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CHANGES IN CETACEAN OCCURRENCE IN FAXAFLÓI BAY, ICELAND, AS OBSERVED FROM WHALE WATCHING VESSELS

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ABSTRACT

The distribution of animal species is shaped by environmental conditions and their ecological niches. The understanding of these niches is essential for conservation, especially for cetaceans, as cetacean species may adjust their geographical range in response to ecological changes. Long-term data is vital to monitor these shifts and guide conservation efforts. While environmental changes are occurring globally, localised effects on specific species and habitats, particularly marine ecosystems, remain understudied. This gap in knowledge is evident in Artic regions. As key trophic species, cetaceans can act as indicators of potential significance and contribute significantly to the economy of local communities via the practice of whale watching. Iceland, a biodiversity hotspot, has experienced significant warming as part of global climate change, possibly affecting the abundance of prey species. Cetaceans such as humpback whales, minke whales, white-beaked dolphins, and harbour porpoises inhabit these waters year-round and may be affected by such changes. This paper focuses on the bay of Faxaflói in southwest Iceland, utilising semi long-term data (2016-2023) from whale watching tours to discern potential changes in the occurrence of these four species.

Sightings Per Unit Effort (SPUE) for the four targeted species was calculated for each month and year. ANOVA test ($p<.005$) and Tukey HSD test were conducted for humpback whales revealing significant differences in Spue in the years 2022-2017 ($p=0.006$), 2023-2017 ($p=0.003$), 2023-2018 ($p=0.04$), 2022-2019 ($p=0.02$), and 2023-2019 ($p=0.009$). Seasonal analysis suggests shifts in SPUE, with increased observations during non-touristic periods after 2021. Results indicate intriguing trends in species occurrence, with a significant increase in humpback whale sightings and a steady decline in mine whale sightings since 2018. The inverse relationship between minke and humpback whales suggests possible competition or distributional shifts.

Acknowledging limitations and biases from tourism-centric data collection his study highlights the importance of whale watching records as a year-round monitoring tool. Collaborative efforts between operators and researchers are crucial to enhance data quality. Understanding and addressing the observational changes in cetaceans in Faxaflói is imperative for effective conservation measures in this ecologically significant region.

Keywords: Climate change, long-term, marine mammals, North Atlantic, SPUE, whale watching

INTRODUCTION

The distribution of most species is determined by the interplay between the prevailing environmental conditions and the ecological niches they inhabit. In the case of cetaceans, ecological niches are defined by water depth, temperature, and abundance and distribution of their prey (MacLeod, 2009). Recognising the ecological niche occupied by a species is crucial for its conservation. Specifically, many species are believed to respond to environmental changes by adjusting their distribution to align with the ecological envelope represented by their niche. This means that the geographical range of a species may change over time because of ecological changes (MacLeod, 2009; Wiens & Graham, 2005). To observe potential shifts occurring in specific species over time and in specific environments, long-term data is particularly valuable as well as necessary to inform conservation measures (Silber et al., 2017). For example, studies combining long-term data and modelling have illustrated distributional changes linked to climate change in various marine fish populations (e.g., Nye et al., 2009; Poloczanska et al., 2013); shifts in cetacean distribution have also been predicted (e.g., Gregr et al., 2013) as the shifting environmental impacts on the abundance and distribution of prey species extended to cetaceans, potentially affecting their conditions as well (Learmonth et al., 2006; MacLeod, 2009; Piatt et al., 1989).

As environmental changes accelerate worldwide, there is a noticeable gap in understanding the localised effects on specific species and their habitats (Malinauskaite et al., 2021; Pearce-Higgins et al., 2017). In this context, this is especially the case for marine ecosystems, which remain particularly understudied despite rapid effects being reported globally (Gissi et al., 2021). Arctic regions exemplify this, experiencing a surface temperature increase double the global average over the past 50 years (AMAP, 2021; IPCC, 2021). As cetaceans are key trophic species, variations in their presence, abundance, and

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distribution in Arctic regions can serve as indicators of potential environmental changes (MacLeod, 2009; Moore et al., 2019). Their substantial body size and abundance require them to ingest significant quantities of prey and result in a significant role in shaping marine ecosystems (Baum & Worm, 2009). For example, in 1997, the total annual consumption by 12 cetacean species in Icelandic waters was approximately 6 million tons of biomass (Sigurjónsson & Víkingsson, 1997). Thus, alterations in cetacean abundance can lead to cascading effects throughout the food web, exerting top-down control on the structure of the ecosystem. This underscores the significance of these marine predators (Greenhalgh, 2016; Learmonth et al., 2006).

Furthermore, cetaceans play historical significance in human societies, especially in the Arctic and subarctic, contributing to culture, sustenance, and more recently, tourism (Malinauskaite et al., 2021). Thus, changes in their abundance and distribution can have profound implications for these societies. In the context of tourism, for example, whale watching has emerged as a significant contributor to the industry, globally increasing since the early 1990s, additionally creating opportunities for coastal communities. It generates a minimum of 2.1 billion USD, provides employment for over 13,000 people, and draws in more than 13 million tourists annually (O'Connor et al., 2009).

