before results can be more broadly applied.

RÉSUMÉ

Gómez-Salazar, C and Moors-Murphy, H.B. 2014. Évaluation de la répartition des cétacés dans la biorégion du plateau néo-écossais à l'aide de modèles de qualité de l'habitat. Can. Tech. Rep. Fish. Aquat. Sci. 2993: iv + 49p.

Les prévisions en matière de répartition des espèces et la délimitation des aires de répartition peuvent servir à déterminer les habitats importants des cétacés et à indiquer les principales zones à prendre en compte aux fins de conservation. La plupart des données sur les cétacés dans la biorégion du plateau néo-écossais ont jusqu'ici été obtenues au gré des occasions plutôt que de façon systématique, et la répartition des espèces a été principalement évaluée grâce à des cartes à main levée qualitatives. Des modèles de qualité de l'habitat ont été proposés comme nouvel outil pour tirer le meilleur parti de l'information disponible. Afin d'examiner la pertinence de ces modèles dans l'étude de la répartition des cétacés sur le plateau néo-écossais, on a réalisé une analyse documentaire des modèles de qualité de l'habitat utilisés pour les cétacés, compilé et évalué les données sur les cétacés et les données environnementales disponibles pour le plateau néo-écossais, puis appliqué les modèles de qualité de l'habitat choisis aux espèces sélectionnées. Des modèles d'entropie maximale ont été réalisés pour la baleine à bec commune et la baleine à bec de Sowerby à partir de cinq variables environnementales : la profondeur, la pente du fond marin, l'aspect du fond marin, la température de la surface de la mer et la concentration de chlorophylle-*a*. Ce travail met en évidence la possible pertinence des modèles de qualité de l'habitat dans les prévisions relatives aux principales zones de conservation des cétacés dans la biorégion du plateau néo-écossais. Toutefois, il est nécessaire de procéder à des ajustements avant que les résultats puissent être mis en œuvre à plus grande échelle.

INTRODUCTION

Prediction and delineation of species' distribution can be used to identify important cetacean habitat including breeding or foraging grounds, or other sites that play an important role in life history; highlighting key areas to consider for conservation activities such as areas of concentration or areas where vulnerability is increased through increased sensitivity and exposure to risk. Predicting cetacean distribution is particularly important for informing management initiatives such as identifying critical habitat (CH) and ecological hotspots, and in the planning of marine protected area (MPA) networks, including those designed primarily for the conservation of top-predators (Hooker et al. 2011).

Habitat suitability models (HSMs) are a statistical tool that can be used to assess the relationship between species occurrence data (*e.g.,* sightings) and environmental variables, and subsequently quantitatively predict and delineate species range and distribution (Redfern et al. 2006). HSMs have been used to investigate the distribution of various cetacean species over a variety of spatial scales. Large-scale patterns of cetacean distribution, such as global or ocean basin-wide distribution, have been identified using HSMs. For example, Kaschner et al. (2006) mapped the worldwide distribution of cetaceans using descriptive distribution data derived from available expert knowledge against depth, sea-surface temperature, and ice edge using a relative environmental suitability (RES) modelling approach. Cetacean distribution over medium (*e.g.,* bioregional) and smaller-scales (*e.g.,* local) have also been analyzed using HSMs, providing higher resolution information on species distribution patterns. For example, Ingram et al. (2007) used generalized linear models (GLMs) and generalized additive models (GAMs) to evaluate if the distribution of minke (*Balaenoptera acutorostrata*) and fin whales (*Balaenoptera physalus*) recorded from whale-watching vessels in the Bay of Fundy were related to ocean depth or benthic slope. While both species were found to have a preference for deeper waters, slope was only important to minke whales suggesting some degree of habitat partitioning between these species.

HSMs have also been used to identify areas where cetaceans are more likely to occur to propose key areas for conservation such as CH, MPAs and delineated ecological hotspots (*e.g.,* Cañadas et al. 2005, Hooker et al. 1999). Gregr and Trites (2001) used GLMs and historic whale catches off British Columbia to determine if the distribution of sperm (*Physeter macrocephalus*), sei (*Balaenoptera borealis*), fin, humpback (*Megaptera novaeangliae*), and blue (*Balaenoptera musculus*) whales were related to depth, slope, temperature, salinity or month. Their results were used to delineate CH for these species, in this case defined as the ability of an area to provide the resources necessary for the persistence of a population (Gregr and Trites 2001). Abgrall (2009) used an Ecological Niche Factor Analysis (ENFA) approach to determine if blue, sei and fin whale distributions off Newfoundland and Labrador were related to water depth, seabed slope, sea surface temperature, or chlorophyll concentrations. The results were used to provide support for proposed CH of these species in Newfoundland waters. Wheeler et al. (2012) also used an ENFA approach to identify summer and autumn CH for bowhead whales (*Balaena mysticetus*) in the eastern Canadian Arctic using a variety of data sets (governmental, private, and historical whaling) and considering five environmental variables: sea surface temperature, chlorophyll, ice, depth, slope, and distance to shore. In the context of MPAs, Embling et al. (2010) used GAMs to investigate harbour porpoise (*Phocoena phocoena*) distribution on the west coast of Scotland, which was best explained by maximum tidal current (with higher densities predicted in areas of low current) to propose special areas of conservation for the species. Cañadas et al. (2005) used GLMs to explain the variation in cetacean distribution in Spanish Mediterranean waters as related to physical and environmental variables, with the intent of predicting important areas for species that should be considered for protection.

The Scotian Shelf Bioregion (hereafter referred to as the Scotian Shelf), is located in the Northwest Atlantic, encompassing Nova Scotia off eastern Canada (Figure 1). It is delineated in the north by the Laurentian Channel and in the south by the Fundian (or Northeast) Channel. It consists of a wide continental shelf characterized by a complex topography of shallow banks, basins and submarine canyons, the latter of which is considered one of the most prominent features of the shelf (Breeze et al. 2002, Zwanenburg et al. 2002). Additionally, it includes the Bay of Fundy, which is characterized by extremely high tides and ecosystem dynamics very different than the rest of the shelf (Zwanenburg et al. 2002, Araujo and Bundy 2012).

Information on the distribution of cetacean species on the Scotian Shelf has been primarily derived from hand-drawn maps of the maximum range of occurrence developed using qualitative processes based on expert knowledge and sightings information (Figure 2; Breeze et al. 2002). Such methods are biased because they tend to identify habitats primarily in areas that have been surveyed in detail, while areas not surveyed are not considered (Hamazaki 2002). HSMs have been proposed as a potential alternative tool for assessing cetacean distribution patterns in the Scotian Shelf region that would make the most of the limited information currently available (King et al. 2013).

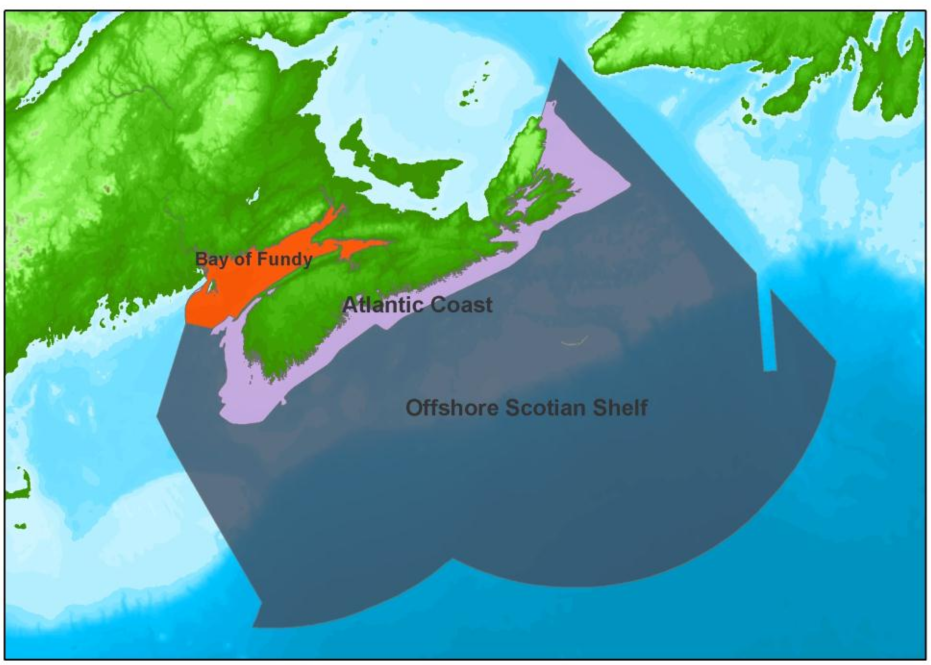

Figure 1. The Scotian Shelf Bioregion includes the Bay of Fundy, Atlantic Coast around Nova Scotia and the Offshore Scotian Shelf (source: Fisheries and Oceans Canada).

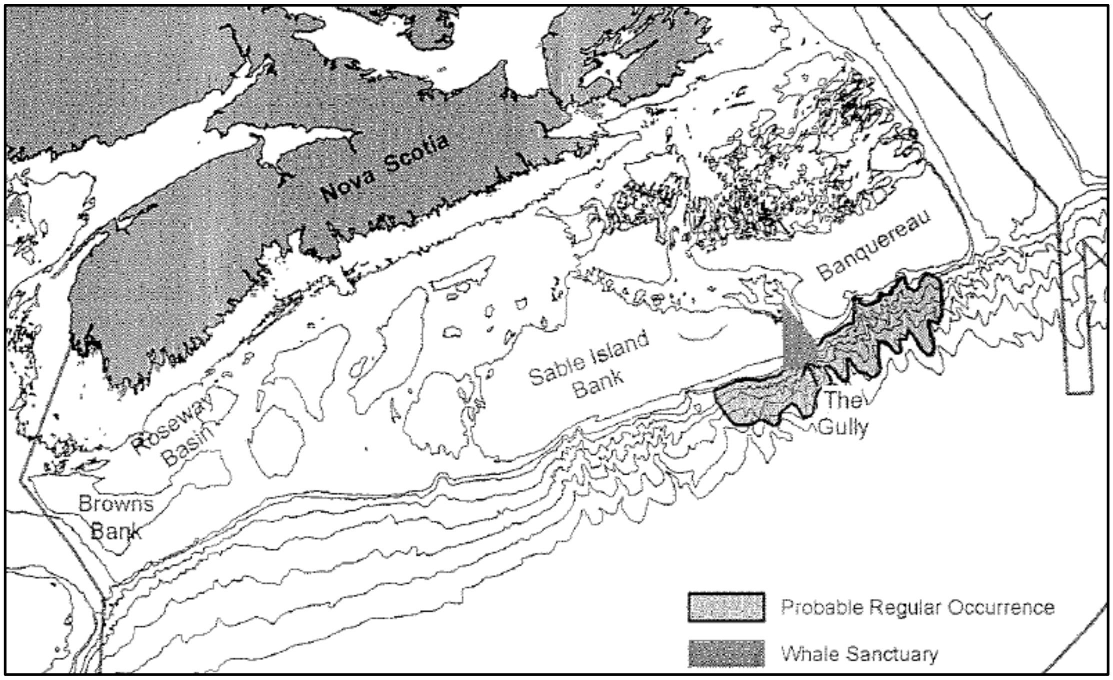

Figure 2. Distribution of northern bottlenose whales within the Scotian Shelf Bioregion based on known and probable occurrence derived from sightings, catch records, known habitat, and prey preferences (figure from Breeze et al. 2002: Figure 7.8).

The purpose of this study was to explore the effectiveness of using HSMs to predict cetacean distribution on the Scotian Shelf. This was done by compiling information from scientific literature, regional cetacean sightings data and environmental data for the Scotian Shelf to evaluate the data available for HSMs. Based on these available data, an HSM approach that was quantitatively well-suited to predicting the distribution of cetaceans on the Scotian Shelf was then chosen and performed on select species to investigate potential usefulness.

