Master's thesis

Using tag data to assess behaviour, vocal sounds, boat noise and potential effects on Humpback whales *(Megaptera novaeangliae)* in response to whale watching boats in Skjálfandi Bay (Húsavík), Iceland

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Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

Belén García Ovide

Abstract

The rapid development of whale watching in Iceland can represent a serious threat to whales during their critical feeding season. Humpback whales *(Megaptera novaeangliae)* are one of the most desired whales for wildlife encounters. However, little is known concerning potential effects from whale watching. Furthermore, there is little knowledge regarding vocal humpback whales vocalizations in the area. In this study, acoustic tags were attached to seven humpback whales during summers 2013 and 2014 in Skjálfandi Bay, Húsavík, Iceland. Boat noise levels were measured to investigate possible changes in natural behaviour. A customized breath and lunge detector was built and behavioural patterns were described and analysed statistically. Generalized linear models were used to test for changes in mean dive depth, jerk rate, breath rate, vertical speed, dive rate and dive duration before, during and after exposure to boats. Effects of tagging, boat noise intensity and whether boats were just passing or actively approaching were also tested. Whale vocalizations were assessed and described. Upsweep grunts were the most common vocalizations detected and high frequency calls were also registered during the foraging stage.The results included a significant reduction of jerk rate during active boat approaches compared to boat passes, and increase of mean depth during exposure to high noise intensity compared to low noise intensity. No differences were found between the before, during and after phases. Whales responded by diving deeper and performing longer dives when the boat exposure started during the first hour of the record compared to later boat exposures (suggesting a tagging effect). No significant changes were found for breath rate, vertical speed and dive rate. The observed changes in jerk rate and mean depth might indicate a disruption of foraging behaviour. These immediate responses could lead to impacts affecting the energy availability in the long term. Further, the registered levels of boat noise may impair whale communication (masking) for critical functions (e.g., feeding or socializing).

“Knowing is not enough; we must apply,

Willing is not enough; we must do”

Johann Wolfgang von Goethe (1749-1832)

Foreword

As an academic, few experiences are more gratifying than publishing your own work. But more significant than that, as a nature passionate and biologist I am incredibly happy for having completed this work that can be used for a better relation between humans and the ocean.

I was certainly pursuing this project since I started working in Skjálfandi Bay as a whale watching guide, and eventually I could perform it through the University Centre of the Westfjords. Looking back, I feel that another dream has been accomplished but also that this is just the opening to new opportunities and challenges that will come in the near future.

I am happy to highlight the fact that boat noise and effects on cetaceans have never been assessed before in Iceland. This combined with the high motivation of the team for success, have resulted in a more complex and extensive research project than it was originally programmed in the context of a master thesis. As the University only accepted two official advisors, I would like to especially thank my friend and professional partner Pierre Lang, who I consider my advisor as well, for his unconditional support during this project since the beginning, for helping overcome the impediments found during the project, and for his efforts on contributing on noise monitoring projects in Skjálfandi Bay by providing his sail boat and cognisant advice. For the same reason, I will finally thank my friend and scientist Charla Basran for her remarkable work helping out on the academic language and the technical writing portion of the project.

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Acronyms

AIS: Automatic Identification System

RMS: Root Mean Square

SL: Source level

SP: Sound pressure

SPL: Sound pressure level.

RL: Received level

RIB: Rigid-inflatable boat

Acknowledgements

I would like to thank Marianne H. Rasmussen and the Research Centre in Húsavík for offering me the opportunity to arrange this attractive project and supervise it. Thanks to Tom Akamatsu for providing the tag data. Special thanks to Pierre Lang, experienced sailor and good friend, for his support and great help since the beginning of the project and to truly believe in me. Big thanks to Paul J.Wensveen from the University of St Andrews, for being a great co-advisor and for sharing his extensive knowledge of the topic, particularly in regards to the statistics. Thanks to Charla Basran, for helping me with the writing.

Further, I would like to thank the scientists Dr. Kristian Beedholm at Aarhus University, Denmark and Dr. Alison Stimpert at Moss Landing Marine Labs in California for their collaboration in the acoustic part. Thanks to Dr. Magnus Walhberg at University of Southern Denmark and Paul Frater at the University of Reykjavík for their enthusiasm and specific assistant when it was needed. Thanks toDr. Filipa Samarra at the Marine and freshwater Institute in Reykjavik, Iceland. Thanks to the volunteers at Húsavík research Centre for helping in the photo-ID.

Lately, thanks to all my friends and family for their unconditional support and patient, but also to encourage me to follow my dreams and reach my goals, during this particular adventure, but always.

1. Introduction

1.1 Whale watching development in Iceland

Tourism has been rapidly increasing in Iceland, especially since 2010 in an alarming rythm. In 2016 the total number of tourists reached 1.767.726 (near 6 times more visitors than locals) (see figure 1).

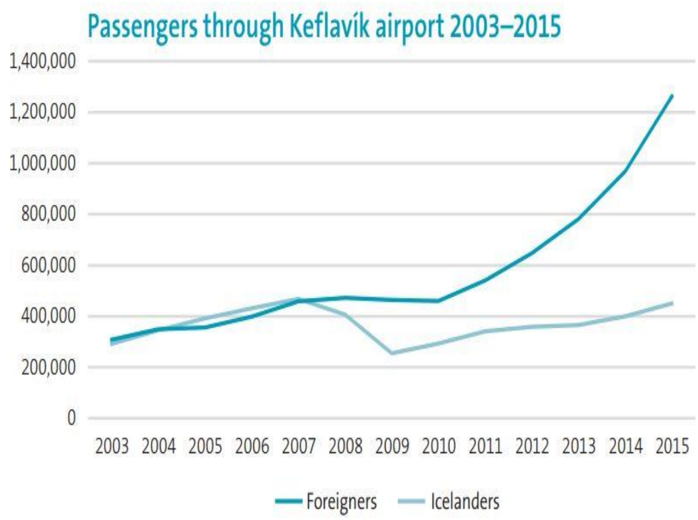

Figure 1.Visitors in Iceland (2003-2015)

Icelanders have always been living off fishing as the main industry and they are proud of having also one of the most responsible fisheries (Fisheries Iceland, January 2015). Nowadays, Iceland is still considered the second-biggest fishing nation in Europe, according to the official statistics updated until 2013 (IceFishNews, January 25th, 2016). At the regional level, small fishing has been dismissed in comparison with the big fishing entrepreneurs. A worth noting change occurred from being small communities based on fishing to a society where tourism is becoming very important, gradually replacing fisheries and other traditional sources of incomes (e.g., aluminium factories) (figure 2); for instance, some fishermen nowadays use their old small fishing boats for whale watching trips and are changing their way of living.

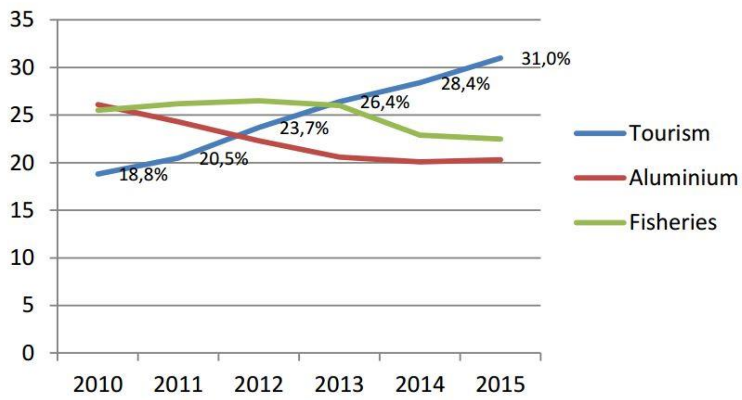

Figure 2. Exports of goods and services in Iceland (2010-2015)
(Source: Icelandic Tourist Board, 2016). Percentage of total foreign exchange income from the three largest industries in Iceland; tourism, aluminium smelting and fisheries.

Nevertheless, during the last 20 years, Iceland has undergone a huge transformation from being a whaling nation to becoming a whale watching country. According to the whale expert M.H. Rasmussen:

"Iceland is a unique example of a country being a former whaler nation transforming to a whale watching country, where whale-watching today is a very important industry for the Icelandic economy" (Rasmussen et al, 2014).

Whale watching started in Iceland in 1991 in Höfn, in the southeastern part of Iceland. Ever since, the whale watching industry has evolved fast within the country, becoming one of the major important economic incomes at national level in the present (figure 3). The last report made by IFAW in 2009 about whale watching worldwide, points that the majority tourists went to Reykjavik (51%) followed by Húsavík (36%) (O'Connor, S., Campbell, R., Cortez, H., & Knowles, T., 2009)

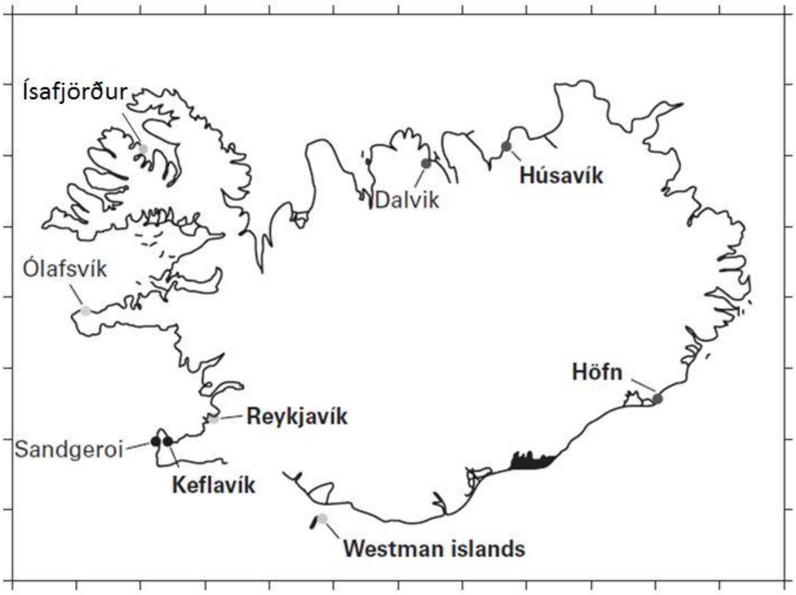

Figure 3. Map of Iceland with the indicated whale watching areas (retrieved by Rasmussen, 2014 and updated)

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1.1.1 The special case of Húsavík

Húsavík is a small fishing town located in the north east of Iceland, with approximately 2.500 inhabitants. During the past 10 years, Húsavík has undergone an incredible growth in whale watching business, with an increasing number of companies engaged in the whale watching sector every year. Since whale watching business started in 1995 in Húsavík, the town has experienced a considerable growth of tourists, particularly whale watchers. Hence, in 2009, Húsavík was nominated as *"*the capital of whale watching of Europe*"* (O'Connor., et al 2009). According to the Icelandic whale scientist Einarsson:

"Húsavík is not the only place in Iceland to see whales and there are now six other locations, but in no other place has whale watching been such a success story" (Einarsson, 2009).

From 2010 to 2015, the number of whale watching visitors increased quickly, reaching around 10.000 more visitors each year. Moreover, this increase has increased by double in 2016 (21.000 more tourists than in 2015) reaching a total number of whale watchers of 110.500 in comparison with 89.500 visitors in 2015 (figure 4).

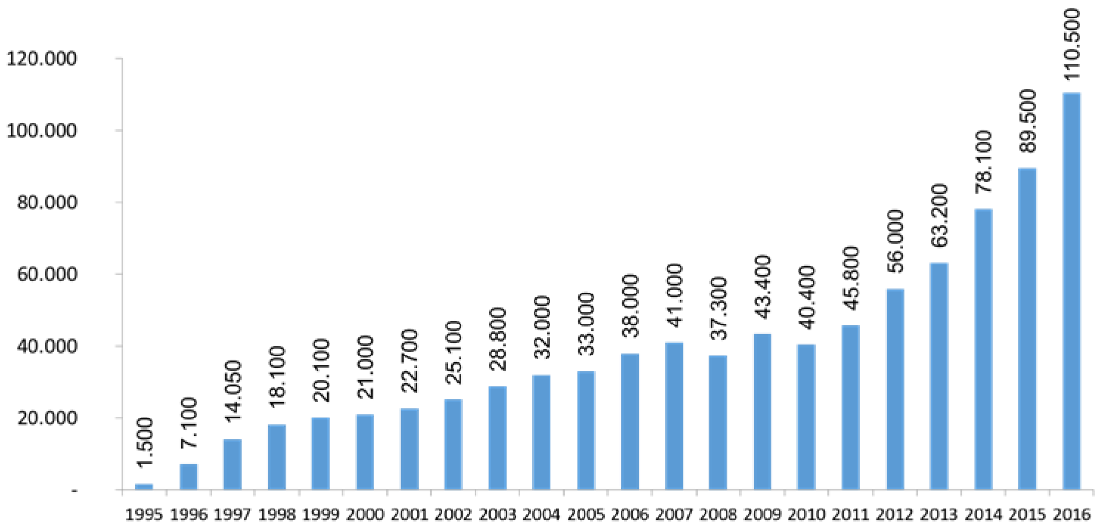

Figure 4. Number of whale watchers in Húsavík (1995-2016). The number of whale watchers is shown in the y-axis and years in the x-axis.
Source: Rögnvaldsdóttir L. B (2016)

According to a recent economic survey, in 2015 the total number of whale watching visitors in Iceland exceeded 272.000, whereof Húsavík accommodated 33% of the whale watchers (Rögnvaldsdóttir, 2016; Anderson, Gothall, & Wende, 2014; Huijbens & Johanesson, 2013; Icelandic Whale Watching Associations, 2016). In addition, the rapid change of the perception of whales driven by the benefits for the local community resulted in a generalized positive outcome among the locals, as whales were proven to have much higher profitable value when they are alive. This pragmatic approach was substantially supported by the local Whale Museum and the Art Center, bringing new opportunities for conservation and education while establishing a new activity for the resilience of the local economy.