Iceland, located at the intersection of two large submarine ridges and four oceanic currents, is a region of interest for studying environmental changes. Variations in water mass flow over time result in the fluctuation of hydrographic conditions across the country (Valdimarsson & Malmberg, 1999; Víkingsson et al., 2015), particularly in the southern and western areas, influencing biological processes such as the productivity and distribution of zooplankton (Gislason et al., 2009). The resulting water mixing from such fluctuations have made Iceland a hotspot for many cetacean species, some of which inhabit its waters year-round (Sigurjónsson & Víkingsson, 1997). However, considerable warming and salinification have been documented in Icelandic waters over the last twenty years (Hátún et al., 2005) with consequent reports highlighting distributional and abundance changes of numerous species, many of which are relevant prey to cetaceans (Víkingsson et al., 2015).

Fish species such as sand eels (*Ammodytes marinus*), herring (*Clupea harengus*), capelin (*Mallotus villosus*), haddock (*Melanogrammus aeglefinus*), and cod (*Gadus morhua*), as well as krill (*Euphasia sp*.) are all found in the productive Icelandic waters, providing sources of food for cetacean species such as harbour porpoises (*Phocoena phocoena*), white-beaked dolphins (*Lagenorhynchus albirostris*), killer whales (*Orcinus orca*), minke whales (*Balaenoptera acutorostrata*), humpback whales (*Megaptera novaeangliae),* fin whales (*Balaenoptera physalus*), and many more (Moore et al., 2019; Víkingsson et al., 2015). Iceland is therefore a biodiversity hotspot for marine life; however, it is at the same time a remote island which does not always allow for easy accessibility for the monitoring of species. Located at high latitudes weather, sea, and light conditions in the region limit the study of marine life, particularly for species with large dispersal patterns such as cetaceans (Poupard et al., 2020). Therefore, relying on any sort of long-term data can be rare, difficult, and costly. Here is when tourism companies such as whale watching operators can play an important role in the acquisition of such data. The whale watching industry is well-established in the country, having started in the Southeast in 1991 and having expanded around the rest of the country in the following decade (Blankenstein, 2021). Due to the rapid surge in tourism since 2010, the industry has experienced explosive growth, making the country one of Europe's most popular whale watching destinations (Carwardine, 2016). The industry can therefore be of high value for long term research, as vessels gather valuable information that can be used to inform science in many different fields.

This paper aims to contribute to the understanding of potential local environmental changes in a specific region, by focusing on shifts in cetacean occurrence in Faxaflói, a highly productive bay frequented by whale watching tours departing from the capital, Reykjavík. Emphasising the importance of long-term data, the study relies on information collected between 2016 and 2023 by a local whale watching tour operator, Special Tours Wildlife Adventure, to discern potential shifts in species occurrence. The study centres on the four main cetacean species sighted in the bay: humpback whales, minke whales, white-beaked dolphins, and harbour porpoises. While other cetacean species such as blue whales (*Balaenoptera musculus*), fin whales, sei whales (*Balaenoptera borealis*), North Atlantic right whales (*Eubalaena glacialis*), northern bottlenose whales (*Hyperoodon ampullatus*), long-finned pilot whales (*Globicephala melas*), and killer whales occasionally visit the bay, these occurrences are comparatively rare and are therefore excluded from the analysis.

MATERIALS AND METHODS

Study Location

Faxaflói (N64°24 W23°00) is a bay in southwest Iceland approximately 50 km long and 90 km wide, located between two large peninsulas (Figure 1). The water depth is relatively shallow, ranging from 16 to 60 metres. It is considered a highly productive area where Atlantic waters are diluted and mix with the outflow of many glacier rivers. This creates a rich environment where numerous species at different trophic levels come to spawn, nurse, and hunt (Stefánsson & Guðmundsson, 1978), including cetaceans. These qualities make the area highly attractive for tourism, as approximately five whale watching companies based in Reykjavík frequent the bay. The main whale watching area extends from the eastern and southern shores to the edge of the Syðra-Hraun lava field.

Data Collection

From January 2016 until December 2023, sightings data were collected in the southeast area of Faxaflói aboard whale watching boats operated by Special Tours Wildlife Adventures, an established tour operator, within an approximate 20 km radius off the shores of Reykjavík (Figure 1). In Faxaflói, whale watching tours are operated year-round, 365 days per year, weather permitting. The number of tours operated per day varies between one 3-hour tour in winter (December through February) and six 2 to 3-hour tours in summer (June and July), largely based on daylight availability. Due to Reykjavík's high latitude, the amount of daylight varies from ~ 4 hours during the winter solstice to ~ 21 hours during the summer solstice. Most of the data effort therefore took place during summer months. Effort was significantly reduced in 2020 and 2021 due to the onset of the COVID-19 pandemic, which was taken into consideration when analysing data however, not for the statistical analysis (to avoid bias).

