Temporal variation in the occurrence of whale and dolphin species in the Azores from 2010 to 2017

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ABSTRACT
Global climate change (CC) affects marine mammals, such as cetaceans, by exposing them to an altered marine environment. Cetaceans are indirectly influenced by CC (e.g. through their prey, warmer environment). They are indicator species, significant to marine ecosystems and one of the most endangered vertebrate groups on this planet. Since oceanic water temperatures have increased, a noticeable shift in diversity of cetaceans present in marine hotspots is expected. In this paper, the community structure (occurrence) of cetacean species present around São Miguel Island, Portugal were investigated to contribute to the current understanding of the effects of CC on cetaceans.

Keywords
whale watching, tourism, opportunistic data, Azores, sea surface temperature, global climate change.

INTRODUCTION

The Earth's climate is changing rapidly due to global climate change (CC)[1]. In fact, the Intergovernmental Panel on Climate Change already recorded an increase in the global mean surface temperature of 0.6°C ± 0.2°C in the 20th century[2]. The upper level of the ocean (0-2000m) increases in temperature as well[3], exposing marine mammals, such as cetaceans, to an altered environment. One of the factors that appears to be of significant influence on cetaceans is water temperature[4]. Since cetaceans are eurythermic, CC will probably influence them indirectly by e.g. the re-distribution of prey species as a response to the warming water[5,6,7], forcing them to migrate to avoid starvation. Therefore, CC will influence the cetacean's distribution[8]. Moreover, cetaceans are one of the most endangered vertebrate groups on Earth[9], while these top predators[e.g.10] are significant to marine ecosystems. Considered indicator species[e.g.10,11], changes in their community structure (e.g. occurrence, diversity and abundance) may be of significance to contribute to the current understanding of the effects of CC on cetaceans and the ecosystems they inhabit. Marine diversity hotspots are present around the globe; one of them being the archipelago of the Azores, Portugal. Companies, such as Futurismo Azores Adventures (Futurismo) located on São Miguel Island, collect data on marine life as a "by-product" of whale watching. They contribute crucial data to improve the current understanding of cetaceans around São Miguel Island and to investigate possible temporal changes in cetacean occurrence due to global CC. Since oceanic water temperatures have increased[3], a noticeable shift in the cetacean occurrence present around São Miguel Island is expected, but not yet proven. Therefore, this study investigates temporal variation in cetacean occurrence in the Azores from 2010 to 2017.

METHODS

Study area
This study was conducted in the Azores (36°55' - 39°43' N and 25°01' - 31°07' W, Figure 1), an archipelago composed of nine volcanic islands, located in the North Atlantic Ocean, and an autonomous region of Portugal[12]. The Azores stretch more than 600km wide[12], with a contiguous shelf depth of <500 m[13]. The study area was located in the waters off the southern coast of São Miguel Island. All data were collected by the whale watching company Futurismo Azores Adventures (Futurismo), with its homeport in Ponta Delgada.

Study species
In total, 22 species of whales and dolphins were researched, including six Rorqual whales (Blue whale *Balaenoptera musculus*, Bryde's whale *Balaenoptera edeni*, Common minke whale *Balaenoptera acutorostrata*, Fin whale *Balaenoptera physalus*, Humpback whale *Megaptera novaeangliae*, Sei whale *Balaenoptera borealis*), six Beaked whales (Blainville's beaked whale *Mesoplodon densirostris*, Cuvier's beaked whale *Ziphius cavirostris*, Gervais' beaked whale *Mesoplodon europaeus*, North Atlantic bottlenose whale *Hyperoodon ampullatus*, Sowerby's beaked whale *Mesoplodon bidens*, True's beaked whale *Mesoplodon mirus)*, nine

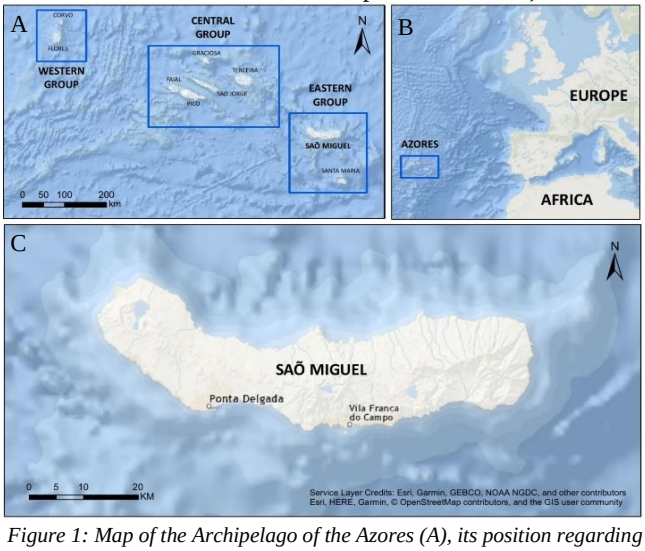

Figure 1: Map of the Archipelago of the Azores (A), its position regarding Europe (B) and São Miguel Island (C), (Beek, 2019).