Húsavík is a unique place for whale encounters due to the great chances to spot different species of whales (up to 23 recorded species) (Víkingsson, 2015;Ice Whale, February 12th 2017). Commonly observed species of baleen whales (*Fam Balaenopteriidae*) include, humpback whales (*Megaptera novaeangliae*) and minke whales (*Balaenoptera acutorostrata*), but fin whales (*Balaenoptera physalus*) and blue whales (*Balaenoptera musculus*) are becoming more regular year by year in Skjálfandi Bay during summer time. Regarding toothed whales (*Fam Delphinidae*) it is common to see white-beaked dolphins (*Lagenorhynchus albirostris*), harbour porpoises (*Phocoena phocoena*), and occasionally bottlenose whales *(Hyperoodon ampullatus)*, and killer whales *(Orcinus orca).*

In order to cope with the high demand of tourists, whale watching companies have not only increased the number of boats, services and facilities but also the whale watching season has been extended being from May to September through 2014 to almost all year round in 2016. A total of 16 watching boats within 4 companies were operating in Skjálfandi Bay during summer 2016; 7 boats from "North Sailing", 6 from "Gentle Giants", 1 boat from "Salka" and 1 from "Húsavík Adventures", including old oak boats, schooners and RIB boats. Hence, a total of 45 boat trips were scheduled daily assuming favourable weather conditions during the peak season of 2016 and at least 49 total trips are daily scheduled already for summer 2017 (Haukur O. A, pers. comm., 2017 February 25th)

1.2. Guidelines and regulations of whale watching

Within the last decades, many former whaling countries (e.g., the United States, Australia, Brazil and the United Kingdom) stopped whaling when the industry was not profitable and sustainable any more and laws were enforced by The International Whaling Commission in 1986 for banning commercial whaling. Over the years, these countries have adopted a sustainable alternative for using these "marine resources": the whale watching business. Currently, there are 87 overseas countries that have developed the whale watching industry as an important part of their economy (IWC, 2017 January 12th).

In 1996, the International Whaling Commission Committee developed the first official principles for managing whale watching activities based on the commitment of all the participant countries (IWC, 2017 January 12th). These principles involve a list of recommendations for managing the development of whale watching practices in the way that minimizes the risk of adverse impacts on cetaceans. The guidelines include practices for reducing disturbance from noise, optimization of boats or platforms used for these activities and allowing the animals to take control of the duration of the encounters (e.g., trying to limit the duration of the approach, distance and number of boats) (IWC, 1996). The recommendations are usually summarized in codes of conduct (see figure 5). A remarkable fact is that the use of codes of conduct has been mainly " market driven" due to high competence among operators, as eco-tourism has recently become a useful way of attracting more tourists.

The guidelines can be flexible or more restricted according to the parties in charge and in many cases there is a considerable lack of commitment and fulfilment. In some locations of developed countries such as the US, Canada, and Australia there are strict regulations and enforced laws for operators which include penalties and fines if the regulations are violated. Hence, marine protected areas worldwide also follow the same policy.

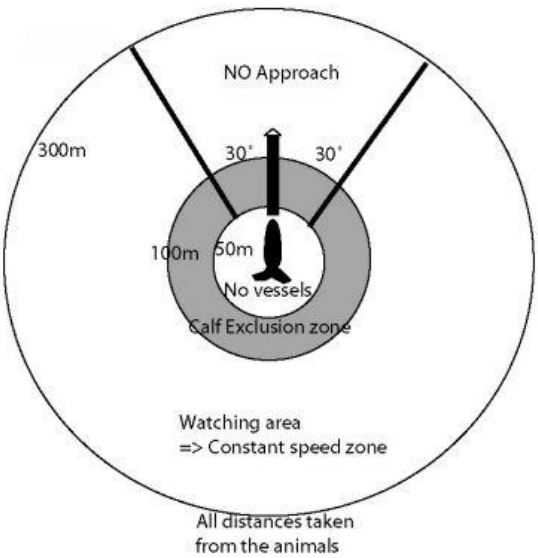

Figure 5. Code of conduct proposed by ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area). The code of conduct proposes the most sustainable way of boats approaching an animal in order to avoid whale disturbance.

Nonetheless, the existence of voluntary guidelines, regulations, or laws in an area is no guarantee of responsible practices as often there is not enough enforcement or control for compliance of these guidelines, causing negative impacts (E. C. M. Parsons, 2012).

In Iceland recent ‘soft’ guidelines were developed by Ice Whale organization in 2015 for responsible whale watching, including a code of conduct, in response to the increase in numbers of boats in a short amount of time and the high demand of whale watching visitors (Ice Whale 2017, February 18th). However, often this is not enough and guidelines tend to be violated without any penalty, putting cetaceans at risk and disrupting their natural behaviour.

In order to achieve and maintain economic, social and environmental benefits in Skjálfandi Bay it is an issue of high importance to success on the development of sustainable activities in a fast-growing tourism development scenario by responsibly using adequate guidelines and required regulations.

On the other hand, the use of eco-labels and the implementation of innovative quieter boat designs are becoming more common within the Icelandic whale watching companies. Such measures should not be used only to attract visitors and implementation of eco-friendly practices should be stimulated in all branches of whale-watching companies. Likely, among recent years tourists are becoming more aware and concerned regarding environmental problems in the ocean, so that they generally feel better by choosing “an environmentally friendly” company for wild natural encounters (Haukur O. A, pers. comm., 2017, July 20th). This is a great opportunity for enhancing ecotourism that promotes education while minimizing negative anthropogenic impacts on the marine environment.

1.2 Negative effects of whale watching on cetaceans

While whale watching development is a profitable source of income that can bring excellent opportunities for education and research, little is known regarding the negative impacts and potential threats that these encounters might have on cetaceans in critical areas, such as the Icelandic feeding grounds. Therefore, there is a growing concern that these tourism activities are detrimental for the targeted species.

There is still a lack of understanding regarding how commercial whale watching activities can produce negative impacts on cetaceans. The study of short-term reactions in cetaceans is becoming important for optimizing whale watching practices and understanding how these practices can impact the targeted specie. Scientists agree that the effects and level of impact are highly context dependent (e.g., location, vessel type, type of approach, number of boats, distance) but it also depends on the specie of interest (Williams, Triter, & Bain, 2002; Corkeron, 1995). Studies regarding short-term behavioural reactions have been carried out on different species: killer whales (e.g., Williams *et al*., 2009; Williams *et al.,* 2002b), *Fam Delphinidae* (e.g., Filby *et al*., 2014; Matsuda *et al*., 2011; Constantine *et al*., 2004; Meissner AM *et al.*, 2015; Lusseau, D, 2006) and humpback whales (Scheidat *et al*., 2004). These studies demonstrate that short-term responses are disrupting important behavioural functions such as feeding or resting behaviour. The experts affirm that these behavioural reactions can be expressed in many different forms involving changes in surfacing and dive patterns, speed, directionality and avoidance behaviour as has been compiled in the recent report carried out by New, L. F *et al* 2015.

It is important to mention that short-term disturbances may lead to the impairment of vital functions (e.g., reproduction, calving and foraging), affecting at the population level and diminishing the survival rate of the species. A good example would be the study carried out during 2003 - 2005 by Parsons & Scarpaci, 2011 on the North Pacific southern resident stock of killer whales in the United States and Canada. In this study scan sampling is used to estimate whales and number of vessels and probability models to determine behavioural changes under different boat exposure conditions. The estimation points that there are high probabilities of that killer whale population has been affected by intense boat traffic, reducing substantially foraging efforts, which could have led to the decline of the population. Currently, this stock is listed as endangered under the United States and Washington State Endangered Species Acts, and Canada's Species at Risk Act (Lusseau, D., Bain, D. E., Williams, R., & Smith, J. C, 2009). Thus, further research needs to be conducted to identify where is exactly the start point for any whale disturbance to occur, in order to avoid irreversible consequences on the species of interest.

Long-term effects driven by an anthropogenic cause is difficult to address due to the inherent temporal dynamism of the populations in their activity stages and additional environmental factors. Thus, there is a big concern among researchers and whale watching operators that whales or dolphins could eventually leave the area due to accumulative high levels of disturbance. Recent systematic models have been published aiming to predict consequences on vital rates based on modelled management scenarios in order to help the stakeholders and to highlight the importance of including all the different aspects of disturbance when assessing human impacts (Christiansen, F & Lusseau, D, 2015).

A summary of the most recently published research in regards to whale watching impacts is a yearly update since 2004 and present the main findings in the Whale Watching Sub-Committee of the IWC Scientific Committee (IWC, 2017).

Humpback whales are one of the most desired whales for whale watching encounters worldwide and in Iceland as they present social character, they can be relatively easy to approach in comparison with other species and they can also show many different behaviours. There is an extensive debate within the scientific community to understand whether or not humpback whales can be disturbed by whale watching boats as the literature shows quite diverse reactions types. On the coast of Queensland, Australia, when investigating humpback whale groups reactions due to whale watching vessels, it was discovered that 46% of the groups did not respond to boats, 23% approached the vessels, and 17% moved away making longer dives (Stamation *et al.*, 2010). Also some social behaviour such as tail slapping and spy hops were detected, behaviours which can be understood as aggression signs according to some authors (Parsons & Scarpaci, 2011), or a different way to communicate with conspecifics which is more effective under masked conditions (Dunlop *et al.*, 2007). In other study carried out in Ecuador during the breeding season, short-term behavioural reactions were successfully reported in humpback whales In this case, the whales decreased linearity of swimming patterns and also increased speed in reaction to exposure to vessel activity (Scheidat *et al.*, 2004).

In Iceland, studies have been carried out to study potential disturbance in minke whales. They demonstrated that whale watching vessels caused stress and reduction in foraging activity, as animals responded by performing shorter dives and had shorter inter-breath intervals indicating an increase of energetic costs (Christiansen *et al*., 2013). Spacially explicit capture - recapture models combined with photo identification were performed after to detect cumulative exposure based on the probability of that whale would be encountered a whale-watching boat and no long-term effects were found on minke whales vital rates. (Christiansen *et al.*, 2015).

An alternative for measuring whale disturbance to humans made impacts is the detection of chronic physiological responses by looking at the "stress"-related hormone levels of blood samples as they could serve as biological indicators. More recently, in order to overcome the challenge of collecting blood samples on large whales, new techniques are available to estimate stress levels applied on faecal samples, respiratory vapour samples, blubber and skin biopsies (Kathleen E. Hunt, *et al*.,2013).

1.3 Humpback whale foraging behavior

As other baleen whales (Mysticete), humpback whales are filter feeders that use keratinized plates for filtering small zooplankton. Feeding season is a critical period for humpback whales and other migratory species of cetaceans as they limit foraging to only a few months in specific productive areas, where their principal prey is available. Humpback whales in the North Atlantic Ocean can travel thousands of kilometres from their breeding grounds in tropic coastal waters of North Africa, Cape Verd Islands or Caribbean waters, towards high-productive cold waters where they feed during summer time (Stevick *et al.*, 2011). Nonetheless, recent changes in the distribution of humpback whales in Icelandic waters have been reported linked to variations in prey availability and distribution as a consequence of changes in the marine environment (Víkingsson, 2015).

Humpback whales diet consists of small aquatic organisms that are part of the zooplankton and small fish such as mackerel, capelin and herring (*Scomber scombrus*, *Mallotus villosus* and *Clupea harengus,* respectly*)* (Katona and Beard, 1991; Stevick *et al.*, 2006; Weinrich *et al.*, 1997). In Icelandic waters humpback whales feed mainly on euphausiid crustaceans and capelin (Sigurjónsson 1995, Stefánsson *et al*., 1997, Víkingsson 2004, Stevick *et al*., 2006) but diet can vary upon prey availability.

Humpback whales are well known for their variety and complexity of their feeding techniques. As with other whales and dolphins, they can either feed at depth or at the surface according to prey distribution. Humpback whales feeding skills also differ among whale populations and locations. For instance, in the feeding grounds of Gulf of Maine, humpback whales were recorded using bottom side-rolls (BSRs) to feed along the seafloor (Ware, C *et al*., 2013). Vertical and horizontal foraging feeding (U- shaped dives) has been described in detail in studies by Ware *et al*., 2011 conducted in the feeding areas in the fjords of the West Antarctic Peninsula. Furthermore, humpback whales may use groups feeding tactics to maximize foraging efficiency. In Iceland, humpback whales have been observed feeding individually and in groups (Rasmussen M. H, pers. comm., May 2013). During group feeding, different individuals usually collaborate in order to maximize the captures by using a sophisticated technique called “bubble net feeding” where they surround the prey ball by performing a net of bubbles while disorienting and keep the prey from escaping. This cooperative method has been well described in Alaska feeding grounds. (Witteveen *et al*., 2003; Clapham, 2000; Sharpe, 2001; Weinrich *et al*., 2006 and Jurasz, 1979), in the North Atlantic (Ingebrightsen, 1929), Pacific and Arctic waters (Wolman, 1978). Particularly, in Icelandic waters humpback whales feeding techniques are not yet fully understood.