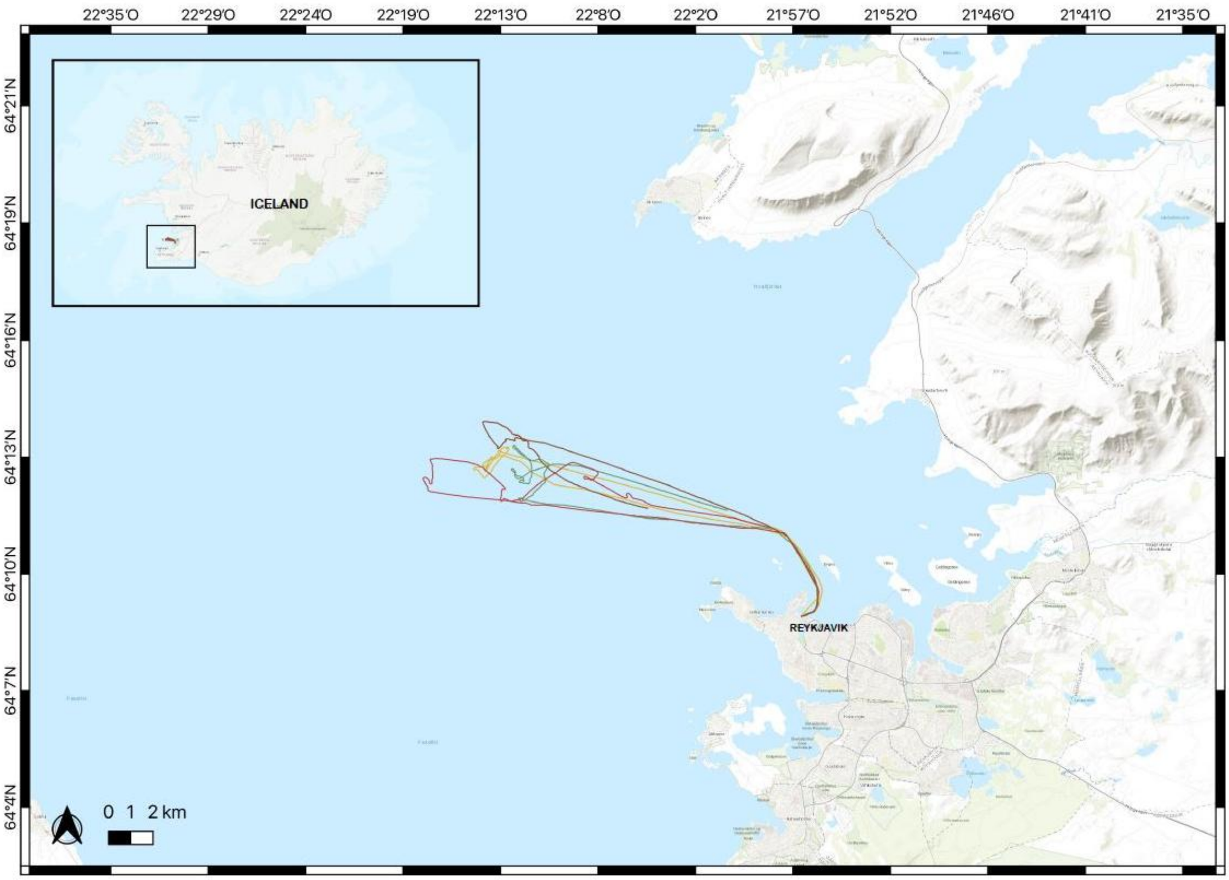

Figure 1. Map of Faxaflói. Transect lines represent one week of recording data taken during summer 2024 to highlight the area in which the whale-watching operation generally takes place.

Spotting and species identification were conducted by one experienced tour guide on each whale watching tour, either with marine biological background or carefully trained in cetacean identification. Spotting took place aboard 3 different passenger vessels: a 15-metre passenger boat with a spotting height of 5.5 metres above sea level; a 26.78-metre passenger catamaran ferry with a spotting height of 8 metres above sea level; and a 34.11-metre passenger boat with a spotting height of 9.5 metres above sea level.

Species occurrence was recorded by tour guides in a Microsoft Excel workbook for every tour, aiming to broadly visualise possible changes of the four most abundant species (minke whale, humpback whale, white-beaked dolphin, and harbour porpoise). Occasional visitors, such as killer whales or fin whales, were also recorded but are not included in the analysis. Occurrence was recorded based on the presence or absence of species sightings for each tour. When there were no sightings of a species they were not noted, while those with one or more sightings were listed. No information on the number of individuals, number of sightings, duration of the sighting, or environmental conditions (i.e., weather, Beaufort scale, or sea state) that may have influenced the chance of sightings was provided. Trips where no sightings were observed were recorded as "NOTHING", whereas cancelled trips (meaning zero effort) were recorded as "CANCELLED". Especially for 2016, some trips showed no recorded information, which were labelled as "---".

Data analysis

For each month between 2016 and 2023, total observation effort, measured in hours, was calculated by multiplying the number of whale watching tours that took place by the number of hours those tours were scheduled for. No information was provided on tours that were cut short due to factors such as weather conditions, delayed returns, or rare minor emergencies. It was therefore assumed that each tour stayed at sea for the scheduled amount of time. Tours where no cetaceans were sighted ("NOTHING") were included in the total effort, as the boats did go out to search and observational effort was undertaken. Tours that were cancelled ("CANCELLED") because of factors such as bad weather or COVID-19 restrictions, and tours where no information was provided ("----") were not included in the calculation of the total effort. Table 1 summarises the survey effort subdivided in hours and number of trips for each study period.

The monthly sightings per unit effort (SPUE) for the four targeted species was calculated by dividing the number of tours a species was sighted on by the total effort in hours for that month. The monthly SPUE's per year were plotted for each species. Annual SPUE for each species was also plotted to observe potential trends. The months where all operations were shut down due to the COVID-19 pandemic are also included in the analysis but are carefully monitored due to the bias caused. Therefore, months in the years of 2020 and 2021 where the SPUE is zero should be interpreted as periods with no effort. An overall seasonality graph was developed by calculating the SPUE of the combined targeted species for each year, to visualise if any trends or changes over time were present. Years were equally subdivided into three quadrimesters which include two ''low season'' periods (January to April and September to December) and one ''high season'' period (May to August). This subdivision reflects the highly weather-dependent nature of whale watching in Iceland, where tour frequency varies significantly between summer and winter due to shorter daylight hours and harsher weather conditions, resulting in reduced tours and therefore effort in those periods. Consequently, the high season, when the greatest effort occurs, is concentrated in the short summer period from May to August.