Oceanic dolphins (Atlantic spotted dolphin *Stenella frontalis*, Common bottlenose dolphin *Tursiops truncatus*, False killer whale *Pseudorca crassidens*, Killer whale *Orcinus orca*, Long-finned pilot whale *Globicephala melas*, Risso's dolphin *Grampus griseus*, Short-beaked common dolphin *Delphinus delphis*, Short-finned pilot whale *Globicephala macrorhynchus*, Striped dolphin *Stenella coeruleoalba*) and the Sperm whale *Physeter macrocephalus.*

Sightings

Cetacean sightings were recorded year-round (2010-2017) during Futurismo's commercial whale watch tours, whenever weather and sea state were good enough, and enough tourists had booked a tour. From look-out points on land, experienced observers used binoculars (Steiner 20x80mm) to search for cetacean activity in the ocean before and during trips. Sightings were passed on to the boats, directing them towards the animals. Data collected per sighting were date, time, GPS location, species, group size and other observations.

Only sightings with reliable species identification, Ponta Delgada as departing harbor and complete trips (start and end time present, with and without cetacean sightings) were included in the analysis. Data collected concurrent from different boats were omitted from the database (duplicate trips present in 2010-2012 and 2017). "Pilot whale spp." and "Beaked whale spp." were both grouped, as they could often not be identified at the species level in the field. The North Atlantic bottlenose whale was also included in the "beaked whale" group during data preparation.

Estimated value

To decrease the amount of data gaps in the database, an estimated value was added to the sightings lacking a group size estimation. In total, 5.5% of sightings lacked a group size estimation. "Gap-free" species were Bryde's whale, Blue whale, Killer whale and False killer whale.

$$Estimated\ value = \frac{total\ number\ of\ individuals\ of\ a\ species\ of\ a\ month}{(total\ number\ of\ sightings\ of\ that\ species\ of\ that\ month - number\ of\ sighting/s\ with\ gap/s)}$$

If no group size values were present in a month, values of surrounding months were used to calculate the estimated value. In total, 8.7% individuals were added to the database.

Effort

Data collection was restricted to a minimum, as the main goal of the activity was tourism. Hence, sail routes were not tracked, and cannot be used to calculate the search effort per sighting. However, recorded number of trips were documented and used as a rough indicator of effort by determining the average number of individuals of species encountered per trip, calculated per month, year and over the entire study period (also used for the occurrence rate).

Data analysis

Study period overview

Study period characteristics were assessed by the study period (ST) sighting rate ([a]), species abundance ([b]) and occurrence rate ([c]):

$$ST\ sighting\ rate\ (\%) = \frac{sum\ of\ all\ sightings\ of\ a\ species}{total\ number\ of\ sightings} * 100$$

$$ST\ species\ abundance\ (\%) = \frac{sum\ of\ the\ number\ of\ individuals\ of\ a\ species}{total\ number\ of\ individuals\ of\ all\ species} * 100$$

$$ST\ occurrence\ rate\ (\%) = \frac{occurrence\ rate\ of\ a\ species}{summarized\ occurrence\ rate\ of\ all\ species} * 100$$

Species occurrence

Species occurrence was analyzed by first determining presence/absence per species, followed by yearly occurrence rate (number of individuals of a species per year/number of trips made in that year) and its index (reference year 2012, from here on yearly species occurrence):

$$Index_{yearly\ occurence\ rate} = \frac{yearly\ occurence\ rate\ of\ a\ species}{yearly\ occurrence\ rate\ of\ a\ species\ of\ the\ reference\ year}$$