METHODS AND RESULTS

ASSESSMENT OF ECOLOGICAL SIGNIFICANCE OF SCOTIAN SHELF CETACEANS

Twenty-two cetacean species are known to occur in the Scotian Shelf region. A summary of the information available on the distribution of these 22 species is provided in Appendix 1 including an assessment of permanence on the shelf (migratory or resident), known habitat, prey preferences and potential key habitats. Based on this information, the species were categorized into five ecological groupings:

1. Migratory (present seasonally), specialist (Figure 3)
2. Migratory (present seasonally), generalist (Figure 4)
3. Resident (present year-round), deep diving (Figure 5)
4. Resident (present year-round), generalist (Figure 6)

5. Occasional visitor (Figure 7)

Of the 22 cetacean species that occur on the Scotian Shelf, only 15 have been regularly sighted; the remaining eight species are relatively rare or uncommon in the region (Appendix 1). A preliminary assessment of the ecological significance of these 15 most commonly occurring cetacean species was conducted to identify species that may be particularly significant for maintaining ecosystem structure and function (Appendix 2). The criteria against which these species were assessed were:

1. Forage species - characterized by rapid population turnover rates, high natural (non-fishing) mortality, can become more abundant or assume higher density when environmental conditions are favourable for recruitment and growth;
2. Highly influential predators - characterized by being at the top of the food web and consuming many prey species and/or particularly important forage species;
3. Nutrient importing/exporting species - such as migratory species;
4. Rarity - existence of a species at a relatively low abundance; and
5. Sensitivity - easily depleted by at least some human activities and does not recover easily.

These six criteria were developed by DFO (2006) to assess potential Ecologically Significant Species (ESS) in the marine environment. Criteria 1-3 are related to trophic role, while 4 and 5 are related to species rarity and vulnerability to human impacts, which may enhance priority ranking (DFO 2006).

Four cetacean species fulfilled all of the criteria except one (–the forage species criteria, which is not applicable to marine mammals); therefore, these species ranked high as potential ESS. These four species are North Atlantic right whales (*Eubalaena glacialis*), Scotian Shelf northern bottlenose whales (*Hyperoodon ampullatus*), Northwest Atlantic blue whales and Sowerby's beaked whales (*Mesoplodon bidens*) (Appendix 2). The first two species have been the focus of long-term systematic surveys (see Case Studies 1 and 2 below) and thus information on key habitat for their conservation is at a more advanced stage of knowledge. Conversely, detailed information on key habitats for the other two species is not available despite their conservation status and potential role as ESS (see Case Studies 3 and 4 below).

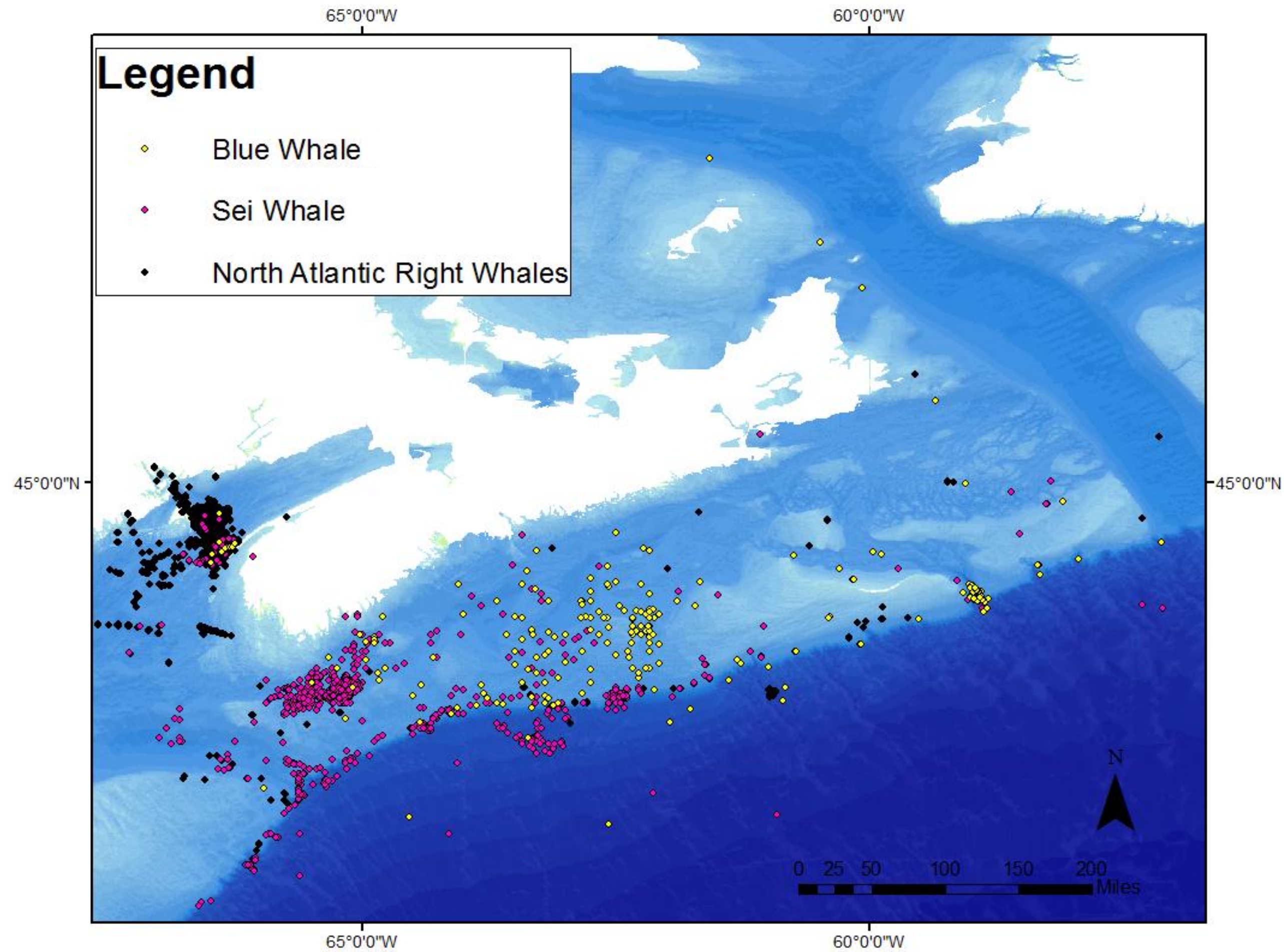

Figure 3. Sightings of migratory/specialist cetacean species that occur in the Scotian Shelf Bioregion. See 'Cetacean sightings data' section for information on the sources and limitations of this data. Note that these data are not weighted by effort, and equal effort did not occur across the region shown.

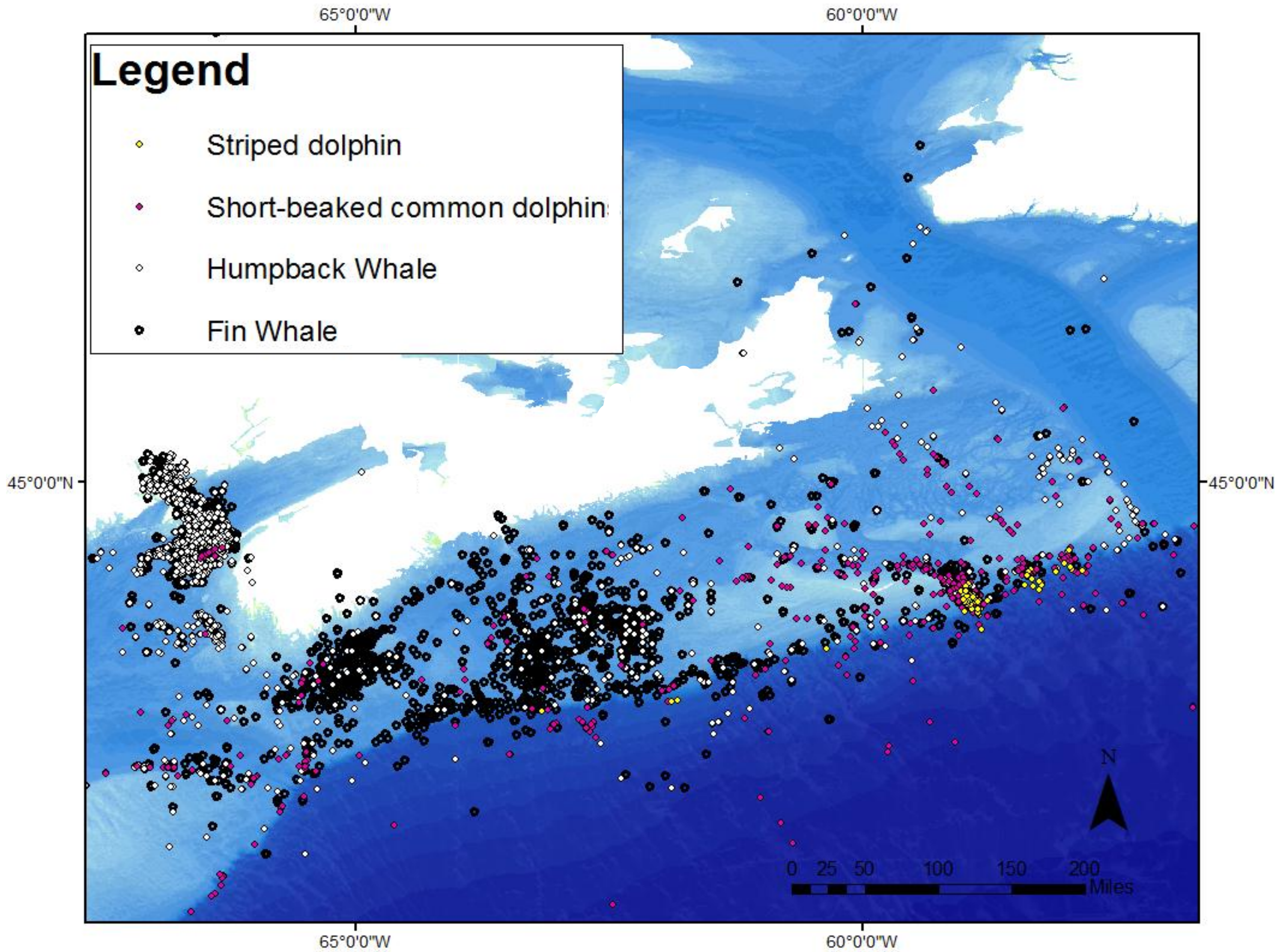

Figure 4. Sightings data of migratory/generalist cetacean species that occur in the Scotian Shelf Bioregion. See 'Cetacean sightings data' section for information on the sources and limitations of this data. Note that these data are not weighted by effort, and equal effort did not occur across the region shown.

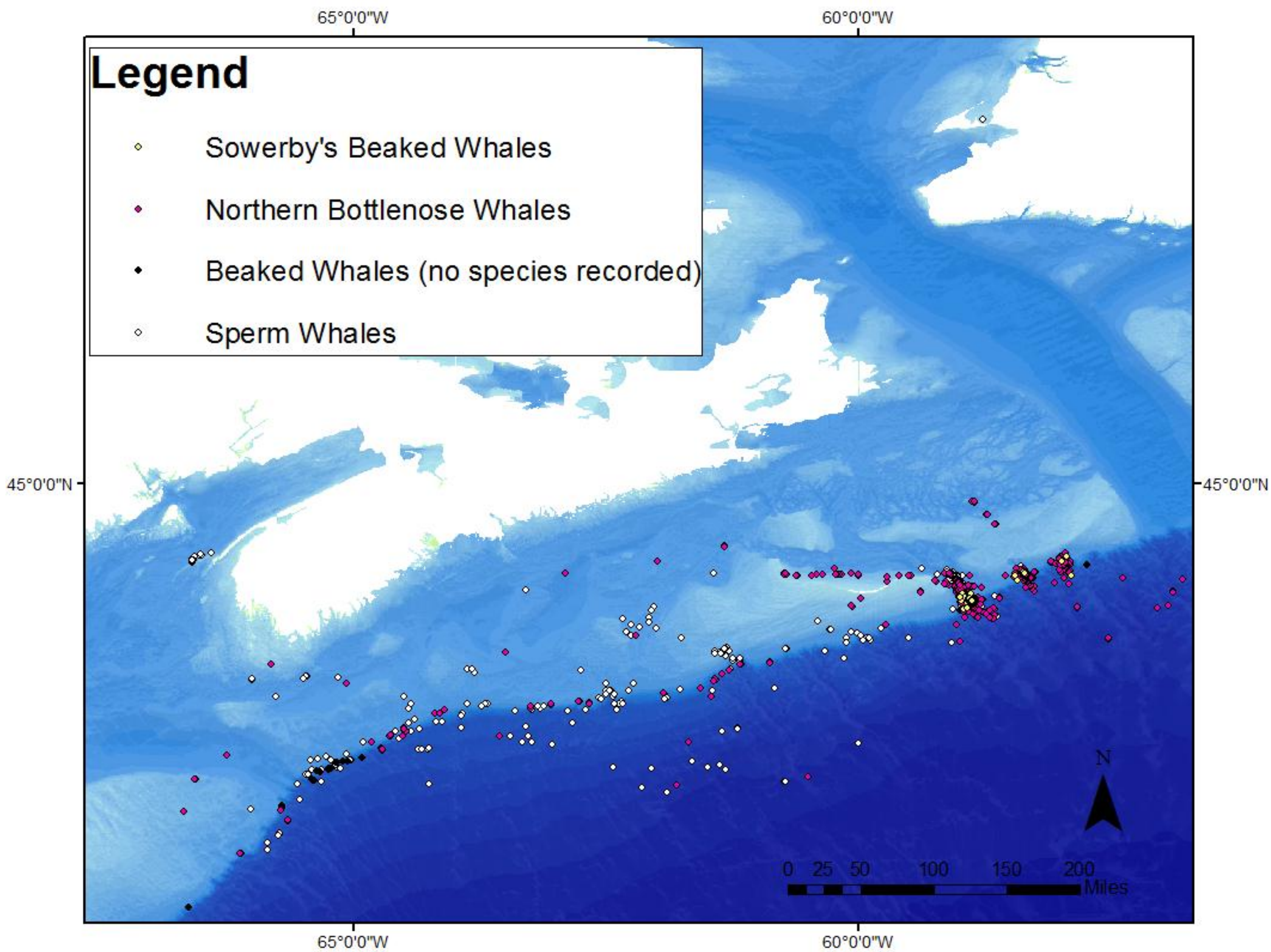

Figure 5. Sightings data of resident/deep-diver cetacean species that occur in the Scotian Shelf Bioregion. See 'Cetacean sightings data' section for information on the sources and limitations of this data. Note that these data are not weighted by effort, and equal effort did not occur across the region shown..