To conduct statistical analysis of the data, and initial exploratory analysis was performed. This involved plotting the SPUE for each species and each year to identify possible patterns, such as strong increase or declines in sightings. Due to the gaps in the data for 2020 and 2021 because of COVID-19, these years were not included because of the few available effort days. Following the general analysis, species showing the most noticeable trends were further investigated. Preliminary results showed that such trends were present for humpback whales (Mn) and for minke whales (Ba). An ANOVA test was subsequently conducted for sightings of these two species, to measure potential significant differences between the mean presence of each species sighted during whale watching tours, and between multiple years. The test was carried out by using R software (package: "stats"). As previously stated, the sightings for COVID years were excluded from the statistical tests (i.e., 2020 and 2021).

The ANOVA test revealed strong evidence that the means of humpback whale sightings varied significantly across at least two years. Subsequently, a Tukey Honest Significant Differences (Tukey HSD) test was performed to investigate the difference between each year (package: "stats"; Chambers et al., 1992). To ensure the assumptions for those statistical tests were met, both the Shapiro Wilk test (to evaluate normality of residuals; package: "stats"; Royston 1982; 1995) and Levene test (to assess equality of variances between samples; package: "car", Fox, 2016) were performed in R.

RESULTS

Table 1 summarises the total number of trips where each species was observed, the sightings per unit effort, and percentage of trips where the four targeted species were observed for each year. When comparing years with similar survey efforts - specifically, the years before and after the COVID-19 pandemic - an increase in the overall observation of humpback whales (Mn) is observed. The average percentage of trips humpback whales were observed on prior to 2020 was 28.5%, increasing to 62% for the trips of 2022 and 2023. In contrast, an opposite but less pronounced trend can be observed for minke whales (Ba) and harbour porpoises (Pp). Before 2020, minke whales were seen on 60% of the trips, which decreased to 50% in 2022 and 2023. For harbour porpoises, this decreased from 24% before 2020 to 18.5% in 2022 and 2023. The observations of white-beaked dolphins (La) also declined, although to a lesser extent, from roughly 51% of trips before 2020, to 50% in 2022 and 2023.

Table 1. Summary of the survey effort in terms of number of hours and number of trips conducted in Faxaflói Bay between January 2016 and December 2023. *Mn* = *Megaptera novaeangliae*, Ba = *Balaenoptera acutorostrata*, La = *Lagenorhynchus albirostris*, Pp= *Phocoena phocoena*. '% trips' refers to the percentage of trips a species was observed each year. h = hours; t = trips; Obs = Observations.

Study Period	Survey Effort (h)	Survey Effort (t)	Mn OBS. (t)	Mn SPUE (h)	Mn % trips	Ba OBS. (t)	Ba SPUE (h)	Ba % trips	La OBS (t)	La SPUE (h)	La % trips	Pp OBS (t)	Pp SPUE (h)	Pp % trips
2016	2387	882	353	0.15	40	468	0.20	53	423	0.18	48	212	0.09	24
2017	2459	926	227	0.09	25	586	0.24	63	532	0.21	56	254	0.10	27
2018	2506	932	253	0.10	27	600	0.24	64	482	0.19	52	236	0.09	25
2019	2414	881	154	0.06	22	532	0.22	60	430	0.18	49	198	0.08	20
2020	576	192	85	0.15	44	110	0.19	57	59	0.10	31	51	0.09	27
2021	954	318	211	0.22	66	141	0.15	44	164	0.17	52	38	0.04	12
2022	2169	787	532	0.25	68	396	0.18	50	378	0.17	48	148	0.07	19
2023	2143	781	440	0.21	56	394	0.18	50	406	0.19	52	140	0.07	18

Annual SPUE between 2016 and 2023 for each targeted species is depicted in Figure 2. Whilst the SPUE for harbour porpoises and white-beaked dolphins remained fairly constant throughout the years (the dip in 2020 for white-beaked dolphins is due to the halt of operations because of the COVID-19 pandemic), interesting changes are shown for minke whales and humpback whales. As can be initially observed in Table 1, SPUE for minke whales shows a slight but constant decrease between 2016 and 2021 (from 20% to 15%), only partially attributable to the shutdown of operations because of the COVID-19 pandemic. Meanwhile, SPUE for humpback whales shows a drastic increase in observations, more than doubling between 2019 and 2020 (from 6% to 15%), and increasing steadily until 2022 (25%), as can be additionally observed in Figure 3.

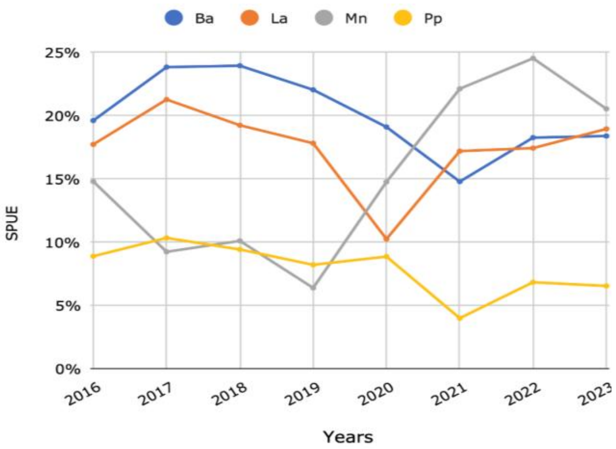

Figure 2. Annual Sightings Per Unit Effort (SPUE) in percentage, for each targeted species between 2016 and 2023. Ba = *Balaenoptera acutorostrata*, La = *Lagenorhynchus albirostris*, Mn = *Megaptera novaeangliae*, Pp = *Phocoena phocoena*.