Thereafter, the moving average and its index were calculated. Each subset consisted of 12 months; subset 1 went from January 2010 to December 2010, subset 2 from February 2010 until January 2011, etc. By calculating the moving average (Σ monthly occurrence rates of a subset/12), a series of averages from all the subsets were created. This resulted in 85 new datapoints, where point 1 represents the average of subset 1, point 2 the average of subset 2, etc. Bryde's whale and Killer whale were excluded since the outcome of subset 1 of both species equaled 0. The moving average index (hereafter species occurrence averages) were used to visualize trends and to correct for seasonal effects. Correlation was analyzed with Pearson's correlation in IBM SPSS 25. The R^2 (coefficient of determination) was used to clarify the proportion of variance in the dependent variable (species occurrence averages) that can be explained by the independent variable (time: 85 datapoints).

$$Sp.occurrence\ average = \left(\frac{Each\ subset\ individually}{Subset\ 1}\right) * 100$$

RESULTS

During the eight years of research (2010-2017), a total of 1,842 days were surveyed, and 2,891 trips were made. Cetaceans sighting rates were 98% or higher for each year. In total, 16 whale and dolphin species were recorded. As not all species were present each year, yearly species richness varied between 13 to 15.

Overall, the Spotted dolphin, Bottlenose dolphin and Common dolphin were the most dominant species for the entire research period. Common dolphins registered the highest sightings (32%[a]), the largest number of individuals (45%[b]) and the highest encounter rate during a whale watch trip (45%[c]). Sperm whales were sighted regularly (25%[a]), but in very small groups or as single individuals (2.3%[b]). However, the encounter rate was very low (0.2%[c]). Common minke whales were the hardest to be sighted (0.1%[a]), as it was nearly impossible to find an individual (<1%[b]). As a result, the likeliness of encountering the Common minke whale during a whale watch trip was close to zero (<0.1%[c]).

Species occurrence

Presence and absence of species

Over the entire research period, 11 out of 16 species (69%) were consistently present each year. The Humpback whale and False killer whale were both absent for one year. The Common minke whale and Killer whale were absent for three years. The Bryde's whale occurred once every four years (Table 1).

Yearly species occurrence

Yearly frequency of occurrence differed a lot between the species. For Bottlenose dolphins and Humpback whales, occurrence rates were consistently at least 80 points higher than the reference year (2012). Fin whales occurred more frequently from 2013 on. Pilot whales were the most sighted during the first two years of the study period. Noteworthy is the peak in Killer whale presence in 2013. The chance of encountering them during that year

	2010	2011	2012	2013	2014	2015	2016	2017
Bryde's whale				■				■
Common minke whale	■	■	■	■			■	
False killer whale	■		■	■	■	■	■	■
Humpback whale	■	■	■		■	■	■	■
Killer whale			■	■	■		■	■

Table 1: Species occurrence (present-absent) per year (2010-2017). Green box = present, white box = absent.

increased by 400% in comparison to the reference year.

Species occurrence averages

False killer whales (r=0,758; p=0,000) and Fin whales (r=0,973; p=0,000) were observed with a significant increasing frequency during boat trips throughout the study period. In contrast, Spotted dolphin (r=-0,764; p=0,000) and Pilot whale (r=-0,755; p=0,000) occurrence rates decreased significantly with time. The R^2 values of all remaining cetaceans were too low to have a moderate or strong effect size (Figure 2).

DISCUSSION

Methodology

The data used in this research were collected as a by-product of whale watching and was set up for its primary purpose of the platform (tourism). For this reason, of all the boats that went out for whale watching, only one data on the cetaceans, possibly missing out on species encountered by other boats. Though, it also ensured that no species/individuals were recorded more than once in the same encounter. Considering these previously mentioned limitations and the logistical constraints imposed by the nature of whale watching, the study area may not be equally covered and findings from this research may not be representative for the entire research area. However, whale watching activities offer a source of valuable data and funding for cetacean research. It is a cost-effective method to collect opportunistic data on the cetaceans that otherwise would have been inaccessible, especially for those species that are rare or (very) hard to sight. As whale watching tours were offered year-round, this data is a potential tool for detecting long term changes, as shown in this research.

Sightings

Eight years of data confirm the presence of 16 cetacean species in the ocean on the southern side of São Miguel Island. Spotted dolphins, Bottlenose dolphins and Common dolphins were predominant. They were also the most sighted species, next to the Sperm whale. In contrast, historic data from the entire Azores shows that the most sighted species were Spotted dolphin, Common dolphin, Bottlenose dolphin and Risso's dolphin (summer and autumn, 1999-2000)[14], whereas these were the Bottlenose dolphin, Common dolphin, Risso's dolphin and Sperm whale later on (1999-2009)[15]. In contrast to this study, the historical data was collected by either systematic sampling or in combination with opportunistic sampling over a larger area and in one case based on data collected during two seasons. As the top three most sighted species of the previous records are included in the top four most sighted species of this study, it can be concluded that the most sighted species stayed about the same. Even though Risso's dolphins were sighted around São Miguel Island, it was not often enough to be one of the most sighted species. This may be geographically related[16,17].