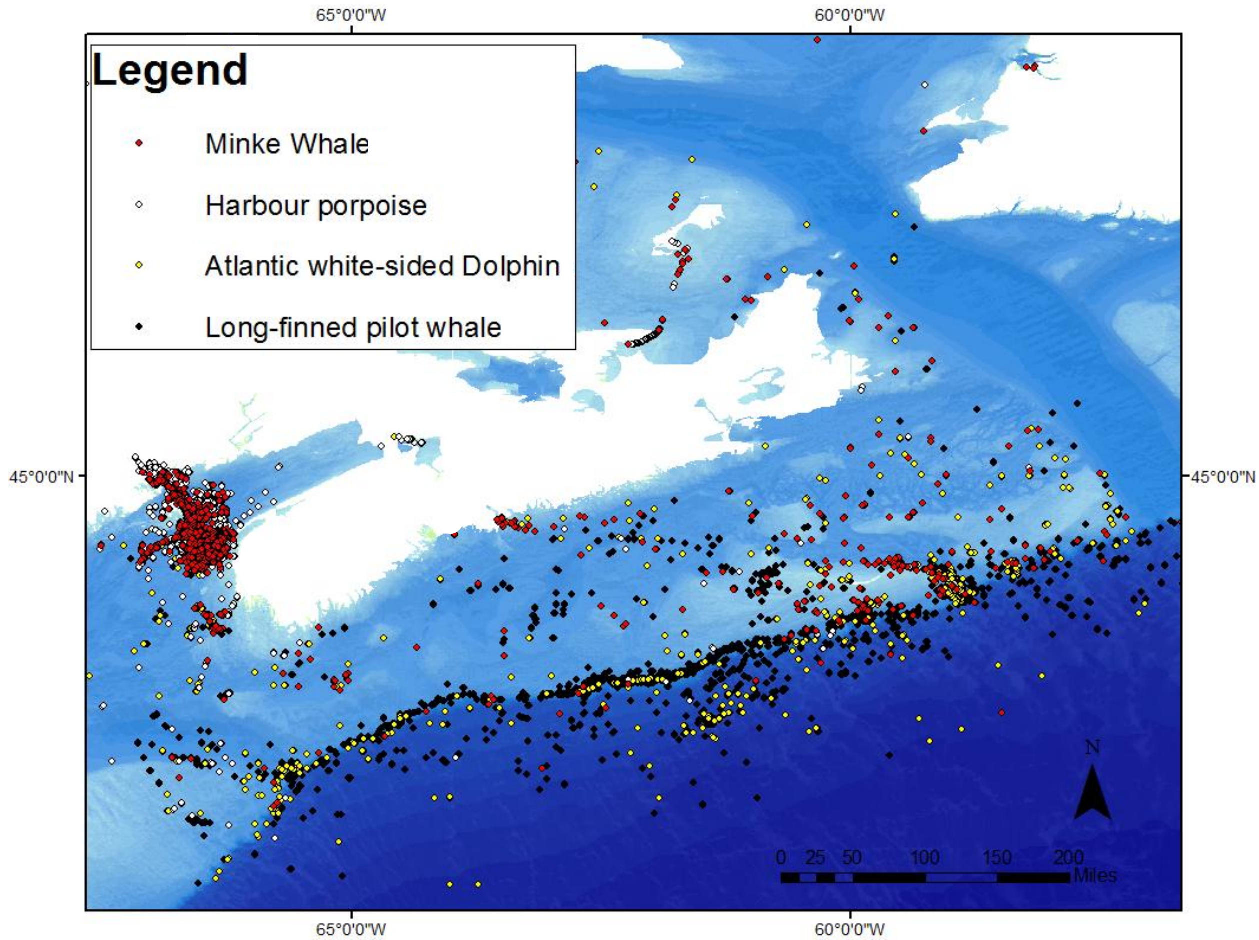

Figure 6. Sightings data of resident/generalist cetacean species that occur in the Scotian Shelf Bioregion. See 'Cetacean sightings data' section for information on the sources and limitations of this data. Note that these data are not weighted by effort, and equal effort did not occur across the region shown.

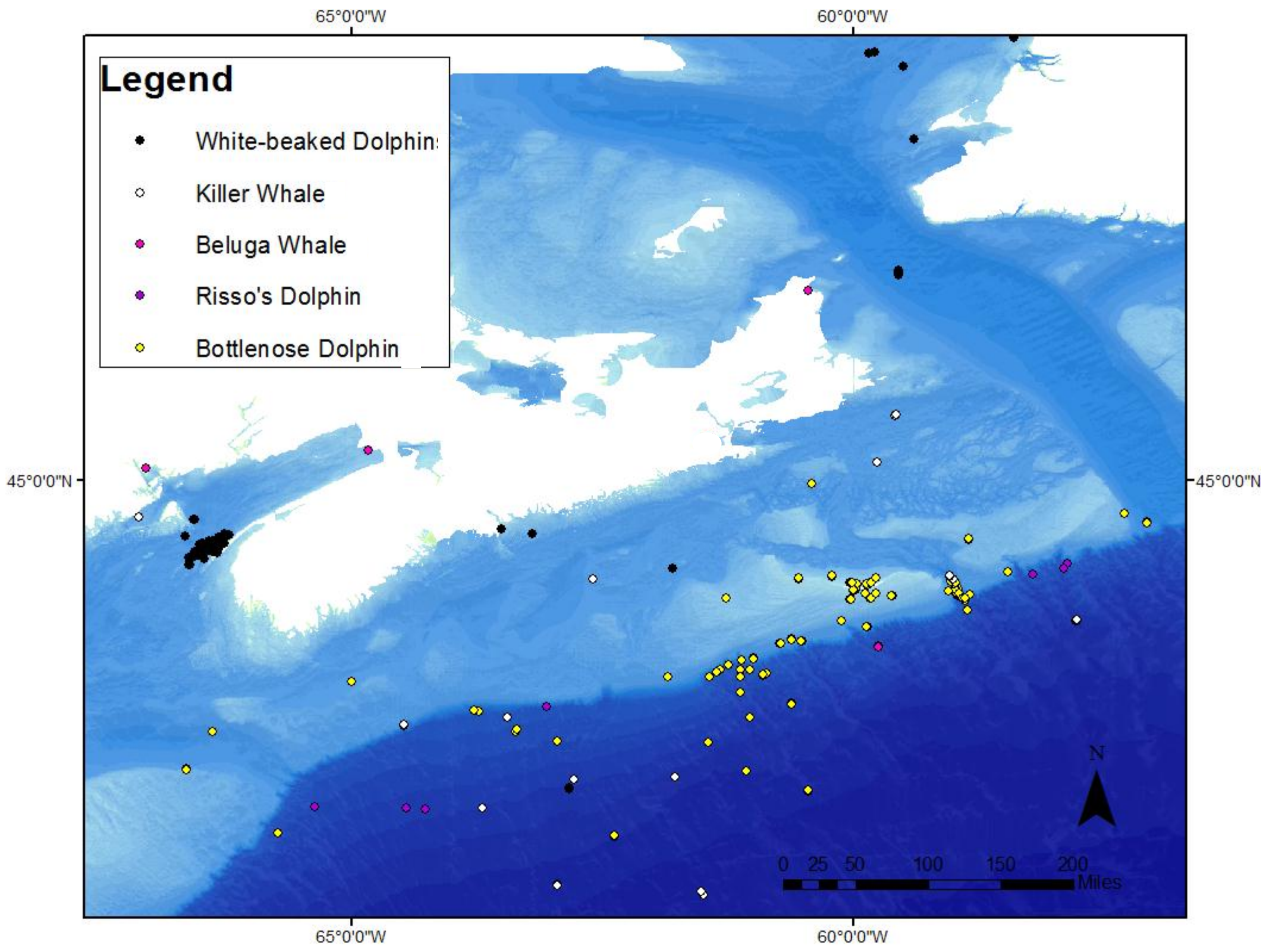

Figure 7. Sightings data of cetacean species that occur in the Scotian Shelf Bioregion on an occasional basis. See 'Cetacean sightings data' section for information on the sources and limitations of this data. Note that these data are not weighted by effort, and equal effort did not occur across the region shown.

Case Study 1: North Atlantic right whales

The North Atlantic right whale (Figure 8) population was seriously depleted by whaling efforts prior to the 1930's and the population is still being negatively impacted by vessel strikes, entanglements and other threats to survival (Brown et al. 2009). With a current population size of about 500 individuals (Pettis 2013), North Atlantic right whales are considered highly at risk and are listed as Endangered by both the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the Canadian Species at Risk Act (SARA) (Brown et al. 2009).

North Atlantic right whales are distributed in the Northwest Atlantic off the eastern U.S. and Canadian coastline. They typically spend the winter months at calving grounds off the east coast of Florida and Georgia, and then migrate north along the eastern seaboard of North America to summering grounds in the Gulf of Maine, Bay of Fundy, Gulf of St. Lawrence and on the Scotian Shelf (see Baumgartner et al. 2003, Brown et al. 2009). North Atlantic right whales occupy two primary summer feeding habitats in Canadian waters: Grand Manan Basin in the outer Bay of Fundy and Roseway Basin on the southwestern Scotian Shelf between Browns and

Baccaro Banks (Kraus et al. 1986, Moses and Finn 1997, Brown et al. 2009).

Environmental variables have previously been used to predict important habitat areas for North Atlantic right whales. Moses and Finn (1997) used a GIS-based logistic regression model using right whale sightings data collected in the Roseway Basin from 1978 to 1994 to evaluate if bathymetry and sea surface temperature could provide good predictive power for distribution. The model was then tested for an area where right whale distribution patterns were known (Massachusetts Bay) and correctly predicted occurrence where right whales have been observed. Areas of right whale summering for the entire North Atlantic were also predicted, which coincided with historical whaling grounds (Moses and Finn 1997).

The presence and abundance of right whale prey, specifically older stages of the calanoid copepod *Calanus finmarchicus*, on the Scotian Shelf, during the summer/fall season, has been proposed as the most direct and important explanatory variable in the distribution and identification of North Atlantic right whale CH (see Baumgartner et al. 2003, Brown et al. 2009 and references therein). Baumgartner and Mate (2003) found a strong correlation between the dive depths of individual right whales and the depth of maximum *Calanus* abundance, confirming that the species is able to locate and exploit layers of highly concentrated prey. Patrician and Kenney (2010) show that *Calanus* summer abundance was the best predictor of right whale foraging and residence locations in Roseway Basin, and that the absence of whales from Roseway Basin during some years in the 1990s was best explained by lower relative levels of *Calanus* abundance. Pittman and Costa (2009) found that the temporal and spatial presence of right whales in the Gulf of Maine was synchronized with the temporal and spatial occurrence of *Calanus*. Pendleton et al. (2012) used the MaxEnt approach (see Elith and Leathwick 2009) to evaluate potential right whale habitat on a weekly time-scale in Cape Cod Bay and the Great South Channel (two important areas for the right whale in U.S. waters). Results highlighted changes in habitat preferences of the species with season, and it was found that the precision of the HSM improved when abundance of *Calanus* copepods was incorporated as an explanatory variable.