The seasonality graph (Figure 4) shows that whilst the high season period (May to August, summer) is the one in which most encounters for all the targeted species are usually observed over the years, there is an evident increase in sightings in the summers of 2022 and 2023. The average SPUE for the high season between 20q6 and 2021 was 0.72, which increased to 0.82 in 2022 and 0.95 in 2023. In addition, the low season months between January and April, show a dramatic increase in overall observations between the years pre- and post- COVID-19 pandemic, between 2019 and 2022 respectively. The average SPUE for the low season between 2016 and 2019 was 0.43, which increased to 0.75 in 2022 and 0.61 in 2023. An increase for this period can already be observed in 2021 (SPUE = 0.67), however, this information is biased and cannot be compared to the other years because there was a large difference in sampling effort due to the shut-down of operations for most of that period. Although to a lesser extent, the same increase can be observed for the low season period between September and December, from 2021, and especially for 2022. The SPUE in this season increased from an average of 0.54 between 2016 and 2019, to 0.84 in 2022 and 0.69 in 2023. The September-December low season period of 2020 also cannot be used for comparison as it is not representative of the usual effort, given that only 3 tours were conducted during that period. During these 3 tours, sightings' success was 100%. However, the drastically reduced effort means that the high SPUE is unreliable for this time period.

Figure 3 subdivides the monthly SPUE for each year and each target species. This subdivision was carried out to have a further visual close-up of potential trends month by month. Similar to the overall annual SPUE (Figure 4), sightings for harbour porpoises and white-beaked dolphins show minimal variation over time. In the years between 2016 and 2019, harbour porpoises were most commonly observed between April and June (average SPUE = 0.124) whilst usually maintaining a relatively low SPUE for the rest of the time (average SPUE = 0.057). For the years after COVID, 2022 and 2023, observations are relatively constant throughout April to September (average SPUE = 0.224), with a peak in September 2022 (SPUE = 0.448). White-beaked dolphins show a trend that remains reasonably constant through the months and years, with the exception of some winter months (March to May 2021 and October 2021 to March 2022) where no observations are present because of the shutdown of operations.

Minke whales show a very similar trend over the years, with low sightings per unit effort between February and April and October and November, and often no sightings present in January and December (Figure 3). The months between May and September seem to be when the species is most commonly encountered in Faxaflói feeding grounds. Humpback whales seem to have a more varied trend through the years. Overall, the SPUE is generally highest in the spring and summer between April and July, but many shifts are present. A first peak in sightings between December 2018 and January 2019 (average SPUE = 0.265) can be observed. This was, however, followed by a winter where no SPUE were recorded between October 2019 and February 2020. In the winter between October 2020 and March 2021, unfortunately no data is present for comparison. However, it emerges that in the winter months between October 2022 and February 2023, a drastic increase in SPUE (average = 0.272) can be observed. Although it decreases slightly, SPUE for October to December 2023 also remained reasonably high (average = 0.174). In addition, a certain relationship between the decreasing trends in minke whale SPUE and of humpback whales SPUE can be observed between October and December of 2021, 2022, and 2023. No further analysis was done over this observation, however; given the tourism-derived nature of the data, this trend could be biased by the choice of species the whale watching operator prefers to approach.

Statistical Analysis

Statistical analysis was carried out on humpback whale, harbour porpoises, and minke whale trends on SPUE, as they showed the most prominent trends over time. The temporal trends for minke whales and harbour porpoises did not show any significant/strong difference between years from the ANOVA test hence, no further statistical analyses were performed for this species. On the other hand, the ANOVA analysis reported significant differences between at least two years in the means of humpback whale SPUE (Table 2).

Table 2. ANOVA test output for humpback whales' sightings per unit effort between years (2016-2023).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	5	0.273	0.055	5.648	< .001
Residuals	64	0.618	0.009		

The Tukey HSD test was run on SPUE of humpback whales. It reported the presence of a strong difference in SPUE for the years: 2022-2017 (p=0.006), 2023-2017 (p=0.003), 2023-2018 (p=0.04), 2022-2019 (p=0.024), and 2023-2019 (p=0.009). This test thus confirms initial observation of a net change in humpback whale SPUE, in terms of increase of sightings in the last two years, 2022 and 2023.

DISCUSSION AND CONCLUSIONS

Species Occurrence Over Time

The results presented provide noteworthy insights into the changes in occurrence of cetacean species observed in Faxaflói, although they are limited by numerous factors (described in detail below) due to the use of the non-scientific platform of whale watching vessels. The relatively long-term nature of the dataset allowed for comparison over several years, showing variability in species occurrence. All four focal species were consistently observed throughout the years, however, occurrence varied between species and between and within periods of time.

