Potential Effects of Global Climate Change on Cetaceans Distribution in a Small Scale Feeding grounds in Iceland, Skjálfandi Bay

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60 ECTS thesis submitted in partial fulfillment of a
Magister Scientiarum degree in Join Nordic Master Programme in Marine Ecosystems and Climate

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Um þessar mundir eru örar loftslagsbreytingar að gerast, með miklum áhrifum á vistkerfi sjávar. Íslandsmið eru auðug af næringarefnum og lífmagni og fjöldi lífvera leita á þessi mið til að afla sér næringar. Rannsóknirnar beindust að umfangi hvala, einkum á þeirra helsta fæðuöflunartíma (maí-september). Útbreiðsla hvalategunda í Skjálfandaflóa var metin út frá talningum frá hvalaskoðunarbátum árin 2004 til 2012. Rannsóknirnar beindust að hrefnu (*Balaenoptera acutorostrata*, N=593), hnýðingi (*Lagenorhynchus albirostris*, N=281), hnúfubak (*Megaptera novaeangliae*, N=363) og hnísu (*Phocoena phocoena*, N=89). Útbreiðsla hvalanna var metin með hjálp landfræðilegra upplýsingakerfa, og tengsl á milli umhverfisþátta og tilvistar/fjarvistar hvalanna var metin með hjálp líkana (General Additive Models, GAMS). Við gerð líknanna var miðað við að tilvist/fjarvist hvalategundanna væri svarbreyta, á meðan umhverfisþættir (þ.e. dýpi, fjarlægð frá landi, halli undirlags (botnsins), staðalfrávik halla undirlagsins, yfirborðshiti sjávar (SST), staðalfrávik SST og blaðgræna (chlorophyll-a)), framboð af fæðu (þorskur, loðna og síld) og tími ársins (mánuður) voru skýribreytur. Niðurstöður sýna að útbreiðsla hvalanna mótaðist einkum af dýpi og fjarlægð frá landi. Fyrir hnýðing og hnísu var fjarlægðin frá landi mikilvægasta skýribreytan, en fyrir hrefnu og hnúfubak var dýpið mikilvægasta skýribreytan. Líkönin útskýrðu 9.95, 12.6, 14.3 og 7.34% af fráviki fyrir hverja tegund. Breytan mánuður var á mörkum marktækni fyrir hnýðing, hnísu og hnúfubak. Hrefnan og hnúfubakurinn dvöldu einkum á dýpra vatni (200-350 m dýpi), en hnýðingur og hnísa einkum á svæðum með 100 til 300 metra dýpi. Niðurstöðurnar benda til þess að loftslagsbreytingar hafi um þessar mundir óbein áhrif á ofangreindar hvalategundir og einkum þó á útbreiðslu fæðutegunda þeirra, auk annara líffræðilegra þátta (samkeppni, far). Það er því mikilvægt að skipuleggja framtíða mælingar á þann hátt að þær nýtist til verndar og stjórnunar og auðveldi skilning á vistfræði og útbreiðslu hvala í tíma og rúmi á svæði sem er mikilvægt vegna hvalaskoðunar, þ.e. Skjálfandaflóa.

Abstract

Global climate change is having major impacts in marine ecosystems. Icelandic waters represent an area rich in nutrients that enhance marine biodiversity. This study focuses on providing a baseline data on cetacean distribution and habitat preference in Skjálfandi Bay during the feeding season (May-September) and how these may be influenced by current and future global climate scenarios. Distribution patterns were investigated by analyzing cetacean sightings data collected onboard whale watching platforms from 2004–2012. The species included in this study comprise White-beaked Dolphins (*Lagenorhynchus albirostris*, N=461), Harbour Porpoises (*Phocoena phocoena*, N=236), Humpback Whales (*Megaptera novaeangliae*, N=711) and Minke Whales (*Balaenoptera acutorostrata,* N=*856*). Cetacean presence and survey effort were incorporated into a Geographical Information System (GIS) and relationships between environmental variables and cetacean presence/absence were determined using General Additive Models (GAMS). The presence/absence of each cetacean species were considered as the response variable while at set of eco-geographical variables (i.e. depth, distance to coast, bottom slope, standard deviation of slope, sea surface temperature (SST), standard deviation of SST, chlorophyll-*a* and prey abundance from cod, capelin and herring) were considered as explanatory variables together with month. Models explained 9.95%, 12.6%, 14.3%, and 7.34% of deviance respectively. The distribution of the species was influenced by depth and distance to coast. White-beaked dolphins and harbour porpoise presence was better explained by distance to coast while minke and humpback whales presence was better explained by depth. Humpback and minke whales seem to be associated with more productive areas (i.e. higher chlorophyll-*a*) while white-beaked dolphin and harbour porpoise presence seem to be associated with higher variability in seabed steepness and rugosity. The results from this study suggest that climate change can have effects on the studied cetacean species, specifically by influencing their prey distribution promoting interspecific competition. Therefore, it will be essential to promote measurements for conservation and management in order to understand temporal patterns of cetacean distribution in an area intensively used by whale watching platforms such as Skjálfandi Bay.

Dedication

I dedicate this important part of my career and life to all the people who were there for me during this time. My parents and brothers for always being there and support me at all times. Family and friends, thank you for all your help, advice, support and love. For the amazing journey that this event brought me, the people, places and cultures, I now value, appreciate and will always be memorable.

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Abbreviations

AW – Atlantic water

CHL-*a* – Chlorophyll *a*

EGV – Eco-geographic variables

ENSO – El Niño-Southern Oscillation

GIS – Geographic information systems

GAM's – Generalized Additive Models

IPCC – International panel of climate change

NAO – North Atlantic Oscillation

OA – Ocean acidification

PW – Arctic water

SAC – Special areas of conservation

SD – Standard deviation

SSB – Spawning stock biomass

SST – Sea surface temperature

US EPA – United States Environmental Agency

Acknowledgements

1 Introduction

Oceans covered 71% of the Earth's surface and play a principal role regulating its climate (Hoegh-Gudberg & Bruno, 2010). Global climate change is happening rapidly therefore, the need for research and understanding the future of the ecosystems it is essential for conservation and management. Life in the oceans depends upon many factors such as ocean circulation, temperature, salinity, sun light among others; thus is very important for the marine ecosystems.

Icelandic waters represent an area rich in nutrients for marine diversity, from primary production, demersal fish and invertebrates to top predators such as marine mammals. In Icelandic waters 18 species of cetaceans can be found, 12 belong to the odontocete suborder and 6 are mysticete (Sigurjónsson and Víkingsson, 1997). Some cetaceans such as humpback (*Megaptera novaeangliae*) and blue whales (*Balaenoptera musculus*) make long migrations to the North Atlantic including the waters around Iceland due to relatively productive areas making them important feeding grounds. As some species might take long migrations to get to these Icelandic rich waters others cetaceans can be found all year round as resident species (Cecchetti, 2006; Cooper, 2007). The most common species present in Icelandic waters are the minke whales (*Balaenoptera acutorostrata*), humpback whales, white beaked dolphins (*Lagenorhynchus albirostris*) and harbour porpoises (*Phocoena phocoena*) among others (Cecchetti, 2006; Cooper, 2007). Interactions between environmental conditions such as water temperature, water depth, seabed, oceanographic fronts and other changes may be influencing the ecological habitat and subsequently the spatial distribution and abundance of these species (MacLeod *et al.* 2004; MacLeod, 2009). Knowing the habitat preferences of these species can aid in the establishment of protected areas (Hoyt, 2003).

1.1 Global climate change and environmental variables

Climate is influenced by a variety of ecological processes. These processes work around parameters such as temperature, atmosphere, land surface, wind, rain, ice, ocean circulation and biosphere (together with human influences) which interact among them (US EPA 2012). Changes in global climate change are difficult to predict. One way to predict changes in climate for the future is through the use of Global Climate Models (GCM) which simulates and gives plausible scenarios and representations of climate processes (IPCC 2007). The predictions of these scenarios cover both global and regional areas and this study will be discussing the latest presented by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth/Fifth Assessment Report (IPCC 2012/2013)

Global climate change has impacted marine and terrestrial environmental processes (Hoegh-Gudberg & Bruno, 2010). Phenomenon's such as North Atlantic Oscillations (NAO) and El Niño-Southern Oscillations (ENSO) also contribute to these changes. In the present study, ENSO and NAO will be briefly described since they have been mention for a

hand full of scientist (Zhang *et al.* 1996; Napp & Hunt, 2001; Edwards *et al.* 2010) whom made the observation of the exposure of species to severe weather and temperature stress (Stenseth *et al.* 2002; Laidre *et al.* 2008).

The El Niño-Southern Oscillation (ENSO) is a naturally occurring phenomenon that involves fluctuating ocean temperatures in the equatorial Pacific (Zhang *et al.* 1996). The warm phase of ENSO cycle features warmer than normal sea surface temperature across central and eastern equatorial Pacific along with weaker low-level atmospheric winds along equator, enhanced convection across the entire equatorial Pacific, effects are stronger during northern hemisphere winter due to the fact that ocean temperatures worldwide are at their warmest. This increased ocean warmth, enhanced convection, which then alters the jet stream such that it becomes active. It has been suggested that El Niño phenomenon as well as La Niña episodes increases every 3–5 years even though historically records showed intervals that varied from 2–7 years (NOAA, 2005). El Niño is an unpredictable phenomenon and is one of the reason climate change scenarios cannot precisely include the frequency of these patterns (Mann, Rahmstorf, Sinclair, conference Climate Science and Climate Communication. October 5th, 2013). Even if there is no change in El Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rain fall, increasing the risk of floods and droughts that occur in many different regions (Learmonth *et al.* 2006).

The North Atlantic Oscillation (NAO) is a climatic phenomenon in the North Atlantic Ocean, is a north and south alteration in atmospheric masses between the subtropical high pressure centered over the Azores and the subpolar low pressure centered over Iceland (Learmonth *et al.* 2006). Through oscillation motions between the Icelandic low and Azores high the westerly winds and storm tracks strength and direction across the North Atlantic are determined. During the positive NAO the westerly winds are strengthened and move northwards, subsequently there is an increased in precipitation and temperatures over northern Europe and southeastern U.S. along with dry anomalies in the Mediterranean region (Stenseth *et al.* 2002).

Icelandic waters and nearby marine regions are, due to their location near the polar front, highly susceptible to climatic changes. At the same time these have a remarkable influence on the distribution and behaviour of marine organisms (Hunt *et al*, 2005); as it has been demonstrated by the changes in abundance and distribution in many species during the warm period in the 1930's and the cold period in the late 1960s as well as during the recent warm years (Astthorsson *et al.* 2007). Additionally, observed variations in horizontal and vertical distribution of marine organisms are related to physical and biological processes, both with respect to space and time (Stefánsson & Ólafsson, 1991).

Climate change has also had effects on cetaceans that can be affected in a direct or indirect way (Learmonth *et al.* 2006). Directly, happens with species only being able to survive within specific temperature ranges; for example species found only in Arctic waters such as bowhead whales (*Balaena mysticetes*) and narwhals (*Monodon monoceros*) (Learmonth *et al.* 2006). Indirectly, climate change can cause changes in the main prey availability affecting distribution, abundance, migration patterns, community structures, susceptibility to disease and contaminants (Learmonth *et al.* 2006). For instance, geographic and seasonal variations on sea surface temperature as well as spatial and temporal patterns variations of primary productivity can influence the distribution of marine mammals and their prey. Food availability for marine mammals is established by patterns of marine primary

production and the trophic levels between primary production and the marine mammal consumers. Consequently, these effects of climate change over marine mammals have a number of implications for their conservation (Learmonth *et al.* 2006).

In order to protect critical habitat it is critical to understand the ecology of animals. Assuming the distribution of cetaceans is non-random and it is relative to environmental variability, incorporating these variables into modelling can potentially increase the predictive capacity of habitat use. The following are the variables used in this study.

1.1.1 Fixed parameters

This study includes the fixed parameters such as depth, distance to coast and slope. These parameters have in common the fact that they do not change temporally however they may be modified with factors such as sea level rise.

i. Depth

Many studies have described the importance of bathymetry for cetaceans; (Davis *et al.* 1998; Baumgartner *et al.* 2001; Jaquet & Gendron, 2002; Yen *et al.* 2004; Friedlaender *et al.* 2006; Stephanis *et al.* 2008) becoming more efficient when there are several hundred of kilometers from the coast (Davis *et al.* 1998). In the study carried out by Yen *et al.* (2004) it was found that there were similar relationships between cetaceans and bathymetric features at both interannual and weekly time scales. For example, it has been suggested that the distribution of sperm whales (*Physeter macrocephalus*) in the Gulf of Mexico is related to deep waters either continental or in the deep Gulf, resulting in the possible encounter of prey species (Baumgartner *et al.* 2001, Jaquet & Gendron, 2002). Stephanis *et al.* (2008) describes three groups of cetaceans in the Strait of Gibraltar in relation to oceanographic features. The first group included common (*Delphinus delphis*) and stripped dolphins (*Stenella coeruleoalba*) that were found at surface Atlantic waters, second group mainly composed by bottlenose dolphins (*Tursiops truncates*), long-finned pilot whales (*Globicephala melas*) and sperm whales were found over the deep waters of the central part of the strait. Lastly, the third group formed by killer whales (*Orcinus orca*) was found in the southern part of the strait. All these areas were correlated to prey species as well. Other studies have mentioned the relationship of cetacean body size and diving patterns, suggesting that as optimal dive depth generally increased with body size, larger animals should be diving deeper to find prey while smaller diving animals would be more successful when prey patches were located in shallower waters (Friedlaender *et al.* 2006). Other studies have found that depth is a critical factor in determining the distribution of humpback whales in breeding areas off the Ecuadorian coast (Felix & Haase, 2005).

ii. Slope

Equally important as depth is bottom slope or steepness of the seabed topography; occasionally both parameters are correlated to one another when studies have been done looking at habitat selection of cetaceans. Enhanced productivity in coastal regions is the result of bottom topography which plays a determinant role on the oceanographic processes (Allen *et al.* 2001; Dalla Rosa *et al.* 2012). A series of studies revealed the significance of the seabed structure as possibly one if the drivers of cetaceans spatial and temporal distribution. Continental shelf-breaks and slope appear to be highly productive habitats, which frequently support high density of marine predators (Sourisseau *et al.* 2006). For

instance, throughout the Gulf of St. Lawrence it was determined that the presence of abrupt sloping bottoms areas which were of major trophic exchange in response to local biomass aggregation, notably for vertically migrating organisms (Sourisseau *et al.* 2006). Other studies have found the reason of whale and dolphin aggregation during specific areas, for example, areas where upwelling and downwelling occurs (Baumgartner *et al.* 2001; Jaquet & Gendron, 2002). Sei whales (*Balaenoptera borealis*) displayed strong responses to the interactions between bottom topography and flow gradients a various depth, most notably at depths shallower than 100 m in Icelandic waters (Skov *et al.* 2008). This finding relates to oceanographic characteristics where nutrient rich water in primary production is present.

iii. Distance to coast

Distance to the coast could matter in different situations for example, if we are referring to breeding or feeding grounds. Felix and Haase (2005) determined the distance from coast of humpback whales within their breeding grounds. There were some areas between Ecuador and Colombia where humpback whales were absent in offshore records while the southwest and north of Peru whales were abundant. The proximity to this regions could also be attributed the feature of the Equatorial Front that causes the humpback whales to move towards the coast. Other species such as marine birds are also commonly related to the distance of the open ocean to land (Yan *et al.* 2004). For example, in the study by Yan *et al.* (2004) it was establish that common murre (*Uria aalge*) was consistently found at higher densities over shallower waters close to land finding a linear relationship between distance and distance to mainland and changing their distribution offshore overtime. In the same case study cetaceans such as Dall's porpoise and white-sided dolphin were found in greater abundance further from the mainland.

