UNIVERSITY OF
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MASTER THESIS

Distribution of cetaceans in Vestfjorden, Norway, and possible impacts of seismic surveys

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Abstract

Vestfjorden is an important feeding and breeding ground for many cetacean species, but no study has been published on the distribution and composition of cetaceans in the fjord. This thesis uses data from independent research trips from 2006 to 2014 to estimate the distribution of the eight species found in the fjord: Killer whales (*Orcinus orca*), Long-finned Pilot whales (*Globicephala melas*), Atlantic white-sided dolphins (*Lagenorhynchus acutus*), Harbour porpoises (*Phocoena phocoena*), Minke whales (*Balaenoptera acutorostrata*), Sperm whales (*Physeter macrocephalus*), Humpback whales (*Megaptera novaeangliae*) and Fin whales (*Balaenoptera physalus*). Killer whales have two areas of preference based on prey availability, and pilot whales where encountered mostly in deeper areas which houses cephalopods. Vestfjorden is currently closed for seismic survey activity, even so, ongoing seismic surveys up to 400 km away have been recorded inside the fjord since 2010. The study could not find a significant effect of seismic surveys on harbour porpoise or minke whale counts, and the amount of individuals encountered in the fjord each summer does not seem to have changed despite periodical seismic survey noise since 2010. Due to an opportunistic sampling design, a new investigation is proposed and possible noise impacts are discussed.

Introduction

Ecological research on population sizes, habitats, feeding and breeding grounds, etc. is key to understanding how and where to best focus protection efforts. This is especially important for cetaceans, of which many species have been almost hunted to extinction in the last few centuries, and many still have not recovered (Reilly et al. 2012; Reilly et al. 2013). Predators like cetaceans usually serve an important role in the ecosystem as for example maintaining a prey population in balance so they do not grow unchallenged destroying not only their habitat but themselves in the process (Pace et al. 1999). Even when a predator is not a so called key-stone species, it still influences the environment. Environments are not external, un-mouldable backdrops (ex. 'the' forest, 'the' ocean), but rather evolving four dimensional mediums influenced by the infinite interactions between its inhabitants (Singh and Uyenoyama 2004).

Cetaceans include a variety of species in different niches, from giant planktivores like the blue whale to predators like the killer whale (*Orcinus orca*), and they play important roles in the ecosystem. Giants like the blue whale (*Balaenoptera musculus*), and specially deep divers like sperm whales (*Physeter macrocephalus*) contribute back to primary production by the whale pump phenomena, were nutrients trapped for thousands of years out of reach for producers are carried by whales and distributed in the photic zone by their feces (Roman and McCarthy 2010; Roman et al. 2014).

Cetacean distribution

The growth of a population is limited by the carrying capacity in the species' niche, i.e. food availability and habitat (space) availability (Singh and Uyenoyama 2004). The distribution of a species in an area is also defined mainly by these factors. Other natural variables that also play a role in a population's distribution are physical properties in an area, such as temperature, light, salinity, oxygen, etc. These may affect a species either directly or indirectly, either by physically affecting the individuals (as for example the temperature requirement for the germination of a certain plant species), or affecting some other variable which in turn affects the individual (for example salinity limiting primary production which then limits food availability).

Cetaceans are endothermic so they tolerate variations in temperature. Therefore, their distribution is not directly affected by temperature. It is however indirectly affected by temperature, which limits the distribution of their prey, as is the case with pilot whales (Fullard et al. 2000) and other dolphins (Doksæter et al. 2008). Cetaceans have evolved to tolerate salinity as well, so it has not a direct effect on their distribution either. Rather, prey availability is the main factor predicting the presence of cetaceans (Hastie et al. 2004; Friedlaender et al. 2006). Proxies for prey availability in the ocean include temperature and salinity, as discussed above, but also topography. Slopes and coastal areas are often areas with high nutrient input from deeper waters, due to water masses being driven to the surface by the sudden increase in sea floor height (upwelling) (Mann and Lazier 2013). This process is regulated by current directions though, so not all slope areas have this same outcome. The increase in nutrient availability leads to an increase in primary production which in turn leads to higher fish availability. The occurrence of fish feeding cetaceans at the Mid-Atlantic Ridge illustrate this (Doksæter et al. 2008).

Cetaceans prey preference varies between species. Baleen whales feed mostly on plankton and pelagic fish, and toothed whales feed mostly on pelagic fish, squid and mammals (Mann 2000). These prey species often dictate the distribution of their predator. Deep water squid, for example, is the primary prey of sperm whales and long-finned pilot whales (*Globicephala melas*), which means they are often found in deeper waters. Fish eating killer whales on the other hand are often found in coastal areas where fish is abundant (Similä et al. 1996).

Noise pollution

The distribution of organisms are also affected by unnatural disturbances. Human impacts on habitats is a well known phenomena and often the reason environmental protection is needed. In the oceans, humans impacts include chemical pollution, overfishing, habitat destruction, temperature increase trough climate change and noise pollution.

Noise pollution in the ocean is amplified in comparison to noise pollution in the air, due to the physical properties of sound in air versus water. Sound waves are propagated by the vibration of molecules in a medium, and the speed is dependent on the density and elasticity of the medium (Hawkins 1986). Water has a much higher density and lower elasticity than air, therefore the particles have to travel less in water than air to propagate the same sound pressure. This is also referred to as the acoustic impedance of a medium (velocity of propagation times density of the medium). In conclusion, sound waves propagate faster and further in water than air (Hawkins 1986). Because of the different reference pressure in air and water, decibel levels are not entirely comparable between these mediums. Decibels is the measure of sound pressure levels in a medium given by $20 \bullet \log_{10} p/p_{\mathrm{ref\ dB}}$, where p is measured sound pressure and p_{ref} is a reference pressure (20 μPa (micro pascal) in air and 1 μPa in water).

Due to sound travelling further and faster in fluids than air, cetaceans have evolved to rely on sound on a much higher scale than most terrestrial animals. It's their main form for communication and also used for echo location in many species (Hoelzel 2009). The advantages include communication over longer distances aiding in mate finding and group cohesion, the ability to anticipate danger outside visual range, and, in the case of echolocation, a better navigation method than vision (Hoelzel 2009). Their sound production and recognition is more capable than most other mammals both in terms of frequency range and loudness. Bottlenose dolphins (*Tursiops truncatus*), for example, have hearing capability from 100 Hz to 150 kHz (Johnson 1967), although with optimal range from 30 kHz to 120 kHz (Au 1993). Mysticeti auditory systems are more adapted to infrasonic frequencies (Ketten 1992), with optimal sensitivity below 3 kHz (Ketten 2000). Their communication frequency range are of course within their hearing spectrum, with some odontocete calls including low (80–2000 Hz) and high frequency (2–12 kHz) components (Ford and Station 1987) and echolocation clicks with a broad high frequency range(100–130 kHz, Au 1993), while mysticeti calls and songs are mainly low frequency (below 1 kHz).

The vocal repertoire in cetacean communication differs between species, but most species have a broad range of conspecific calls. The famous songs of humpback whales (*Megaptera novaeangliae*) are divided in themes and repeating phrases, each phrase consisting of discrete sound elements (units). Songs usually last from a few minutes (5–7) up to half an hour (Suzuki et al. 2006). Songs also change each year, and males will adapt their song to each other's, so all males in a group sing basically the same song (Payne and Payne 1985). Matrilineal odontocetes, like the killer whale and pilot whale have call types that are vertically transmitted through vocal learning. That leads to repertoire differentiation between genetic unrelated groups, most documented in killer whales (*Orcinus orca*) (Yurk et al. 2002). Bottlenose dolphins create their own personal whistle, called *signature whistle*, which identify them as an individual and can be referenced by others, even when the individual being referenced is not present (Janik and Sayigh 2013). These are few examples of the complexity in cetacean communication and sound production.

The discovery of their reliance on sound and complex acoustic signals has led to increasing discussion about sound pollution in the ocean. Ambient noise in the oceans was mainly caused by natural occurrences before the industrial revolution, like wind, waves, biological signals, earthquakes, etc. However, anthropogenic noise is now present in almost all oceans, and has contributed to a significant increase in background noise (Hildebrand 2009). Animals that had adapted for millions of years to a certain background noise and sound dissipation, were suddenly (evolutionary speaking the change was indeed sudden) in a sea of strange loud noises.

In the last 50 years, merchant vessels quantity has almost tripled and their total size (in tons) has increased over six times, leading to an increase in ambient noise of 12 dB re 1 μPa (Hildebrand 2009). In this same period, oil exploration has moved further into deep sea, increasing the usage of seismic surveys, which is now the second biggest contributor of total anthropogenic sound pollution, behind vessel noise (Hildebrand 2009).

The effect of anthropogenic noise on cetaceans can be categorised into four different zones of influence, as suggested by Richardson and Thomson (1995). (i) Zone of audibility: the animal can detect the noise above ambient noise level. (ii) Zone of responsiveness: the animal presents a behavioural response to the noise. (iii) Zone of masking: the noise may interfere and mask biological sounds of importance to the animal. (iv) Zone of hearing loss, discomfort or injury: the noise may cause threshold shifts or physical damage to the animal. The size and reach of these areas for a particular sound source is dependent on the local environment and the differences in sound sensitivity for each species. The propagation ratio of an air gun array used during seismic surveys, for example, may vary by a few thousand times in different environmental conditions, so the area and number of possible individuals affected could then vary by a factor of millions (Gordon et al. 2003). For this reason, a good model of sound propagation should be investigated for each new environment.

The sound pressure levels necessary to cause injury are not documented for most species, however captive experiments with dolphins have shown masked temporary threshold shifts (MTTS, “masked” refers to the presence of significant ambient noise, which have shown to increase hearing threshold and decrease observable temporary threshold shift (TTS) in humans) after exposure to pulses with 192–201 dB re 1 μPa, at frequencies above 3 kHz. However no MTTS was observed at 0.4 kHz (Schlundt et al. 2000). While there is no data on TTS or permanent threshold shift (PTS) on mysticetes, one can assume they would be more affected by lower frequency noises than odontocetes, due to their higher sensitivity to those frequencies. Gedamke et al. (2011) developed a model of individual variation and population uncertainty to simulated baleen whales being exposed to seismic surveys. The model found possible TTS on 29% of whales at ~1 km range, but empirical data are still needed to draw any conclusions. We are still far from predicting TTS and PTS on cetaceans due to anthropogenic noise, and for that reason a seemingly nominal value of 180 dB re 1 μPa is used as an exclusion zone during seismic surveys in some countries, while others use a fixed distance radius from the source (Weir and Dolman 2007).

The third zone of influence, masking, is not easily observable but has potential negative effects at the population level. A recent report by the German Federal Environment Agency (Siebert et al.

2014) modelled the propagation of air gun sounds and overlaid it to cetacean vocalisations. Their results suggest propagation of noise up to 2000 km from the source, with possible loss in communication range for blue and fin whales at distances of 500–2000 km. Considering the importance of vocal communication for baleen whales for finding mates and foraging grounds, the decreased range could lead to lower population fitness. Masking could also be the cause for vocalisation changes in cetaceans when exposed to seismic survey sounds, as mentioned above.

In order to mitigate the impacts of seismic surveys on marine mammals, many countries have developed survey guidelines (reviewed by Weir and Dolman 2007). The main mitigation means currently used are (i) operational procedures (like the gradual increase in sound level, also called “soft-start”), (ii) real-time mitigation and animal detection (like marine mammal observers and exclusion zones) and (iii) seasonal and local consideration (like protected grounds and seasonal migrations). The efficacy of the guidelines varies between countries as there is still no worldwide standard. Some countries include all marine mammal species in their practices (UK, US (California only), Brazil, New Zealand and Sakhalin (Russia)), while others exclude a few odontocete species. As mentioned above, the exclusion zones are mainly arbitrary with a California and New Zealand applying a variation of the 180 dB radius. However most other regions use a fixed length radius (including New Zealand, based on dB measurements), independent of the volume of the air guns or the survey-site environment. The current guidelines clearly still have room for improvement (Parsons et al. 2009), but their existence is a step in the right direction, and should be followed by many other industrialised countries. As of 2014 Norway still has no guidelines regarding marine mammals and seismic surveys, although there are mitigation measures for economically important fish stocks, and some of those measures (soft-start) indirectly “benefit” marine mammals.

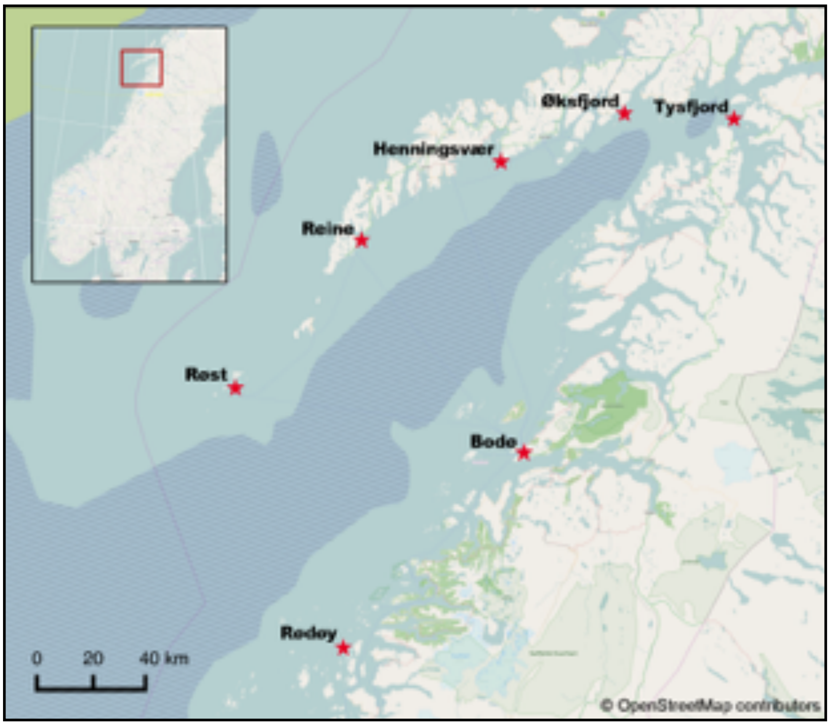

Figure 1: Vestfjorden, Norway. Dark blue area represents areas deeper than 200 m.

