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Annual and seasonal distribution of humpback whales (*Megaptera novaeangliae*) in Skjálfandi Bay

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“He is the most gamesome and light-hearted of all the whales, making more gay foam and white water than any other of them.”

Herman Melville (“Moby-Dick”, 1851)

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Contents

List of abbreviations

B. acutorostrata / Ba	-	*Balaenoptera acutorostrata*
Bm	-	*Balaenoptera musculus*
Hafro (MRI)	-	Hafrannsóknastofnunin - Marine Research Institute
IWC	-	International Whaling Commission
La	-	*Lagenorhynchus albirostris*
L_T	-	Minutes effort
M. novaeangliae / Mn	-	*Megaptera novaeangliae*
n	-	Number of humpback whale individuals
photo-ID	-	photo-identification
Pp	-	*Phocoena phocoena*
SPUE	-	Sightings per Unit Effort
SST	-	Sea Surface Temperature

Abstract

Since commercial whaling of *Megaptera novaeangliae*, which strongly decimated the number of individuals, was stopped in the mid 20^{th} century, populations are increasing again. Humpback whales are distributed worldwide and belong to the most common whale species occurring in Skjálfandi Bay, Northern Iceland. These baleen whales migrate from their winter breeding grounds close to the equator to summer feeding areas in higher latitudes. Data show increasing sighting rates in Skjálfandi Bay during the summer research season (April – October) from 2003 (0.0001/minute) to 2012 (0.0246/minute), whereas no significant variations in sighting frequencies between different months were reported.

However, sighting rates as well as distribution patterns within Skjálfandi Bay fluctuated between the years. Although no relationships between humpback whale occurrence and sea water temperature were determined, environmental factors such as local currents, upwelling etc. may influence prey distribution, thus effecting humpback whale abundance. To determine the most influencing environmental parameters, further studies are necessary.

Since 2001, photographed humpback whales which were sighted in Skjálfandi Bay were identified and cataloged. With always less than 27 % the resighting rate in Skjálfandi Bay is on a low level. Also the time the humpback whales spent in the bay varied between individuals. In 2012, 11 out of 77 identified humpback whales were sighted in this bay before, probably indicating that they belong to a bigger population with various feeding areas around Iceland. Only few individuals return to Skjálfandi Bay for several years, especially the humpback whale named Mn33 in the catalogue, which was observed in this bay every year from 2006 to 2012.

The increase in sightings may be due to enhanced feeding conditions within the bay, giving rise to increasing potential for whale watching operations.

To develop effective management and protection efforts including animal and habitat protection, and strict guidelines for whale watching tourism, further studies on the humpback whale population around Iceland, including their population size, migration routes and preferred feeding locations, are necessary.

Zusammenfassung

Nach dem Beenden der kommerziellen Jagd von *Megaptera novaeangliae* Mitte des 20. Jahrhunderts, die zu einer starken Dezimierung der Individuenzahl geführt hatte, nehmen die Populationen weltweit wieder zu. Buckelwale sind kosmopolitisch verbreitet und gehören zu den am häufigsten auftretenden Walarten in der Skjálfandi Bucht im Norden Islands. Diese Bartenwale wandern jährlich von ihren winterlichen Fortpflanzungsgebieten in der Nähe des Äquators zu den Nahrungsgründen in höhere Breiten, die sie im Sommer aufsuchen.

In der Skjálfandi Bucht ist in der Forschungssaison (April bis Oktober) von 2003 (0.0001/Minute) bis 2012 (0.0246/Minute) eine Zunahme der Sichtungshäufigkeit von Buckelwalen zu verzeichnen. Der Vergleich der verschiedenen Monate untereinander zeigte jedoch keine signifikanten Unterschiede in den Beobachtungshäufigkeiten im Laufe der Saison.

Innerhalb der Bucht konnten dagegen variierende Sichtungsraten sowie unterschiedliche örtliche Verteilungsmuster nachgewiesen werden.

Obwohl zwischen dem Auftreten der Buckelwale und der schwankenden Wassertemperatur keine Abhängigkeit ermittelt werden konnte, können weitere Umweltfaktoren wie lokale Strömungsmuster, Auftriebsströmungen u.a. die Verteilung der Beute der Wale und somit wiederum deren Vorkommen beeinflussen. Um die Umweltparameter zu bestimmen, die dabei die wichtigste Rolle spielen, müssen weitere Studien durchgeführt werden.

Seit 2001 wurden in der Skjálfandi Bucht gesichtete Buckelwale fotografiert, identifiziert und katalogisiert. Allerdings wurden in dieser Bucht nie mehr als 26 % der identifizierten Individuen in den Folgejahren wieder gesichtet. Auch die Zeitspannen, die die Buckelwale in der Bucht verbrachten, unterlagen großen individuellen Schwankungen.

Im Rahmen dieser Studie wurden 2012 von April bis Oktober 77 Buckelwale in der Skjálfandi Bucht identifiziert, von denen 11 bereits in vorhergegangenen Jahren gesichtet worden waren.

Nur wenige Individuen kehrten mehrere Jahre in Folge in die Bucht zurück. Der im Katalog als Mn33 benannte Buckelwal sticht dabei besonders hervor: Von 2006 bis 2012 kehrte er jeden Sommer in die Skjálfandi Bucht zurück.

Die steigende Anzahl an Buckelwalen, die diese Bucht im Sommer aufsucht, kann höchstwahrscheinlich auf verbesserte Nahrungsbedingungen zurückgeführt werden. Das bietet wiederum ein steigendes Potential für den Walbeobachtungs-Tourismus.
Um effektive Schutzmaßnahmen für die Wale und deren Lebensraum sowie strenge Richtlinien für den Walbeobachtungs-Tourismus zu entwickeln, sind weitere Studien über die Buckelwalpopulation um Island, einschließlich ihrer Populationsgröße, Wanderrouten sowie bevorzugte Nahrungsgebiete, erforderlich.

1 Introduction

1.1 *Megaptera novaeangliae*

The humpback whale *Megaptera novaeangliae* (Borowski, 1781) belongs to the Balaenopteridae (Figure 1), including all the rorquals such as blue whale (*Balaenoptera musculus*), minke whale (*Balaenoptera acutorostrata*) and fin whale (*Balaenoptera physalus*), characterized by a reduced tongue and several longitudinal grooves of elastic and extensible blubber on the ventral body side (Orton and Brodie, 1987).

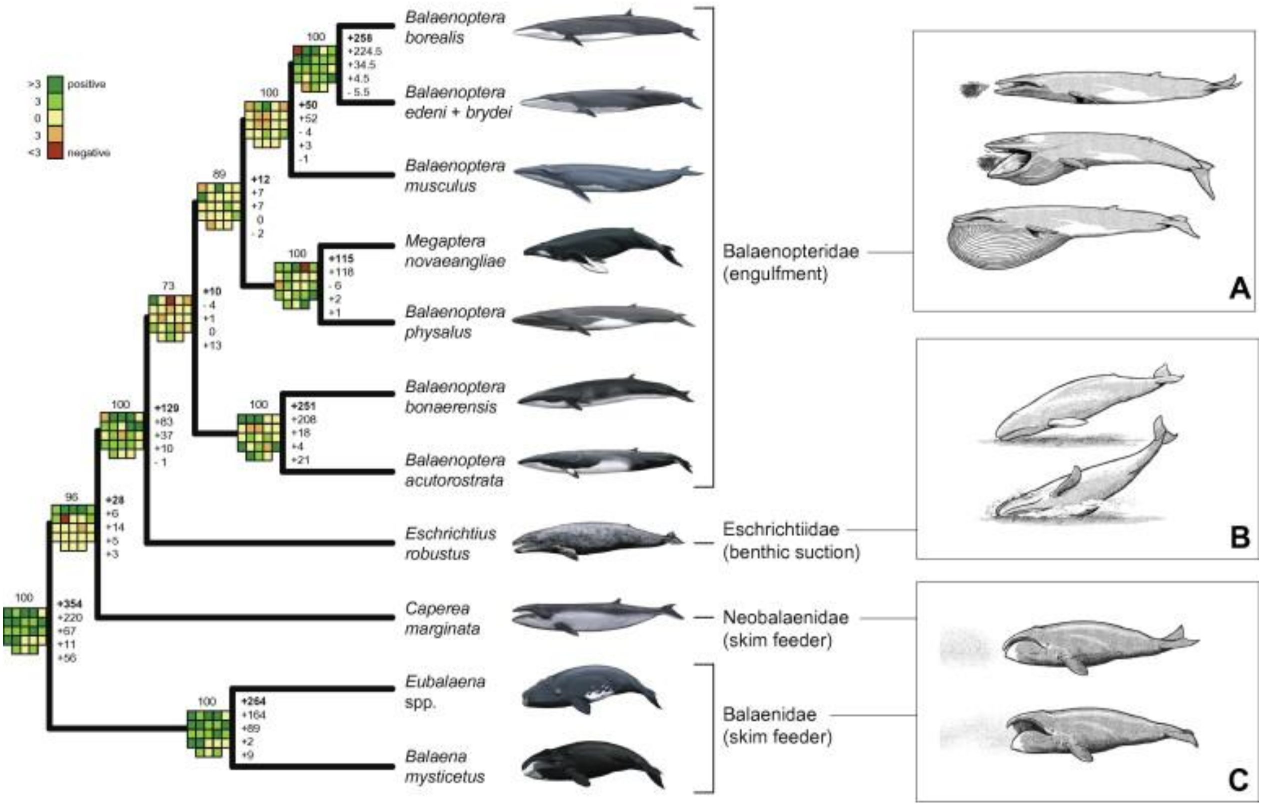


Figure 1: Phylogenetic relationships of recent baleen whales (*Mysticeti*). Besides the *Balaenoptera*, the monotypic genus *Megaptera* constitutes the second genus within the rorquals (Balaenopteridae). Image from Gatesy *et al.*, 2013.

Fully grown humpback whales may reach a length up to 13 - 15 m; females are usually somewhat larger than males (Johnson and Wolman, 1984).

Characteristic of this species are the extraordinary long flippers, reaching one-fourth to one-third of the total body length, equivalent to five meters in a fully grown individual.

A wide range of theories explain the presence of these long appendages, including maneuverability and assistance in regulating the body temperature (Edel and Winn, 1978; Johnson and Wolman, 1984). A remarkable feature of these pectoral fins is that whales living in the Atlantic show a white upper side, whereas the flippers of individuals in the Pacific are black (Chittleborough, 1965; Pike, 1953). In contrast to other whale species the humpback whales are less sleek, making them the slowest members of the Balaenopteridae (Clapham, 1996). This facilitates taking photos of them. Such images are important for identifying individuals, as described in the chapter below on photo-identification.

1.2 Migration

Megaptera novaeangliae occurs in all oceans of the world but not in polar pack ice zones (Figure 2) (Chittleborough, 1965).

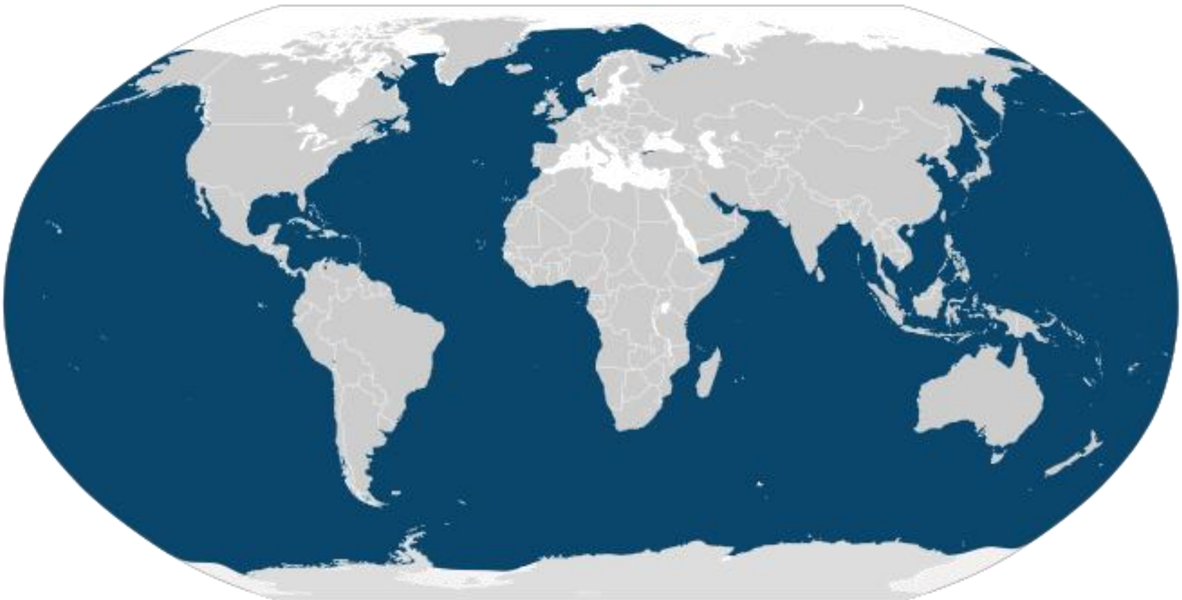


Figure 2: Distribution of *Megaptera novaeangliae.* *M. novaeangliae* occurs in all oceans of the world but not in polar pack ice zones (Chittleborough, 1965). Image from Cypron-Range_Megaptera_novaeangliae.svg.

Between winter and summer season they migrate over long distances, dependent on sex and age. During the winter season from approximately November to March in the northern hemisphere they stay in warmer tropical breeding areas, where they mate and give birth to their calves. In summer they go further poleward (Norris, 1977; Pomilla and

Rosenbaum, 2005). In those low-temperature waters they find rich feeding grounds because of more abundant planktonic crustaceans and fish in northern latitudes (Figure 3). Humpback whales' diet mainly consists of zooplanktonic euphausiid krill and pelagic schooling fish, for example capelin (*Mallotus villous*), herring (*Clupea harengus,*), mackerel (*Scomber scombrus*) and sand lance (*Ammodytes* sp.) (Katona and Beard, 1991; Stevick *et al.* 2006; Weinrich *et al.*, 1997).

Figure 3: Feeding humpback whales. Baleen whales filter food such as krill and small fish out of the water by pressing the engulfed water with their tongue through their baleen plates. (Photos: Luisa Klotz)

Brown *et al.* (1995) detected a high shift in sex ratio of humpback whales towards males in breeding areas; consequently some females clearly remain in their feeding grounds in higher latitudes also during winter.

Stevick *et al.* (2003) published a study on humpback whales in the North Atlantic, where they determined that the whales' migration patterns depend on their feeding grounds. The further north their summer feeding grounds are located, the later they arrive in their breeding latitudes. Furthermore females stay longer in those breeding areas than male individuals because of their offspring. Craig *et al.* (2003) also discovered in their studies on humpback whales in the Central North Pacific, that migratory timing of *M. novaeangliae* varies with age, sex and reproductive status. The juveniles have been observed migrating first, followed by males and females without calves. The last individuals starting their migration are most likely males and females accompanied by their offspring.

Nonetheless, reasons for the long migration routes of baleen whales remain still unclear. Brodie (1975) published the most popular explanation, which states that migration patterns result from optimizing energy budgets. Humpback whales breed in areas close to the equator during the season of lowest temperatures in polar waters to minimize the costs of sustaining the body temperature. This especially benefits the calves with less body fat. Though it remains unproven that the offspring would not survive in colder waters. According to Watts *et al.* (1993) all baleen whale calves which are larger than minke whales should be thermo neutral even in polar regions during winter time. Another theory proposes that offspring survival increases in calmer waters because of energy saving when surfacing compared to the usually rougher sea conditions in higher latitudes during winter time (Whitehead and Moore, 1982). Though other studies showed that there is no evolutionary pressure on choosing breeding grounds in lower latitudes, researchers such as Brown *et al.* (1995), Straley (1990), Clapham *et al.* (1993) and Swingle *et al.* (1993) recognized that some humpback whales do not undertake the complete migratory route every year but stay in higher latitudes. This could support for Evans' theory (1987) that the whale migrations are some kind of tradition without clear advantages. Corkeron and Connor (1999) favor the theory of predation pressure as a reason for migration. In their paper on baleen whale migration they claim that killer whales, occurring mainly in higher latitudes, represent a higher predation risk for newborn calves than predators living in warmer waters, such as sharks and false killer whales. Consequently, migration could be one option to avoid high predation pressure.

1.3 Distribution in the North Atlantic

Humpback whales mainly occur close to the shore, but also in deeper waters, especially during migration (Clapham and Mattila, 1990). In the eastern part of the North Atlantic distribution of *M. novaeangliae* ranges from Iceland, Scotland and Norway to Novaya Zemlya in the Barents Sea. Their breeding grounds are located in the West Indies, the north of the Dominican Republic and close to the coastal area of Puerto Rico (Balcomb and Nichols, 1982; Whitehead, 1982) but also close to the Cape Verde Islands and West Africa (Baker *et al.*, 1990; Katona, 1986; Kellogg, 1929; Vigness-Raposa *et al.*, 2010; Wenzel *et al.*, 2009). Humpback whales summering in the western North Atlantic have their feeding grounds in Denmark Strait west of Iceland, Southern Labrador and Greenland and the Gulf of Maine (Stevick *et al.*, 2003) (Figure 4). Tests on mtDNA haplotypes by Baker *et al.* (1990) assume that within the major populations several distinct seasonal subpopulations exist. Exchange rates in summer feeding grounds are relatively low, but mixing in lower latitude breeding areas has been recorded (Palsbøll *et al.*, 1997).

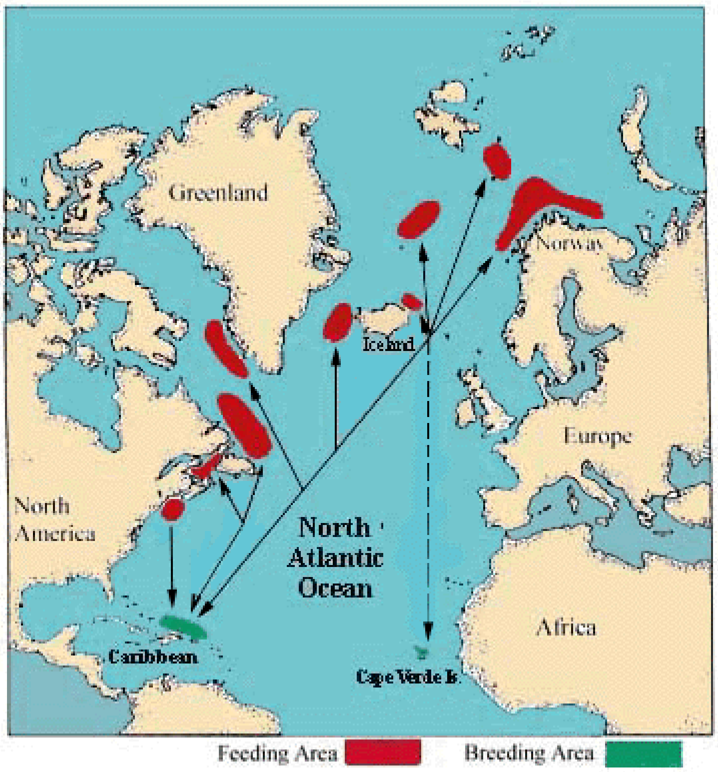


Figure 4: Known feeding and breeding grounds of *M. novaeangliae.* Feeding grounds are located in the Gulf of Maine, Canada, West-Greenland, Iceland, Norway, and the Mid-North Atlantic. Breeding grounds are close to the Cape Verde Islands and mainly in the West Indies. Lines show exchange between regions but no actual migration routes. Image from http://www.coastalstudies.org/what-we-do/humpback-whales/years-of-humpback-whale_files/image001.png.

Those humpback whales with feeding grounds in the eastern North Atlantic usually travel alone and show, in contrast to humpback whales in the Gulf of Maine or South-eastern Alaska, no cooperative foraging. There they form fluid fission fusion groups and developed cooperative feeding techniques, for example the so-called *bubblenet feeding* (Clapham, 2000; Sharpe, 2001; Weinrich *et al.*, 2006).

M. novaeangliae is thought to be a philopatric species, which means individuals return to their home area for reproduction (Boye *et al*., 2010; Mitchell, 1974; Palsbøll *et al*., 1997; Whitehead, 1982). Weinrich (1998) proved with his studies in the Gulf of Maine, that mature humpback whales showed significantly higher return rates to areas where they already have been sighted as calves, suggesting that early experience influences the choice of habitat and feeding area. Consequently, humpback whales seem to learn the way to their feeding areas from their mother during their first migration (Clapham 2000).

Further studies, based on photo-ID (see chapter 1.6), also support the theory of strong large-scale site fidelity (Palsbøll *et al.*, 1997; Stevick *et al.*, 2006).

In contrast to those results, Stevick et al. (2011) published a report on female humpback whales migrating 10000 km between their breeding grounds. These facts lead to the assumption that Humpback whales are quite variable in their migration routes and possibly not in every case as philopatric as they were expected to be.

1.4 Whaling

Humpback whales were commercially hunted mainly during the 1860s and early 1900s (Tønneessen and Johnsen, 1982). Consequently abundance of *M. novaeangliae* strongly decreased during those whaling periods. It was often the first species to be hunted close to extinction (Clapham *et al.*, 1997). In 1955 the International Whaling Commission (IWC) protected humpback whales from commercial whaling in the North Atlantic, in 1964 in the southern hemisphere and finally in 1966 in the North Pacific (Best, 1993).

In Iceland modern whaling started in the early 1880s and continued until 1915, when it was stopped by a prohibition for land-based whaling of the Icelandic parliament. The whaling industry focused mainly on bigger whale species and the total amount of catch is estimated at around 6000 blue whales, 8000 fin whales and 3000 humpback whales. Whereas former whaling stations have been located in the northwest and east of Iceland, a station in the western part started whaling again in 1935 for five years, catching 469 whales of which two were humpback whales. Whaling continued until 1985 from Hvalfjörður, a land station in South West Iceland (Sigurjónsson and Gunlaugsson, 1990).

Estimates for humpback whale abundance before whaling suggest around 240000 humpback whales in the North Atlantic (Roman and Palumbi, 2003). In contrast, current estimates by Smith *et al.* (1999) and Stevick *et al.* (2003) assume a North Atlantic population size of approximately 10600 and 11570 individuals, respectively, based on data collected during the mid-90s. Multiple partial-area surveys from 1996 to 2001 estimated about 3246 humpback whales in the North East Atlantic (Øien, 2009). As the stocks are constantly increasing again, the IUCN changed the red list category for *M. novaeangliae* from Vulnerable to Least Concern (Reilly *et al.*, 2008).

1.5 Study area

Data were taken in Skjálfandi Bay, located in the north of Iceland, 66°05′N 17°33′W (Figure 5). This bay is about 25 km long and the maximum depth reaches down to 220 m (Gíslason, 2004).

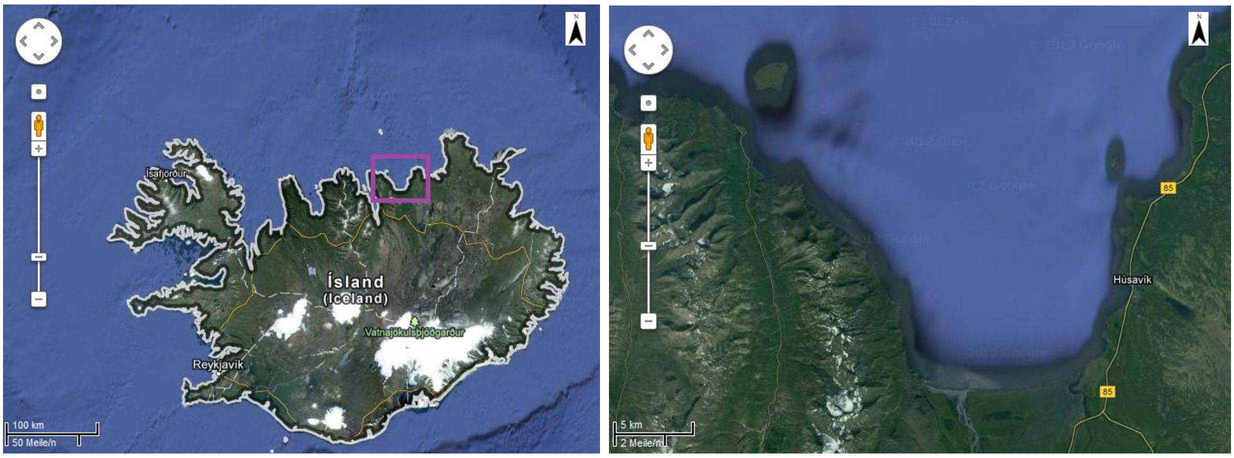


Figure 5: Study area Skjálfandi Bay. The bay is located in the northeast of Iceland, approximately 50 km south of the Arctic Circle. Two freshwater rivers flow into the southern part of the bay. Along the western coast the Viknafjöll mountains reach up to 2000 m. Two islands are located in Skjálfandi Bay: Flatey in the northwest and Lundey in the mid-eastern part. Images from maps.google.de.

The waters around Iceland show differences in temperature, nutrient content, salinity and other factors. The northern and eastern areas are subject to stronger fluctuations, depending on the variable influence of Atlantic, Arctic and Polar waters (Figure 6) and as a result less constant than the waters south and west of Iceland (Jonsson and Valdimarsson, 2005). Consequently mean annual production is higher in southern and western parts of the sea around Iceland, due to less varying Atlantic sea water (Astthorsson *et al.*, 2007).

Water masses from the south show higher temperatures and salinity, mixing in the north of Iceland with colder, less saline waters from Arctic regions, also influenced by freshwater input from rivers. In Skjálfandi Bay, two freshwater rivers, rising from Lake Mývatn and Iceland’s biggest glacier Vatnajökull, flow into the southern part of the bay, raising nutrient concentrations and decreasing salinity in those areas (Gíslason, 2004).

Several studies revealed increasing water temperature and salinity in previous years (Astthorsson *et al.*, 2007).

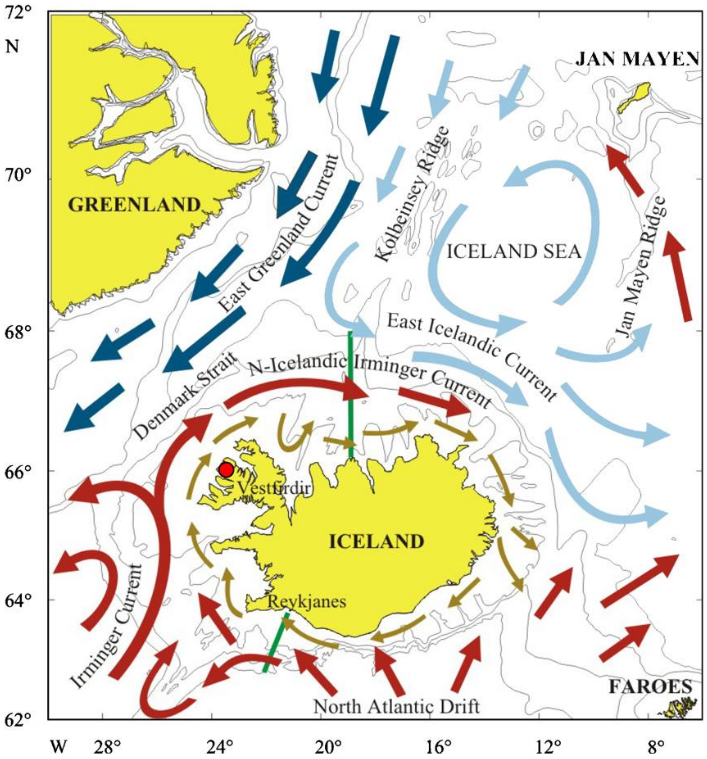


Figure 6: Surface ocean currents around Iceland. Green lines mark hydrographic monitoring transects (Siglunes, north of Iceland; Selvogsbanki, south of Iceland), the red dot the position of the meteorological station at Thverfjall. Image from Astthorsson *et al.*, 2007; modified from Vilhjalmsson, 2002.