1.1.2 Non- fixed parameters

The non-fixed parameters including here are the following: Sea Surface Temperature (SST), Chlorophyll or primary production and prey. Non-fixed parameters normally vary through time and spatial scale; nevertheless their variation may be greater than expected due to climate change.

i. Sea Surface temperature (SST)

The regional or global distribution of marine mammals species are often related to water temperature (Sigurjónsson 1995; Learmonth *et al.* 2006). A species range may be limited in some cases because is not adapted for living in certain environments (Learmonth *et al.* 2006). For example, residents in the Arctic waters include the bowhead whales (*Balaena mysticetus*) and narwhals (*Monodon monoceros*). The Atlantic white-beaked dolphin are only found in cold temperate waters and species such as pantropical spotted (*S. attenuate*) and spinner (*Stenella longirostris*) are restricted to tropical waters (MacLeod, 2008). Studies have shown restricted ranges to some species due to temperature constraint where species have limitations on their abilities to thermoregulate in cold water or find food in different habitats. Temperature variation can affect marine mammals either in a direct way or indirect; Directly, as mention previously happens with species only being able to survive within specific temperature ranges and indirectly with temperature affecting competitive abilities of ecologically similar species (Learmonth *et al.* 2006). Some examples where temperature ranges have been found for marine mammals include temperature range of white-beaked dolphins, were they are found to be dominant in waters below 13˚C in the

UK and Irish waters (MacLeod, 2008). Other studies supported by observations have determined the different mechanisms long-finned (*Globicephala melasand*) and short-finned pilot whale (*G. macrorhynchus*) populations have with respect of their relative distribution when isolation occurs between populations in areas of the ocean which differ in sea surface temperature (Fullard *et al.* 2000). Indirectly, prey availability is likely to be particularly critical for marine mammals. Therefore,s distribution of preference prey affects presence and distribution of whales and dolphins (Learmonth *et al.* 2006). The effects on prey species can in turn have several indirect effects on marine mammals, including changes in distribution, abundance and migration, community structure, susceptibility to disease and contaminants and reproductive success (Learmonth *et al.* 2006).

ii. Chlorophyll-*a*

Upwelling and mixture of surface water masses enhance rich biological production (Smith *et al.* 1986). Studies have suggested and linked the distribution and abundance of marine mammals, to the productive coastal waters more than in offshore oceanic waters. Therefore, oceanic chlorophyll may be used as a habitat descriptor for selected marine mammals (Smith *et al.* 1986). The results from a study using remote sensing and in situ data demonstrate that cetaceans tend to be most abundant where chlorophyll is most concentrated and was hypothesized that the distribution of cetaceans was proximally related to the meso-scale distribution of primary productivity through links in the food web (Smith *et al.* 1986). Planktonic 'indicator species' are highly sensitive to environmental variability and have a long history in ecological monitoring of the marine environments. They represent a relatively quick and easy way to monitor different water masses, defined marine habitats and to observed changes in food-web structures (Edwards *et al.* 2010). The seasonal nutrient rich water supports high primary production and associated higher trophic levels (prey and predator), which are linked through transport, reproduction, growth and development (Croll *et al*, 2005). For example, Croll *et al.* (2005) suggested that abundance of blue whales is correspondent to the linkages through a sequence of bottom-up biological processes, including peak in primary production and physical forcing. Cetacean distribution, particularly in relation to local geomorphology and oceanography, could play a role in designating and managing marine protected areas (Croll *et al.* 2005).

iii. Prey

The dynamics between predator and prey determines the availability of resources and the temporal and spatial scale of their interactions (Torres *et al.* 2008) thus, prey availability can determined predator habitat selection patterns. Many of the pelagic fish species undergo major natural fluctuations that can greatly influence the day to day survival of the whale population in the areas off Iceland, such as capelin and herring (Sigurjónsson, 1995). The spawning sites for capelin can be restricted to beaches or shoals with highly specific substrate characteristics and their occurrence is correlated with water temperature and tidal oscillations (Vilhjálmsson, 2002). One capelin stock occurs to the north and west of Iceland in large amounts and another is also reported to be a major prey item in the eastern North Atlantic and in the Barents Sea (Astthorsson *et al*, 2007). Capelin distribution in these waters is highly unpredictable; however both stocks are associated with meso-scale oceanographic features. The Icelandic stock spawns to the southwest of Iceland, moving north and east through the summer in association with the Polar Front and the winter capelin grounds often occur in the deep waters of Iceland (Sigurjónsson & Gunnlaugsson, 1990). Herring are observed to make regular annual return migrations to and from specific

spawning sites and to seasonally inhabit waters of consistent temperature and depth characteristics. Another valuable prey item for whales, dolphins and porpoises is the gadoid fish cod. As mature fish they are widely distributed over large parts of the North Atlantic Shelf seas throughout most of the year; cod also migrates often over long distances to spawn within very restricted areas during a short season (Pálsson & Thorsteinsson, 2003

). Location and timing of spawning are regular and appear to be related to the seasonal cycles of plankton production (Brander *et al.* 2001). In Iceland the main spawning grounds are at in the southern Icelandic waters where there seems to be different populations that display different life histories (e.g growth patterns) (Jónsdóttir *et al.* 2001). Additionally, there have been observed short migrations localised in areas at the east and northeast coast (Marteinsdóttir *et al.* 2000). These fish and also euphausiid are largely planktivorous with a wide overlap in diet.

1.2 Iceland physical oceanography - topography and current circulation

Iceland is located on large marine ridges. The Reykjanes Ridge and Kolbeiney Ridge, that run in a southwest –northeast direction. On the other hand, the Greenland-Iceland Ridge and the Iceland-Faroe Ridge lie in a northwest-southeast direction (Fig 1.1.; Valdimarsson & Malmberg, 1999). Icelandic oceanic circulation patterns and water masses distribution are influenced by this bottom topography (Greenland-Iceland and Reykjanes Ridge to the West and the Jan Mayen and Iceland-Faeroe Ridge to the East) (Valdimarsson & Malmberg, 1999).
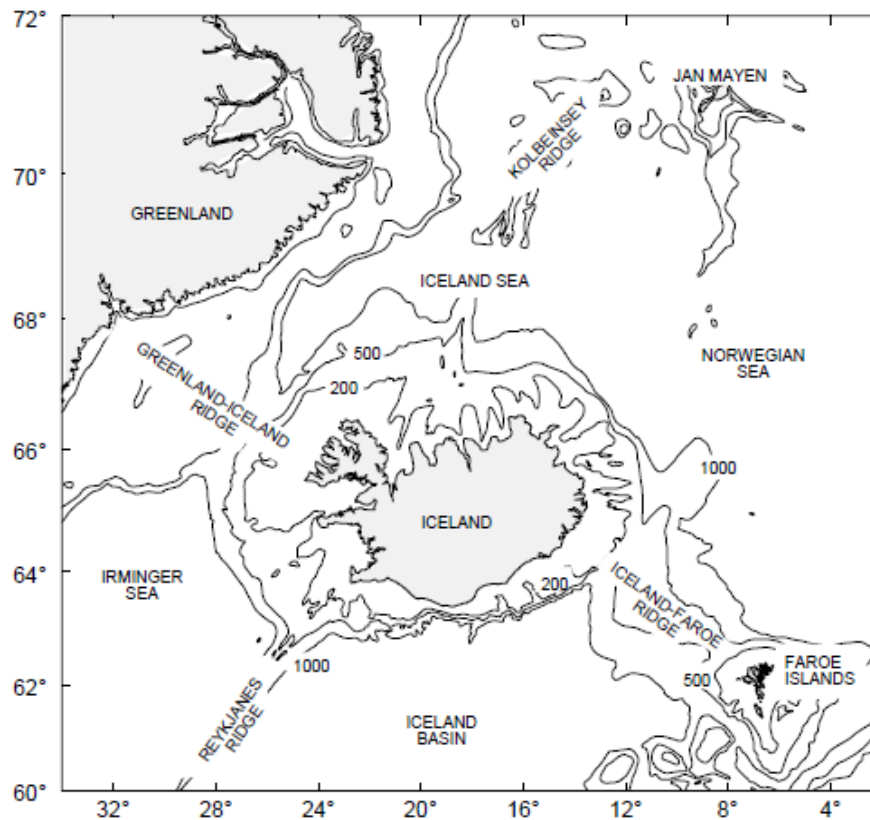
Figure 1-1 The continental shelf and bottom topography around Iceland, which influence oceanic circulations and water masses disturbances. The 400 m depth contour is considered to mark the Icelandic shelf area (Obtained from Hunt & Drinkwater, 2005)

The current oceanic circulation around Iceland has been described as a complex system of primary two water masses characterized by very different origins and properties; relatively warm and an arctic water mass that forms permanent (Valdimarsson & Malmberg, 1999; Astthorsson *et al.* 2007). As mentioned above, Iceland is located on the Greenland-Scotland Ridge where strong, permanent boundaries are formed between the relatively warm waters of the northeastern Atlantic and the Arctic waters of the Nordic Seas (Stefánsson & Ólafsson, 1991). Four major currents surround Iceland; the warm and saline Atlantic water (AW) (6–8°C), cold and low salinity water, Arctic water (PW) and Icelandic coastal water. The warm Atlantic water or Irminger Current branches forming a cyclonic eddy to the west and southwest of Iceland and one following the Icelandic shelf and continuing eastwards along the north coast and in warm years reached shelf areas east of Iceland (Gudmundsson, 1998; Valdimarsson & Malmberg, 1999; Jónsson & Valdimarsson, 2012). The cold and Arctic waters located farther offshore to the northwest, north and east of Iceland are the East Icelandic Current and East Greenland Current (<0° to 2°C). Lastly, the Icelandic Coastal Current runs in a clockwise direction around Iceland (Valdimarsson & Malmberg, 1999; Jónsson & Valdimarsson, 2012) mainly flowing the 400–500 m depth contour (Astthorsson *et al.* 2007). The oceanographic character in the southern and western parts of the Icelandic marine ecosystems are characterized by being bathed by warm and saline AW passed by a branch of the Gulf Stream and flowing clockwise (Valdimarsson & Malmberg, 1999). On the other hand the north and eastern areas are influenced by Atlantic, Arctic and even Polar water masses subjected to interannual variations (Valdimarsson & Malmberg, 1999; Malmberg & Valdimarsson, 2003; Jónsson & Valdimarsson, 2005).

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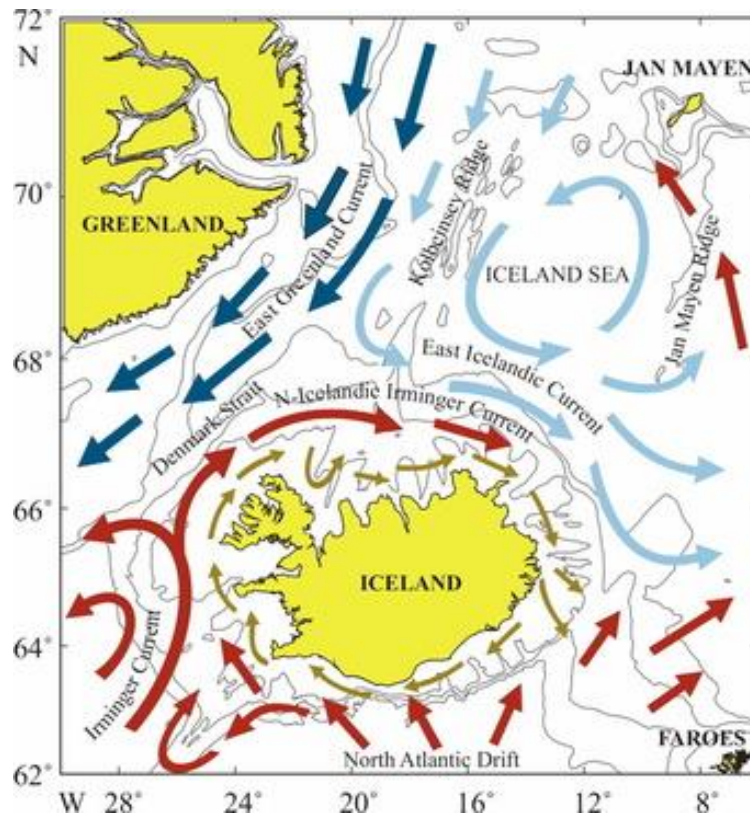
Figure 1-2 Water circulation systems around Iceland. Relative warm, saline Atlantic water (red arrows), cold, low-saline polar water (dark blue arrows), arctic water (light blue arrows), Icelandic coastal water (yellow arrows) (Obtained modified map from Stefánsson & Ólafsson, 1991)

The rich biological productivity and diversity of marine populations in Icelandic waters is influenced by the submarine ridges, the oceanic circulations and water mass distribution around Iceland (Jónsson & Valdimarsson, 2005; Astthorsson *et al*, 2007); Specifically, interannual variations in primary productivity are mainly attributed to changes in inflow of the Atlantic water and its influence on stratification of the water column (Gudmundsson, 1998). The nutrient content of Icelandic shelf water depends mainly on the concentrations found in the oceanic water masses entering the region, but near-shore they will be modified by the admixture of fresh water which may have an entirely different nutrient composition (Valdimarsson & Malmberg, 1999; Malmberg & Valdimarsson, 2003). Productivity generally is higher in southwest regions than in the northeast-Iceland and shelf regions when compared to oceanic regions (Gudmundsson, 1998). Rates of primary production can vary by several orders of magnitude over geographic areas and also between seasons. Seasonal and spatial variation in primary production are related to differences in light intensity, water temperature, density and the pattern of vertical mixing of water, with the magnitude of these variations between the summer and the winter becoming more pronounced in higher latitudes (Valdimarsson & Malmberg, 1999). In Iceland, the highs and lows in spring productivity measurements have been explained by differences in spring bloom development in "cold" versus "warm" years due to differences in stability of the water column (obtained from Valdimarsson & Malmberg, 1999; Malmberg & Valdimarsson, 2003; Jónsson & Valdimarsson, 2005 citing Thórdardóttir 1984). In addition, in Iceland the mean productivity increase homogeneously is characterized by a relative high surface salinity, indicative of Atlantic water and turbulent water column in spring. salinity criterion is influence by Polar water, melted water from drift-ice or fresh water run-off, which is indicative of a stable surface layer. The timing of the spring bloom

is affected by prevailing environmental conditions (obtained from Astthorsson *et al*, 2007 citing Thórdardóttir 1984) and the stability of the water column in particular (Stefánsson & Ólafsson, 1991).

1.3 Cetaceans biology and ecology

There is a wide diversity of cetaceans in the Icelandic continental shelf area including both toothed and baleen whales. Historically, whaling first commenced in the 1880s in Iceland, landing large whales such as blue, fin, sei and humpback whales (Sigurjónsson, 1995). Whaling then played a major role in the history of modern whaling in the North Atlantic (Sigurjónsson, 1995). On the other hand, minke whaling with cold-harpoons and motor vessels did not commence until last century (Sigurjónsson, 1995). These species either migrate or remain in Icelandic waters specifically during the summer due to the rich and diverse food supply. Some of the places where these cetaceans can be spotted and have been the source for whale watching include Faxaflói Bay and Skjálfandi Bay. In Skjálfandi Bay, four of the most common cetaceans in the bay are minke and humpback whales, white-beaked dolphin and harbour porpoise (Rasmussen, 2009).

Baleen whales usually undergo seasonal long migrations between their breeding (temperate waters) grounds during the local winter and feeding (polar and temperate waters) grounds during the local summer (Martinez & Pastene, 1999).

1.3.1 White-beaked dolphins

White-beaked dolphins distribution includes cold temperate and subarctic shelf waters of the North Atlantic (Reeves *et al.* 1999) from Cape Cod (USA), southwest and central East Greenland to extreme West Barents Sea (Shirihai & Jarrett, 2006) and the Bay of Biscay (Fernandez, 2011 Pers. Comms.). The northern limits of the range are not very clear, but include Newfoundland, Greenland, Iceland, Svalbard and the North Cape of Norway (Shirihai & Jarrett, 2006). It is the most northerly member of the genus *Lagenorhynchus*, in its wide distribution (Weir & Stockin, 2001; Weir *et al*. 2009). At least a few thousand white-beaked dolphins inhabit Icelandic waters and (Reeves *et al.* 1999). The estimated abundance in Icelandic waters were 31,653 animals (95% CI: 17,679–56,672) (Gunnlaugsson *et al.* 1988; Pike *et al.* 2009). They feed on variety of small pelagic schooling fishes but also demersal species (such as cod, haddock, cod, bib, hake, and whiting (*Merlangius merlangus*)), squid, and crustaceans (Canning *et al.* 2008; Reeves *et al.* 1999). It has been suggested that *L. albirostris* are benthos and prefer cod, whiting and capelin in contrast to similar species such as white-sided dolphins (*L .acutus*) (Reeves *et al.* 1999). White-beaked dolphins are sometimes associate, while feeding, with large whales (such as fin and humpback whales), and are known to form mixed groups with a number of other dolphin species (including bottlenose and Atlantic white-sided dolphins) (Reeves *et al.* 1999). In Icelandic waters there has been few studies mentioning cod as one of their main prey (Rasmussen, 2004; Víkingsson & Ólafsdóttir, 2004). Although white-beaked dolphins have not been a target of any large commercial fisheries, there has been a long history of small-scale hunting in some countries, such as Norway, the Faroe Islands, Greenland, Iceland, and Labrador, mostly for food (Reeves *et al.* 1999). Other threats which affect this species consist of by-catch taken by fishing gear, habitat degradation and pollution such as anthropogenic compounds, noise and heavy metals (Reeves *et al.* 1999; Evans & Teilmann, 2009). It has been suggested that even though the effects of pollutants

are not well understood in this species, they may affect reproduction or render them susceptible to other mortality factors (Hammond *et al.* 2012).