Currently, the CH of North Atlantic right whales in the Northwest Atlantic encompasses areas where *Calanus* aggregates, such as Grand Manan Basin which hosts the highest concentrations of copepods in the Bay of Fundy and Roseway Basin (DFO 2007, Brown et al. 2009). These are areas of known right whale aggregations in Canadian waters and were designated as right whale Conservation Areas in 1993, which served to alert vessel crews moving through these areas of the possible presence of right whales in the area to reduce the risk of ship strikes (Brown et al. 1995). These areas were subsequently designated as CH for the population in 2009 (Brown et al. 2009) and are protected under the SARA. The Recovery Strategy for the North Atlantic right whale recommended additional research to evaluate current CH and to potentially locate additional CH in Canadian waters through evaluating the temporal and spatial distribution of prey (Brown et al. 2009).

Figure 8. North Atlantic right whales in the Bay of Fundy. Photo credit: Catalina Gomez.

Case Study 2: Scotian Shelf northern bottlenose whales

Northern bottlenose whales of the Scotian Shelf region (Figure 9) are genetically distinct from populations further north (Dalebout et al. 2001, 2006) and are managed as a distinct population known as the Scotian Shelf population (DFO 2010). The population consists of approximately 160 individuals (Whitehead and Wimmer 2005). Due to this small population size, as well as year-round residency in a relatively small area at the extreme southern limit of the species range, these whales are especially sensitive to human activities and are listed as Endangered by COSEWIC and SARA (DFO 2010).

The Gully, Shortland and Haldimand canyons on the eastern Scotian Shelf provide habitat for feeding, mating, calving and socializing for Scotian Shelf northern bottlenose whales throughout the year (Hooker et al. 1999, Wimmer and Whitehead 2004, DFO 2010, Moors 2012). These canyons were therefore designated as CH for the population in 2010 (Canada Gazette 2010) and are protected under the SARA. Slope areas between these canyons were originally assumed to be transient corridors; however, a recent study has shown that northern bottlenose whales also forage in these areas, particularly during summer months, and thus might also constitute CH for the population (Moors 2012). The Scotian Shelf northern bottlenose whale Recovery Strategy recognizes that additional CH for the population may exist on the Scotian Shelf; for example, because beaked whales prefer canyon habitats it is possible that Verrill, Dawson, Bonnechamps and Logan canyons located west of the Gully area could potentially be important habitat for northern bottlenose whales, although sightings of this species have been rare at those locations (DFO 2010, Wimmer and Whitehead 2004).

Besides long-term studies conducted in the Gully, Shortland and Haldimand canyons (Whitehead 2013), little is known about the distribution of northern bottlenose whales in the Scotian Shelf region as a whole. Compton (2004) used an ENFA to identify key habitat (steep-sloped, deep shelf-edge waters and cold sea surface temperature) for northern bottlenose whale in the Northwest Atlantic based on presence data derived from sightings and whale catch data. Given that the number of explanatory variables included in a model can affect precision and accuracy in the identification of key habitat for a given species, Compton (2004) recommended that additional variables, such as chlorophyll-a concentration, fish catch, distribution of fish species with a similar niche (e.g., Greenland halibut), and, ideally, the distribution of northern bottlenose whale primary prey (*Gonatus* spp. squid), be included.

Figure 9. Scotian Shelf northern bottlenose whales in the Gully Marine Protected Area. Photo credit: Catalina Gomez.

Case Study 3: Northwest Atlantic blue whales

Blue whale (Figure 10) numbers were greatly reduced by whaling efforts prior to the 1970’s and current threats to the species include ship strikes, disturbance from whale-watch activities, entanglements and pollution. There are fewer than 250 mature individuals in Canada and strong indications of low calving and recruitment rates (COSEWIC 2002). The North Atlantic population is listed as Endangered by COSEWIC and SARA (Beauchamp et al. 2009).

CH for the Northwest Atlantic blue whale population has not been identified (Beauchamp et al. 2009). Based on large numbers of sightings, Shortland and Haldimand canyons have previously been proposed to constitute important habitat for the species on the Eastern Scotian Shelf (Wimmer 2003). A large number of sightings have also been recorded in the Gully MPA (Whitehead 2013). Efforts to identify CH for the blue whale in Newfoundland and Labrador was conducted using whaling records and recent cetacean sightings, resulting in the identification of potential important areas near the south coast of Newfoundland during spring and summer and the Strait of Belle Isle/Gulf of St. Lawrence during spring (Abgrall 2009). An ENFA was then used to test the strength of these candidate CH areas and other potential key habitat by using an analysis that incorporated water depth, seabed slope, distance from shore, and measures of primary productivity. The ENFA analysis indicated that areas characterised by deep water and steeper seabed slopes, particularly off the south coast of Newfoundland, were most important for blue whales (Abgrall 2009).

Wimmer (2003) reported that individual blue whales photographed on the Scotian Shelf have not been matched with photographs of individuals in the Gulf of St. Lawrence, which suggests that individuals that frequent the Scotian Shelf region might be less likely to occur in the Gulf of St. Lawrence. In order to identify key habitat for the blue whales on the Scotian Shelf, the blue whale Recovery Strategy recommends determining locations where aggregations of blue whales’ preferred prey (krill) occur to establish potential foraging areas (Beauchamp et al. 2009).

Figure 10. Northwest Atlantic blue whales in the Gully Marine Protected Area. Photo credit: Catalina Gomez.

Case Study 4: Sowerby's beaked whales

Little is known about the distribution, abundance or biology of Sowerby's beaked whales (Figure 11); however, there is cause for concern about potential population-level effects of anthropogenic noise impacts on the population. These whales are listed as Special Concern by both COSEWIC and SARA (COSEWIC 2006, SARA 2010).

Sowerby's beaked whales prefer deep-water habitats, including submarine canyons and slope areas where they feed on deep-water fish and squid (COSEWIC 2006). Little is known about the fine-scale distribution of this species in the Scotian Shelf region in general due to limited sightings (COSEWIC 2006), although the Gully, Shortland, and Haldimand canyons appear to constitute important habitat for Sowerby's beaked whale on the eastern Scotian Shelf (Whitehead 2013). Prior to 1994, there was no Sowerby's beaked whale sightings reported on the eastern Scotian Shelf, but since then sightings have increased substantially. Whitehead (2013) reported a 21% per year increase in sightings of Sowerby's beaked whale in the Gully area over a period of 23 years, and the whales were sighted three times more often in Shortland and Haldimand canyons than in the Gully in recent years. Whitehead (2013) postulates that the dramatic increase in sightings in recent year may be due to a reduction of anthropogenic noise disturbance (*i.e.*, a decrease in vessel and industrial development noise). HSM approaches for this species may need to consider anthropogenic variables in addition to physiographic environmental variables such as water depth and slope.

Figure 11. Sowerby's beaked whales in the Gully Marine Protected Area. Photo credit: Catalina Gomez.

MODELLING KEY HABITAT FOR SELECTED SPECIES

Cetacean distribution data

Sightings of cetacean species that occur in the Scotian Shelf region were compiled from multiple sources to evaluate their utility for HSMs. A total of 61,113 records were included. The database created for this analysis was the result of the merging and error checking of three database sources:

1. The Department of Fisheries and Oceans Cetaceans Sightings Database includes whaling records from 1966 to 1972 and records from a variety of other sources from 1990 to 2012, including aerial and at-sea cetacean surveys, dedicated research surveys by DFO and other academic institutions, data collected during whale-watching activities, and data collected from at-sea fisheries observers, fisheries officers, consultants, and marine mammal observers onboard military and oil and gas platforms (contact: Lei Harris, Lei.Harris@dfo-mpo.gc.ca).

2. The Whitehead Lab (Dalhousie University) Sightings Database includes records from 1988 to 2011 largely on the Scotian Shelf, but particularly focused within the region of the Gully and adjacent canyons. This database is the result of long-term research focused on Scotian Shelf northern bottlenose whales and includes incidental sightings of other cetaceans (contact: Hal Whitehead, hal.whitehead@dal.ca).

3. The Environment Canada (Canadian Wildlife Service) Eastern Canada Seabirds at Sea (ECSAS) database includes sightings collected from ships of opportunity from 2006 to 2013. The primary focus of the ECSAS program is to survey seabirds; sightings of cetaceans, sea turtles, large pelagic fish and marine debris at the surface are collected as part of the protocol but are secondary to judicious gathering of seabird data (contact: Carina Gjerdrum, Carina.Gjerdrum@ec.gc.ca).

Systematic, long-term, vessel-based surveys dedicated to examining the distribution of cetacean species at the scale of the Scotian Shelf are lacking. Only two species have been the focus of dedicated but geographically limited long-term studies: northern bottlenose whales in the Gully MPA and nearby canyons (see Whitehead 2013) and North Atlantic right whales in the Bay of Fundy (particularly in Grand Manan Basin) and on the southwestern shelf (particularly in Roseway Basin) (Kraus et al. 1986, Baumgartner et al. 2003, Brown et al. 2009, Michaud and Taggart 2011).

Systematic aerial surveys in the Scotian Shelf region are rare. In the early 1980s, the Cetacean and Turtle Assessment Program (CETAP) employed dedicated aerial platforms to characterize the distribution and abundance of cetaceans between the coastline to the surface projection of the 2,000 m depth contour in mid- and north-Atlantic areas of the U.S. outer continental shelf from Cape Hatteras, North Carolina to Nova Scotia, Canada (CETAP 1982). Most recently, the Trans North Atlantic Sightings Survey (TNASS) conducted systematic aerial surveys in the summer of 2007 to estimate the distribution and abundance of cetacean species in Atlantic Canadian waters, including the Scotian Shelf region (Lawson and Gosselin 2009).

Opportunistic surveys provide the majority of the information on species occurrence and distribution in the Scotian Shelf region, including whaling records (*e.g.,* Sutcliffe and Brodie 1977), surveys from ships of opportunity (*e.g.,* Gjerdrum et al. 2012), and whale-watching excursions (*e.g.,* Ingram et al. 2007). Opportunistic surveys have limitations in terms of data quality (such as observer experience) and restrictions in space and time depending on the research priorities of the platform (*e.g.,* surveys from fishing vessels, surveys focused on other species). Most importantly, opportunistic survey data is rarely complemented with observer effort so it is difficult or impossible to estimate cetacean densities in many study areas.

Table 1. Number of sightings per season and cetacean species collected from 1966 to 2012.

Species (common name)	**Season**				
	Autumn	**Spring**	**Summer**	**Winter**	**Total**
Total	**13,045**	**2,024**	**46,011**	**233**	**61,113**
Atlantic Bottlenose dolphin	27	30	78	4	139
Common dolphin	199	27	625	17	868
Risso's dolphin		8	9		17
Striped dolphin		1	82		83
White-beaked dolphin	42	11	233	2	288
White-sided dolphin	456	145	1,460	16	2,077

Species (common name)	Season Autumn	Spring	Summer	Winter	Total
Total	**13,045**	**2,024**	**46,011**	**233**	**61,113**
Harbour porpoise	1,804	228	11,396	36	13,464
Long-Finned Pilot whale	683	680	1,626	63	2,852
Blue whale	154	12	246	5	417
Fin whale	2,497	166	6,382	13	9,058
Humpback whale	3,716	191	10,690	17	14,614
Killer whale	16	18	12	6	52
Minke whale	826	264	7,073	17	8,180
Northern Bottlenose whale	186	148	2,214	24	2,572
North Atlantic Right whale	1,258	15	2,655	8	3,936
Sei whale	1,061	20	725	1	1,807
Sowerby's Beaked whale			52		52
Sperm whale	120	60	453	4	637

Environmental Data

For HSM, the putative predictive environmental variables that exhibit a spatial relationship with cetacean occurrence records are used to more broadly predict the distribution of cetaceans within an area. The distribution of many cetacean species can be predicted based on ecological variables including the distribution and abundance of prey (*e.g.*, Kenney et al. 1996, Patrician and Kenney 2010, Pendleton et al. 2012). However, studying the diet of cetaceans and obtaining information on the distribution and abundance of their prey is often difficult (for example, long-term data on the distribution and abundance of squid, the primary prey of beaked whales, is not available for the Scotian Shelf). Therefore, an alternate strategy relies on the input of environmental factors and oceanographic features as proxies for missing or limited prey abundance and distribution data. In this framework, the distribution of some cetacean species has been linked to environmental variables such as ocean depth (Cañadas et al. 2005), seafloor slope (Hooker et al. 1999), sea surface temperature (Whitehead et al. 2010, Wong 2012), and frontal systems

(Hamazaki 2002).