Vestfjorden

The study area for this thesis, Vestfjorden (Figure 1), has experienced local changes recently due to warmer waters. Herring, which used to be abundant in the fjord, has begun to move further north and outside the fjord since 2006 (von Quillfeldt 2010). Species that feed on herring in winter now have to travel further to reach a feeding site. However, the warmer waters has also brought mackerel further north and into the fjord, perhaps bringing more cetaceans in the summer seasons (Lorentsen and Lyngmoe 2010). Possible effects of climate change on cetaceans can include direct effects based on the animals temperature requirements, and indirect effects by changing the distribution of a prey population, for example (Simmonds and Eliott 2009).

The fjord also contains various possible disturbance sources including fishing activity, boat transport, whaling, sea safari, private boats and seismic survey sounds. Fishing may in some cases be in direct competition with cetaceans in the fjord by catching fish species of interest for cetaceans. The main species caught in the fjord are Atlantic cod (*Gadus morhua*), Atlantic herring (*Clupea harengus*), Atlantic Mackerel (*Scomber scombrus*), saithe (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*) and, in a smaller scale, Atlantic salmon (*Salmo salar*). Killer whales have been seen around active fishing boats, probably attracted by the fish being caught (Vester, personal communication).

Boat traffic a significant cause of noise pollution in Vestfjorden. In addition to private boats, fishing boats and transport ferries, many tankers and cargo ships have routes through the fjord to reach the Narvik port. Whale watching differs in disturbance levels from other boat sources in that they actively search and stay close to cetaceans, that can also be the case for private boats. There is no current whale watching regulations that take in consideration the whales' welfare in Norway.

The Lofoten area including Vestfjorden is currently closed for industrial seismic surveys and oil extraction. A survey in 2009 by the Norwegian Petroleum Directorate found vast oil reserves on the north of Lofoten, but pressure from the fishermen and local community lead the government to wait with any oil drilling projects and further surveys in the area until more research is done on the possible effect of seismic survey noise on the fish stocks. The Institute of Marine Research published one study done in conjunction with the 2009 survey, and concluded with a clear behavioural effect on fish, leading to both increases and decreases in fish catch during the survey, depending on the species (Løkkeborg et al. 2010). Since then, seismic surveys have been ongoing further south in Norway, however, those taking place in the west of Norway can still be heard inside Vestfjorden since 2010 (Vester, unpublished data), even though they are outside the areas which are closed off from seismic surveys.

Earlier research of cetaceans in Northern Norway include killer whale feeding strategies on herring (Similä et al. 1996) and salmon (Vester and Hammerschmidt 2013), killer whales response to sonar activity (Kuningas et al. 2013) and minke whale movement tracking (Heide-Jorgensen et al. 2001). So far, no research on the distribution of cetacean species in Vestfjorden has been published.

This thesis aims to give an overview of the cetacean distribution and niche in Vestfjorden through the use of encounter data and behavioural notes. I will also investigate whether the long distance seismic surveys have had an effect on the distribution and frequency of encounters of cetaceans in the fjord. The thesis is based on already collected data from 2006 to 2014 by Heike Vester (Ocean Sounds), supplemented with my own observations from summer 2014 in cooperation with Ocean Sounds.

Methods

Vestfjorden, the study site for this thesis, is not technically a fjord but a sea area between the Norwegian mainland and Lofoten, still it will be referred to as a fjord. The fjord's opening stretches over 80 km from Rødøy municipality in the mainland (66°43'12.00" N, 12°46'39.88" E) to Røst municipality in Lofoten (67°31'02.85" N, 12°07'03.53" E). Vestfjorden then stretches northeast for around 180 km (Figure 1). The deepest point in the fjord is 700 m, in the middle area.

This thesis uses data from (i) independent cetacean research trips made by Heike Vester at Ocean Sounds, (ii) seismic survey data from the Norwegian Petroleum Directorate (npd.no) and (iii) hydrography data from the area retrieved from the Norwegian Institute of Marine Research (imr.no).

(i) The cetacean survey data was collected from 2006 to 2014 at Vestfjorden, Norway (Figure 1). Table 1 contains a summary of the frequency of the trips each year. The data collected that are used in this thesis are date and time, location (GPS waypoints and boat tracks), whale species encountered, number of individuals, photo-id data and field notes with behaviour details and general comments. Figure 2 shows all record GPS tracks for trips in the years 2011 to 2014 (n=161). There are no GPS tracks of trips before 2011.

The trips were conducted in a 7.3 meters Zodiac boat with a 250 HP outboard engine. The route started from Henningsvær (Figure 2) and south-east towards the 100 m depth line from the shore, then towards Skrova. At the 100 m depth line and at Skrova, a hydrophone (Reson TC 4032 Hydrophone, Etec custom built amplifier, Sound Devices 744T audio-recorder, 20 m cable) was used to listen to possible cetacean vocalisations. From there, the trip continued either northeast to Øksfjord, south towards the middle of Vestfjorden, or east

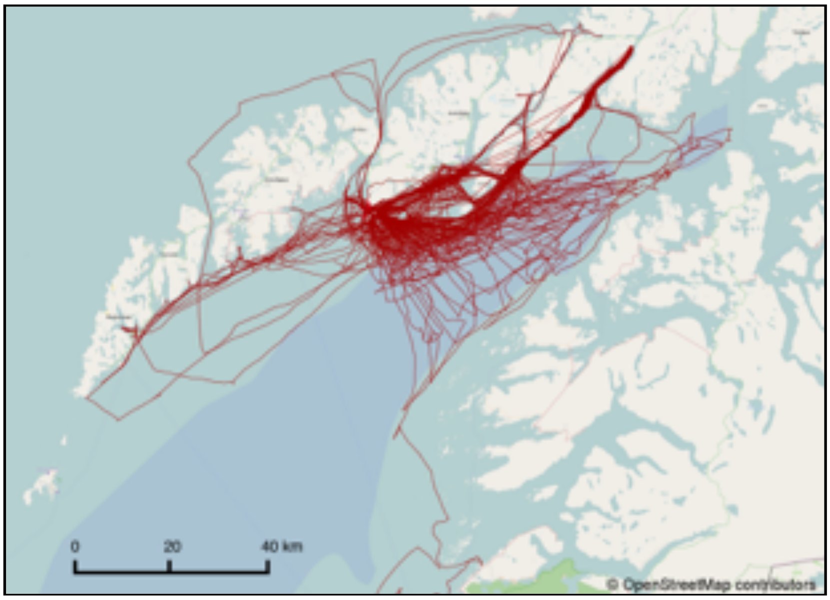

Figure 2: Tracks for years 2011-2014. Tracks that went outside the fjord in the north (n=4) were removed from the statistical analysis. Dark blue area represents areas deeper than 200 m.

towards the inner part of Vestfjorden. Trips after 2010 had an increase in the amount of hours at sea, the possible effects from this change are addressed in the discussion. Photos were taken using a Canon 1D Mark IV with a Canon 100-400 mm 4.0-5.6 IS L, and a Canon 50D with a Canon 70-200 mm 2.8 IS L. The GPS used to record waypoints and tracks were a Garmin GPSmap 78S and a Garmin eTrex 20. All hydrophone recording were made between 0-30 dB amplification at the amplifier, in addition to a +10 dB pre-amplification from the hydrophone.

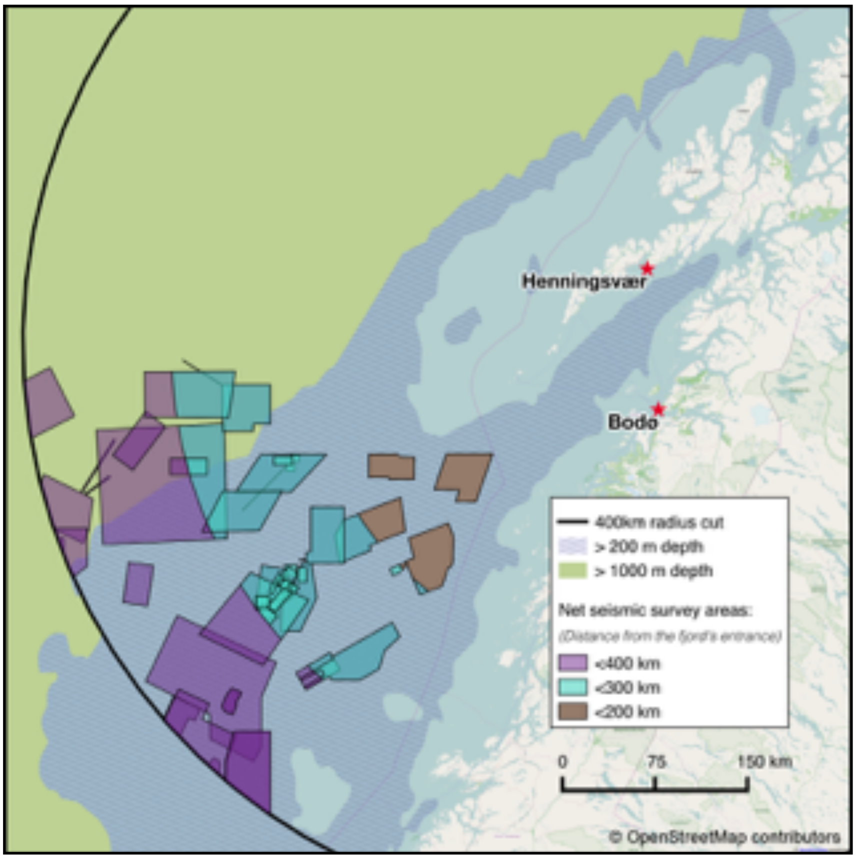

Figure 3: Net seismic survey areas outside the coast of Northern Norway from 2009 to 2014. Surveys further than 400 km from Vestfjorden were cut out. Also not included are surveys north of Vestfjorden (n=3 inside the 400 km radius), since their propagation is assumed to be diminished by the land masses.

Reports received by Ocean Sounds from reliable sources such as fishermen, safari boats and tourists with pictures are used to aid in the qualitative results of species distribution in Vestfjorden.

(ii) Seismic survey data was downloaded from npd.no. The data consists of geographical shape files with the following relevant attributes for this thesis: survey name, survey type and subtype, number and size of sources, start and end date. Seismic surveys started being reported by the Norwegian Petroleum Directorate only from 2009, so there is no data on surveys before that year.

Table 1: Frequency of trips and encounters each year.

Year	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**
Number of trips	30	59	60	53	17	41	38	43	40
Trips with encounters	17	33	17	28	13	31	29	22	29
% encounters	56,7	55,9	28,3	52,8	76,5	75,6	76,3	51,2	72,5

Sound from seismic surveys have been recorded in the fjord since 2010. All 3D and 4D surveys within a radius of 400 km from the opening of Vestfjorden were included in the analysis, categorised by their distance from the fjord (Figure 3). Sound pressure levels were not recorded.

(iii) Hydrography data retrieved from imr.no was collected by a fixed hydrography station outside Skrova. The data includes monthly mean temperature at 1 m depth.

An effort was made to acquire fish catch statistics from Statistics Norway (ssb.no). The data included yearly total catches of pelagic fish, cod species and flatfish & other bottom species, from 2006 to 2013. Only catches received by landing sites around Vestfjorden were included (following municipalities: Lødingen, Røst, Værøy, Flakstad, Vestvågøy, Vågan, Moskenes, Bodø). Ultimately this data was not included in the analysis due to the low resolution in the data. Yearly catches is not necessarily a good representation of summer catches.

Ship traffic data retrieved from ssb.no contained the number of transport ships admitted to Narvik port, divided into the following categories: tankers, bulk carriers and other cargo ships. The data comprised the years 2006 to 2010. This data was not included in the analysis in the end since including it would exclude the years 2011-2014 and reduce the sample size further.

Statictical methods

Statistical analysis and graphs were done using R version 3.0.2. (R Core Team 2013). Distribution maps were made using Quantum GIS version 2.4 (Quantum GIS Development Team 2012) and Photoshop CS5. Reference maps were acquired from OpenStreetMap.org (available under the Creative Commons Attribution-ShareAlike 2.0 licence) and depth shapes acquired from NaturalEarthData.com (Creative Commons public domain).

A one-sample proportion test was done to compare frequencies of pilot whale encounters (all years) in the deep area of the fjord (>200 m) with expected frequencies based on the proportion of deep

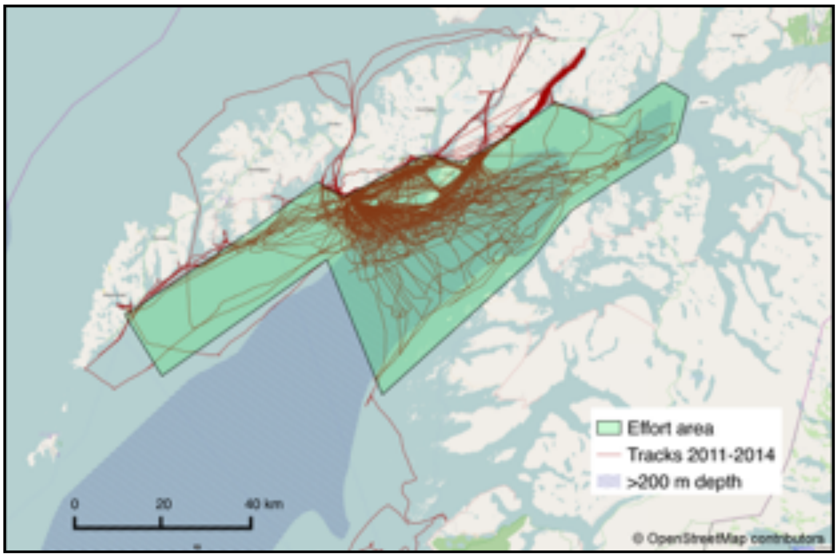

Figure 4: Effort area used in proportion test.

area and total area of the effort area in the fjord, shown in Figure 4. The same test was done to compare the frequency of Atlantic white-sided dolphins in an area 3.5 km inwards and 2 km outwards from the edge of the 200 m depth area in Figure 1, with expected frequencies based on the proportion of the 5.5 km wide line and total area of the effort area.

For the other analysis, the encounters data was filtered to include only the summer season for statistical analysis (from 1st of May to 31st of September). Harbour porpoise and minke whale encounters from 2011 to 2014 were analysed by analysis of covariance with count data, using a general linear model with poisson distribution. Both species were analysed with two models, model 1 based on seismic surveys as reported by the Norwegian Petroleum Directorate (Figure 3) and model 2 based on days were seismic survey noise was recorded in the fjord. Table 2 shows an overview of the models. Trip length was transformed to a categorical variable by dividing the trips into three equal size categories: low, medium and high length, defined by 0 to 77.4, 77.5 to 126, and 127 to 198 km respectively. Only the years 2011 to 2014 were included in this analysis, since these years had detailed distance travelled for each trip. The model for harbour porpoises used a quasipoisson distribution to account for over-dispersion. All models were simplified by comparing the change in explained deviation between models, as described by Crawley (2005).

