UNIVERSITÀ DEGLI STUDI DI PADOVA

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First Cycle Degree (B.Sc.)
in Animal Care

Investigation on the influence of whale watching boats on the respiratory and diving behaviour of humpback whales *(Megaptera novangliae)* in Skjálfandi bay, Northeast Iceland.

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SUMMARY

The humpback whale *(Megaptera novaeangliae)* is one of the most abundant species of mysticeti (baleen whales) found around the coast of Iceland, especially in the north-east area. Due to their spectacular aerial behaviours, they are one of the most popular target species of whale watching tours. Nowadays, as the whale watching business is skyrocketing, the concern among researchers is understanding the possible impacts of said human activity on the cetaceans, with a focus on potential behavioural disruption.

The present study aims to investigate whether the presence of whale watching boats is affecting the respiratory pattern and diving behaviour of humpback whales in Skjálfandi bay, northeast Iceland. In order to achieve this goal, the study has been carried out focusing on the number of vessels present during each whale sighting and how closely the animals were approached by the boats. Analysis of the records of humpback sightings from the year 2020 to 2024 was done and from the inspection of the respiratory behaviours collected during each whale sighting the time spent diving, the surface time, the number of breaths per surfacing and the breathing rate were calculated. Afterwards, statistical inference was done using linear regression models and generalized linear models. The most interesting results showed signs of vertical avoidance with a statistically significant increase in the time spent diving as both the number of boats increased and the distance from the humpback decreased. Associated with an increase in the diving time, the number of breaths taken for each surfacing decreased as the distance of approach to the animal decreased. As a result, it can be concluded that humpback whales seem to respond to anthropogenic disturbance with vertical behavioural avoidance.

1. INTRODUCTION

1.1 Cetaceans and baleen whales

The Cetacea order is a highly specialized order of mammals composed of fully water-dwelling animals. Having evolved from terrestrial ancestors, all cetaceans are air-breathing and homeotherms vertebrates (Würsig & Perrin, 2009). The Cetacea order comprises of roughly 90 heterogenous species characterized by a broad size range: from the less than 1-meter long Vaquita (*Phocoena sinus*) to the largest mammal ever existed, the blue whale (*Balaenoptera musculus*), known to reach up to 33 meters of length in adult specimens (Würsig & Perrin, 2009). Cetaceans are divided into two main suborders: Mysticeti, the baleen whales such as the blue, minke (*Balaenoptera acutorostrata*) and humpback (*Megaptera novaeangliae)* whales and Odontoceti, the toothed whales such as sperm whales *(Physeter macrocephalus*), killer whales *(Orcinus orca)* and white beaked dolphins (*Lagenorhynchus albirostris*; Berta et al., 2005). These suborders differ on various aspects, the main ones being: the presence in Odontoceti of numerous conical teeth in contrast to the baleen plates of Mysticeti; the characteristic feature of the latter suborder of having two blowholes and not a single one like the toothed whales and the fact that Odontoceti rely on their echolocation system in order to orientate in the water (Fahlman et al., 2023) while Mysticeti are only capable of producing complex and various songs, probably used as a communication tool (Segre et al., 2020).

The baleen whales can be divided into four main families: the right whales (Balaenidae), the pigmy right whales (Neobalaenidae), the grey whales (Eschrichtiidae) and the rorquals (Balaenopteridae) (Würsig & Perrin, 2009). Regardless of the enormous size of mysticeti, they are batch feeders (Christiansen et al., 2014) and they use the filter feeding method to engulf great quantities of water containing invertebrates and small fish (Goldbogen, 2017). Then, the baleen plates create a complex filtration system (Clapham et al., 1999) thanks to which the food, engulfed together with the water, gets trapped within the baleen plates while the excess of water is expelled (Carwadine, 2022).

1.2.1 The humpback whale (*Megaptera novaeangliae*):

The humpback whale (*Megaptera novaeangliae)* is a baleen whale belonging to the family of the rorquals (Balaenopteridae). The origin of its name comes from the Greek word "μεγα- πτερα" meaning "big wing", referring to their remarkably long flippers which correspond to one third of the total body length (Würsig & Perrin, 2009). It is specifically this feature that differentiates the body plan of the humpback whale from the one of the other species included in the family of rorquals (Jefferson et al., 2011). Humpbacks are easily distinguishable from any other whales thanks to their peculiar individual-specific pigmentation on the underside of the fluke, which ranges from all white to completely black (Würsig & Perrin, 2009). Also the flippers present white coloration on their ventral side while the colours of their dorsal side are population dependent: the North Atlantic population's flippers tend to be more white while the ones belonging to the individuals inhabiting the North Pacific waters are more black. For what concerns their total length, females appear to be 1-1.5m longer than males (Jefferson et al., 2011). The maximum length range of adult specimens ever recorded is between 16-17 meters while the more frequent measures observed are between 14-15 meters of length.

1.2.2 Humpback whale distribution and migration

The humpback whale is a cosmopolitan species (Jefferson et al., 2011), distributed all around the world with the exception of the Arabian Sea and the Mediterranean where they are rarer to find (Mittermeir & Wilson, 2014). As results from genetic analysis have shown, the global population of humpback whales can be further divided into three smaller ones characterised by little exchange between one another: the North Atlantic, the North Pacific and the Southern Hemisphere populations (Gunnufsen, 2022). One peculiar feature of the humpback whale, which is making it one of the best known and easily monitored species of large whales, is that they tend to inhabit continental shelves, often near to human dense areas (Jefferson et al., 2011). Humpback whales, just like the majority of baleen whales, are highly migratory species (Würsig & Perrin, 2009). They preform annual long migrations at the beginning of spring, typically moving from the tropical waters towards the feeding areas in the northern hemisphere and then in late autumn they move back to the equatorial breeding grounds. However, the migratory pattern differs depending on the population of whales taken into consideration (Zubiri, 2017). For instance, the North Atlantic population tend to feed in the summer grounds of Newfoundland, Labrador, Greenland and Iceland, while, during winter, they are found in the breeding waters of Cape Verde and the West Indies (Kettemer, 2023). The exact reason why humpback whales perform these migrations remains unknown: it may be associated with the fact that these movements allow them to gain great quantity of energy due to the high productivity of the summer grounds and the energy saving qualities of the warm winter waters (Magnúsdóttir et al., 2014). Moreover, during winter, in warmer waters the abundance of killer whales, the main predator of the humpbacks, tends to be less than the one in the norther grounds (Jefferson et al., 2011). To conclude, humpback whales are characterised by strong site fidelity to their feeding waters and philopatry to their breeding grounds, which is most probably maternally driven (Gunnufsen, 2022).