1.3.2 Harbour porpoise

The harbour porpoise is a small odontocete found in cold temperate to sub polar waters of the North Hemisphere (Read, 1999; Shirihai & Jarrett, 2006). Found mainly in continental shelf waters, shallow bays, estuaries and tidal channels in the North Pacific and North Atlantic (Bjørge & Tolley, 2009). They occur around southeast and western Greenland, Iceland and the Faroe Islands (Hammond *et al.* 2012). The global abundance of harbour porpoise has been estimated to be at least 700.000 individuals (Hammond *et al.* 2012), where preliminary results have shown that the total abundance estimates were 43,179 porpoises (CV=0.45; 95%CI: 31,755–161,899) for Icelandic waters (Preliminary results from Gilles *et al.* 2011). Even though harbour porpoises do not have long migrations as do large whales, they are known to have onshore/offshore migrations and movements parallel to the coast are known to occur (Bjørge & Tolley, 2009). They have a very short life cycle compare to the large whales (Hohn & Read, 1995). Normally found in small groups of 1–3 animals, often consisting of a mother-calf pair, however larger groups of 6–8 animals can be seen occasionally (Bjørge & Tolley, 2009). This species eats a variety of fish and prey on squid, cephalopods and small crustaceans; their main prey items vary between regions (Bjørge & Tolley, 2009). In Iceland harbour porpoises mostly preyed on capelin (Víkingsson *et al.* 2003), Atlantic cod and small crustaceans (Kaponen, 2013). Harbour porpoise used to be hunted but now a day only in Greenland occurs (Hammond *et al.* 2012). In addition, several major threats have been observed including incidental bycatches or entanglement in fishing gear (bottom-set gillnets but primary gill nets), chemical pollution, vessel traffic, noise and depletion of prey by habitat degradation and by overfishing (Bjørge & Donovan, 1995; Bjørge & Tolley, 2009; Hammond *et al.* 2008).

1.3.3 Humpback whales

Humpback whales were targeted by the modern pelagic whaling industry between the 1860s and the early 1900s (Stevick *et al.* 2003) and most stocks were severely depleted within a few years of the commercial operations (Tønnessen & Johnsen 1982). The North Atlantic stock has increased in recent years because they have been protected from hunting since 1995 by the International Whaling Commission (Sigursson & Gunnlaugsson, 1990; Best, 1993). Humpback whales were listed by the IUCN as endangered during the late 80's and vulnerable in the early 90's (Reilly *et al.* 2008). At present, under the red list of the IUCN humpback whales are in the category of "Least Concern" (Reilly *et al.* 2008). Humpback whales are widely distributed, capable of large-scale movements between tropical calving grounds in winter and high latitude feeding grounds in summer, long-lived and have relatively low reproductive capacity (Stevick *et al.* 2003; Learmonth *et al.* 2006). In the western North Atlantic their primary prey include schooling fish of capelin, sandeel, herring and mackerel and also euphausiids; and in the Norwegian Sea, euphausiids have been reported as a principal prey in spring and early summer (NMFS, 1991). Little data are available on humpback whale prey off Iceland, however, it was suggested that euphausiids are the primary prey of fin whales caught south and west of Iceland (Víkingsson, 1998) and mentioned that humpback whales were assumed to be feeding also on euphausiids but mainly on capelin, north off Iceland (Sigurjónsson, 1995; Stefánsson *et al.* 1997).

1.3.4 Minke whales

Minke whales are considered as one of the cetaceans with the most extensive distribution worldwide and temporal distribution (Martinez & Pastene, 1999; Arnold *et al.* 2005; Robinson & Tetley, 2007); some individuals may be cosmopolitan in temperate waters (MacLeod *et al.* 2004). There are two species recognised including; the Antarctic minke (*Balenoptera bonaerensis*) and common minke whale (*Balaenoptera acustorostrata*) (Arnold *et al.* 2005). The latter one is further classified into subspecies: the North Atlantic minke whale *(B. a. acutorostrata),* the North Pacific minke whale (*B. a. scammoni (= B. a. davidsoni))* and the yet unnamed Dwarf minke whale. Common minke whales spend at least part of their life cycle in low latitudes where the water is clear (tens of meters), in coastal areas (50–100 m) and in the open ocean (Arnold *et al.* 2005). The current population estimated for the North Atlantic stock is thought to be around the 100.000 (Sigurjónsson, 1995). In Iceland, minke whales are the most numerous and well distributed stock of baleen whales (ca. 60.000 animals) (Astthorsson *et al*, 2007). Minke whales diet appears to be highly opportunistic in food selection according to local availability of prey (Robinson & Tetley, 2007). In the northern hemisphere *B. acutorostrata* eats both different fish species and euphausiids (mainly *Meganyctiphanes norvegica*) (Sigurjónsson & Gunnlaugsson, 1990; Haug *et al.* 1995). In Iceland the major prey is capelin (*Mallotus villosus*) followed by herring (*Clupea harengus*) and cod (*Gadus morhua*) (Astthorsson *et al.* 2007; Smout & Lindstrøm, 2007). In the study conducted by Haug *et al.* (1995), for the Northeast Atlantic, the stomach contents of minke whale showed heterogeneity in species composition between various sampled areas. One, presented a dominance of capelin while in the other herring was the most important prey item accompanied by significant amounts of sandeel (*Ammodytes* sp.), cod, haddock (*Melanogrammus aeglefinus*) and saithe (*Pollachius virens*) (Haug *et al.* 1995); suggesting that minke whales diet varies considerably among areas of large temporal variations. Knowledge on minke whale diet in Icelandic waters and adjacent areas have been very limited (Víkingsson *et al.* 2013). The literature suggests nevertheless that their diet has changed in prey composition (Sigurjónsson *et al.* 2000). Sigurjónsson (1995) mentioned that minke whales are perhaps the most extreme opportunistic feeder on the North Atlantic balaenopterid whales and that their diet includes mainly fish and also krill varying greatly between seasons and areas. Recent studies corroborate these findings, suggesting that minke whales have pronounced spatial and temporal variations in their diet as it has been observed in other areas of the North Atlantic (Víkingsson *et al.* 2013). Their diet nonetheless, has change in prey items quantity and quality throughout time (Sigurjónsson *et al.* 2000). Earlier studies (1977-1997) suggested a diet mainly on krill (*Thysanoessa raschii* and *Meganyctiphanes norvegica*) and capelin (Sigurjónsson *et al.* 2000; Stefánsson *et al.* 1997); recent studies (2003–2007) show a tendency for more gadoids, sandeel (*Ammodytes tobianus*) and herring (Víkingsson *et al.* 2013). Other studies suggested the ability of mink whales to switch between different prey according to their seasonal availability and allowing them to readily respond to temporal changes in prey concentrations at different scales (Anderwald *et al.* 2012).

Minke whales have been known to be hunted in Iceland dating back to 1914. They stopped commercial and scientific whaling in 1986 and 1989 respectively. Afterwards scientific whaling resume in 2003 and commercially in 2007 until today (Víkingsson *et al.* 2013). Common minke whales are classified as "Least Concern" according to IUCN red list of threatened species (Reilly *et al.* 2008).

1.4 Whale watching platforms and scientific co-operation

The whale watching industry has grown worldwide (Martin, 2012), contributing to the local economy; additionally, providing the opportunity for thousands of tourist and locals, on a yearly bases, to learn and enjoy the wildlife in that area. Whale watching in Iceland did not begin until 1990 (Fisher, 1998). The town of Húsavík, located in the Northeast of Iceland, lies over Skjálfandi Bay which has one of the most important and recurrent whale watching spotting places of the country (Martin, 2012). North Sailing has been one of the pioneer companies who started whale watching in Húsavík since 1995. Tourism in this area has been increasing since year by year (North sailing, 2013).

It has been known that some of the data collected to study cetaceans has been through scientific research using whale watching as opportunistic platforms. This co-operation has been of great aid to both, whale watching as a business and to have more information for cetacean research. North Sailing works closely with the Húsavík Research Center (University of Iceland) and the Húsavík Whale Museum conducting research on whales and dolphins. Scientists can often be observed on board the boats, taking notes on species presence, behaviour, photo-ID and among others tasks. Additionally, scientist on board can provide with the crew scientific information to tourist.

1.5 Aims

This study includes three main objectives: 1) to determine the habitat preferences of the most common cetacean species in Skjálfandi Bay, 2) to associate these habitat preferences to scenarios of global climate change, and 3) to provide management recommendations for conservation.

2 Materials and Methods

2.1 The Study Area: Skjálfandi Bay
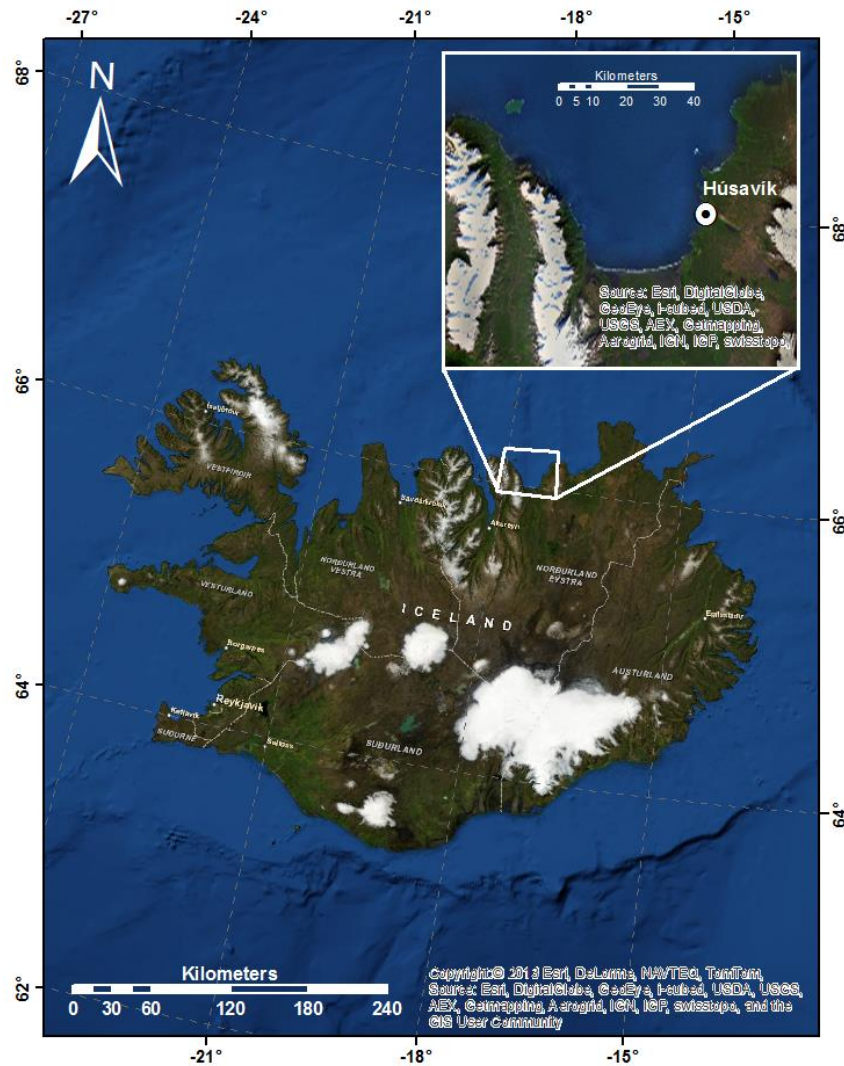
Figure 2-1 Study area Skjálfandi Bay, located in the Northeast of Iceland.

Skjálfandaflói (Skjálfandi bay, N 66° 2' 51.4134", W 17° 20' 37.032"), NE Iceland, is 10 km wide at its southernmost part and approximately 51 km wide at its northernmost part between Gjögurtá and Tjörnnestá (Figure 2.1). Skjálfandi bay is approximately 25 km long and depth is around 220 m (Gislason, 2004). Two large rivers meet the ocean in Skjálfandi bay. On the southwest it is found Skjálfandaflói which is a glacier river and on the southeast stands Laxá í Aðaldal (Gislason, 2004). In Skjálfandi Bay, from the layout of rivers seen in Stefansson and Ólafsson (1991) study, there is the influence of the river Fljotaa.

2.2 Data Collection

Cetacean distribution data in Skjálfandi Bay was gathered from 2004-2012 and for the purposes of this study the months from May to September were processed. These months have been established as the peak feeding season in Icelandic waters. The data was collected using opportunistic platforms (whale watching company "North Sailing"). The research was obtained onboard traditional oak wooden fishing boats Gardar (28m length), Náttfari (23 m length), Bjössi Sör (16.4 m) Knörrinn (15.2 m length), Schooner Haukur (21, 5 m (Hull 15, 6 m) length) and Schooner Hildur (26 m (Hull 18 m) length). Observers were located in the wheelhouse where cetacean sightings and effort data (environmental conditions) were collected during 1486 tours, approximately having three trips per day for each given boat, given the adequate weather conditions although this was variable dependent upon season due to daylight hours.

2.2.1 Cetacean sightings and Effort

 Data was gathered by trained volunteers who collected the information using standardized protocols (see Appendix A). Surveys were conducted by at least two committed marine mammal observers positioned ahead of the bow of the vessel with an angle of 180° (90° per observer); working simultaneously searching for cetaceans and recording at all times data of cetaceans presence. Environmental conditions (e.g. sea state, visibility, weather conditions, wind) were collected every 15 minutes. Information on cetacean presence was recorded by scanning the horizon continuously using the help of binoculars and with naked eyes. The data recorded for both sightings and environmental conditions included information such as date, start and end time of the sighting, vessel, position (GPS coordinates, latitude and longitude), cetacean species (identified to the lowest taxonomic level of certainty when possible), group size and sea state (Beaufort scale). Sea state is the term used to describe the wave formation created by the wind. Walker & Cresswell (2008) have stated that sea state of three or less is when the waves have few or no white caps, generally considered to be the most conductive to whale watching and cetacean surveying anything higher is more likely to miss small species such as harbour porpoises. Therefore, only sea states 3 or less were used in the analysis, sea states exceeding level 3 (4 or higher) were removed from the analysis.

In addition to this data, presence/absence was included in the main data base as 1 and 0 respectively. Absence data was obtained by leaving points of environmental data which were either 5 minutes before or 5 minutes after a cetacean sighting.

For each of the four species, the boat surveys sightings data were examined for monthly and yearly variations in the number of sightings per unit effort (SPUE). SPUE was found calculating the number of sighting per number of tours. SPUE were calculated for the years 2004–2012 and the months May-September to allow comparison between the years and months.

2.3 Data Analysis

2.3.1 Spatial data Analysis

The Icelandic area covered was delimited by 68° N to 61° N in latitude and -25° W to -11° W in longitude. Nine eco-geographic variables (EGVs) were used to determine the habitat preference for the most common cetacean species in the NE of the Icelandic waters. Fixed variables were depth, slope, standard deviation (SD) of slope and distance to coast. The non-fixed variables used were Sea Surface Temperature (SST), SD of SST and Chlorophyll (Chl-*a*), prey Spawning Stock Biomass (SSB) and month.