In the Scotian Shelf region, several environmental variables are correlated to the presence of cetacean species. For instance, sei whale, Sowerby's beaked whale, and Atlantic white-sided dolphin (*Lagenorhynchus acutus*) are presumed to prefer western waters, cooler temperatures and steeper slopes; while blue whale, sperm whale, and Risso's dolphin (*Grampus griseus*) appear to prefer warmer waters at lower slope inclines (Wimmer 2003, Gowans and Whitehead 1995). Several cetacean species are sighted more often in canyons (*e.g.*, northern bottlenose whales, sperm whales and long-finned pilot whales) and some species have been frequently sighted over the continental slope (*e.g.*, blue whale, sei whales, Mesoplodont beaked whales, Risso's, striped (*Stenella coeruleoalba*), common (*Delphinus delphis*) and Atlantic white-sided dolphins; Wimmer 2003). In the Gully submarine canyon and adjacent areas, ocean depth was the model variable that best predicted the distribution of several cetacean species, while sea surface temperature and month of year were also strong predictive variables (Hooker et al. 1999). In general, several studies have highlighted the importance of submarine canyons and the continental slope as key habitat for cetaceans in the region (Wimmer 2003, Hooker et al. 1999, Whitehead 2013).

In this study, five environmental layers (ocean depth, seafloor slope, seafloor aspect, sea surface temperature and Chlorophyll-a concentration) were selected on a preliminary basis due to their relevance for predicting distribution of cetacean species and based on the accessibility and transferability of the data sets into a GIS (Table 2). These environmental layers were processed in order to have the same geographic extent and cell size and then converted to an ascii raster grid format using ArcGIS 10.

Habitat suitability model for Scotian Shelf cetaceans

Cetacean sightings data, the response variable in a given HSM, can be categorized into two fundamentally different types: 1) presence-absence data, 2) presence-only data. The data type depends on whether or not absences (lack of sightings or 'true' zeroes) were recorded in addition to the sightings themselves.

Presence-absence data are more often derived from systematic surveys that include measurements of the effort employed in surveying a particular area (*e.g.,* those that rely on transects) and can also include zero values (such as records of a particular species not sighted at a particular location during the survey). However, in many other data sets lack of sightings at a location does not necessarily imply that cetaceans do not occur at that location. Rather, it could mean that there was insufficient, inconsistent or no observer effort at all at that location. In instances where "absence" data are unavailable or unreliable, presence-only modelling methods can be effective alternatives to predict cetacean species distributions (e.g., Elith et al. 2006, Tittensor et al. 2009, Table 1).

Several cetacean studies have used HSM techniques based on presence-absence data (Table 1), which have been deemed to be more precise in predicting cetacean distribution than techniques based on presence-only data, particularly in highly complex habitat (Praca et al. 2009, Hirzel et al. 2002 and Brotons et al. 2004 in Mandleberg 2004). However, presence-only methods are an alternative where presence-absence data are unavailable (Elith et al. 2006). For example, Mandleberg (2004) compared presence-only versus presence-absence modelling approaches to predict the distribution of harbour porpoises on the west coast of Scotland, and concluded that presence-only techniques performed as well as presence-absence methods, but that ideally both approaches should be used in concert to better predict the distribution of a species as long as large body of data are available. The general consensus; however, is that presence-absence data approaches are the preferred method if supporting data are available (e.g., Cañadas et al. 2005).

Table 2. Examples of habitat suitability models (HSMs) used to predict distribution of cetaceans.

Habitat suitability model	Cetacean sightings data	Species used	Use	References
Maximum entropy method (MaxEnt)	Presence-only	Right whale, Humpback and Minke whales	Predict distribution, identification of breeding and calving habitat	Pendleton et al. 2012, Gregr 2011, Smith et al. 2012, Ainley et al. 2012
Ecological Niche Factor Analysis (ENFA)	Presence-only	Northern bottlenose whale and other beaked whales, Sei, Blue, Sperm, Bowhead and Fin whales, Harbour porpoise	Identification of critical and key habitat	Abgrall 2009, Compton 2004, MacLeod 2005, Mandleberg 2004, Praca et al. 2009, Schweder 2003 in Macleod 2005, Wheeler et al. 2012
Genetic Algorithm for Rule-set Prediction (GARP)	Presence-only	Harbour porpoise	Predict distribution	Mandleberg 2004
PCA-based technique	Presence-only	Harbour porpoise, Sperm whale	Predict distribution	Mandleberg 2004, Praca et al. 2009
Generalized Linear Modelling (GLM) and generalized additive models	Presence/ absence	Harbour porpoise, Minke, Fin, Sperm, Humpback, Blue, Beaked, Pilot, Right whale, Blainville's	Identification of critical, key habitat and marine protected areas, mating areas	Moses and Finn 1997, Gregr and Trites 2001, Hamazaki 2002, Mandleberg 2004, Ingram et al. 2007,

Habitat suitability model	**Cetacean sightings data**	**Species used**	**Use**	**References**
(GAMs)		beaked whale, Bottlenose, Striped, Risso's, Spotted, White-sided and Common dolphin		Embling et al. 2010, Cañadas et al. 2005, Whitehead et al. 2010, Wong 2012, Praca et al. 2009, MacLeod 2005, Pirotta et al. 2011, Cole et al. 2013
Multiple logistic regression	Presence/ absence	Beaked, fin, humpback, minke, pilot, and sperm whales, bottlenose, common, Risso's, spotted, white-sided and dolphins, harbour porpoise	Identification of cetacean habitat during summer months	Hamazaki 2002
Classification and Regression Trees and Multivariate Adaptive Regression Splines	Presence/ absence	Several species, including right whales	Ecological characterization, support marine sanctuary management review process	Pittman and Costa 2010
Relative Environmental Suitability	Descriptive	115 species of marine mammals	Mapping worldwide distribution of cetaceans	Kaschner et al. 2006

Presence-only statistical methods (Hirzel et al. 2002, Phillips et al. 2006) were selected as the main tool for this project because much of the information on cetacean sightings on the Scotian Shelf has been obtained opportunistically and effort has not been equal across the region; therefore, reliable absence data are lacking. Furthermore, adoption of this approach meant that a greater quantity of available data could be used, despite the cost in terms of loss of absence information. MaxEnt was the selected HSM tool since it has consistently outperformed other presence-only techniques (such as ENFA) during cross-validation of models (Phillips et al. 2006, Tittensor et al. 2009). MaxEnt predicts environmental suitability for cetacean species as a function of the given environmental variables described above (Table 3, Phillips et al. 2006). The MaxEnt approach evaluates the distribution of habitat suitability by finding the model cetacean distribution pattern with maximum entropy under constraints given the relationship of environmental layers with cetacean presence data (Phillips et al. 2006, Elith et al. 2011, Pendleton et al. 2012).

Table 3. Environmental variables selected for a preliminary analysis on the distribution of cetaceans within the Scotian Shelf Bioregion.

Variable	**Units**	**Resolution**	**Source**
Ocean depth	Metres	2·minute gridded	Oceans and Coastal Management Division, Maritimes Region, Fisheries and Oceans Canada, Bedford Institute of Oceanography
Seafloor slope	Degrees	2·minute gridded	Calculated in ArcGIS
Seafloor aspect		2·minute gridded	Calculated in ArcGIS
Sea Surface Temperature	Degrees Celsius	4-km binned product	Seasonal and entire mission climatologies (2003-2012) were obtained from semi-monthly and seasonal composites (2003-2012) respectively, which were derived from the MODIS instrument on the Aqua Satellite. Contact: Carla Caverhill, Caverhillc@mar.dfo-mpo.gc.ca
Chlorophyll-a concentration	mg/m^3	4-km binned product	Seasonal and entire mission climatologies (2003-2012) were obtained from semi-monthly and seasonal composites (2003-2012) respectively, which were derived from the MODIS instrument on the Aqua Satellite. Contact: Carla Caverhill, Caverhillc@mar.dfo-mpo.gc.ca

MaxEnt software version 3.3.k (http://www.cs.princeton.edu/~schapire/maxent) was used to build the HSMs. The analysis was conducted by using default model parameters (for further details see: Phillips et al. 2006). A cross-validation approach was used, with 10 repetitions for each of parameter models in which 30% of the sightings data were randomly selected and set to validate the performance of the model while the other 70% of the data were used to train the model. For any HSM there is a possibility of predicting presence where the species was observed as absent (false positive) and the possibility of predicting absence where the species was observed as present (false negative).

The cross-validation allows these misidentifications to be evaluated and summarized, thereby indicating model performance. For this, receiver operating characteristic (ROC) curves were used to evaluate model performance, where the area under the ROC curve (AUC) provides a single measure of model performance (Phillips et al. 2006). AUC values of 0.5 indicate when the performance of the HSM is not better than random; AUC values closer to 1.0 indicate the best possible model performance (note that for presence-only models the theoretical maximum is actually less than 1.0; Phillips et al. 2006). The logistic output generates habitat suitability maps with values between 0.0 and 1.0, which can be interpreted as probability of presence of the cetacean species of interest.

<u>**Model results**</u>

This section presents the preliminary results of the MaxEnt modelling conducted for two of the ESS that were identified in previous sections: Scotian Shelf northern bottlenose whales and Sowerby's beaked whales. Models for North Atlantic right whales and Northwest Atlantic blue whale were not considered due to the current lack of critical environmental layers needed to predict their distribution (specifically copepod and zooplankton aggregations, respectively; Pendleton et al. 2012). Note that these preliminary results demonstrate the <u>potential</u> of using HSMs to predict key areas and hotspots for cetacean conservation within the region. However, <u>further refinement of these HSMs is needed before results can be used effectively</u> (see the Recommendations section below for further discussion on this). Models were run separately for each species and season, and all models provided a significant fit to the data, at $p<0.001$.

Preliminary predicted habitat suitability maps derived from the MaxEnt analyses are presented for the summer only, which is the season when most of the effort to gather species observation records occurred (Figures 12 and 13).

The preliminary habitat suitability maps indicate a general preference for deep waters along the continental slope for both species, with areas around the eastern Scotian Shelf canyons and in slope waters beside the Northeast Channel on the western Scotian Shelf highlighted (Figures 12 and 13). The environmental variable that contained the most useful information for each model prediction was slope for both northern bottlenose whales and Sowerby's beaked whales. However, caution must be taken when interpreting this information because some environmental variables may be missing (*e.g.*, presence of prey) or slope may be correlated to other important variables (*e.g.*, presence of prey), and independence between variables might not necessarily be reflected in the model.

The maps for northern bottlenose whales showed a high proportion of area highlighted as suitable habitat that did not have sightings data for the species associated with it (Figure 12). This could be due to limited effort across the entire shelf or due to other environmental or biological variables that were not factored into the models. In addition, some of the highly suitable habitat suggested for the northern bottlenose whales on the Scotian Shelf included areas away from high slope relief or great depths (Figure 12). Northern bottlenose whales have been observed around such areas in Newfoundland, for example, in very shallow waters where the whales appear to be pursuing aggregations of nearshore squid or fish (J. Lawson, pers. comm.). The maps for Sowerby's beaked whales also highlight areas where no Sowerby's sightings occurred such as the slope area near the Northeast Channel (Figure 13). Interestingly, additional sightings data that have been recently obtained for this species show an aggregation of sightings (at least 12 sightings) in this very area.

Table 4. AUC values for all model runs. AUC were calculated from test data (30% of occurrence points), and all model runs fit significantly better than random (P < 0.0001).