1.2.3 Humpback whales in Iceland and Skjálfandi Bay

Icelandic waters, with their great abundance of nutrients, are one of the most important feeding grounds of the North Atlantic humpback whale population. Individuals that are present in Iceland are following migratory patterns starting from the Caribbean and Cape Verde breeding grounds (Brown et al., 2019). In the past decades there has been a rapid increase in the abundance of the Icelandic feeding stock (Pike et al., 2005) all around the coast of Iceland, with a particular focus on the north-eastern part of the island. Indeed, affluence surveys carried out in Skjálfandi Bay (northeast Iceland) have revealed an annual increase of approximately 12% of humpback whales with an estimate of 85 individuals coming back yearly (Morin et al., 2019). As a matter of fact, it has been proven that humpbacks show Icelandic feeding grounds fidelity which is sustained on an evolutionary time scale (Würsig & Perrin, 2009). Humpback whales show a season-dependent distribution in Skjálfandi bay. Indeed, a higher distribution of the whales closer to the coast, in the deepest part of the bay, has been detected during early spring (from April to June). On the other hand, from August to October, humpbacks tend to be sighted more in the northern part of the bay (Pike et al., 2019). This seasonal variation is probably associated with whales' energy restocking needs. Indeed, at the beginning of the feeding season (April), humpbacks not only come from breeding grounds with minimal nutrients, but they also have performed a long migration, hence, they are in need of very nutrient-rich waters that are found in the southern part of the bay. On the other hand, at the end of the feeding season (October), humpbacks move up in the northern area due to food-exhaustion in the southern grounds (Klotz et al., 2021). Moreover, it is from here that they have direct access to the open sea for performing the winter migration back to the tropics (Corkeron, 1999).

1.3 Whale watching

Whale watching is defined as the activity of observing cetaceans in their natural habitat (Würsig & Perrin, 2009). A broad variety of whale watching vessels can be utilised, ranging from big oak boats to small paddleboards and zodiacs (Cisneros-Montemayor, 2010). This activity is an ever-increasing economic business and source of income in many regions of the world (Villagra et al., 2021). In Iceland, whale watching has started in the 90s and it has become one of the main reasons attracting tourist from all around the world. Whale watching has an uttermost economic importance for Húsavik, a small town in the Northeast of Iceland located on the coast of Skjálfandi Bay. It is this town that has been nominated, in 2009, the whale watching capital of Europe. The most common species found in Skjálfandi Bay are humpback whales, minke whales, white-beaked dolphins and blue whales (Rasmussen, 2009).

1.3.2 Humpback whales as target of the whale watching industry

The humpback whale is known for being the most acrobatic of all the large whales (Jefferson et al., 2011). They are capable of performing a vast variety of scenic aerial behaviours over the surface of the water such as breaching, head rise and head slap, fluke slap and many others (Figure 1; Würsig & Perrin, 2009). In addition, humpback whales are the most curious whales out of all the other species: on many occasions they have approached the whale watching vessels, showing a particularly friendly behaviour. Thus, it is their social and curious nature that is making humpback whales the most sought-after species during whale watching tours (Ovide et al., 2017).

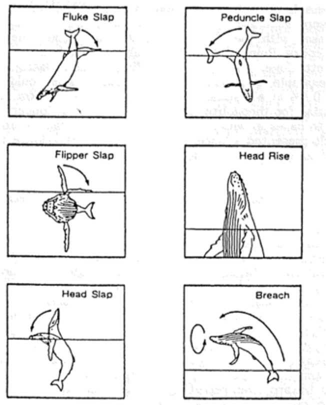


Figure 1. *Characteristic aerial behaviour of humpback whales (Baker & Herman, 2016)*

1.3.3 Whale watching concerns

The whale watching industry has developed greatly in the past decades, so much that it has outrun research investigating its integrity and long-term sustainability (Blankenstein, 2021). Indeed, even though the research community has acknowledged the potential of the whale watching business to increase awareness of the marine world, there is an increasing concern for the detrimental effect that human disturbance might have on the animals (Schuler et al., 2019). It has been reported that prolonged disturbance may affect many fundamental behaviours of whales such as resting, mating and feeding, thus leading to a potential decrease in fitness (Stamation et al., 2017). However, it is still not clear how the vessels are causing the disturbance. It has been understood that the detrimental effects are dependent not only on the species taken into consideration but also on the context of how the sighting takes place such as its location, the size of the vessel, the number of boats surrounding the whale and the distance between the vessel and the animal (Ovide et al., 2017). The animals' reactions caused by whale watching vessels have been divided into three main effects: short term, long term and non-visible. Short term effects are described as behavioural responses used to cope with perceived threats and dangers (New et al., 2015), which, in our case, are represented by the whale watching vessels. These behavioural responses are mainly resulting in either vertical or horizontal avoidance. Vertical avoidance can be recognised by observing an increase in the time spent diving coupled with a decrease in the surface time. In the horizontal avoidance an increase in the swim velocity and changes in direction are observed, most likely in order to outrun the boats (Blankenstein, 2021). Due to their curious nature and tendency of approaching the vessels, understanding whether humpback whales are perceiving the whale watching boats as stressors, it is not only of great interest for researchers, but also a challenge since literature shows contrasting results (Ovide et al., 2017). As a matter of fact, a study conducted in Maui, Hawai'i by Currie and collaborators (2021) demonstrated that humpback whales employed horizontal avoidance by increasing swim speed and directness of travel (Currie et al., 2021). On the other hand, the results of a research carried out in the coast of Queensland (Australia) showed that in the group of humpbacks studied, 46% of the individuals did not seem to be affected by the presence of the vessels and only 17% showed an increase in the diving time (Ovide et al., 2017). Even though the short-term behavioural variations may be beneficial for whales since they minimise the immediate anthropogenic disturbance, studies have indicated that these short-term changes are giving rise to long term detrimental consequences (Lusseau & Beider, 2007). The latter can be described as harmful impairments in vital functions such as reproduction, calving and feeding, which could all lead to a decrease in the survival of the species (Ovide et al., 2017). In addition, it is feared that there could be a range shift of whale populations which may abandon, for instance, a former feeding area due to the persisting human disturbance. The issue is that throughout understanding the biological effects of the whale watching activity on cetaceans is rather complex: the main reason being the long lifespan of these animals and their vast migratory range, which makes it difficult to follow one individual for their entire life. However, there have been some studies in which there were given some proofs of long-term disturbance effects on mysticeti (Blankenstein, 2021). Indeed, grey whales have been reported by De Jesús and collaborators (2013) to have relocated further offshore in the coast of San Diego as a result of an increase in the whale watching business in the area (De Jesús et al., 2013). Finally, anthropogenic disturbance can lead to non-visible effects, mainly in the form of chronic stress responses (Frid & Dill, 2002). Physiological stress is associated with an increase in the level of the stress hormones, cortisol and aldosterone. The onset of the stress response in cetaceans is concerning especially since studies have proven how prolonged exposure to stress might lead to diseases and cause a negative impact on reproduction and overall survival of animals (Blankenstein, 2021). To conclude, it is of great interest underlying that the activation of the stress response in cetaceans is likely to happen as a result of the whales' perception of the presence of whale watching vessels analogous to a predation risk (Corkeron, 1995).