A depth grid of one arc-minute (approximately 1km2) resolution was obtained from the General Bathymetric Chart of the Oceans (IOC, IHO and BODC (2003) GEBCO Digital Atlas, published on CD-ROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization as part of the General Bathymetric Chart of the Oceans; British Oceanographic Data Centre, Liverpool)). The data was processed with the software ArcGIS 10.1.The depth grid was then converted into 1 km depth grid using ArcGIS with an appropriate conformal projection the Lambert conformal conic before it was used to derive slope using the surface analysis tools with in the Spatial Analysis extension for ArcGIS 10.1. A grid of Standard Deviation (SD) of slope was calculated based on the slope grid and using 5 by 5 cell square centred on an individual grid cell, applying neighbourhood statistics within the Spatial Analysis extension of ArcGIS 10.1. Distance to coast, was in a grid of 1 km resolution (Euclidean distances); was created on a Lambert projection of the European coastline file provided by the General Bathymetric Chart of the oceans (http:www.gebco.net/) centred in this study area using ArcGIS Spatial Analysis tools.

Monthly SST (C°) and Chl-*a* (mg/m^3) data were obtained as monthly packages (May 2004) from satellite data obtained using the data services Giovanni parameters for MODIS 4 km SST and Chl-*a* retrieved from NASA Earth Data website http://disc.sci.gsfc.nasa.gov/giovanni. The data for each month was transformed to regular grids using ArcGIS and re-sampled to a 1km resolution grid. The data points were interpolated with an inverse distance weighting (IDW) technique that preserves local variation between sample points creating raster grids. Grids of SD of SST were calculated based on the monthly SST packages using a 5 by 5 cell square centred on an individual grid cell, applying neighbourhood statistics within the Spatial Analysis extension.

For each presence and absence, based on its GPS coordinates, values of each EGV were extracted using ArcGIS. However, satellite derived information on SST and Chl-*a* was unavailable on some occasions because of cloud cover and/or proximity to coastline.

2.3.2 Statistical Analysis

Statistical analyses were performed using the statistical program "R" 2.15.0. Relationships were determined between environmental variables and cetacean presences/absences using Binomial General Additive Models (GAMS) with a smoothing function and backwards variable selection (were first all the variables were evaluated in one model and then one by one were deleted to determined the best fitted model). To build the models, the presence/absence of each cetacean species were considered as response variable while at

least nine eco-geographical variables were considered as explanatory variables (depth, distance to coast, slope, standard deviation of slope, sea surface temperature (SST), standard deviation of SST, chlorophyll-a, month, and prey Spawning Stock Biomass (SSB). Annual SSB (unit: thousand tonnes) of all available potential prey species were included as an explanatory variable these include cod (*Gadus morhua*), herring (*Clupea harengus*) and capelin (*Mallotus villosus*) retrieved from the Marine Research Institute in Iceland annual reports. The explanatory variables were classified as fixed and non-fixed parameters. Fixed parameters (depth, slope, standard deviation of slope (SD Slope), distance to coast and month) are so-called because f their static nature (do not change over time) while the non-fixed parameters (SST, SSB of cod, capelin and herring) change through time. Data exploration was performed and for explanatory variables showing a correlation of >0.8, only one of the variables was retained in the analysis. GAMS will highlight the values of the environmental variables that are more related to cetacean presence and will indicate the nature (e.g. positive, negative, linear, and non-linear) of this relationship. The GAMs are particularly good at identifying and describing nonlinear relationships that are more typical than linear relationships in ecology (Oksane & Minchin, 2002) and are an appropriate technique to model species with complex distribution and behaviour patterns relative to environmental variables (Torres *et al.* 2008) . The Akaike's Information Criterion (AIC) was used within R to select the optimal model among all possible environmental variable combinations; the model which best fitted the observed data was based on the lowest AIC, ensuring that all were individually statistically significant. GAMs have been used in previous studies to detect significant nonlinear relationship between cetacean distribution and environmental variables (MacLeod *et al.* 2005; Torres *et al.* 2008). Validation of each model was done using Cooks Distance, commonly used to estimate the influence of the variables.

3 Results

3.1 Data Collection

The data presented here were collected between May and September (2004–2012). The number of tours and sightings per year varied depending on weather conditions and are summarized in Table 3.1. Odontocetes, white-beaked dolphins were seen in 329 tours and sighted 461 (Table. 3.1) and harbour porpoise was observed in 173 tours and had 236 sightings. On the other hand, humpback whales were seen in 449 tours and sighted 771 times while minke whale was observed in 535 tours and sighted 856 times (Table 3.1). For analysis, sightings that were recorded within 10 minutes of each other were considered as the same event in order to reduce duplication. Therefore, in total 2264 sightings (Table 3.1) were included in the analysis from 1486 tours.

Table 3-1 Number of tours and sightings for white-beaked dolphin, harbour porpoise, humpback and minke whales from 2004-2012.

	White-beaked dolphin		Harbour porpoise		Humpback whale		Minke whale	
Year	Tours	Sightings	Tours	Sightings	Tours	Sightings	Tours	Sightings
2004	12	16	2	2	5	7	25	46
2005	47	59	8	8	12	14	41	58
2006	29	40	11	13	65	95	56	88
2007	35	45	13	13	74	97	60	82
2008	23	33	24	35	47	65	50	67
2009	24	30	21	23	64	101	71	117
2010	62	102	52	86	29	31	122	253
2011	32	45	13	22	46	67	33	42
2012	65	91	29	34	107	234	77	103
Total	329	461	173	236	449	711	535	856

Tables 3.2 and 3.3. described the sighting frequency for each species observed over a period of time. In the present study, the duration time covers the duration of the tours where each species was sighted. Monthly SPUE shows, not much variability in SPUE for white-beaked dolphins and humpback whales (Table. 3.2). On the other hand, harbour porpoise and minke whales seem to have a slightly variability between months (Table 3.2)

Table 3-2 Sighting per unit effort (SPUE) for each species throughout months May to September covering years from 2004 to 2012. SPUE=Sightings/Tours-hours

	SPUE			
Month	White-beaked dolphin	Harbour porpoise	Humpback whale	Minke whale
May	0.46	0.56	0.51	0.55
June	0.46	0.43	0.52	0.58
July	0.48	0.40	0.57	0.55
August	0.46	0.44	0.50	0.48
September	0.42	0.33	0.58	0.43

Annual SPUE was obtained by the number of sightings and the total duration of tours throughout the period 2004-2012. Table 3.3. presents a visual general information of the frequency each species was sighted during the years 2004-2012. Species with a slightly high variability in the frequency of sightings during the study period may include humpback and minke whales (Table 3.3.)

Table 3-3 Sightings per unit effort (SPUE) for each species from 200-4-2012. SPUE=Sightings/Tour-hrs

	SPUE			
Year	White-beaked dolphin	Harbour porpoise	Humpback whale	Minke whale
2004	0.44	0.33	0.47	0.61
2005	0.42	0.33	0.39	0.47
2006	0.46	0.39	0.49	0.52
2007	0.43	0.33	0.44	0.46
2008	0.48	0.49	0.46	0.45
2009	0.42	0.37	0.53	0.55
2010	0.55	0.55	0.36	0.69
2011	0.47	0.56	0.49	0.42
2012	0.47	0.39	0.73	0.45

3.2 Binomial Generalized Additive Models

The data was analyzed compiling all the years together (2004–2012). In the following figures (Figs. 3.2– 3.4) the y-axis represents the partial fit of each covariant on the scale of the link function versus x-axis link-scale spline smooth. The dotted lines represent 95% point-wise intervals based on GAM standard errors and the mass of fine ticks on the x-axis (a 'rug' plot) indicating observations.

The best model for white beaked dolphins explained 9.95 % of the deviance and included the following significant parameters: distance to coast, slope, standard deviation of slope, SST, standard deviation of SST, chlorophyll-a, month and prey abundance from cod and capelin spawning stock biomass (SSB). All variables p-values are presented in Table 3.2.

					EGV's p - values						
Species	Depth	Distance to coast	Slope	SD_Slope	SST	SD_SST	CHl-a	Cod SSB	Capelin SSB	Herring SSB	Month
White-beaked dolphin	N/A	7.07e-06 ***	6.93e-10 ***	0.000290 ***	0.000574 ***	0.004889 **	0.012819 *	2.30e-11 ***	1.22e-06 ***	N/A	8.221e-09 ***
Harbour porpoise	N/A	0.000948 ***	0.049444 *	0.000818 ***	0.036315 *	X	0.039592 *	2.91e-07 ***	0.030253 *	N/A	3.091e-05 ***
Humpback Whale	< 2e-16 ***	N/A	N/A	2.97e-06 ***	7.69e-06 ***	0.000541 ***	0.000235 ***	N/A	0.004708 **	< 2e-16 ***	8.792e-12 ***
Minke whale	7.27e-13 ***	N/A	0.083682 .	0,130962	0.000847 ***	0.043219 *	5.79e-07 ***	1.07e-07 ***	2.38e-06 ***	8.07e-09 ***	X

Table 3-4 EGV'a p-values from GAMs for all fours species.

Higher presence of white-beaked dolphins was generally found over a large range of distances from land, with a higher relative peak from the 5–10 km (Fig. 3.1. a). Additionally, it was found that the greater the variability in seabed steepness and angle the higher the presence of white-beaked dolphins (Fig 3.1. b and c). The range of SST values differs greatly across the SST temporal scale selected, higher presence of white-beaked dolphins were observed in temperatures below 4 °C and in temperatures higher than 8°C (Fig. 3.1. d). The standard deviation of temperature is a proxy to the currents and water circulation, and dolphins' encounters seem to have a slightly positive relationship at 0.5 and peaks again at approximately 1.7 (Fig. 3.1 e). The presence of white-beaked dolphin was higher when chlorophyll-a concentration levels were lower (0.2–1.3 mg/m^3) (Fig. 3.1. f). Prey abundance of cod and capelin (i.e.SSB) was also significant; there seems to be a positive relationship between both cod SSB (ranging from 225000 and 480000 tonnes) and capelin SSB (ranging from 400000 – > 600000 tonnes) and white-beaked dolphin occurrences (Fig. 3.1. g and h). Additionally, during the feeding season, presence of white-beaked dolphins seem to be higher in May, June and July (Fig. 3.1).

The best model for harbour porpoise explained 12.6 % of the deviance and included the following significant parameters: distance to coast, slope, standard deviation of slope, SST, chlorophyll-a, month and prey abundance from cod and capelin SSB. Table 3.2. shows the p vales of the variables in this model.

Harbour porpoise presence was generally found over a large range of distances from land; presence peaked at 5–10 km distance. (Fig. 3.2 a). Additionally, it was found that the greater the variability in seabed steepness and angle, the higher the presence of harbour porpoise (Fig. 3.2 b and c). The range of SST values differs greatly across the SST temporal scales selected, harbour porpoise were generally observed between 2°–10 °C range with higher numbers at 7° – 10°C (Fig. 3.2 d). The presence of harbour porpoise was higher when chlorophyll concentration was lower (1–2.5 mg/m^3). Harbour porpoise presence was positively influenced as well by the prey abundance of capelin although, when capelin reached 400000 tonnes almost a flat linear relationship was observed (Fig. 3.2 g). Meanwhile cod SSB (between the 260000 and 360000 tonnes) had a positive influence for porpoises presence (Fig. 3.2 h). None of the months had a positive influence in the presence of harbour porpoise (Fig. 3.2 i).
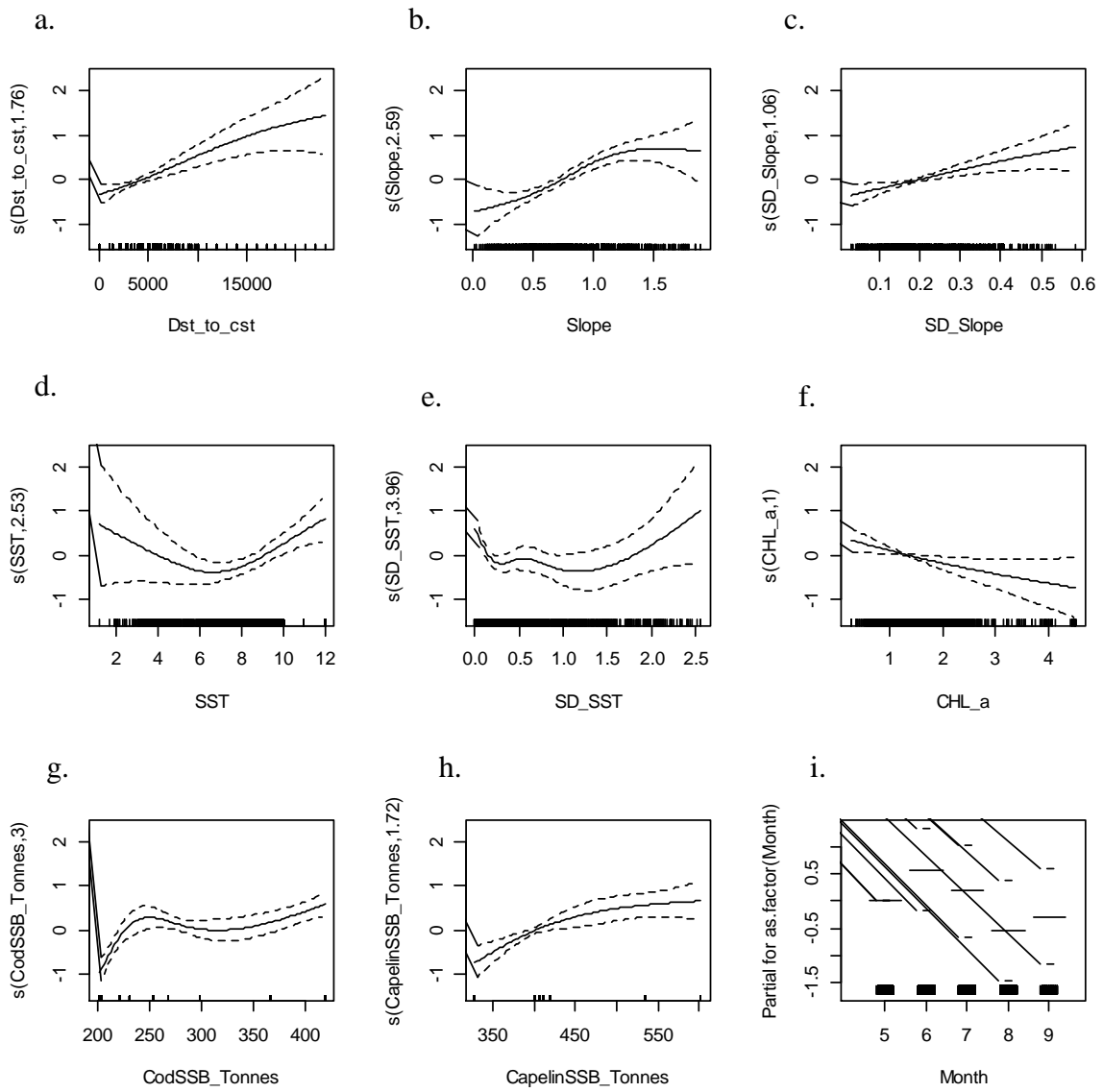
Figure 3-1 **Relationships between visual detections of white-beaked dolphin groups and (a)distance to coast (d.f. = 1.76), (b) slope (d.f. = 2.59), (c) standard deviation of slope (d.f.=1.06), (d) sea surface temperature (SST) (d.f.=2.53), (e)standard deviation of SST (d.f.=3.96), (f)chlorophyll-a (d.f.=1), (g) cod SSB (d.f =3) and (h)capelin SSB (d.f =1.72) . The estimated 95% confidence intervals are shown by the dotted lines around the smoother liners. (*An SSB tonnes value represents thousands of tonnes)**