SPUE for white-beaked dolphins and harbour porpoises showed some variation throughout the study period. In 2020, SPUE for white-beaked dolphins was considerably lower than other years, while harbour porpoises SPUE slightly decreased after 2021. Changes in abundance have been previously suggested to follow changes in prey availability and ultimately, temperature and salinity for white-beaked dolphins (Bertulli et al., 2015), and prey availability for harbour porpoises (Gilles et al., 2020). This is of particular importance given the recorded rise in sea temperatures around Iceland (Hanna et al., 2006). As this study lacks information on population trends for these two species during the COVID-19 pandemic years, the drop in SPUE could be linked to a change in search effort itself. Normally, searching primarily takes place aboard the two largest vessels in the Special Tours fleet, with observation heights of 8 metres and 9.5

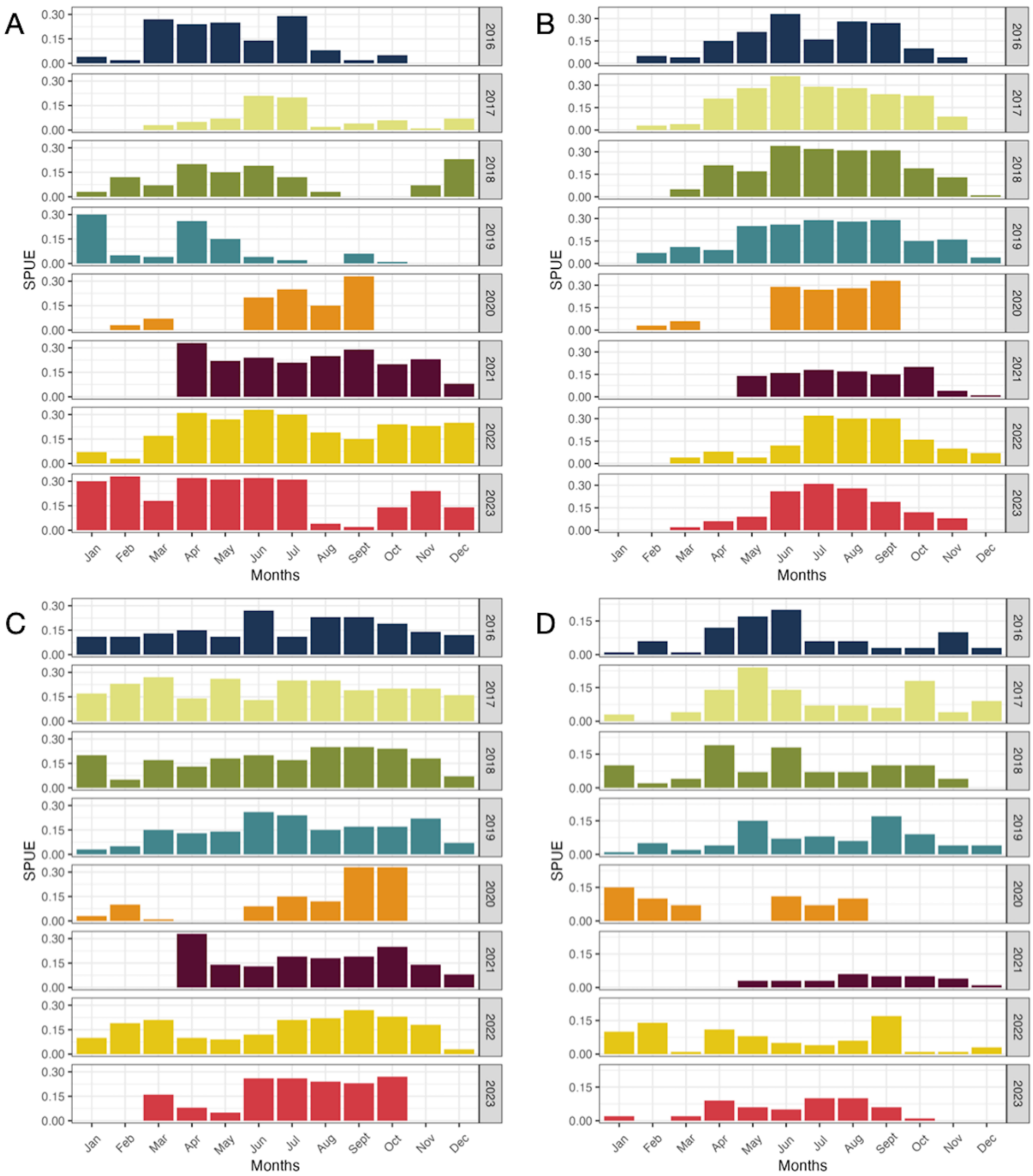

Figure 3. Sightings per unit effort for each species throughout the months for each year: A) Humpback whale sightings, B) minke whale sightings, C) white-beaked dolphin sightings, and D) harbour porpoise sightings.

metres above sea level. However, during the pandemic, due to significantly reduced passenger numbers, whale watching (and therefore, observation) was primarily conducted aboard a smaller boat, Rosin, where the spotter height is approximately 5.5 metres above sea level (Rempel, personal data). The lower spotter height could potentially obscure smaller cetacean species behind waves, especially when tours are conducted at higher Beaufort levels, which have previously demonstrated to reduce the probability of dolphin and porpoise sightings (Bas et al., 2018).