1.3.4 Whale watching guidelines and regulations

The rapid growth of the whale watching business has led to management issues including an excessive number of boats surrounding the whales during each sighting, hazardous approaches and sometimes even collisions with the animals (Würsig & Perrin, 2009). Due to these problematics, a need for guidelines regulating the whale watching activity has raised between the scientific community and tour operators. Major work has been done by the International Whaling Commission (IWC) which in 1996 developed a series of common guidelines to minimise anthropogenic disturbance (Blankenstein, 2021). The main goals of these regulations are to establish a minimum distance of approach to the whales, to reduce the noise disturbance and to guarantee complete freedom of the animals, allowing them to be in charge of deciding the nature and the extent of the encounter with the vessels. Regardless of the IWC attempt of making a common set of regulations, there are several more guidelines around the world, each with the same purpose but with different rules. The main issue is that only few governments have imposed proper laws that make any non-compliance punishable with sanctions (this is the case of the

USA). For the majority of them, the regulations tend to be voluntary and in the form of codes of good conduct with flexible and up to interpretation guidelines. Thus, it is not so uncommon to have a lack of regulations fulfilment from the whale watching operators (Ovide et al., 2017). In Iceland, whale watching companies are collaborating in an association, called IceWhale, whose goal is to promote whale watching as well as safeguarding the wellbeing of cetaceans. In 2015 they created a code of conduct for all the whale watching companies part of the IceWhale to be followed, containing voluntary measures to minimise human disturbance and to increase public knowledge on the importance of regulating whale watching. Icewhale's guidelines are especially focused on how to approach the animal. Inside the code, there is the distinction of three different areas around a spotted whale (Blankenstein, 2021): the searching, the approaching and the caution zones. The searching area ranges from 3000 to 300 meters from the cetacean and it is the lookout area for signs of animals in the water. The approaching zone is described as the area up until 50 meters from the animal and it is here where the vessels try to get as close to the animal as the whale will allow them. Finally, the caution zone (below 50 meters from the animal) is "the area of cetacean choice" (IceWhale, 2015): the vessels are not allowed to make any attempt of further approaching the whales, it should only be the animal's choice whether to come closer to the boats or to end the sighting by swimming away. Regardless of the code of conduct being in use, it is concerning the fact that it is voluntary and that the guidelines can be violated without any sanctions (Ovide et al., 2017). For this reason, the scientific community and animal welfare experts are questioning whether the current regulations really are sufficient for safeguarding animal welfare and avoiding cetacean behavioural disruption.

1.4 Aim of the study

The aim of the present study was to investigate whether the presence of whale watching boats is affecting the respiratory pattern and diving behaviour of humpback whales in Skjálfandi bay, northeast Iceland. In order to achieve the aforementioned goal, the study has been carried out focusing on the number of vessels present during each whale sighting and how closely the animals were approached by the boats. By performing this investigation, the intention was to understand if humpbacks are showing signs of short-term behavioural variations such as either vertical or horizontal avoidance. Finally, after the analysis of the study's results, whale watching management implications and possible improvements will be discussed.

2. MATERIAL AND METHODS

2.1 Study site

The present study has been conducted in Skjálfandi Bay (Figure 2), located 70 kilometres from the Arctic Circle (Moroz et al., 2022). The bay has a total length of 25 kilometres, and it is approximately 10 kilometres wide, from east to west, in the southernmost part while in the widest point, which is located in the northernmost area, it has a width of 51 kilometres. The mean depth of the water is more or less 150 meters, but the deepest point reaches up to 220 meters of depth. There are two rivers, resulting from glacial activity, that are merging in the ocean waters of the bay: the Laxá, positioned in the southeast area, and Skjálfandifljot, found in the southwest (Moroz et al., 2022). In Skjálfandi Bay two islands are present: Flatey island is the largest of the two and is located further north from the bay while Lundey island, or also called Puffin Island, is the smallest one but also the most famous. Indeed, Lundey represents an important nesting site for thousands of puffins that come in the bay yearly, from mid-April to the end of summer, to nest and lay their eggs. Skjálfandi bay is one of the most important Icelandic feeding grounds for baleen whales, especially the humpback whale: the reason for this is the fact that the waters in the bay are highly rich in nutrients (Jónsson & Valdimarsson, 2012). Indeed, due to the presence of different currents, such as the East Icelandic and East Greenland ones, the morphology of the bay and the presence of the two aforementioned rivers, Skjálfandi bay is characterized by a composite hydrodynamic system (Valdimarsson & Malmberg, 1999). Thanks to the latter, there is plenty of vertical water mixing which is responsible for an increase in the primary production and the upwelling of water and thus, an increase in the nutrients found in the surface of the ocean (Muir, 1915).

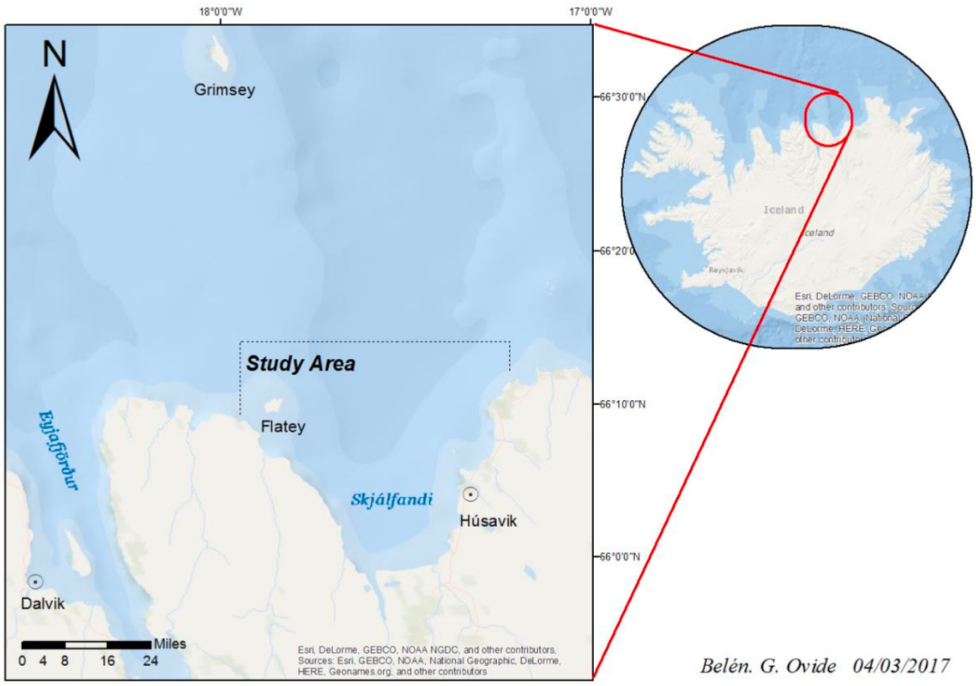


Figure 2. *Map of the Skjálfandi bay (Ovide et al., 2017)*

2.2 Data collection

Humpback whales sighting data collected from 2020 to 2023 and behavioural data, personally taken by me from March to June 2024, were analysed. In order to gather the behavioural data, two locations of observation were used: boat-based cetacean sighting and on-land field work, the latter consisting in looking for humpbacks from the Húsavík lighthouse. For what concerns boat-based monitoring, researchers, in partnership with whale watching companies, were allowed to join on the organizations' whale watching boats. The main companies operating in Skjálfandi bay are "North Sailing", "Gentle Giants" and "Húsavík Adventures". The one in which most of the observations were done was "North Sailing", which is equipped with multiple oak boats: the mostly used vessels were named Garðar (the longest of all the boats, measuring 28 meters), Bjössi Sör (16.4 meters long) and Náttfari (23 meters in length) and the tours typically lasted for three hours (Vallejo, 2013). On average, boat-based data were collected at least 5 times per week. In order to observe the whales' behaviour without human disturbance, efforts to observe cetaceans from the lighthouse, with the aid of binoculars, were made. However, not only is it quite difficult to be able to see the animals clearly enough to monitor their behaviour from such a distance, but also, the lighthouse is accessible only during late spring and summer, provided that the meteorological conditions allow good visibility. Hence, the vast majority of data were taken from the boat-based field work.