Season	**Species**	**# of training samples**	**AUC**
Summer	Northern bottlenose whale	482	0.967
	Sowerby's beaked whale	31	0.989
Winter	Northern bottlenose whale	10	0.942
Fall	Northern bottlenose whale	70	0.953
Spring	Northern bottlenose whale	79	0.954
All seasons combined	Northern bottlenose whale	482	0.967

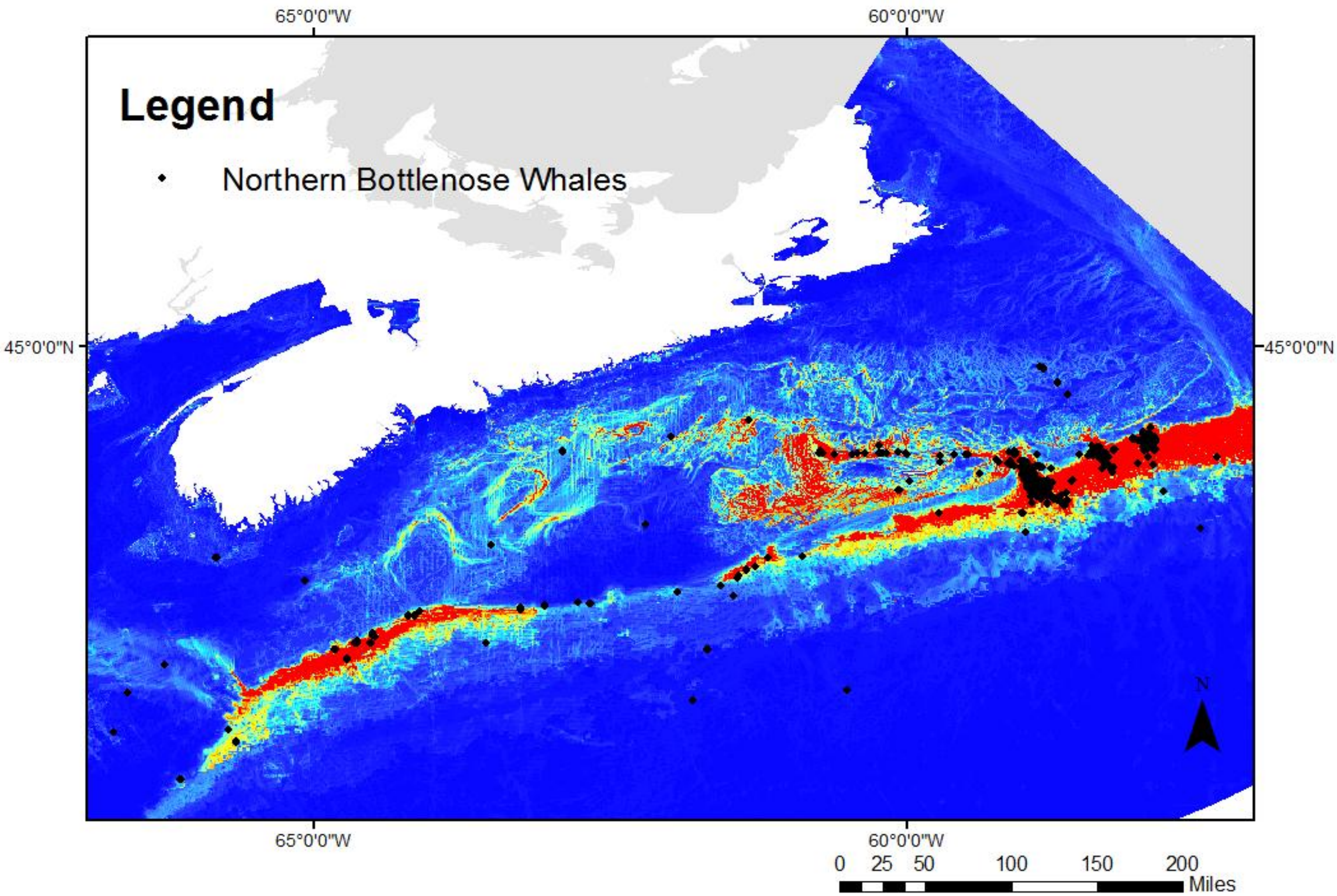

Figure 12. Preliminary predicted suitable habitat for the deep-diving northern bottlenose whale in the Scotian Shelf Bioregion. Warmer colors represent areas with better predicted conditions. Black dots represent sighting information available for the area. Note that further refinement of the habitat suitability model is needed before this map can be used effectively.

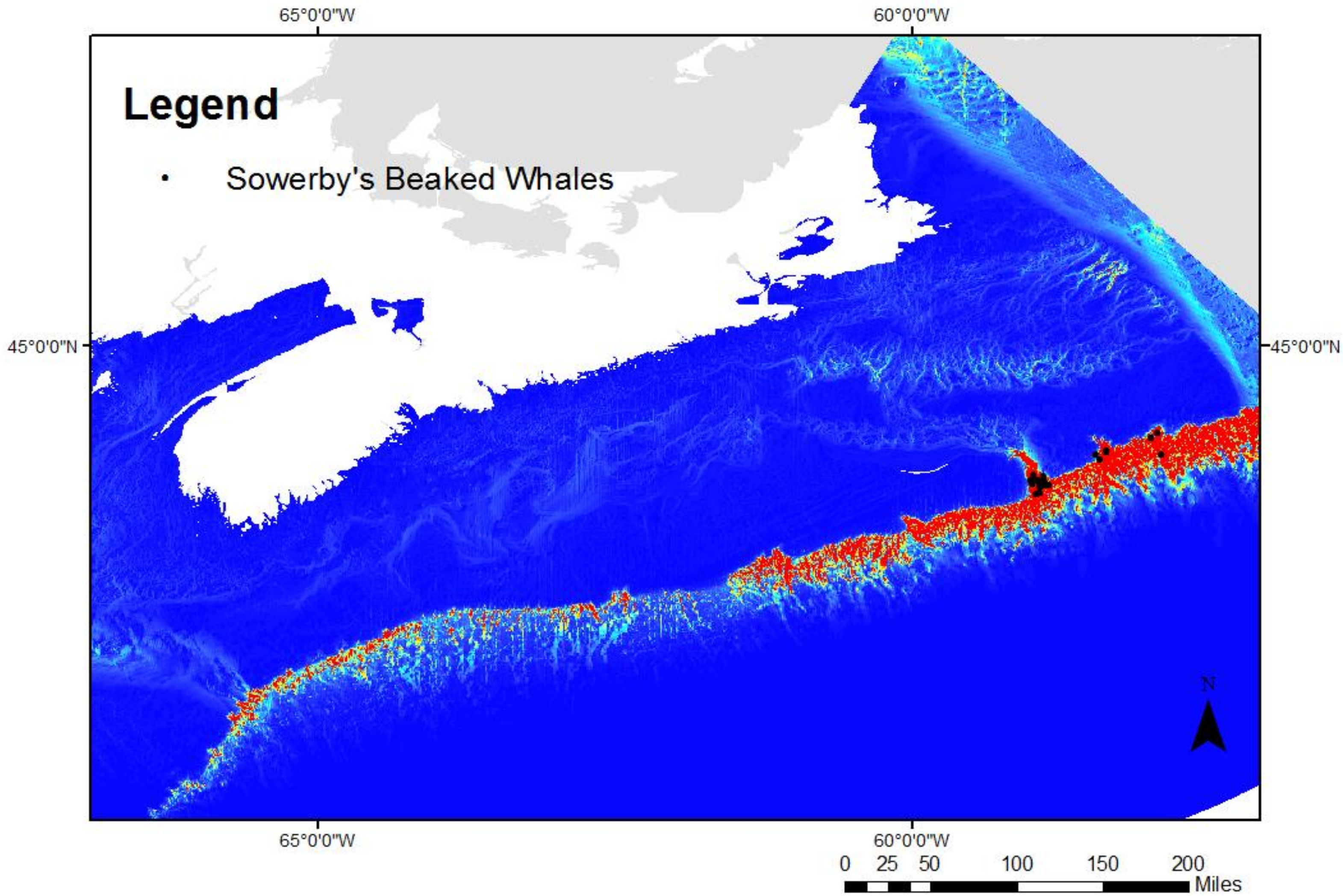

Figure 13. Preliminary predicted suitable habitat for the deep-diving Sowerby's beaked whale in the Scotian Shelf Bioregion. Warmer colors represent areas with better predicted conditions. Black dots represent sighting information available for the area. Note that further refinement of the habitat suitability model is needed before this map can be used effectively.

KEY HABITATS FOR SCOTIAN SHELF CETACEANS

This study presents a draft list of key habitat areas for cetacean species in the Scotian Shelf Bioregion (Table 5) based on a literature review (Appendix 1) and preliminary results of the MaxEnt analysis conducted for two deep-diving resident beaked whale species (Figure 12 and 13). The draft list was compiled based on two important components in the scheme of identifying key habitat (Abgrall 2009):

1. Population concentrations: areas with the highest concentrations of a given species can be considered as hotspots and warrant special attention.
2. Limiting resources: areas limited spatially and temporally with predictable feeding patches, as well as limited deep or shallow habitat which can be considered as key habitat for the survival of a given species.

The key habitat areas for cetaceans that have been identified include Roseway Basin, the Grand Manan Basin, the Scotian Shelf edge and submarine canyons.

Submarine canyons, particularly the Gully, are emphasized as especially important habitats for a number of species (Appendix 1) and were highlighted by the MaxEnt analyses performed for northern bottlenose whales and Sowerby's beaked whales (Figures 12 and 13). At a global scale, submarine canyons have been proposed as hotspots for cetacean diversity and abundance; they are considered important foraging areas and thus deserve enhanced protection (NRDC 2001 in Wimmer 2003, Smith et al. 2010, Moors-Murphy 2013). Moors (2013) highlighted that toothed whales tended to associate with submarine canyons year-round, especially beaked whales and sperm whales, which feed primarily on deep-water squid. Conversely, baleen whales tend to associate with canyons on a seasonal basis likely to feed primarily along the margins of canyons where upwelling occurs, which is enhanced during summer months when shelf-break upwelling occurs (Moors 2013). Based on the preliminary HSMs, several submarine canyons and areas in the Scotian Shelf edge could constitute suitable habitat for the two selected deep-diving beaked whale species, and further work should investigate the role of these areas for other cetaceans.

Table 5. Draft list of important areas to cetacean species within the Scotian Shelf Bioregion based on information compiled from the literature review[L] and preliminary results of the maximum entropy (MaxEnt) analysis[M]. This list is a work in progress, and results from future modelling results will be incorporated.

Area	**Protection/status**	**Cetacean species**
The Gully submarine canyon[L,M]	Marine Protected Area and critical habitat for northern bottlenose whales	Northern bottlenose whale and potentially Sowerby's beaked whale
Shortland and Haldimand canyons[L,M]	Critical habitat for northern bottlenose whales	Northern bottlenose whale and potentially Sowerby's beaked whale and blue whale

Area	Protection/status	Cetacean species
Shelf areas between the Gully, Shortland and Haldimand canyons[L,M]	Proposed critical habitat for northern bottlenose whale (Moors 2012)	Northern bottlenose whale and potentially Sowerby's beaked whale and blue whale
Roseway Basin[L]	Right Whale Conservation Areas (Brown et al. 1995), critical habitat (Brown et al. 2009) and mating ground for right whales (Cole et al. 2013)	North Atlantic right whale, potentially Sei whale which have similar prey preferences
The Grand Manan Basin[L]	Right Whale Conservation Area (Brown et al. 1995) and critical habitat for right whales (Brown et al. 2009)	North Atlantic right whale, potentially Sei whale which have similar prey preferences
Scotian Shelf edge[L,M]	Not Applicable. Further evaluation through habitat suitability models is needed.	Important migratory corridor for cetacean migratory species

RECOMMENDATIONS

Preliminary results illustrate the potential value of obtaining maps derived from HSMs to highlight key habitat areas for cetacean conservation. However, to apply this information effectively, further refinement of the HSMs developed here is required. The following provides several recommendations that should be taken into consideration when conducting further modelling exercises for cetaceans in the Scotian Shelf region.

<u>Quality of cetacean sightings data</u>

To date, the complete DFO cetacean database was not error checked. Therefore, before conducting additional efforts it is critical to check and clean the DFO cetacean database because errors may exist (D. MacDonald and L. Harris pers. comm.).

The majority of the available data on cetacean sightings comes from platforms of opportunity and thus there are several limitations in terms of data quality and utility. The most critical limitation is unequal geographic coverage due to the lack of regular or repeated systematic surveys across the Scotian Shelf region. This has resulted in a significant proportion of the region remaining poorly surveyed (or not surveyed at all) across seasons and years. In addition, the majority of the cetacean sightings data obtained is vulnerable to effort bias related to the main priorities of the platform from which data were collected, whether these priorities were established based on geographical scope or on target species (*e.g.*, studies targeting specific cetacean species, or seabirds). Ultimately, data quality depends on whether or not detections of non-target species should be deemed 'incidental'.

For further refinement of this project, a more systematic assessment of the quality of the cetacean sightings available for each species for the different datasets used is recommended. To accomplish this, a qualitative value can be provided for each sighting and thus sightings with high quality values (such as those derived from systematic-surveys and/or derived from platforms with experienced observers) can be selected for potentially more exhaustive modelling efforts. In addition, further efforts should attempt to focus on HSMs derived from presence-absence data, which in general are more robust than presence-only data. Absence data can be derived from systematic surveys in which observer effort has been recorded. Based on the cetacean data provided for this project, data from the Whitehead Lab and from the Canadian Wildlife Service of Environment Canada (ECSAS data) would be the most appropriate data sets to explore. Additional efforts should be focused on enhancing the compilation of available cetacean data and exploring how concurrently collected ecological data (such as the ECSAS data) might be used to improve model performance and consequently understanding patterns of habitat use across taxa (K. Allard pers. comm.). Additional attention should also be directed at enhancing efficiency of ongoing and future data collection efforts such that data quality is optimized across surveys.