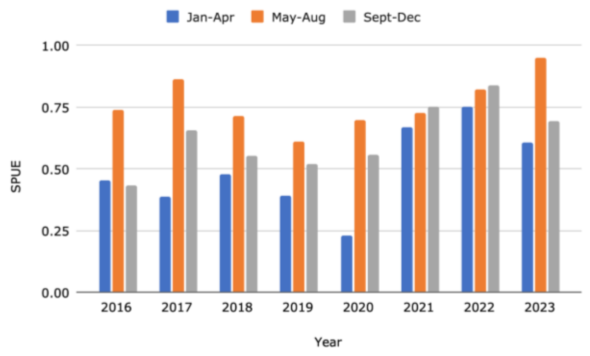

Figure 4. Total SPUE for all targeted species combined. SPUE is subdivided into three seasons for visual aid to observe changes over time. Non-touristic seasons include January to April and September to December; the touristic season includes May to August.

A peak in SPUE was observed for humpback whales during the winter of 2018-2019; while humpback whale sightings are generally rarer during this time of the year in Faxaflói, 2 individuals could be observed near the coast of Reykjavík for weeks on end, much closer to land than the usual whale watching area (Rempel, personal data). In recent years, humpback whales have been observed in greater numbers in Icelandic waters during the winter, suggesting that these individuals give up a potential breeding season in favour of feeding (Magnúsdóttir et al., 2019). In addition, since 2017 a new fish species potentially coming from Faroe Islands, the sprat (*Sprattus sprattus*), has started reproducing in Icelandic coastal waters, including Faxaflói (Pállsson et al., 2021). Because the sprat is similar in size to other fish species favoured by the humpback whales, it is possible that individuals overwintering in Faxaflói are taking advantage of the new fish species and feeding on the sprat as well.

Interestingly, these results indicate that when minke whale occurrence in Faxaflói decreases, humpback whale occurrence increases, as visualised in Figure 2 and Figure 3. This could be due to a variety of factors. Minke whale population levels in Iceland have been previously observed to have decreased, possibly due to shifts in distribution and abundance of their primary prey species, the sand eel; minke whales may then shift their distribution in response (Hjörvarsdóttir, 2014; Pike, Gunnlaugsson & Víkinsson, 2008). Humpback whales are thought to prey primarily on capelin in Iceland; if the capelin moves in to fill the niche abandoned by the sand eel, this would result in an increased occurrence of humpback whales. However, this is purely speculation, as one of the limitations of whale watching vessels as research platforms is that it is rarely possible to observe the prey that animals are feeding on during encounters. Another possibility is that humpback whales outcompete minke whales for prey in Faxaflói, forcing the minke whales to forage elsewhere, as humpback whales are thought to also include sand eels in their diet (Víkinsson et al., 2015).

The effects of whaling cannot be discounted as yet another possibility; while humpback whales have not been hunted in Iceland since 1955, minke whales were hunted as recently as August 2021 (Kári Gautason, Directorate of Fisheries in Iceland, personal communication, February 2022), which may cause them to be more fearful of approaching boats than humpback whales. This speculation is supported by anecdotal evidence from whale watching guides, who have witnessed minke whales tending to be more wary and less curious of approaching vessels than other species. Regardless, the data seems to suggest an inverse relationship between minke whale and humpback whale SPUE.

For 6 out of the 8 study years, SPUE was greatest during the summer (May-August) quadrimester. This is consistent with previous data recorded in Faxaflói (Bertulli, 2010). For the years 2021-2023, there was a steady increase in SPUE during the summer months. SPUE for the January-April quadrimester remained relatively stable from 2016-2019, before declining significantly in 2020, and then experiencing a large increase from 2022-2023. While no data is available on prey species abundance for the last 3 years, this recent upward trend may suggest an increase in prey in Faxaflói Bay during the first two quadrimesters. Meanwhile, SPUE for the September-December quadrimester appeared to be nearly cyclical in nature, with an increase from 2016-2017, followed by a decrease from 2017-2019, followed again by an increase from 2019-2022 (excluding 2020 and 2021), and finally a decrease from 2022. Further research is recommended to investigate this possible cyclicity and potentially link it to larger-scale trends. The increments observed in Figure 4 for the September-December 2020 and January-April 2021 quadrimesters can be explained by the fact that if effort was low because boats were not often going out due to the COVID-19 pandemic, but sightings still occurred when they did go out, then it is evident that even with less effort the SPUE results to be higher. In other words, the frequency of whale observation is higher when boats go out less often but see the same number of whales, as when they sail on a regular basis. This is the reason why the two quadrimesters were excluded from the statistical analysis described above.

Major Drawbacks to the Research

One potential drawback of this study is that sightings data was Boolean, limited to the presence (or absence) of each of the four focus species, rather than the number of individuals for each species. While this does provide valuable data on species occurrence, it does not provide any information on abundance, which could be used to specifically define trends over time.

The significant gaps in the sightings data from March through June 2020, and again from September through May 2021, are due to a near-total lack of whale watching operations during the peaks of the COVID-19 pandemic. This explains the anomalies in the data for those two years affecting, to a certain extent, the results, and reducing possibilities for comparison. Additionally, the dataset spans only eight years, which is relatively limiting. This short timeframe poses challenges for conducting robust statistical analyses and detecting significant trends. Unfortunately, systematic data collection by the whale watching operator contributing to this data did not commence before 2016, resulting in a lack of long-term data. To address this limitation, ongoing data collection in the coming years is essential, as it will enhance the reliability of the findings and allow for more comprehensive trend analysis.