In order to collect the data, a specialised application, called “SpotterPro” (Conserve.io) was used, running through the “OceanAlert” app. This technology allows researchers to track the trip of the boat, as well as every single sighting of an animal and the behaviours it exhibited, including specific time and GPS location. Humpback whale’s behaviours were classified into four main categories: respiratory, aerial, feeding and social behaviours (Baker & Herman, 2016). For the aim of the present study, the major focus was on the recording of respiratory behaviours, as they are the most sensitive indicators of anthropogenic disturbance. These include blow, the explosive behaviour done to expel the stale air from the whale’s lungs, and it is corresponding to a breath. Normally subsequent to a blow there is a deep dive. The latter action is especially easily recognisable in humpback whales, since it is signalled by the arching of the tail with the exposure of the underside of the fluke. There are some instances where the animal is performing a “shallow dive” after a blow. The difference between the former behaviour and the latter is that, in the second one, there is neither exposure of the fluke or arching of the tail and generally the whale is coming back on the surface quite soon for another breath. Finally, for each humpback whale sighting other information was collected including the number of boats surrounding the animal and their distance from the whale.

2.3 Data manipulation

Not all the initial data that were recorded in the four previous years were used, but a selection and manipulation has been performed with Excel. Using the “What-If” function, automatically computing the same operation multiple times in each Excel cell where different values are present (Rajgopal & Soman, 2010), it is indeed possible to obtain the desired results for thousands of data at a very fast pace. As mentioned above, from all the raw data gathered in the past years, a selection has been made based on the following criteria. First, only behavioural recordings focusing on one single humpback whale at time were analysed to have a description of the animal’s behaviour as precise as possible. Moreover, the observations where the number of boats surrounding the whale per each sighting was not present were eliminated. The same procedure was done with the data in which, due to technical issues during the sightings’ program formatting, the vessels’ distance kept from the humpback was recorded either as 0 or -999. Furthermore, since the study is restricted to Skjálfandi bay only, the data recorded from sightings that had a latitude different from 66° north were not taken into consideration to have a narrow focus. Finally, to make sure that the behavioural pattern analysed for each humpback whale was consistent, only the sightings with a minimum of two full breathing cycles were kept. A breathing cycle was considered complete when a rapid and strong exhale (the “blow”) was instantly followed by a less powerful inhale and tailed by a deep dive, either with or without the whale’s exposure of the fluke.

After the aforementioned selection, further processing of the material has been done to calculate, from scratch, the variables of interest for the subsequent statistical analysis. First of all, the number of breaths per surfacing was computed by counting how many times a blow was performed by the whale for each surfacing. Then, the breathing rate was calculated by dividing the number of breaths done per second for the time spent on surface. Moreover, the time spent on surface and the one spent diving were calculated. In order to compute the time spent on surface, the seconds passed between a deep dive and another were calculated, while to find out the diving time the seconds between two aerial, respiratory or feeding behaviours were counted.

2.4 Data analysis

After the initial raw data manipulation and processing, proper statistical analysis has been performed by using the software R. R is an open-source programming language used mainly for data computation, manipulation, statistical inference and graphical display (Venables et al., 2024).

The statistical analysis has been performed on a total of 16172 observations collected between the year 2020 and 2024. The aim of the study was to assess whether humpback whales in Skjálfandi bay showed behavioural variations in response to whale watching vessels disturbance. In order to achieve said goal specific parameters (Table 1) have been taken into consideration during the statistical inference. The variables of choice were the following:

Variables	*Description*	*Units*
Distance_slider	The distance from the whale and the vessel	Meters *(m)*
Number_of_breaths_per_surfacing	How many breaths the sighted whale is performing per each surfacing	Numerical values
Time_spent_on_surface	Total time spent on surface for each surfacing	Seconds *(s)*
Time_spent_diving	Total time spent diving	Seconds *(s)*
Breathing_rate	Number of breaths within one surfacing/ surface time in seconds	n. of breaths/seconds
Number_of_boats	Total number of boats surrounding each sighted whale at the same time	Numerical values

Table 1. *Variables tested to assess the possible behavioural changes due to human disturbance in humpback whales*

As first step a statistical exploratory analysis has been performed: the mean, median and standard deviation of all the variables have been calculated. Secondly, the distributions of the continuous variables have been observed, followed by their normalisation in the case the variables appeared not normally distributed. It is indeed important to normalise the values' distribution of variables since most of the statistical models are based on the assumption that the response variable is normally distributed (Figure 3). In order to normalise a distribution, the "squared root transformation" or the "logarithmic transformation" were used.

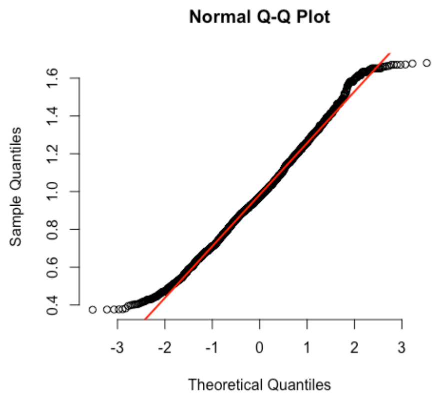


Figure 3. *Example of the normal distribution of the "breathing rate" variable. The graph has been obtained by using the "Q-Q plot" function in R.*

Finally, in order to have statistical results as precise as possible, a further step of the exploratory analysis was removing the outliers from all the continuous variables. An outlier is defined as a data that is far outside the norm and mean of the overall variable's values (Osborne & Overbay, 2004). Removing the outliers is important since an excessive amount of them increases the variability of the data thus leading to a decrease in the statistical power (Frost, 2024). To check for the presence of outliers the "boxplot" graph has been used (Figure 4).

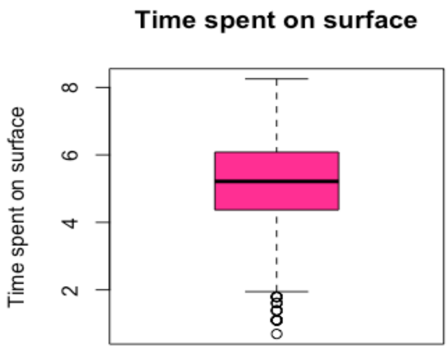


Figure 4. *Example of the box plot of the variable "time spent on surface" where outliers, represented by white dots, can be seen in the lower whisker.*

Furthermore, two continuous variables have been transformed into categorical ones to fit in the statistical models for the final analysis. These variables were "number_of_boats" and the "distance_slider". The reason why this transformation was done is because, for the number of boats, the range of values was too small to be able to assess a statistically significant effect with the variation of the values (indeed the maximum number of boats observed was 9, but in the vast majority of observations they were no more than 4). Secondly, the continuous variable "distance_slider" was transformed into a categorical parameter since the aim of the study was to assess whether a too close approach to the whale is affecting the animal's behaviour and thus, it was decided to focus more on the categories "close" and "far" distance rather than a precise measure in meters. Hence, the various boat's distances were divided into categories, each within a range of meters. The levels identified for these two variables are reported in Table 2:

Categorical variable	*Description*	*Levels*
nboats	Categories of the total number of boats surrounding each sighted whale at the same time	1. Low (n. of boats < 3) 2. High (n. of boats ≥3)
boat_distance	Categories of the distance from the whale and the vessel	1. Short (≤ 150m) 2. Far (>150m)

Table 2. *The two categorical values chosen to fit in the statistical models.*

In addition, as a preliminary step for the subsequent statistical analysis, a Pearson correlation test between continuous variables was tested. It is important to underline that correlation cannot be used to predict the amount of variation that is to be expected in one variable because of the variation occurring in the other (Gogtay & Thatte, 2017). Thus, we can affirm that by looking at the strength and direction of the relationship of two variables no assumptions or considerations about causality can be made.
Since the correlation test can be done only with continuous variables, the two variables number of boats and the distance of the vessels from the whale were not used to investigate on correlation. However, correlation between the other continuous parameters had been analysed. This investigation on the strength of correlation of the variables is fundamental for different reasons. First, it is necessary since if there is no correlation between the response variable and the independent ones, the latter must be transformed into categorical values to be put in the statistical model. Secondly, performing a correlation test is an important preliminary step which allows a better interpretation of the results of the statistical inference.
As the last part of the data analysis of the present study, analysis was carried out using regression models. In each regression model, the dependent variable, which is also referred to as the response variable, is the parameter of which we want to study the variability. Said variability is dependent on the independent parameters, also called the explanatory variables or effects. Furthermore, the independent variables can be divided into fixed effects, covariates, and random effects. The fixed effects are the categorical variables, and they are so called due to their replicability in different experiments while the covariates are the continuous variables, which are exclusive to one precise model. Finally, the random effects are those parameters whose influence on the response variable's variability cannot be controlled.
Regression analysis has two main aims: either an explanatory or predictive goal. For this study, the purpose of the regression analysis was the explanatory aim, as its main goal was to understand if changes in the various humpback whales' behaviours (the response variable) are affected by human disturbance (the independent variables).
Two types of regression models have been used: the linear model (LM) and the generalised linear model (GLM). The linear model is a simple regression model used to investigate on the relationship between one single response variable and various independent ones. This model is built under the assumption of linearity between the variables and that the response variable is normally distributed (Faraway, 2016). The generalised linear model is also implying linearity, but it is not requiring normal distribution of the response variable (Faraway, 2016). To understand which regression model is the best fitting for each single analysis the coefficient R^2 was used. Indeed, the coefficient's value, that ranges between 0 and 1, is used to assess how much of the response variable's variability is explained by the used model. The closer the R^2 is to 1, the stronger is the fit of the model.
Moreover, to check the goodness of fit of the models and their linearity we investigated the residuals and their normality with some plots (Figure 5). The residuals of a model measure the distance of each observation from the regression line. In a residuals *vs* fitted plot showing linearity it is expected to see

the residuals around and following the 0 and red lines, while in a normality plot the residuals' distribution shows a normal pattern.

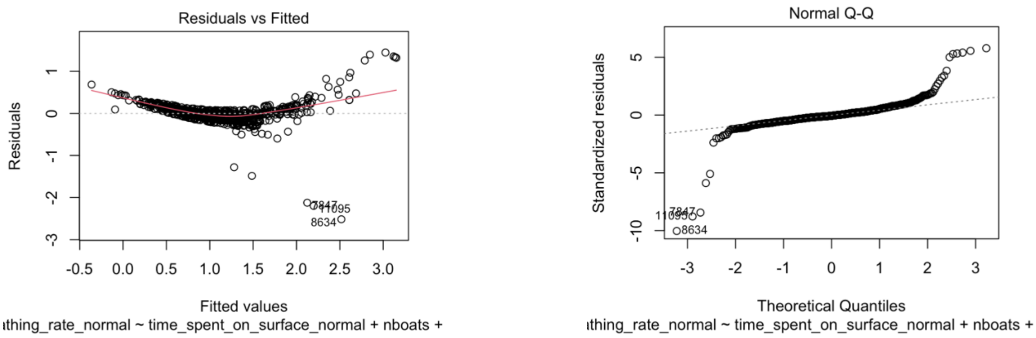


Figure 5. *Plots showing the distribution of the residuals for the linear model with "breathing rate" as response variable. The left graph is the residuals vs fitted plot while the right one represents the residuals' normality.*

In order to identify short term behavioural variation associated with whale watching disturbance, such as vertical or horizontal avoidance, four different regression models have been performed.

The first model was linear and had as response variable the breathing rate and as independent variables the categorical parameters (fixed effects) number of boats around a whale per sighting, the distance kept by the vessel from the animal and diving time duration, which had been beforehand transformed into a categorical variable as there was no correlation between the latter and the response variable. In addition, the time spent on surface and the number of breaths taken per each surfacing were fitted in the model as covariates.

For the second statistical analysis a generalised linear model was selected with the time spent diving as the response variable. Also in this case number of boats and their distance from the whale were put into the model as fixed effects together with the breathing rate. In addition, the time spent on surface and the number of breaths per surfacing were inserted as covariates.

The third model performed was linear, with the time spent on surface as response variable. As fixed effects number of boats and distance maintained from the whale were used; while as covariates the breathing rate, the time spent diving and the number of breaths per surfacing were selected.

Finally, the last linear model had as response variable the number of breaths per surfacing. Also in this case the covariates fitted in the model were the breathing rate, the time spent diving and the time on surface; the fixed effects were the number of vessels around the humpback and their approaching distance.

3. RESULTS AND DISCUSSION

3.1 Results from the statistical analysis

Before presenting the results from the proper statistical models, some of the most relevant outcomes from the correlation tests are shown. Indeed, although these tests were not including the two variables of main interest for the present study, investigating on the presence of correlation or not between the response and the independent variables was necessary to understand how to outline the statistical models (what type of variables to use).

First, a statistically significant negative correlation (correlation coefficient -0.55; $p < 2.2e-16$) between the breathing rate and the time spent on surface was detected (Figure 6). The fact that there was a negative correlation does not directly imply that when the time spent on surface increased, then the breathing rate decreased or vice versa. What we could assume from this correlation analysis was that the two variables moved together in an inversely proportional way.

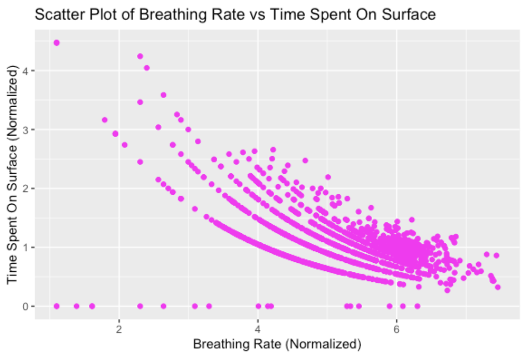


Figure 6. *Scatter plot showing the negative correlation between the breathing rate and the time spent on surface.*

On the other hand, no statistically significant correlation (p 0.69) was found between the breathing rate and the time spent diving (Figure 7).