1.5 Multisensor tags to study feeding lunges

Bio-logging and telemetry techniques are innovative tools that have been applied to diverse research fields ranging from ecosystems functioning, fisheries, biodiversity management, animal ecology, population dynamics and habitat modelling (Evans *et al* 2013). Bio-logging devices have enhanced the study of cetaceans, particularly of large baleen whales that cannot be studied in captivity or laboratory settings. The usage of high-resolution multisensory tags has revolutionized whale research, as scientists are gaining deep knowledge about important life functions of these animals underwater.

These sophisticated devices can be attached to the whales for hours or even days constantly recording different data types. Whales can be tagged with different bio-loggers that measure depth, acceleration, water temperature and speed. Other devices such as hydrophones provide insights into the sound field at the location of the whale, or even small video cameras, can be integrated into the small tag that helps understanding whale movements. One of the most comprehensive achievements from applying these devices in large whales has been the findings regarding whale kinematics as a tool to explain whales foraging skills and abilities (Nowacek *et al*., 2007).

Due to their body shape and physiology, it has been demonstrated that only rorquals (*Fam Balaenopteriidae*) use drag-based feeding (Orton and Brodie, 1987). In a foraging dive, these baleen whales can make one or several lunges. When a whale is lunging it means that it is taking a large gulp of water, which is then filtered through the baleen plates while keeping the prey before swallowing it. During a lunge, the rorqual first incites a rapid acceleration while increasing the speed towards the prey ball. As soon as the whale opens its mouth, an extreme drag occurs generated from the high resistance of the expanded mouth with the surrounded water, reducing the animal speed. These patterns have been extensively described in previous studies regarding kinematics in Balaenopterids (rorquals) using bio-logging techniques (Goldbogen *et al*., 2006, Goldbogen *et al*., 2007, Goldbogen *et al*., 2008, Friedlaender *et al.,* 2009, Potvin *et al*. 2009, *Goldbogen et al*., 2010, Potvin *et al*., 2010, Doniol-Valcroze *et al.,* 2011, Goldbogen *et al*., 2011, Ware *et al*., 2011, Wiley *et al*. 2011, Potvin *et al*., 2012, Simon *et al*., 2012, Tyson *et al.,* 2012, Friedlaender *et al*., 2013, Goldbogen *et al*. 2015, Ware *et al*. 2013, Sivle, *et al.,* 2016). For example, suction tags and acoustic surveys were conducted in Kodiak, Alaska to study foraging dives and prey selection in humpback whales. The results showed that foraging occurred at a mean maximum depth of 106 m with 62% of dives occurring between 92 m and 120 m and that the whales' preferred prey was capelin (Witteveen *et al.*, 2008). Lunging is an extremely powerful feeding method that has obvious energetic costs. Interestingly, these costs can be compensated (reduced) by the whale afterwards by adjusting their breathing rate (number of post-dive breaths) (Goldbogen *et al.,* 2008). When lunging, the sudden decrease in whale acceleration generated when the whale opens its mouth can be measured in terms of change in acceleration, or "jerk" which is useful for studying foraging behaviour on baleen whales (Simon *et al.*, 2012). A peak in jerk during a lunge is associated with the acoustic signal by a drop in flow noise which is detected by the hydrophone in the acoustic tag. This has served to support kinematic studies that used tag data (e.g., acceleration, speed, roll, pitch angle, sound) (Cade *et al.,* (2016) (figure 6).

In their attempts at detecting lunge feedings, Curé *et al.,* (2015) and Sivle *et al*., (2016) used the criterion established by Simon *et al*., (2012) that lunge feeding events occur when a drop of at least 12 dB re 1 µPa within 5 sec in flow noise is present in the acoustic signature (figure 6). Flow noise is the sound of water flowing around the hydrophone. Flow noise in whale tags often occurs when the animal reaches a certain speed and can interfere with measurements of sounds in the environment. Flow noise is caused by whale movement and it varies upon the tag type and tag position. Furthermore, flow noise has been widely used for estimate motion parameters (e.g., speed and jerk derived from the speed) in bowhead whales *(Balaena mysticetus)*, humpback whales and blue whales by Goldbogen *et al*., 2006, Simon *et al*., 2009; 2012 and Goldbogen *et al*., 2011, respectively, and more recently by Allen *et al*., 2016.

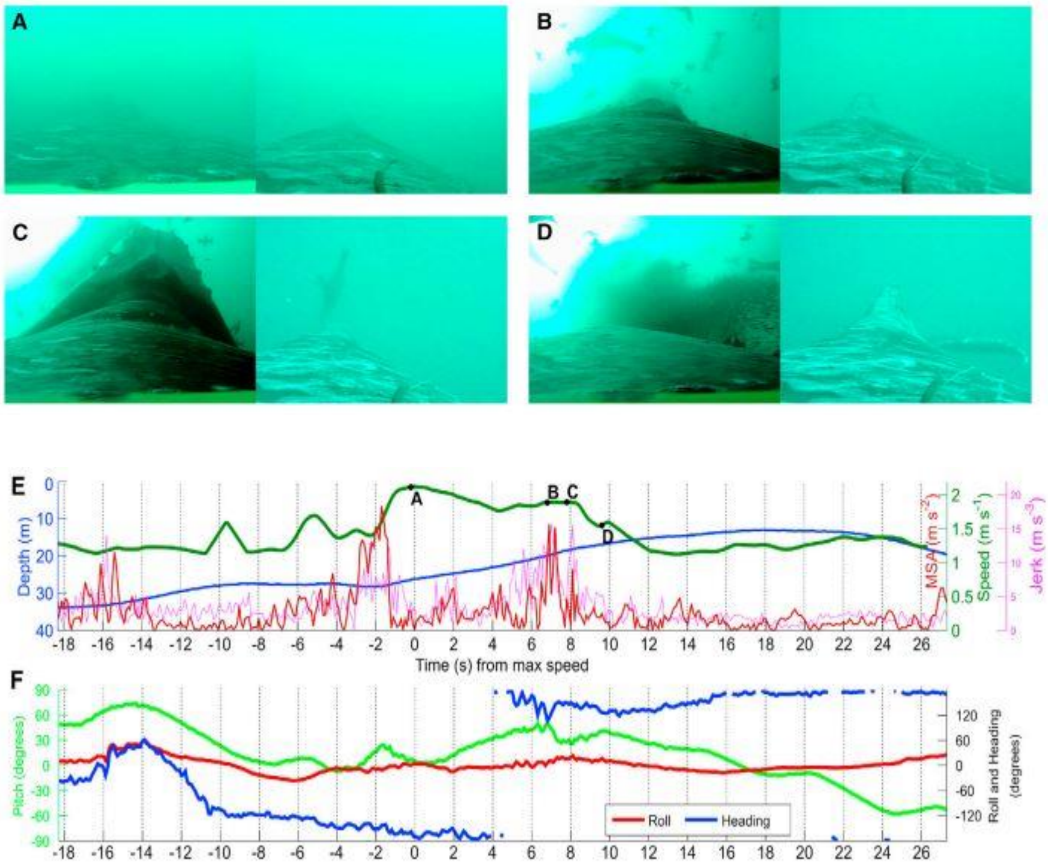

Figure 6. Visualization of a lunge event in a humpback whale foraging on anchovies from acoustic tags. Source: Cade et al., (2016).The devices include video cameras with orientation and locomotion sensors (speed, jerk acceleration, roll and heading).

***A**: Start of the acceleration phase (before lunging). Slow speed and acceleration. The whale is in an upwards position at 70 degrees (roll and heading). Point A in panel E indicates whale maximum speed.*

B: The whale starts opening the mouth. In the picture the blow hole and part of the upper jaw is visible. Target prey is visible in the video capture.

***C**: "Maximum gape" (complete open mouth). The whale pitch is 32.*

***D**: The moment just before closing the mouth and the previous moment to the return to a normal position (spins to his left)*

***E**: The figure shows the whale speed (calculated by the flow noise), depth, maximum specific acceleration (MSA) and jerk (sudden changes in acceleration).*

***F**: The figure shows the whale orientation indicating roll (red), pitch (green) and heading (blue). The letters (A, B, C, D) correspond to the figures above.*

In Iceland, the first bio-logging tags were deployed on white-beaked dolphins *(Lagenorhynchus albirostris)* in order to gain knowledge regarding dive patterns and echolocation behaviour which was linked to feeding behaviour (Rasmussen *et al.*, 2013). Last year, an innovative humpback whale tagging project was launched at the Arctic Circle Conference in Reykjavik in October 2016. This project aims to deploy long-term tags on humpback whales to allow the monitoring of these animals during their long migration, providing groundbreaking information not only about whale migratory routes but also oceanographic information across the seas for better understanding and supporting climate change research and other global environmental problems. (Icelandic times, January 2017.) According to the marine biologist Edda Elísabet Magnúsdóttir:

"If we can follow a whale for more than a year, it can give us invaluable insight into their lives, their behaviour and why they are in a particular area. It will also give us 3-dimensional surroundings which are full of animals and geological features. "The possibilities are virtually limitless and the project promises so much from a scientific standpoint." (Icelandic times, January 2017).

1.6 Underwater noise pollution

Since the Industrial Revolution, anthropogenic noise has been dramatically increasing in our oceans worldwide due mainly to shipping (e.g., cruise ships and cargo vessels) and fast-growing industrial development. Only during the first decade of 21st century, the number of cargo vessels has steadily increased by 8%–14% (Simard *et al*., 2010). Nowadays, another important source of noise particularly in coastal waters is growing recreational boat activity.

Only during the last few decades man-made noise has been recognized as a source of "pollution" that can potentially harm marine environments (Simmonds *et al*., 2014). Intensive sonic pulses are produced by military activity (high-power narrow band sonars that can scan vast areas), seismic surveys for exploring new energy resources (e.g., blasting, air guns producing powerful sonic pulses) and marine or near-shore constructions (e.g., broadband pile driving pulses) (Richardson *et al*., 2013). Examples of reported anthropogenic noise are compiled in the following table (table1).

Types of the Anthropogenic Sound	Frequency	Intensity Level	References
Bottom-founded oil drilling and mining	4–38 Hz	119–127 dB re 1 μPa	Richardson et al., 1995
Pile driving	30–40 Hz	131–135 dB re 1 μPa	Richardson et al., 1995
Drillship	20–1000 Hz	174–185 dB re 1 μPa	Richardson et al., 1995
Semisubmersible drilling vessel	10–4000 Hz	~154 dB re 1 μPa	Richardson et al., 1995
Seismic airguns	100–250 Hz	240–250 dB re 1 μPa	Richardson et al., 1995
The Acoustic Thermometry of Ocean Climate Project (ATOC)	~75 Hz	~195 dB re 1 μPa	Buck, 1995
Navy Sonar	100–500 Hz	~215 dB re 1 μPa	Conservation and development problem solving team, University of Maryland, 2000
High Frequency Marine Mammal Monitoring Sonar (HF/M3)	~3000 Hz	~220 dB re 1 μPa	Conservation and development problem solving team, University of Maryland, 2000
Supertanker & container ship	6.8–70 Hz	180–205 dB re 1 μPa	Richardson et al., 1995 Gisiner et al., 1998
Medium size ship (ferries)	~50 Hz	150–170 dB re 1 μPa	Richardson et al., 1995
Boats (<30 m in length)	<300 Hz	~175 dB re 1 μPa	Richardson et al., 1995
Small ship (support & supply ship)	20–1000 Hz	170–180 dB re 1 μPa	Richardson et al., 1995

Table 1. Examples of noise sources, frequency ranges and intensity. Source: Peng, C., Zhao, X., & Liu, G. (2015)

Quantifying the effects due to noise exposure on marine mammals is a challenging subject for researchers because of difficulties studying these animals in their natural habitat. For example, these effects depend on the hearing range of the targeted species, frequency, intensity, duration and other characteristics of the noise (Board, O. S., & National Research Council, 2005).

Researchers have demonstrated successfully that intense underwater noise can directly or indirectly affect not only marine mammals but many marine organisms in the ecosystem, for instance, causing auditory masking (Codarin *et al.*, 2009), physiological damage (McCauley *et al.*, 2003), and changes in behavioural patterns in fish (Schwarz, 1984). More recently, it has been demonstrated that even the pressure waves caused by noise can alter body metabolism and impede the embryogenesis processes in fish eggs and larval stages of small invertebrates (Aguilar de Soto, N., 2016).

Cetaceans and other marine mammals rely on sounds for communication and vital life functions. It is well-known that depending on the noise characteristics (e.g., intensity, duration, dominant frequencies) and the biology characteristics of the targeted species (e.g., hearing range, hearing sensitivity, age, sex), noise exposure can lead to numerous and diverse negative effects ranging from change in behaviour, masking (impairment of communication), temporal or permanent hearing loss, physiological stress and death (Richardson, W. J., *et al*, 2013). This could result in non-reversible cascade effects, impacting population trends (U.S. National Research Council, NRC, 2003).Furthermore, the potential effects of noise on baleen whales are of special concern as their most used frequency range (from 15 Hz–8000 Hz) overlaps in frequency with the most common chronic, continuous anthropogenic noises from shipping and small boats (whale watching boats or recreational boats), indicating that they might be the most affected by noise pollution (Clark, 1993; Houser *et al*., 2001) (figure 7).