A different approach was taken with the remaining species, for reasons discussed below (see Discussion). A Pearson's product-moment correlation analysis was conducted for killer whales, pilot whales and Atlantic white-sided dolphins individually, looking at the number of groups / individuals in the fjord each season correlated with year, and also correlated with mean summer temperature. Assumptions of normal distribution were tested with a Shapiro-Wilk normality test. All years were used in this analysis, again filtered for only the summer months to avoid natural seasonal variation (2006 was therefore not included since it has no observations in summer). Humpback whales were analysed in the same manner. Fin whales and sperm whales were not

Table 2: Overview of variables included in the general linear models. Daily count of harbour porpoise and minke whale individuals were analysed individually by both models.

Model 1		**Model 2**	
Variable	**Type**	**Variable**	**Type**
Year	Categorical (4 levels)	Year	Categorical (4 levels)
Trip’s length (km)	Categorical (3 levels)	Trip’s length (km)	Categorical (3 levels)
Temperature	Continuous	Temperature	Continuous
All seismic surveys <400 km	Binary	Recorded seismic survey noise in the fjord	Binary
Seismic survey distance	Categorical (3 levels)	-	-

included in any analysis due to low amount of data points. Number of individuals for pilot whales were estimated in real time out in the field, i.e. there was no active counting of individuals, only an educated guess based on group size. Pilot whale amount values were transformed by natural logarithm to conform to a normal distribution.

Results

The qualitative results of the observations, field notes and reports to Ocean Sounds are as follows:

Table 3: Species seen in the fjord in the period 2006-2014. "x" represents visual encounters, "o" represents reports from other sources without visual confirmation in the field by Oceans Sounds. Sperm whales observations are only recordings and not visual observations (except in 2014, where one was seen on the surface).

		Year in Vestfjorden								
Common name	**Scientific name**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**
Killer whale	*Orcinus orca*	x	x	x	x	o	x	x	o	x
Long-finned Pilot whale	*Globicephala melas*	x	x	x	x	x	x	x	x	x
Atlantic white-sided dolphin	*Lagenorhynchus acutus*			x	x		x	x	x	x
Habour porpoise	*Phocoena phocoena*		x	x	x	x	x	x	x	x
Minke whale	*Balaenoptera acutorostrata*	o	x	x	x	x	x	x	x	x
Sperm whale	*Physeter macrocephalus*			o				x	x	x
Humpback whale	*Megaptera novaeangliae*			x	x		x	x	x	x
Fin whale	*Balaenoptera physalus*	o		o	x		x			x

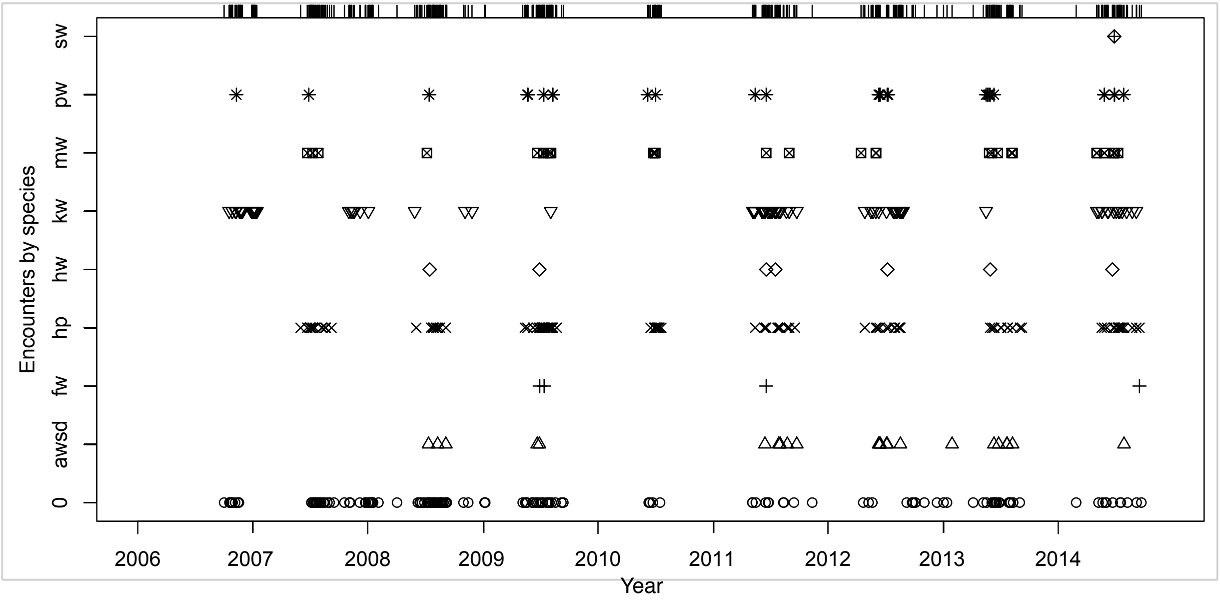

Figure 5: Encounters of different species through time. Yearly marks in X-axis represent the first of January of the marked year. Ticks at the top show effort days. Species legend: 0: day with no encounters, awsd: Atlantic white-sided dolphin, fw: fin whale, hp: harbour porpoise, hw: humpback whale, kw: killer whale, mw: minke whale, pw: pilot whale, sw: sperm whale.

Figure 5 shows a scatter plot of each encounter for each species in all years. Figure 6 shows the number of days each species was encountered in the fjord. Table 3 gives an overview of which species were seen each year.

Below is a summary of the presence of each species and their behaviour in the fjord based on observations and field notes by Heike Vester at Ocean Sounds. Years marked with "*" are cases based on reports from third parties as detailed in materials and methods, with no visual confirmation by Heike Vester/Ocean Sounds.

Killer whales:

Figure 7 shows a detailed distribution map of killer whales in the fjord from 2006 to 2014. Killer whale groups where seen in Tysfjord in the winter season (November to March) of 2006, 2007, 2008* and 2009*. There were no active trips to the Tysfjord area after 2008, and no reports of groups in the area after 2009. In the middle of Vestfjorden, killer whale groups were seen in the winter seasons of 2006, 2007, 2008 and 2013*. Although in summer 2013 only a single male was seen once. In Øksfjord, killer whale groups have been seen in the summer (April to September) of 2008, 2010*, 2011, 2012 and 2014. A few groups have also been seen in the west part of Vestfjorden, close to Reine (Figure 1) in the summers of 2008*, 2009, 2012, 2013* and 2014.

Many groups in the summer have newborn individuals. In the winter seasons in Tysfjord, many different groups feed together. In the summer seasons, only one or two groups stay in an area for prolonged periods (i.e. Øksfjord, west of Vestfjorden) which have been observed feeding on herring, mackerel and salmon.

Pilot whales:

Figure 8 shows a detailed map of pilot whale encounters from gps points from 2008 to 2014. Pilot whales were seen each year in Vestfjorden. Groups sizes ranged from 20 to over 100 individuals. In 2013 and 2014 many groups totalling around 200 individuals were seen simultaneously in the fjord (outside Svolvær) before travelling further. Newborns were often present in the groups. 80% of encounters happened where sea depth was over 200 m (27 out of 33). The proportion analysis shows a significant higher encounter rate in the deep area than what would be expected randomly (χ^2: 31.879, df: 1, p-value < 0.001, chi-square test)

Atlantic white-sided dolphins:

Figure 9 shows encounters each year. Figure 10 shows all encounters together. Atlantic white-sided dolphins were encountered in the summer seasons of 2008, 2009, 2011, 2012, 2013 and

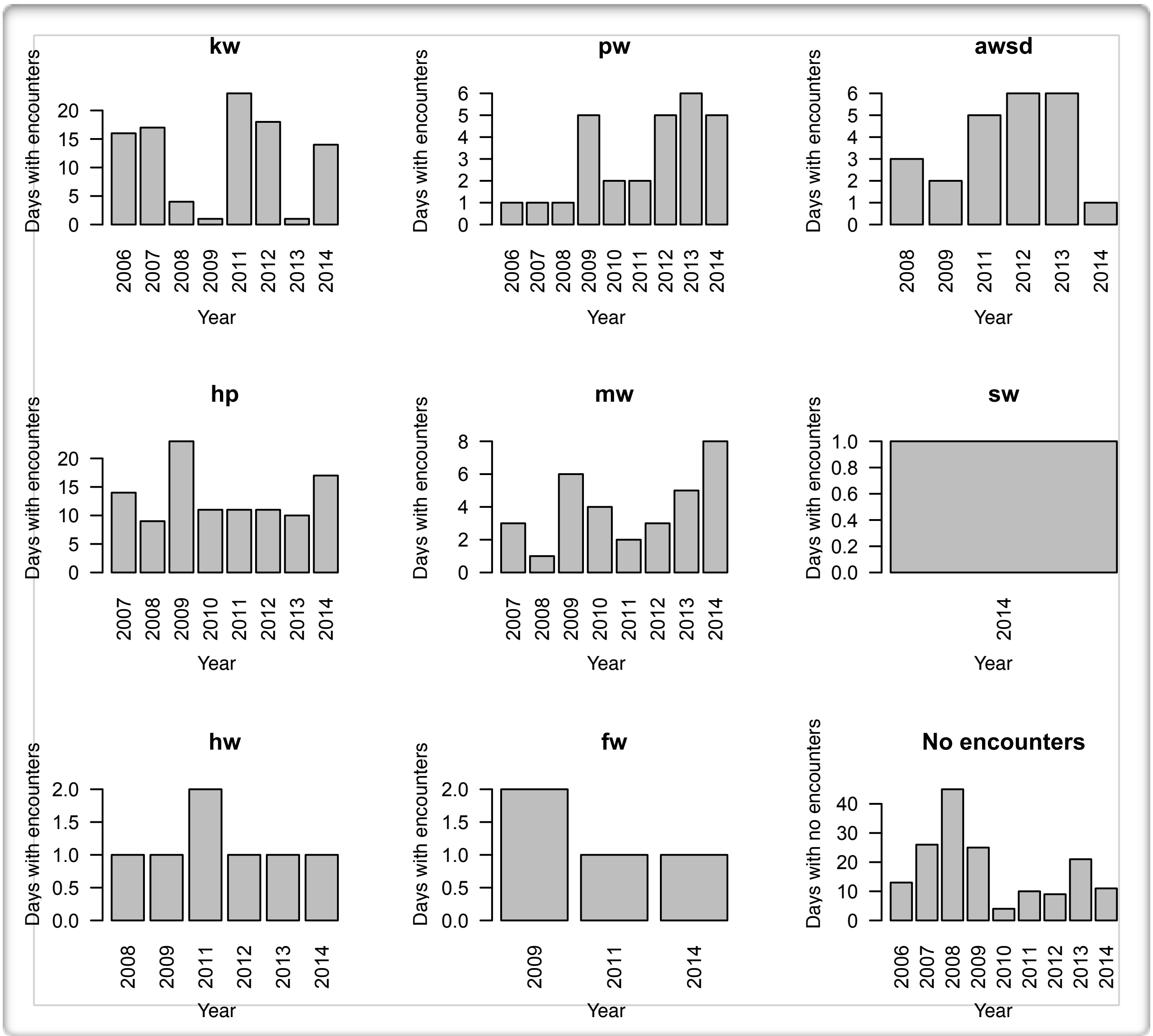

Figure 6: Number of days with encounters of each species for each year. Missing years means the species in question was not encountered that year. Species legend: kw: killer whale, pw: pilot whale, awsd: Atlantic white-sided dolphin, hp: harbour porpoise, mw: minke whale, sw: sperm whale, hw: humpback whale, fw: fin whale.

2014. Encounter rates were not significantly different between years, although group size did vary, ranging from a pair of individuals to over 50 (see Figure 22). They have been observed feeding on mackerel. Only 36% of encounters took place 4 km from the 200 m slope, resulting in a non significant proportion test result (χ^2: 0.424, df: 1, p-value: 514, chi-square test).

Harbour porpoises:

Figure 11 shows harbour porpoise encounters each year. Figure 12 shows all years combined. The frequency of encounters has been fairly constant each year (Figure 6). There are higher encounter rates in areas with higher track density (Figure 2).

Minke whales:

Figure 13 shows minke whale encounters in each year, while figure 14 shows a combination of all years. As with harbour porpoises, areas with higher track densities (as seen in Figure 2) show higher encounter rates for minke whales.

Sperm whales:

Figure 15 shows where sperm whales were heard in 2012 and 2013. In 2014 a whale was seen starting to dive. In 2012 and 2014 it is assumed only one sperm whale was in the fjord, judging by its echolocation clicks. In 2013 the echolocation clicks of two sperm whales could be heard simultaneously. The recordings were all made in the 200 m plus depth area in the fjord.

Humpback whales:

Figure 16 shows all humpback encounters in all years. Humpback whales have been observed in the summer seasons of 2008, 2009, 2011, 2012, 2013 and 2014. There was only one encounter per year, except in 2011, which had two (Figure 6). In all cases the observations were of a single whale, except in 2014, where three whales were seen together. Humpback whales have been seen feeding on krill in the fjord, specifically in 2011 and 2013.

Fin whales:

Figure 17 shows all fin whale encounters in all years. Fin whales were observed once in 2009, 2011 and 2014. Although there has been reports of fin whales in 2006, 2008 and 2014. In 2006 there were three reports separated by a few days, so it is assumed it regarded the same individuals (two). In all other years except 2014 there was only one encounter/report. In the observation of 2011 there were two individuals, assumed to be mother and calf (one was noticeably bigger). The observation of 2014 consisted of 20 individuals. 100% of the encounters happened at over 200 m sea depth.

Seismic surveys:

Figure 18 shows points where seismic survey sounds were heard in 2014. It also shows areas where seismic survey sounds were not heard even though they had been heard elsewhere in the fjord the same day. The timing of the recording coincides with ongoing seismic surveys in a 400 km radius from the opening of Vestfjorden. In a few cases up to three simultaneous surveys could be heard in the fjord, again coinciding with three simultaneous surveys at the time. However, as seen in the map, the seismic survey sounds could not be heard in the whole of Vestfjorden, specially in Øksfjord, where seismic survey sounds were never heard (represented by only one point in Figure 18). Figure 19 shows periods with ongoing seismic surveys used in the analysis.