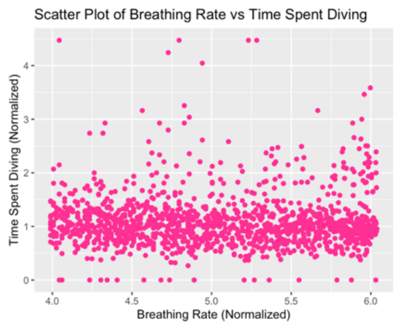


Figure 7. *Scatter plot showing the distribution of the breathing rate and time spent diving.*

Finally, a statistically significant positive correlation (coefficient 0.39; p= <2.2e-16) was present between the time spent diving and the one spent on surface (Figure 8).

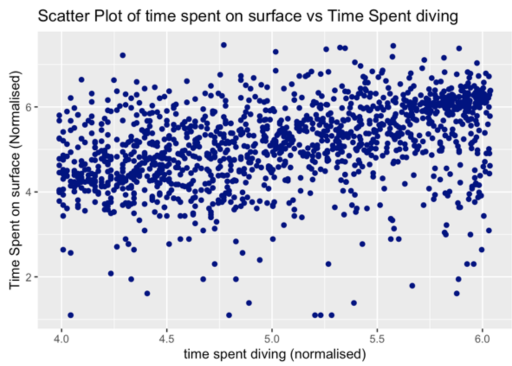
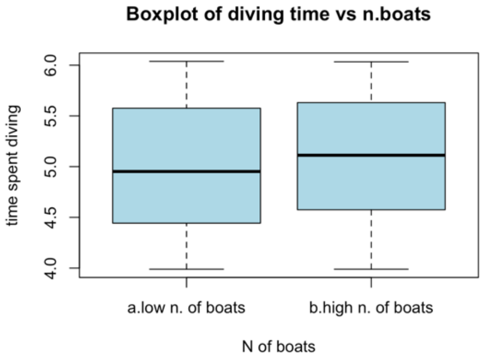


Figure 8. *Scatter plot showing the positive correlation between diving time and time spent on surface.*

Because the specific aim of the study was to investigate the possible changes in humpback whales' behaviour in response to whale watching boats' presence, the analysis and discussion of the statistical results will be centred on the two independent variables associated with the vessels: number of boats and their distance from the whale.

The linear regression model (R^2 coefficient = 0.80) with the breathing rate as response variable showed that the breathing rate was not significantly affected either by a high number of boats (≥ 3 boats) surrounding the whale nor by a small number of vessels (< 3 boats) (p =0.47). Also in the case of the distance the boat kept from the humpbacks, neither a far (>150 meters) nor a close (≤ 150 meters) approach significantly influenced the breathing rate (p = 0.35).

The most interesting results were the ones of the generalized linear model investigating the effects on the humpback whales' time spent diving (R^ coefficient = 0.65). When there was a high number of boats (≥ 3 boats), a statistically significant increase in time spent diving (p = 0.006) was present (Figure 9). Also, when the vessel was at a short distance from the whale (≤ 150 meters) there was a statistically significant increase in the whale's diving time (p= 4.59e-06; Figure 9). The aforementioned results are particularly interesting as an increase in the time spent diving is a sign of vertical avoidance, a strategy utilised by cetaceans as an evasive tactic (Ovide et al., 2017).



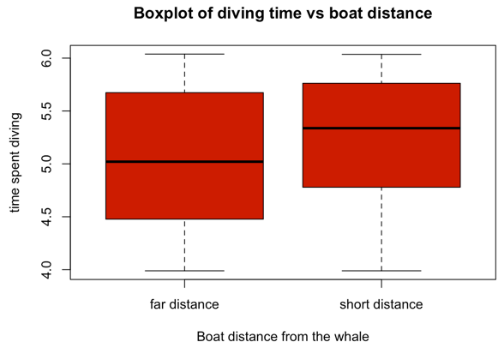


Figure 9. *Boxplots of the different time spent diving in relation to high (≥ 3) or low (<3) number of boats (left) and to short (≤ 150m) or far (>150m) distance of the boat (right).*

The third statistical analysis, performed through a linear model (R^2 coefficient= 0.88) with the humpback whales' time spent on surface as response variable, showed that a variation in the number of boats did not affect the whale's surface time (p = 0.18). The same non-influencing results were seen when analysing the influence of the vessel's distance from the whale. Indeed, both a close (≤ 150m) or far (>150m) distance did not seem to significantly affect the whale's time spent at the surface (p = 0.12).

Finally, the results from the linear model (R^2 =0.80) with the humpbacks' total number of breaths performed each time they surfaced as response variable showed an almost significant decrease in the number of breaths in response to a high number of boats (≥ 3 boats) surrounding the whale (p= 0.06). A statistical decrease in number of breaths (p= 0.03) was also observed when the boats were closely approaching the humpbacks (≤ 150m; Figure 10). These results were consistent with the aforementioned signs of vertical avoidance. Indeed, from this last analysis, we can assume that the decrease in the number of breaths when the boats were closer to the animal is associated with the previously discussed increase in the time spent diving as a response to anthropogenic presence.

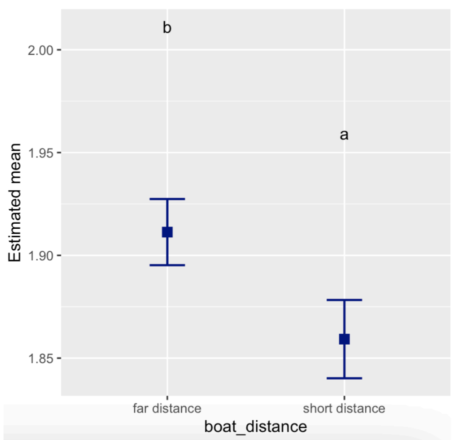


Figure 10. *GGplot comparing the different means of the number of breaths for each surfacing depending on the vessel distances (either ≤ 150m or >150m). The different letters "a" and "b" imply that the two means are statistically different from each other.*

The results obtained from the present study seem to be consistent with the humpback whale's responses to anthropogenic disturbance observed in previous investigations carried out in both the animals' feeding and breeding grounds. In a study conducted in New Caledonia a significant increase in the diving time of humpbacks was detected when the vessels were approaching the animals within 1000 m (Madon et al., 2014). The same result was observed by Stamation and collaborators (2017) in the investigation on humpback whales' response to whale watching vessels performed along the coast of South Australia. Here, they detected no difference in number of dives per minute but a significant increase in the time spent diving when the vessels were surrounding the animals (Stamation et al., 2017). Finally, interestingly enough, in a study conducted in Skjálfandi bay, humpbacks were reported to respond to anthropogenic disturbance by increasing their breathing rate but there was not detection of an increase in the time spent diving nor on surface. On the contrary, shorter dives and straighter direction of travel were observed, which were both associated with strategies used to outrun the vessels (Ovide et al., 2017).