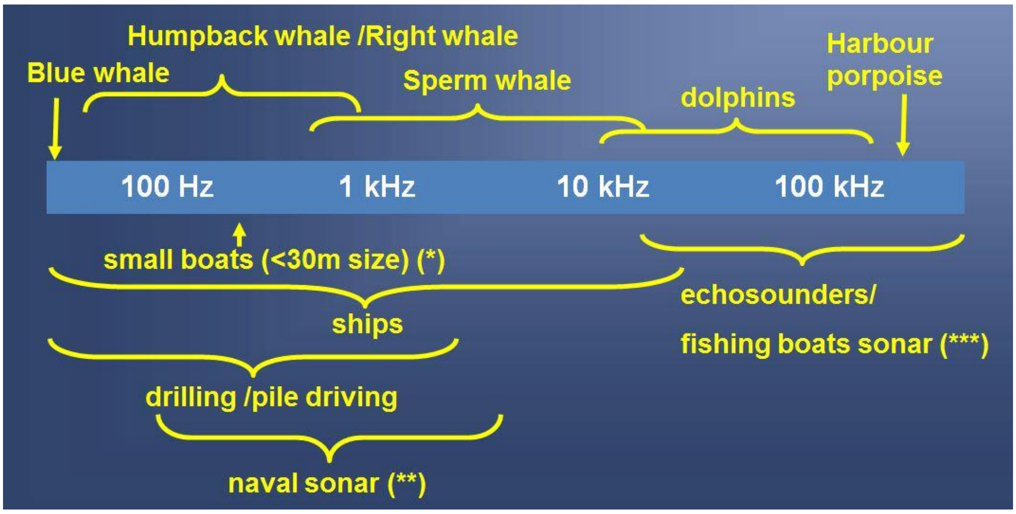

Figure 7. Overlap between cetacean vocalization frequency ranges and anthropogenic noise as shown by De Soto, N. A., 2012).

The figure shows some examples of overlap between cetaceans and underwater noise. Intense high-frequency noise sources include echo sounders (e.g., for sea bed monitoring) and fishing boats sonar, which overlap with the high-frequency sounds typically used by the Odontocetes. Mid and low frequency human noise sources include naval sonars. Big ships and cargo vessels cover a broadband frequency range from low to mid frequencies. Small boats main frequency ranges fall around 300 Hz. Low frequency noise sources include ships, drilling noise, seismic survey exploration for oil & gas energy, and near-shore constructions. These activities are more likely to interfere with the frequency range used by baleen whales and produce masking (Payne and Webb 1971, Richardson et al., 1994;2003). (*) symbols indicate examples gathered from other authors: (*)(Richardson et al., 1995); (**) (Convention of Biological Diversity, 2014) and (***) (Hansen, 2009).

1.6.1 Concerns about noise pollution in Skjálfandi Bay

In Iceland, there is no national regulation regarding noise pollution and little research has been conducted regarding this study field. Besides the existent intense noise generated from whale watching boats during the summer, there is a major concern among the researchers in Húsavík regarding the recent start in 2016 of the construction of a new silica factory developed by the German company PCC SE and its subsidiary PCC Bakki Silicon hf. (PCC.SE.,2015). In 2016 the construction included constant dredging required for expanding the harbour, and several daily explosions for a tunnel construction next to the harbour for facilitating the material transport from the port to the factory. In summer 2016, a pilot project was conducted by students for monitoring noise levels generated by the construction. The estimated SPL for the explosions was from 184 to 195 dB re 1 µ Pa within 6 nautical miles from the epicentre of the blast, lasting for 21.53 seconds and 67 dB above the ambient noise at 50 Hz. For constant dredging, SPL was 153 dB re 1 µ Pa and 29 dB above the ambient noise at 300 Hz. These preliminary results indicate that both low frequency noise levels (explosions and dredging) reported during the study are likely to cause masking particularly in baleen whales and in case of the explosion noise levels, temporally or even permanent auditory threshold shift (García.B, Giesler, F, Jonsdottir, S, Hamran, E, Levin, C, Mandewirth, M, Saarmans, P and Parteka, R., 2016,in preparation). Yet, potential effects on cetaceans due to these activities are still pending issue. Further, the expected opening of the factory at the end of 2017 or beginning of 2018 (Atvinnuvega- og nýsköpunarráðuneytið, 2015) is a cause for concern as heavy shipping traffic is expected in the Bay in order to transport the required materials.

It is interesting to mention the recent paper published in 2016 by Culloch *et al.,* which reported accumulative effects of underwater noise generated by vessel traffic activities and constructions based on multi-year observations, revealing that the noise was diminishing successful whale communication to 84%. Indeed, the results showed temporal displacement of both baleen whales and toothed whales during the construction (including boat and dredging activities). Further, the author studied the susceptibility of different species in exposure to the different noise type. The study points that harbour porpoises and minke whales reacted to dredging but common dolphins (*Delphinus Delphis*) were more likely to be displaced by the boats. Eventually, non-short-term consequences were found due to these activities that could alter the seasonal migration patterns and natural habits of the animals (Culloch, *et al*., 2016).

1.6.2 Boat noise from whale watching activity

Generally, boat noise is characterized as low-frequency noise that can be generated by various ships and vessels (Codarin *et al.*, 2009). Low frequencies overlap with the frequency range used by all baleen whales suggesting that they are the more susceptible to boat noise than Odontocetes (Payne and Webb 1971, Richardson *et al*. 1995).

Generally, the frequency range of the noise of small boats used for whale watching cover the low- and middle frequencies (below 10 kHz) (Evans, 1996). Boat noise is mainly generated by the motor engine and the propeller. Generally, big and old vessels tend to be noisier than small and newer boats (Gordon and Moscrop, 1996). Often, one of the sources of boat noise is cavitation. The cavitation is the rapid transformation cycle generated by the sea water and vapour due to the very low pressure in front of the propeller and it is generated by the rotation of the propeller. At low speeds, propeller cavitation noise might not be the prime component (Ross, 1976).

No received sound pressure level (SPL) thresholds for predicting the behavioural effects of boat noise have been established because the responses of humpback whales and other baleen whales are likely driven not only by SPL or other characteristic of the noise, but also by a range of contextual factors. To determine what is the main factor that is disturbing the whales (e.g., the noise generated by the boats, the presence of boats or both) is a difficult task as the responses on cetaceans can be highly context dependent (e.g., the number of boats around, distance to the animals, speed, time of exposure, boat type) and in case of whale watching boats, the way of approaching during an encounter play an important role.

Some research has been conducted to monitor noise generated by whale watching boats and determine the start points for whale disturbance in order to guide the operators towards sustainable practices. In British Columbia, Erbe *et al* (2001) recorded noise from whale watching boats and estimated a safe zone for killer whales by using sound propagation and impact assessment models. They found that boat noise source levels ranged from 145 to 169 dB re 1μPa @ 1m, increasing with speed. According to the model, killer whales could hear fast boat noise at a maximum distance of 16 km, masking (overlapping between killer whale calls and boat noise) occurred at 14 km and potential behavioural reaction occurred at a distance of 200m. In addition, it was suggested that temporary threshold shifts in hearing of 5 dB within 450m. For slow boat passings, levels were lower (Erbe, C, 2002). Another study conducted in the same area showed that irresponsible whale watching practices, in this case, boats speeding up to get close to the whales or interfering in the whale's predicted path, showed that boat noise increased up to 14 dB at a distance of 100m causing avoidance and changes in behaviour in killer whales, increasing the energetic cost to the animals. They found that a fast-moving boat had to be at least at a distance of 500m to produce the same levels of noise than a slow-moving boat at a distance of 100m (Williams *et al*., 2002). Whale watching guidelines should therefore encourage boaters to slow down around whales and not to resume full speed while whales are within 500m. This type of research is necessary for helping developing whale watching guidelines.

In summer 2016, a pilot project was conducted in Skálfandi Bay for monitoring noise generated by different type of whale watching vessels operating in the area (e.g., motor boats, RIB boats, schooners). Further, these noise levels were compared with a more recent schooner that uses an electric engine in order to reduce noise pollution. This schooner is using its electrical motor most of the time, but not when the batteries are empty. The results showed that considering the same distance and similar speed, the relative boat noise levels were similar for RIB boats and for the schooner the with the electric propulsion system, at the dominant frequency range of baleen whales (50 Hz to 300 Hz). The results suggested that the main noise from the boat with the electric engine (with charged batteries) was likely to be generated by the propeller and not with the engine, explaining the obtained noise levels (higher than the ones predicted). This pilot project evidenced the importance of studying whale watching boat noise in order to understand boat noise production while promoting alternatives and new designs for quieter boats (García.*et al*., 2016).

1.7 Humpback whale sound production in feeding grounds

Humpback whale vocalizations are produced in a wide frequency range from 10 Hz to 10 kHz (Thompson *et al*., 1979; Payne and Payne, 1985; Au *et al.*, 2001; Cerchio *et al.*, 2001). Although, humpback whales are legendary for their complex songs produced by the males during the breeding season in tropical areas which can reach higher frequencies up to 24 kHz (Au.*et al.*, 2001;2003 and 2006). In contrast, during their feeding season in high cold latitudes, they tend to use low frequency vocalization types for communicating, "non-song social sounds", during the feeding season (Stimpert *et al*., 2011). The frequency range of these social sounds varies from ≤ 50 Hz up to 12 kHz (Silber 1986; Dunlop *et al*., 2007; Dunlop *et al*., 2008; Stimpert *et al*., 2011) with dominant frequencies at 300 and 500 Hz (Erbe. *et al.*, 2002). Certain low frequency vocal sounds with frequencies from 20 to 1900 Hz are described as "grunts" or "moans" to distinguish them from other sound types. According to Thompson *et al*., (1986), "prolonged vocalizations of at least 400ms duration and were classified as moans while shorter vocalizations were termed grunts". In Alaskan feeding grounds they recorded moans of 0.2-1s duration, 175-192 dB re 1 μPa @1m source level, with dominant frequency at 300-500 Hz and 20-2000 Hz bandwidth (e.g., Thompson *et al*., 1986, Cerchio and Dalheim, 2001). Another common low frequency vocal sound is the "whup", which was recorded in Glacier Bay National Park and Preserve in 2003 (Erbe & Gustavus, 2003).

In 2007, Dunlop *et al*., 2007 noted that these low frequency social sounds are often accompanied by social behaviour next to the surface such as flipper/tail- slapping or breaching, typical humpback whale active behaviours which have been recently proved to play specific and important roles for communication (Kavanagh, 2016). It is suggested that social sounds can serve as a way to indicate location, identity or size but are highly context-dependent (Tyack, 1983; Silber, 1986; Thompson *et al*.,1986; Dunlop *et al*., 2007).

While humpback whales tend to be quieter away from breeding grounds, singing humpback whales have been recorded in their migration routes and on high latitudes feeding grounds (Vu, *et al*., 2012). Indeed, in 2009 the first report of humpback whales singing in the subarctic waters of Northeast Iceland (Skjálfandi Bay) was reported by Magnúsdóttir, *et al.*, (2014), suggesting that this area could be a potential location for whale mating during winter. Furthermore, group-specific feeding calls have been reported (Cerchio *et al.*, 2001) in southeast Alaska suggesting that humpback whales could use these to coordinate hunting in groups. In addition, mysterious click trains during night while foraging were reported by Stimpert *et al*., (2007) in the northwest Atlantic feeding area. Despite the lack of understanding of non-songs social sounds, little research has been conducted for cataloguing and comparing these call types among areas. In 1986, five vocal categories were described by Thompson *et al*. (1986) in the high latitudes feeding grounds of Southeast Alaska. Moreover, in 2007 a total of 34 social vocalizations were described during migrating seasons in Australian waters (Dunlop *et al.*, 2007). Later, 16 individual call types were nested within four vocal classes in Southeast Alaska (Fournet *et al*, 2015). A recent study carried out by Björnsson (2014) described for the first time non-social call types within 11 categories in the study area of this project, Skjálfandi Bay, Iceland.

1.7.1 Humpback whale hearing

In order to understand noise effects in cetaceans and other marine mammals, it is necessary to know what is the hearing range of the species of interest as it is assumed that the reaction thresholds for marine mammals is somewhat higher than the hearing range (Erbe *et al.*, 2002) This information is only available for some Odontocetes, and the amount of information on baleen whales hearing is very limited.

Experiments in captivity have been carried out on Odontocetes (Pacini, 2011; Wensveen *et al*., 2014) and pinnipeds (e.g., Mulsow *et al.*, 2012), including hearing sensitivity measurements (audiograms) which gives useful information about how they can perceive sounds. It is useful to measure hearing thresholds for exposure to noise for each species. The best sensitivity (best hearing) for Odontocetes and pinnipeds falls at 40-70 dB re 1 μ Pa at frequencies from 1 to 20 kHz. Some Odontocetes display their peak sensitivity in the ultrasonic ranges (Richardson, 2013).

Yet, audiograms for baleen whales are currently not available because these large whales are not kept in captivity and therefore not accessible to hearing measurements. However, humpback whales are one of the most monitored whales in the field and their calls have been widely studied. A study based on vocalizations recordings the maximum sensitivity is estimated around 120 Hz - 24 kHz, with good sensitivity from 20 Hz to 8 kHz and higher (Au *et al*., 2001; 2006). However, the assumption made by Au *et al* is not very strong; there is no reason why all harmonics produced should be audible to the producer, they could simply be byproducts. An alternative audiogram based upon anatomical data of humpback whales and prediction models, indicated that maximum sensitivity fell around 2-6 kHz, and good sensitivity between 700 Hz-10 kHz (Houser *et al.,* 2001; Erbe *et al*., 2002) (figure 8).