The most common fish species are capelin (*Mallotus villosus*) and cod (*Gadus morhua*), which are potential prey for humpback whales (Borobia *et al.* 1995). Due to fluctuations in the impact of Atlantic, Arctic and polar water masses, waters north of Iceland are less constant in relation to nutrient availability than in the south. Consequently, food chains show higher variability, ultimately influencing the occurrence of whales (Astthorsson *et al*., 2007).

1.6 Photo-Identification

Scientists developed a variety of methods for researching marine mammals to conduct more information on their population biology, their behavior as well as their ecology. Some of those methods require direct contact with animals or disturbing them in various ways, as happens when catching or tagging the animals to mark them, to examine their sensory perceptions, their behavior etc. Although those methods may provide scientists with reliable data, they also imply strong interference factors for the wildlife. One possibility to avoid disturbances is to use so-called non-invasive methods such as photo-identification (Larsen and Hammond, 2004). Clearly, those methods have limitations. Thus some species are unsuitable because they lack permanent markings, which are useful for photo-ID (Auger-Méthé *et al*., 2007). Furthermore, weather conditions, visibility, the available equipment and other external factors may limit the potential of those studies. Importantly, however, those methods enable researchers to study individuals in their natural habitat without disturbing or manipulating them. Animals' natural markings have a variety of advantages: Scientists have no effort or costs with marking their study subjects. Furthermore they do not affect the individual's behavior - in contrast to artificial approaches. In the majority of cases those natural markings are permanent, which means that they can be utilized for identification throughout the lifespan and even after the individual's death.

Though natural markings may change or some individuals show very similar patterns impeding distinguishing between them, the error rate in the case of humpback whales is relatively low and the advantages predominate by far (Carlson, Mayo and Whitehead 1990).

The already mentioned photo-identification employs natural markings of animals such as color patterns, scars, shapes etc. to identify individuals. This so-called capture-recapture method provides a wealth of information, offering valuable clues to determine the species' abundance and, with the help of statistic models, to calculate the population increase rate, mortality or other parameters; as well as identify patterns of residency, site fidelity as well as annual and seasonal patterns of migration (Hammond, 1986). Furthermore one may assess the health status of individuals by more closely examining scars, parasites and the individuals' general appearance. Last but not least those studies provide information on the animals' movement patterns, if they have been spotted in different places (Larsen and Hammond, 2004).

Such findings are necessary for generating the scientific principles of conservation programs or protection plans.

Photo-ID of humpback whales

Photo-identification is a very common method for studying cetaceans. Already in 1979, Katona *et al.* studied humpback whales of the western North Atlantic by using photo-ID.

In Skjálfandi-Bay, photo-identification is applied for different species, for example blue whales, minke whales and white beaked dolphins (*Lagenorhynchus albirostris*) as well as *Megaptera novaeangliae*. Humpback whales show a unique black and white pattern on their flukes' ventral surface. But also the shape of the dorsal fin, which is variable in size as well as shape, and markings such as scars are important for identifying different individuals (Clapham and Mayo, 1987; Katona and Whitehead, 1981). Moreover humpback whales lift their flukes when going down for a deep dive, which enables taking photos of the ventral surface of the tail fluke (Figure 7). These markings are unique for every individual and therefore suitable for identifying individual animals. Note, however, that several studies revealed coloration pattern changes. Especially scars and scratches varied over time, whereas the main color pattern of the fluke and particularly dorsal fin shape remained on the whole unchanged (Blackmer *et al.*, 2000). Researchers must be aware of such variations, but they occur very rarely and mainly in calves and should not limit the practicability of photo-identification (Carlson *et al.*, 1990). Allen *et al.* (2004) even assumed that local differences in coloration pattern, regarding the amount of pigmentation, are noticeable and refer to distinct subunits in the North Atlantic humpback whale population.

Figure 7: Flukes of humpback whales. The pattern on the lower side is unique for every individual and therefore used for photo-identification. (Photos: Luisa Klotz)

1.7 Aims

In the past, humpback whales were overexploited by commercial whaling and most of the populations reduced to small sizes. Since the stop of commercial whaling, populations seem to increase again. In addition, a change of mind has taken place. Instead of hunting the animals, whale watching is increasingly popular in many regions. Especially in Iceland whale watching is a booming industry. In Húsavík, Northern Iceland, two whale watching companies offer a wide range of different trips.

But although commercial whaling has been stopped, further treatments such as marine pollution, habitat degradation and rising disruption by whale watching operations still endanger the animals.
To evolve effective protection efforts and management policies it is important to investigate the animals' occurrence and distribution patterns as well as preferences for feeding grounds.

This study is aimed to investigate annual and seasonal distribution patterns of humpback whales in Skjálfandi Bay, focusing on following priorities:

1. With the help of data from previous years collected by researchers and volunteers, North Sailing logbooks and own data from 2012 the annual development in humpback whale occurrence is to be examined. Follows this population the global trend and increases?
Are there differences between the main species occurring in Skjálfandi Bay, including *Megaptera novaeangliae*, *Balaenoptera acutorostrata*, *Balaenoptera musculus*, *Lagenorhynchus albirostris* and *Phocoena phocoena*?

2. Are differences in sighting frequencies of humpback whales between different months recognizable? And are encounter rates dependent on the time of the day?

3. In case annual or seasonal differences of sighting rates are determined, is there a correlation between humpback whale occurrence and sea water temperature, which likely influences plankton growth and prey distribution?

4. Furthermore the distribution within Skjálfandi Bay is to be investigated. Are there regions the whales prefer to visit? Are there seasonal differences in these distribution patterns as well?

5. Photo-ID is to be used to investigate the number of new and resigthed individuals. How many individuals show strong small scale site fidelity and return for many years to Skjálfandi Bay? Do they stay in the bay for weeks or only for several days?

6. Finally, an overview over life histories of selected individuals, which were sighted for at least three years in Skjálfandi Bay, should help to identify common migration and distribution patterns.

This information about general distribution patterns, trends in abundance and individual characteristics is intended to improve insights into the humpback whales' behavior connected with their habitat and thus, assist conservation efforts.

2 Materials and Methods

2.1 Data acquisition

2.1.1 Study area

Data collection took place in Skjálfandi Bay, which is located in the northern part of Iceland (Figure 8).

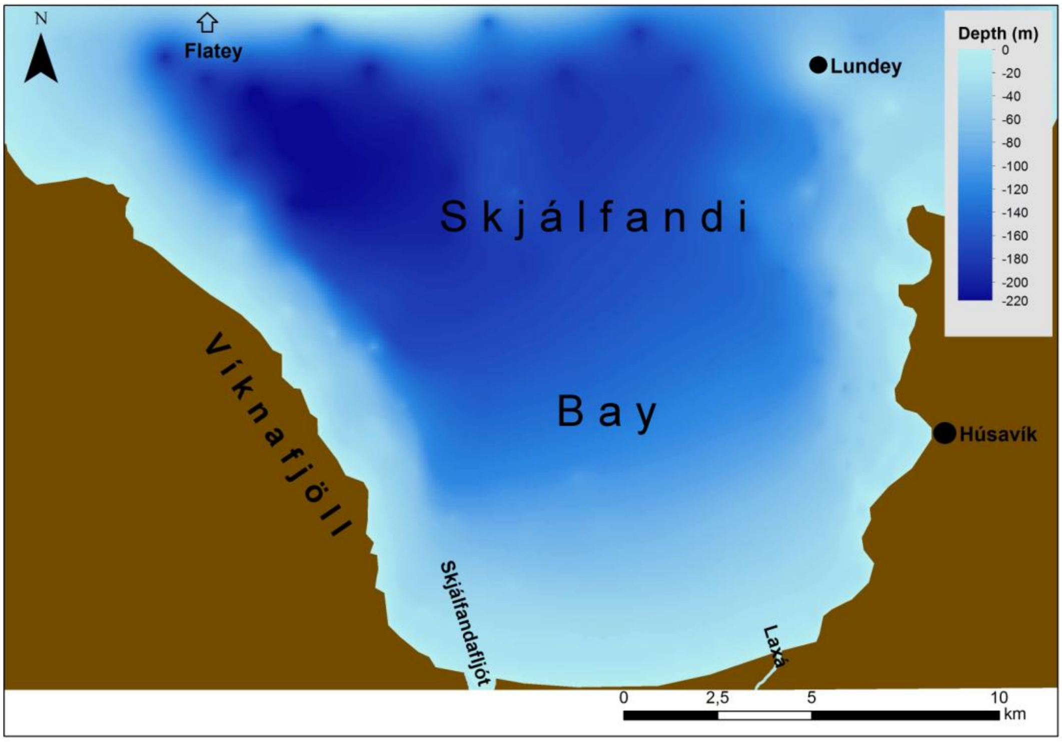


Figure 8: Research area of Skjálfandi Bay. Deepest areas reach up to 220 m depth and are mainly located in the western part of the bay.

For this thesis, data collection started in May 2012 and continued until October to cover almost one complete summer season. Weather conditions permitting, every day one to three whale watching tours have been attended. Researchers are permitted to go on board of the six whale watching boats operated by North Sailing and use them as research vessels (Figure 9).

Figure 9: Whale watching boats operated by North Sailing. Researchers were permitted to use six different whale watching boats, including two sailing schooners, as research vessels. (Photo: Luisa Klotz)

2.1.2 Data collection

The time of day for sailing out depended on offered trips, weather conditions and number of tourists. For every tour the route was tracked, with GPS-positions, determined every five minutes with GPSmap 60CSx GARMIN. Additional marks were set when approaching a whale or dolphin because data collection included not only humpback whales but all marine mammal species. Every fifteen minutes, weather conditions were recorded, using IC Recorder ICD-P110 SONY, including cloud coverage, visibility, glare, sea state, swell and wind direction. All data were entered in Excel files. Table 1 shows an example.

Table 1: Effort files for data collection. Besides sighting data every 15 min environmental parameters such as sea state and weather conditions were noted.

DATE/ BOAT	*TRIP*	*BOAT START /END*	*EFFORT*	*15 MIN BLOCKS*	*SPECIES*	*ENC. NO.*	*TIME START*	*TIME END*	*BEST*	*MIN/ MAX*	*CLOUD COV.*	*SEA STATE*	*PRECIP.*	*WIND DIREC.*	*GLARE*	*SWELL HEIGHT*	*VISIBILITY*	*COMMENTS*
14.07.	08:50	08:53/	08:58	09:00							overcast	1	0	NW	0	light	good	
2012		11:32	11:06	09:15	La	D1	09:18	09:27	8	8 - 15	overcast	2	0	NW	0	light	good	Waypoint 066 - 069; Dolphins jumping, bow-riding; 3 calves
Náttfari				09:30	Mn	H1	09:42	10:37	2	2	overcast	2	0	NW	0	light	good	Waypoint 073; surface feeding; bubble net feeding; 12 arctic turns, 1 fulmar;
				09:45	La	D2	09:47		5	5	overcast	2	0	NW	0	light	good	Dolphins further away, 1 Mn lobtailing, flipper slapping
				10:00	Mn	H2	10:14	10:37	1	1	overcast	2	0	NW	0	light	good	Waypoint 076; third humpback arriving, joining the other two; Waypoint 082 leaving the 3 humpbacks
				10:15							overcast	2	0	NW	0	light	good	
				10:30							overcast	2	0	NW	0	light	good	
				10:45							overcast	1	0	NW	0	light	good	
				11:00	Pp	P1	11:02		3	3	overcast	1	0	NW	0	light	good	Waypoint 082; boat didn't stop
				11:15							overcast	1	0	NW	0	light	good	
				11:30							overcast	1	0	NW	0	light	good	

2.1.3 Provided data

For analyzing annual and seasonal distribution patterns, data have been provided from the Húsavík Whale Museum, offering a Humpback Whale Catalogue, which contains all humpback whale individuals that have been identified since 2001. The catalogue contains information about ID-characteristics (see chapter 2.2.1), sighting data (date, number of trip on which the whale has been sighted, number of available photos) and - if available - additional information, for example information on sightings in other areas than Skjálfandi Bay.

Furthermore, Effort files created by volunteers of the Húsavík Whale Museum and the Research Center were used to obtain data from previous years (April/May – September/October from 2003 to 2011) as well as from April and early May 2012.

The whale watching company North Sailing provided access to their logbooks with sighting data from 1995 on.

2.2 Data analysis

2.2.1 Photo-identification

Once humpback whales were sighted, photos were taken (Camera: EOS 60D CANON 28-135 mm) – if possible – of the dorsal fin, ideally from both sides and positioned perpendicular to the animal. Furthermore the ventral pattern of the tail fluke was photographed. To achieve best quality for identifying the individuals, the photos' size, brightness or contrast were modified with the help of image editing programs such as GIMP and Paint. In a final step the pictures were compared with those in the Humpback Whale Catalogue of the Húsavík Whale Museum. Most of the information was therefore gained from the black and white pattern on the lower side of the fluke, but also from the shape of the dorsal fin and sometimes additional marks such as scars or barnacles (Figure 10), as already explained in detail in the Introduction chapter (Katona and Whitehead, 1981; Larsen and Hammond, 2004).

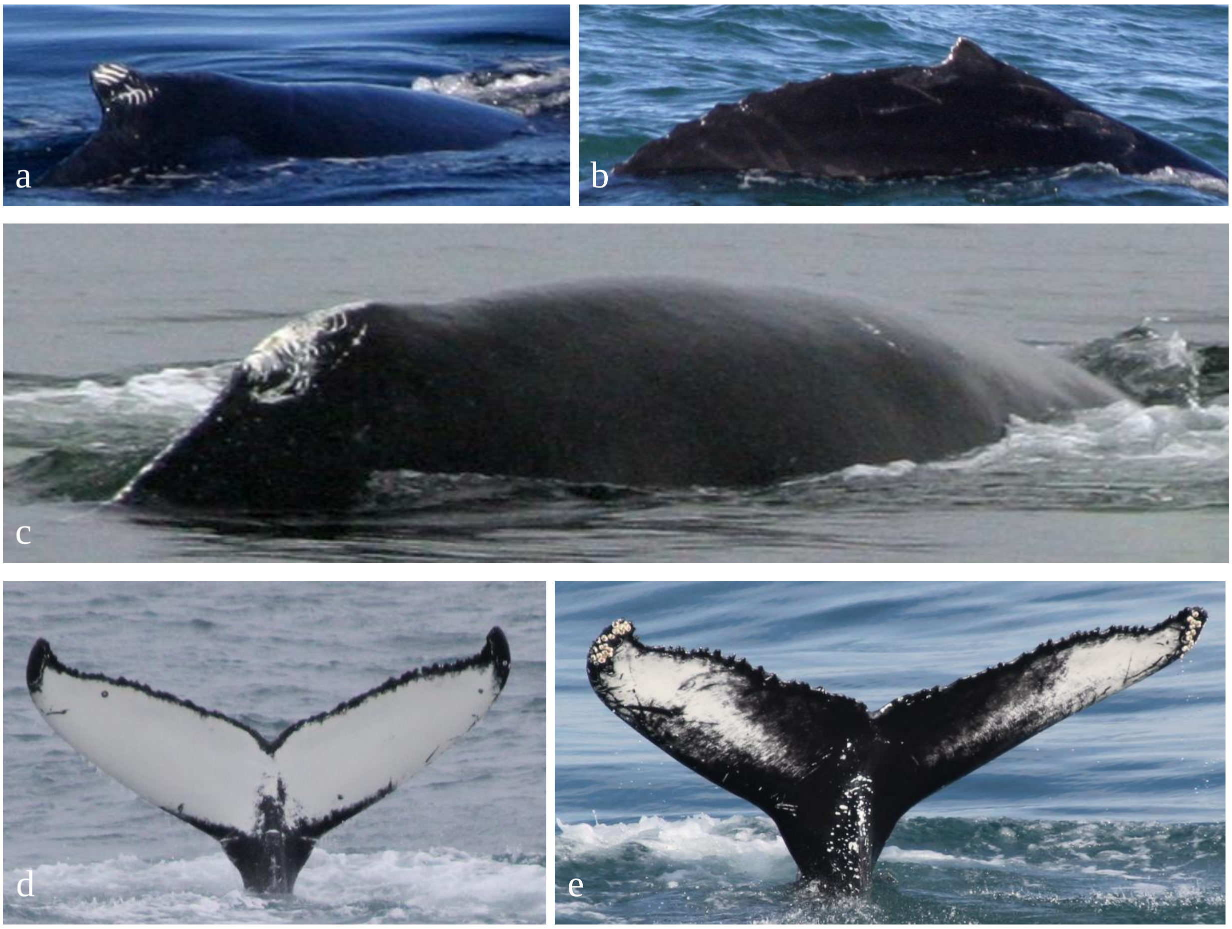
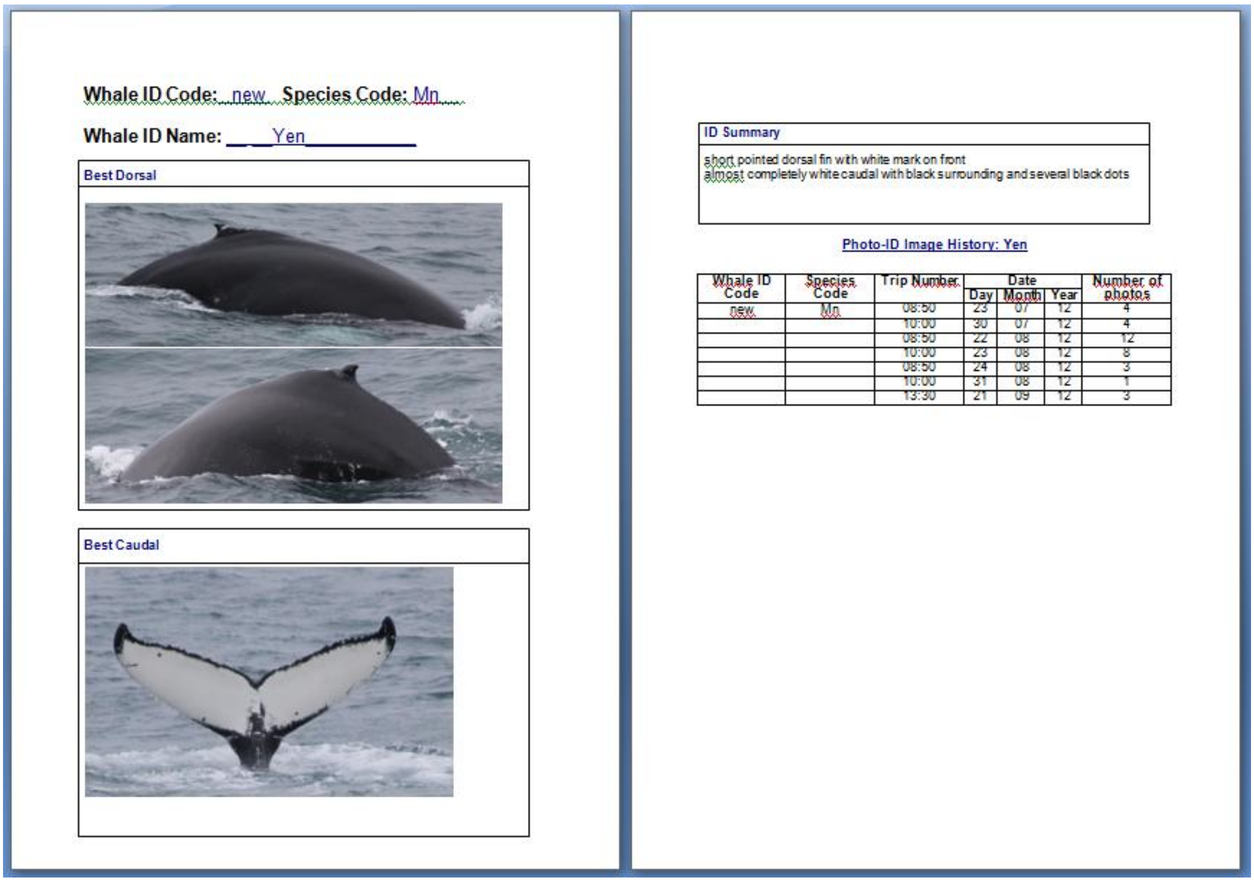


Figure 10: Pictures of dorsal fins (a – c) and flukes (d, e) of *M. novaeangliae*. Especially marks such as scars and injuries as well as the color pattern of the flukes facilitated the identification of individuals. (Photos: Luisa Klotz)

Resightings – meaning the individual has been sighted in Skjálfandi Bay in previous years – were recorded, for newly identified humpback whales a profile was created, which contained photos and characteristics as well as sighting data of the individual (Figure 11).



Whale ID Code: new Species Code: Mn

Whale ID Name: Yen

Best Dorsal

Best Caudal

ID Summary

short pointed dorsal fin with white mark on front
almost completely white caudal with black surrounding and several black dots

Photo-ID Image History: Yen

Whale ID Code	Species Code	Trip Number	Date			Number of photos
			Day	Month	Year	
new	Mn	08:50	23	07	12	4
		10:00	30	07	12	4
		08:50	22	08	12	12
		10:00	23	08	12	8
		08:50	24	08	12	3
		10:00	31	08	12	1
		13:30	21	09	12	3

Figure 11: Profile of an identified humpback whale in the Humpback Whale Catalogue of the Húsavík Whale Museum. Data included photos, characteristics and sighting data. The individual shown in the example has no ID code, because analysis of photos from the summer season 2012 is not yet completed.

Matching programs

The photo comparison was mainly done manually but two computer matching programs, DARWIN and Fluke Matcher, were also tested.

DARWIN

DARWIN was primarily created to compare dorsal fins of dolphins, but is also useable for humpback whales, because they also show unique differences between their dorsal fins. Using the program requires sharply focused photos of the fins, in a perpendicular angle to the animal. For comparison only a small cut-out is used – solely the dorsal fin without any part of the back. The photo must show the whale swimming to the left. After getting the right orientation, one can modify the brightness and the contrast of the image. In the next step the outline of the fin is either automatically or manually. Finally the program compares the shape of the dorsal fin with those already stored in the catalogue.

Fluke Matcher

The program ‘Fluke Matcher’ is used for comparing the whales’ flukes. The photos have to be taken from directly behind the animals and they must be cropped before being entered into the database, so that the line between the fluke tips runs parallel to the top of the frame. The program offers numerous marking options. One can measure the distances between several points, focus on the shape and different angles, do additional measurements, highlight scars, injuries, color variations etc. This yields very detailed information of the fluke of one individual. It is also possible to store more than one photo of one individual taken from different angles, which enlarges the matching quota.

2.2.2 Effort analysis

For analyze the number of whales sighted in Skjálfandi Bay it was necessary to use a comparable value instead of the total number of sightings. This is because the amount of effort differed between years and months. Consequently cetacean sightings per unit effort (SPUE) were calculated by using the following formula:

$$Sightings\ per\ Unit\ Effort = \frac{Number\ of\ Sightings}{Minutes\ Effort} \qquad SPUE = \frac{n}{LT}$$

where n corresponds to the total number of sightings. L_T is the total amount of time spent on surveys (total effort = minutes spent per trip).

2.2.3 Statistics

Statistical analyses were performed using SigmaPlot 11.0.
For the tests, SPUE values rather than total numbers were used. First of all values, presented as means with standard deviations, are introduced in graphs to give an overview over the years or months.
To analyze whether the amount of humpback whales, which have been sighted in Skjálfandi Bay, changed between different years or seasons, Kruskal-Wallis one way analysis of variance (ANOVA) was performed. If data failed to meet the criteria of normality, square root transformation was done to achieve stronger tests. All significance

levels were set at p values < 0.05. Same procedure was done to analyze the duration of stay, sighting rates of the main species occurring in the bay (minke whale (*Balaenoptera acutorostrata*), blue whale (*Balaenoptera musculus*), humpback whale (*Megaptera novaeangliae*), harbor porpoise (*Phocoena phocoena*), white beaked dolphin (*Lagenorhynchus albirostris*)). When focusing on identified individuals, the number of sightings and resightings per year, t-tests and in addition to that linear regressions were done to show the general increase or decrease of sightings over time.
To determine if the number of humpback whale sightings correlate with sea surface temperature averages in Skjálfandi Bay (available until 2011), Pearson Product Moment Correlation was chosen. Temperature data are published on http://www.hafro.is/Sjora/.

2.2.4 Distribution analysis

To visualize distribution patterns of humpback whales within the bay, maps were constructed with the help of ArcGIS 10.1.
The first step was to create a basic map of Skjálfandi Bay, showing the correct coordinates and the different depths. Therefore data from two different maps showing points and contours of depths were combined in one map.
Furthermore, GPS data were entered, showing the positions of humpback whale sightings.
For analyzing the data, Kernel Density Estimation, a method for estimating probability distribution of a random variable, was performed, providing continuous estimation of the unknown distribution (Silverman, 1986). Kernel Density Estimation represents a uniformly consistent, continuous estimator of an unknown probability measure by a series of densities, often used in ecological analysis. Thus, the probability with which one animal stays in a specified geographical area can be calculated. Action-space predictions are represented by colored lines (Rodgers and Kie, 2011).

The life histories of selected individuals were analyzed by using the information recorded in the Humpback Whale Catalogue. This information included all years in which the individuals have been sighted as well as the day (regardless of the number of tours on which the whale has been spotted at particular) and month of the first and last sighting for each year. Furthermore the number of days on which the whale has been sighted in

Skjálfandi Bay was determined. Therefore the days the whale was observed were counted, regardless of the time in between.

3 Results

3.1 Annual distribution

Sighting data provided by the Húsavík Whale Museum and the Húsavík Research Center included all years since 2003. In addition to this in 2012 data collection took place over nearly the whole whale watching season. The tracked routes of the whale watching boats which have been unsed as research vessels are presented in Figure 12.

3.1.1 Effort analysis

Since 2003, encounters with humpback whales on whale watching tours were recorded. However, only the number of sightings have been recorded, without distinguishing between sightings and resightings.

Figure 12: Vessel tracks of research season 2012. The routes the whale watching boats sailed were tracked to visualize the spatial effort within the study area.

Figure 13 shows the monthly vessel tracks from May – October 2012.