Distribution maps

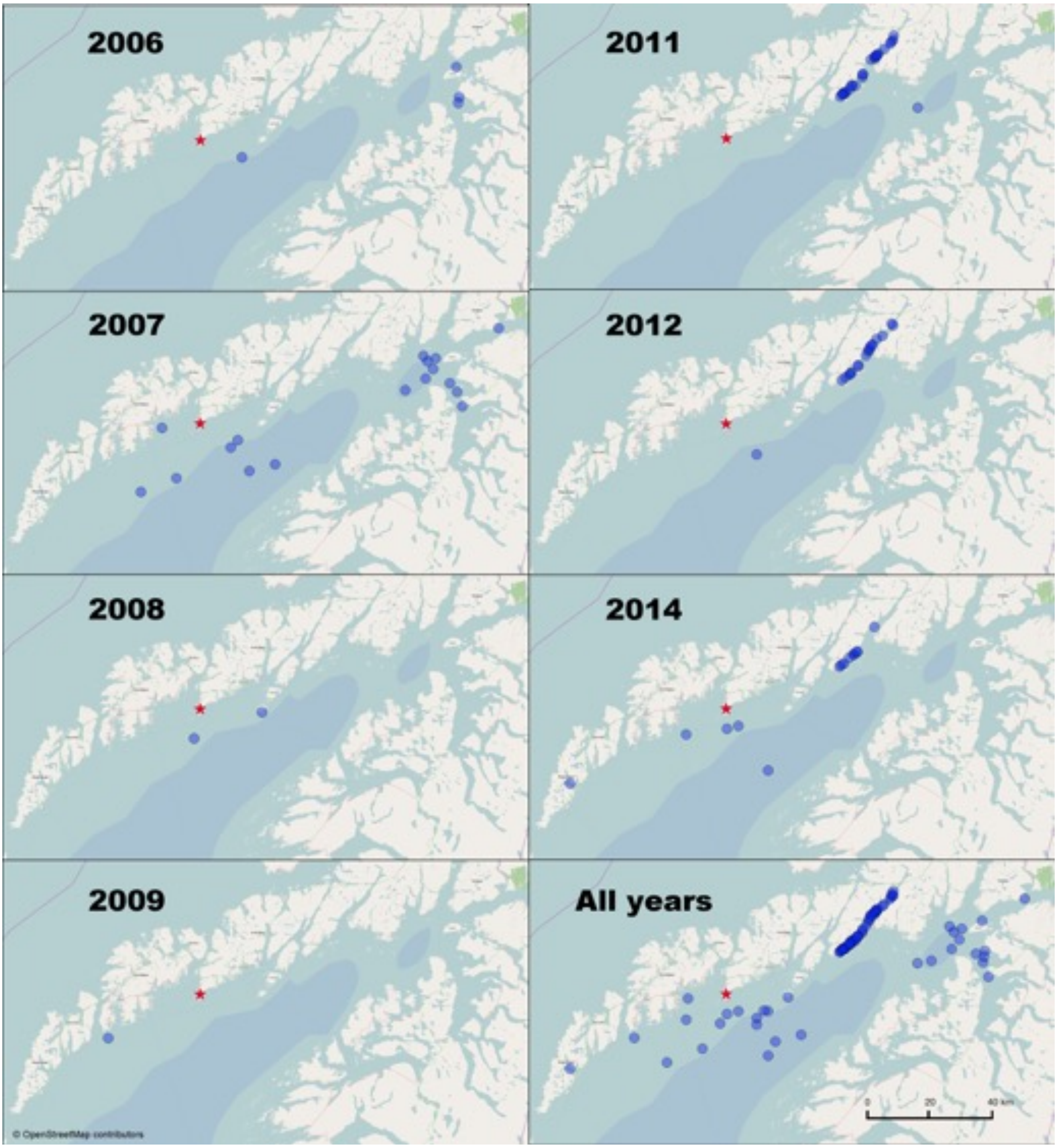

Figure 7: Encounters with killer whales through the years. Points represent the first encounter of a group in the day. Even though there are many points in Øksfjord, they all represent only one group each season. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

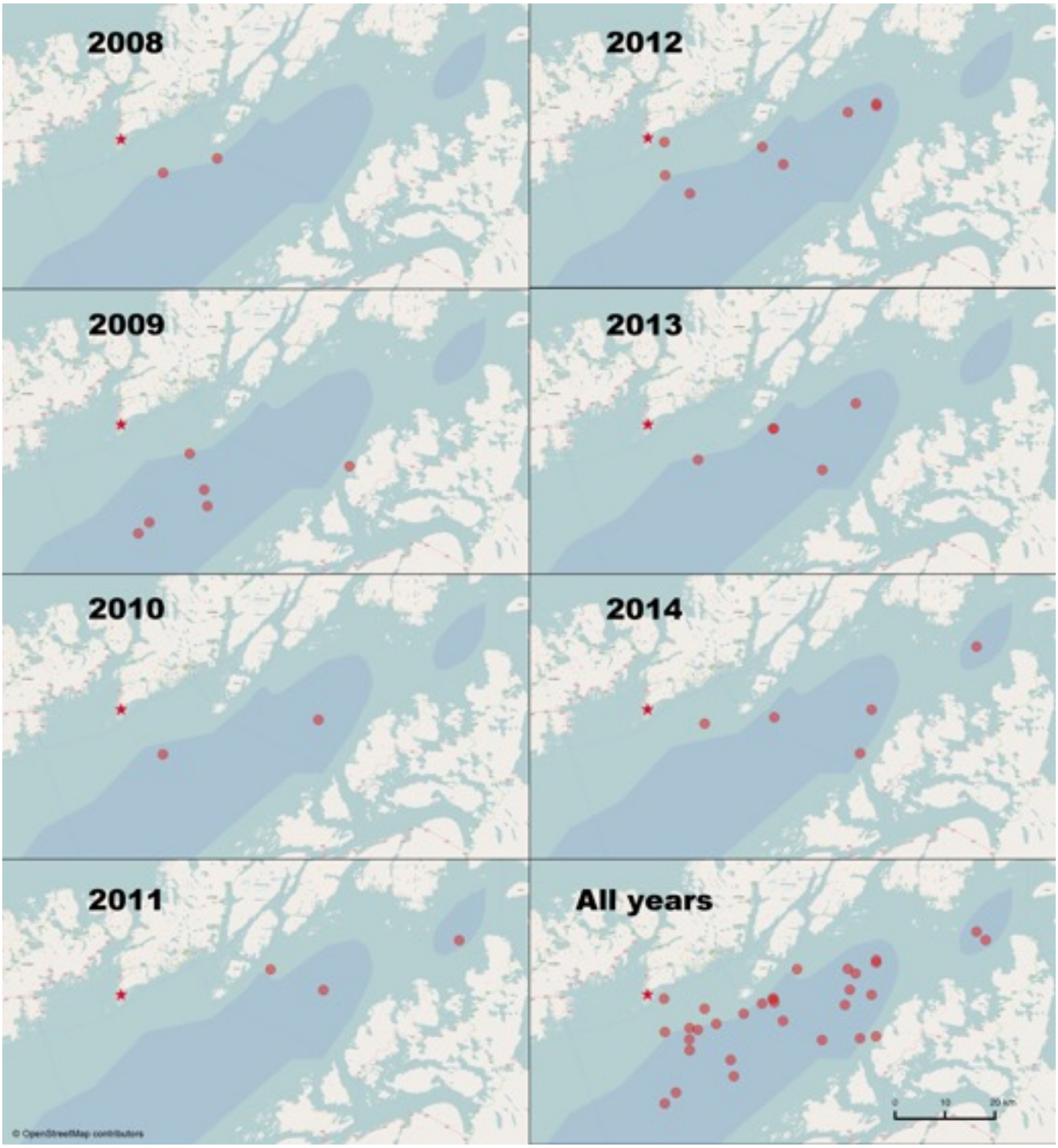

Figure 8: Encounters with pilot whales through the years. Points represent the first encounter of a group in the day. One encounter, outside Bodø, is omitted from the figure. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

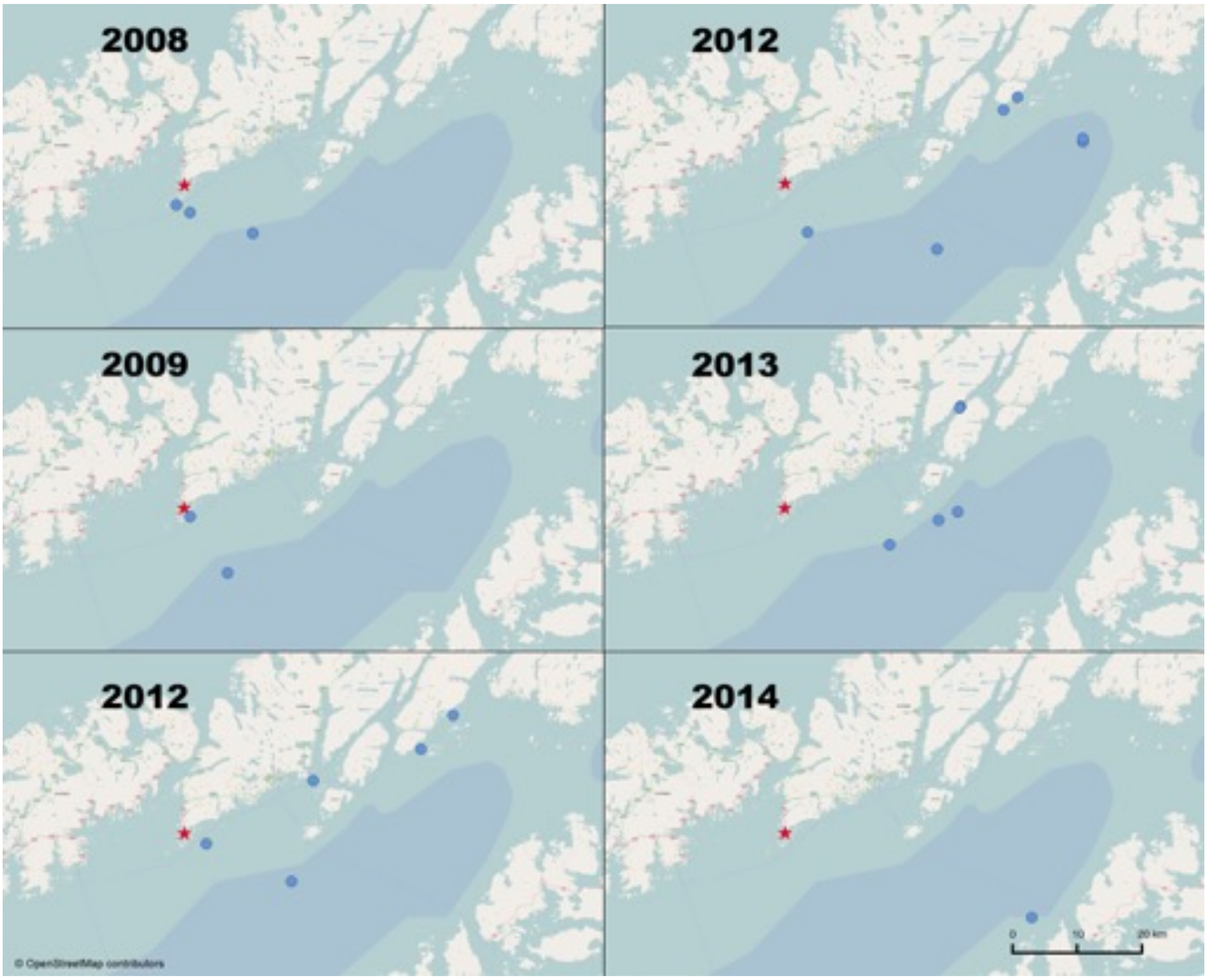

Figure 9: Encounters with Atlantic white-sided dolphins through the years. Points represent the first encounter of a group in the day. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

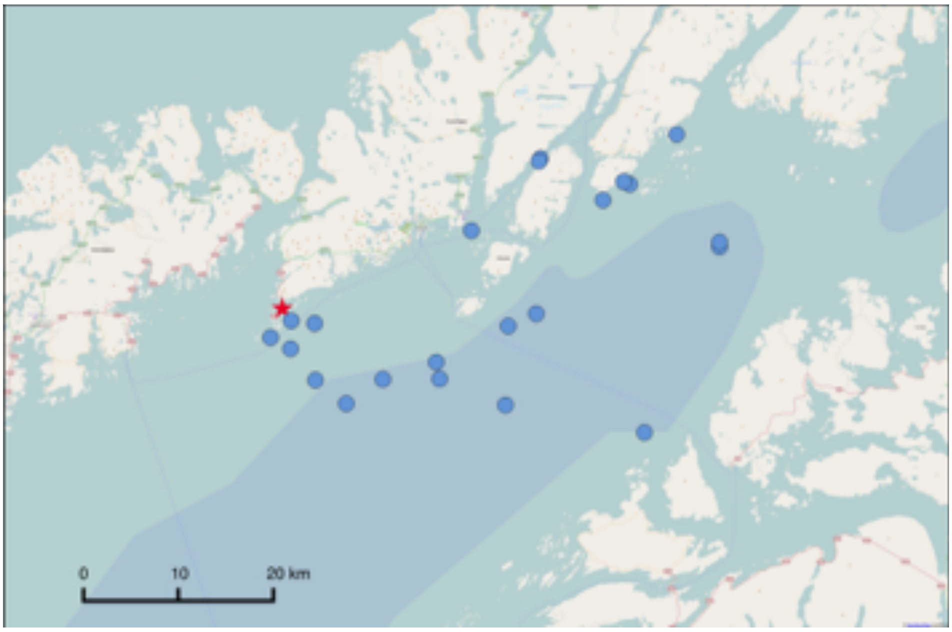

Figure 10: Encounters with Atlantic white-sided dolphins all years combined. Points represent the first encounter of a group in the day. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