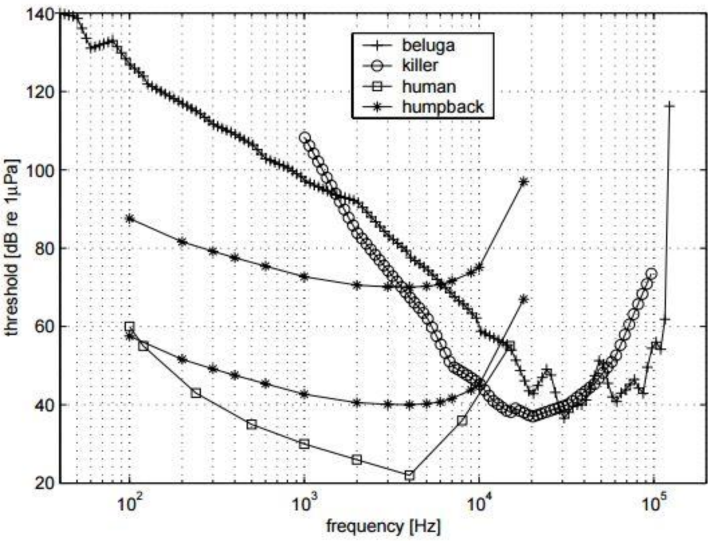

Figure 8. Suggested audiogram for humpback whales (Erbe et al., 2002)
The figure shows the audiogram of 2 Odontocetes; killer whales and belugas (Delphinapterus leucas) in comparison with the human and the predicted audiogram for humpback whales based on anatomical data. Erbe et al., (2002) suggested that the true humpback whale audiogram likely lies somewhere between the 2 humpback whales audiograms drawn. This audiogram is based on the study of Houser et al., (2001) who predicted relative sensitivities.

1.8 Present study

The present study address three main research topics: natural behaviour, whale watching boat noise levels and short term effects due to whale watching pressure.

More specifically, it is the first time that humpback whale behaviour is monitored on Icelandic feeding grounds by using multisensor acoustic tags and that research regarding whale behavioural reactions in humpback whales due to vessel exposure are examined in Iceland. Such efforts are needed in order to help the stakeholders to define good whale watching practices for responsible development in the upcoming years. In addition, noise levels of whale watching boats are recorded using an incorporated hydrophone in the tags. This is a pioneer project for estimating boat noise levels that whales are receiving during whale watching activities and therefore, it allows linking noise levels with measured behavioural reactions in humpback whales. This approach could serve to determine possible start points for whale disturbance (e.g., estimated distance from the targeted whale to the vessel, boat speed and noise thresholds that can lead to whale disturbance reactions), bringing new knowledge towards to improve the existent guidelines or the implementation of new procedures based on scientific information.

Humpback whale vocalizations recorded in the acoustic tags during 2013 and 2014 are described and analysed in this project. It is the first time that humpback whale vocalizations are examined by using bio-logging devices in Iceland. This will support previous research regarding the humpback whale vocalization on Icelandic feeding grounds.

1.9 Project aim and objectives

The aim of this study is to investigate the potential effects and risks of underwater noise caused by whale watching activities in Skjálfandi Bay, Húsavík, as well as to gain understanding about humpback whale acoustics and natural behaviour in the subarctic feeding grounds of Húsavík, Iceland.

This aim is pursued by,

- investigating whether or not the presence and noise from whale watching boats operating in Skjálfandi Bay, Húsavík is triggering temporary behavioural responses in humpback whales during the peak dates of their feeding season (June- August).

- characterizing boat noise levels from whale watching boats that the whales are receiving within a regular whale watching day and to determine whether or not, boat noise is interfering with the low frequency range used by the humpback whales (masking).

- expanding the knowledge from previous studies regarding humpback whale behaviour, dive patterns, and non-song vocalization during feeding seasons based on multisensor bio-logging devices and acoustic data.

2. Research methods

2.1 Tagging methodology

Tagging was carried in June 2013 and June 2014 in Skálfandi Bay. The tag was attached from a small rigid inflatable boat using a 8 metres carbon fibre pole. The tag is presumably deployed in the back of the whale, between the dorsal fin and the blowhole. Once the tag releases from the whale, it ascends to the surface and floats until a sign is transferred via VHF transmission. Then, the tag is retrieved and the data is downloaded to a computer (figure 9). The tags can be released when life duration ends, but often they fell before that time, due to bad weather conditions or sharp whale movements. For ethical reasons, the tagging event took place under the permission of the Icelandic Ministry of Fisheries.

Picture1. Embarcation used for tagging.Photo credit: Richard Mardens

Picture2. Pole with the attached tag. Photo credit: Marianne Rasmussen

Picture3. Tag attached in the back of a humpback whale. Photo credit: Tom Akamatsu

Figure 9. Tagging methodology

2.2 Study area

This study was performed in Skjálfandi Bay off Húsavík, Northeast Iceland (N66.05,W17.31). Skjálfandi Bay is approximately 8.5 nautical miles wide, from the harbour to the mountains (west to east) and 13 nautical miles from its inner part to the open end (from the south to the north) (figure 10). The complexity of currents, climatic and geomorphology characteristics of the island in this area represent the ideal conditions for foraging, particularly for highly migratory species of baleen whales (such as fin, blue whales and humpback whales) which can travel thousands of kilometres annually for feeding in specific high latitudes productive areas. Skjálfandi Bay average depth is around 100m but the maximum depth reaches down to 220m (Gíslason, 2004).

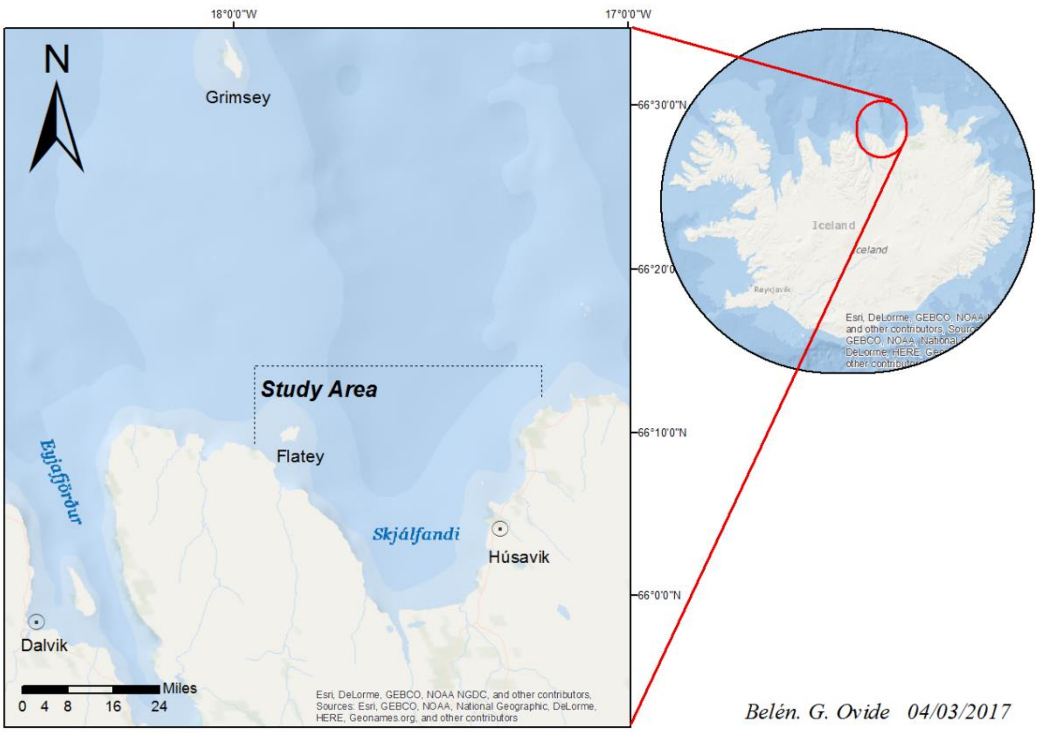

Figure 10. Skjálfandi Bay,Húsavík, Iceland map

Skjálfandi Bay is located in the North east of Iceland, next to Húsavík town. The small island in the North West part of the Bay is named Flatey. Eyjafjörður (the biggest fjord in Iceland) is the next fjord located next to Dalvík and Akureiry town in the West part of Húsavík.

2.3 Provided data and processing

- **Provided data**

For this study, data gathered from different bio-logging devices were provided by the researcher Dr Tom Akamatsu, member of the National Research Institute of Fisheries Engineering in Japan and Dr Marianne Rasmussen, director of the Húsavík Research Centre. A total of six tags were attached in June 2013 and another six tags were deployed in June 2014.

For data collection, mini AUSOMS Automatic Underwater Recording System was used (Aqua Sound Co., Ltd., Kyoto., Japan., http://aqua.sound.com/;), manufactured by Little Leonardo Corp., Tokyo Japan., http://l-leo.com/eng/data-logger. The mini AUSOMS recorder is a floating cylindrical pressure-resistant TAG recorder with 192 mm long and 51 mm in diameter (figure 11). The device has a small hydrophone incorporated with sensitivity of 210 dB re V/1 Pa. The sample rate used for the recorder was up to 44100 Hz in the acoustic tags deployed during summer 2013 and up to 48000 Hz for the tags attached in summer 2014.

Bio logging devices contained accelerometers W1000- 3MPDEGT: 21 mm × 114 mm, 59 g ∼ (in air) bio loggers and sensors for measuring swim speed, 3-axis acceleration, depth and temperature. The pressure resistance is up to 2000m.

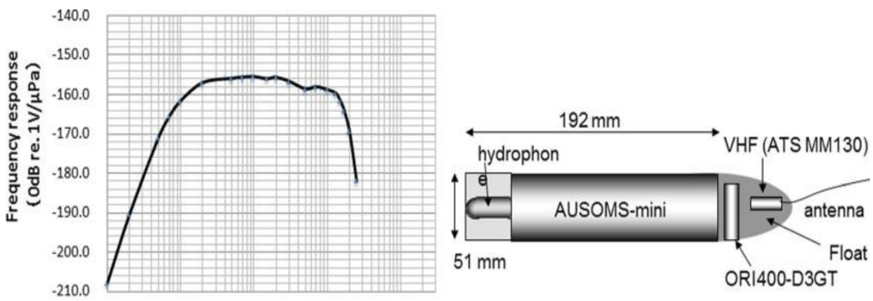

Figure 11 . W1000-3MPD3GT tag model used for the project. AUSOMS mini recorder (Akamatsu,T et al, 2014)

From 12 total deployed tags during 2013 and 2014, finally 7 tags were analysed in this study. Considering that the tags were deployed with different purposes at that time (E.G., a ph D project regarding whale ecology) and not necessarily for analysing whale reactions to human activities, not all the devices gathered the minimum requirements in order to pursue the aims of this particular study (e.g., lacking acoustics or tag data). Nonetheless, the choice of using those tag data for this study case was interesting and tempting. The sampling interval rate (tags resolution) was 1 second for the three whales tagged in 2014 (Mn215_2014, Mn200_2014 and MnNI_2014) and two of the tagged whales in 2013 (Mn270_2013 and Mn255_2013) and 10 seconds for the other two whales tagged in 2013 (Mn240_2013 and MnNI_2013). This means that a data point was given in an interval time of 1 second or 10 seconds. The maximum on-mode tag duration is approximately 9 days and 30 days for the long term AUSOM, but tags felt off before that time, lasting less than 5 days (table 2).

PHOTO ID CODE	Mn240_2013	Mn270_2013	Mn255_2013	MnNI_2013
Attached time	08/06/2013 15:17	05/06/2013 13:03	05/06/2013 17:44	06/06/2013 15:14
Attached time (audio file)	Rec DS800046.WMA (2h17'04")	Rec DS750194(0h 03'19")	Rec DS750129 (4h 44' 17")	Rec DS750066 (2h 13' 50 ")
Attached GPS position	NA NA	NA NA	NA NA	NA NA
Detached time	13/06/2013 5:22	05/06/2013 23:49	06/06/2013 7:09	07/06/2013 14:59
Dettached time (audio file)	Rec DS800060.WMA (03h 22'00")	Rec DS750194.WMA (10h 50'02")	Rec DS750131 (7h 09' 13")	Rec DS750069 (2h 01' 10")
Attached duration	110.08h	10.78h	41.17h	19.94h
Retrieved time	17/06/2013 17:16	06/06/2013 10:45	07/06/2013 10:54	06/07/2013 2:01
Retrieved GPS position	NA NA	NA NA	NA NA	NA NA
Tag sampling rate	1 sec	10 sec	1 sec	10 sec

PHOTO ID CODE	Mn215_2014	MN200_2014	MnNI_2014
Attached time	25/06/2014 6:31	27/06/2014 5:41	29/06/2014 3:17
Attached time (audio file)	Rec 0000081.wav	Rec 00000257.wav (32")	Rec 00000 135.wav(18")
Attached GPS position	N 66°01'54" W 17°32'57"	N 66°01'30" W 17°38'08"	N 66°04'52" W 17°45'41"
Detached time	25/06/2014 18:52	27/06/2014 18:46	29/06/2014 9:50
Dettached time (audio file)	Rec 00000815.wav (01")	Rec 000001029.wav(43")	Rec 00000521.wav (40")
Attached duration	12.53 hr	13.08 hr	6.55 hr
Retrieved time	26/06/2014 0:40	28/06/2014 2:02	30/06/2014 0:58
Retrieved GPS position	N 66°05'86" W 17°31'16"	N 66°05'28" W 17°43'27"	N 66°01'26" W 17°25'09"
Tag sampling rate	1 sec	1 sec	1 sec

Table 2. Tagged whales used for the project and tagging characteristics. N whales=7. Tagged whales were recognized and named by using Photo-ID humpback whale catalogue provided by the Húsavík Research Centre. Two of the seven whales could not be identified (NI) in the catalogue (MnNI_2013 and MnNI_2014).