<u>Improvement of current environmental data</u>

Some of the dynamic environmental data used in this project (such as sea surface temperature and chlorophyll-a concentrations) could be used to control for inter-annual variability. For instance, models can be run separately for each year and the most highly suitable areas could be amalgamated across years.

a) Additional environmental data would be important for further refinement of HSMs, particularly for species for which distribution patterns are largely influenced by prey distribution (such as North Atlantic right whales; Pendleton et al. 2012). Additional environmental data that can be used to improve the habitat suitability maps include: Areas of persistent high concentration of chlorophyll-a derived from MODIS (C. Fuentes-Yaco, pers. comm.);
b) Lagged values for sea surface temperature and chlorophyll-a concentrations (at lagged time intervals of one week and eight weeks before an individual sighting; Wong 2012);
c) Sea Surface Height Anomaly (SSHA) can be used to identify water eddies and upwelling, which are physical processes that play a role in ocean mixing and in the concentration of biological productivity (Wong 2012);
d) Eddy Kinetic Energy (EKE), which is a measure of turbulence and flow of a region (Wong 2012);
e) Thermal fronts (Podesta et al. 1993);
f) Zooplankton biomass (Baumgartner et al. 2003);
g) Copepod (*Calanus* spp.) biomass, particularly for the North Atlantic right whale and sei whale (Pendleton et al. 2012);
h) Areas of upwelling and downwelling, and warm-core rings (Reilly and Thayer 1990);
i) Thermal front probabilities and Bottom Mixed Layer (Baumgartner and Mate 2003);
j) North Atlantic Oscillation (Patrician and Kenney 2010);
k) Pelagic fish biomass (e.g., http://www.dfo-mpo.gc.ca/Library/337080.pdf);

Exploring the correlation between environmental data variables would be a critical step in further model runs to understand how each environmental variable affects the MaxEnt prediction within the contexts of autocorrelation and cross-correlation processes.

Biological considerations

Modelling tools could also be expanded to characterize multi-species hotspots that warrant special attention. For example, HSM could be used to help highlight and evaluate the importance of the shelf-edge areas or submarine canyons specifically as key habitat for deep-diving cetaceans.

Given that many cetacean species that occur in the Scotian Shelf region are thought to be seasonal migrants (Appendix 1), consideration of movement patterns (such as migration timing and routes) is fundamental in determining cetacean distribution and abundance within the region. Consequently, additional effort and appropriate modelling tools should be investigated to account for temporal and spatial movement, particularly for migratory species such as blue whales (see Gregr and Trites 2001).

There are other features that are important in the context of selecting key habitat for cetaceans that were not considered in this study, such as the vulnerability and resilience of species and habitat, population trends, and fluctuations of prey over time (Abgrall 2009). For instance, the decrease of herring and mackerel fish stocks in the 1960s followed by the increase of sand lance in the Gulf of Maine to Cape Hatteras seemed to explain shifts in the distribution of large baleen whales (humpback, fin, sei and North Atlantic right whales) and small cetaceans (white-beaked dolphins, Atlantic white-sided dolphins and harbour porpoises) in the late 1970s and early 1980s (Kenney et al. 1996). In addition, a potential decrease in anthropogenic ocean noise may explain an increase in the number of Sowerby's beaked whale sightings in the Gully, Shortland and Haldimand canyons (Whitehead 2013). Thus, additional variables, such as the temporal variation of biological, environmental, and anthropogenic factors across time, may also be important to explore and identify suitable habitat for cetacean species (Abgrall 2009, Whitehead 2013).

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APPENDICES

Appendix 1. Summarized available information on the distribution of 22 cetacean species that frequent the Scotian Shelf Bioregion, including their permanence on the shelf (migratory or residents), their conservation status, habitat and prey preferences, and potential key habitat.

Common name (latin name)	**SARA status**	**Presence in the Scotian Shelf**	**Key habitat in the Scotian Shelf**	**Habitat preferences**	**Diet**
North Atlantic right whale (*Eubalaena glacialis*)	Endangered	Migratory, distributed mainly in the Bay of Fundy and west Scotian Shelf especially during June throughout November	Roseway and the Grand Manan Basin critical habitats which are areas with large aggregations of *Calanus* copepods (particularly stage 5 copepods, Brown et al. 2009). In Roseway Basin whales prefer the southern margins of the basin between the 100 and 160 m isobaths (Vanderlaan et al. 2008). Concentration of Copepods (stage 5) and depth seems to be very important.	Physical features and processes that enhance dense concentrations of calanoid copepods.	Older stages of the calanoid copepod *Calanus finmarchicus*
Sei whale (*Balaenoptera borealis*)	NA	Migratory and cosmopolitan, preference for temperate oceanic waters, seem to migrate along the continental slope (Mitchell 1975b, Mitchell and Chapman 1977 in Reeves 2000).	Not identified. Potentially areas with large aggregations of zooplankton, particularly *Calanus* copepods (might have similar habitat preferences with right whales, see Mitchell et al. 1986 and Oayne et al. 1990 in Breeze et al. 2002) and the continental slope as potential migratory corridor.	Distribution is mainly in canyon and bank edge areas or on the slope, rarely seen in the Gully (Whitehead et al. 1998 in Reeves 2000), associated with exceptionally copepod densities (Payne et al. 1990, Schilling et al. 1992). Seem to prefer eastern waters in cooler temperatures at steeper slopes inclines (Wimmer 2003).	Plankton, particularly copepods (*Calanus finmarchius*) (Kenney et al. 1996)

Common name (latin name)	SARA status	Presence in the Scotian Shelf	Key habitat in the Scotian Shelf	Habitat preferences	Diet
Blue whale (*Balaenoptera musculus*)	Endangered	Migratory, frequent on the Gulf of St. Lawrence and eastern Scotian Shelf between January and November (Sears et al. 1990, Reeves et al. 1998 in Reeves 2000), in the Gully region during mid to late Augusts (Hooker et al. 1999), frequent sightings on Shortland and Haldimand canyons (Wimmer 2003), seen in the vicinity of Emerald bank and between Emerald bank and LaHave bank (Reeves 1999 in Breeze et al. 2002), present in the southwestern Scotian Shelf from June through November mostly along or inshore of the 100-fathom contour.	Not identified. Potentially areas of high primary productivity (Reeves 1999 in Breeze et al. 2002), krill aggregation areas? (e.g., krill concentrate in basins and along the shelf edge of the Scotian Shelf; gyres at the head of the canyons allow retention of euphasiids which attract larger baleen whales, Harrison and Fenton 1998, Sameto and Cochran 1996 in Wimmer 2003).	Distribution in areas with large seasonal concentrations of euphasiids (Yochem and Leatherwood 1985 in Reeves 2000).	Feed almost exclusively on euphasiids but can also consume copepods (*Calanus*) (see Kenney et al. 1996)
Humback whale (*Megaptera novaeangliae*)	Special Concern	Migratory and widespread, majority of sighting occur particularly during summer time in the Bay of Fundy and west Scotian Shelf, occasional sightings in the entire east Scotian Shelf but seen often in the Gully area (Hooker et al. 1999). Probably migrate across or along the edges of the Scotian Shelf (Reeves 2000).	Not identified. Conduct large movements, migratory corridor (edges of the Scotian Shelf) might be very important.	Distribution correlated to abundance of prey species and bottom topography (Payne et al. 1986, 1990 in Kenney et al. 1996).	Feeds on small pelagic fish, large zooplankton (euphasiids), small pelagic squid (Whitehead 2013 and references therein). Fish species preferred include herring (*Clupea harengus*), sand lance (*Ammodytes* spp.) and capelin.

Common name (latin name)	**SARA status**	**Presence in the Scotian Shelf**	**Key habitat in the Scotian Shelf**	**Habitat preferences**	**Diet**
Fin whale (*Balaenoptera physalus*)	Special concern	Migratory, widely distributed along the east coast of the US and Canada, broad distribution across the continental shelf, extending offshore into waters deeper than 2,000 m (Hain et al. 1992 in Reeves 2000), observed frequently in the Gully during July and August (Whitehead et al. 1998).	Not identified. Aggregation of prey but seems to eat a diverse range of species.	Broad distribution across the continental shelf and extending offshore into waters deeper than 2,000 m.	Feeds on small pelagic fish, large zooplankton and small pelagic squid (Whitehead 2013) particularly on sand lance in the western North Atlantic (Kenney et al. 1996), herring mackerel and capelin in the northwest Atlantic (Mitchell et al. 1986, Katona et al. 1993 in Breeze et al. 2002).
Striped dolphin (*Stenella coeruleoalba*)	NA	Migratory, present on the Scotian Shelf during the summer time particularly in deep regions (Whitehead et al. 1998, Gowans and Whitehead 1995), most abundant cetacean in the Gully during July and August (Whitehead et al. 1998 in Reeves 2000).	Not identified. Deep waters during the summer, and the continental slope might be important for migrations.	Preference for deep waters (deeper than 1,000 m) with higher slope inclines particularly during the late summer, preference for the edge and seaward of the continental shelf and areas influenced by warm currents (e.g., the Gulf Stream) (Waring et al. 1997 in Reeves 2000, Whitehead 2013, Hooker et al. 1999).	Feed on fish, squid and crustaceans (Perrin et al. 1994 in Breeze et al. 2002).

Common name (latin name)	SARA status	Presence in the Scotian Shelf	Key habitat in the Scotian Shelf	Habitat preferences	Diet
Short-beaked common dolphin (*Delphinus delphis*)	NA	Migratory, present on the Scotian Shelf during the summer time, preference for deeper and warm waters (Gowans and Whitehead 1995).	Not identified.	Preference for deeper and higher slope inclines (most abundant over depths of 1,000 – 2,500 m) as well as warm waters, sighted in the Gully early in mid-summer (Gowans and Whitehead 1995, Wimmer 2003, Whitehead 2013). Seem to migrate to higher-latitude areas in summer and fall and move farther south (or possibly just offshore) for the winter (Gowans and Whitehead 1995).	Feed mainly on mackerel and long-finned squid, in addition they also feed on herring, whiting (*Merlangius merlangus*), pilchard (*Sardina pilchardus*), and anchovy (*Engraulis encrasicolus*) (Gowans and Whitehead 1995).
Northern bottlenose whale (*Hyperoodon ampullatus*)	Endangered	Present year-round, particularly in the Gully, Shortland and Haldimand canyons and adjacent regions.	The Gully, Shortland and Haldimand canyons are important for feeding, mating, calving and socializing throughout the year and slope areas between these canyons are important foraging areas and migratory corridors (Wimmer and Whitehead 2004, DFO 2009, Moors 2012).	-	Feed on deep-water squid, primarily on *Gonatus* squid (Gowans and Whitehead 1995, MacLeod et. al. 2003, Whitehead et. al. 2003).
Sowerby's beaked whale (*Mesoplodon bidens*)	Special concern	Might be present year-round, distributed in the Scotian Shelf particularly near the Northeast Channel and in the submarine canyons on the eastern Scotian Shelf (Gully, Haldimand and Shortland, Wimmer, 2003, Whitehead 2013).	Gully, Haldimand and Shortland canyons (Whitehead 2013)	Deep waters (e.g., submarine canyons) and slope areas where they prey on squid and deep-sea fishes; seem to be particularly sensitive to anthropogenic ocean noise (Whitehead 2013, COSEWIC 2006).	Mesopelagic fish and likely mesopelagic squid (Whitehead 2013).

Common name (latin name)	**SARA status**	**Presence in the Scotian Shelf**	**Key habitat in the Scotian Shelf**	**Habitat preferences**	**Diet**
Sperm whale (*Physeter macrocephalus*)	NA	Maturing or adult males are present in the area year-round (Whitehead et al. 1992, 1998, Reeves and Whitehead 1997, Lucas and Hooker 2000).	Not identified, prefer deep areas and the continental edge.	In the Scotian Shelf, sperm whales are present in areas between 200-1,500 m, occur regularly along the edge of the Scotian Shelf, particularly during summer months due to potential movements to winter breeding and feeding grounds (CETAP 1982, see Moors 2012, Whitehead et al. 1992). Found in areas where waters mix to create zones of high productivity, such as the edges of continental shelves, offshore banks, and in areas of submarine canyons (Reeves and Whitehead 1997).	Feed on deep-water squid and fish.
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	NA	Widespread, distributed in most of the Scotian Shelf region throughout the year (Hooker et al. 1997, 1999, Gowans and Whitehead 1995). Seem to be more common in the Eastern Scotian Shelf (Reeves 1999 in Breeze et al. 2002).	Not identified.	Present in western waters of the Scotian Shelf, in cooler temperatures and at steeper slopes inclines (Wimmer 2003). Preference for deep >200 m waters and most abundant over depths of 1,000 – 2,500 m (Gowans and Whitehead 2005, Hooker et al. 1999).	Feed on small pelagic squid and small pelagic fish (e.g., herring, whiting, cod, and mackerel (see Gowans and Whitehead 2005 and Whitehead 2013). Feed on sand lance in northeastern United States (Selzer and payne 1988 in Breeze et al. 2002).