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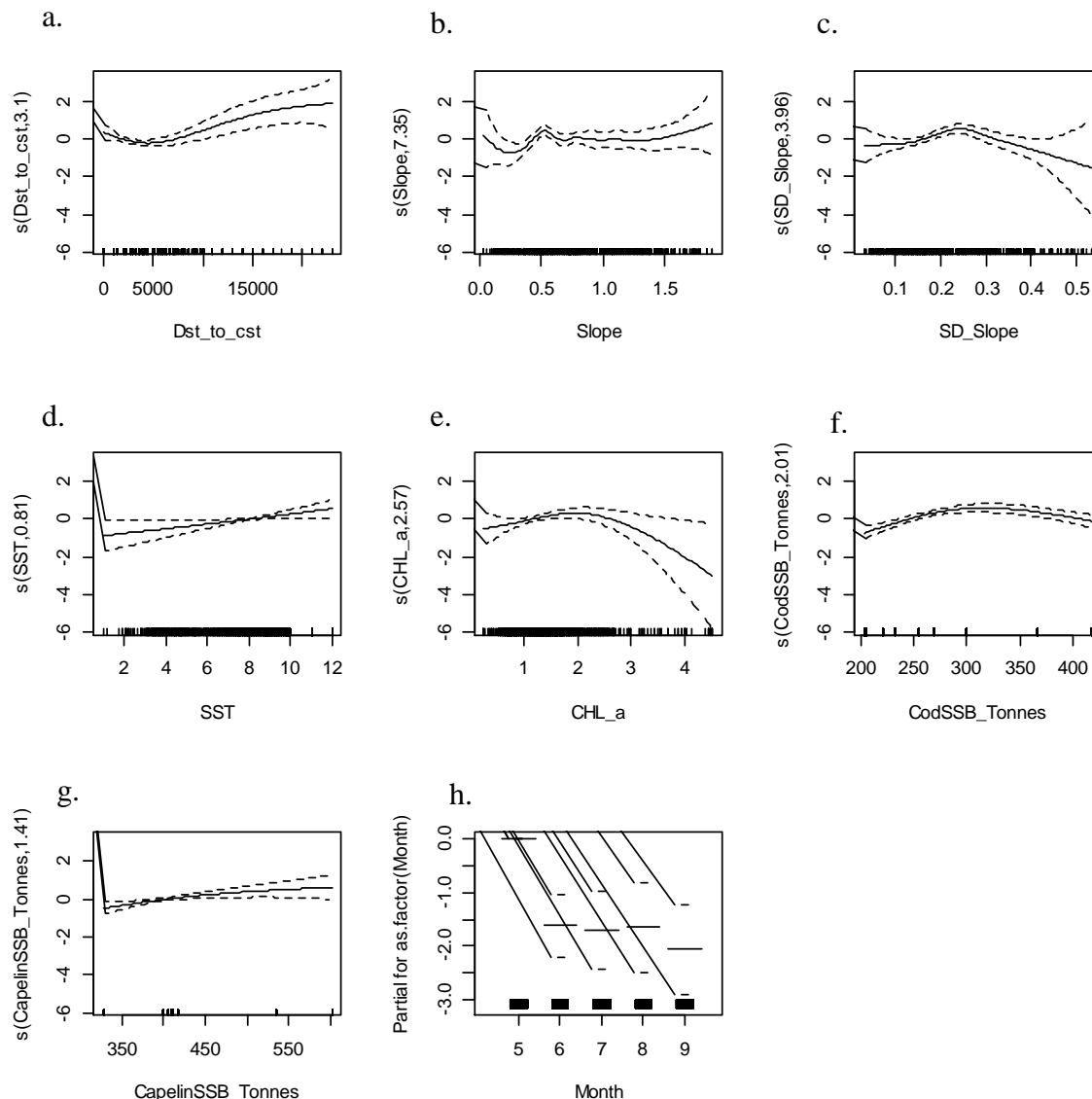
Figure 3-2 Relationship between visual detection of harbour porpoises and (a) distance to coast (d.f=3.1), (b) slope (d.f=7.35), (c) standard deviation of slope (d.f=3.96), (d) sea surface temperature (d.f=0.81), (e) chlorophyll-a (d.f.=2.57), (f) cod SSB (d.f =2.01) and (g) capelin SSB (d.f =1.41) . The estimated 95% confidence intervals are shown by the dotted lines around the smoother liners. (*An SSB tonnes value represents thousands of tonnes)

The best model for humpback whales explained 14.3 % of deviance and included the following significant parameters: depth, standard deviation of slope, SST, standard deviation of SST, chlorophyll-*a*, month and prey abundance from herring and capelin SSB. Parameters p values are presented in Table 3.2.

Humpback whale presence was generally found over a large range of depths with a relatively higher peak in waters between 50-100 m depth and fewer sightings in deeper waters (100–250 m) (Fig. 3.2.3. a). Additionally, it was found that the greater the variability in seabed, the higher the presence humpback whales (Fig 3.2.3. b and c). The range of SST values differs greatly across the SST temporal scales selected; humpback whales were generally observed between 1°– 10°C with higher numbers at 1°– 6.5°C (Fig.

3.3. d). The standard deviation of sea surface temperature has a slightly positive influence in humpback presence when its values range between 0.5° and 1.5 (Fig. 3.3. e). The presence of humpback whale was higher when chlorophyll-*a* concentrations were high (1.8–3.2 mg/m^3) (Fig. 3.3. f). Humpback whale sightings were related to herring abundance. Herring SSB had more influence in the sightings of humpback whale especially when SSB reaches 600000 tonnes (Fig 3.3 f). On the other hand, capelin spawning stock biomass did not have much influence in humpback whale presence (Fig 3.3. g). The variable month had positive influence in the occurrences of humpback whales with more sightings being recorded in June, July, August and September. There was a negative effect found with the month of May. (Fig 3.3. h).
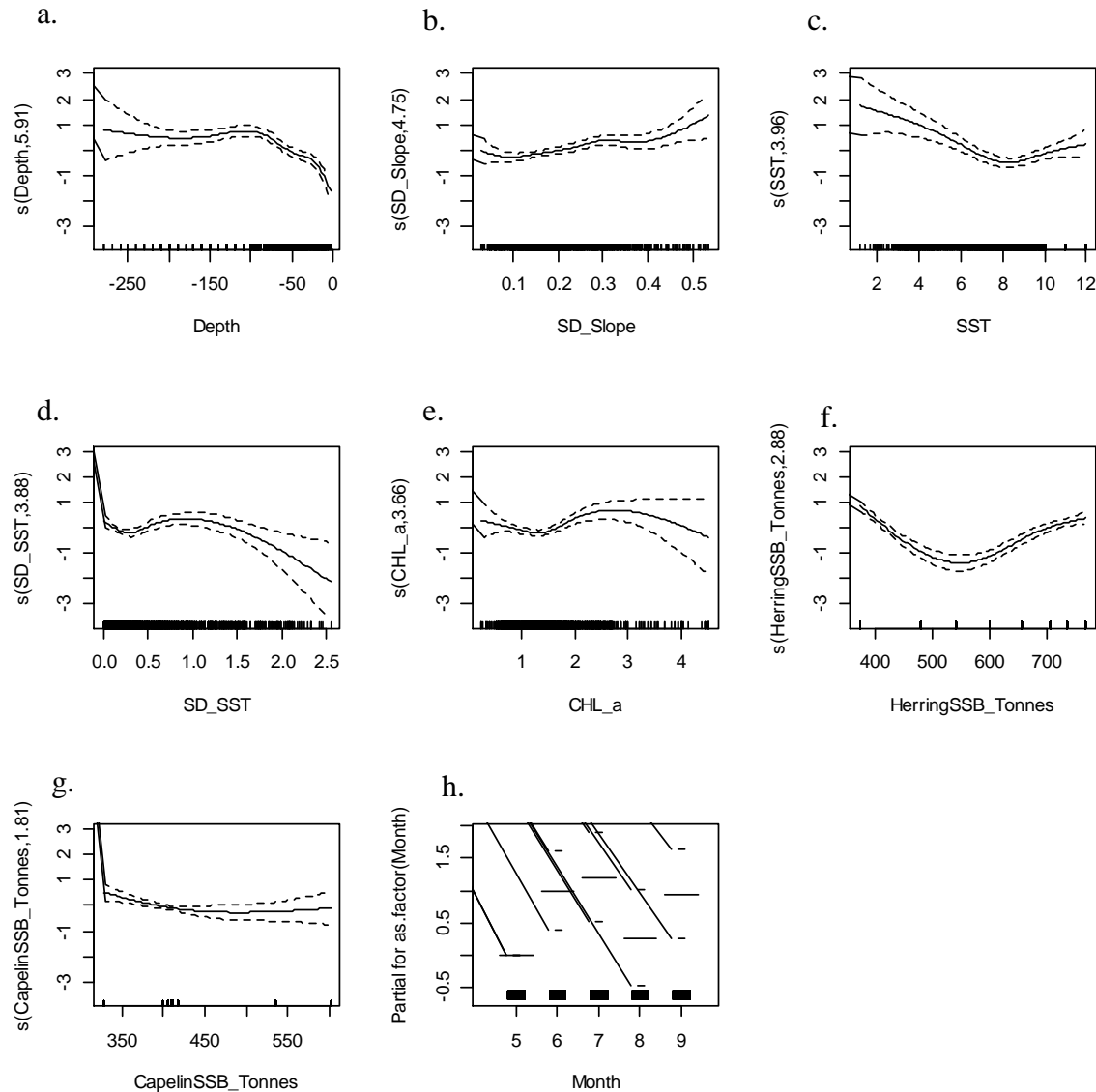
Figure 3-3 Relationships between visual detections of humpback whale individuals and (a) depth (d.f. = 5.91), (b) standard deviation of slope (d,f.=4.75), (c) sea surface temperature (SST) (d.f.=3.96), (d) standard deviation of SST (d.f.=3.88), (e)chlorophyll-a (d.f.=3.66), (f) herring SSB (d.f.=2.88) and (g) capelin SSB (d.f.=1.81). The estimated 95% confidence intervals are shown by the dotted lines around the smoother liners. (*An SSB tonnes value represents thousands of tonnes)

The best model for minke whales explained 7.34 % of the deviance and included the following significant parameters: depth, SST, standard deviation of SST, chlorophyll-*a* and prey abundance from herring and capelin SSB (p values presented in Table 3.2)

Minke whale presence peaked over two distinct ranges of depth; one peak at waters between 50–100 m depth a small peak in deeper waters (100–250 m) (Fig. 3.4. a). Additionally, the range of SST values differs greatly across the SST temporal scales selected, minke whales were generally observed between 1.5°–12°C with higher numbers at 2°–10°C (Fig 3.4. b).

On the other hand, there seem to be no effect of SST standard deviation and the occurrences of minke whales (Fig. 3.4. c). The presence of minke whale was higher when chlorophyll-*a* concentrations were high (1.5–5 mg/m^3) (Fig 3.4. d).

Slope and standard deviation of slope improved the model however they were not significant (p values presented in Table 3.2). Data analysis indicates cod, capelin and herring SSB had different effects over minke whale presence (Fig. 3.4. e, f and g). Whale presence was higher when cod SSB ranged from 200000 and 270000 tonnes and lower at higher values (Fig. 3.4. e). There was a positive effect of capelin SSB in minke whale presence until SSB reaches about 400000 tonnes when the relationship starts to be negative (Fig. 3.4. f). Results also suggest a negative relationship with herring SSB (Fig. 3.4 g).
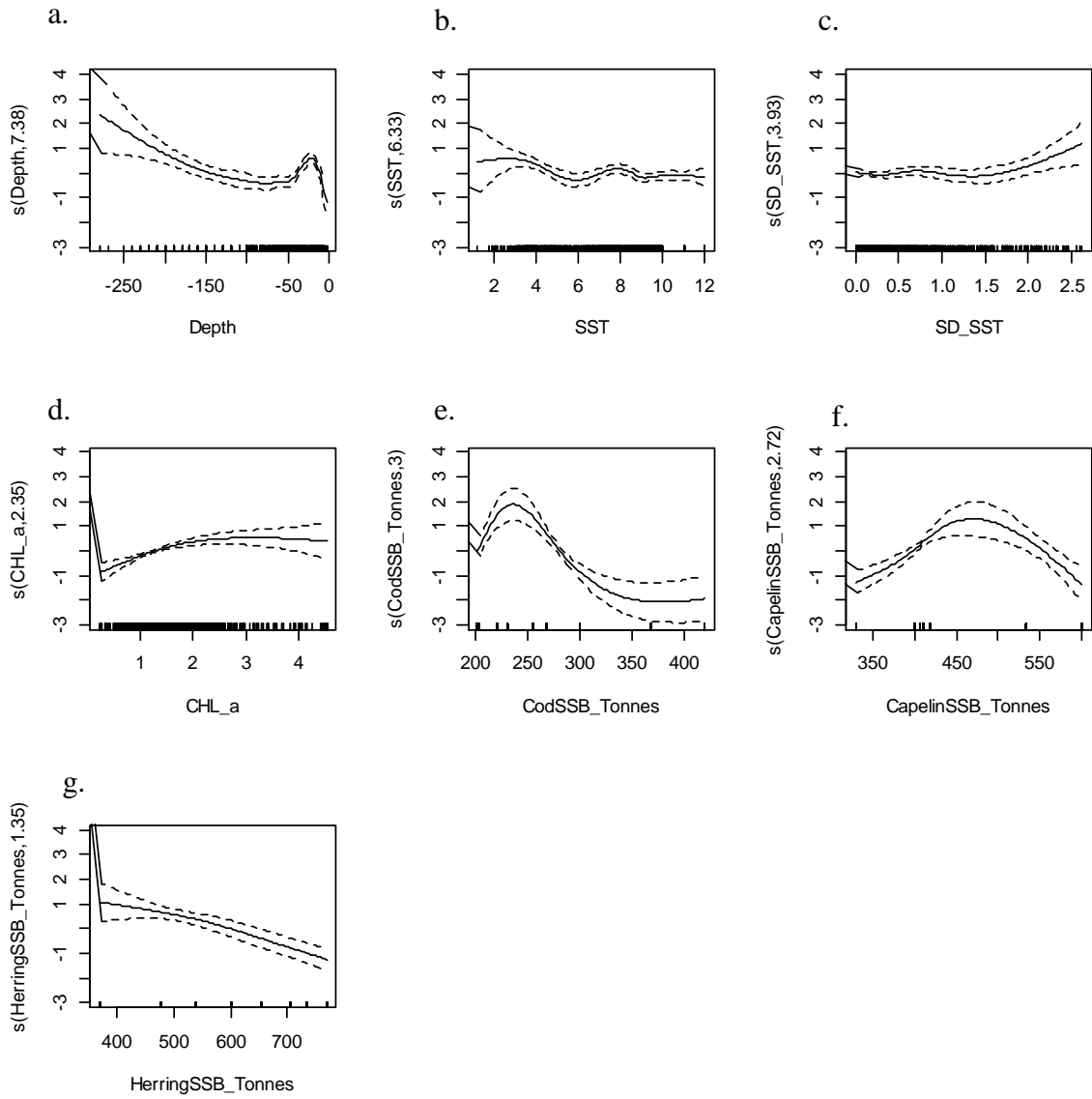
Figure 3-4 Relationships between visual detections of minke whale individuals and (a) depth (d.f. = 7.38), (b) sea surface temperature (SST) (d.f.=6.33), (c) standard deviation of SST (d.f.=3.93) and d) chlorophyll-a (d.f.=2.35), (e) cod SSB (d.f=3), (f) capelin SSB (d.f.=2.72) and (g)herring SSB (d.f.=1.35). The estimated 95% confidence intervals are shown by the dotted lines around the smoother liners. (*An SSB tonnes value represents thousands of tonnes)

3.3 Annual Average Temperatures
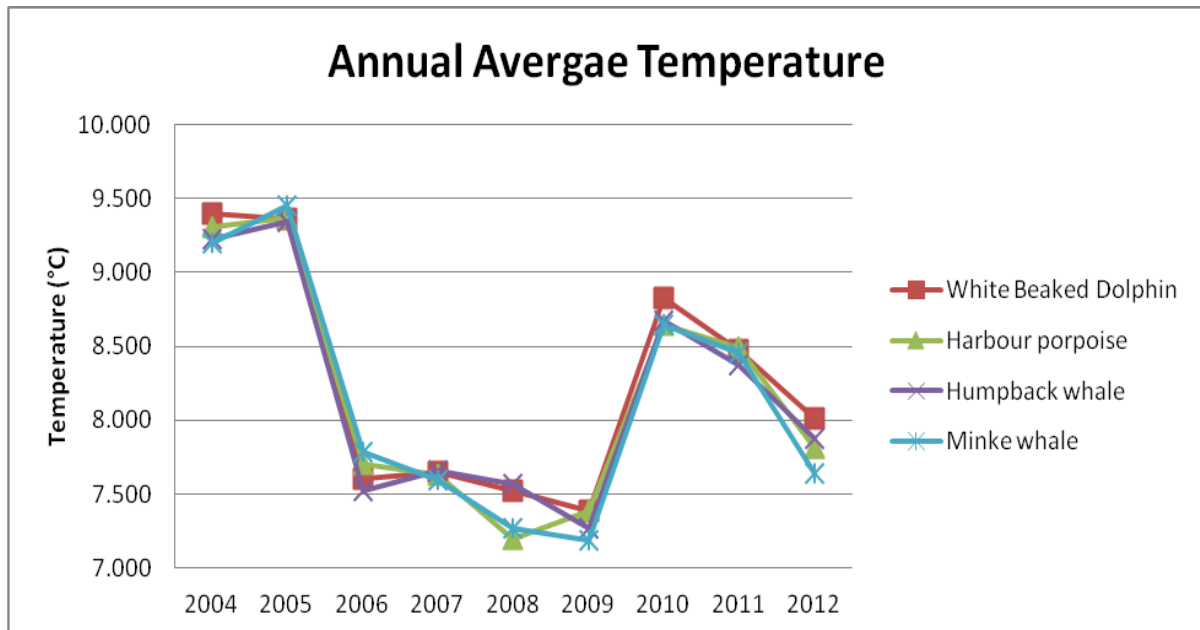
Figure 3-5 Annual Average Temperature (˚C) between the years 2004-2012. Color lines represent the following species: red- white-beaked dolphin; green - harbour porpoise; purple – humpback whale and blue – minke whale

Annual average temperature readings show similar annual values for the four species. There seems to be a sharp decrease in temperature from the year 2005 to 2006 with values from (9.2˚–7.5˚C) and sharp increase in temperature once again from 2009 to 2010 (7.2˚–~8.5˚C) (Fig. 2.1.). There also seem to be an overlap in areas of same temperature between white-beaked dolphins and minke whales while there was an overlap between harbour porpoise and humpback whale during the year 2008.