- **Data processing**

Raw tag data from the multi-sensor devices included: time (seconds), propeller, which measures the number of its rotations in a period of 1 sec (counts/sec), depth (m), 3-axis acceleration which measures the gravity but also the accelerations related to animal movement in m/s^2 and 3-axis compass, which measures the magnetic field intensity in microTesla units. However, 3-axis acceleration, 3-axis compass and propeller data were not present in all the tags. The acoustic data was recorded in 1 minute .wav audio files for tagged whales in 2014 and in 10:58:59 WMA or 1:58:59 wav audio files for whales 2013.

Excel was used as a first tool for computing and managing tag data. In addition, IGOR Pro 5.05 (WaveMetrics, Inc., Lake Oswego, OR, USA) was used for tag data visualization and analysis. Adobe Audition 3.0 software was used for listening to the audio files.

For each whale, time series data obtained from the data loggers was imported and computed in customized worksheets in Excel (one worksheet per tagged whale), linked and synchronized in time with the audio files. This audio data include behavioural events such as breaths, foraging lunges, social behaviour, vocal sounds, and boat noise (see Appendix 1). In total 214.13 hours of recordings among the seven whales were carefully listened, examined and computed in Excel.

The speed of the animal was recorded in rotation counts. This refers to the number of rotations made by the propeller mounted on the actual tag. Rotation counts were converted to m/s based on the calibration experiment that was developed by using an experimental designed water flow tunnel (Akiyama Y., 2015). In this experiment the accelerometers are set inside the tunnel and the rotation counts are obtained from flow speed ranging from 0.1 to 1.1m /s in a regression. The correlation coefficient was 0.999 (N=10).

$$Speed\ (m/s) = 0.0933 * Propeller + 0.0194$$

a= 0.0933 and b= 0.0194 are the coefficients obtained from the regression

Vertical speed and vertical acceleration were also computed straight from the depth data by using the following the formula:

$$V.Speed = (Depth[t] - Depth([t-1]\ )\ /\ \Delta t$$

And the vertical acceleration at the time (t) is computed from the vertical speed, divided by time:

$$V.Acceleration(t) = (\ V.Speed[t\ ] - V.Speed[t-1]\ )\ /\ \Delta t$$

To have a close estimation of the actual whale speed and acceleration, it was necessary to account with the 3-axis acceleration data. By doing so, whale speed derived from the kinematics of the body (Vk), could be estimated by dividing the vertical speed obtained from the depth profile by the sine of the body pitch angle (Miller *et al*., 2004).

The actual acceleration can be computed by choosing one of the 3-axis for acceleration. Hence, to obtain the pitch, it is necessary to have a good calibration of the accelerometer and/or the compass.

For this project, due to the lack of three axis acceleration data for all the whales, for simplicity and time constrictions, the data chosen for this study were propeller, speed (counts), vertical speed and vertical acceleration. Notice that the accurateness of using these vertical parameters follows a positive relation as the whale is closer to his vertical position. Thus, for the whales with sampling interval rate of 1 second (Mn215_2014, Mn200_2014, MnNI_2014,Mn270_2013 and Mn255_2013) the accuracy of Vspeed/acc is higher than for those who had 10 seconds sam-pling interval rate (Mn240_2013 and MnNI_2013).

3. Data analysis

3.1 Characterization of whale behaviour

It is important to mention that after a preliminary inspection of tag data collected by the 7 tagged whales, one of the individuals (Mn215_2014) was chosen as a "baseline" (due to little flow noise) for testing the feasibility of conducting the different analysis and that due to time restrictions, some particular analysis were limited to this whale. In this case, whale Mn215_2014 was used to initially recognize and studying behavioural trends evidencing the naturally well-defined distinction between foraging and non-foraging stages. This allowed to apply this discrimination (foraging vs non-foraging state) to all the tagged whales. In addition, further descriptive analyses were carried on Mn215_2014 aiming to provide more extensive information of specific behavioural stages. Descriptive analyses were performed based on previous studies found in the literature regarding whale behaviour by using the parameters given in the tag data combined with the acoustic data gathered by the hydrophone.

For further analysis involving all the tagged whales a dive was defined as any time when whale was submerged deeper than 5m for a period longer than 10 seconds. Surfaces are any time when the whales are at the surface for breathing. Then for this study, surface events were defined as the time periods when the whale is diving below 5 metres.

3.2 Using flow noise and whale movement for lunge and breath detection

The objective of developing an automatic tool for lunge and breath detection was to enhance the characterization of natural whale behaviour while optimizing the detection of potential behavioural changes (i.e jerk rate and breath rate) used for analysing whale watching boat effects on whale behaviour (section 3.4).

- **Lunge detection**

The acoustic signature of a lunge consisted of a clear increase of flow noise in the low frequencies (up to 6000 Hz). The peak at maximum flow noise is followed by a sudden decrease in flow noise that is clearly registered in the spectrogram (figure 12). The acoustic signals for lunges varied greatly among tags. Part of this variation comes from tag types and position, but also from natural variation regarding size, age and power used by the whale in each lunge.

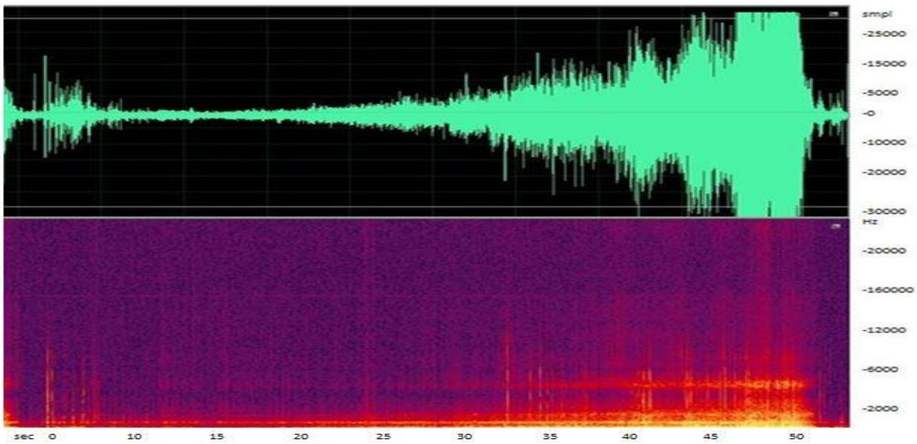

Figure 12. Example of an acoustic signature of a lunge plotted in Adobe Audition 3.0. The top image represents the waveform of the audio signal. It shows the amplitude on the y-axis along the time (seconds) within the duration of a lunge. In the bottom image the spectrogram signal represents the frequency range (Hz) at the y-axis versus the time in the x-axis. The colour gradient from yellow to purple indicates noise intensity from high to low. The flow noise at low frequencies reaches its peak when the whale makes the strongest fluke stroke before opening the mouth for prey engulfment.

The drop in flow noise in the acoustic signature coincides with a drop in acceleration and speed just when the whale opens his huge mouth for prey engulfment. As a consequence, a great drag is generated between the body and the surrounding water that forces the whale to slow down. This relationship between speed, acceleration and flow noise was used for detecting lunges.

The 3-axis acceleration and propeller data were not provided for all the tagged whales and sample rate differed among the tags. Furthermore, after checking with experts in manipulating tag data, it was found that the propeller data in the tag did not give accurate information for low speed. Considering this and the lack of homogeneous data, it was concluded that the best option for data analysis was the usage vertical parameters for speed and acceleration that were calculated based on depth variations along time meaning that only vertical lunges were investigated by the detector. Thus, when monitoring the depth profiles not bottom side (rolling at one side along the seabed), horizontal or downwards lunges were found along the seven tags. The vertical speed and vertical acceleration were computed from the depth (m) by following specific formulas explained in the section 2.3. The following plots show variations in flow noise, vertical speed and vertical acceleration that provide evidence for a lunge (figure 13).

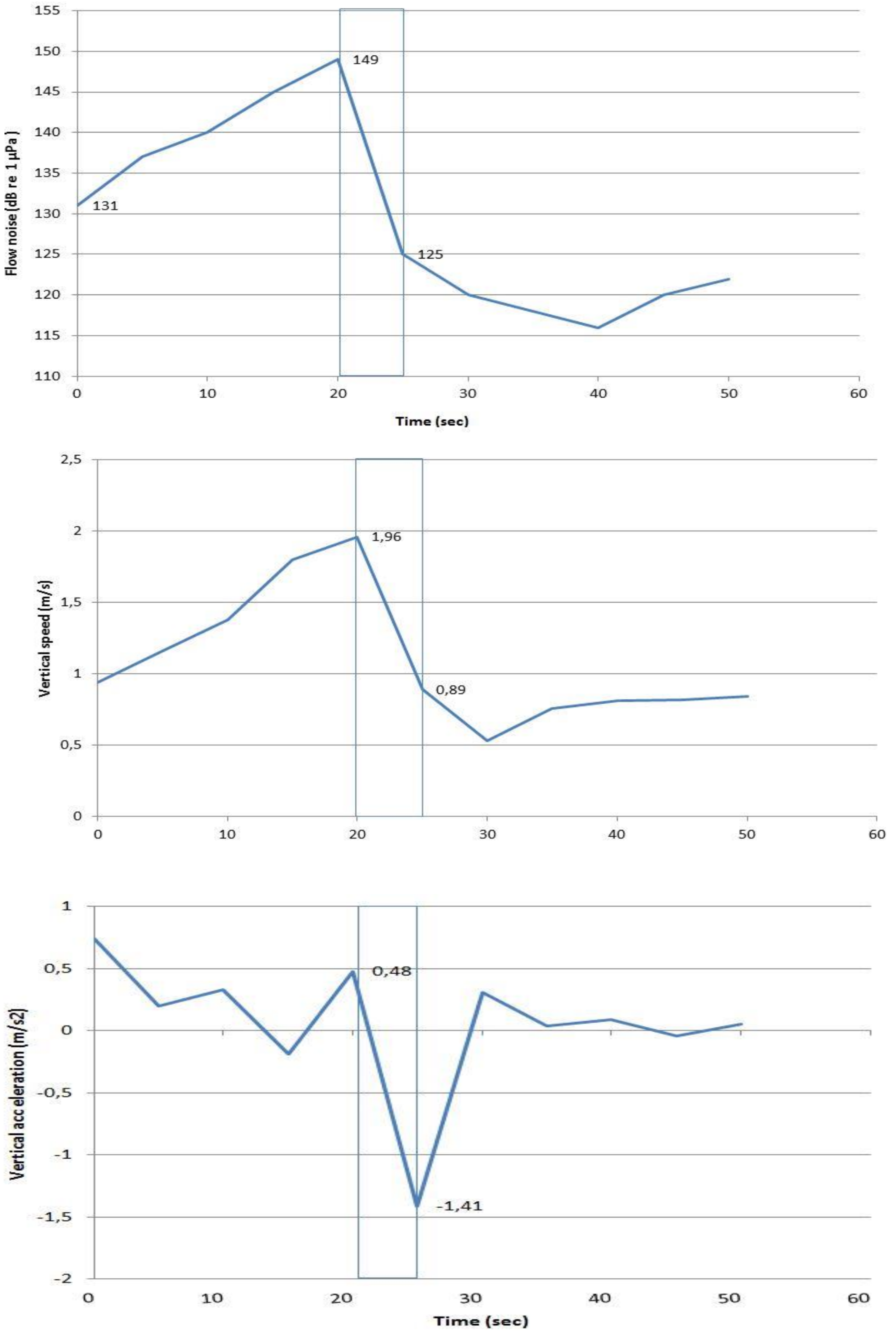

Figure 13. Examples of the drop in flow noise, speed and acceleration during lunge feeding for whale Mn215_2014

In this case, the peak of flow noise is at 149 dB re µPa. The drop in flow noise is 24 dB within the 5 second window just after the speed and acceleration reach the maximum value. The maximum speed is 1.96 m/s and the drop is of 1.07 m/s within 5 seconds. The maximum acceleration is at 0.48 m/s² followed by a deceleration of -1.41 m/s ² within 5 seconds.

For drops in acceleration and speed we calculated the differences between the maximum value and the minimum value within 5 seconds of the lunge peak. The acceleration near the lunge varies from low positive to negative value (when the whale opens its mouth). This motion (sudden change in acceleration) is also defined as "jerk" and it is associated with whale lunge feedings according to Simon *et al*., 2012.

Further, the correlation between the speed calculated from the propeller data (m/s) and the speed calculated from the depth (m/s) was tested. For acceleration, speed from the propeller divided by time was compared with the vertical acceleration calculated from the depth. The obtained curves were useful to test the reliability when using vertical parameters for lunge detection.