Species occurrence

Findings show an increase in species occurrence averages of False killer whales and Fin whales, and a decrease in Spotted dolphins and Pilot whales from about the first research year on. These findings could demonstrate adaptation to the altered environment, as a result of CC, since all four cetaceans migrate to the Azores on a seasonal basis. The increasing occurrence of False killer whales and Fin whales might indicate that they are better suited to the altered environment[18] while the decline in Spotted dolphins and Pilot whales indicate that they can cope less with the altered environment, resulting in a change in distribution or even re-distribution[18]. This process of adaptation to the altered environment is also seen in other large species in the Azores, i.e. the Whale shark (*Rhincodon typus*). This species also migrates seasonally to the Azores. As sea surface temperatures (SST) increased, more Whale sharks occurred, up to the point where its occurrence can be predicted by the SST in this region[19]. Another explanation for the change in occurrence of Spotted dolphins, False killer whales, Fin whales and Pilot whales is the re-distribution of their prey species as a response to the warming water, forcing them to follow their food[5,6,7].

Literature research revealed no explanation for the peak in Killer whale numbers in 2013; it only showed that this species is generally rare in the Azores[20]. It is therefore likely that this is an artefact of the chosen reference year. Nonetheless, since the decision was made to A) include as many species as possible and B) to select the first year that met this criterion, 2012 was the first study year to fulfill

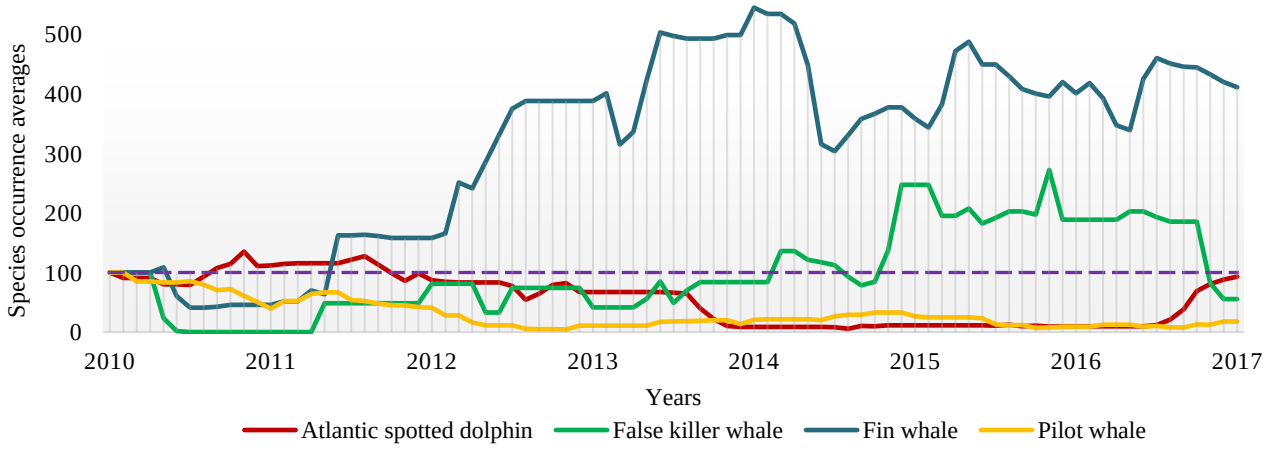

Figure 2: Species with a moderate effect size: Atlantic spotted dolphin, False killer whale, Fin whale and Pilot whales. Dotted line shows the reference line (reference year 2012). Vertical lines embody a subset of the database.

the selection requirements. Another option would be to use 2016 as the reference year as all selection requirements are met too or to set different parameters for the suitability preferences.

CONCLUSION

The occurrence of several whale and dolphin species has changed between 2010 and 2017. Over time the populations of False killer whales and Fin whales increased, whereas the populations of Spotted dolphins and Pilot whales decreased which could indicate a response of these cetaceans to CC in the Azores.

ROLE OF THE STUDENT

Annelie Milou Bron was an undergraduate student working under the supervision of Okka E. Jansen and Miranda L. van der Linde when the research in this report was performed. This entire project, from proposing the topic to its design, processing and writing, was done by the student.

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