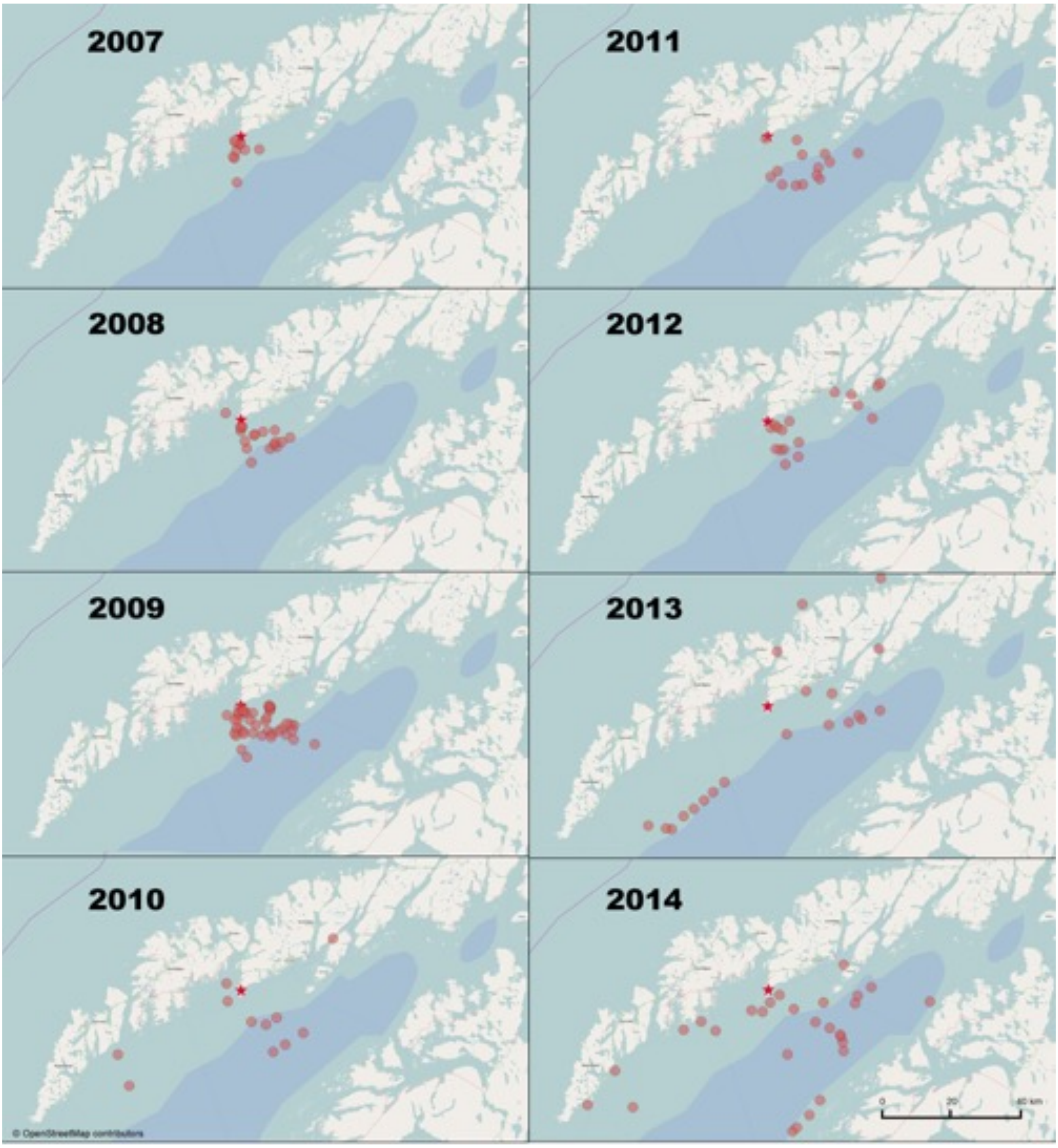

Figure 11: Encounters with harbour porpoises through the years. Points represent the first encounter of a group in the day. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

Figure 12: Encounters with harbour porpoises in all years. Points represent the first encounter of a group in the day. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

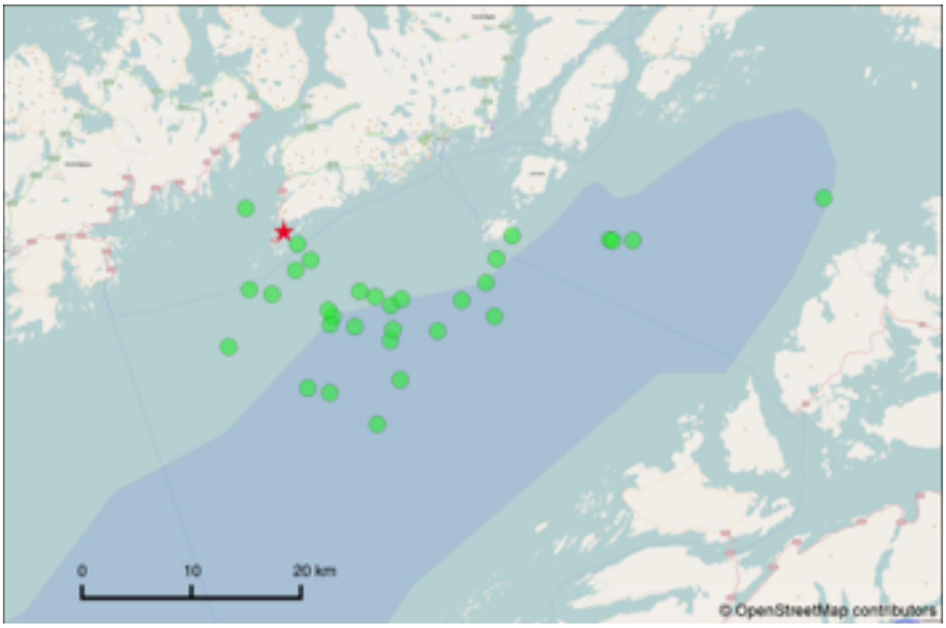

Figure 14: Encounters with minke whales in all years. Points represent the first encounter of a group in the day. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

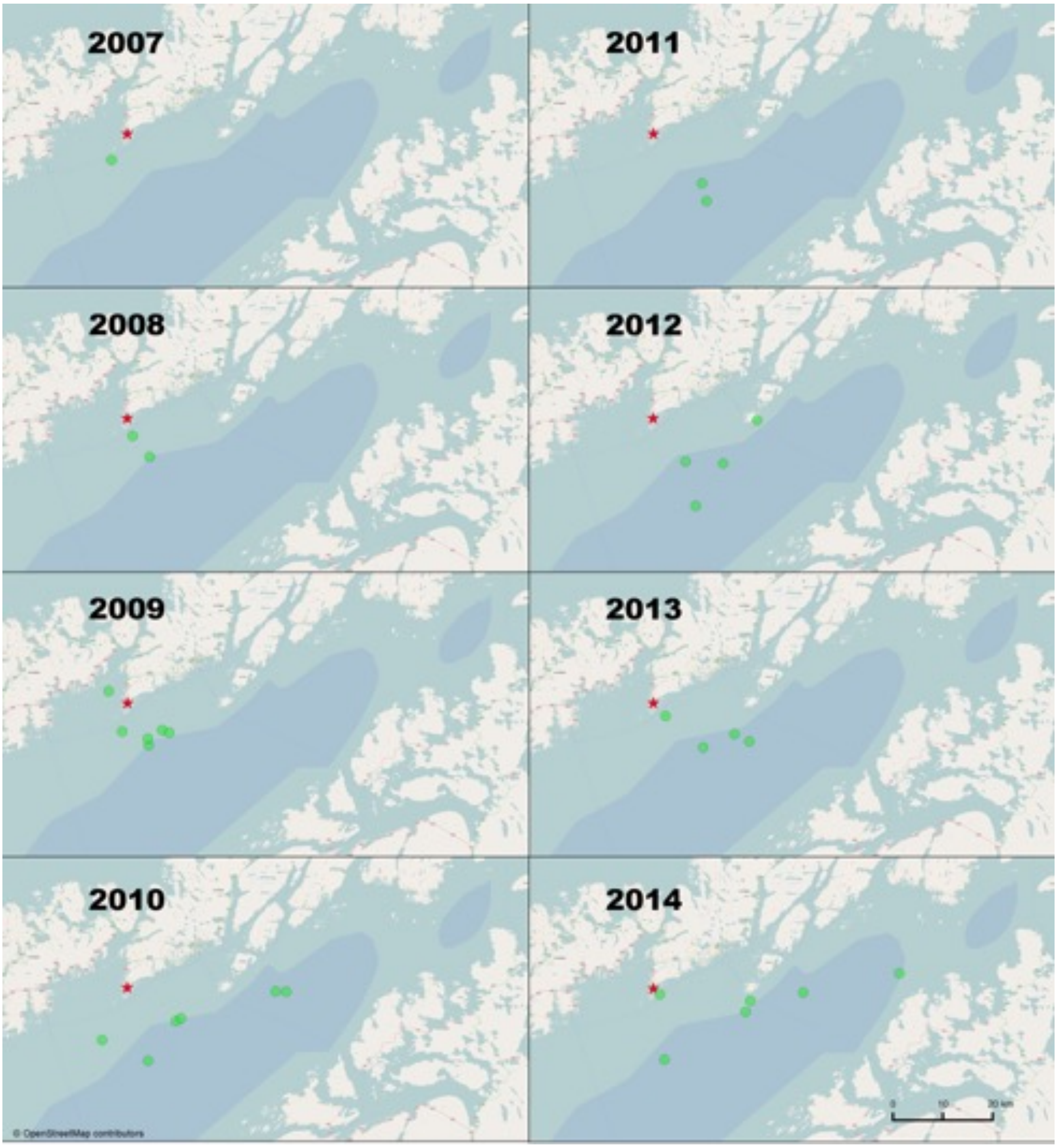

Figure 13: Encounters with minke whales through the years. Points represent the first encounter of a group in the day. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

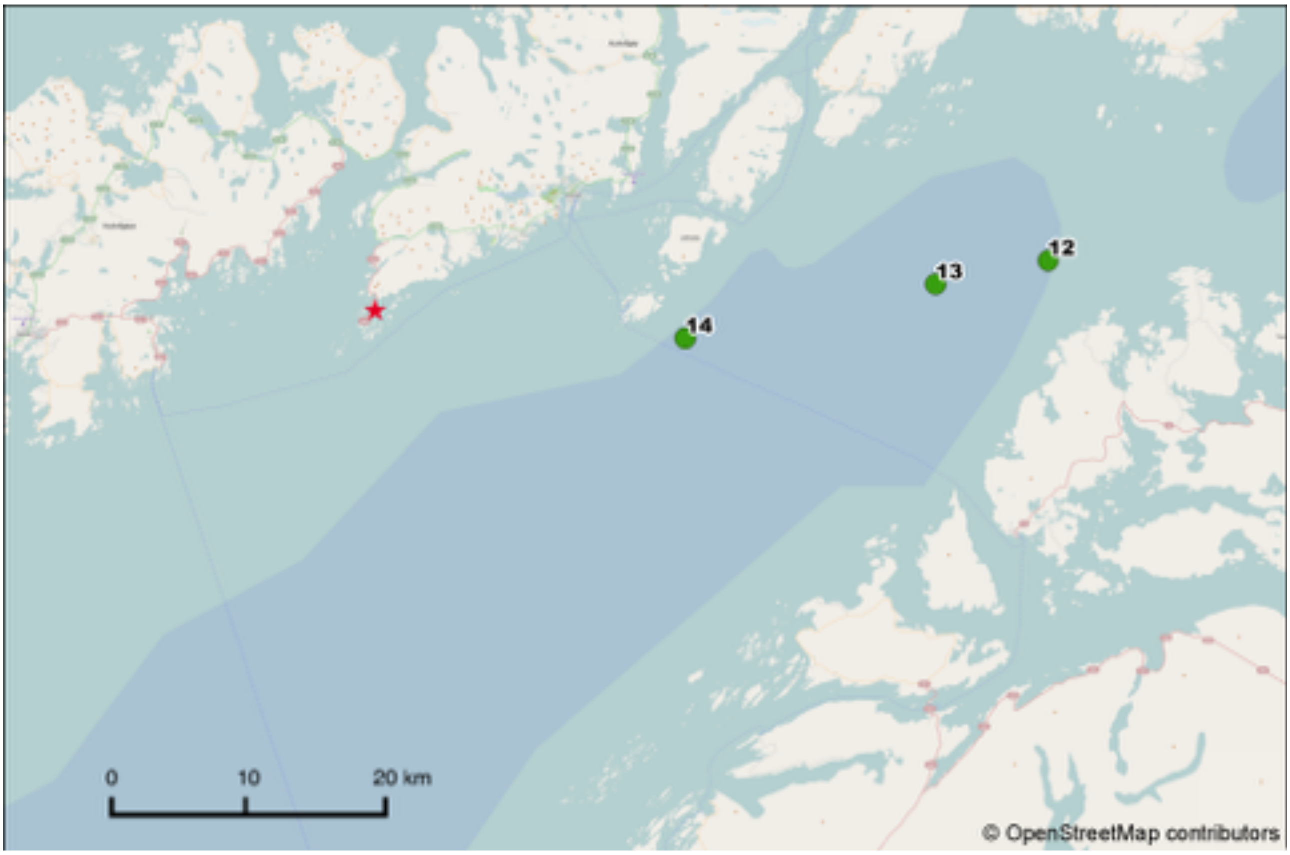

Figure 15: Encounters with sperm whales in all years. Numbers represent the year were the encounter took place. Point 12 and 13 is where the whale was recorded that year. Point 14 is a visual observation. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