3.2 Limitations of the study

The present study has various limitations to be mentioned. First, all the behaviours were observed just by sight and recorded manually thus there was no use of tagging or bio-logging instruments that could have followed the humpback whales for a prolonged period. The usage of the latter instruments could have allowed to perform a more accurate analysis of the behavioural differences observed with or without the vessels and monitoring the animals' behaviour after the encounter with the boat. This could have been informative on whether the anthropogenic disturbance is causing not only short but also long-term effects. Moreover, part of the observations gathered in the previous years had to be removed because, due to a crash in the data, the sightings were not tracking the vessel's distance from the whales nor the number of boats surrounding the animals. For this reason, the dataset could have been larger than the final one used for the analysis. It also must be mentioned that the measures indicating the distance of the boats from the whales ("distance_slider" variable) might not be very accurate as a range finder was not used and estimating distance over water with a precise measurement of animals constantly moving was not an easy task. In addition, there was little data taken from control i.e the lighthouse with no boats around the whales. This is because the lighthouse is accessible only in good weather conditions in late spring and summer, and because it is very difficult to track all the behaviours done by the whales from such a distance. Finally, in this study no investigations on the swimming speed nor swim direction could be made. However, keeping track of changes in such behaviours could have been relevant to assess signs of horizontal avoidance. Indeed, in a study conducted near the coast of Isla de la Plata (Ecuador) an increase in the humpback whales' swimming speed and change in direction were observed during and after whale watching vessel interactions (Scheidat et al., 2023). Also in Skjálfandi bay, humpbacks have been reported to change and straighten their swimming direction, as avoidance strategy (Ovide et al., 2017). Also, investigating on signs of horizontal avoidance could have added an insight on the whales' response to the noise produced by the vessels as this type of behavioural change is associated to a protective strategy from boats' engine sounds (Currie et al., 2021).

3.2.1 Difficulties to assess behavioural variations in humpback whales

It must be highlighted how challenging it is to observe clear results when investigating behavioural changes of cetaceans, in general, and especially of humpback whales. Indeed, behavioural responses are highly individual specific, which means that each single whale might react differently to the presence of whale watching vessels. Hence, this is a limiting factor that might lead to not complete results when trying to assess the overall trend in a population. In addition, the whales' responses to anthropogenic disturbance vary depending on the area where they are, their current activity, the type of vessels and the dimensions of said boats. Interestingly enough, it has been reported that whales seem to respond less to anthropogenic disturbance when actively feeding in comparison with when resting or performing other activities (Scheidat et al., 2023). This hypothesis was formulated in a study where the feeding behaviour of humpbacks was not disrupted by a big tanker passing within 800 meters of distance (Watkins et al., 1981). For this reason, in the specific case of the feeding humpbacks in Skjálfandi bay, the aforementioned hypothesis could be the reason why in other studies there were more behaviours clearly associated with avoidance responses rather than the only increase in diving time observed in this investigation. Moreover, humpback whales are known to easily habituate to changes in their environment, thus individuals might get used to the presence of the boats and not respond to the disturbance (Gill et al., 2001). However, it is relevant to underline that a lack of clear behavioural reaction does not exclude an unobserved stress response (New et al., 2015).

3.3 Discussion of the results

The results from this study underline that humpback whales in Skjálfandi bay seem to respond to whale watching boats' disturbance with behavioural changes associated with vertical avoidance, with the most evident sign being an increase in the diving time when the vessels are high in number and within 150 meters of distance. Consistent with the increasing time spent underwater is the statistically significant decrease in the number of breaths associated with a close approach to the whales made by the boats.

The vertical avoidance behaviour resulting from the present investigation might be of concern as such strategy can lead to damaging physiological consequences like a modification and increase of oxygen consumption, potentially affecting the whale's metabolism (Madon et al., 2014). This is due to the fact that, with an increase in the time spent underwater, the animal has to utilise much more oxygen stores than it would do in normal diving instances. Moreover, the vertical avoidance strategy is causing a temporal disruption of other very important behaviours and in the specific case of the feeding humpback whales in the waters of Skjálfandi bay, the main concern is a disruption of the foraging behaviour. What is of concern is that this short-term disturbance might imply long-term consequences (Ovide et al., 2017). Indeed, associated with the disruption of the humpbacks' feeding behaviour there is a decrease in the whales' foraging success which might lead to non-sufficient energy storage at the end of the feeding season. This lack of proper amount of energy is problematic since it might affect humpbacks' migration and the following breeding activity. As a matter of fact, humpbacks whales do not feed much in their breeding grounds, but they mostly rely on the energy resources obtained during the feeding season. (Christiansen & Lusseau, 2015). The individuals of most concern are the breeding females and their calves: indeed, a consequence of feeding disruption is a decrease in females' body condition thus responsible for a decrease in breeding success. Moreover, proper amount of energy reserves in the mother are fundamental for the proper growth and nursing of calves since their survival relies on energy transfer from the mother (Christiansen & Lusseau, 2015). Thus, it is easily understood how anthropogenic disturbance in feeding grounds can have a major negative impact on humpback whales' vital rates (Christiansen, Rasmussen, & Lusseau, 2014). This possible decrease in the breeding success and vital rates because of human disturbance is particularly alarming in small, endangered populations of humpbacks, as the one living off the coast of New Caledonia (Madon et al., 2014). The fact that, as a result from the present study, humpback whales in Skjálfandi bay seem to perceive whale watching boats as a disturbance is of concern especially since these whales have a high rate of annual return to their feeding grounds. Consequently, humpbacks might be repeatedly and continuously exposed to anthropogenic disturbance, season after season, for several years. Indeed, through photo-identification, constant annual sightings of many of the same individuals have been reported in the bay, showing high site fidelity. This is of concern since a continuous exposure to disturbance might be responsible for the occurrence not only of short-term effects (vertical and horizontal avoidance strategies) but also of long-lasting ones, which could put in danger humpback whale populations. In conclusion, the annual return of humpbacks to the same feeding grounds, where levels of anthropogenic disturbance have been observed, is an aggravating factor despite some researchers interpreting this return as a sign of whale watching activity not being disruptive. This information only is not enough to support the just mentioned theory as different studies highlighted how humpbacks' site fidelity patterns can be found in grounds with both low and high human disturbance (Scheidat et al., 2023).

3.4 Implications for the management and regulation of whale watching

The present study highlighted some relevant humpback whales' behavioural changes in response to whale watching vessels' presence: this implies that the current regulations for a responsible whale watching in Skjálfandi bay might not be sufficient to properly safeguard the wellbeing of cetaceans. In order to understand what could be the reasons associated to an improper managing of whale watching activities in Húsavík and its bay, an analysis of the IceWhale code of conduct (Figure 11) has been performed and from said investigations the following issues have been identified.