It is important to consider that when using vertical parameters (V.speed/acc):

- If the whale is diving 100% vertically, V.speed/acc are the same as the speed/acc so that more the whale is diving in the vertical position, better is the accuracy of the vertical speed/acc.
- If the whale is diving horizontally, V.speed/acc are always equal 0.
- Between vertical and horizontal, the V.speed/acc is equal to the speed and acceleration (from the propeller) multiplied by the cosinus of the angle between the vertical and the direction of the whale.

This is the reason why the four curves (V.speed and speed:V.acc/acc) have the same behaviour (figure 14).

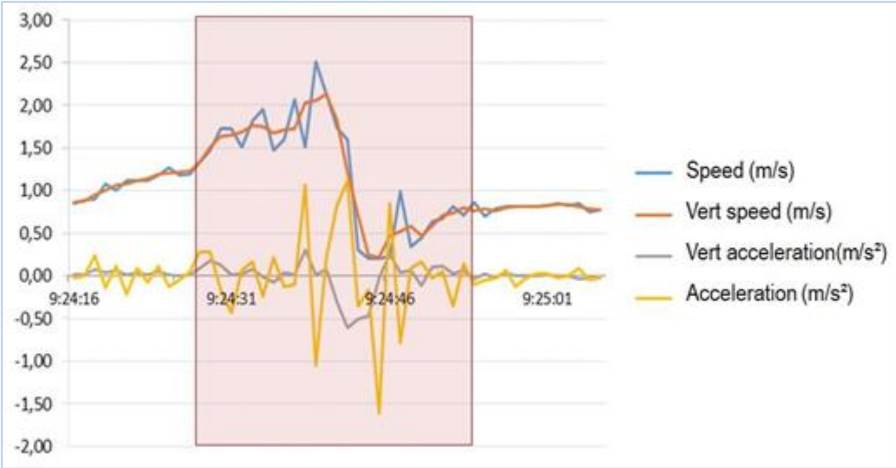

Figure 14. Example of comparison of vertical speed and acceleration (V.speed/acc) with non-vertical speed and acceleration (Speed/acc).
The blue curve represents the speed calculated from the propeller (m/s). The yellow curve represents the acceleration calculated from the speed from the propeller. The orange and blue curves show the vertical speed (m/s) and vertical acceleration (m/s²) respectively calculated from the depth. The red square represents one lunge. The formula for speed calculation based on the propeller is explained in the section 2.3.

The fact that curves for speed and V speed/acc showed the same trend, confirms that all the whales were making mainly vertical or near vertical lunge feedings.The peaks in the speed and the acceleration suggested that humpback whales use fluke strokes to make lunges.

Based on these observations, an automatic lunge feeding detector was built in Excel by following the methodologydeveloped by Goldbogen *et al*., (2006; 2007) for detecting the upward lunges using vertical parameters. The detector was based on the idea that the most reliable indicator for lunge in the tag data is a sudden change in the animal speed and acceleration as a result of the enormous drag generated when the whale opens his mouth for prey engulfment.

The rules and criteria for automatic detectors were selected manually and implement in Excel. As it was expected, there was high variance among whales regarding speed and acceleration values for detecting lunge values as well as what was previously described for the acoustic signature during a lunge. However, the presence of relatively drastic drops in flow noise, speed, and vertical acceleration remained in all the tagged whales when lunging. These variations have been shown and justified in other studies as artificial variation due to the tag placement on the body of the whale as well as natural variation driven by the kinematic behaviour during lunges (Simon *et al*, 2012) These variations were overcome by carefully adapting the values in the criteria for each whale.

Sometimes, the whale was near the surface and the hydrophone recorded bird sounds or constant bubbles during lunge feedings confirming the active whale foraging behaviour. The detector also registered presumed foraging lunges made at the surface. However, as following the example in the study carried by Goldbogen *et al.*, (2008) we did not consider them real lunges. It cannot be assumed that they are actual lunges as the increase in speed and the sudden drop in speed and acceleration could have been driven by the force generated by the whale when taking a breath and powerfully breaking the surface (surfacing splashes) and therefore it did not have to be necessarily related to feeding. To avoid false detections, the detection was restricted to deep vertical foraging lunges.

The rules for the final lunge detections included a combination of thresholds for depth, speed and acceleration, meaning that a lunge is only detected when the three parameters met the set up criteria at a given time. A threshold for depth at 5 m excluded those potential cases of false lunge at the surface so that only lunges that were recorded deeper than 5m were valid for the detector. A drop in vertical speed was computed by using the maximum and minimum speed between the last five seconds before and the first five seconds after the lunge peak respectively. A low threshold for acceleration was set in the detector to intercept the typical deceleration during jerks (for example $<0.36 m/s^2$ for whale Mn215_2014) (figure 15). Eventually, a minimum interval between lunges (10 seconds) was added because the large size of a humpback whale would prevent them from lunging at this rate or higher. While minimum depth and minimum time interval between lunges remained constant for all the whales, values for speed and acceleration had to be estimated for each whale independently. These values were calculated after carrying out an exploratory analysis regarding the maximum, minimum and average of vertical speed and acceleration in the whole tag duration and considering the tag sample rate for each whale.

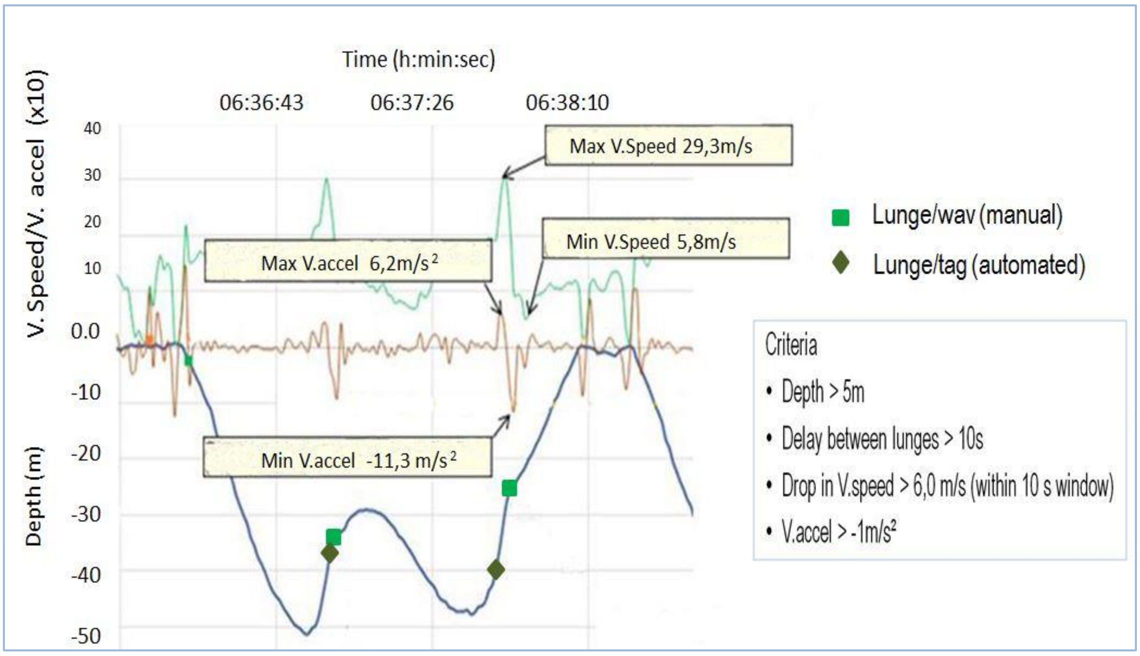

Figure 15. Example of two lunges feeding detections for Whale Mn215_2014.

The figure shows two deep upward lunges, type1 and type2 (section 4.4.1). The green line corresponds to the vertical speed. The brown line indicates the vertical acceleration and the blue line shows the depth profile. Green squares are lunges manually detected, while green diamonds are lunges registered by the detector. The rules used for detecting deep vertical lunges in this whale are represented in the criteria located in the right part of the figure. According to the criteria, a lunge is automatically registered only if: depth is below 5m, the delay between lunges is more than 10 seconds the drop in speed between 5 seconds before and 5 seconds after the maximum value is higher than 6m/s and the vertical acceleration is lower than -1m/s² (deceleration).

- **Breath detection**

To identify breaths, the most reliable way was the visualization of the acoustic signal via spectrograms (figure 16). When low flow noise was present, the blows were easily audible in the recordings, although the quality of the sound differed among whales and tag position on the back of the tagged whale. In cases with relatively high flow noise and high whale speed, blows were easier to recognize by the loud surfacing splashes generated by the tag when crashing the surface up and down at the same time that the whale was surfacing.

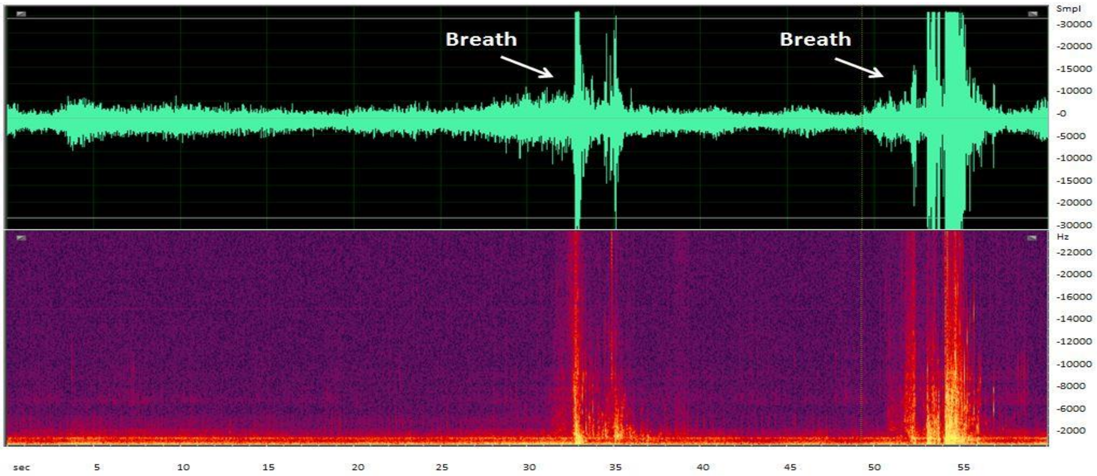

Figure 16. Example of acoustic signatures for two breaths in Adobe Audition 3.0. The waveform is located at the top indicating wave amplitude (smpl) in the y-axis along time in the x-axis. The bottom figure represents the spectrogram where frequencies (Hz) are represented in the y-axis and time (seconds) in the x-axis. The gradient colour in the spectrogram (from yellow to purple) indicates sound intensity from high to low sounds respectively. Often the blows were clearly audible and aurally detected if flow noise is relatively low. When breathing, most of the noise fell in the low frequencies but it can reach higher frequency ranges (up to 22000 Hz) especially when it is a powerful breath.

To help with the breath recognition, a simple breaths detector was built by using the depth data from the tag.

The automatic detector was programmed to identify a breath every time that the whale's depth was equal or smaller than 0.1m from the surface. In addition, a minimum time interval between breaths was implemented after aurally detecting breaths in the audio recordings. While this minimum interval between breaths was adjusted for each whale, being 10 ± 4 seconds, the 0.1m depth threshold remained constant for all the whales (figure 17).

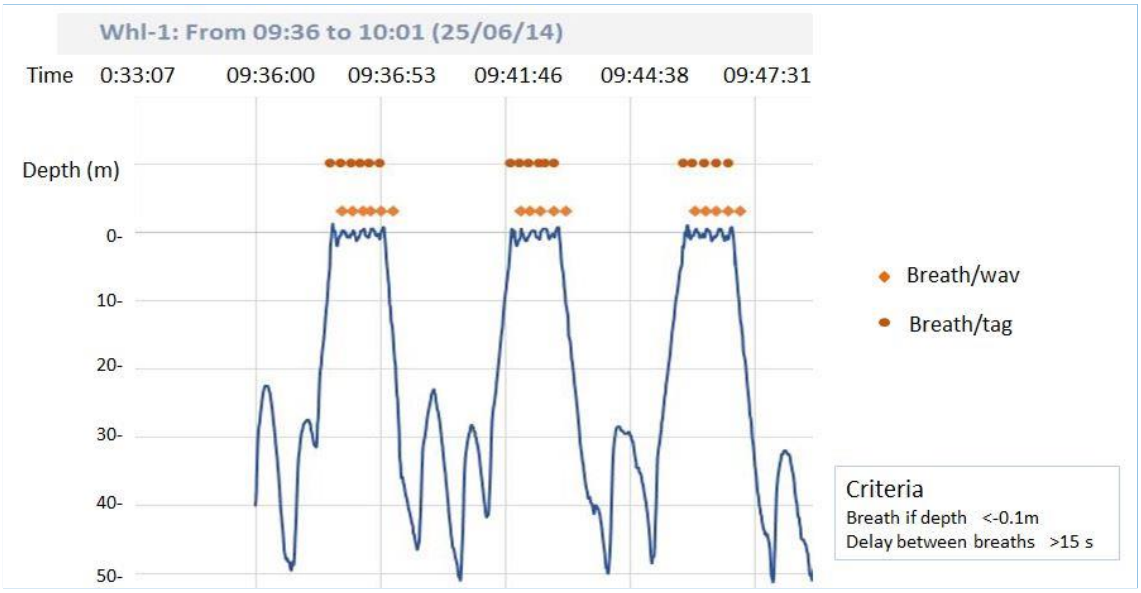

Figure 17. Example of breaths detector

The figure shows an example of breath detector functioning for whale Mn215_2014. Breaths reported manually (aurally and visually) from the recordings are represented by orange diamonds (breath/wav). The orange dots represent the breaths given by the detector (breath/tag).