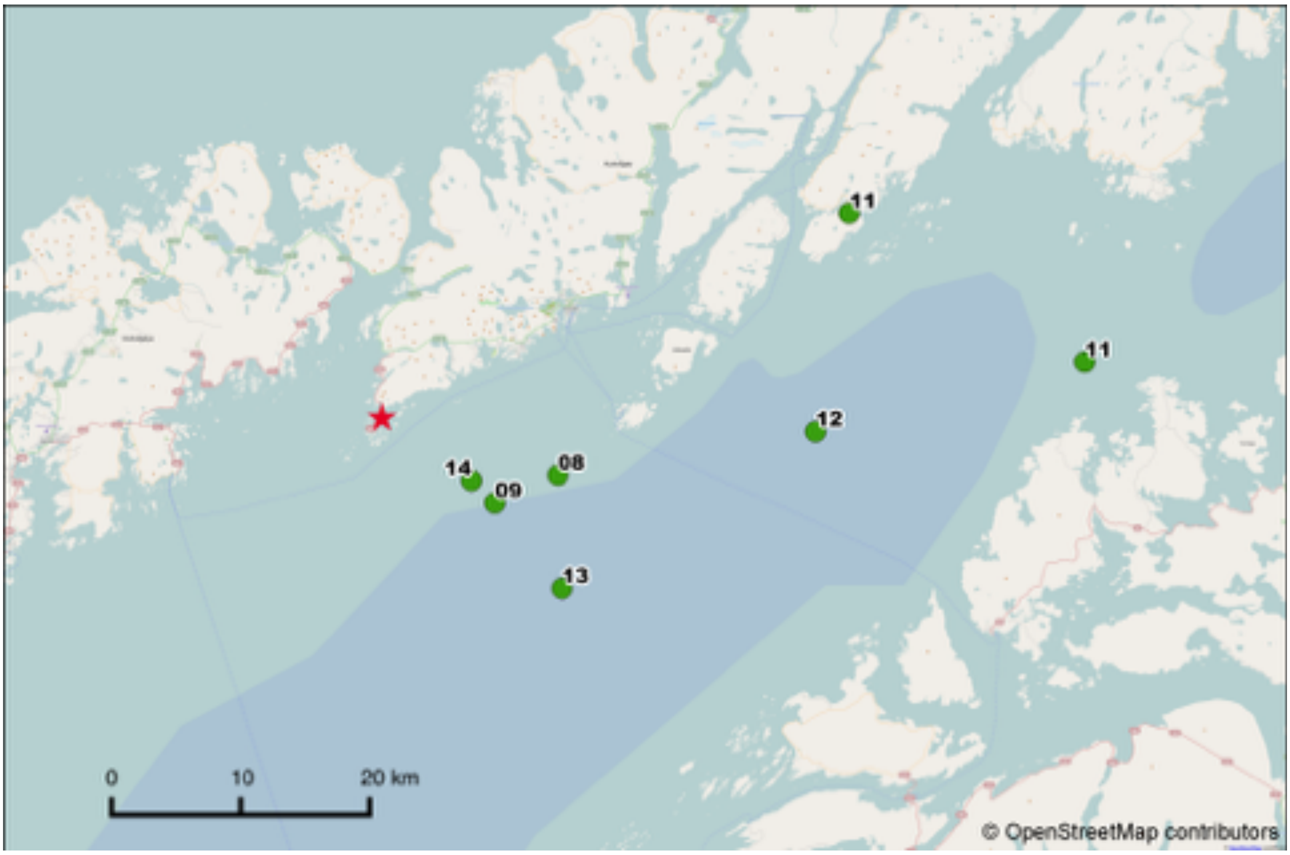

Figure 16: Encounters with humpback whales in all years. Numbers represent the year were the encounter took place. Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

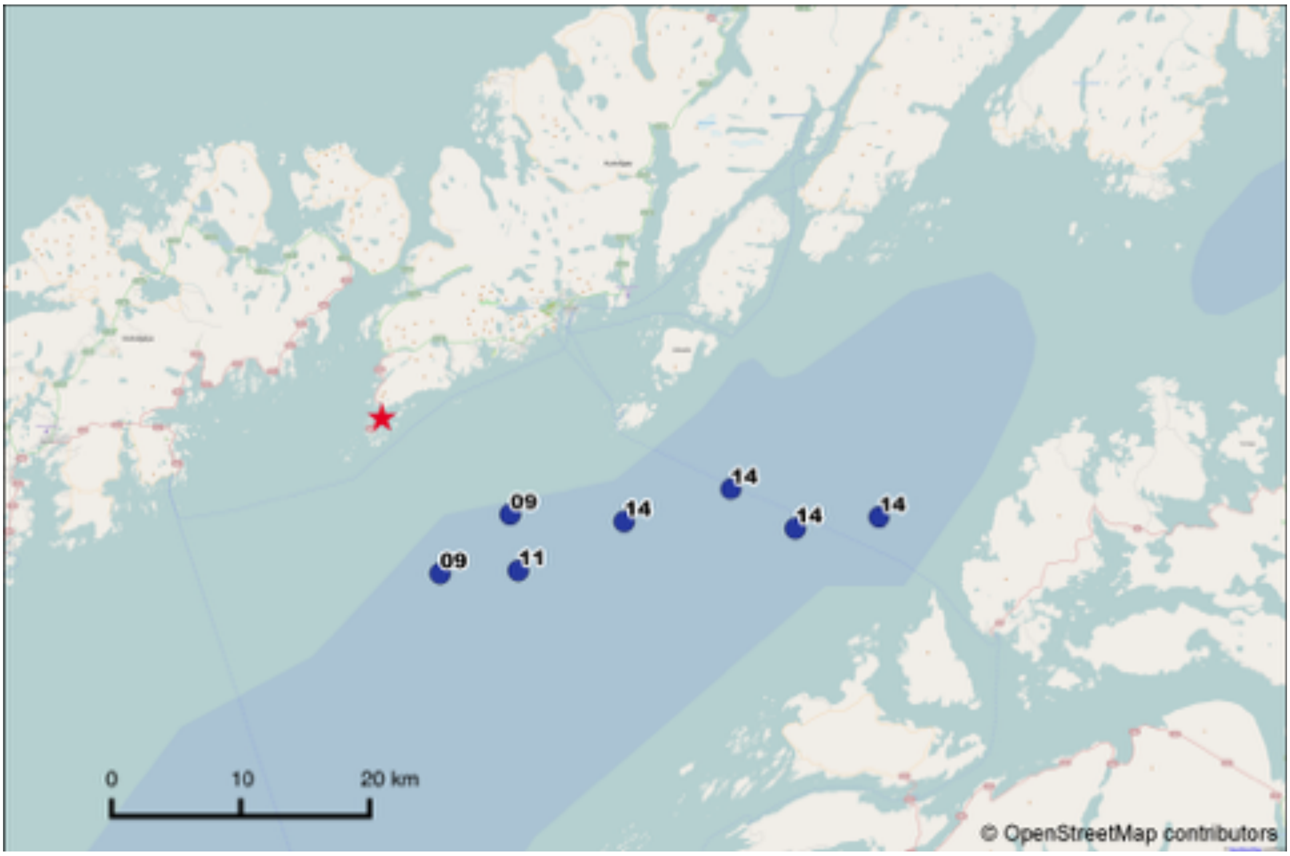

Figure 17: Encounters with fin whales in all years. Numbers represent the year the encounter took place. 2014 points took place the same day, but represent different individuals (several for each point, 20 total). Dark blue area represents areas deeper than 200 m. Red star marks Henningsvær.

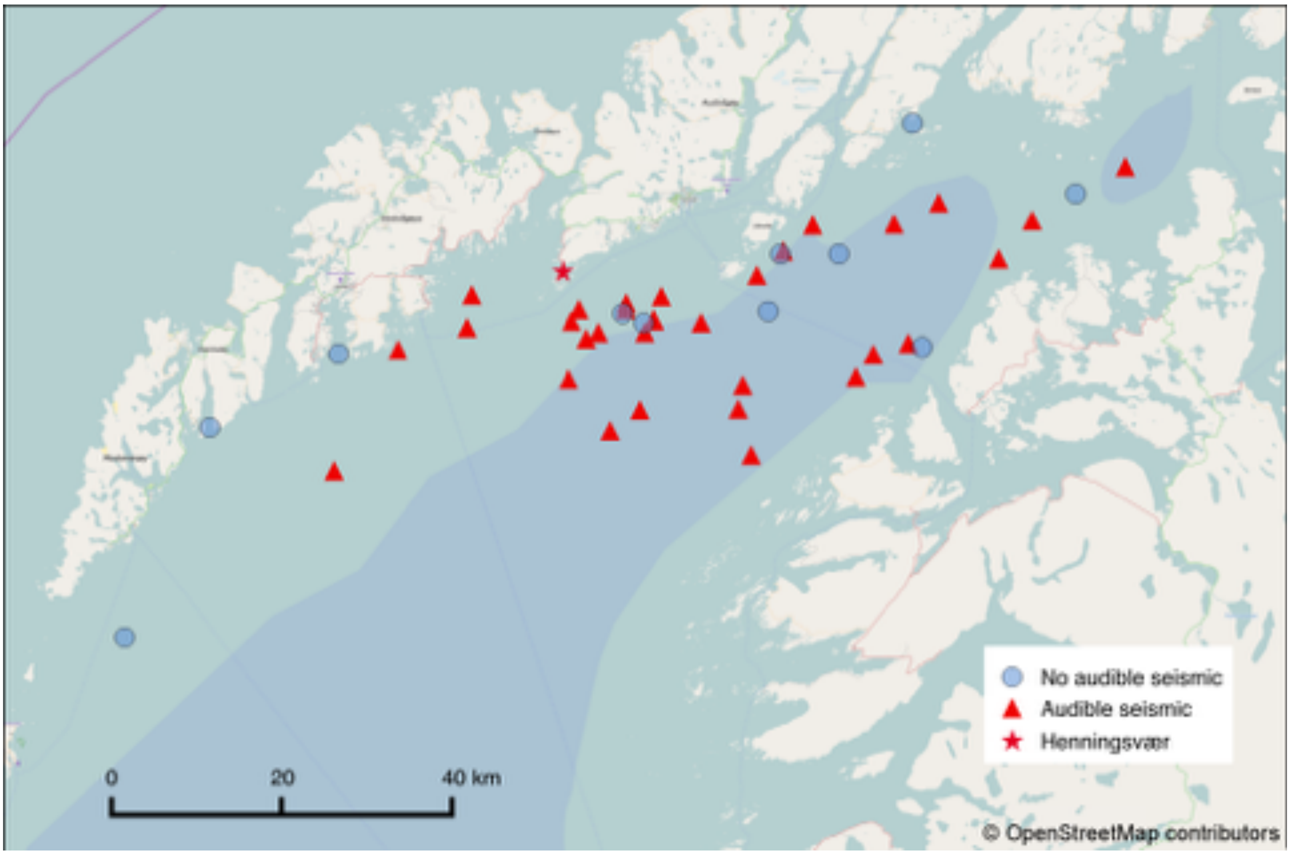

Figure 18: Areas where seismic survey was audible and not audible in 2014. Included in "no audible seismic" are only days where seismic survey noise was heard somewhere else the same day. There has been many cases of "no audible seismic" in Øksfjord, where seismic survey sounds have never been heard. It is only represented in the map as one point for simplicity. Dark blue area represents areas deeper than 200 m.

The analysis results

Table 4: Analysis results for harbour porpoises in 2011-2014. Final simplified model.

Harbour Porpoises				
Coefficients	**Estimate**	**Std. Error**	**t value**	**Pr(>ltl)**
Intercept	-2.761	1.364	-2.024	**0.044**
Temperature	0.283	0.115	2.452	**0.015**
Null deviance: 660.89 on 134 df			Residual deviance: 603.30 on 133 df	

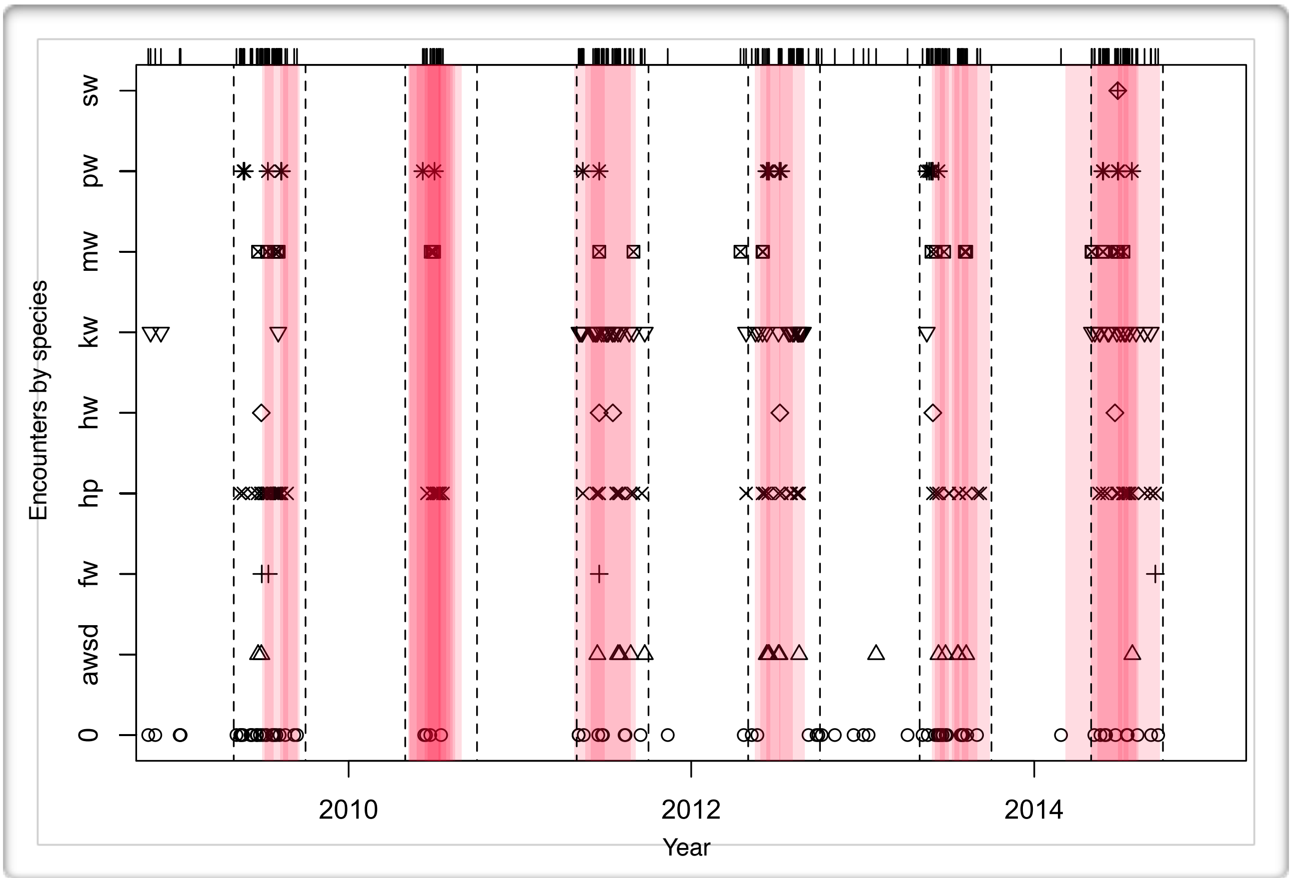

Figure 19: Periods with active 3D and 4D seismic surveys in the 400 km area shown in Figure 2. Darker colour means multiple simultaneous surveys. Dashed lines mark periods from 1st of May to 1st of October. Ticks at the top show effort days, i.e. days with trips by Heike Vester. Species legend: 0: day with no encounters, awsd: Atlantic white-sided dolphin, fw: fin whale, hp: harbour porpoise, hw: humpback whale, kw: killer whale, mw: minke whale, pw: pilot whale, sw: sperm whale.