4 Discussion

4.1 Environmental variables and global climate change

This study is going to discuss, explain and refer to these models as looking at the recent 'niche' of our 4 species of interest and whenever relevant put them into perspective in relation to current and future climate change. This assessment can give us an insight on plausible effects that may cause these species' re-distribution in the north of Iceland and/or other direct and indirect effects.

The IPCC and other climate reports (US EPA) have assessed that the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen and the concentrations of greenhouse gases have increased (Summary IPCC 2013). The ocean will continue to warm up during the 21st century; heat will penetrate from the surface to the deep ocean and affect ocean circulation (Summary IPCC 2013). Having this in mind, here it will be discuss how some of this conclusion will affect the habitat preferences of the species presented in this study.

In this study the habitat preference of white-beaked dolphins, harbour porpoises, humpback and minke whales have been established by models that best described their habitat use from 2004-2012 in Icelandic waters, specifically in their feeding grounds in Skjálfandi Bay.

Warmer Ocean and SST

SST was significant for each of the four species-specific models, describing particular temperature ranges. As mentioned above, temperature ranges can affect directly the distribution of marine mammals restraining them to certain parts of the world (MacLeod C, 2009).

The results showed that white-beaked dolphins presence was higher at temperatures lower than 4˚C and higher than 8˚C. Encounter of humpback whale showed two peaks one higher between 2˚–7˚C and one at around 9˚C and negative effect in waters around 8˚C. Meanwhile, harbour porpoises seem to prefer warmer temperatures (6˚ –10˚ C) and minke whales do not show a clear tendency of temperature range. This study included the standard deviation of SST which can give as a proxy of currents and the influence for each species.

The fours species in the present study show different temperature preferences; a few possibilities have been hypothesized explaining these differentiations. First of all, could be a result of a direct relationship between water temperature and the species thermal limits; secondly, species' range is determined by preferred prey distribution, which in turn, is directly affected by temperature (Learmonth et al. 2006). Lastly, variation in water temperature affects the outcome of competitive interactions between ecologically similar species and species 'niche' (MacLeod et al. 2008). For instance, harbour porpoises and white-beaked dolphins are cold and warm water limited white humpback and minke whales are cosmopolitan (MacLeod et al. 2009) .

These results show similar temperature range with other studies addressing white-beaked and humpback whale distribution; for example, the temperature range from 4˚ –11.5˚C was also found for white-beaked dolphins in Skjálfandi bay between the years 2004–2007 (Cecchetti, 2006; Cooper, 2007) and in the UK and Irish waters white–beaked dolphins preferred SST below 13˚C (MacLeod, 2008). The study of Paxton et al. (2009), suggests that humpback whales congregate in waters between 6–8˚C similar to the general temperature range that was found in the present study. Around the British Columbia coast, humpback whales encounters rates were higher between 8 and 11˚C (Dalla Rosa et al, 2012). Humpback and minke whales are found globally and as a result they have several temperature ranges; they are seasonal and migrate between their feeding and breeding grounds, making them more resilient to sharp temperature changes (Martinez and Pastene 1999).

On the other hand, studies in the western Bay of Fundy Canada, mentioned that harbour porpoises encounter temperature ranges from 2 to 15°C with an average 8°C (Yasui & Gaskin, 2012) where in Icelandic costal shelf area it is clear that the higher the temperature the higher the probability of harbour porpoise presence.

Since whales and dolphins distribution ranges can depend on their ability to cope with different temperatures predicted increased of global SST by the IPCC (increase of between 0.6° to 2°C in the top one hundred meters and about 0.3 to 0.6 at a depth of about 1000 m) by the beginning of the 21st century, suggest potential changes in their distribution. Warming could force species to migrate to higher latitudes where temperatures are more optimal to their survival, as it has been mention by MacLeod (2005). A couple of examples related to that involved the decline in occurrences from cool water species such as white-beaked dolphins, long-finned pilot whale (*Globicephala melas*), northern bottlenose whale (*Hyperoodon ampullatus)* and Sowerby's beaked whale (*Mesoplodon bidens*) between the 1990s to 2000s in the northwest of Scotland; while warmer water species such as Curvier's beaked whale (*Ziphius cavirostris*) have expanded northwards in this region. In Icelandic waters we can then anticipate higher competition among species, if there is already a displacement of species from Scotland moving towards northern waters. If the species then cannot keep moving towards colder waters, and are already at the edge of the range their survival may be negatively affected. The variability observed in this study does not affect whales and dolphins since the changes in temperature are still within the adequate temperature ranges for each species.

Nonetheless, while the variability of SST may not affect directly the distribution of cetaceans, yet, other taxa such as fish species may be impacting by SST changes and may be having an indirect effect on whales and dolphins. In Icelandic waters is not likely that cetaceans species will migrate to other areas to fit their preferred temperature ranges. However, it can be expected competition among new species that are making their way higher latitudes.

As mentioned in the introduction, the north and eastern areas in Iceland are influenced by Atlantic, Arctic and Polar water masses subjected to inter-annual variations. These water masses form a cyclonic eddy that follows the Icelandic shelf and continues eastwards along the north coast than in warm years reaches shelf areas east of Iceland. In addition, there are cold currents offshore to the northwest, north and east of Iceland (Valdimarsson & Malmberg, 1999; Jónsson & Valdimarsson, 2012; Gudmunsson, 1998; Malmberg & Valdimarsson, 2003; Jónsson & Valdimarsson, 2005). Off the south coast, however, where Atlantic water predominates, yearly variations are normally less conspicuous (Stefánsson 1970). In warm years a strong influx of Atlantic water from the southwest enters the shelf area north of Iceland in late spring and can be traced all along the north coast and even south of Langanes. Conversely, in cold years, only a weak influx of Atlantic water reaches the Kogur section, whereas no Atlantic influence is observed farther east in north Icelandic area. As an index of the variability in the volume of Atlantic water flowing into the region north of Iceland, Ólafsson (1999) computed the deviations from the mean temperature and salinity of the uppermost 200 m on the Siglunes section. The authors found marked inter-annual variations, which may be summarized as follows: a) in the period prior to 1965 the temperature was comparatively high and the Atlantic influx large; b) the period 1965-1971 was characterized by a negligible inflow of Atlantic water but by pronounced polar influence over the whole north Icelandic area; c) in the years since 1972 warm and cold

years have alternated. In this study, difference between annual temperatures averages were found; especially dropping temperature from 2006 to 2009.

Variations in hydrographical conditions, in particular salinity, greatly affect vertical mixing in the north Icelandic area. Thus in cold years with appreciable admixture of polar water, a strong pycnocline renewal prevents by mixing from below. On the other hand, in years with strong Atlantic influx, and consequently relatively high near-surface salinities, vertical mixing is favored (Jónsson & Valdimarsson, 2005). This variation in stratification explains the large differences between years in near-surface concentrations of dissolved nutrients in spring and summer (Stefansson & Ólafsson, 1991). In Skjálfandi Bay an important factor influencing the mixing of the water column is the wind. The sea in Skjálfandi bay changes from being cold, relatively even in salinity and mixed from the surface to the bottom to being stratified and there is a considerable impact of the freshwater. In this study, the SD of SST was used as a proxy for current within Skjálfandi Bay. It was found that lower SD SST influence humpback whale encounters while higher SD SST are related to occurrences of white- beaked dolphins. No relationship was found between SD SST and minke whales presence. Studies done along the coast of British Columbia suggest that humpback whales encounters are associated in part with distances to sea surface temperature fronts (Dalla Rosa *et al*, 2012). It has been suggested that fronts enhanced horizontal gradients in temperatures, salinity and density among others, often leading to enhanced phytoplankton, zooplankton and fish biomass (Cullen *et al*, 2002; Dalla Rosa *et al.* 2012).

Based on the results shown here, the studied species can be separated in two groups based on similar preferences for shelf tendency (distance to coast or water depth) and slope one group is formed by white-beaked dolphins and harbour porpoises (odontocetes) and a second one by humpback and minke whale (baleen). Occurrences of white-beaked dolphins and harbour porpoise seem to be driven more from the EGV's distance to coast, seabed steepness and rugosity or angle (topography variability). Both species have a higher presence in distances from the coast that range 5–10 km although both have few sightings in distances of more than 10 km. Presence of harbour porpoise has a positive relationship with the angle of the seabed. For white beaked dolphins it is observed that the greater the variability in seabed steepness and angle, the higher their presences. Similar studies done in Skjálfandi bay have shown that white beaked dolphins had a wide spatial distribution with encounters both near the shoreline and further out. However, sightings appear to be associated with shallow waters and steeper slopes (Cecchetti, 2006). Other studies west of Scotland, found that porpoises were primary related to topographic variables where they preferred distance to coast of <14.6 km as well as shallower waters less than 200 m (MacLeod *et al.* 2007). The preference for the steeper areas and higher variability in seabed slope suggested the importance of such physical variable in odontocetes habitat choice within Skjálfandi Bay. This positive correlation has been thought to be associated with the importance of sea bottom topography in food distribution and availability (Hastie *et al.* 2004). Skjálfandi Bay is characterized by a wide area of steep slope extending along the coast and following the bay's shape. It is likely that in areas closer to the coast with steep sea floor, ocean dynamics features such as upwelling and vertical mixing contribute to the relocation of nutrients in the water column, promoting primary production and bottom up food web (Cecchetti, 2006). White-beaked dolphins can benefit from those dynamics aggregating in nutrient-reach areas (Allen *et al.* 2001); additionally, it has been suggested that seamount might be implicated in prey concentration and, thus, food supply lessen their energy expenditure required to feed (Cooper, 2007). It has been suggested that harbour porpoises use the sea bottom and the sea surface as back walls when they are chasing fish

(Bjørge & Tolley, 2009; Hamazaki, 2002). Additionally, agreement with our results, a positive relationship between cetacean presence and steeper slopes was found in dolphin species such as short-beaked dolphin, striped dolphin, bottlenose dolphin, Risso's dolphin, white-beaked dolphin (Cecchetti, 2006).

On the other hand, humpback and minke whales appeared to be strongly associated with bathymetry. Presences of both species were higher at depths between 50 to 100 m and lower at depths from 100 to 250 m depth. On the contrary, previous studies in Canadian waters suggested that the maximum number of minke whale observations occurred in shallow waters at depths between 20–40 m and that there were other geomorphology parameters such as substrate type and hydrodynamic conditions that better explained minke whales aggregation patterns in specific areas (Naud *et al.* 2003). The study presented here is supported by other studies in the Bay of Fundy and Isle of Mull in Scotland where they showed positive a linear relationship between minke whale presence and increasing depth and a non-linear relationship with increasing benthic slopes (Ingram *et al.* 2007; MacLeod *et al.* 2004). MacLeod *et al.* (2004) suggested that minke whales preference for deeper waters was related to the spatial and temporal location of their prey, in that case, herring. Additionally, mike whales preferred shallow waters no deeper than 200 m in the largest submarine canyon off the coast of eastern Canada (Hooker *et al.* 1999). Humpback and fin whales of the north Atlantic shelves were sighted in waters of SST 17–18˚C and over depths less than 400 m in the northern coastal side of the mid-Atlantic shelf regions; in addition showed a habitat shifts for humpback whales (Hamazaki, 2002). It was suggested that the higher encounter rates of humpback whales in shelf waters was related to the horizontal distribution of prey, but may have been also influenced by the energetic cost of diving and foraging efficiency (Dallas Rosa *et al.* 2012). Oviedo and Solis (2008) examined also the relationship between water depth and ocean floor slope with humpback whales distribution in critical breeding areas near Osa Peninsula, Costa Rica. They found that both eco-geographical variables determined habitat requirements and were an aid to locate the key breeding and nursing habitats of this species within the continental shelf domains.

Geomorphology is determined by structural geology, topography, sediment type and hydrodynamic conditions. Additionally, bottom topography plays a determinant role on the oceanographic processes that lead to enhanced productivity in coastal regions (Dalla Rosa *et al*, 2012). Because geomorphology is an integral part of the habitat and has a direct impact on prey distribution, it affects whales when foraging for prey (Naud *et al.* 2003). For example, the simulated krill aggregation areas are associated with three processes (tidal interactions with bathymetry, wind-driven upwelling and mean circulation (Sourisseau *et al.* 2006).

Cetacean distribution depends not only on environmental parameters but their distribution and abundance on feeding grounds depend on the distribution of their prey and predator-prey interactions (Naud *et al.* 2003; MacLeod *et al.* 2004; MacLeod *et al.* 2007). Prey is therefore one of the drivers in the distribution, especially important in this study that relates to cetacean feeding areas. Therefore, changes in prey distribution might drive switchs in prey preferences or cetacean displacements following their preferred prey. Climate also plays an important role in the distribution and recruitment of the major fish species (Hunt *et al.* 2005).

It has been suggested that physiographic and hydrographic features alone may not fully explain cetacean distribution. Hydrographic features influence prey availability which explains better the distribution of cetaceans (Davis *et al.* 2002). The results from the models shown in the present study indicate that, in general, prey species SSB was significantly important for the encounters of the four species we focussed on. In this study, the information of SSB for each of the prey items (cod, capelin and herring) used in the models was gathered per year, thus year was not used as a temporal variable but instead months were used. White-beaked dolphins and harbour porpoises show a preference for similar prey items (cod and capelin). Thus, it can be expected an overlap in their habitat preferences between them. White beaked dolphins occurrences were higher when capelin SSB was higher than 400000 tonnes while SSB of cod was had a positive effect when it reached values of 225000 tonnes. Porpoise's habitat selection was more influenced by cod SSB than by capelin SSB. White beaked dolphins are known to be a year-round resident species in the study area although might show spatial and temporal fluctuations in their habitat range. White-beaked dolphins are common in different open areas around Iceland and are sighted through the entire summer around Icelandic coasts, especially at one of their hot spots, Skjálfandi Bay. Prey, at individual sites will vary in abundance throughout a season and between years; likely species regularly return to a number of closes by sites with occasional exploration at greater distances. Thus, the duration of remained at, and, an inclination to return to each site relates to relative prey density (Stevick *el al.* 2006). Cod has previously been recorded in UK waters as part of white-beaked dolphin's diet, representing 11% of the total stomach contents by weight (Canning *et al.* 2008). In Icelandic waters there has been few studies mentioning cod as one of white-beaked dolphin main prey based on stomach contents (Rasmussen, 2004, Víkingsson and Ólafsdóttir, 2004). Correlation between harbour porpoises presence and their prey could be affected by different time and spatial scales as was for white-beaked dolphin. A previous study shows that presence of porpoises was also strongly positively correlated with capelin and that *Phocoena phocoena* usually forages near the sea bottom in waters less than 200 m depth and close to the surface (MacLeod *et al*, 2007). In addition, harbour porpoises experience different ecological habitats during the year along the Scandinavian coast, adapting their feeding habits to local available prey, without performing extensive migrations (Fontaine *et al.* 2007). Consequently, the significance of each prey species in the diet of harbour porpoises may change both spatially and temporally according to the availability of prey as it will most likely happened with other marine mammals.