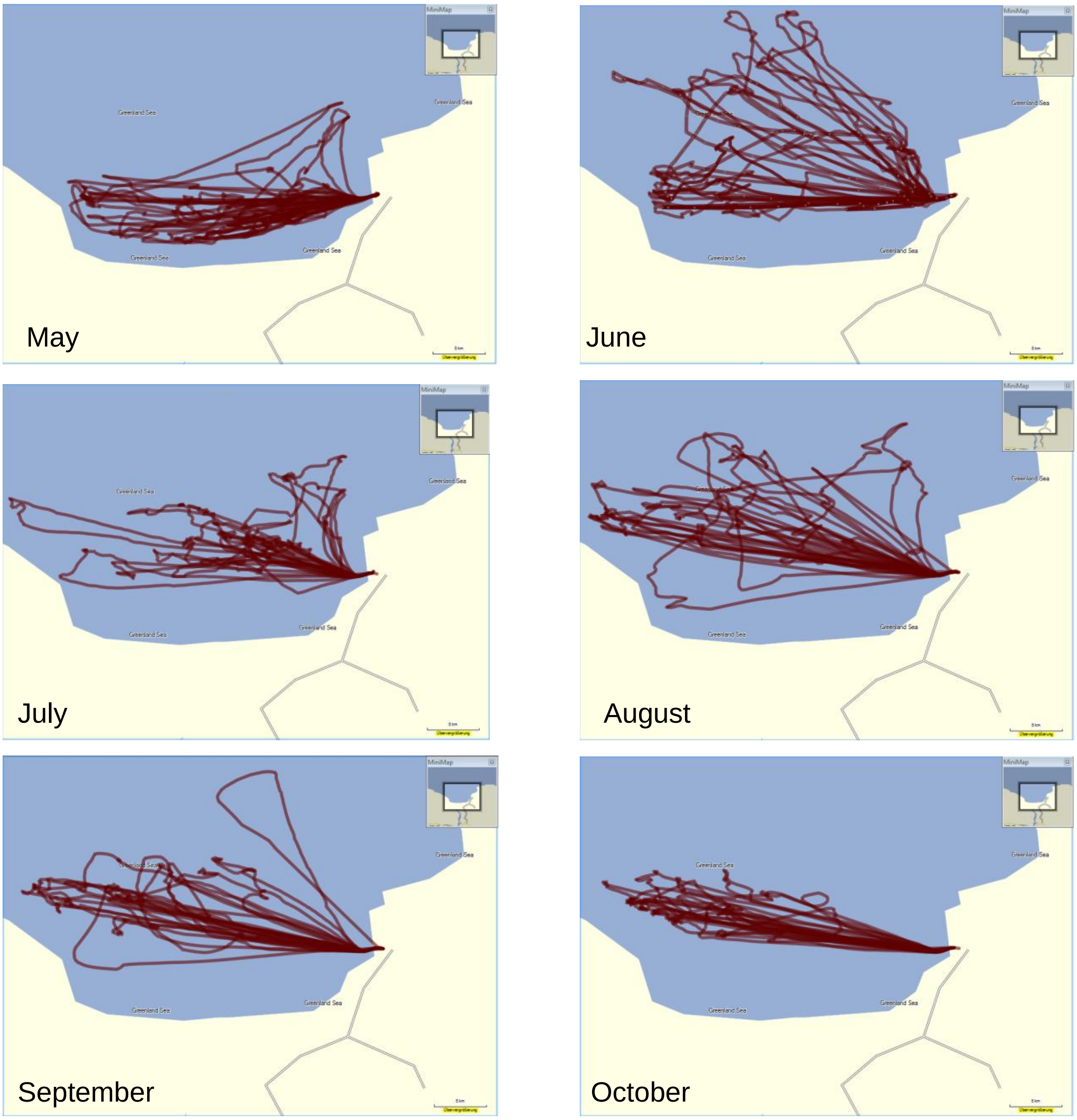


Figure 13: Vessel tracks from May to October 2012. The number of tours as well as the routes depended on factors such as the number of offered whale watching tours, weather conditions etc. and consequently show differences between the months.

The survey area depended on the whale watching routes. Typically the boats sailed into the western part of the bay, infrequently further south or north. During the main season from 1st June to 20th August, frequent tours to Lundey were offered, which provided information about sightings in the northeastern part of Skjálfandi Bay. To scan a broad area, all the boats stayed in contact, informing each other about sightings.

Table 2 shows the amount of for survey effort, expressed in minutes, since 2003.

Table 2: Survey effort for 2003 to 2012 during summer research seasons. For each year both monthly and total effort data, expressed in minutes, are reported. Data from 2003 to June 2012 from the Húsavík Research Center.

	May	June	July	August	September	October	Total Effort
2003	245	184	1373	946	0	0	2748
2004	0	0	1698	1996	0	0	3694
2005	0	3046	4201	3497	778	0	11522
2006	1360	4340	3585	3478	175	0	12938
2007	2164	4488	4449	3279	470	0	14850
2008	2308	4229	3022	4321	2018	0	15898
2009	4277	4441	3673	2848	526	0	15765
2010	1806	4758	5165	4294	2435	624	19082
2011	863	4702	7711	5003	539	0	18818
2012	4677	4408	4620	2886	2486	2111	21188

The number of minutes spent for effort differed over the years, starting at a low level in 2003 and 2004, but continuing on a high, slightly increasing level from 2005 to 2008 and a major effort of 19082 minutes in 2010. 2012 was the year with the greatest effort (21188 minutes). Except in 2010 and 2012, no effort was undertaken in October. Moreover, in 2003 no effort was reported for September, in 2004 for May, June and September, as well as in 2005 for May. Consequently no sighting data are available for these months. In all years the months May to August showed the greatest effort, with the peak value being 7711 minutes in July 2011, whereas in spring and autumn, effort was low on average.

For the research seasons from 2003 to 2012 a total of 1401 sightings of humpback whales was reported, of which 519 took place during the summer of 2012 (Table 3).

Table 3: Number of humpback whale encounters for 2003 to 2012 during summer research seasons. For each year both monthly and total numbers of sightings are reported. Data from 2003 to June 2012 from the Húsavík Research Center.

	May	June	July	August	September	October	Total
2003	0	0	0	1	0	0	1
2004	0	0	8	0	0	0	8
2005	0	16	10	6	3	0	35
2006	19	87	41	24	0	0	171
2007	20	62	49	19	0	0	150
2008	12	24	55	21	2	0	114
2009	45	36	49	7	2	0	139
2010	21	14	2	1	8	9	55
2011	11	34	67	95	2	0	209

2012	134	54	168	41	38	84	519
Total	262	327	449	215	55	93	1401

3.1.1.1 Comparing means of SPUE between years

Table 4: Sightings per Unit Effort (n/minutes). For each year both monthly and average SPUE are reported. Data from 2003 to June 2012 from the Húsavík Research Center.

	May	June	July	August	September	October	Average
2003	0	0	0	0.001	0	0	0.0001
2004	0	0	0.0047	0	0	0	0.0007
2005	0	0.0053	0.0023	0.0017	0.0038	0	0.0021
2006	0.0139	0.02	0.0114	0.0069	0	0	0.0087
2007	0.0092	0.0138	0.011	0.0057	0	0	0.0066
2008	0.0051	0.0056	0.0181	0.0048	0.0009	0	0.0057
2009	0.0105	0.0081	0.0133	0.0024	0.0038	0	0.0063
2010	0.0116	0.0029	0.0003	0.0002	0.0032	0.0144	0.0054
2011	0.0127	0.0072	0.0086	0.0189	0.0037	0	0.0085
2012	0.0286	0.0122	0.0381	0.0142	0.0152	0.0397	0.0246
Average	0.0091	0.0075	0.0107	0.0055	0.003	0.0054	

2003 marked the year with fewest sightings per unit effort, with an average of 0.0002/minute, whereas after a brief increase in 2006 the year 2012 shows the highest SPUE (average: 0.0247/minute), which is illustrated in Figure 14.

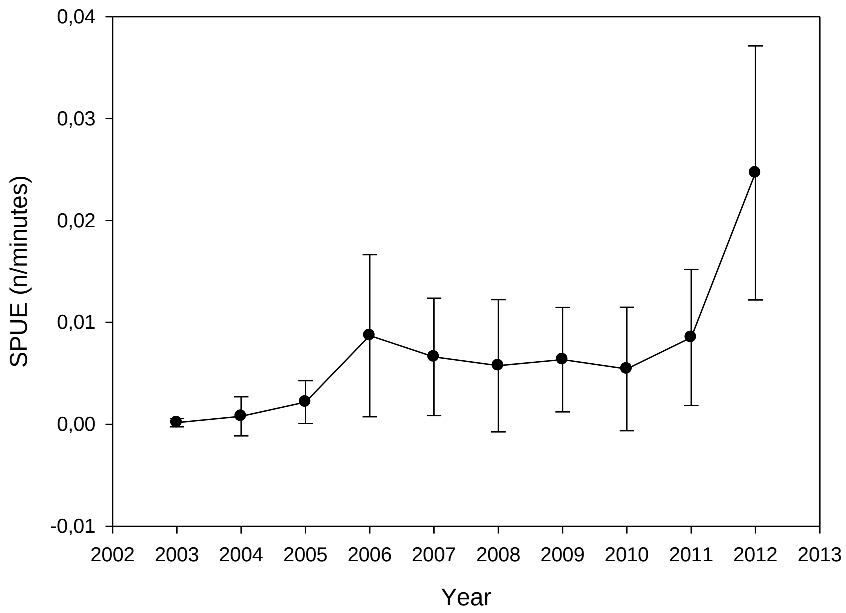


Figure 14: Mean *M. novaeangliae* abundance and standard deviations in SPUE from 2003 to 2012 (n/minutes). The number of humpback whale sightings per effort increased until 2006, then decreased 2010, interrupted by an increase in 2009. From 2011 to 2012 the number of sightings increased considerably.

The difference in SPUE between the years is significant (H(9)=27.754, *p*=0.001) (Table 5).

Table 5: *M. novaeangliae* abundance in SPUE from 2003 to 2012. There is a significant difference in SPUE between the years (H(9)=27.754, *p*=0.001).

SPUE from 2003 to 2012					
Group	**N**	**Missing**	**Median**	**25%**	**75%**
2003	6	0	0.000	0.000	0.000
2004	6	0	0.000	0.000	0.000
2005	6	0	0.00200	0.000	0.00380
2006	6	0	0.00915	0.000	0.0139
2007	6	0	0.00745	0.000	0.0110
2008	6	0	0.00495	0.000900	0.00560
2009	6	0	0.00595	0.00240	0.0105
2010	6	0	0.00305	0.000300	0.0116
2011	6	0	0.00790	0.00370	0.0127
2012	6	0	0.0219	0.0142	0.0381

Statistical testing	Test	Detail	*d.f.*	Critical	*p* value
	One-Way ANOVA	All years compared	9	H=27.754	0.001

3.1.1.2 Sightings of different species in previous years

As visualized in Table 6 and Figure 15, the encounter rates of different species in Skjálfandi Bay changed over the years. In 1995, on 93.3 % of all whale watching trips minke whales where sighted and humpback whales on 63.3 % of all tours. In 1995 no blue whales have been sighted in the bay. During the following years humpback whale encounters strongly decreased (lowest value in 1999: 0 %) until 2006, when they suddenly became the most common species in Skjálfandi Bay (73.2 %), whereas the number of minke whale sightings decreased. The number of harbor porpoise and white beaked dolphin sightings remained more or less on a constant level and the number of encountered blue whales increased in 2004. In contrast to a sudden peak of minke whale sightings in 2010 (83 %), the number of humpback and blue whale encounters (12 %, 4 %, respectively) was remarkable low in that year but increasing again since 2011. Since 2011 *M. novaeangliae* is the most common species in Skjálfandi Bay.

Table 6: Whale positive surveys (%) from 1995 to 2012. Data on humpback whales (*Mn*), minke whales (*Ba*), blue whales (*Bm*), harbor porpoises (*Pp*) and white beaked dolphins (*La*) from North Sailing logbooks.

	Mn	Ba	Bm	Pp	La
1995	63.3	93.3	0.0	11.7	46.7
1996	0.5	98.5	0.0	16.7	30.0
1997	6.8	94.5	4.0	9.1	37.5
1998	33.0	78.0	0.0	20.0	40.0
1999	0.0	93.7	0.0	26.0	74.0
2000	2.7	94.8	0.2	14.2	57.3
2001	24.3	95.4	0.2	10.5	62.0
2002	28.7	91.7	0.0	22.7	85.2
2003	3.0	84.0	0.0	29.0	48.0
2004	16.0	74.0	17.0	18.0	56.0
2005	20.0	53.5	9.1	10.0	22.0
2006	73.2	66.7	14.8	18.1	35.2
2007	74.5	47.9	11.8	14.2	35.3
2008	68.0	48.0	10.3	15.2	26.8
2009	55.5	57.5	14.1	16.6	22.0
2010	12.0	83.0	4.0	27.0	51.0
2011	72.4	50.1	16.5	19.5	42.1
2012	85.1	39.3	11.5	12.4	37.1

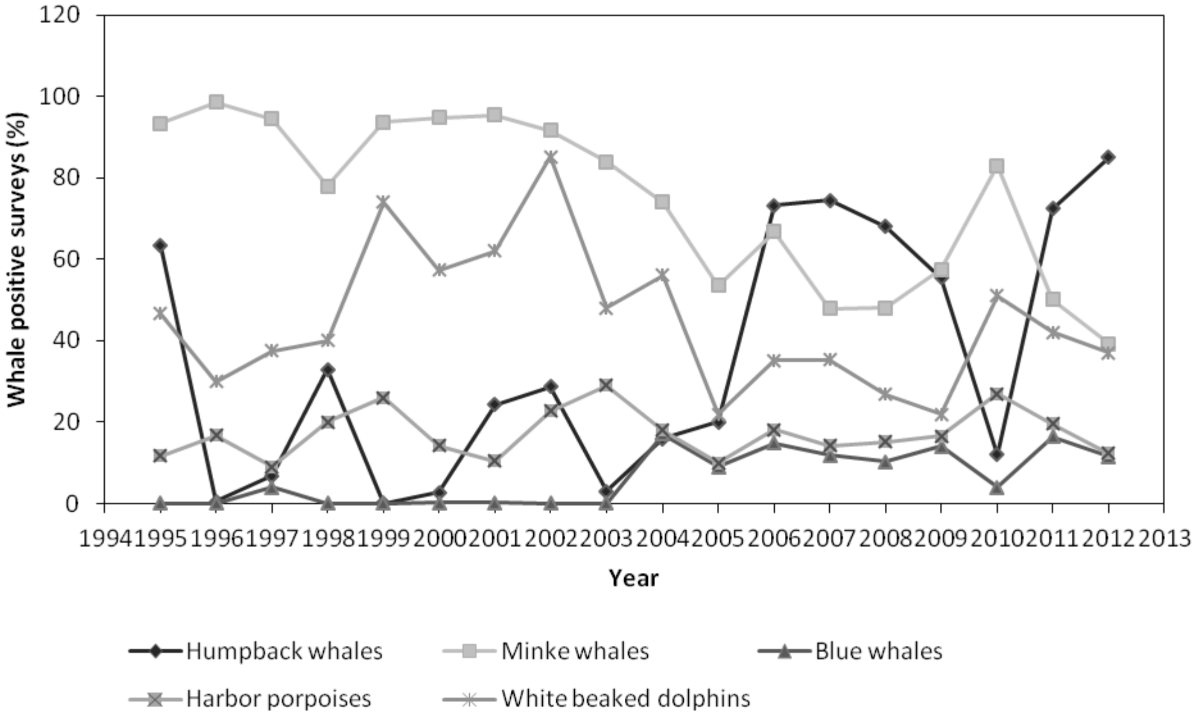


Figure 15: Whale positive surveys (%) from 1995 to 2012. Until 2005 and in 2009 and 2010 *Balaenoptera acutorostrata* was the most common whale species in Skjálfandi Bay, but from 2006 to 2008 and since 2011 *Megaptera novaeangliae* took over this position.

The sightings of different species showed significant differences between the years (H(4) = 58.466, *p*=<0.001) (Table 7).

Table 7: Sightings of humpback whales (*Mn*), minke whales (*Ba*), blue whales (*Bm*), harbor porpoises (*Pp*) and white beaked dolphins (*La*) from 1995 to 2012. The sightings of different species showed significant differences between the years (H(4) = 58.466, *p*=<0.001).

Sightings of different species from 1995 to 2012						
Group	**N**	**Missing**	**Median**	**25%**	**75%**	
Mn	18	0	26.500	6.800	68.000	
Ba	18	0	80.500	53.500	93.700	
Bm	18	0	4.000	0.000	11.800	
Pp	18	0	16.650	12.400	20.000	
La	18	0	41.050	35.200	56.000	

Statistical testing	*Test*	*Detail*	*d.f.*	*Critical*	*p value*
	One-Way ANOVA	*All species compared*	*4*	*H=58.466*	*<0.001*

3.2 Seasonal distribution

3.2.1 Effort analysis

Research took place only during the summer months, depending on the whale watching tours. Consequently, data collection covered May to September or October (Table 2).

The highest average number of sightings per minutes was recorded for July (0.011/minute), the lowest for September (0.003/minute).

Nonetheless, the differences in SPUE between the months are not significant (F(5,59)=1.731, *p*=0.143) (Table 8).

Figure 16 shows monthly sightings per unit effort (SPUE) relative to humpback whale sightings during 2003 – 2012 research seasons.

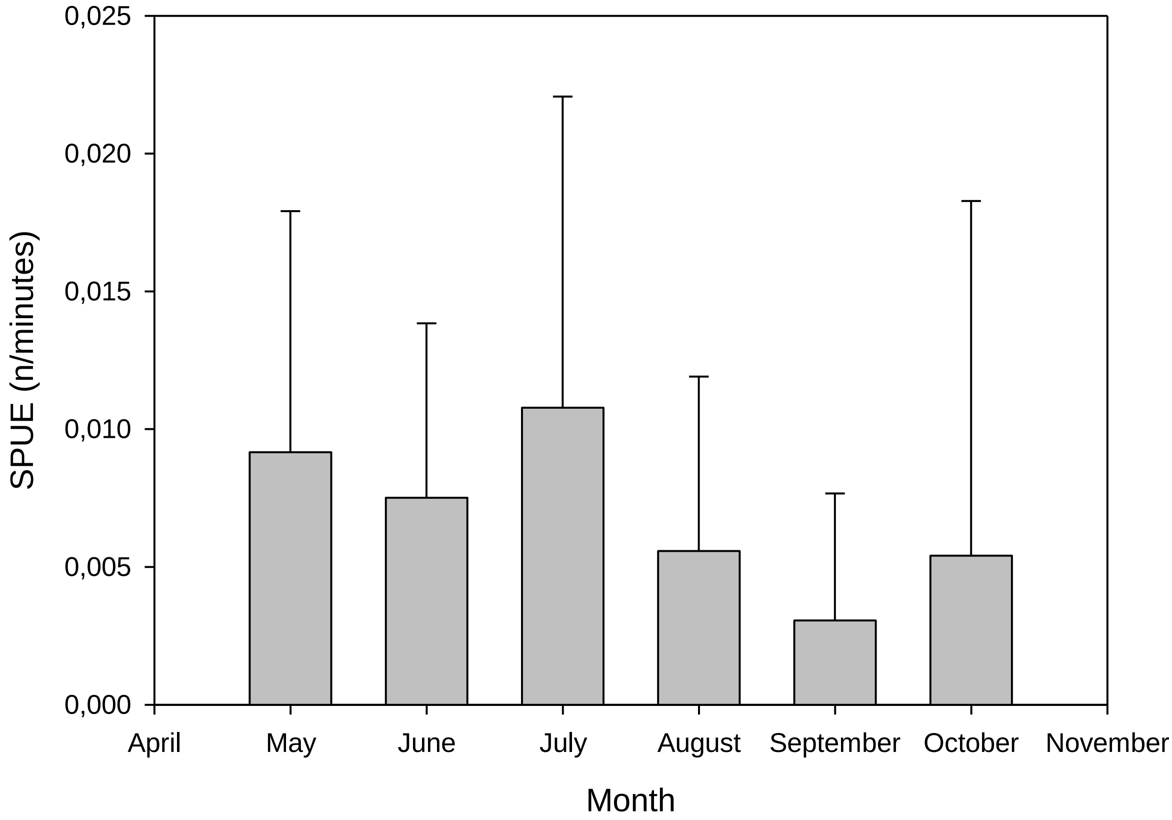


Figure 16: Means and standard deviations of *M. novaeangliae* SPUE during summer research season (May to October), including data from 2003 to 2012 (n/minutes). The number of humpback whale sightings per effort decreased from May to June with a high peak in July, and decreased from July to September with a finally increase in October. The difference between the months was not statistically significant (F(5,59)=1.731, *p*=0.143).

Table 8: Means of *M. novaeangliae* SPUE from May to October. There is no significant difference in SPUE between months (F(5,59)=1.731, *p*=0.143).

SPUE from May to October					
Group Name	**N**	**Missing**	**Mean**	**Std Dev**	**SEM**
May	10	0	0.0777	0.0589	0.0186
June	10	0	0.0746	0.0465	0.0147
July	10	0	0.0883	0.0575	0.0182
August	10	0	0.0620	0.0438	0.0139
September	10	0	0.0394	0.0409	0.0129
October	10	0	0.0319	0.0698	0.0221

Statistical testing	Test	Detail	*d.f.*	Critical	*p* value
	One-Way ANOVA	All months compared	5, 59	F=1.731	0.143

3.2.1.1 Daytime dependency

Depending on weather conditions and offered whale watching tours, daily data collection took place at different times of the day. In 2009 nearly every day the researchers joined the trip which started at 10 am. To check whether the number of sightings depends on the daytime, data collected solely on these 10:00 o' clock tours was selected and compared with the results of the other years, where the time the researchers sailed out varied more (Table 9, Figure 18). In 2009 highest number of sightings per unit effort was recorded in May (0.014/minute), lowest both in August and September (0.002/minute) (Figure 17).

Table 9: *M. novaeangliae* abundance in SPUE from May to October (n/minutes). To check whether the SPUE depended on time of the day, for 2009 data collected solely on 10:00 o' clock tours was compared with means of seasonal SPUE from 2003 to 2012. Data from 2003 to June 2012 from the Húsavík Research Center.

	All Years (all tours)	2009 (10:00 o‘ clock tour)
May	0.0098	0.014
June	0.009	0.0086
July	0.008	0.0131
August	0.0058	0.0025
September	0.0024	0.0025
October	0.0144	-

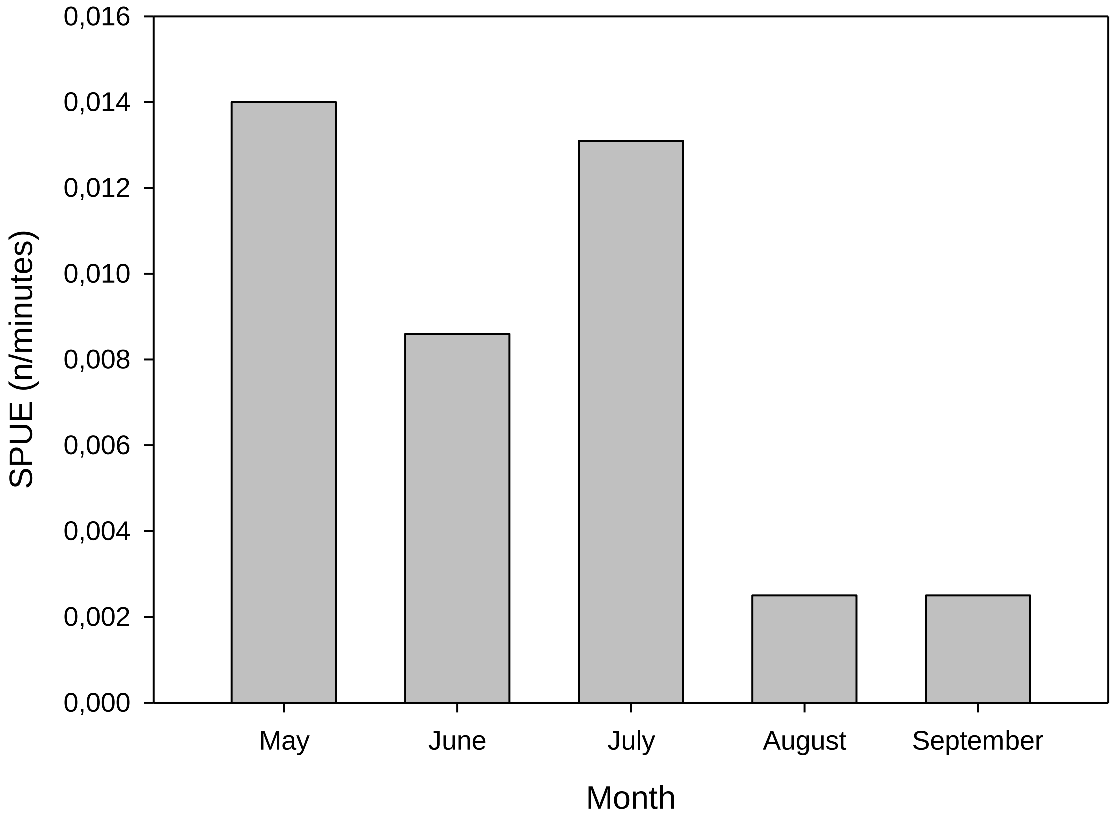


Figure 17: *M. novaeangliae* abundance in SPUE during summer research season (May to September) on 10:00 o' clock tours in 2009 (n/minutes). In 2009 there were high numbers of sightings per unit effort in May. After fewer sightings in June, the number per unit effort increased in July and was low in August and September.

After comparing the average SPUE of all years from 2003 to 2012 with the 10:00 o' clock SPUE for 2009, the statistical test showed no significant differences between the data (H(1)= 0.0335, *p*=0.931) (Table 10).