The analysis for harbour porpoises showed a small but significant effect of temperature on the amount of individuals encountered (Figure 20). The complete model 1 and model 2 gave only temperature effect as significant, and a simpler model using only temperature effect on harbour porpoise amount did not have a significant reduced explanatory power in both cases, so the simpler model was used (model 1: -8 df, -49.092 residual deviance, p-value: 0.472; model 2: -6 df,

-36.503 residual deviance, p-value: 0.503). Table 4 shows the results for the analysis of the simpler model.

Minke whale encounters were not significantly affected by temperature, however the year 2014 was found to have a significantly different encounter amount (Figure 21). The complete model 1 and model 2 were not significantly better fit than a simpler model including only year as a categorical variable (model 1: -6 df, -6.87 residual deviance, p-value: 0.332; model 2: -4 df, -3.63 residual deviance, p-value: 0.457), so the simpler model was used instead. Table 5 shows a summary of the simplified model. Figure 21 shows the increase in minke whale amount in 2014.

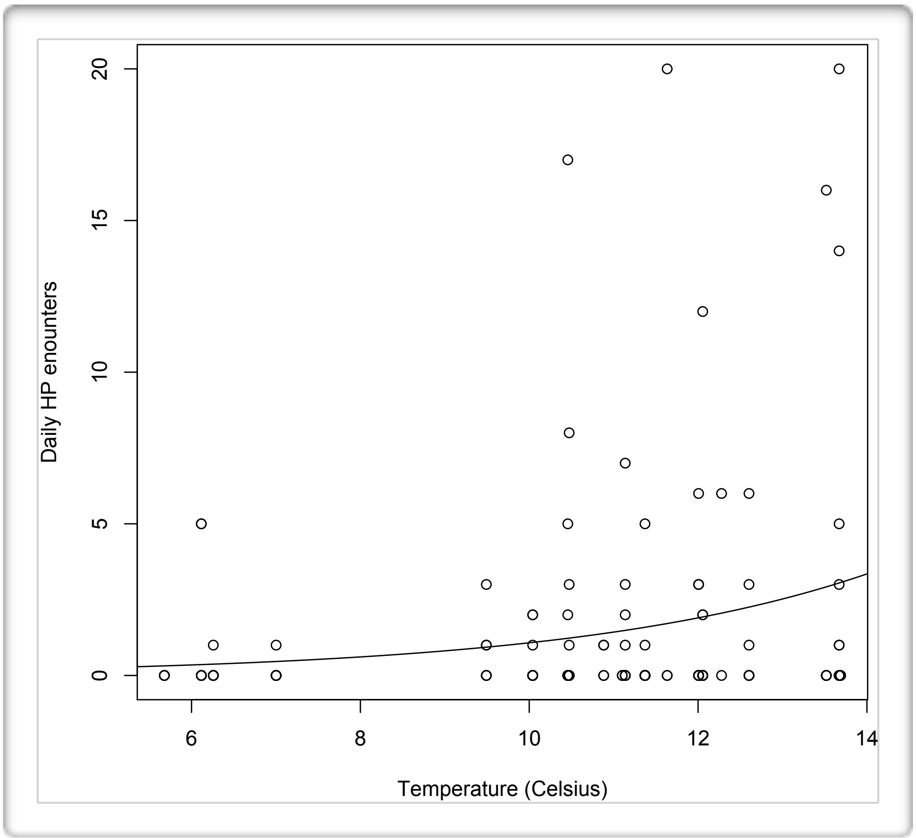

Figure 20: Significant increase in harbour porpoise count with increased monthly mean temperature. Line fitted by anti-logged prediction of the general linear model.

Table 5: Analysis results for minke whales in 2011-2014. Final simplified model.

Minke whales

Coefficients	**Estimate**	**Std. Error**	**z value**	**Pr(>lzl)**
Intercept	-2.944	0.707	-4.164	**<0.001**
Year 2012	0.236	1.000	0.236	0.813
Year 2013	0.970	0.836	1.160	0.246
Year 2014	1.707	0.781	2.184	**0.028**

Null deviance: 86.399 on 134 df

Residual deviance: 78.475 on 131 df

Table 6 shows the correlation analysis results for each species. Pilot whales were the only species with a significant increase of individuals amount with year. No species showed a significant correlation with temperature. Figure 22 shows the yearly trends for each species analysed. Figure 23 shows the temperature relationship.

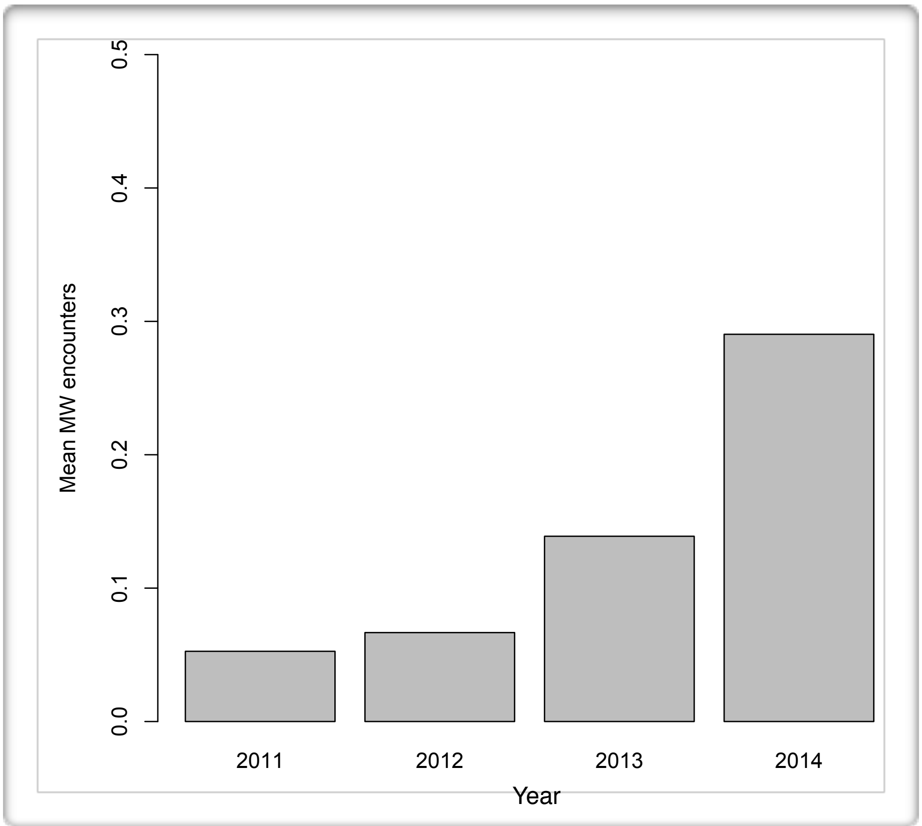

Figure 21: Increase in mean minke whale count each year, with 2014 being significantly higher than the other years.

Table 6: Pearson's product-moment correlation results for the remaining species trough all years. All tests had 6 degrees of freedom.

Species	**Coefficients**	**T-value**	**Cor. index**	**P-value**
Killer whales	**Year**	0.617	0.244	0.559
	Temperature	-2.396	-0.699	0.053
Pilot whales	**Year**	2.970	0.771	**0.024**
	Temperature	-0.810	-0.314	0.448
A. white-sided dolphins	**Year**	1.057	0.396	0.331
	Temperature	-1.035	-0.389	0.340
Humpback whales	**Year**	2.251	0.676	0.065
	Temperature	-0.878	-0.337	0.413

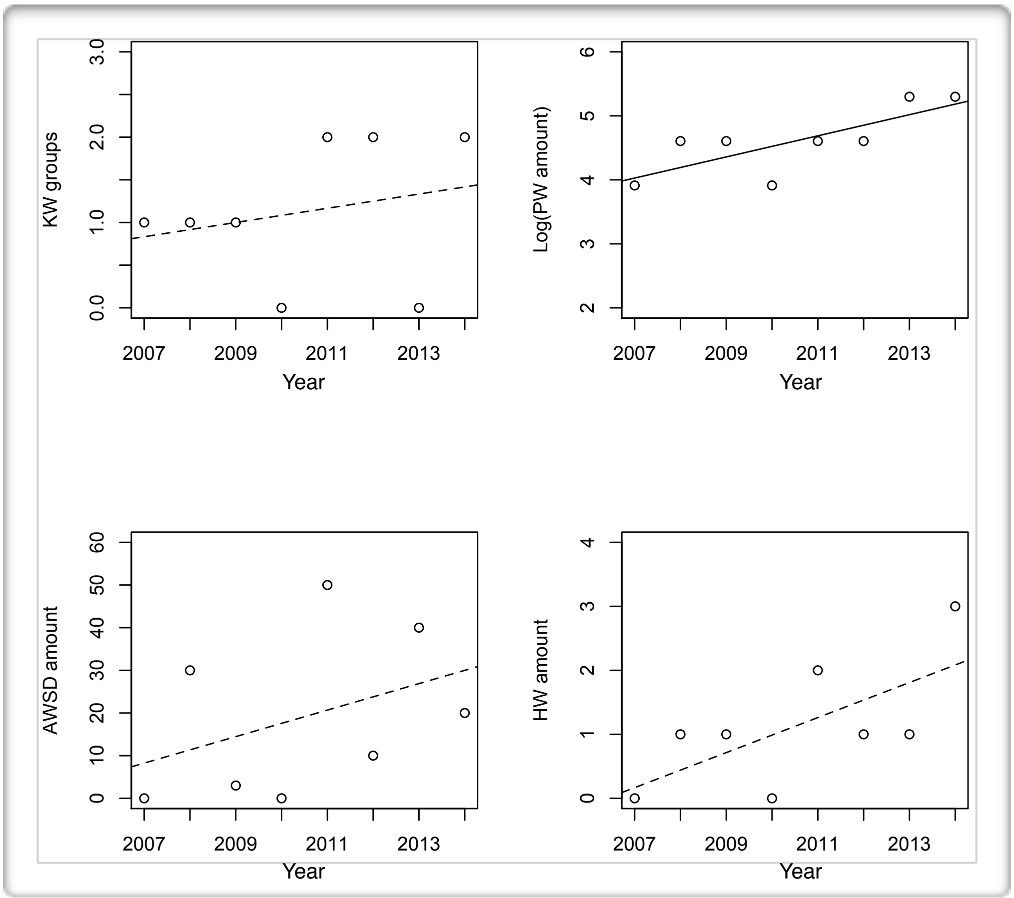

Figure 22: Trend in species amount through the years. Lines fitted by linear model. Dashed lines are non-significant.

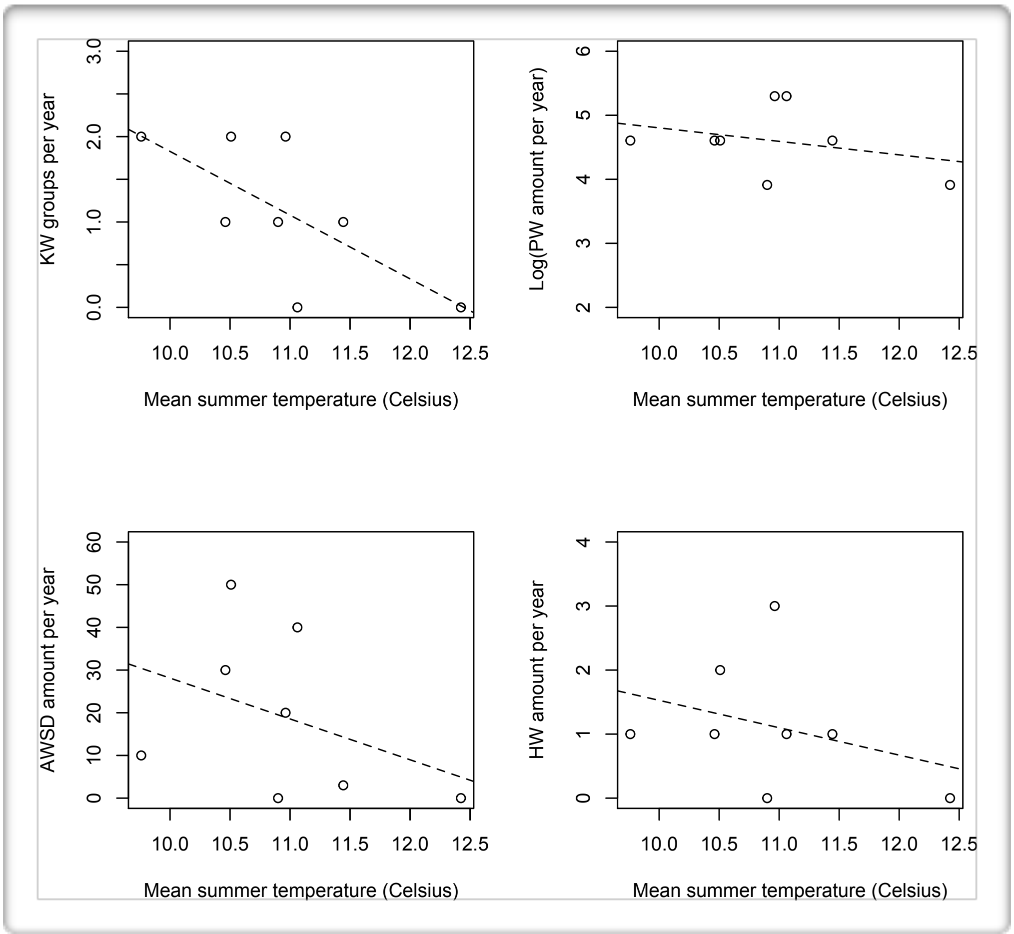

Figure 23: Trend in species amount and mean summer temperature. Lines fitted by linear model. Dashed lines are non-significant.

Discussion

Eight cetaceans species have been observed in Vestfjorden in the last 8 years, and since almost all species have been seen each year the area must have some importance to them. The data-set did not reveal any effect of ongoing seismic surveys on amount of harbour porpoises or minke whales encountered. Harbour porpoise encounters had a small positive correlation with summer temperature, and minke whale encounters were higher in frequency in 2014 when compared to 2011, 2012 and 2013. No increasing or decreasing trend in killer whale, Atlantic white-sided dolphin or humpback whale individuals could be detected in the fjord since 2007. Pilot whale individuals however seem to have been more abundant with time since 2007. Mean summer temperature was not correlated with the number of killer whale, Atlantic white-sided dolphin, humpback whale or pilot whale individuals per year.