On the other hand, minke and humpback whales also share some potential prey (herring and capelin). However, minke whales are known to be more generalist and thus cod was also integrated in the model (Astthorsson *et al.* 2007; Smout & Lindstrøm, 2007). Interestingly and despite its classification as generalist, the three prey species investigated here show a significant relationship with minke whale presence. The presence of the whales was higher at cod SSB of 200000–275000 tonnes, capelin SSB 425000 to 550000 tonnes, and herring SSB of up to 500000 tonnes. Even though visually there seem to be not much relationship between prey and humpback whale encounters and they were statistically non significant, their inclusion improved model performance since when each prey was removed from the model, the AIC became larger especially when removing herring. In addition, it appears that the summer distribution of humpback whales is highly variable around Iceland, perhaps in response to variation in the distribution of pelagic prey (Pike *et al.* 2008). It has been suggested that changes in minke whales distribution may be a response to changes in prey availability even though their diet is flexible and can vary spatially and temporally (Haug *et al.* 1995). For example gadoid fish species were

dominant in the spring while krill (*Thysanoessa* spp) and to a much lesser extent capelin, characterized the summer diet and autumn diet. It appears that minke whales will generally favour capelin and herring over krill and gadoid fish species (Haug *et al.* 1995). In Iceland, recent studies have shown changes in minke whale diets from stomach content analysis (Víkingsson *et al.* 2013). Changes in minke whale diet included a decrease in the proportion of sandeel and increase in herring and haddock, particularly in the south. These finding also differed from previous studies where diet consisted on krill and capelin, both cold water species (Víkingsson *et al.* 2013). Víkingsson *et al.* (2013) study suggests that changes in minke whale diet composition are consistent with recent changes in Icelandic continental shelf ecosystems, increased sea surface and bottom temperatures and changes in distribution and abundance of several fish species including sandeel and capelin. In North Norway, herring was the most important food item for minke whales both in summer and autumn (Haug *et al.* 1995); the same pattern may apply to the present study.

Capelin abundance and distribution in Iceland and the Barents Sea, has been correlated with SST, reflecting changes in these larger-scale features (Gislason & Astthorsson, 1998). The reduced temporal and spatial predictability of prey is consistent with greater mobility of predators, with larger scale of certainty resulting in regular seasonal distribution shifts. These factors suggest that during the feeding season, humpback whales initially congregate in areas of euphausiid concentration, following capelin later in the season (Stevick *et al.* 2006). It was mention by Stevick (2006) that the possible segregation of individuals from eastern and western Iceland is also consistent with this prey distribution, suggesting that those whales to the west of Iceland in early summer follow the Icelandic capelin stock north along the Polar Front into the Greenland Sea, whereas those to the east are more likely to move to the Barents Sea. In the North Atlantic, humpback whales demonstrate high levels of persistent site fidelity on the feeding range. However, the specific patterns of movement observed vary between areas and over time. Such differences appear to reflect foraging responses to patterns of prey abundance. Specifically, differences in movement patterns in the eastern and western North Atlantic reflect a similar strategy of return to areas of concentrated prey. In eastern regions, however, preys are principally associated with meso-scale features that are especially less predictable (Stevick *et al.* 2006).

Many marine species have certain temperature ranges at which they can survive; for example, cod in the North Atlantic requires water temperatures below 12˚C. Even sea-bottom temperatures above 8˚C can reduce their ability to reproduce and for young cod to survive. In this century, temperatures in the American region likely exceed both thresholds. Moving into new areas may put these species into competition with other species over food and other resources (USGCRP, 2009). In Iceland, it has been suggested that the distribution of cod larvae from the main spawning grounds south of Iceland to the nursery grounds on the north Icelandic shelf benefit from year where there is an increase of the AW inflow (Jónsson & Valdimarsson, 2005)

The importance of sandeel has been highlighted for the four cetacean species addressed in this project in different feeding areas including Icelandic waters (MacLeod *et al.* 2004; Rasmussen, 2004; Víkingsson & Ólafsdóttir, 2004). Even though, this bottom fish is very important for the diet of the four species in Icelandic waters, it has not been incorporated in our models due to lack of information. It was until 2006 when this was fist surveyed and its abundance and distribution were estimated. Cetaceans and sea birds like puffins (*Fratercula arctica*) and kittiwakes (*Rissa tridactyla*) relay on this very important food source. Indeed, the recent decline on puffin's population was related to decrease in sandeel

population (Helgasson, 2012). The decrease in sandeel number was due to changes in ocean temperature, migrations and invasion of other species, such as mackerel (*Scomber scombrus*) which numbers have multiplied exponentially in Icelandic waters in recent years having a major impact on the ecosystems. It is believed that this significant shift is occurring because mackerel depends on warmer water that has moved further north as a result of climate change. The dramatic increase in the population and the individual fish's vast appetite may cause significant harm to other fish and seabird species and to the marine ecosystems at large (Astthorsson *et al*. 2012).

A potential mismatch in the food availability peak will have an effect on all the food chain, particularly on species that undertake long distance feeding migrations, such as humpback and minke whales. As temperatures increase, primary production is favoured and the process of photosynthesis starts earlier. As a consequence the timing between prey availability and predator arrival is disrupted. As temperature increase, the habitat ranges of many species are moving northwards in latitude and upward in elevation (MacLeod *et al*. 2008). While this means a range expansion for some species, for others it means a range reduction or a movement into less suitable habitat of potential higher competition. Some species have nowhere to go because they are already at the northern or upper limit of their habitat. As water warms, the area of feasible cooler habitats to which species can migrate is reduced and range shifts disturbed the current state of the ecosystems.

In addition, ocean warming dominates the increase in energy stored in the climate system, it has been suggested that the upper ocean (0–700 m) has warmed from 1971–2012 (IPCC summary 2013) and the anthropogenic CO_2 still resides in the surface, in the upper 100m where can impact the marine organisms (Feely, 2013). Oceans have stored energy between the first couple of meter and then the energy has move to deeper waters (700–2000 m). This change in temperature and accumulation of CO_2 through the water column affects all species.

Chlorophyll-*a* and acidification

As mentioned above, ocean warming could affect oceanic circulation, which may have an impact on the influx of Atlantic water to the North Icelandic area which generally provides and important nutrient source (Stefansson & Ólafsson, 1991). Ocean warming can change the chemical composition of the water column affecting the nutrients concentration of nutrients and having a ripple effect to all other organisms starting for the base of the food web, primary producers (Feely, 2013).

The results from this study showed a positive relationship between the presence of humpback and minke whales and primary production (i.e Chlorophyll-*a*). On the contrary, a negative relationship was found between both white-beaked dolphin and harbour porpoise and primary production in agreement with Cecchetti (2006). This finding seems to contradict the rational outcome that higher concentrations of chlorophyll lead to greater prey availability and hence, it could enhance the presence of predators such as humpback and minke whales. Mysticetes are migratory species, which overtake long distance movements between feeding and breeding grounds. Therefore, primary production may be a stronger driver of baleen whale presence. For the mysticetes, this might indicate the presence of krill, an important prey item in their diet and other larvae organisms, which at the same time feed on the algae blooms. For example in the study carried by Anderwald *et al*. (2012) found that minke whales distribution off the west coast of Scotland is dependent

largely on temporally variable parameters such as sea surface temperature in spring and chlorophyll concentrations in autumn. On the other hand, previous studies, in Skjálfandi Bay where the concentrations of chlorophyll-*a* was detailed geographically within the Bay. It was found higher concentration levels of chlorophyll-*a* in the southern and eastern parts of the Bay. Considering the differentiation of chlorophyll concentrations within the Bay and that this study suggests the existence of habitat partitioning between the odontocete and mysticetes species analysed based on topographic variables, it may as well be that the two groups show a preference for different area of the Bay that happen to have different chlorophyll concentrations. However, it has been shown than during the latter decades there has been marked variations (regional, seasonal, and annual) in primary production in Icelandic waters (Stefansson & Ólafsson 1991) therefore plankton production and trophic interactions may be significantly altered by changes in climate.

The increase in SST has created what is known as ocean acidification, is the process of uptaking anthropogenic carbon dioxide by the surface of the ocean, creating carbonic acid that, in turn, lowers the pH of the oceans (Feely, 2013). Acidification is a process that has been happening and still in process thus is not the end state of the oceans. It has been recognized that the current rate of acidification is nearly 10 times faster than any period over the past 50 million years and suggested that ocean acidity has increased by a 30 % since the start of the industrial age and ocean acidity is projected to increase 100–150% by 2100 (IPCC 2013). In Iceland ocean acidification is considered to be a stronger threat than global warming (Hrönn Egilsdóttir, personal communication). Studies that are currently in process by the Marine Institute in Reykjavik, Iceland are showing that data collected in the ocean north of Iceland acidifies considerably faster than further south in the world (Hrönn Egilsdóttir, personal communication).

Fastest acidification rates take place in the Arctic and Antarctic regions along with coastal waters where we can find upwelling (Feely, 2013). Studies in Antarctica highlight that sea ice decline, ocean warming and other environmental stressors act in synergy to modify the abundance, distribution and life cycle of the Antarctic krill (*Euphausia superba*) (Flores *et al.* 2012). It was suggested that even though some of these changes can have positive effects on krill, the cumulative impact is mostly negative and probably the population parameter most susceptible to climate change is the recruitment, driven largely by the winter survival of larval krill and the association with sea ice at all stages. Although the krill found in Icelandic waters do not rely on sea ice as the Antarctic krill does, partial pressure of CO_2 generally increases with depth affecting the routinely extensive vertical migrations where krill spends much of their life thus exposing to higher and more variable levels of ocean acidification than other organism living in surface waters (Flores et al, 2012). Addition of nutrients (CO_2) leads an enhancement of some cyanobacteria and nano-phytoplankton outcompete the diatoms at high CO_2 levels causing dramatic changes in the ecosystems at different levels (Feely, 2013). For example, plankton blooms have started earlier than normal which consequently has derived on a mis-match between phytoplankton bloom, presence of zooplankton such as krill and fish larvae. In marine ecosystems, about 11% of phytoplankton is cocolitopheres which produce calcium carbonate shells, eaten by copepods which then are eaten by fish (Feely, 2013). Shift in nutrient and pH chemistry of seawater, promoted by acidification, can have major impact on phytoplankton diversity, ecology, growth and development of larval stages of marine organisms, usually more sensitive than adult stages (Feely, 2013).

Seasonality

Temporal scales such as month or year are directly related to cetacean migration and abundance breeding and feeding areas. In the present study it was included the months of May through September, considered to represent the duration of the feeding season in Skjálfandi Bay. There were only two species, white-beaked dolphins and humpback whale that had a significant relationship with month. Humpback whale presences were higher in June, July, August and September while white-beaked dolphin's encounters were higher in June and July. In the study done by Dalla Rosa *et al.* (2012), higher humpback whale encounters rates were associated with May and July. The authors suggest that within those moths there seasonal events such as wind-driven upwelling, which are related to primary production. Month is also related to SST as during the summer water temperatures increase and promote primary production. As mention above, SST, fronts, wind-driven upwelling, salinity and others physical properties affect the food chain from primary production to fish biomass and top predators. The partial effects of month could potentially represent inter-seasonal differences in whale and dolphin encounter rates.

Modeling considerations

In this study the habitat preference of white-beaked dolphins, harbour porpoises, humpback and minke whales have been established by models that best described their habitat use from 2004-2012 in Icelandic waters, specifically in their feeding grounds in Skjálfandi Bay. The models explained 9.52%, 11.3%, 15.4% and 7.34% respectively. A study done around the Galician coast found that the model explained 16.1% of deviance in cetacean presence and the relationship with the duration of observations, field of view area, time of day and location on presence of cetaceans over a period from September 2003 to October 2007 (Pierce *et al.* 2010). On the other hand, Dalla Rosa *et al.* (2012) humpback whale study, done in feeding areas off British Columbia (BC) from spring to fall, have shown high deviance explanation, 39% of deviance over a combined three year model and 76% for one year model (2004). Nonetheless, models could explain more, potentially considering a larger study area, longer temporal scale, species abundance estimate or encounter rates (as a stronger indication of presence) and possibly other potential variables. Even though the present study represents a small area, it provides information necessary to understand their distribution in relation to eco-geographic variables and start relation to eco-geographic variables and start considering plausible direct or indirect impacts on cetaceans distributions at the rate at which global climate change is affecting the oceans. It has been suggested that these 'preferred' areas or 'critical habitats' are probably particularly important for survival and reproduction; and if there are changes to these areas, then it is most likely to affect the distribution and abundance of marine mammals (Harwood, 2001).

4.2 Other parameters and Impacts

Additional stressors not incorporated in the present study may have also an indirect impact on marine mammals. Some of these stressors include salinity and thus it is important to mention that the Atlantic has become saltier, which as a result affects the biology of prey species for whales and dolphins and which is also an important driver of the density and circulation of the ocean(Blindheim & Østerhus, 2005; Learmonth *et al.* 2006). In addition, there is a sea level raise coming from the sum of ocean thermal expansion, glacier mass loss especially during the 20th century. Arctic sea ice extent has decreased over the period 1979 – 2012 (IPCC 2012). Other very important factor that has changed due to climate change is dissolved oxygen which has decreased due to anthropogenic forcing (Feely,

2013). Additionally, cumulative impacts may lead to dramatic ecological effects as climate change can be coupled with other regional stresses such as overfishing, oil spills and pollution (Feely, 2013).

Furthermore some diseases affect aquatic life and may become more prevalent in warm water. Changes in temperature and seasonal cycles could affect the timing of reproduction and migration (Beaugrand *et al.* 2003). Many steps within an aquatic animals lifecycle are controlled by temperature seasonal changes. The impact of climate change on particular species can ripple through a food web and affect a wide range of other organisms (Harwood, 2001; Learmonth *et al.* 2006).

4.3 Adaptations

Species were able to evolve with their environments and adapt to it. However the environmental changes that we are observing now, occur in such a faster rate species exposed to unpredictable changes may not be able to adapt to new conditions (Feely, 2013). Potential for adaptations for some species e.g 500 generation can be rescue through genetic changes over time; organisms have the ability of changing their genetic structure through time due to external changes. Whales and dolphins do show some plasticity but the rate at which climate is changing is much faster than the rate at which they might be able to adapt. For example, organisms in coastal areas and other organisms dependant to certain environmental parameters learn to adapt to low pH, in region of low variability adaptation and which are not so good. Scientists have suggested that the expected changes within the next 30-40 years (Harwood, 2001; Feely, 2013; IPPC 2013) and will be drive the extinction of several species; for instance, the extinction of the Baiji (*Lipotes vexillifer)* (or Chinese river dolphin) (functionally extinct, since 2006) (Turvey *et al.* 2010). Potential for adaptations depends dramatically on metabolic processes and tolerance of fish and other organisms to temperature which are greatly reduced due to the higher mono-CO^2, impacting habitat by the physiological process occurring to the blood systems at higher CO^2 levels (Feely, 2013). Organisms can evolve and adapt to new circumstances however, anthropogenic factors may prevent to occur at its normal pace.

Near term- long term

There are near-term and long-term climate change projections. Even though the present study looks at cetacean habitat preferences over the last decade, climate models predict long term (mid 21st century and beyond) global warming. From near term scenarios presented by the IPCC 2013, it was mentioned that it is "very likely" that warming levels over the Arctic in winter will be greater than the global mean warming. Not only the projections for changes in ocean temperatures but also in the atmosphere and cryosphere (ice) could have direct or indirect effects over marine mammals species.