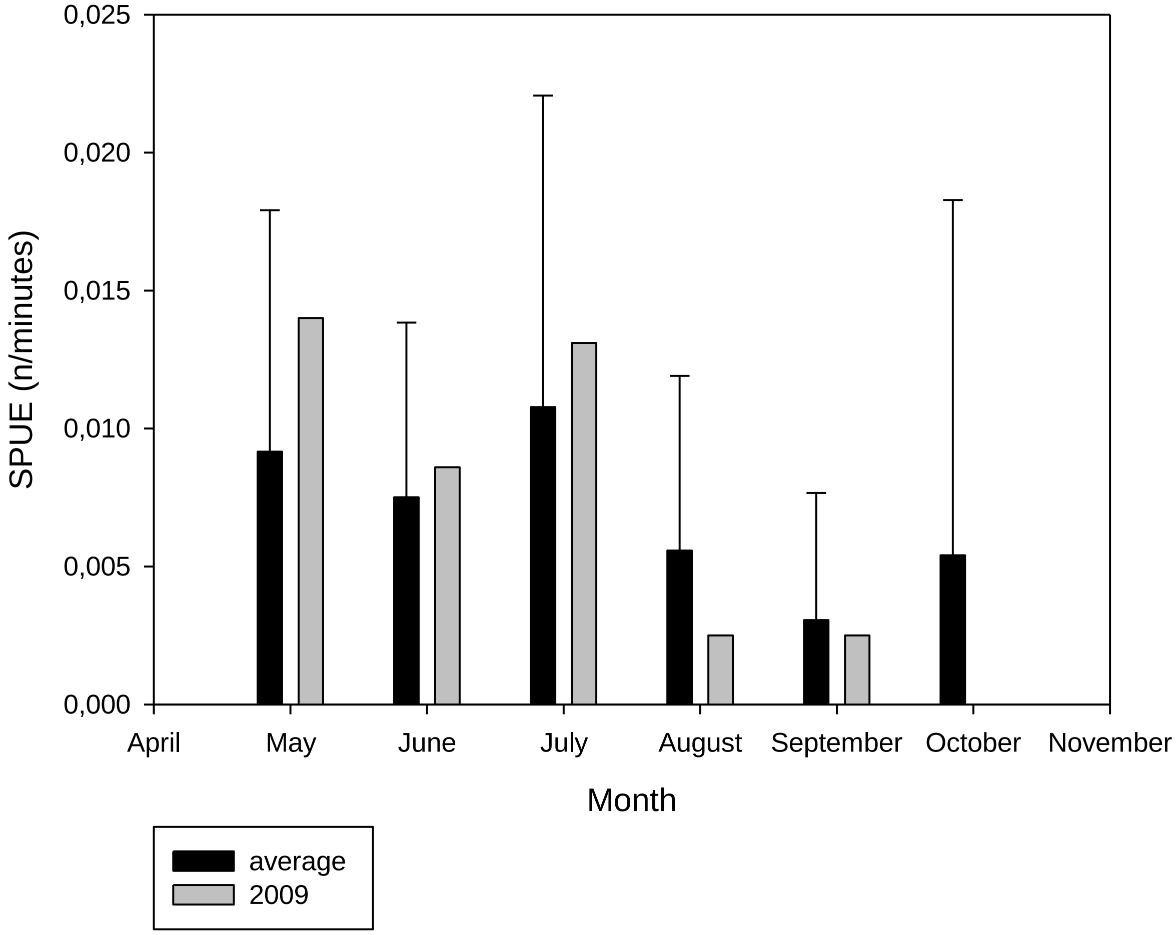


Figure 18: *M. novaeangliae* abundance in SPUE during summer research seasons (May to September/October), comparing means of SPUE (including standard deviations) from 2003 to 2012 with SPUE on 10:00 o' clock tours in 2009 (n/minutes). There is no significant difference in SPUE between 2009 and all years concluded (H(1)= 0.0335, p=0.931).

Table 10: *M. novaeangliae* abundance in SPUE during summer research seasons (May to September/October), comparing means of SPUE from 2003 to 2012 with SPUE on 10:00 o' clock tours in 2009 (n/minutes). There is no significant difference in SPUE between months (H(1)= 0.0335, p=0.931).

SPUE from May to October compared to SPUE 2009					
Group	**N**	**Missing**	**Median**	**25%**	**75%**
average	6	0	0.00655	0.00541	0.00916
2009	5	0	0.00860	0.00250	0.0133
Statistical testing	Test	Detail	*d.f.*	Critical	*p* value
	One-Way ANOVA	All months average compared with all months 2009	1	H=0.0335	0.931

3.3 Sea Surface Temperatures

Monthly and yearly average sightings per unit effort were compared with monthly and yearly average sea surface temperatures.

As illustrated in Figure 19, yearly average sea surface temperature fluctuated considerably. Lowest average sea surface temperature was measured in 2006 (5.73 °C), the highest average temperature in 2003 (7.29 °C). When this thesis was written, no complete dataset for 2012 was available (Table 11).

Table 11: Average SST in Port of Grímsey for April – October in 2003 – 2011. For 2012 no data was available. Data from www.hafro.is.

	2003	2004	2005	2006	2007	2008	2009	2010	2011
April	4.28	3.56	2.86	2.52	-	2.70	2.51	2.72	3.35
May	4.29	4.57	3.48	3.70	3.61	3.76	3.73	4.00	4.32
June	6.93	7.00	5.29	5.40	5.66	6.28	6.51	6.80	5.23
July	8.58	8.98	7.85	7.24	7.85	8.16	8.62	8.41	7.43
August	10.20	10.13	8.40	8.31	8.74	9.61	8.83	8.89	8.43
September	9.56	9.22	7.04	7.33	7.71	8.92	7.84	8.33	7.04
October	7.20	6.94	5.28	5.62	5.17	6.99	5.91	7.00	5.53

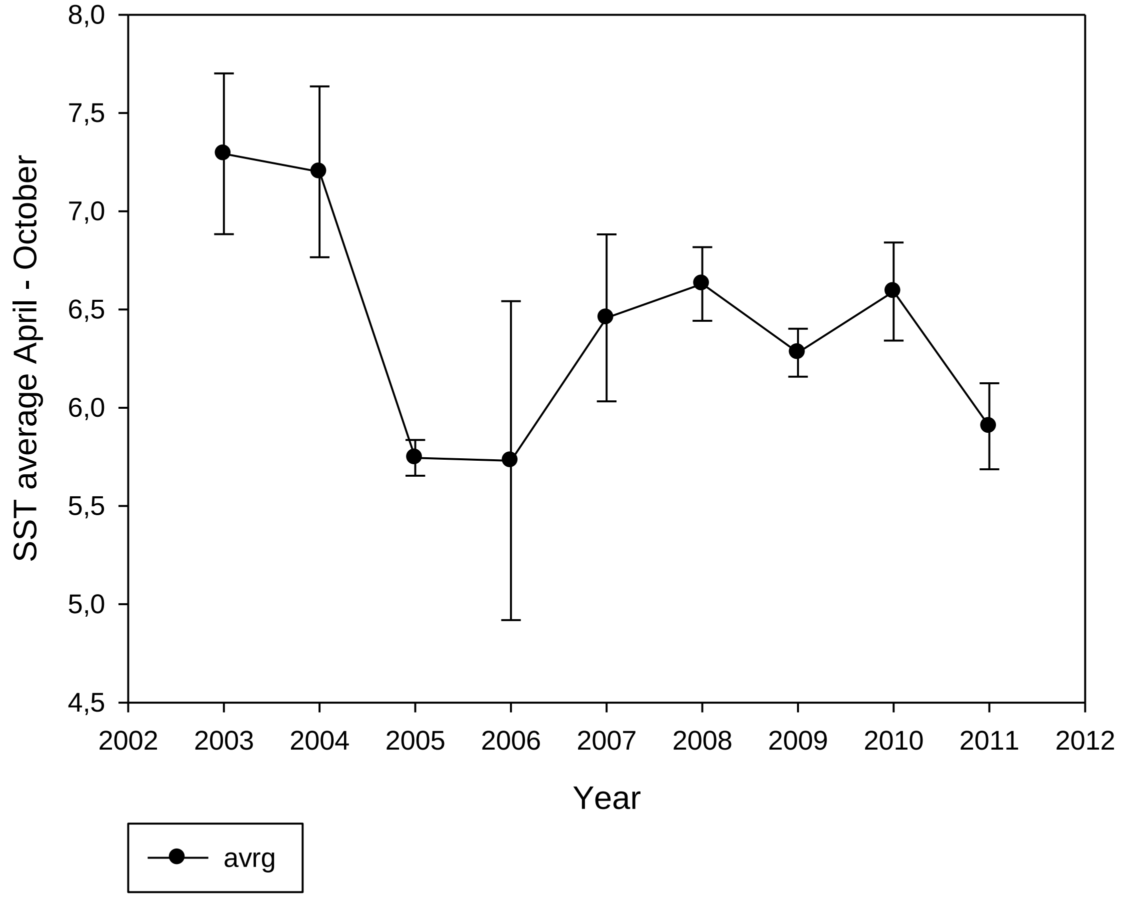
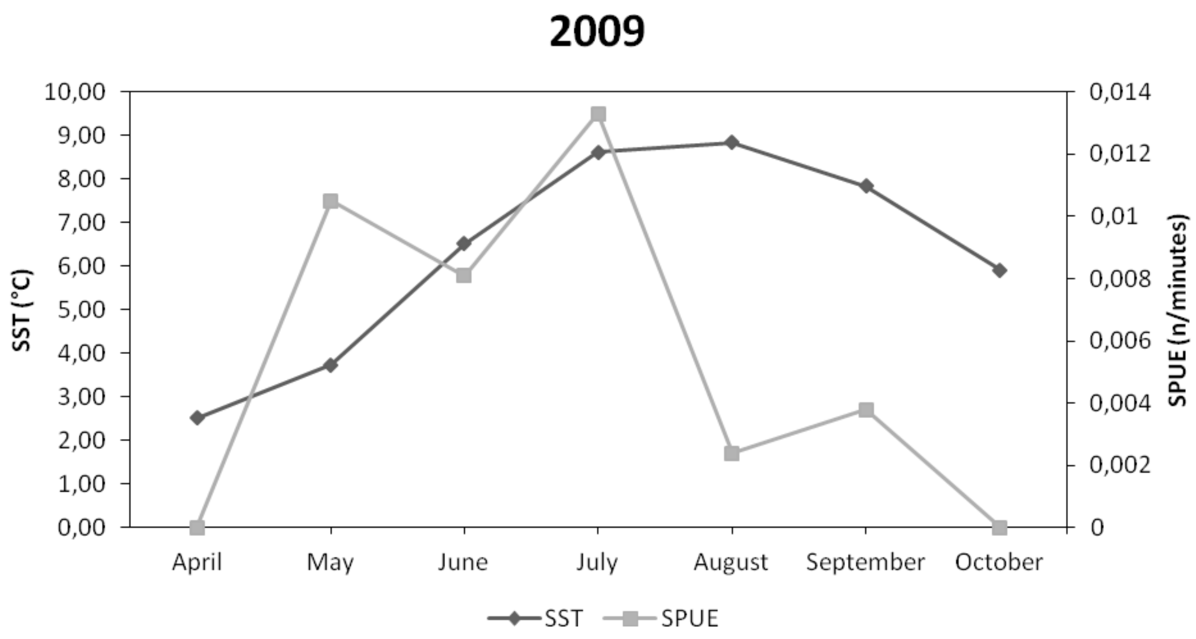


Figure 19: Yearly May – October average SST (including standard deviation) in Port of Grímsey. The average sea surface temperature decreased from 2003 to 2005. From 2007 on there was an increase and then the temperatures decreased again with a short interruption of increase in 2010.

The comparison of SPUE and sea surface temperature showed no significant relationships between any pair of variables in the correlation table (p>0.05) (Table 12). As an example Figure 20 shows an increasing SPUE with increasing SST in 2009, whereas in 2010 the sightings per unit effort decreased with increasing temperatures.



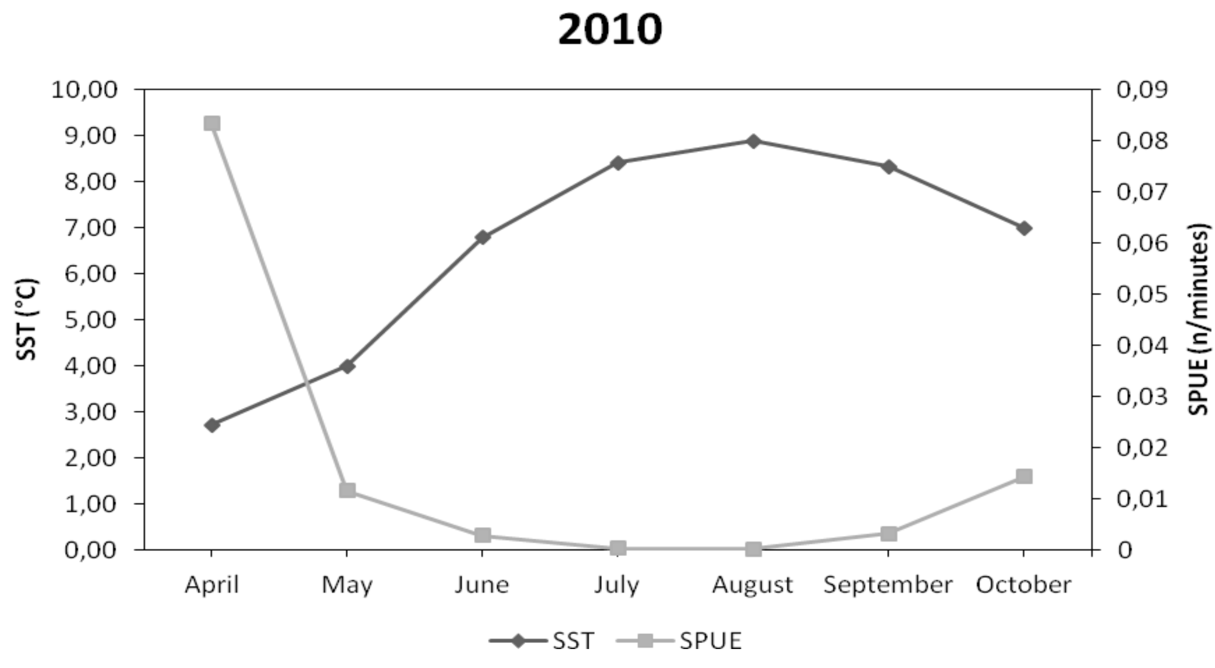


Figure 20: Monthly average SST in Port of Grímsey and SPUE in Skjálfandi Bay for April – October in 2009 and 2010. Whereas in 2009 both temperature and SPUE increased during early summer, in 2010 SPUE showed an inverse curve compared to SST.

Table 12: Mean SST (in Port of Grímsey) and SPUE (in Skjálfandi Bay) from April – October in 2003 to 2011. There are no significant relationships between SST and SPUE (p=0.504).

Correlation between SPUE and SST						
Year	**SST**	**Mean**	**Variance: SD**	**SPUE**	**Mean**	**Variance: SD**
2003		72.918	0.409		0.0001	0.0004
2004		72.003	0.4342		0.0007	0.0019
2005		57.452	0.0911		0.0021	0.0021
2006		57.306	0.8116		0.0087	0.0079
2007		64.573	0.4245		0.0066	0.0057
2008		66.299	0.1876		0.0057	0.0064
2009		62.803	0.122		0.0063	0.0051
2010		65.917	0.2493		0.0054	0.006
2011		59.054	0.2188		0.0085	0.0066

Statistical testing	Test	*Correlation Coefficient*	*p* value
	Pearson Product Moment Correlation	-0.0921	0.504

3.4 Distribution in Skjálfandi Bay

The whales stayed in different regions of Skjálfandi Bay. Sometimes they were close to the harbor, sometimes the boats had to sail further into other regions of the bay to find the animals.

Figure 21 shows the positions of the whale encounters from April to October in 2012.

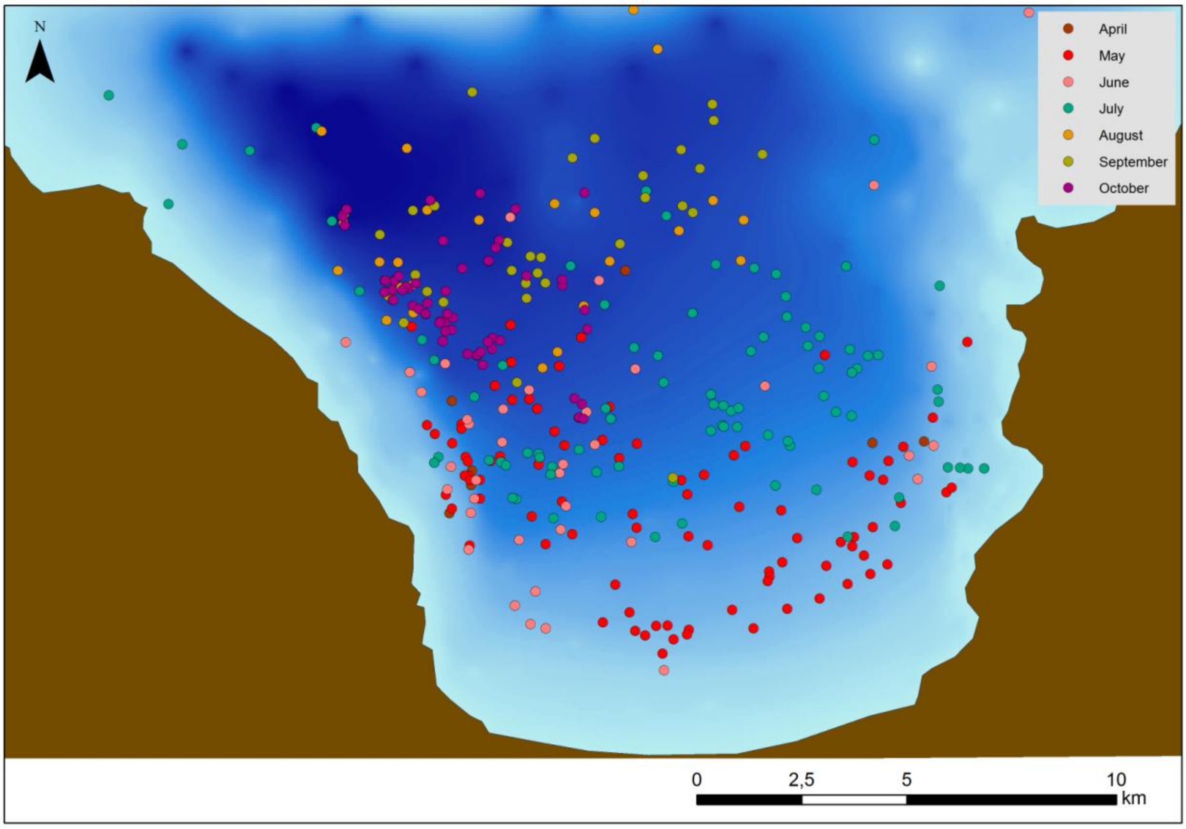


Figure 21: *M. novaeangliae* encounters in Skjálfandi Bay during summer research season 2012. Encounters in different months are visualized with different colors. Data from April to June from the Húsavík Research Center.

To visualize the number of encounters in parts of the bay, the Kernel Density was calculated. This measure visualizes the probability with which the whales stay in a specific geographical area (Silverman, 1986) (Figure 22).

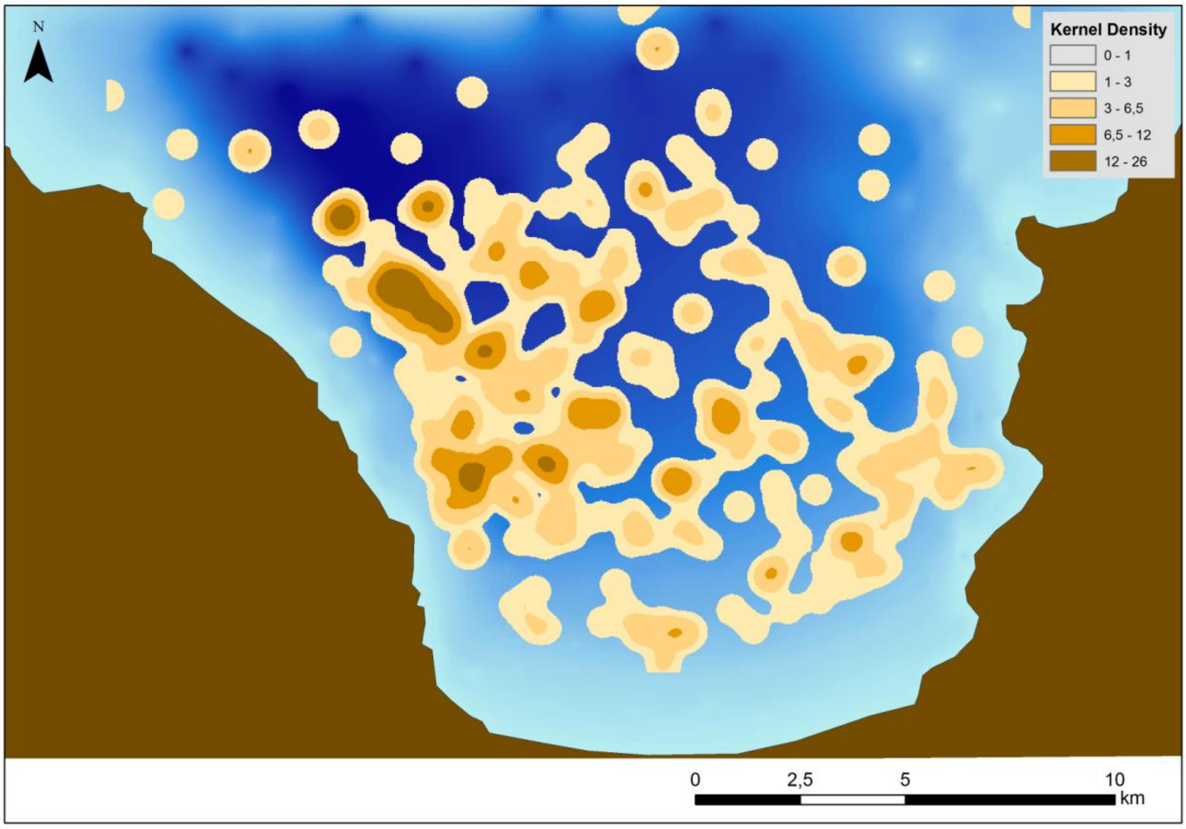


Figure 22: Kernel Density of *M. novaeangliae* encounters in Skjálfandi Bay during summer research season 2012. Darker areas, occurring mainly in the western part of the bay, correspond to hot spots of sightings. Data from April to June from the Húsavík Research Center.

Kernel Density reaches highest values in the western part of the bay, which represents the deepest area of Skjálfandi Bay. Although high density values are recorded for regions close to the shore as well, most of the whales were encountered in deeper waters.

To assess whether the distribution of the humpback whales differed between the months, the following maps for every month show the positions of whale encounters.

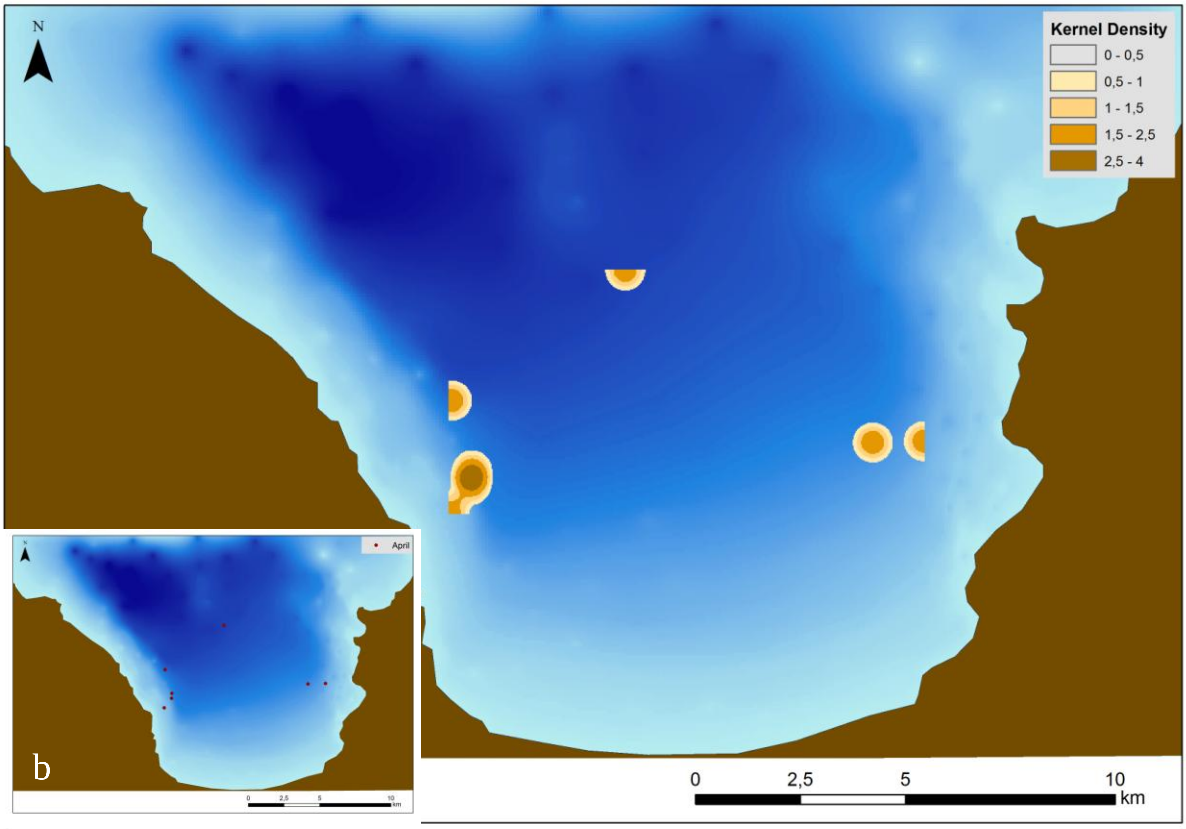


Figure 23: Kernel Density and b) individual locations of *M. novaeangliae* encounters in Skjálfandi Bay during April 2012. In April only few sightings, spread over the whole bay, were recorded. Data from the Húsavík Research Center.

The few sightings of humpback whales in April are spread over the whole bay, but most of the time close to the shore (Figure 23).

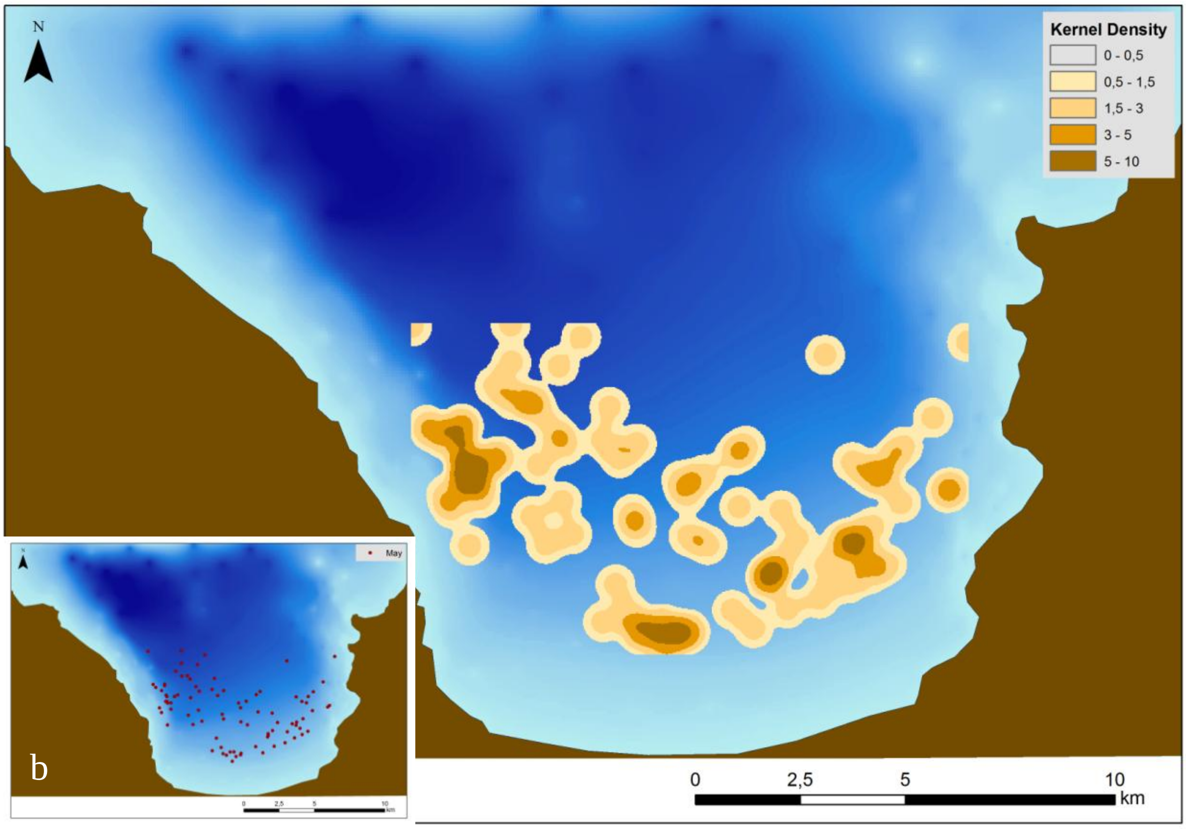


Figure 24: Kernel Density and b) individual locations of *M. novaeangliae* encounters in Skjálfandi Bay during May 2012. Sightings were recorded in nearly all areas of the bay except further north in direction of the open ocean. Data from the Húsavík Research Center.