Cetacean distribution in Vestfjorden

The distribution maps for killer whales (Figure 7) and pilot whales (Figure 8) show some areas of preference: Tysfjord and Øksfjord for the former and deep areas in the fjord for the latter. This distribution agrees with their known niche. Tysfjord has been an area with high herring abundance in the winter, and consequently with high killer whale abundance (Kuningas et al. 2013). However, there has been a decline in herring abundance in Tysfjord starting in 2003 (Kuningas et al. 2013), with herring schools moving further north, and killer whales following this migration (Vester and Hammerschmidt 2013). Øksfjord has many peripheral salmon rivers in addition to a few salmon farms, so there is high salmon activity in the fjord from April to the end of autumn (in preparation for the spawning season in October and November) (Skilbrei 2009), and killer whale groups spend the season feeding on them (Vester and Hammerschmidt 2013). Long-finned pilot whales are deep divers that feed mainly on cephalopods (Gannon et al. 1997), so it is expected if the fjord was indeed a feeding spot they would be more often encountered in the deeper areas where their main prey is available. The proportion analysis shows that pilot whales prefer areas deeper than 200 m, so the area is probably a feeding spot. The presence of sperm whales in the fjord, which have a similar diet, further support this hypothesis.

Atlantic white-sided dolphins were often encountered near the shore and near the 200 m depth line. However, the proportion analysis showed no significant preference for the slope area, defined by 3.5 km inwards and 2 km outwards from the 200 m line. This could mean the selected area as the “slope” is not representative of the areas with high food availability, or the sampling was not extensive enough to create a balanced picture of the species distribution.

The distribution of harbour porpoises (Figure 12) and minke whales (Figure 14), in the other hand, seem more random, as the observations aggregate where effort is more dense (Figure 2). Harbour porpoises are not migratory species as many of the other species in Vestfjorden, so it is assumed that harbour porpoises encountered were local individuals. The nature of their behaviour makes encounters more random. They break the surface for only a few seconds and often flee when a boat is near, making it difficult to track and identify individuals. The inability to identify harbour porpoise and minke whale individuals also means that some of the observations could be duplicates. This should not have a big impact on the results of this thesis however, since I look at daily encounters, and there was never a decision to go where these animals had been seen before, so initial encounters did not influence subsequent encounters for these species.

This thesis does not address the re-sightings of individuals from year to year, but certain pilot whale groups have been identified and re-encountered in subsequent years in Vestfjorden (Vester, unpublished data). Atlantic-white sided dolphins have also been re-sighted (Hamran 2014). Several killer whale pods have been identified and re-sighted in the Tysfjord area in winter (Similä et al. 1996), although with the reduction of herring population in the area the last years killer whales are less abundant in the area (Kuningas et al. 2013).

Temperature has been found to be a significant predictor of whale distributions (Fullard et al. 2000), as it is often a proxy for primary production and prey availability. However, that applies mostly to large intercontinental areas or other cases where the temperature variance is high. In Vestfjorden, mean summer surface temperatures varied by up to 2 °C (Figure 23), and while this could affect primary production, our results showed no significant correlation between temperature and the abundance of most cetacean species. However, harbour porpoise encounters increased slightly with a higher summer temperature.

Design limitations

The data used in this thesis was collected by Heike Vester at Ocean Sounds, a non-profit organisation that studies mainly cetacean’s behaviour and vocalisation. For that reason, their survey protocol/design is mainly opportunistic and not optimal for non-biased ecological statistics. Most observations are not independent as usually is the case when using transects. For example, when the location of killer whales is known, trips are made towards that location more often. For that reason encounters with species that migrate in groups are autocorrelated, i.e. after the first encounter of the group in the fjord, following encounters are more likely. To remedy these design problems two different analysis methods were used. An analysis of trends used aggregates in all years, instead of autocorrelated single encounters each season. Species which encounters were considered to not be autocorrelated (harbour porpoises and minke whales, as they are widespread in the fjord) were analysed with the general linear model. The model also included travelled kilometres as effort values to mitigate the high variation in trip length. The duration of trips increased after 2010, although it was not used as a measure of effort due to the nature of Heike Vester's research. Often times many hours would be spent in the same location studying the same group of individuals, and therefore there was no effort in finding other species/individuals. The separated analysis methods also mitigate possible effects of this increase in duration, since years before 2011 were not added in the generalised linear models.

Figure 19 illustrates another challenge with the analysis: comparing encounters with seismic survey presence when there is almost no cases of data without seismic survey presence. Two steps were taken to mitigate that: (i) surveys were divided by distance from the fjord's entrance, to introduce more variation in the periods with seismic survey activity, and (ii) a model was created using days were seismic survey noise was recorded in the fjord instead of all surveys in Figure 3, giving a higher variability in seismic survey activity. Another solution could be increasing the effort periods to more than just the summer months, but that would then introduce the problem of intrinsic seasonal variation in species distribution. The correlation analysis was done to see whether the periodical exposure to seismic survey noise in the last 5 years would change the presence rate of migratory species. As discussed earlier, I could not find changes for most species, except a possible increase in pilot whale abundance. This simplistic analysis could not take into account other factors, however, so there are many possible explanations to this result, like variations in prey abundance or survey effort.

Seismic surveys sound impacts

The negative results regarding effects of seismic survey noises in harbour porpoise encounters agree with a study by Thompson et al. (2013), where harbour porpoises have been shown to not alter long term displacement due to seismic surveys <100 km away. Although the survey in that study was two-dimensional, using a 470 cubic inches airgun array, while in this study only three-dimensional surveys with airgun arrays ranging from combined 4000 to 5000 cubic inches at 2000 psi were included in the model. At any rate, harbour porpoises have evolved to communicate using narrow band high frequency clicks with frequencies above 100 kHz, mainly due to predation pressure from killer whales (Morisaka 2012). This means harbour porpoises are not as sensitive to low frequency sounds found in seismic survey noise as other species in the fjord, and therefore the influence zones described in the introduction are smaller for this species.

As described in the introduction, mysticeti auditory systems are more sensitive to lower frequencies (Ketten 1992), and therefore would be more effected by seismic survey noises. Their communication also uses the lower frequency spectrum (under 1 kHz) and is more likely to be masked by seismic survey sounds (most energy at 200 Hz) up to 2000 km from the source (Siebert et al. 2014). Species that would be most susceptible to the lower frequency sounds of seismic surveys are not overrepresented in Vestfjorden. Only a few individuals of humpback whales are encountered each year, and fin whales are even fewer and further between. Baleen whales in Northern Norway are more often encountered on the outer side of Lofoten and in the Barents Sea near the continental shelf (Christensen et al. 1992). The big discrepancy between the number of individuals in Vestfjorden and in the Barents Sea could be explained by differences in food abundance or disturbance sources. Background noise levels from both sites should be measured to investigate whether there is any difference that could be significant. Masking effects by background noise could lead the individuals to modify or reduce their vocalisations (fin whales stop singing: Castellote et al. 2012; humpback whales change song rates: Risch et al. 2012), so a comparison of vocalisations between periods with and without seismic survey noises could clarify whether that is the case in Vestfjorden and the Barents Sea.

There are many migrating cetacean species in Vestfjorden. The exact migration routes for most of them is unknown, however. Humpback whales in the Barents Sea in the summer have been seen in the West Indies the following winter (Stevick et al. 1998), and individuals seen in Ireland and in the Netherlands in the summer/autumn have been seen in Northern Norway in the end of autumn (Ryan et al. 2015). Fin whales, blue whales and sperm whales where recorded in the Polar North Atlantic close to Spitsbergen with peaks between July and October for blue whales and sperm whales, and fin whales being present from August to April (Klinck et al. 2012). We already know their destination (i.e. feeding grounds in the north) has seismic survey noise in the summer, as described in this thesis and by Klinck et al. (2012), but their migration route along the continental slope must also be noisy since surveys usually are conducted from early May until the end of September (Figure 19, although it is only a small subset of the total survey activity). This could possibly have many negative effects, such as masking by background noise impeding communication and group cohesion, unnecessary evasion causing longer migration time, loss of hearing sensitivity or physical injury. A few of the vulnerable species are currently endangered (Reilly et al. 2013).

The effects of anthropogenic noise on cetacean behaviour has been reviewed extensively (Myrberg Jr 1990; Gordon et al. 2003; Hildebrand 2005; Weilgart 2007; Parsons et al. 2008; Weilgart 2013, and others). In regards to seismic surveys, behavioural responses include avoidance in for example bowhead whales (*Balaena mysticetus*) (Ljungblad et al. 1988), changes in vocalisation in fin whales (Castellote et al. 2012), blue whales (Melcón et al. 2012) and humpback whales (Cerchio et al. 2014), changes in diving and foraging patterns in sperm whales (Miller et al. 2009) and long term displacement of fin whales (Castellote et al. 2012). However not all cases show apparent behavioural changes. Madsen et al. (2002) found no visible behaviour changes or avoidance of male sperm whales to an active seismic survey vessel outside Andenes, Norway. Gailey et al. (2007) couldn't find any differences in behaviour and abundance of feeding grey whales to seismic surveys in Sakhalin. Contradictions like these make prediction of behavioural responses harder, but are not surprising when studying animals with complex behaviour patterns. They will often weight the energy benefits of feeding against the energy costs of displacement and finding another feeding place, influenced by their previous experiences, before reacting. Both mentioned studies where whales did not react to seismic survey noises took place at feeding grounds, so the costs of moving away and finding another feeding area is probably too high. Another explanation could be acclimatisation either by individual differences or temporary threshold shift, although TTS is still not well documented in cetaceans so it would not be easily proved.

Recommendations

The many published cases of negative influences of seismic survey sounds on cetaceans warrants the use of Best Available Technology/Best Environmental Practice outlined by the OSPAR commission when planning and conducting surveys, and that includes strict preventive regulations. Many countries already have regulations for seismic surveys in regards to marine mammals, as discussed in the introduction. However, Norway has no such regulations focusing on marine mammals. There was concern by Norwegian politicians and fishermen on the effects of seismic survey noises on commercially important fish species, so Norway has created guidelines for the coexistence of seismic surveys and fisheries, which contain a few preventive regulations, such as temporal restrictions in spawning areas (MPE/MCFA 2013). A similar effort should be made to create guidelines to protect marine mammals, which have an important influence on the local environment (Roman et al. 2014), and an economically important resource for the local community in the form of tourism. A precedent for such regulations has already been set by other nations such as USA, UK and New Zealand, as noted in the introduction (Weir and Dolman 2007), and should be adapted to conditions in Norway, after more investigation of sound propagation and impacts in marine mammals.

The soundscape inside Vestfjorden is an important matter which has not yet been measured. Noise propagation is dependent on topography and can be highly variable (Gordon et al. 2003). Figure 18 shows areas where seismic surveys could not be heard even when there was ongoing seismic surveys. Some of the areas intersect with areas where seismic surveys are audible, however. A possible explanation would be a temporary halt in the survey by the survey ship due to technical problems or weather conditions. Still, in some areas seismic survey noises were never heard, like in Øksfjord. If seismic survey sounds penetrate some areas but not others in the fjord, whales could change their migrating behaviour to find areas with less disturbance. A detailed soundscape would allow for the comparison between individuals in "noise-affected" areas with individuals in "noise-protected" areas. The killer whales groups in Øksfjord presumably do not hear the seismic survey sounds, or hear it much fainter than killer whales in the middle of Vestfjord. However, their presence and prevalence in Øksfjord is has been suggested to be mainly driven by prey availability (Vester and Hammerschmidt 2013).

The soundscape would also aid in identifying the different zones of influence in the fjord, as described by Richardson and Thomson (1995) and expanded upon in the introduction. The size of the zones of influence are dependent on the sensitivity of the species to the sound in question, in this case seismic survey noise. As mentioned, a possible explanation as to why seismic survey activity did not seem to affect harbour porpoises might be that they are in the auditory zone if it is at all audible. Humpback whales and fin whales, however, would probably be at least in the auditory zone, but might even be in the masking zone, since the propagation of seismic surveys can mask low frequency communication up to 2000 km range (Siebert et al. 2014). Boat noise would also have a significant effect in noise pollution in the fjord, and they produce their own zone of influence, with frequencies from 10 to 50 Hz for commercial ships and 1 to 5 kHz for small boats (Hildebrand 2009). Although the effect is temporary and cetaceans can avoid their trajectory to a degree. Seismic survey sounds on the other hand are periodically present for many months on end.

Even though the results in this thesis are non-conclusive, the sheer amount of studies showing a real impact of seismic surveys on marine mammals (Weilgart 2013) warrants further research in the topic in Vestfjorden. As shown in this thesis, the fjord is an important feeding and breeding ground for eight cetacean species, many of which have migrated long distances to feed. And even though the Norwegian government has closed the area for seismic surveys temporarily, the fjord is not free from its noise due to long distance sound propagation. The goal of keeping Vestfjorden unaffected from seismic survey noise pollution is then lost.

For investigating the effects of seismic survey sounds, a possible option would be a combination of passive acoustic monitoring and either the use of a focus whale group of interest or transects at the entrance of the fjord. The passive acoustic monitoring would give exact data on seismic survey sounds, so an accurate source (or sources) could be identified and the exact propagation and sound levels investigated. The focus group, followed by either tags or vessel, could give continuous response of a group during start, ongoing and end of a seismic survey. Transects in the opening of the fjord would give information on which groups/individual whales come in the fjord and when, it could then give us an idea on whether their arrival could be influenced by seismic survey sounds by comparing it to live seismic survey noise. A hypothesis which could not be tested in this thesis is whether the presence of seismic survey noise in the entrance of Vestfjorden would impede cetaceans from coming in or exiting the fjord. Depending on the zone of influence experienced by the individual, swimming through the sound barrier to exit or enter the fjord could cause physical injuries.

Conclusion

Vestfjorden is habitat to eight cetacean species: Harbour porpoises, minke whales, killer whales, pilot whales, Atlantic white-sided dolphins, humpback whales, sperm whales and fin whales. It is an important feeding and breeding ground containing different niches which influence the distribution of each species. This is the first study to demonstrate cetacean distribution and their possible site preference in Vestfjorden over eight years. Mean summer temperature has a small positive effect on the amount of harbour porpoise encountered, but seismic survey noises did not correlate with the amount of harbour porpoises or minke whales encountered. The presence of most species in the fjord seems not to have changed in the last years despite periodical seismic survey activity since 2010. The statistical results in this study are not conclusive, however, so a dedicated study should be conducted in the area to closer investigate possible impacts of sound pollution in the cetacean populations.

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