Furthermore, due to the tourist-focused nature of the whale watching tours, there exists some potential for missed sightings. While normal cetacean surveys may perform transects of an area with observers positioned onboard in such a way as to provide 360 degree coverage at all times, without preference or focus on certain species, whale watching tours tend to focus on the largest and most charismatic of species, in this case humpback whales; as attention is diverted towards a single focus animal, other species in the area may go unnoticed, for example if a lone harbour porpoise passes behind a boat while the crew and passengers watch a breaching humpback whale towards the front. In such a possible scenario, recorded sightings data may not provide the full picture of species present in the bay during that specific tour. Encounters are therefore likely to be biased towards species that are easily found or hold the greatest appeal to tourists (Vinding et al., 2015).

In addition, given the nature of whale watching tours, data that is usually collected on surveys is not present. For example, no environmental or quality data assessment are collected. Within safety limits, tours proceed in all weather conditions, not taking into consideration information such as Beaufort scale and/or visibility. Sea state values can directly influence cetaceans' presence (visibility), behaviour, and distribution (Vinding et al., 2015). Transect or effort lines, as well as GPS locations, of where cetaceans are observed are also lacking. These kinds of information are particularly important to make observations on potential distributional changes over time.

When using data from tourism operators such as whale watching, it is also important to mention that if the right mitigation measures are not observed by the operators, they have the potential to cause negative impacts on cetaceans (Blankenstein, 2021). A fundamental issue with whale watching data arises from the inevitable interaction between cetaceans and the vessel. The underwater noise generated during encounters and the presence of multiple vessels can lead to an antipredator response. This response may manifest in altered behaviours and a tendency to avoid areas with high vessel impact (Bejder et al., 2006). For example, there are occasions where the same individual is observed in a region over long periods of time. Repeated exposure of the same individual to short-term impacts may result in lasting adverse effects on their survival and reproductive rates, depending on the activity state most frequently affected (Christiansen & Lusseau, 2014). Although a code of conduct exists for the country (IceWhale, 2016) it is only voluntary and often those in charge (i.e., captains, company owners, and managers) are not aware or choose not to adhere to the code. This is especially the case for weathered captains who are used to a hierarchical system from previously working on fishing vessels and who chose not to listen to guides who are often the most knowledgeable about the mitigation measures (Blankenstein, 2021). Pressure may also rise on whale watching operators when numbers of cetaceans in a specific area are low and operator competition is high. Thus, taking a proactive and precautionary stance on regulations might prove more effective than attempting to exert control after whale watching has already become firmly established (Hoyt & Parsons, 2014).

Nonetheless, whale watching boats provide an incredibly valuable, yet affordable platform for long-term monitoring of cetacean occurrence, distribution, and abundance, as well as photo-identification (Robbins, 2000; Robbins & Mattila, 2000). The year-round nature of these tourist operations goes far beyond the scope of traditional cetacean research, which generally is limited to certain times of the year and funding. Maintaining long-term sightings data in this way is crucial as it can assist in monitoring cetacean populations and provide insights into occurrence trends and dynamics over time. As marine ecosystems are sensitive to environmental changes, monitoring cetacean occurrence over time can help link any changes to wider climatic shifts, be they natural or anthropogenic. For example, the establishment of enduring collaborations between whale watching tour operators and researchers in the Gulf of Maine has led to the publication of more than 75 peer-reviewed scientific papers, incorporating data collected aboard whale watching vessels (Robbins, 2000). Similarly, data collected between 2003 and 2012 in the south-western Cape, South Africa, was used to assess distribution and seasonality of the cetacean species found in the region (Vinding et al., 2015). To further expand this partnership in Iceland, whale watching guides could easily be trained to gather additional data beyond occurrence, such as GPS coordinates, effort lines, and number of individuals spotted per encounter, which would significantly enhance the future understanding of cetacean trends in these areas.

Conclusions

Despite the limitations associated with the use of non-scientific platforms, the findings presented in this study offer valuable insights into the dynamics of cetacean occurrence in Faxaflói. The relatively long-term dataset allowed for meaningful comparisons over several years, revealing variability in species occurrence. While SPUE for white-beaked dolphins and harbour porpoises remained relatively stable, notable exceptions in 2020 and 2021 suggest a potential link to changes in search effort during the pandemic years. The inverse relationship observed between minke whale and humpback whale SPUE prompts speculation about potential ecological factors influencing their occurrence. Seasonal trends indicate a consistent peak in SPUE during the summer months, possibly associated with increased prey availability.

The study's major drawbacks, however, emphasizes the need for cautious interpretation. Despite these limitations, the data highlights the importance of whale watching vessels as affordable platforms for long-term cetacean monitoring. Collaboration between operators and researchers, coupled with additional data collection by trained guides, holds promise for expanding our understanding of cetacean trends and contributing to broader ecological insights.

ADHERENCE TO ANIMAL WELFARE PROTOCOLS

The research presented in this article has been done in accordance with the institutional and national animal welfare laws and protocols applicable in the jurisdictions in which the work was conducted.

AUTHOR CONTRIBUTION STATEMENT

Giulia Bellon: Conceptualisation, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Resources, Supervision, Validation, Visualisation, Writing-Original Draft, Writing-Review & Editing; **Heleen Middel**: Conceptualisation, Data Curation, Formal Analysis, Investigation, Methodology, Validation, Visualisation, Writing-Review & Editing; **Carola Chicco**: Conceptualisation, Data Curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualisation, Writing-Review & Editing; **Jonathan Rempel**: Conceptualisation, Data Curation, Resources, Writing-Original Draft, Writing-Review & Editing.

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