In May the whales stayed mainly in the western and the southern part of the bay, but also in approximately 8 km distance from Húsavík harbor in the middle of the bay (Figure 24).

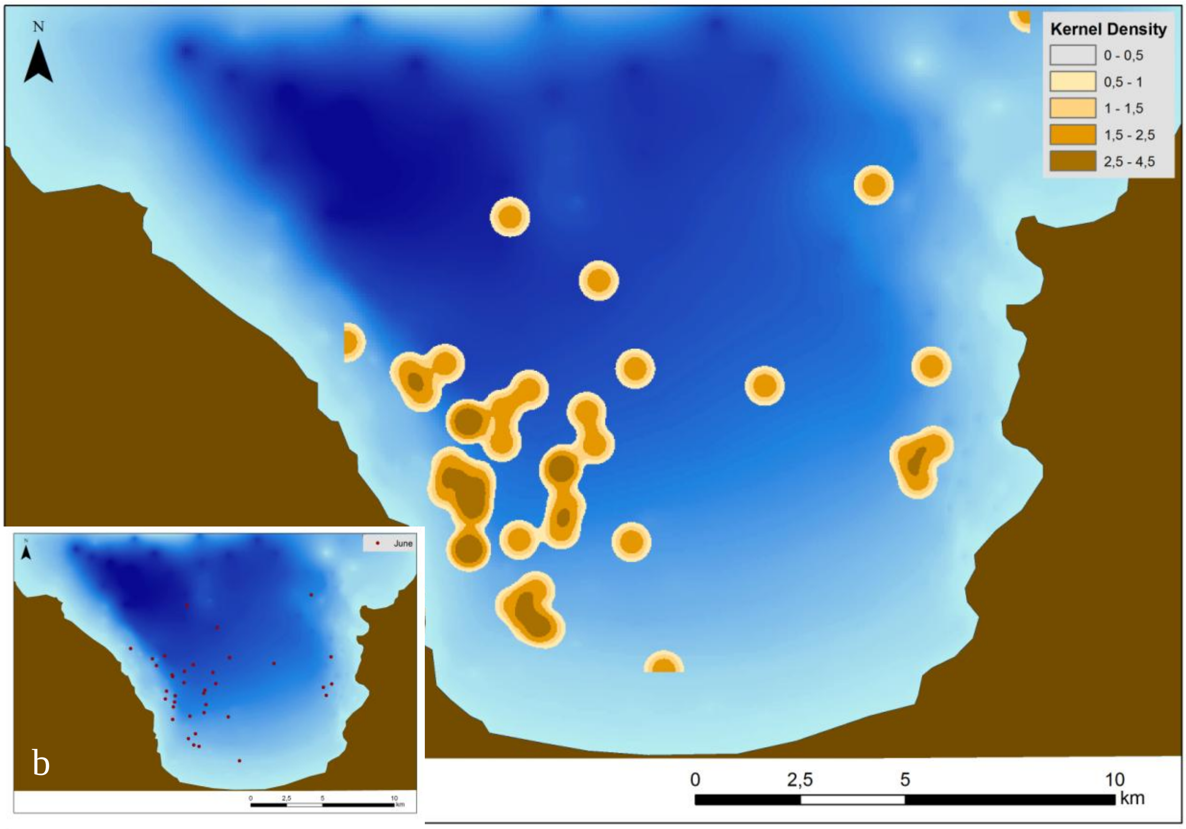


Figure 25: Kernel Density and b) individual locations of *M. novaeangliae* encounters in Skjálfandi Bay during June 2012. In June most of the humpback whales were sighted in the western part of the bay. Data from the Húsavík Research Center.

Most of the humpback whales were sighted in the western part of the bay in June, close to the shore. Furthermore some encounters occurred close to Húsavik harbor in the east (Figure 25).

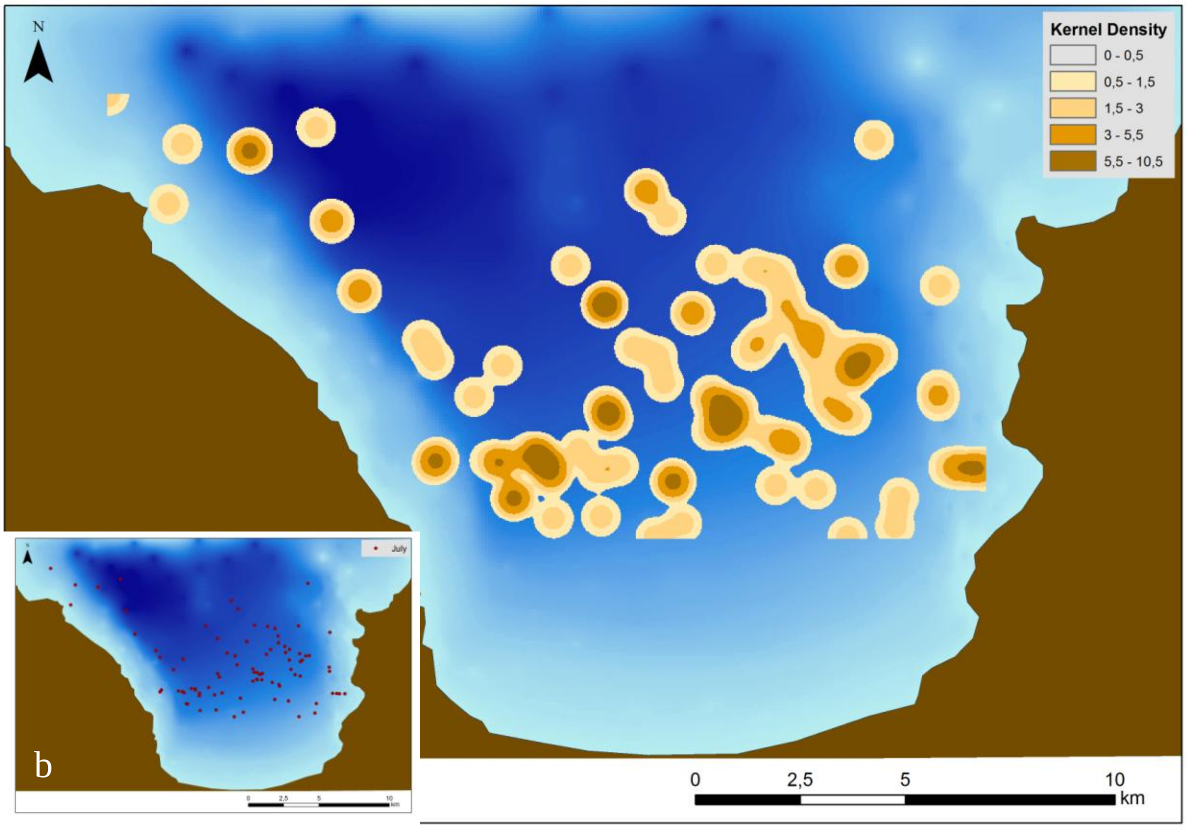


Figure 26: Kernel Density and b) individual locations of *M. novaeangliae* encounters in Skjálfandi Bay during July 2012. Except in the south, humpback whales were sighted in every sector of the bay, also further north in direction of the open Atlantic ocean.

The humpback whales occurred in nearly all areas in Skjálfandi Bay in July, also further north in direction of the open ocean, but never in the very southern part of the bay (Figure 26).

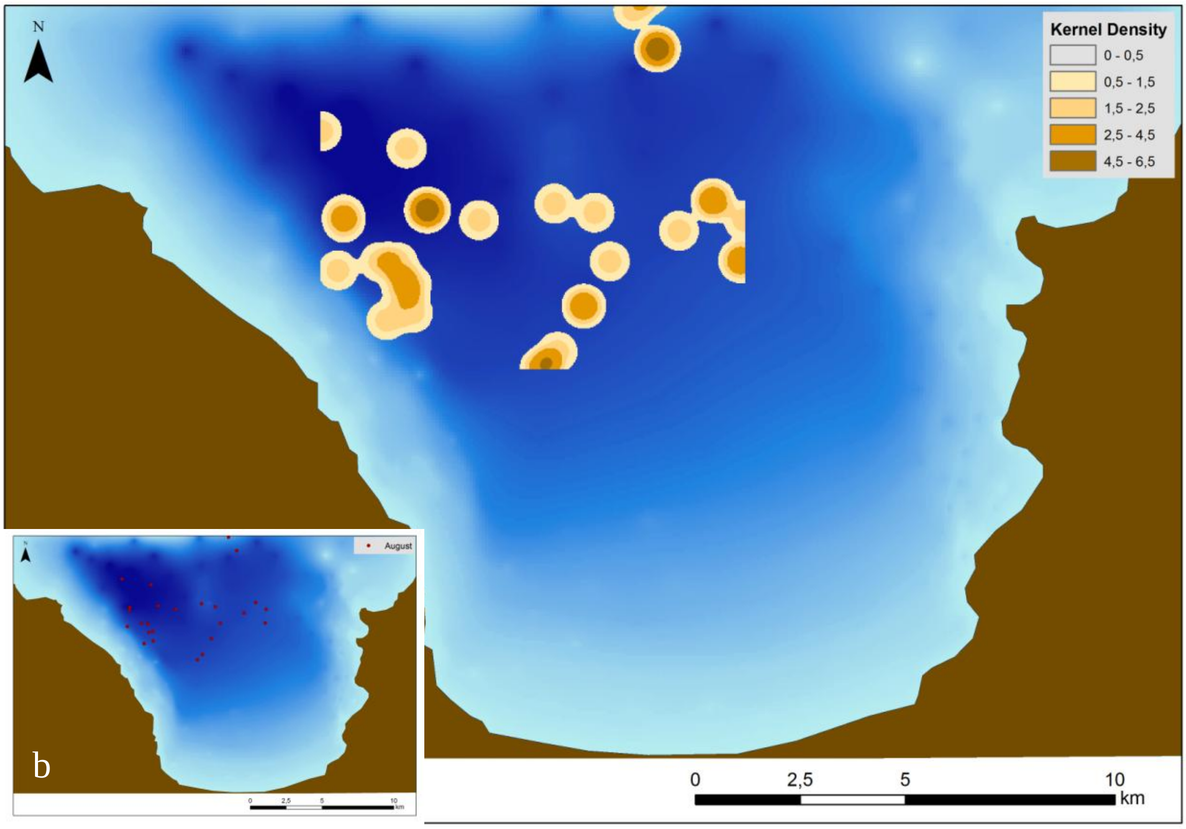


Figure 27: Kernel Density and b) individual locations of *M. novaeangliae* encounters in Skjálfandi Bay during August 2012. Sightings were recorded only in the northwestern part of the bay.

In August, humpback whales were spotted only in the northwestern part of Skjálfandi Bay (Figure 27).

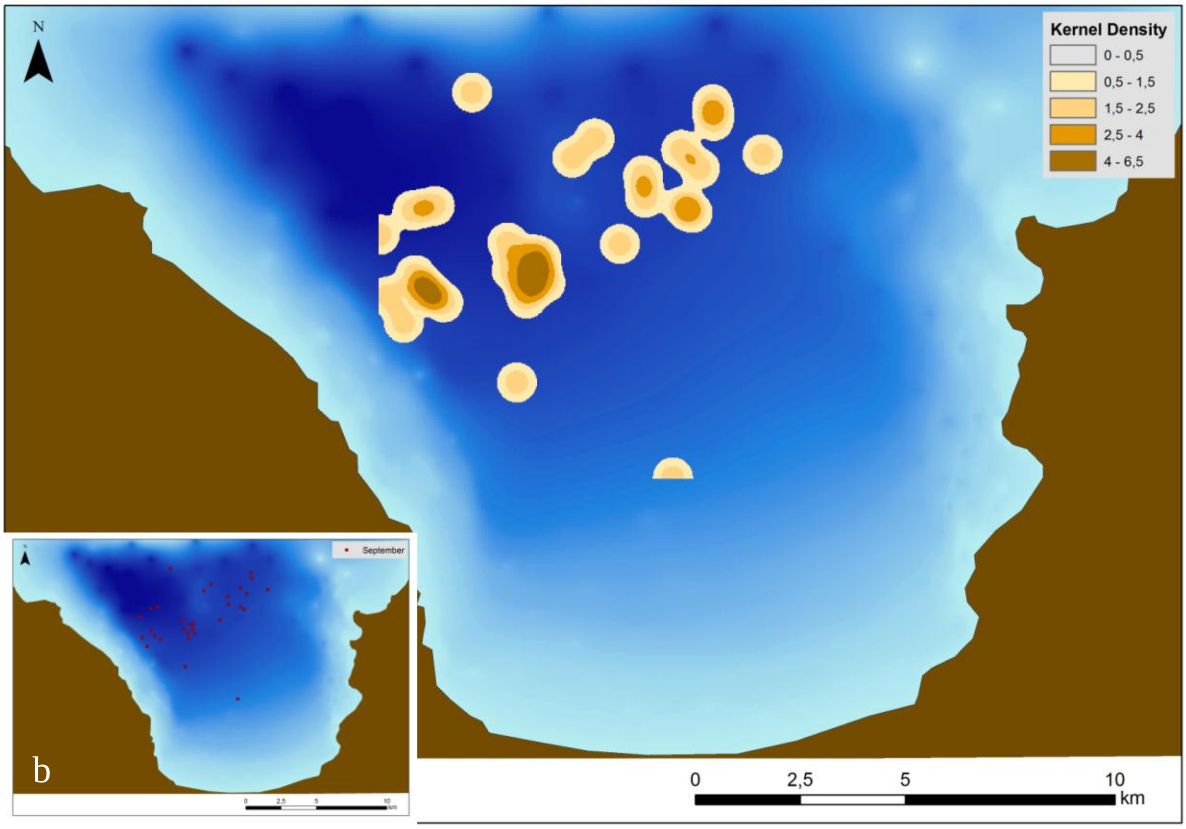


Figure 28: Kernel Density and b) individual locations of *M. novaeangliae* encounters in Skjálfandi Bay during September 2012. Humpback whales were encountered in the northwestern part of the bay in direction of the open ocean.

Also in September the boats had to go further northwest to find the humpback whales (Figure 28).

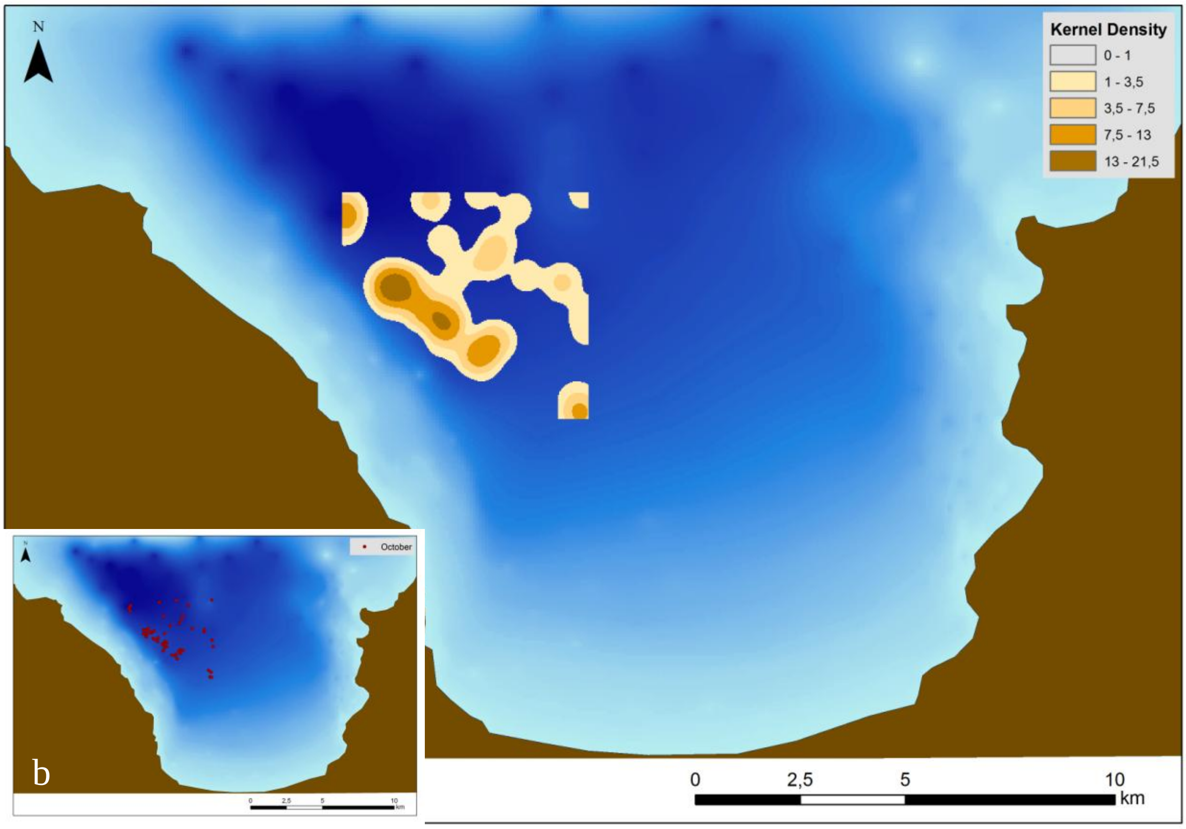


Figure 29: Kernel Density and b) individual locations of *M. novaeangliae* encounters in Skjálfandi Bay during October 2012. Humpback whales were sighted in a smaller area in the northwestern part of the bay.

The area the whales stayed in October was very limited in the northwestern part of the bay (Figure 29).

3.5 Focus on individuals

3.5.1 Sightings and resightings

The Húsavík Humpback Whale Catalogue includes data back to 2001. Since then, every year new data were added, except in 2003, when no data were taken.

The total number of identified humpback whales increased from 2001 with 7 identified individuals to 2009 with 39 identified individuals. After a slight decrease in 2010 (33 identified whales), 42 humpback whales could be identified in 2011. The peak value was reached in 2012, when a total of 77 humpback whale individuals were identified (status November 2012).

The rate of resighted individuals always remained under 27 %. Until 2004 no humpback whales were photographed that had been seen in Skjálfandi Bay the years before. The highest resighting rate was in 2007 with 26 % (10 resights out of a total of 39), lowest in 2005 and 2006 with 7 % (1 resight out of a total of 15, 2 resights out of a total of 27, respectively).

The total resighting rate amounts to 16 %, total numbers are shown in Table 13 and Figure 30.

Table 13: Number and percentages of sighted and resighted humpback whales during summer research seasons from 2003 – 2012. For 2003 no data was available. The number of new identified humpback whales increased, but the resighting rate never exceeded 26 %. Data from 2001 to 2011 from the Humpback Whale Catalogue of the Húsavík Whale Museum.

Year	Total	New	Resights	New %	Resights %
2001	7	7	0	100	0
2002	4	4	0	100	0
2004	5	5	0	100	0
2005	15	14	1	93	7
2006	27	25	2	93	7
2007	39	29	10	74	26
2008	25	21	4	84	16
2009	35	29	6	83	17
2010	33	25	8	76	24
2011	42	35	7	84	16
2012	77	66	11	86	14
Total	309	260	49	84	16

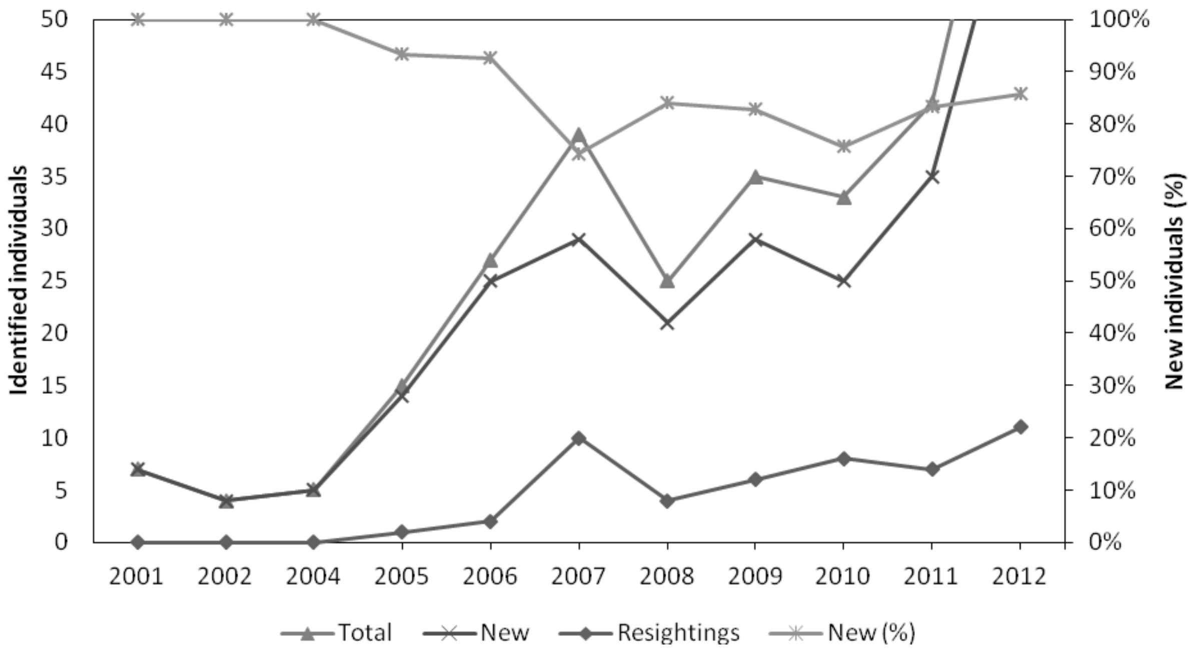


Figure 30: Numbers and percentages of sighted and resighted humpback whale individuals during summer research season from 2001 to 2012. Whereas the number of new identified individuals constantly increased, resighting rate remained low. For 2003 no data was available.

Table 13 shows the number of identified humpback whale individuals from 2001 to 2012 (no data for 2003 available) and visualizes in which years already identified individuals have been resighted. Most of the re-captures are individuals that have been photographed in Skjálfandi Bay the year before their first resighting. In 2012 for example, 11 identified humpback whales out of a total of 77 individuals were already known, and again 9 out of these 11 (compare Table 14) had been sighted already in the bay in 2011. The highest number of individuals resighted during following years were those humpback whales that had been sighted for the first time in 2006: 25.9 % returned to the bay for at least one more year.

Table 14: Number of identified humpback whales in Skjálfandi Bay from 2001 to 2012. Sightings and resightings are noted in total numbers, the values in brackets are percentages. For 2003 no data was available. Data from 2001 to 2011 from the Humpback Whale Catalogue of the Húsavík Whale Museum.

Year first seen	ID	N	No. of whales seen in each subsequent year								No. resighted in
			2005	2006	2007	2008	2009	2010	2011	2012	at least 1 year
2001	7	7	-	-	1 (14.3)	-	-	-	-	-	1 (14.3)
2002	4	4	1 (25.0)	-	-	-	-	-	-	-	1 (25.0)
2004	5	5		-	-	-	-	-	-	-	
2005	15	14		2 (13.3)	2 (13.3)	-	-	-	-	-	2 (13.3)
2006	27	25			7 (25.9)	2 (7.4)	2 (7.4)	1 (3.7)	1 (3.7)	1 (3.7)	7 (25.9)
2007	39	29				2 (5.1)	1 (2.6)	1 (2.6)	-	2 (5.1)	5 (12.8)
2008	25	21					3 (12.0)	2 (8.0)	1 (4.0)	1 (4.0)	5 (20.0)
2009	35	29						4 (11.4)	2 (5.7)	1 (2.8)	6 (17.1)
2010	33	25							3 (9.1)	3 (9.1)	3 (9.1)
2011	42	35								9 (21.4)	9 (21.4)
2012	77	66									
Total	309	260									39 (12.6)

Overall, the statistical test shows a significantly increasing number of identified humpback whales in Skjálfandi Bay since 2001 (Table 15).

The numbers of new identified individuals were plotted against the total number of whale encounters per year (no data for 2003 available). The discovery curve increases without flattening (Figure 31).

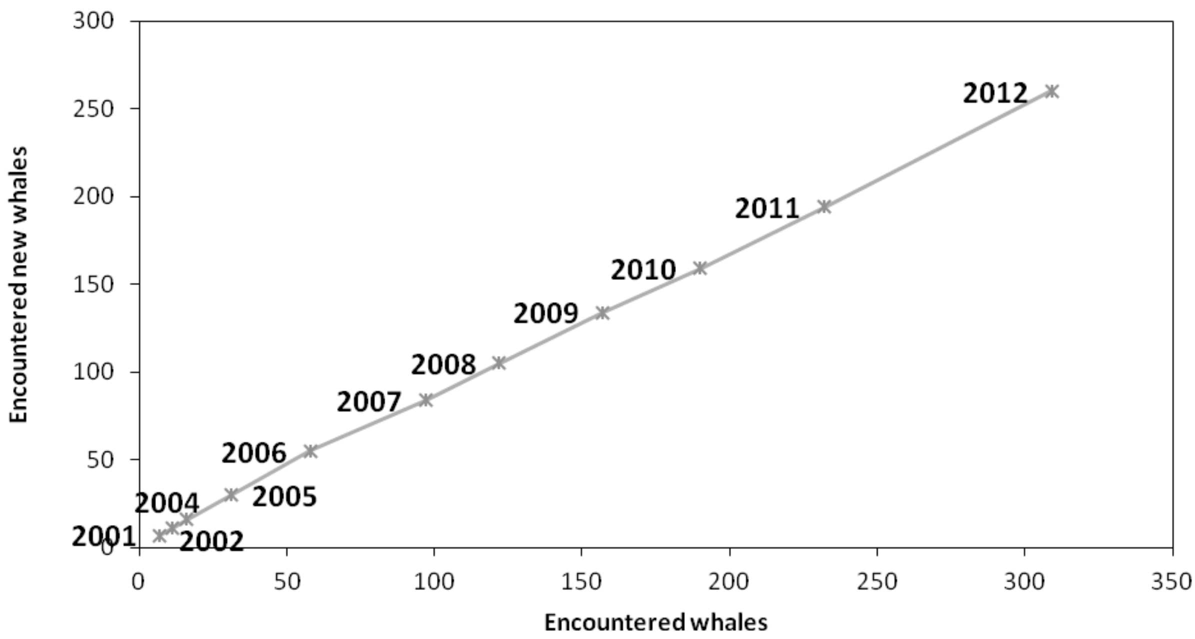


Figure 31: Discovery curve of humpback whale individuals during the summer research season from 2001 to 2012. Both the numbers of encountered and new identified individuals increased. For 2003 no data were available.