Common name (latin name)	**SARA status**	**Presence in the Scotian Shelf**	**Key habitat in the Scotian Shelf**	**Habitat preferences**	**Diet**
Minke whale (*Balaenoptera acutorostrata*)	NA	Widely distributed in the Scotian Shelf, seasonal distribution and migratory patterns are not well understood (some whales migrate to low latitudes in winter like previous baleen whales, while some whales remain at higher latitudes throughout the year, Reeves 2000).	Not identified.	Minkes are able to exploit small and transient concentrations of prey as well as the more stable concentrations that attract multi-species assemblages of large predators (Reeves 2000). In the Gully area, minke whales prefer shallow waters no deeper than 200 m (Gowans et al. 1999, Whitehead 2013).	Feed on fish and invertebrates, feed extensively on sand lance in the western North Atlantic (see Kenney et al. 1996). Also feed on capelin, herring, cod, mackerel, salmon, squid and zooplankton (Stewart and leatherwood 1985, Katona et al. 1993 in Breeze et al. 2002).
Harbour porpoise (*Phocoena phocoena*)	NA	Widespread, seem to be distributed in most of the Scotian Shelf region throughout the year (Hooker et al. 1997, 1999)	Not identified.	Mainly prefer shallow waters (see Reeves 2000)	Feed on small pelagic schoolong fish, especially herring (*Clupea harengus*), mackerel, capelin (*Mallotus villosus*), and demersal species such as silver hake (*Merluccius bilinearis)*, redfish (*Sepastes spp*), Atlantic cod (*Gadus morhua*) and partially feed on sandlance (see Reeves 2000, Kenney et al. 1996).

Common name (latin name)	SARA status	Presence in the Scotian Shelf	Key habitat in the Scotian Shelf	Habitat preferences	Diet
Long-finned pilot whale (*Globicephala melas*)	NA	Widespread, seem to be distributed in most of the Scotian Shelf region throughout the year (Gowans and Whitehead 1995 and see Reeves 2000).	Not identified.	Sighted more commonly in the Gully area during the late summer (August) when the waters were warmer but present in the region year-round; more abundant over the shallowest and deepest waters in the Gully area, and over flatter slope gradients and warmer waters (Gowans and Whitehead 1995, Whitehead 2013, Hooker et al. 1997).	Feed on small pelagic squid, small pelagic fish, mesopelagic squid, mesopelagic fish (e.g. long-finned squid (*Loligo pealei*), short-finned squid (*Illex illecebrosus*), and mackerel, can also feed on cod, haddock, Atlantic herring, butterfish, hake, Greenland halibut (Gowans and Whitehead 1995, Whitehead 2013).
Bottlenose dolphin (*Tursiops truncatus*)	NA	Occasional sightings in the Scotian Shelf; this region is considered as a marginal part of bottlenose dolphin's range (Gowans and whitehead 1995, Hooket et al. 1997, Whitehead et al. 1998, Reeves 2000).	Not identified.	Preference for warmer waters and late summer, its distribution can extend to areas in the Scotian Shelf during the summer and seem to have a strong tendency for association with the shelf edge (centered about the 1,000 m depth contour) at least in US waters (CETAP 1982, Hooker et al. 1999).	-
Risso's dolphin (*Grampus griseus*)	NA	Occasional sighting in the Scotian Shelf, generally it has a more southerly distribution, sighted in deep waters off the continental shelf and in Shortland canyon	Not identified. Deep waters and shelf edge.	Preference for deep waters off the continental shelf, preference for the shelf edge (centered about the 1,000 m depth contour) (Wimmer 2003, CETAP 1982).	-

Common name (latin name)	SARA status	Presence in the Scotian Shelf	Key habitat in the Scotian Shelf	Habitat preferences	Diet
		(Wimmer 2003, Reeves 2000).			
White-beaked dolphin (*Lagenorhynchus albirostris*)	NA	Sighted in the Scotian Shelf. This species has been sighted north of Sable Island in the Laurentian channel in the Cabot Strait (Lawson and Gosselin 2009). Most common delphinid north of the Scotian Shelf (see Reeves 2000). Not sighted in the Gully region. Sighted off Peggy's Cove off Halifax and in nearby waters in early summer (Whitehead, pers. comm. in Breeze et al. 2002).	Not identified. Perhaps spawning concentrations of capelin (*Mallotus villosus*).	Seem to remain at relatively higher latitudes throughout the fall and winter and move northward in summer following spawning concentrations of capelin (*Mallotus villosus*) (Lien et al. 1997 in Reeves 2000).	Feed on schooling fish, mainly Atlantic herring and capelin (*Mallotus villosus*) and squid (Kenney et al. 1996).
Fraser's dolphin (*Lagenodelphis hosei*)	NA	Tropical species which rarely appears in temperate regions; two occasional sightings were reported in the Gully (Whitehead et al 1998 in Reeves 2000).	Not identified. Occasional presence in the area.	-	-
Pigmy and Dwarf sperm whales (*Kogia breviceps* and *Kogia simus*)	NA	Occasionally seen in the Scotian Shelf, and this region is not considered a particularly important part of their range (Reeves 2000).	Not identified. Occasional presence in the area.	Preference for deep waters (Hooker et al. 2000).	Mesopelagic squid (see Reeves 2000)

Common name (latin name)	**SARA status**	**Presence in the Scotian Shelf**	**Key habitat in the Scotian Shelf**	**Habitat preferences**	**Diet**
Beluga whale (*Delphinapterus leucas*)	Threatened	Occasional sightings in the Scotian Shelf, there is a population in the St. Lawrence estuary.	Not identified. Occasional presence in the area.	-	-
Killer whale (*Orcinus orca*)	No status	Occasional sightings in the Scotian Shelf	Not identified. Occasional presence in the area.	-	Herring and other species

Appendix 2. Preliminary species-based assessment of ecological significance to identify cetacean species that may be particularly significant to maintaining ecosystem structure and function and thus may warrant enhanced protection (DFO 2006).

Common name (Species)	**Key Trophic Roles**			**Additional criteria (may enhance priority ranking and complement trophic role criteria)**	
	Forage species	**Highly influential predator**	**Nutrient importing/exporting species**	**Rarity**	**Sensitivity**
Migratory (present seasonally), specialist					
	x	√	√	√	√
North Atlantic right whale (*Eubalaena glacialis*)		Specialist. Preys on large amounts of forage species (older stages of the calanoid copepod *Calanus finmarchicus*)	Migratory. Travels along the east coast of North America primarily from eastern Florida to the Gulf of St. Lawrence and Newfoundland.	Population size is about 450-500 animals; listed as Endangered by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.
	x	√	√	?	√
Sei whale (*Balaenoptera borealis*)		Specialist. Preys on large amounts of forage species (inlcuding plankton, particularly copepods *Calanus finmarchius*).	Migratory. Preference for temperate oceanic waters, seem to migrate along the continental slope in the North Atlantic	Population size is unknown. Listed as Data Deficient by COSEWIC.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.

Common name (Species)	Key Trophic Roles			Additional criteria (may enhance priority ranking and complement trophic role criteria)	
	Forage species	Highly influential predator	Nutrient importing/exporting species	Rarity	Sensitivity
	x	√	√	√	√
Blue whale (*Balaenoptera musculus*)		Specialist. Preys on large amounts of forage species (euphasiids and copepods *Calanus*)	Migratory. Move south to north, from their wintering areas in equatorial latitudes to summer feeding areas.	Listed as Endangered by SARA. Population size is unknown but likely less than 250 individuals (Sear and Calombokidis 2005 in Beauchamp et al. 2009)	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.
Migratory (present seasonally), generalist					
	x	√	√	x	√
Humpback whale (*Megaptera novaeangliae*)		Generalist. Preys on large amounts of small pelagic fish, large zooplankton (euphausiids), small pelagic squid (e.g., herring, sand lance and capelin).	Migratory. Move south to north, from their wintering areas in equatorial latitudes to summer feeding areas.	Population size is unknown. Listed as Not at Risk by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.

Common name (Species)	Key Trophic Roles			Additional criteria (may enhance priority ranking and complement trophic role criteria)	
	Forage species	Highly influential predator	Nutrient importing/exporting species	Rarity	Sensitivity
	x	√	√	?	√
Fin whale (*Balaenoptera physalus*)		Generalist. Preys on large amounts of small pelagic fish, large zooplankton and small pelagic squid (e.g., sand lance, herring mackerel and capelin).	Migratory. Migration patterns are unknown.	Population size is unknown. Listed as unknown by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.
	x	√	√	x	√
Striped dolphin (*Stenella coeruleoalba*)		Preys on fish, squid and crustaceans.	Migratory. Present in the Scotian Shelf during the summer.	Population size is unknown. Listed as Not at Risk by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.

Common name (Species)	Key Trophic Roles			Additional criteria (may enhance priority ranking and complement trophic role criteria)	
	Forage species	Highly influential predator	Nutrient importing/exporting species	Rarity	Sensitivity
	x	√	√	x	√
Short-beaked common dolphin (*Delphinus delphis*)		Preys on mackerel and long-finned squid, herring, whiting, pilchard (*pilchardus*), and anchovy.	Migratory. Present in the Scotian Shelf during the summer.	Population size is unknown. Listed as Not at Risk by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.
Resident (present year-round), deep divers					
	x	√	√	√	√
Northern bottlenose whale (*Hyperoodon ampullatus*)		Specialist. Preys on large amounts of deep-water squid, primarily on *Gonatus* squid.	Present in the Scotian Shelf year-round but conduct movements between their known range in the Gully area.	Population size is about 322 animals. Listed as Endangered by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.

Common name (Species)	Key Trophic Roles			Additional criteria (may enhance priority ranking and complement trophic role criteria)	
	Forage species	Highly influential predator	Nutrient importing/exporting species	Rarity	Sensitivity
Sowerby's beaked whale (*Mesoplodon bidens*)	x	√	√	√	√
		Mesopelagic fish and likely mesopelagic squid.	Movements poorly known. Present in the Scotian Shelf year-round but conduct movements between their known range in the Gully area.	Listed as Special Concern by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors. Particularly sensitive to anthropogenic ocean noise.
Sperm whales (*Physeter macrocephalus*)	x	√	√	x	√
		Preys on large amounts of deep-water squid and fish.	Migratory and some individuals present year-round.	Population size is unknown. Listed as Not at Risk by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.

Common name (Species)	Key Trophic Roles			Additional criteria (may enhance priority ranking and complement trophic role criteria)	
	Forage species	Highly influential predator	Nutrient importing/exporting species	Rarity	Sensitivity
Resident (present year-round), generalists					
	x	√	√	x	√
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)		Preys on small pelagic squid and small pelagic fish (e.g., herring, whiting, cod, sandlance).	Present in the Scotian Shelf year-round but conduct large movements within their range.	Population size is unknown. Listed as Not at Risk by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.
	x	√	√	x	√
Minke whales (*Balaenoptera acutorostrata*)		Preys on fish and invertebrates (e.g. sandlance, capelin, herring, cod, mackerel, salmon, squid and zooplankton).	Migratory patterns poorly understood. Present in the Scotian Shelf year-round, conduct large movements within their range.	Population size is unknown. Listed as Not at Risk by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.

Common name (Species)	Key Trophic Roles			Additional criteria (may enhance priority ranking and complement trophic role criteria)	
	Forage species	Highly influential predator	Nutrient importing/exporting species	Rarity	Sensitivity
	x	√	√	?	√
Harbour porpoise (*Phocoena phocoena*)		Preys on small pelagic schooling fish (e.g., herring, mackerel, capelin) and demersal species (e.g., silver hake, redfish, Atlantic cod, sandlance).	Present in the Scotian Shelf year-round but conduct large movements within their range.	Listed as Special Concern by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.
	x	√	√	x	√
Long-finned pilot whale (*Globicephala melas*)		Preys on small pelagic squid, small pelagic fish, mesopelagic squid, mesopelagic fish (long-finned squid, short-finned squid, mackerel, cod, haddock, Atlantic herring, butterfish, hake, Greenland halibut).	Present in the Scotian Shelf year-round but conduct large movements within their range.	Population size is unknown. Listed as Not at Risk by SARA.	In general, cetaceans are particularly sensitive due to slow growth and maturation, among other factors.