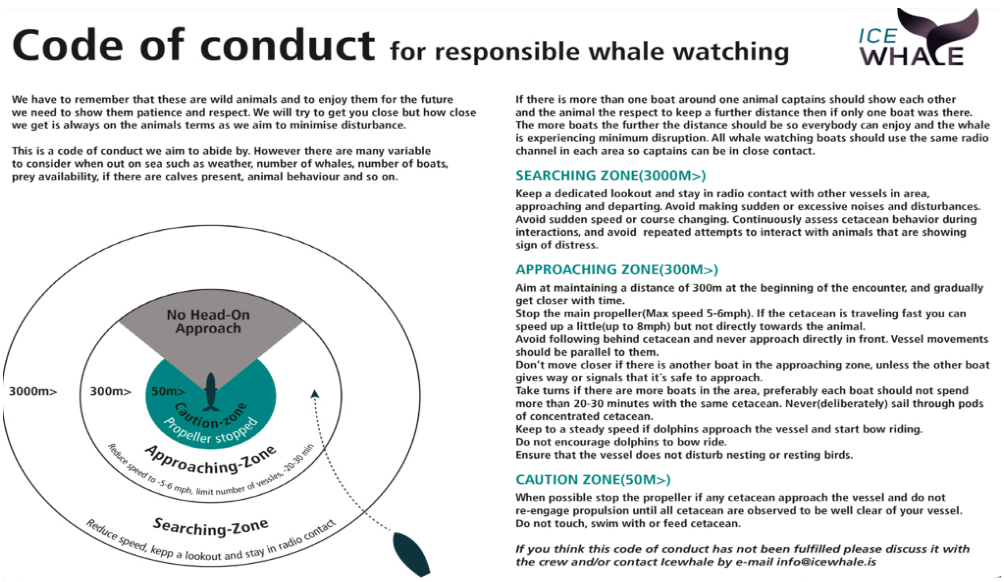


Figure 11. *Public version of the IceWhale's code of conduct. Image taken from Icewhale, 2024 (www.icewhale.is)*

One of the first problems is the voluntary nature of the code of good conduct which implies that its guidelines cannot be enforced by the law and thus there are no fines or real consequences. The code being voluntary is an issue since, as a non-compliance is not punishable, it could be easier for tour operators not to follow the guidelines. As a matter of fact, some witnesses have stated that, regardless of the code of conduct specifying that the time of interaction with cetaceans should not be more than 30 minutes, most of the time a single wildlife encounter lasts an hour or even more, with multiple boats surrounding the individual. Interestingly enough, it has been reported that one of the reasons why crew members of whale watching companies tend not to comply with the code of conduct is because of the pressure exerted on them by tourists. Indeed, due to the lack of awareness among most tourists of the possible negative effects of whale watching, visitors' satisfaction is maximised when the whale encounter occurs as close as possible to the animal. Consequently, for marketing and economic benefits, it might happen for the tour operators to decide not to follow the code's guidelines. Moreover, another possible issue in the code of conduct could be the fact that there are no rules regulating the type of vessels allowed to be used for whale watching. This is relevant since a study from Fumagalli and collaborators (2021) observed that the outboard-powered RIB boat, which is one of the most used types of whale watching vessel in Iceland, is the boat more likely to cause behavioural changes and disruption in cetaceans (Fumagalli et al., 2021). This is due to its very high speed, which, is not only a source of noise disturbance, but it can also increase the risk of lethal incidents like collisions with whales (Blankenstein, 2021). An additional relevant issue, that is not currently addressed in the code of conduct, is the allowed maximum number of boats around a whale in the different approach areas. Indeed, despite the fact that it is stated that boats should take turns in the approaching zone to reduce the number of vessels surrounding the same animal, a clear number of boats allowed at the same time is not defined. Especially, there are no regulations regarding vessel presence in the most delicate and crucial zone out of all, the caution one. Finally, the current methods to monitor the whale watching vessels' conduct are not efficient enough as there are very sporadic controls and when they happen, the tour operators are informed beforehand. Hence, it is possible that the boats follow the code of conduct more closely while being judged during the controls, and it is not completely corresponding to reality.

After having investigated some of the issues of the Icewhale's code of conduct, it can be concluded that some future adjustments and improvements might be beneficial to develop a more responsible whale watching business. One of the most critical ameliorations that should be done is increasing the public awareness, not only on the existence itself of the code of conduct, but also on the possible negative impacts that whale watching could have on cetaceans. One recommendation could be to inform the public before the tour starts: this would be, at the same time, an educational experience for the visitors and a way to reduce the pressure felt by the crew members to satisfy the public. In order to reduce said stress upon the tour operators, it is always best to control and manage the visitors' expectations, so that they won't be disappointed. To ensure this, it could be preferable to choose advertisement images that are actually close to the reality of a “standard” wildlife encounter rather than showing pictures of the cetaceans being very close to the boat and performing spectacular aerial behaviours, which are more rare sightings. Another improvement that could be useful to develop a more respectful whale watching experience could be reviewing the guidelines of the code of conduct yearly, with a focus on ensuring the clarity of its contents. Clarification is mostly needed in the section regarding the number of boats and their approach to the whales. Indeed, as aforementioned, a maximum number of vessels allowed around a cetacean at the same time it is not yet specified. This is a particularly problematic aspect in summertime, where multiple overlapping tours are happening every day. Moreover, the maximum distance of approach to whales should be reviewed: a possible recommendation, as the results of the present study showed behavioural changes when the boats were closer than 150 meters, is to increase the distances of the three different zones of approach. The fact that this study showed behavioural changes already at 150 meters of distance from the whale is particularly interesting. Indeed, not only in the Icewhale code of conduct, but also in most of the whale watching regulations around the world, such as the ones of Antarctica, Argentina and Canada, the current minimum distance of approach to the animals is of only 100 meters which might not be enough to avoid animal disturbance (Carlson, 2008). A further implementation of the code of conduct should focus on the type of vessels to be used for whale watching. Since different studies highlighted that RIB boats may cause alteration to the cetaceans' hearing ability (Ellison et al., 2012) and have a higher risk of accidents, it could be beneficial to allow the use of oak boats only as they seem to be less damaging for the wellbeing of the animals in the bay. Also, to decrease the noise disturbance, the practice of either switching off the engine or switching to higher frequencies, which are less likely to impact cetaceans, is recommended (Wladichuk et al., 2019). Finally, in order to improve the monitoring of whale watching vessels' conduct, a satellite or drone-based monitoring could be implemented. Indeed, such technology has already proven to be successful in keeping track of fishing vessels activity around the coast of Panama (Amrein et al., 2020). Another more accessible option to increase the monitoring efficiency could be to perform vessels' controls undercover so not to have the tour operators already informed.

4. CONCLUSION

The main goal of this thesis study was to monitor humpback whales behaviour in order to investigate on the possible impacts that whale watching vessels' activity in Skjálfandi Bay may have on the cetacean species. The results of the analysis underline a variable behavioural response in humpback whales to whale watching boats. The most interesting outcomes are expression of signs of vertical avoidance as a result of anthropogenic presence and vicinity. Hence, the whale watching business based in the town of Húsavík is possibly impacting the overall short and long-term fitness of cetaceans.

Possible implementations to the IceWhale code of conduct have been suggested and they could be highly beneficial for the achievement of a responsible whale watching activity. Indeed, creating a sustainable business is of uttermost importance since it can establish a healthy interdependent relationship between humans and whales (Amrein et al., 2020). On one hand, people utilise the natural ecosystem for economic and educational purposes, on the other, cetaceans' conservation and wellbeing can increase by improving tourists' awareness and compassion and by decreasing anthropogenic disturbance.

Húsavík and its bay represent the perfect place to build said bilateral relationship as the town has been nominated the "Whale watching capital" of Europe (Martin, 2012). Hence, it is attracting very large numbers of visitors every year, meaning that whale watching companies have the opportunity to greatly expand tourists' awareness on the ecosystem and marine mammals. Moreover, it is here where there are multiple organisations, including the Húsavík Research Centre, focusing on the study of cetaceans and their conservation.

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