Figure 32 shows an increase of identified humpback whales per year since 2001, including a rising number of new individuals which were identified each year. Although the number of resightings increased as well, this curve has a much lower rise than the two mentioned first.

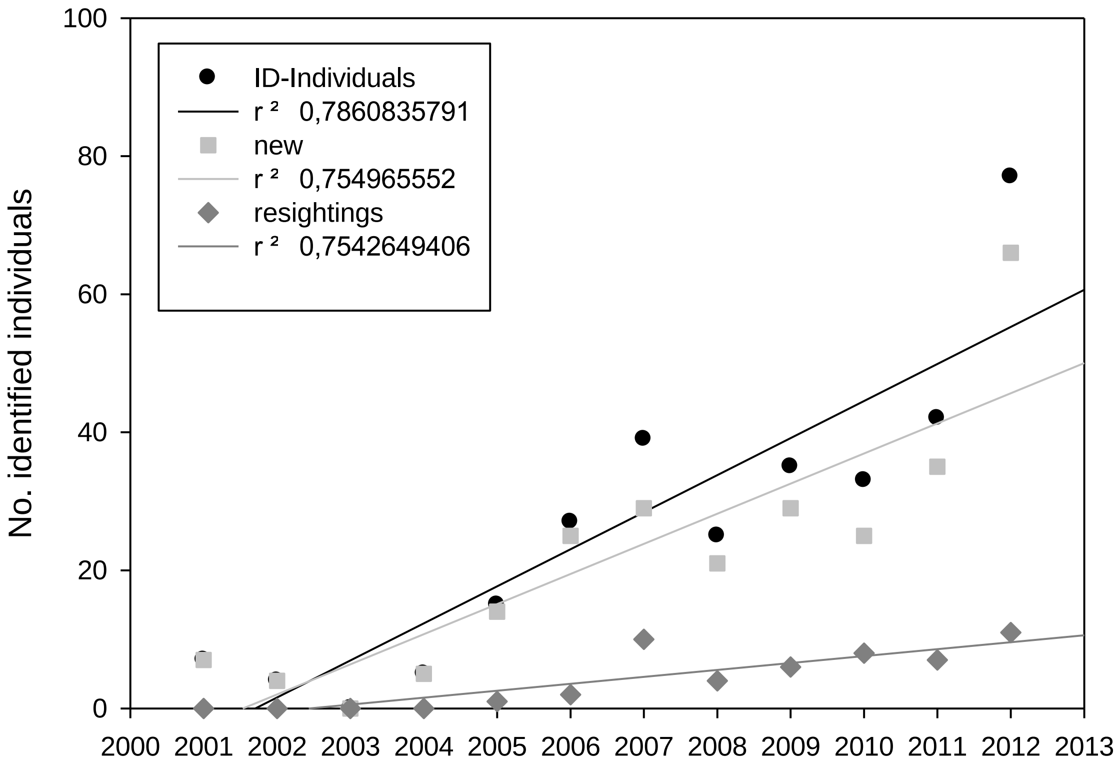


Figure 32: Sights and resightings of identified humpback whales during the summer research season from 2001 to 2012. In contrast to the increasing number of new individuals, resighting rate remained constantly low.

Table 15: Sightings and resightings of identified humpback whales during the summer research season from 2001 to 2012. The total number of identified individuals as well as both new and resighted individuals significantly increased.

Sightings and resightings of identified humpback whales from 2001 - 2012					
	N	**Missing**	**Mean**	**Std Dev**	**SEM**
ID-Individuals	12	0	25.75	21.826	6.301
new	12	0	21.667	18.107	5.227
resightings	12	0	4.083	4.166	1.203
Statistical testing	Test	Detail	*d.f.*	Critical	*p* value
	t-test	All years compared	11	t=4.087	0.002
				t=4.145	0.002
				t=3.395	0.006

3.5.2 Duration of stay

The Humpback Whale Catalogue contains information on every individual which was identified in Skjálfandi Bay, including the days the whale had been sighted. Thus the number of records a whale stayed in Skjálfandi Bay can be determined (Table 16). From 2001 to 2006 the number of individuals that stayed more than two days in the bay increased (14 % - 44 %), except in 2004, where all the identified individuals were sighted for only one day. From 2008 to 2010, fewer humpback whales stayed more than two days (44 % - 27 %), whereas in 2011 and 2012 more than 50 % of the identified individuals were sighted more than two days in Skjálfandi Bay (62 % and 58 %, respectively). Thus, the number of humpback whale individuals encountered for more than one and two days, respectively, in Skjálfandi Bay increased from 2001 to 2012 (Figure 33).

Table 16: Number of humpback whales, which were observed in Skjálfandi Bay and the number and percentages of individuals that were sighted > 1 and > 2 days. Data from 2001 to 2011 from the Humpback Whale Catalogue of the Húsavík Whale Museum.

	Individuals seen	stayed > 1 day	stayed > 2 days	stayed > 1 day %	stayed > 2 days %
2001	7	1	1	14	14
2002	4	2	1	50	25
2004	5	0	0	0	0
2005	15	5	4	33	27
2006	27	20	12	74	44
2007	39	22	13	56	33
2008	25	15	11	60	44
2009	35	18	11	51	31
2010	33	12	9	36	27
2011	42	33	26	79	62
2012	77	63	45	82	58

There is a significant increase in number of animals that stay longer than one day ($F(1,11)=9.378$, $p=0.012$) as well as longer than two days ($F(1,11)=14.125$, $p=0.004$) (Table 17).

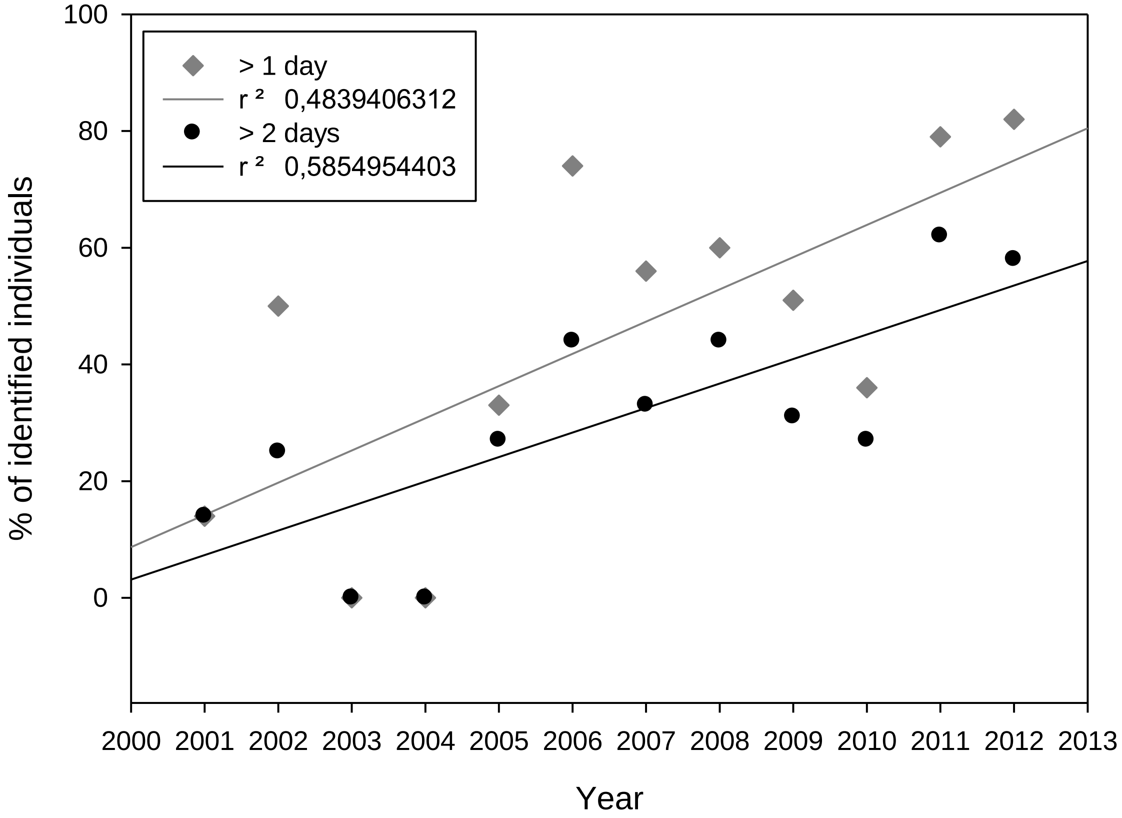


Figure 33: Percentage of identified humpback whales, which were observed in Skjálfandi Bay > 1 and > 2 days. The number of individuals that were observed for more than one and more than two days increased from 2001 to 2012.

Table 17: Humpback whales (%), which were observed in Skjálfandi Bay > 1 and > 2 days. There is a significant increase in number of animals that stay longer than one day (F(1,11)=9.378, *p*=0.012) as well as longer than two days (F(1,11)=14.125, *p*=0.004).

Duration of stay

Stayed > 1 day

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	4358.813	4358.813	9.378	0.012
Residual	10	4648.104	464.810		
Total	11	9006.917	818.811		

Stayed > 2 days

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	2521.680	2521.680	14.125	0.004
Residual	10	1785.237	178.524		
Total	11	4306.917	391.538		

Statistical testing	Test	Detail	*d.f.*	Critical	*p* value

Linear regression	All years compared	1,11	F=9.378 F=14.125	0.012 0.004

3.5.3 Life histories of selected individuals

The author also focused on the life histories of those humpback whales that have been observed in Skjálfandi Bay for at least three years.

Table 18 provides an overview over the sighting history of the selected individuals, including the first and the last sighting date for every year the whale was observed in the bay as well as the number of days on which it was seen.

Table 18: Sighting histories of identified humpback whales which were observed in Skjálfandi Bay for at least three years. The date of the first and last sighting as well as the number of days, the individuals was sighted, are reported. Data from 2001 to 2011 from the Humpback Whale Catalogue of the Húsavík Whale Museum.

Whale ID	first sighting	last sighting	no. of days sighted
Mn10	12.06.2005	31.08.2005	3
	22.06.2006		1
	25.07.2007	24.08.2007	3
	10.10.2008		1
Mn15	20.08.2005	09.09.2005	5
	31.05.2006	03.08.2006	20
	17.06.2007	20.08.2007	8
Mn33	04.06.2006	18.08.2006	16
	08.08.2007		1
	03.07.2008	29.07.2008	7
	24.06.2009	24.07.2009	15
	30.05.2010	03.06.2010	3
	27.05.2011	06.06.2011	2
	01.07.2012	14.10.2012	14
Mn37	30.06.2006	01.07.2006	2
	02.06.2007	22.07.2007	14
	13.07.2008	31.07.2008	4
	17.07.2009	24.07.2009	4
Mn106	23.04.2008	16.08.2008	13
	21.07.2009	24.07.2009	2
	10.06.2010		1

Mn147	04.07.2010		1
	01.05.2011	03.05.2011	3
	26.06.2012	29.07.2012	7
Mn149	18.09.2010	16.10.2010	11
	13.05.2011	31.08.2011	6
	25.06.2012	07.10.2012	6

Table 19 gives an overview over the first and the last year the selected individual was sighted in Skjálfandi Bay, the number of years and days the humpback whale was observed as well as the months in which it was seen in the bay.

Table 19: Sighting histories of identified humpback whales which were observed in Skjálfandi Bay for at least three years. Data from 2001 to 2011 from the Humpback Whale Catalogue of the Húsavík Whale Museum.

Whale ID	First year	Years seen	Days seen	Most recent	Months
Mn10	2005	4	8	2008	6,7,8,10
Mn15	2005	3	33	2007	5,6,8,9
Mn33	2006	7	52	2012	5,6,7,8
Mn37	2006	4	24	2009	6,7
Mn106	2008	3	16	2010	4,6,7,8
Mn147	2010	3	11	2012	4,5,6,7
Mn149	2010	3	19	2012	5,6,8,9,10

Below, characteristics of the individual sighting histories are presented.

Mn10:

The humpback whale with the ID code Mn10 in the Humpback Whale Catalogue has been sighted in Skjálfandi Bay during the summer months (June to August) in three consecutive years, first in 2005. In 2008 it was observed for one day in October.

Mn10 never stayed longer than three days in the bay and always kept at least 5 km distance to the shore (Figure 34).

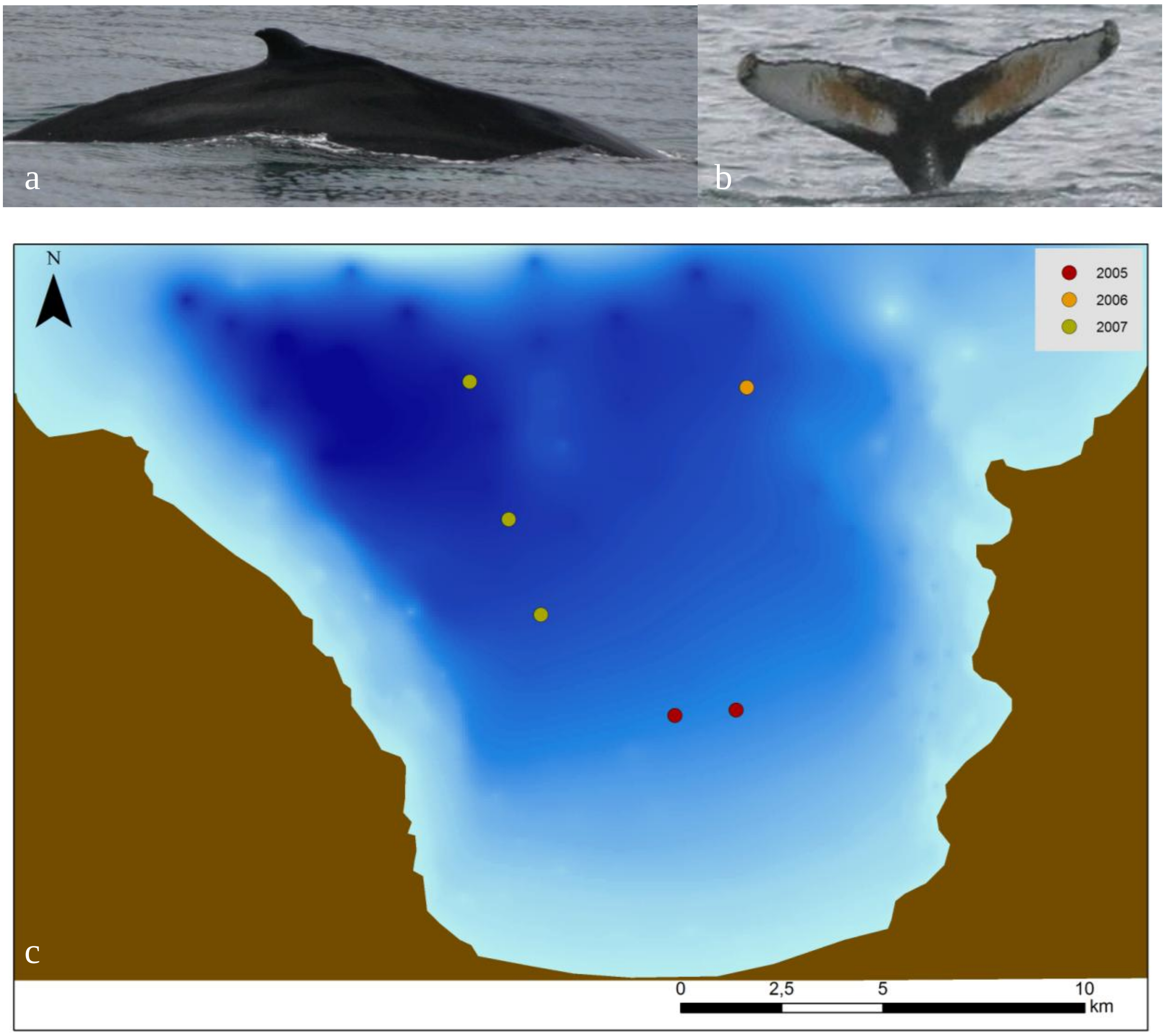


Figure 34: Dorsal fin (a), fluke (b) and sighting locations (c) of Mn10. Mn10 was sighted in different areas of Skjálfandi Bay. Data from 2005 to 2008 from the Humpback Whale Catalogue of the Húsavík Whale Museum. (Photos: Luisa Klotz)

Mn15:

Mn15 (Humpback Whale Catalogue) has been observed in Skjálfandi Bay in three consecutive years from 2005 to 2007. In 2005 and 2007 it was sighted during spring and autumn but not in midsummer. In 2006 the individual stayed the whole summer in the bay. Whereas in 2007 Mn15 was observed in the northern part of Skjálfandi Bay, during its long stay in 2006 it occurred in every sector of the bay (Figure 35).

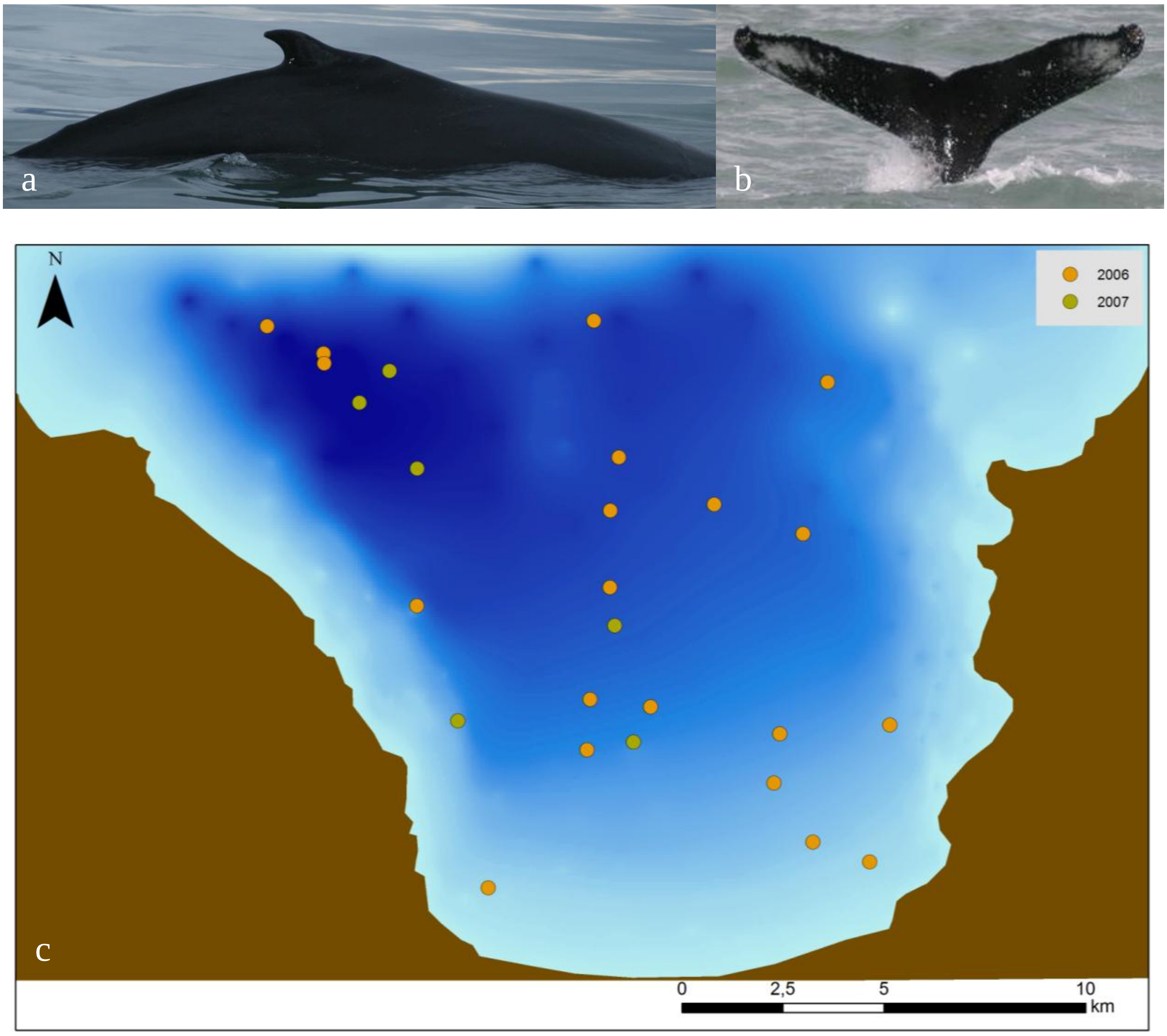


Figure 35: Dorsal fin (a), fluke (b) and sighting locations (c) of Mn15. Mn15 was sighted in different areas of Skjálfandi Bay. Data from 2005 to 2007 from the Humpback Whale Catalogue of the Húsavík Whale Museum. (Photos: Luisa Klotz)

Mn33:

Mn33 returned to Skjálfandi Bay for every year since 2006. The duration of stay differed from one (2007) to 16 days (2006). Likewise the date the whale arrived varied from late May (2010, 2011) to early August (2007). Since the first year this humpback whale was sighted, it always left the bay before the end of August or even earlier in June and July, except in 2012 where it was observed until October.

Furthermore Mn33 has been observed on 18.06.2010 in Eyjafjörður, a bay west of Skjálfandi Bay, during a whale watching tour from Dalvík.

Although Mn33 was sighted in different areas in Skjálfandi Bay throughout the years, different sighting locations for every single year are noticeable. For example in 2006 and 2009 the whale was observed mainly in the southern part of the bay, whereas most of the sightings in 2007 and 2012 were in the middle and the northern part of Skjálfandi Bay (Figure 36).

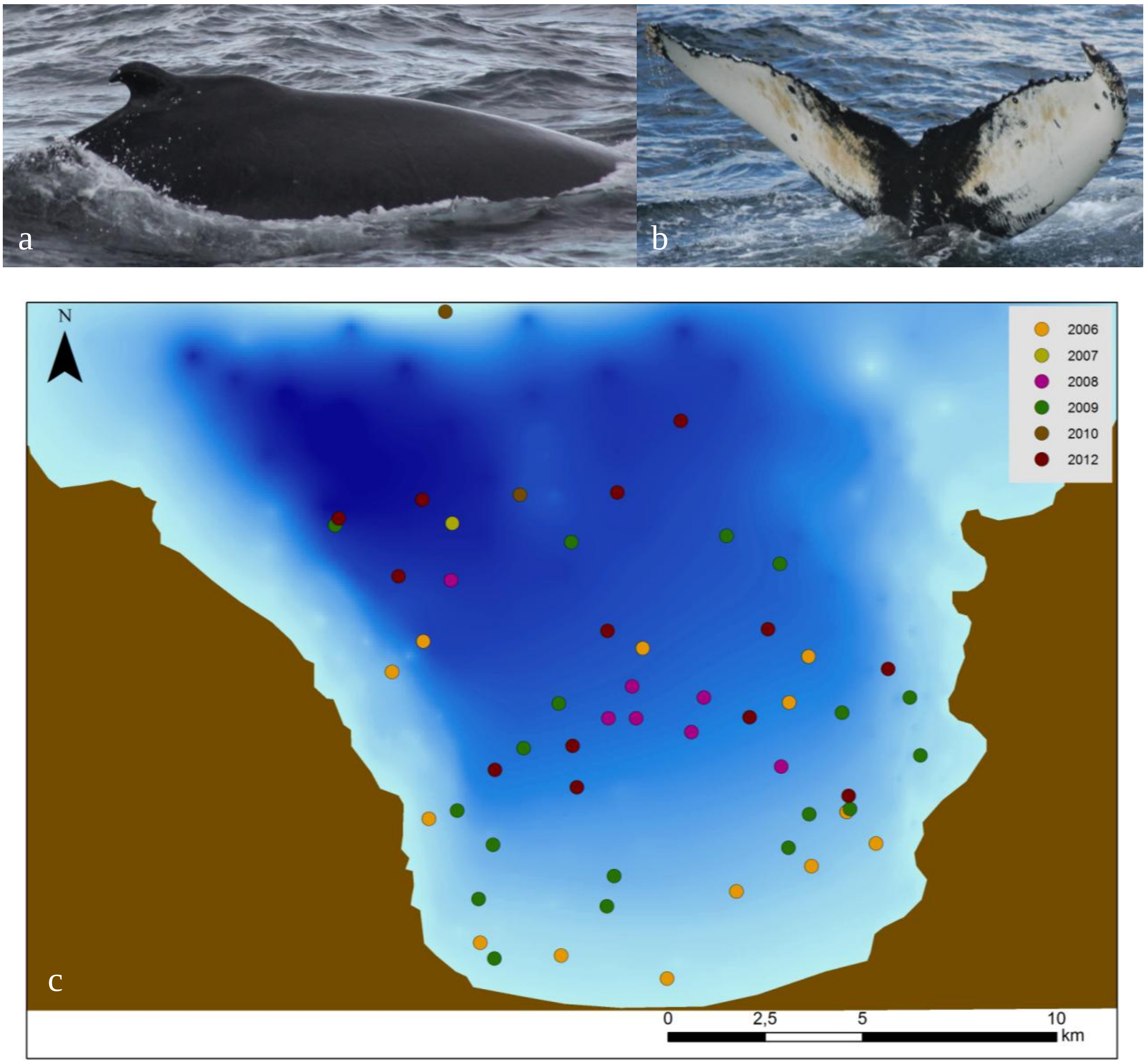


Figure 36: Dorsal fin (a), fluke (b) and sighting locations (c) of Mn33. Mn33 was sighted in different areas of Skjálfandi Bay, showing different location preferences between different years. Data from 2006 to 2011 from the Humpback Whale Catalogue of the Húsavík Whale Museum. (Photos: Luisa Klotz)

Mn37:

Mn37 always arrived in late June or early July in four consecutive years from 2006 to 2009.

Except in 2006 the whale always has observed over a period of one to two weeks, mainly in July. The sighting area covers mainly the southern and the middle part of Skjálfandi Bay (especially in 2008), but Mn37 also has been observed further north in direction of the open ocean (Figure 37).