Even though whales and dolphins seem not to be drastically affected by climate change for the moment (Learmonth *et al.* 2006; MacLeod *et al.* 2007; MacLeod *et al.* 2008), through time this species my confront the same future as now other marine mammals such as ringe seals reduced sea ice extent and cold water fish (i.e. cod) are experience and could even reach extinction (Beaugrand *et al.* 2003; Ferguson et al. 2005)

4.4 Management

This study has identified SST as one of the factors influencing cetacean presence in Skjálfandi Bay. Given the likelihood of changes in local SST due to global climate change, potential changes in cetacean distribution in the study area may occur. Therefore, systematic to estimate cetacean abundance and distribution are recommended to effectively manage cetacean populations in Skjálfandi Bay. Harbour porpoise is in the European Habitats Directive (Directive 92/43/CEE) as species of special interest. Porpoises protection needs the designation of Special Areas of Conservation (SAC), a common regime for conservation, the surveillance for their conservation status and the establishment of a system to monitor their incidental capture and killing. Improved knowledge on the habitat preferences of all species in Skjálfandi Bay is needed to guide surveys that aim to establish SAC. The results presented here van provide baseline information for future conservation efforts.

In addition, Skjálfandi Bay has been proposed to be declaring as a marine protected area MPA for a long time (Hoyt, 2011). Hoyt (2011), suggests that creating and effectively managing MPAs for cetaceans depends upon the identification and strict protection of substantial areas of cetacean critical habitat, (e.g. feeding areas, breeging grounds); and the identification and the effective control of all cetacean threats (e.g. pollution, marine traffic, fisheries interactions) necessary to ensure an ecosystem-based management approach. It is recommended a good management plan with periodic review developed in conjunction with all stakeholders, including researchers, MPA managers, community members, boat operators, visitors and others.

4.5 Research strengths and limitations

The data set used in this model was collected from whale watching platforms. Opportunistic, such as whale watching vessels, have been an important resource for cetaceans studies. Given the increase of whale watching companies around the world, scientists can use a whole set of new data and tools to be applied in cetacean biology research. Thus, complimentary mutual collaboration between stakeholder and scientist can be achieved. However, there are also a few limitations related to whale watching platforms as a mean to gather cetacean distribution data. Using whale watching gathered data may include data inconsistencies as 1) a number of different observers (usually volunteers) collect throughout the season and the year and 2) time and effort spend searching for cetaceans in a line-transect manner (constant speed and direction) may be limited since the main objective of a whale watching trip is to spend a significant amount of time close to a group/several groups of animals to satisfy customers. For example, whale watching cetacean surveys rarely follow systematic designs in space and time, due to specific logistical constraints, especially when conducted from opportunistic platforms (Williams et al. 2006). Nevertheless, these limitations can be usually addressed through a constant and fluent communication between whale watching operators and scientist.

Additionally, in the present study SSB of fish species was obtained as yearly value. This value is an integer including all the regions around Iceland. Thus the estimate of SSB for the study area may have not been accurate enough. Furthermore, in this study krill

abundance was not incorporated in the models, although krill abundance could be one of the variables influencing humpback and minke whales.

5 Conclusion

In light of this study, the existence of habitat partitioning between white-beaked dolphin, harbour porpoise, humpback and minke whale within Skjálfandi Bay is suggested. Of the species analysed here, two main groups can be identified due to ecological similarities; white-beaked dolphins and harbour porpoises and minke and humpback whales. The eco-geographical variables with higher influence in white-beaked dolphins and harbour porpoises presence were distance to coast and seabed steepness and angle. On the other hand, humpback and minke whales encounter depended more upon depth and chlorophyll. All of the species occurrences were significantly related to SST, which given the current scenario of global climate change perhaps represents the most important variable. To determine the habitat selection of these species may help conservation management (i.e. the ongoing discussion regarding the proposal for Skjálfandi Bay as MPA), as pointed out by other studies (Cecchetti, 2006; Hastie *et al.* 2004) In addition, due to the rapid growth of whale watching effort in the area (e.g. companies, boats, tours) the habitat preference of the white-beaked dolphin, harbour porpoises, humpback and minke whales could be affected and modified in the near future.

Differences in habitat selection among these species likely reflects distinct feeding habits and foraging strategies, and also could contribute to reduce ecological competition among species that occur in the same geographical area. Habitat partitioning is most likely to be driven by competition for a limited, shared resource mediated by food preferences (MacLeod, 2007).

On the other hand, cetacean responses to climate change may be primarily driven by how water temperature influences their habitat, resulting in potential competition for space and resources (MacLeod, 2007). Because of its location near the boundary between warm and cold currents, conditions in the area North of Iceland are highly sensitive to meteorological changes (Stefansson & Gudmundsson, 1969). Consequently, variable influx of the Atlantic water and/or variable admixture of polar water in the surface layers north of Iceland, may lead to large temperature and salinity fluctuations, both in space and time.

In summary, the hypothesis we present here include possible cetacean migrations following their prey and their preferred temperature ranges and /or change in prey preferences due to fish community changes and competition for resources. Given the current rate of climatic change and its potential effects in environment, such as more uptakes cetaceans' distribution may experience regional changes and to understand these changes, dedicated surveys as well as assessment of other types of threats (e.g. pollution, fisheries interactions) should be done frequently to aid management procedures and decisions.

5.1 Further studies

Further studies could include determination of specific global warming effects over the current habitat use and to forecast future marine mammals distribution based on SST predictions. In addition, other variables could be included in the models to determine the

distribution of this species such as tidal, substrate type, currents and water stratification in relation to copepod density and bottom topography. Warming oceans are causing marine species to alter their breeding, feeding and migration patterns. In addition, more studies on stomach content and/or stable isotopes could be performed to find out more information on the diet of these species in Icelandic waters, which will aid the inclusion of relevant prey items into future habitat models around Iceland.

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Appendix A

No.	Sight.	Vessel	Day	Month	Year	Start time	End time	Waypoint	Lat degree	Lat minute	Lat second	Lat decimal	Long degree	Long minute	Long second	Long decimal	Species	No.	Bearing(d)	Distance(t)	Sea State	Behavior	Birds Sp.	Birds No.
3		N/A	10	7	2004	12:38:00	12:45:00	66	5	40	66.09444	17	30	50	-17.5139	Mn	1	N/A	N/A	n/a		<10	N/A
5		N/A	11	7	2004	15:22:00	15:39:00	66	12	60	66.21667	17	35	20	-17.5889	Mn	2	N/A	N/A	n/a		<10	N/A
7		N/A	12	7	2004	15:33:00	15:49:00	66	5	20	66.08889	17	34	30	-17.575	Mn	1	N/A	N/A	n/a			0 N/A
15		N/A	17	7	2004	15:29:00	15:54:00	66	11	30	66.19167	17	25	50	-17.4306	Mn	2	N/A	N/A	n/a		<10	N/A
18		N/A	18	7	2004	14:26:00	14:28:00	66	7	30	66.125	17	32	20	-17.5389	Mn	2	N/A	N/A	n/a		<10	N/A
19		N/A	18	7	2004	14:43:00	14:44:00	66	7	20	66.12222	17	32	20	-17.5389	Mn	1	N/A	N/A	n/a		<10	N/A
21		N/A	18	7	2004	n/a	n/a	66	7	10	66.11944	17	33	10	-17.5528	n/a	N/A	N/A	N/A	n/a		<10	N/A
22		N/A	18	7	2004	15:01:00	n/a	66	6	40	66.11111	17	33	40	-17.5611	n/a	N/A	N/A	N/A	n/a		<10	N/A
112		N/A	12	6	2005	14:09:00	14:20:00	66	2	32	66.04222	17	29	35	-17.4931	Mn	1		200	N/A	came clos 7 AT, 7 sec	N/A	N/A
114		N/A	13	6	2005	14:03:00	14:28:00	66	2	29	66.04139	17	31	35	-17.5264	Mn	1		100	N/A	showed fl few	N/A	N/A
115		N/A	13	6	2005	14:32:00	n/a	66	2	22	66.03944	17	34	3	-17.5675	Mn	1		200	N/A	fluke with N	N/A	N/A
116		N/A	14	6	2005	14:14:00	15:06:00	66	1	9	66.01917	17	31	37	-17.5269	Mn	1		200	N/A	feeding N	N/A	N/A
117		N/A	15	6	2005	14:10:00	14:21:00	66	0	21	66.00583	17	30	45	-17.5125	Mn	N/A		50	N/A	feeding Fulmar	N/A	N/A
118		N/A	15	6	2005	14:25:00	15:12:00	66	0	48	66.01333	17	33	30	-17.5583	Mn	N/A		200	N/A	strange noises, mayt	N/A	N/A
119		N/A	15	6	2005	15:15:00	15:26:00	66	1	4	66.01778	17	37	31	-17.6253	Mn	N/A		200	N/A		N/A	N/A
120		N/A	15	6	2005	15:38:00	15:45:00	66	2	37	66.04361	17	39	10	-17.6528	Mn	N/A		300	N/A	only one time	N/A	N/A
122		N/A	18	6	2005	14:15:00	14:49:00	66	1	10	66.01944	17	33	49	-17.5636	Mn	1	4-500	300	N/A	feeding, c few Fm	N/A	N/A
124		N/A	21	6	2005	14:10:00	13:00:00	66	1	25	66.02361	17	28	15	-17.4708	Mn	2		200	N/A	breaching gulls	N/A	N/A
129		N/A	26	6	2005	14:08:00	14:44:00	66	2	33	66.0425	17	32	5	-17.5347	Mn	01-Feb		300	N/A	swimming 9 Fulmars	N/A	N/A
134		N/A	28	6	2005	14:36:00	15:30:00	66	1	13	66.02028	17	37	39	-17.6275	Mn	2		300	N/A		N/A	N/A
136		N/A	29	6	2005	15:21:00	15:44:00	66	2	10	66.03611	17	39	14	-17.6539	Mn	1		500	N/A		N/A	N/A
140		N/A	30	7	2005	14:49:00	15:10:00	66	1	55	66.03194	17	33	41	-17.5614	Mn	1		200	N/A		N/A	N/A
144		N/A	1	7	2005	n/a	n/a	66	1	15	66.0375	17	32	13	-17.5369	Mn	1		300	N/A		N/A	N/A
145		N/A	1	7	2005	14:37:00	15:00:00	66	2	4	66.03444	17	32	38	-17.5439	Mn	1		15	N/A	never shows the fluk	N/A	N/A
149		N/A	1	7	2005	15:30:00	n/a	66	2	6	66.035	17	32	55	-17.5486	Mn	1		30	N/A		N/A	N/A
150		N/A	2	7	2005	14:22:00	14:46:00	66	3	3	66.05083	17	36	51	-17.6142	Mn	2		300	N/A	1 of them not lifting	N/A	N/A
152		N/A	2	7	2005	14:57:00	14:58:00	66	3	58	66.06611	17	39	30	-17.6583	Mn	1		100	N/A		N/A	N/A
201		N/A	27	7	2005	14:54:00	15:45:00	66	8	52	66.14778	17	30	8	-17.5022	Mn	1		50	N/A	very difficult	N/A	N/A
214		N/A	31	7	2005	14:31:00	15:17:00	66	4	18	66.07167	17	38	17	-17.6381	Mn	1		500	N/A	feeding	N/A	N/A
255		N/A	20	8	2005	15:10:00	15:44:00	66	4	20	66.07222	17	37	56	-17.6322	Mn	1		500	N/A		N/A	N/A
258		N/A	22	8	2005	14:15:00	15:14:00	66	5	5	66.08472	17	34	9	-17.5692	Mn	1		600	N/A	very calm, Fulmar	N/A	N/A

Figure A.1. Sightings protocol to collect data

Day	Month	Year	Vessel	Time	Lat degrees	Lat minutes	Lat seconds	Lat decimals	Long degrees	Long minutes	Long seconds	Long decimals	Wind Direction	Wind speed (m/s)	Sea state	Glare	Visibility	Cloud cov	Speed
10	7	2004	N/A	10:07:00	66	2	60	66.05000	17	21	70	-17.36944		N/A	0-1		0 M	2	8.7
10	7	2004	N/A	10:29:00	66	4	50	66.08056	17	25	50	-17.43056		N/A	0-1		1 M	2	7
10	7	2004	N/A	10:47:00	66	7	50	66.13056	17	28	40	-17.47778		N/A	0-1		1 M	2	7
10	7	2004	N/A	11:03:00	66	8	50	66.14722	17	31	20	-17.52222		N/A	0-1		2 M	2	8.6
10	7	2004	N/A	11:13:00	66	10	20	66.17222	17	31	40	-17.52778		N/A	1-2		2 M	2	9
10	7	2004	N/A	11:18:00	66	10	10	66.16944	17	30	0	-17.50000		N/A	1-2		2 M	2	5.1
10	7	2004	N/A	12:27:00	66	6	30	66.10833	17	33	30	-17.55833		N/A	1-2	0-1	M	3	9.3
11	7	2004	N/A	13:51:00	66	2	30	66.04167	17	21	30	-17.35833		N/A	0-1		0 B-M	3	8.7
11	7	2004	N/A	14:31:00	66	6	50	66.11389	17	15	20	-17.25556		N/A		0	0 M	3	8.9
11	7	2004	N/A	15:01:00	66	10	20	66.17222	17	29	50	-17.49722		N/A	0-1		0 M	3	8.7
11	7	2004	N/A	15:17:00	66	12	10	66.20278	17	33	40	-17.56111		N/A	0-1		0 M	3	8.8
11	7	2004	N/A	15:39:00	66	12	50	66.21389	17	35	40	-17.59444		N/A	0-1		0 M	3	9.2
11	7	2004	N/A	16:09:00	66	8	20	66.13889	17	30	0	-17.50000		N/A		0	0 M	3	9.4
11	7	2004	N/A	16:39:00	66	4	40	66.07778	17	24	50	-17.41389		N/A		0	0 M	3	8.9
11	7	2004	N/A	16:56:00	66	2	43	66.04528	17	21	40	-17.36111		N/A		0	0 M	3	8.7
12	7	2004	N/A	14:33:00	66	2	30	66.04167	17	21	40	-17.36111		N/A	0-1		0 G	2	8.6
12	7	2004	N/A	16:12:00	66	8	0	66.13333	17	29	0	-17.48333		N/A	0-1		2 G	1	8.1
12	7	2004	N/A	16:19:00	66	9	10	66.15278	17	29	10	-17.48611		N/A	0-1		2 G	1	9.3
12	7	2004	N/A	16:24:00	66	9	50	66.16389	17	29	40	-17.49444		N/A	0-1		2 G	1	9.1
12	7	2004	N/A	16:42:00	66	9	40	66.16111	17	27	60	-17.46667		N/A	0-1		2 G	1	8.5
12	7	2004	N/A	17:12:00	66	7	0	66.11667	17	22	40	-17.37778		N/A	0-1	1-2	G	2	5.8
12	7	2004	N/A	17:45:00	66	2	30	66.04167	17	21	40	-17.36111		N/A	0-1	1-2	G	2	8.6
15	7	2004	N/A	15:31:00	66	6	50	66.11389	17	22	30	-17.37500		N/A	1-2		0 M-G	2	
15	7	2004	N/A	15:59:00	66	3	20	66.05556	17	22	50	-17.38056		N/A		1	0 M-G	2	
15	7	2004	N/A	16:06:00	66	2	30	66.04167	17	21	40	-17.36111		N/A		1	0 M-G	2	
16	7	2004	N/A	13:37:00	66	2	35	66.04306	17	21	42	-17.36167		N/A	0-1		0 M	3	8.7
16	7	2004	N/A	14:03:00	66	6	23	66.10639	17	23	16	-17.38778		N/A		1	0 M	3	8.7
16	7	2004	N/A	14:06:00	66	6	41	66.11139	17	19	10	-17.31944		N/A		0	0 M	3	2.1
16	7	2004	N/A	14:12:00	66	7	3	66.11750	17	22	35	-17.37639		N/A	0-1		0 M	3	8
16	7	2004	N/A	16:00:00	66	6	50	66.11389	17	23	10	-17.38611		N/A	0-1		0 M	3	8.9
16	7	2004	N/A	16:31:00	66	2	35	66.04306	17	21	42	-17.36167		N/A	0-1		0 M	3	8.7

Figure A.2. Effort protocol to collect data

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