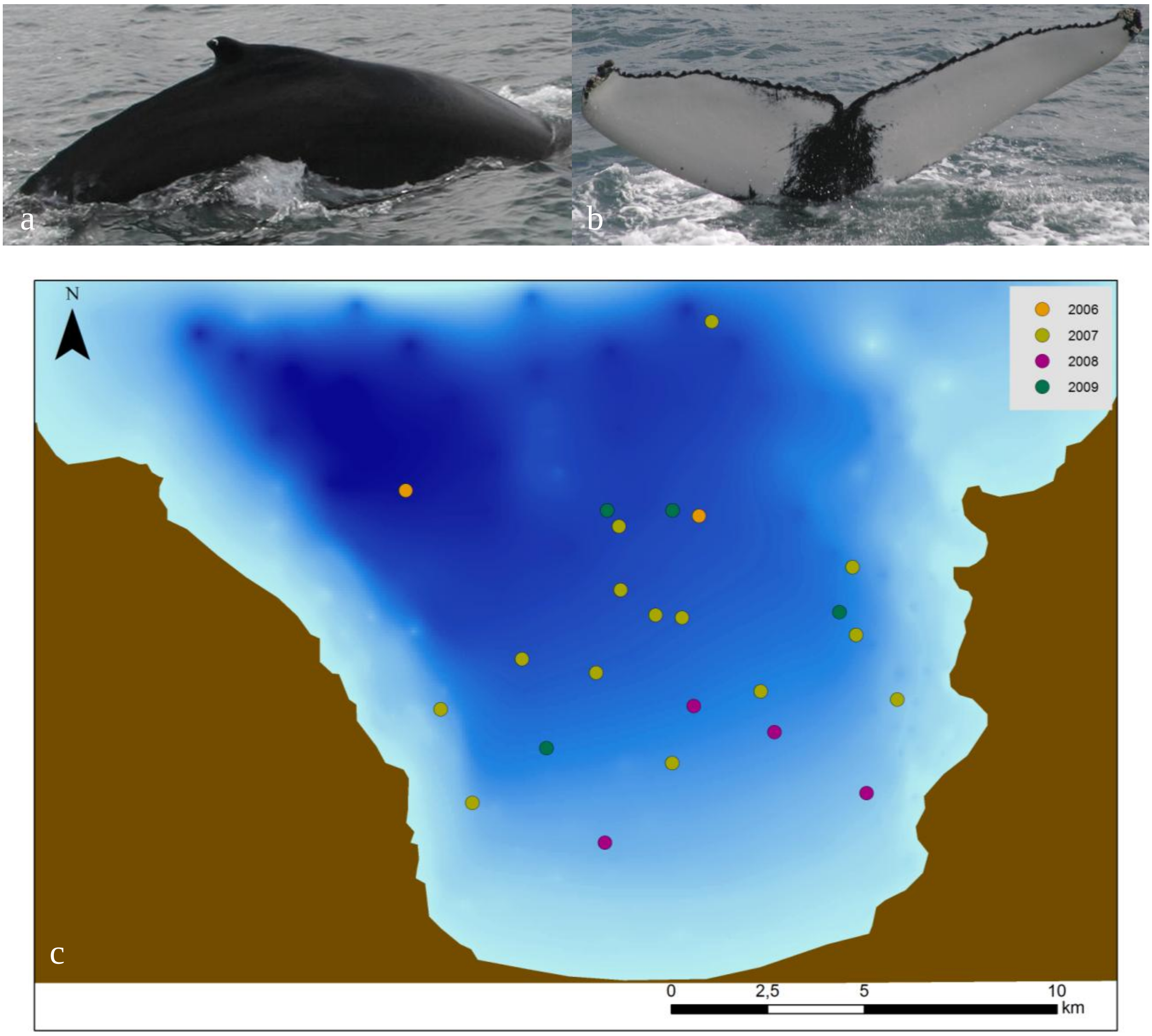


Figure 37: Dorsal fin (a), fluke (b) and sighting locations (c) of Mn37. Mn37 was sighted in different areas of Skjálfandi Bay. Data from 2006 to 2009 from the Humpback Whale Catalogue of the Húsavík Whale Museum. (Photos: Luisa Klotz)

Mn106:

Mn106 has been observed in Skjálfandi Bay from 2008 to 2010 in three consecutive years. The duration of stay decreased considerably (13 days in 2008, one day in 2010). This humpback whale was sighted in Eyjafjörður on 22. and 23.06.2010 as well as on 06.09.2009 in Ísafjörður in the northwest of Iceland. Mn106 occurred in every area in Skjálfandi Bay and has also been observed in the northern most part of the bay (Figure 38).

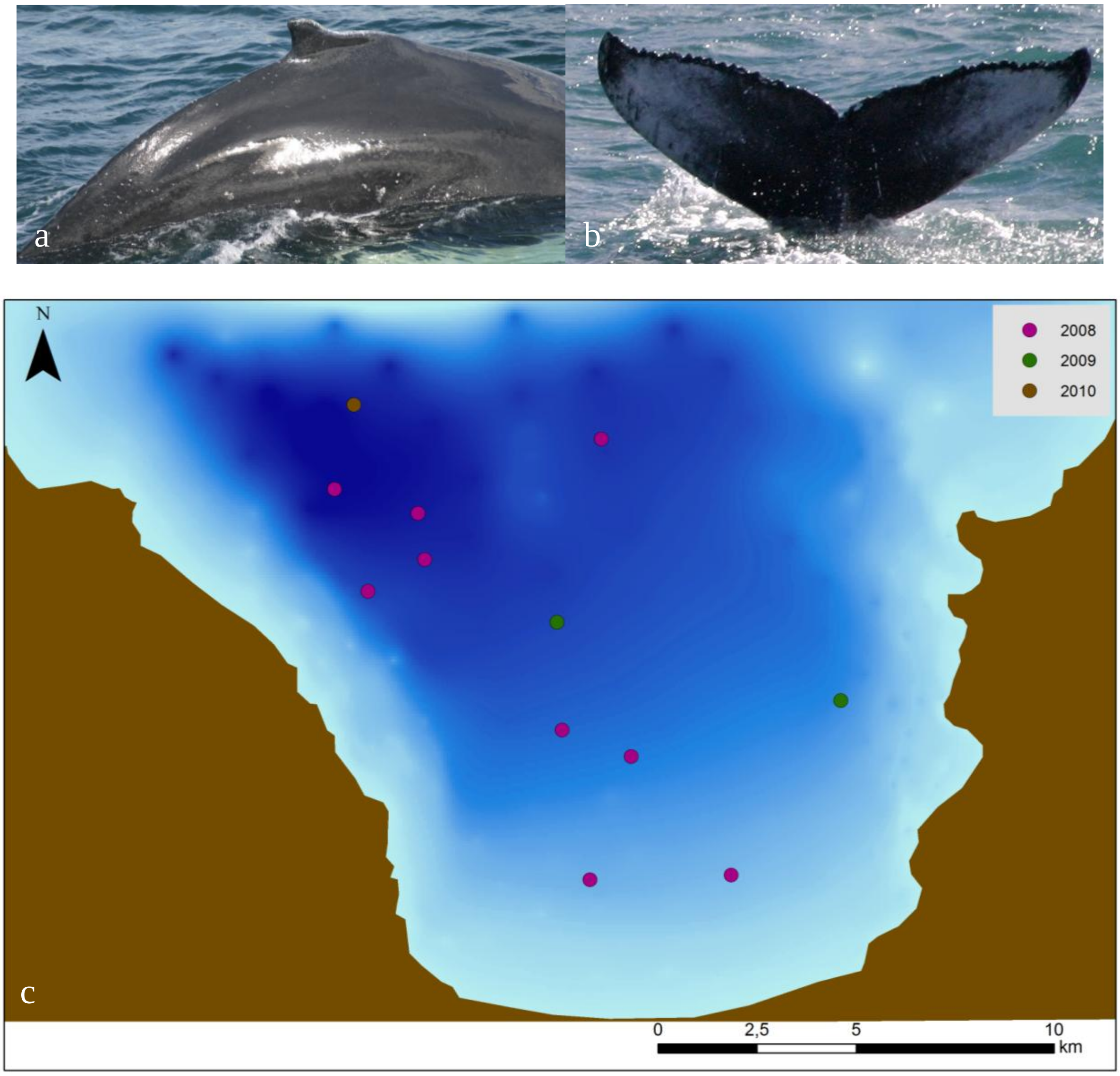


Figure 38: Dorsal fin (a), fluke (b) and sighting locations (c) of Mn106. Mn106 was sighted in different areas of Skjálfandi Bay. Data from 2008 to 2010 from the Humpback Whale Catalogue of the Húsavík Whale Museum. (Photos: Luisa Klotz)

Mn147:

Mn147 has been observed in Skjálfandi Bay since 2010, mainly during early summer months from May to July. The duration of stay increased from one day in 2010 to 7 days in 2012. Mn147 has been sighted mainly in the eastern part of the bay (Figure 39).

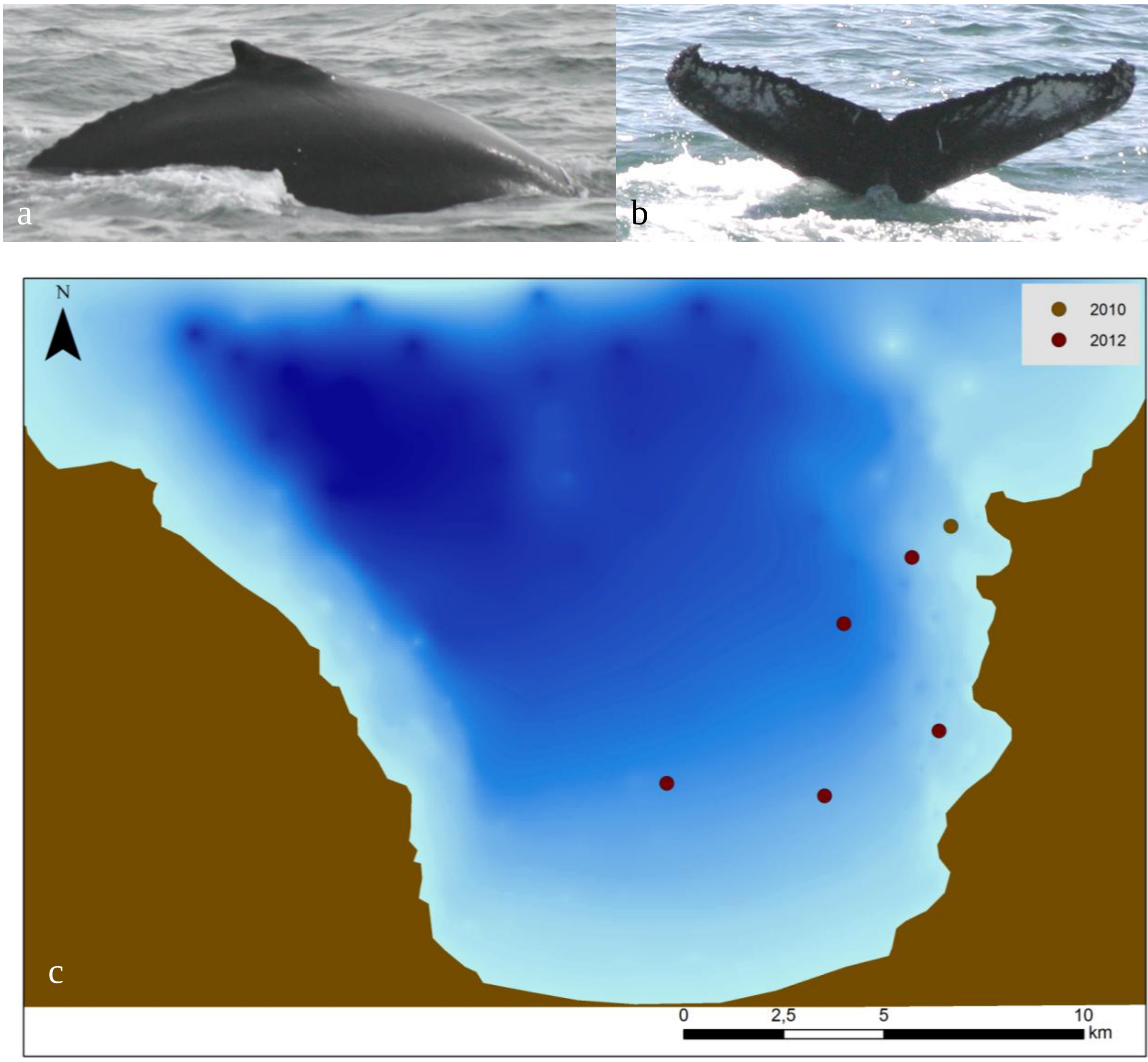


Figure 39: Dorsal fin (a), fluke (b) and sighting locations (c) of Mn147. Mn247 was sighted mainly in the eastern part of Skjálfandi Bay. Data from 2010 and 2011 from the Humpback Whale Catalogue of the Húsavík Whale Museum. (Photos: Luisa Klotz)

Mn149:

Mn149 has been sighted in Skjálfandi Bay since 2010. Whereas in the first year this individual arrived in autumn and has been observed over a period of approximately one month, the last two years it was sighted for only a few days in early summer (May in

2011, June in 2012) until late summer (August in 2011) and autumn (October in 2012) respectively, always in the northwestern part of Skjálfandi Bay (Figure 40).

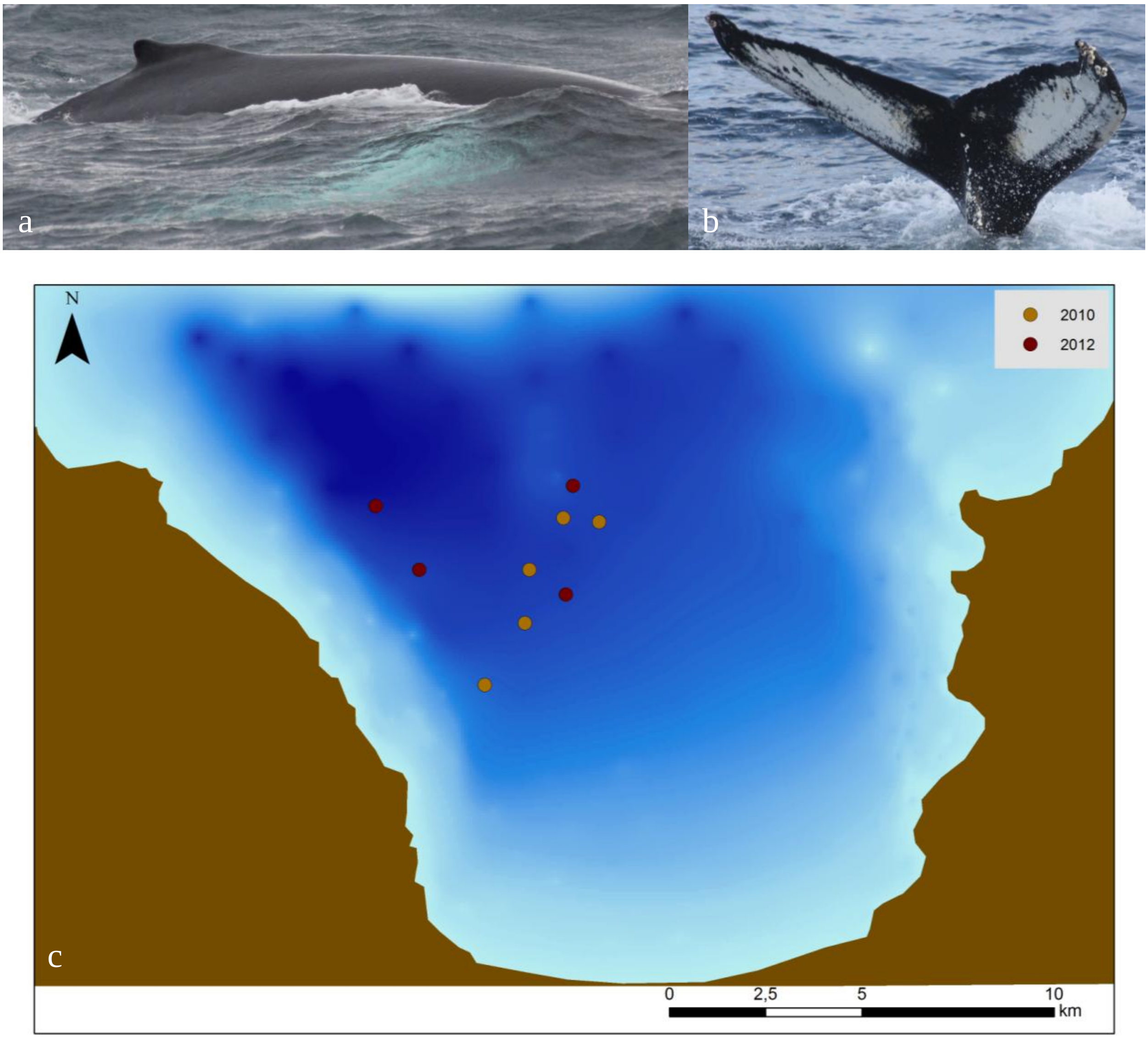


Figure 40: Dorsal fin (a), fluke (b) and sighting locations (c) of Mn149. Mn149 was sighted mainly in the north-west of Skjálfandi Bay. Data from 2010 and 2011 from the Humpback Whale Catalogue of the Húsavík Whale Museum. (Photos: Luisa Klotz)

4 Discussion

4.1 Annual distribution

4.1.1 Effort analysis

The number of humpback whale sightings significantly increased from 2003 (0.0001/minute) to 2012 (0.0246/minute). However, survey effort data contain information solely on the number of whale encounters, not the number of identified individuals. Consequently increasing effort could give a potentially incorrect impression that the total number of humpback whales in Skjálfandi Bay increased over the years. Alternatively, it is also possible that only few individuals were sighted more than once and that sighting frequency increased due to increasing effort instead of increasing actual numbers of whales.

Data collection differed throughout the years. The number of involved researchers and volunteers varied as well as the dates on which data collection started and ended. Whereas in some years researchers already sailed out in April and continued until October, in other years they focused on the summer months from May to September, which reduces the results' significance especially for April and October. Furthermore, the way data had been collected differed, depending on the number of volunteers, their level of knowledge and of course on individual interpretations.

Nonetheless, calculating sightings per unit effort provided comparable values, proving that the number of humpback whale encounters have actually increased since 2003 with an outstanding peak in 2012 (0.0246/minute). Exceptions are recorded for 2007, 2008 and 2010, where lower sighting frequencies were recorded (0.0066/minute, 0.0057/minute and 0.0054/minute).

Previous studies in the North Atlantic also revealed increasing humpback whale sightings. From 1969 to 1988 a clear trend of an increasing number of humpback whales sighted per day has been recorded (Sigurjónsson and Gunnlaugsson, 1990). Those authors already assumed that increasing numbers might be due to changing feeding conditions such as shifts in distribution of small fish or by immigration of humpback whales from different North Atlantic stocks.

4.1.2 Sightings of different species in previous years

Data of North Sailings logbooks support the thesis of increasing humpback whale sightings in Skjálfandi Bay throughout the years.
Interestingly, the blue whales show similar annual distribution patterns to *M. novaeangliae*: increasing sighting frequencies are recorded after 2003, interrupted by a decrease in 2010. Both the populations of humpback and blue whales have increased in recent years - due to protection from hunting since 1955 and 1959, respectively (Sigurjonsson and Gunnlaugsson, 1990). Since 2011 *M. novaeangliae* is the most common species in Skjálfandi Bay. Whereas the number of white beaked dolphin and harbor porpoise encounters remained mostly constant, the sighting frequencies of minke whales were antithetic to humpback and blue whale encounter rates. Once the most common species in Skjálfandi Bay, minke whales seemed to become less common, except in 2006, and also except – which is remarkable – especially in 2010, when only a few humpback whales were observed in the bay but a high number of minke whale encounters was recorded. One possible explanation for those distribution patterns is potential competition between minke and humpback whales. Lynch and Whitehead (1984) recorded spatial segregation between different baleen whale species, including minke and humpback whales. During further studies in Witless Bay, Newfoundland, Piatt and Methven (1992) reported higher minke whale abundance when prey density was low, probably because of their capability to exploit low capelin densities, whereas humpback whales seem to prefer foraging on denser capelin aggregations, as will be discussed below.

4.2 Seasonal distribution

The company North Sailing offered whale watching tours in Skjálfandi Bay only during the summer time from April to October, dependent on the weather conditions. Consequently, the research effort was limited to these months and the occurrence of humpback whales in Skjálfandi Bay during winter remained unclear.
As discussed above, the number of whale watching trips as well as the amount of effort per day varied between the months, affecting the results. Nonetheless, sightings per

unit effort should enable comparing the sighting frequencies of humpback whales between the months without being influenced by different amounts of taken effort.

High sighting rates were recorded for May and October (0.0091/minute and 0.0054/minute). These months mark the beginning and the end of the main feeding season for *M. novaeangliae*. In May, humpback whales migrate to higher latitudes, to Iceland for example, to their feeding grounds, spending the summer there. In autumn they migrate again towards lower latitudes to their breeding areas close to the equator, to mate and give birth to their calves (Norris, 1977; Pomilla and Rosenbaum, 2005). Two humpback whales, Mn20 and Mn125 (Figure 41), satellite-tagged by the Marine Research Institute (Hafro) in 2009 and 2011, showed directed southward migration in November, possibly towards their breeding grounds.

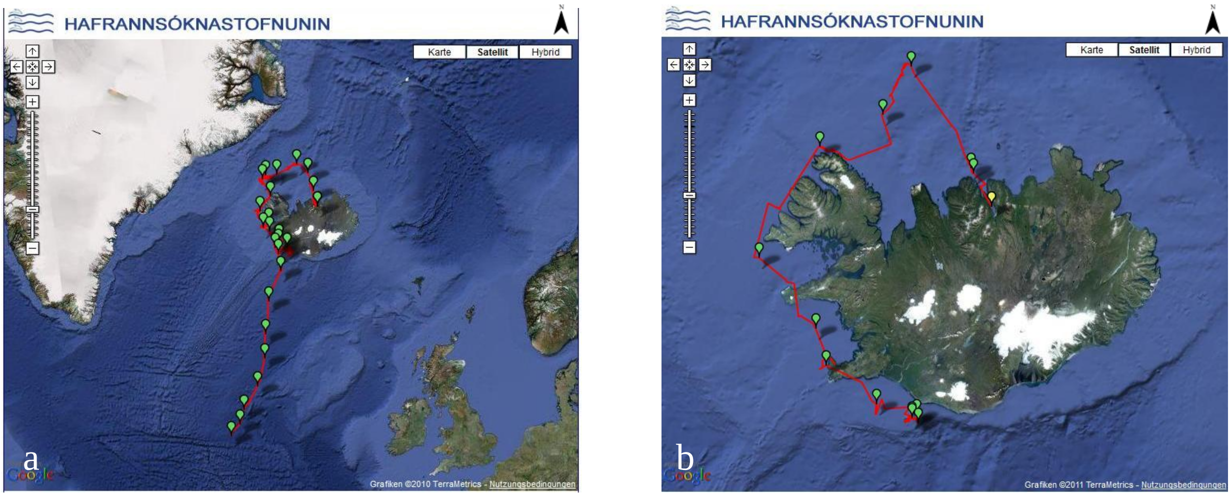


Figure 41: Migration routes of satellite-tagged humpback whales. Mn20 (a) was tagged in 2009, showing southward migration. Image from http://www.hafro.is/hvalamerki/60012.html. Mn125 (b) stayed close to the coast of Iceland. Image from http://www.hafro.is/hvalamerki/93120.html.

Sinking SPUE in August and September might be caused by further north and south migration, as feeding grounds are located up to the Barents Sea (Balcomb and Nichols, 1982; Whitehead *et al.*, 1982). Consequently for many individuals Skjálfandi Bay seems to be an intermediate stop on their migration routes instead of their destination; Ingebrigtsen (1929), for example, observed humpback whales moving northeast in the direction of Spitsbergen in August and September.

Not only the route, also the number of animals travelling depended on the season. Studies off the east Australian coast, for example, revealed that humpback whale pods are significantly larger when migrating towards their breeding grounds than on the way to their feeding latitudes. Although no similar studies are available yet for the northern

hemisphere, humpback whales might also aggregate into larger pods for migrating southward, leading to higher sighting rates in Skjálfandi Bay in autumn (Brown and Corkeron, 1995).
In July the highest sighting rate was recorded (0.0107/minute). In midsummer, most of the whales reach their feeding grounds and stay there to feed as much as possible, building up a thick fat layer on which they live during the breeding season (Norris, 1977; Pomilla and Rosenbaum, 2005). As discussed below in chapter 4.5.1, some individuals leave Skjálfandi Bay after few days, whereas others stay there for longer time up to several months, possibly because this bay represents their major feeding ground.

In their studies on cetacean abundance and food consumption in Icelandic and adjacent waters, Sigurjónsson and Víkingsson (1997) published an overview of the relative seasonal abundance of humpback whales. The highest number of sightings was reached in June, strongly decreasing until September and constantly low from October to April. Remarkable were the low sighting numbers in May and October, whereas in Skjálfandi Bay sighting rates were conspicuously high especially in May. In contrast to high sightings frequencies in Skjálfandi Bay in early summer as well as in October, Sigurjónsson and Gunnlaugsson (1990) registered highest sighting frequencies during the early season but decreasing numbers in mid and late seasons. Possibly those differences result from different study areas: whereas Sigurjónsson and Víkingsson (1997) estimated cetacean abundance all around Iceland, for this study data collection was limited to Skjálfandi Bay. Furthermore time intervals may affect the results, as the study on cetacean and food consumption was published in 1997, while data used for this thesis have been collected since 2003. The environmental parameters may have changed over the years, leading to different results.
Surprisingly, acoustic studies from 2008 to 2009 in Skjálfandi Bay recorded humpback whales singing in winter, suggesting that some whales remain in higher latitudes also during winter time (Magnúsdóttir, 2011). Likewise, Mattila et al. (1987) recorded songs of humpback whales in their feeding grounds in the North West Atlantic, although it was assumed that humpback whales sing only in their breeding areas. Furthermore, the individual named Mn178 in the Humpback Whale Catalogue was observed in Hafnarfjörður in the southwest of Iceland daily from 20.01.2012 to 12.02.2012. Due to lack of data it remains unclear whether this represents a new trend in distribution or if

some humpback whales – possibly still immature individuals – often stay in northern feeding grounds during winter time.

Further tests revealed the independence of humpback whale sightings from the time of day. Feeding behavior is mainly unaffected by this factor (Goodyear, 1989). Humpback whales migrate to northern latitudes primarily for feeding. Consequently, it is not necessary to join always similar scheduled tours every day for data collection in Icelandic waters when focusing exclusively on photo-ID. In contrast, behavior-related observations may differ over the course of the day. Studies showed increased play activities at daytime, whereas at night the whales were observed nearly exclusively feeding (Goodyear, 1989).

4.3 Sea Surface Temperatures

Although the number of humpback whale sightings in Skjálfandi Bay is increasing, some years do not fit into this general pattern. In contrast to the general trend, in 2010 for example sighting frequency fell to a low value. One potential reason would be differences in sea water temperatures, affecting algae growth and thus the availability of krill and small fish, which ultimately represent the food source for baleen whales (Katona and Beard, 1991; Stevick *et al.* 2006; Weinrich *et al.*, 1997). Surprisingly, statistical tests show no relationship between the sea surface temperature and the occurrence of humpback whales in Skjálfandi Bay.

This, however, does not eliminate temperature as a factor. First note that temperature is measured close to Grímsey, an island located approximately 50 km further north of Skjálfandi Bay on the Arctic Circle. The bay itself might show differences in sea water temperature, because it is protected by the Viknafjöll mountains in the west. Bays in general warm up quicker than the open sea due to protection from wind and high water mass exchange by the surrounding land, shallower depths etc. However, wind from north might press cold water from the open ocean into the bay, causing stronger temperature fluctuations (Gíslason, 2004; Jonsson and Valdimarsson, 2005). Studies in the Northern Gulf of St. Lawrence showed the dependency of humpback whale distribution and other rorquals on the sea-bottom topography (Doniol-Valcroze *et al.*, 2007; Naud *et al.*,2003). Those studies, however, also revealed that other, much more variable factors such as upwelling and tidal mixing, which influence the water temperature in very shortterm scales, play an important role for baleen whale distribution. Cold upwelling waters increase biological productivity in warmer surface waters. This leads to higher prey species concentrations, in turn enhancing the attractiveness of these areas for different fish species, finally attracting the larger whales (Olson and Backus, 1985; Fiedler and Bernard, 1987). Tidal- or wind-caused upwelling might, dependent on the sea-bottom topography, create thermal fronts. Such fronts represent regions of increased nutrient accumulation and may vary between weeks or even days (Koutitonsky and Bugden, 1991). Consequently krill and small fish occur in higher concentration in such areas, ultimately attracting their predators including humpback whales (Doniol-Valcroze *et al.*, 2007).

As discussed in the introductory chapter, variable influences of different water masses from Atlantic, Arctic and Polar waters as well as freshwater input lead to fluctuating water characteristics in Skjálfandi Bay (Gíslason, 2004; Jonsson and Valdimarsson, 2005). Furthermore, the bottom topography around Iceland (Figure 42), especially the Greenland-Iceland and Reykjanes Ridge in the west, and the Jan Mayen and Iceland-Faroe Ridge in the east, influence currents and circulation patterns (Hunt and Drinkwater, 2005).

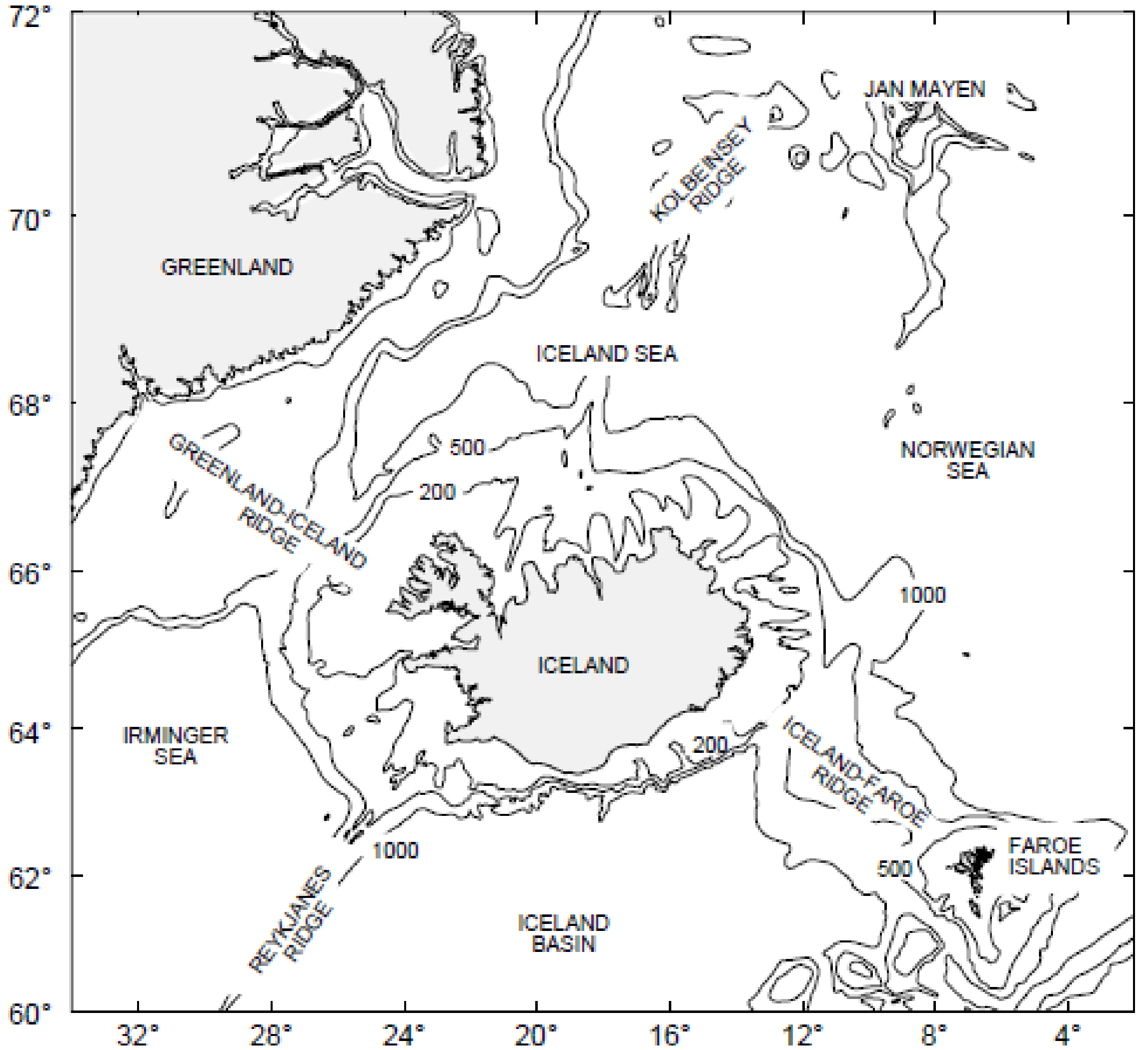


Figure 42: Bottom topography around Iceland. The Icelandic shelf and several ridges, especially the Greenland-Iceland and Reykjanes Ridge in the west, and the Jan Mayen and Iceland-Faroe Ridge in the east, influence currents and circulation patterns (from Hunt and Drinkwater, 2005).

Secondly, deep-water temperatures may differ from sea surface water temperature and again impact plankton growth in different ways. Two freshwater rivers flow into Skjálfandi Bay, leading to increased nutrient concentrations and creating a rich feeding area (Gíslason, 2004). These rivers are also no doubt influenced by different factors such as the amount of precipitation and melting glaciers. Thiele *et al.* (2004) found during their studies in Marguerite Bay, Western Antarctic Peninsula, high baleen whale occurrence in coastal fjords. Complex habitat structures lead to increased prey concentrations, attracting whales such as *M. novaeangliae* and *B. acutorostrata*. Consequently, it is insufficient to focus solely on temperature development: precipitation, currents and nutrient concentration can also influence the distribution and availability of the whales' food sources.

Distribution patterns of humpback whales are strongly influenced by their prey abundance. This prey, based on analysis of fatty acids in the Gulf of Lawrence, is mainly herring and capelin in the first place, but also other fish species as well as krill (Borobia *et al.* 1995).

Previous studies show that *M. novaeangliae* prefer high capelin densities, which is necessary for efficient foraging (Brodie *et al.*, 1978; Kenney *et al.*, 1986). Consequently, whale abundance should vary depending on prey distribution and density, as predicted in 'Foraging by Expectation' models (Green *et al.*, 1980; Iwasa *et al.*, 1981; MacArthur and Pianka, 1966). Marchand *et al.* (1999) state that capelin, when exposed to temperature gradients, try to avoid colder areas and thus accumulate within thermal zones. Such high-density areas minimize the effort whales have to spend for foraging. Metabolic requirements are mainly determined by body size and related to a certain lower limit of prey density (Nagy *et al.*, 1984). If density sinks below the limit, foraging becomes unprofitable and the predators should search for other feeding locations. As predicted in the Optimal Foraging Theory, humpback whales prefer rich feeding areas, meaning less effort in gaining the most possible energy (Doniol-Valcroze *et al.*, 2007; MacArthur and Pianka, 1966). Accordingly, capelin occurrence seems to be main factor influencing humpback whale distribution, with much stronger effect than other environmental factors such as water temperature (Whitehead and Carscadden, 1985; Piatt *et al.*, 1988).

Bryant *et al.* (1981) noted variability in humpback whale distribution in Southeastern Alaska, assuming the reason to be in food availability. Those humpback whales with feeding grounds in the Southern Gulf of Maine have been observed shifting their distribution dependent on herring and sand lance occurrence (Stevick *et al.*, 2006; Weinrich *et al.*, 1997). Data published by the Marine Research Institute in Reykjavik show increasing herring and mackerel stocks around Iceland, meaning potential prey for *M. novaeangliae* (www.ices.dk, www.hafro.is).

Boye *et al.* (2010) presumed a close dependency of humpback whale distribution on capelin appearance in Godthaabsfjord, Greenland. In North West Atlantic regions, humpback and minke whales consume large amounts of capelin (800000 and 610000 ton, respectively; Vilhjalmsson, 2002). Researchers recorded that the humpback whales' arrival times match the beginning of the capelin spawning season. Sigurjónsson and Gunnlaugsson (1990) assumed that fluctuations in capelin occurrence have been one of the reasons for differences in humpback whale sighting frequencies from 1969 to 1988. Astthorsson and Valhjalmsson (2002) published a model for the impact of Sub-

Arctic waters on the northern regions of Iceland, where the food chain from phytoplankton and zooplankton to capelin and cod seemed to be bottom-up controlled and very sensitive to climate variability. Increasing water temperatures during recent years shifted capelin distribution further north and delayed the arrival of adult capelin in northern areas (Astthorsson *et al.*, 2007).

Furthermore, researchers favor the theory of immigrating humpback whales (for example from the Norwegian Sea) as well as increasing numbers in general since the end of the whaling in the mid 20th century (Sigurjónsson and Gunnlaugsson, 1990).

4.4 Distribution in Skjálfandi Bay

In addition to annual and seasonal differences in humpback whale occurrence, locations of whale encounters varied within Skjálfandi Bay.

As whale watching boats operated by North Sailing were used as research vessels, the survey area in Skjálfandi Bay depended on the whale watching routes. Mostly the boats took similar routes and infrequently sailed further south or north. When whales were sighted close to the harbor, the boats stopped there without heading into the western part of Skjálfandi Bay. Accordingly no data for those areas have been collected on these particular days and it remains unclear whether whales were present in other regions of the bay. Moreover, if the day's first whale watching tour was successful, all following tours went into the same region. This also generated a lack of data collection in other parts of Skjálfandi Bay, especially in the low season in April, May, September and October. In contrast, more boats per day went out during the main season from June to August. The routes also varied more in this time, for example the sailing schooners always went to Lundey, the “Puffin Island” in the northeastern part of the bay, which enabled covering a broader area for searching for whales.

Most of the humpback whales have been observed in the western part of the bay close to the coast. These are the deepest areas of Skjálfandi Bay (down to 220 m) and steeply sloping. Upwelling and vertical mixing are likely occurring in these areas, replacing the upper water layer with lower ones. Nutrient concentration increases with depth because of higher solubility in colder water and sinking processes of heavier materials. But different processes such as upwelling, in particular, lead to increasing nutrient concentrations in surface waters, promoting primary production and plankton growth (Allen *et al.*, 2001; Olson and Backus 1985; Woodley and Gaskin, 1996).

Furthermore, whale encounters often took place close to the shore especially in the southern and western part of the bay, where nutrient input from freshwater rivers is highest, which influences plankton growth and thereby availability of food sources for baleen whales, as discussed in the previous chapter.

Interestingly, the distribution of humpback whales within Skjálfandi Bay varied between different months. In April, the beginning of the feeding season, only a few humpback whales had already arrived at their feeding grounds in higher latitudes and stayed mainly close to the shore. In May whales were also encountered close to the shore, mainly in the south and the western part of the bay. As discussed above those areas are most likely rich in food sources, because the western part of Skjálfandi Bay is the deepest and in the south, two freshwater rivers enter the bay. In early summer the humpback whales are very hungry after a period of nearly no feeding and the long journey north. They therefore seek rich feeding grounds to gain as much energy as possible for lowest amount of effort (Doniol-Valcroze *et al.*, 2007; MacArthur and Pianka, 1966). In June this pattern was further amplified and preferred areas for feeding clearly visible in the west.

Distribution changed during July. Numerous encounters were registered further north, which could also reflect increasing numbers of whale watching boats and more extended tours within the bay. Nonetheless, humpback whales apparently occurred in every part of Skjálfandi Bay at this time. July also represents the period, when most of the humpback whales have reached their feeding grounds. Individual density in the bay therefore increased and the whales have to spread to avoid competition. Ersts and Rosenbaum (2006) also revealed that distribution patterns, especially distance to shore, are strongly influenced by the social organization of humpback whales. Mother-offspring pairs, for example, prefer habitats close to the shore. Although no data on age and gender of humpback whales sighted in Skjálfandi Bay are available, these factors also should be taken into account when attempting to explain different distribution patterns. Furthermore, the main feeding areas may become exhausted as the season progresses, which also makes it necessary to seek out other locations. Especially primary production is subject to seasonal variances in thermal stratification of waters. Whereas in spring and autumn mainly wind is mixing the water column, bringing nutrients from deeper areas to the surface, in summer time a strong thermocline leads to decreasing nutrient concentrations, affecting phytoplankton growth and thus influencing heterotrophs' abundance (Behrenfeld *et al*., 2006; Harder, 1968). Finally many individuals already had the opportunity to restock their energy depots, which allows them to expend energy not only for feeding but also for other activities such as breaching, which is independent of location. Indeed observations show frequent breaching events during July and August. Other behaviors besides feeding such as flipper slapping, lobtailing and spyhopping occurred very often during the middle of the summer (Figure 43; pers. obs.).

Figure 43: a) Breaching humpback whales and b) one individual swimming on its back and flipper slapping. These behaviors mainly occurred during the middle of the summer but rarely in spring and autumn. (Photos: Luisa Klotz)

From August to October, whale encounters were nearly completely limited to the north or northwestern part of the bay. This distribution may be due to food-exhausted areas within the bay because of high numbers of feeding humpback whales during the previous months. Some individuals may also already start their migration towards the equator to their breeding grounds and therefore occur further in direction of the open sea. Nonetheless, as discussed above, previous studies revealed the importance of dynamic mesoscale oceanographic processes such as thermal fronts, eddies and upwelling, which, besides from large scale factors such as SST, distance to shore and sea-floor topography, also influence prey distribution (Olson and Backus 1985; Woodley and Gaskin, 1996). Last but not least, fluctuations due to the varying effect of Atlantic, Arctic and Polar water masses have to be taken into account in interpreting whale distribution (Jonsson and Valdimarsson, 2005).

4.5 Focus on individuals

4.5.1 Sightings and resightings

When using the number of humpback whale sightings to estimate whether the number of individuals in Skjálfandi Bay increased or decreased, it is important to consider that the number of sightings does not necessarily match with the total number of whales. Increasing amount of effort could lead to several encounters with the same individual. Accordingly, higher sighting rates may reflect more minutes spent for effort rather than a true increase in the number of whales.

Obtaining an overview of the total number of whales requires identifying the different individuals. Only this approach can help determine whether always the same or different individuals return to the bay.

Since 2001 most of the identified humpback whales were sighted for the first time in Skjálfandi Bay and only a small percentage was observed again in following years. The Discovery curve (Figure 31) showed a linear increase of new identified humpback whales from 2001 to 2012, indicating that the *M. novaeangliae* stock in Skjálfandi Bay is not a closed population returning to the bay every year, but part of a larger population in the North Atlantic with different or broader feeding areas. In contrast to that, a flattening curve would indicate that the humpback whales feeding in this bay belong to a separate stock, mainly isolated from other North Atlantic stocks, which is, as the increasing curve shows, not the case in Skjálfandi Bay. This thesis is supported by sightings of individuals from Skjálfandi Bay in other regions around Iceland, such as Faxaflói, Ísafjörður and Eyjafjörður.

Compared to other humpback whale feeding grounds, the resighting rate in Skjálfandi Bay is always less than 27 % - a low level. In contrast, Boye *et al.* (2010) revealed higher return rates of 30.2 % from 1992 to 2008 in Godthaabsfjord. Previous research in the Gulf of Maine also recorded high resighting rates of even 73.2 % (Clapham *et al.*, 1993). Obtaining more information about site fidelity would require observing a broader area, including the whole north of Iceland or even the complete region around Iceland. Note, however, that Boye *et al.* (2010) and Weinrich (1998) found evidence for small-scale site fidelity within only few kilometers in other regions. Some individuals may have their feeding grounds further north or northeast, close to Norway, or migrate more frequently between different feeding areas. Several sightings of individuals known from Skjálfandi Bay were recorded, for example in Faxaflói in South West Iceland and Eyjafjörður, further west of Skjálfandi Bay. These resightings confirm the theory that some individuals switch between different locations or move on to other feeding areas.

Figure 30 shows increasing numbers of identified humpback whale individuals since 2001, including an increase of newly identified individuals, whereas the resighting rate remained constantly low. Accordingly, the total number of whales in Skjálfandi Bay is apparently increasing, although higher identification rates may also result from increasing effort. As the number of sightings per unit effort as well as the number of identified individuals show significant increase until 2012, it is most likely that the total number of humpback whales spending their feeding season in Skjálfandi Bay is indeed increasing.
This trend has been observed by Punt *et al.* (2006), who determined in his studies about humpback whale abundance in the North Atlantic increasing numbers of *M. novaeangliae* individuals since the mid 20th century, after a strong collapse in numbers of individuals feeding around Iceland during the late 19th and early 20th century. Likewise Pike *et al.* (2009) recorded an increase in humpback whale abundance between 1986 and 2001 at about 12 % off Northeastern and Eastern Iceland. Researchers mainly connect these results with the end of the whaling, but also emphasize the possibility of prey-dependent shifts in distribution of North Atlantic humpback whales.

When focusing on resightings of individuals, most resightings are reported for the following year after the first sighting rather than more than one year later. Possibly, *M. novaeangliae* change migration routes slowly, as already observed on migrating humpback whales in the southern hemisphere (Stevick *et al.*, 2011). One exception was reported by the Húsavík Whale Museum in 2008; one humpback whale (Mn31) that had been sighted in 1982 in Icelandic waters was re-captured nearly 20 years later in Skjálfandi Bay in 2001.
Not only did the number of identified humpback whales increase, but also the amount of days on which the individuals were observed. This could be related to the whales'

migration routes. During the first years in which research started (2003 – 2005), Skjálfandi Bay may have been a stopover but not the final feeding ground on the humpback whales' migration further north. Alternatively, changing feeding conditions or population pressure may have boosted the attractiveness of this bay. Results also might be influenced by increasing amount of effort. Whereas in 2001 and 2002 no research studies took place, research work increased since 2003, leading to more constant observation of humpback whales in Skjálfandi Bay.

4.5.2 Life history of selected individuals

Those humpback whales which returned to Skjálfandi Bay at least three different years apparently behave very distinctly. Common patterns are hardly identifiable.

The individual named Mn10, for example, never stayed longer than three days per year in the bay; this may only represent a short stop on its transit further north or south.

The individual Mn15 also seemed to spend midsummer mainly in feeding grounds other than Skjálfandi Bay. In 2006, however, Mn15 was observed during the whole summer in the bay. This complicates identifying a recurring behavior pattern.

Mn33 showed highest site fidelity for this area. It returned to Skjálfandi Bay every year since 2006, although the duration of stay as well as the time of arrival and departure varied. This could be linked to feeding conditions not only in the bay but also in other locations on its migration route. Moreover, the sighting locations of Mn33 within the bay varied between the years, probably dependent on feeding conditions as well as feeding competition. Further studies on plankton growth and fish occurrence as well as comparisons with sighting locations of other individuals during these months could provide more information about the reasons. Furthermore it would be interesting to know whether Mn33 shows such strong site fidelity also for other areas both in its feeding and breeding grounds, for which satellite tagging and further photo-ID based studies are necessary.

Similar to Mn15, Mn37 also spent approximately one or two weeks in late June and early July in Skjálfandi Bay, possibly on its way to other feeding grounds.

For Mn106 an increasing duration of stay was registered in successive years, and also for this individual the final feeding grounds are most likely located in other regions.

The number of days Mn147 was sighted in Skjálfandi Bay also increased between 2010 and 2012, which might point to improving feeding conditions in the bay. Unlike most of the other individuals, Mn147 clearly preferred the eastern part of the bay.
In contrast to Mn147, Mn149 was sighted mainly in the northwestern part of Skjálfandi Bay in the direction of the open ocean. This may mean that Mn149 was encountered while passing the bay on its way to other feeding grounds.

Most of the humpback whales do not spend the whole summer in Skjálfandi Bay but only a few days or weeks. A majority of them probably have their main feeding grounds in other areas, or their feeding areas are widespread and not limited to one bay (Heide-Jørgensen and Laidre, 2007). Boye *et al.* (2010) described similar patterns in Godthaabsfjord, where humpback whales also showed great variations in duration of stay. The reason for differences in arrival and departure times as well as in duration of stay may reflect varying feeding conditions, competition and other factors (Sigurjónsson and Gunnlaugsson, 1990; Stevick *et al.*, 2006; Weinrich *et al.*, 1997). Two types of movement have been described. The first is daily small-scale migrations of humpback whales, circling the same route every day (Schevill and Backus, 1960). This contrasts with the study of Heide-Jørgensen and Laidre (2007), who revealed quick movements over large distances of humpback whales in West Greenland. They attribute this to variable prey abundance. Possibly, humpback whales around Iceland show similar extended movements within their feeding grounds. Animals satellite-tagged by the Marine Research Institute (Hafro) also showed different patterns of movement (Figure 44). Whereas Mn62 stayed in Ísafjörður for the whole observation time (22.09. – 03.10.2010), Mn117 moved within a broader area (01.07. – 13.07.2009).

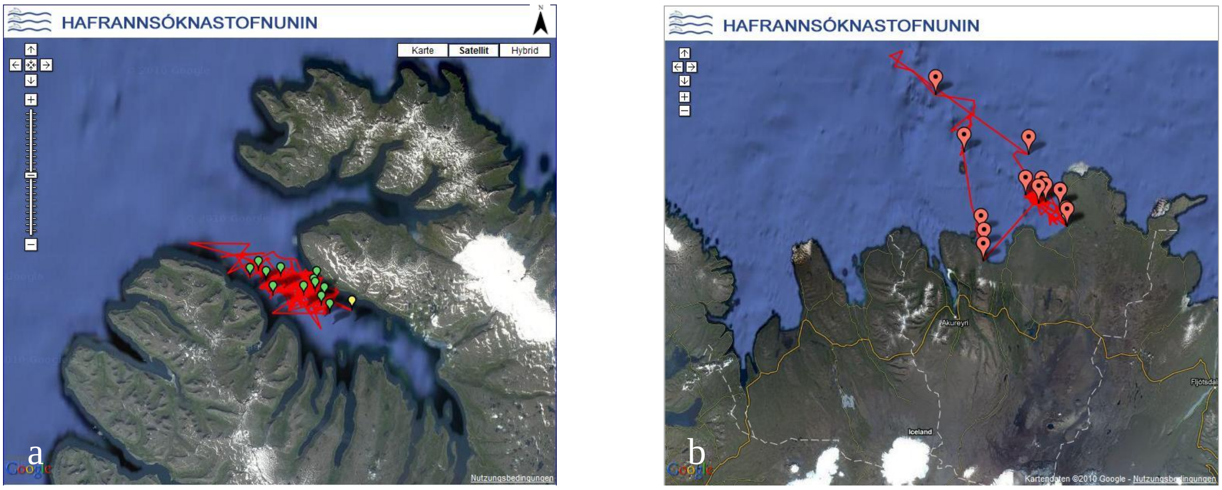


Figure 44: Movements of satellite-tagged humpback whales. a) Mn62 stayed in Ísafjörður, b) Mn117 moved within a wider area. Images from http://www.hafro.is/hvalamerki/93111.html and http://www.hafro.is/hvalamerki/hnufubakur.html.

Importantly, the humpback whales occurring in Skjálfandi Bay spend the winter in different areas. For most of the individuals, however, no data on their breeding grounds are available. As reported in the Humpback Whale Catalogue, several humpback whales were identified in the Cape Verde Islands, for example Mn104 in March 2006 off Maio and both Mn111 in April 2011 and Mn13 in March 2012 off Boa Vista. Nevertheless, the main known present-day breeding grounds of North Atlantic humpback whales are located in the West Indies and near the Dominican Republic (IWC, 2002; Reilly *et al.*, 2008).

5 Conclusions

Since 2001 the number of humpback whales in Skjálfandi Bay is significantly increasing. Nevertheless, the resighting rate remains on a constant low level. Consequently, the individuals which were observed in this bay do not form a closed population but most likely belong to a larger North Atlantic population with further feeding grounds apart from Skjálfandi Bay. This shows again that it would be insufficient to evolve protection plans for this bay only, but also an extensive area must be included.

Increasing numbers of humpback whales could indicate improving feeding conditions in this bay. However, the occurrence of humpback whales in Skjálfandi Bay is subject to fluctuations, probably due to changing environmental parameters, varying feeding conditions in particular. These fluctuations can be both natural and anthropogenic, caused by marine pollution, overfishing and climatic changes, for example. To determine the main reasons for changing distribution patterns further studies on environmental parameters such as sea water temperature, nutrient contents and prey abundance are necessary. Moreover, further research on the whales' actual population size, their migration routes and other preferred feeding areas is needed. These findings should lead to a deeper understanding of the whales' environmental preferences and their dependency on varying conditions.

Although commercial whaling of *M. novaeangliae* has been stopped and the North Atlantic humpback whale population is increasing, further human impacts endanger humpback whales (Reilly *et al.*, 2008). These impacts include fishing gears in which whales may entangle, collisions with boats, disturbance from anthropogenic noise and interruption of migrating, feeding and mating behavior by commercial whale watching (Corkeron, 1995; Neilson *et al.*, 2009).

Especially in Skjálfandi Bay, whale watching operations are increasing due to increasing humpback whale sightings. Although these touristic attractions sensitize people for whale protection, strict guidelines for the vessels are necessary to avoid disrupting the animals. Further studies should provide information on whether whale watching affects the behavior of the animals.

Moreover, the increasing number of whales could mean competition for the local fishing industry, which requires including the fishermen in any action plans.

As humpback whales seem to be very sensitive to changing environmental factors, not only animal protection but also the protection of the humpback whales' habitat is very important. Based on this knowledge appropriate protection efforts should be initiated.

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01.09.–24.09.2010	**Internship in Zoo Dresden** (Primate house)
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