Nevertheless, each breath was identified and confirmed manually using the acoustic signal to address any inaccuracies solve this inaccuracy towards to support further analysis. This means that we did not rely 100% on the detector but we used a combination of both, detector and the acoustic signature for breath recognition.

3.3 Boat noise

3. 3. 1 Flow noise and boat noise measurements

Boat noise was measured within all the tags in order to include these results into further statistic analysis. Water movement noise around the acoustic tag contributes to boat noise measurements from the tag. Flow noise is monitored to separate the relative contributions of flow noise and boat noise, aiming to remove those measurements affected by flow noise in order to achieve better boat noise measurements.

Flow noise was strongly related to whale speed. Most of the flow noise in the recordings was below 2 kHz and was caused by whale movements. Only when the speed was very high or it was very quiet (low ambient noise), the flow noise reached higher frequencies. Flow noise, or sometimes even only the boat noise, became so high that the amplitude of the waveform exceeded the maximum bit depth (around 30k) (meaning the waveform is clipped). Most of the “clipped waves” occurred as a result of high whale speed. Boat noise was not measured in clipped segments.

Boat noise often covered the frequency range up to 9 kHz, especially when boat noise was very loud (figure 18).

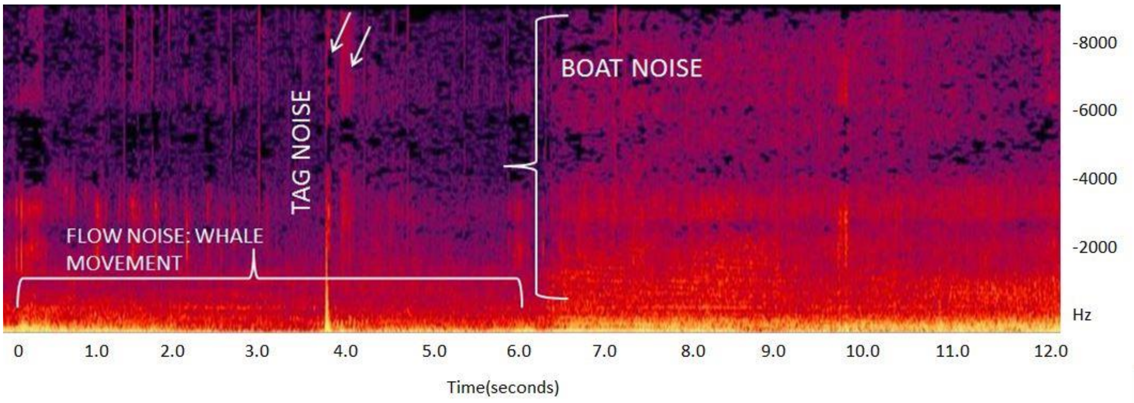

Figure 18. Example of boat noise for whale Mn240_2013.
This graph shows a typical boat noise signal. Thus, intrinsic tag noise was often present in forms of thin lines across all frequency range in the spectrogram. Flow noise was usually below 2 kHz caused by whale movement at a regular speed.

Based on these observations, “sweet spots” for noise measurement were chosen in areas where boat noise seemed to be highest and when flow noise/speed is relatively low. The signals were filtered using a band pass filter (2 kHz - 8 kHz) in Adobe Audition and consequently flow noise was considerably reduced. The following parameters for boat noise measurement were set: Window width =1000 ms 0 dB FS Sine Wave. Order 10. The Sound Pressure Level (SPL) was calculated by measuring the maximum Root Mean Square (rms) in Adobe Audition. To obtain close real values in dB we subtracted the absolute value from the hydrophone constant calibration value 150.9 dB re 1 μPa.

Whale depth can significantly influence the noise received by the tag (in this case boat noise). There is also a strong relationship between depth and boat noise. This is simply because as the whale goes for a deep dive, the distance between the boat and the whale increases and therefore boat noise becomes less audible. As soon as the whale surfaces from a deep dive, boat noise becomes audible again allowing noise measurements. In this case, the estimated depth from which the noise started to become audible was approximately 15m. For this reason whale depth was carefully monitored together with boat noise and whale speed. Boat measurements were taken each time that the whale was ascending heading the surface to take a breath, but cases when the whale was below 5m were excluded. This was made to avoid extreme flow noise commonly linked to surfacing events.

Further, boat Automatic Identification System (AIS) data was available for the tagged whales in 2014 (3 of a total of 7 tagged whales). In these cases, this information was combined with photo-ID data to confirm boats presence detected on the hydrophone.

AIS data gives boat names, GPS position, course and speed in a time period of 10 seconds (figure 19). Pictures from some of the tagged whales were gathered from the photo-ID database. These pictures were taken by the interns or students at the University of Iceland´s Research Centre in Húsavík on board the whale watching boats in the moment of the encounters. By matching this information, tagged whales' and boat´s position were figured when boat events occurred. Nevertheless, this information served to support the acoustic data. The photo-ID data was provided by the University of Iceland´s Research Centre in Húsavík.

Figure 19. Example of boat AIS data plotted in Google Earth.
AIS data, boat name, position, speed and course is given every 10 seconds. This is an example of 30 minutes period when 3 boats are sailing in the Bay. AIS gave boat signals even if the boats are out of service in the harbour (see "Mani" boat). AIS data was provided by the Icelandic Coast Guard.

Eventually, for maximizing confidence regarding boat noise recognition, the actual environmental conditions were correlated in time with the tag time to be able to distinguish whether or not flow noise was caused from whale movements or weather conditions (e.g., rain, high winds, waves) while enhancing boat noise recognition. The environmental conditions were gathered and plotted in zyGrib software (www.zygrib.org) (figure 20). Luckily, during all the tags recordings the weather conditions were rather good and not any case where ambient noise could have been significantly influenced by weathering conditions was reported.

Wed 2013-06-05

⇑ 01:28 UTC ⇓ 00:43 UTC
⇑ 02:02 UTC ⇓ 19:34 UTC 12%

00:00 UTC	03:00 UTC	06:00 UTC	09:00 UTC	12:00 UTC	15:00 UTC	18:00 UTC	21:00 UTC
171 ° 14.6 kts 4 Bf	172 ° 14.7 kts 4 Bf	181 ° 12.0 kts 4 Bf	185 ° 8.6 kts 3 Bf	235 ° 1.6 kts 1 Bf	32 ° 4.9 kts 2 Bf	53 ° 6.4 kts 2 Bf	58 ° 5.3 kts 2 Bf
0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	3.3 %	3.9 %	0.9 %
0.00 mm/h	0.00 mm/h	0.00 mm/h	0.00 mm/h	0.00 mm/h	0.00 mm/h	0.00 mm/h	0.00 mm/h
10.6°C	9.4°C	9.3°C	10.2°C	9.1°C	10.3°C	10.6°C	10.2°C
5.1°C	4.2°C	4.6°C	4.8°C	3.5°C	4.7°C	4.7°C	4.2°C
1023.1 hPa	1023.8 hPa	1023.9 hPa	1024.0 hPa	1024.0 hPa	1023.6 hPa	1022.9 hPa	1023.0 hPa

Figure 20. Example of environmental conditions for 05/06/2013 plotted in zyGrib Data is provided within 3 hours daily. From the top to the bottom: date, sun and moon time (includes moon phase in %, real time (UTC), wind direction, force (kts), and state (Beaufort scale), cloud cover (%), precipitation (mm/h), sea surface temperature (ºC), dew point (ºC), and MSL or mean sea level pressure (h Pa).

The acoustic profile of all the tagged whales was plotted in Matlab Rb 2016 and it was able to extract the frequency centres of the third octave bands and plot them in linear units (Hz). While this method helped greatly to correlate frequency ranges of whale movement with foraging or non-foraging stages, due to time restrictions, boat noise was rendered impossible to confirm and more rigorous improvements needed to be done for detecting boat noise signals.

There is a clear correlation between the tag data (depth and speed) (figure 21, A) and flow noise (whale movement) profile (see figure 21, B). The detector confirmed that the loudest flow noise (yellow colour) corresponds to the time when the whale is fast diving. Indeed, it is noticeable that in the first hours of tagging, the whale is actively foraging going up and down making lunge feedings, which matches with the highest flow noise at high frequencies. Thus, when the whale speeds up for isolated deep dives, intense flow noise was also registered. In contrast, when the whale is resting (just after actively feeding), the flow noise decreases significantly. The dark blue lines at low frequencies in the second graph (figure 21, B) might indicate boat noise presence as there is an apparent correlation between boat noise levels detected manually (figure 21, C) and the flow noise in the graph. However this phenomenon was not clear enough in any of the 7 whales, meaning that it was not possible to detect boat noise by only looking at the acoustic profile of the entire tag. Further investigation is needed to provide evidences of a possible correlation between the acoustic profile and boat noise curve. For this reason, this method was excluded and only a manual detection (listening to all the audio files) was chosen as the best option to accurately find boat presence in the recordings.

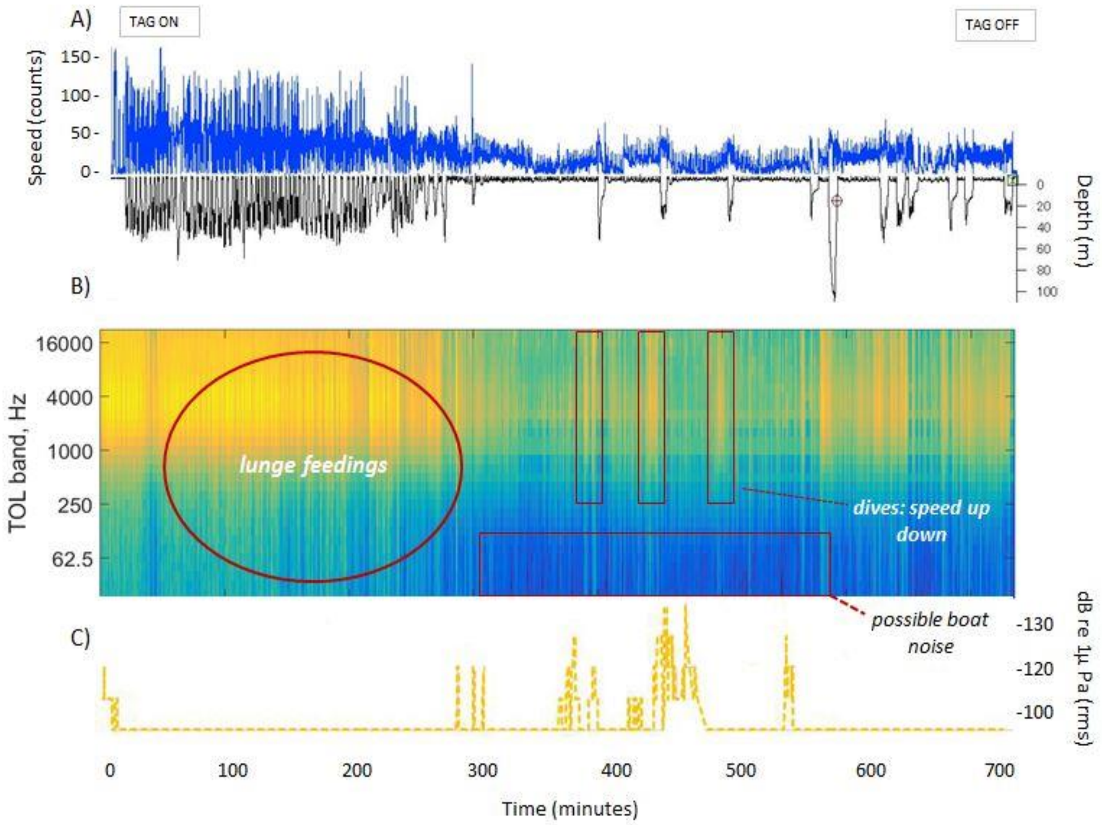

Figure 21. Correlation between tag data (A), acoustic profile (B) and boat noise (C) along the tag time duration for whale Mn215_2014.

The first graph is made by Igor Pro Software. It shows the dive profile of whaleMn215_2014. The speed (blue line) and the depth (black line) are represented in the y- axis along the time x-axis (minutes). The second graph was made by Matlab and it represents flow noise vs time. The frequency centres in the third octave band are represented in the y- axis along the time the tag was on the whale in the x-axis. The yellow colours show the loudest flow noise while light blue is the lowest noise. The third graph shows boat noise levels detected in the recordings along the tag time. This curve was built in Excel after measuring rms values when boat noise was present.

3.3.2 Measuring relative boat noise levels and comparison with ambient noise

In this experiment the objective is to give an estimation of the relative noise levels introduced by whale watching into the marine environment. For obtaining relative measurements of noise levels heard by the tagged whales, only noise measurements from the baseline tag (whale Mn215_2014) were used and classified in three intensity categories (low, medium and high). The reason for limiting this experiment to a single whale was to avoid misleading noise measurements and comparisons which could have been easily driven simply by the variation between tags. Hence, we used SPL dB re µ1Pa (rms) values to develop three categories for relative noise exposure intensity (low, medium and high) recorded in the tag attached in Mn215_2014 (see table 3).

Noise categories for measuring relative received levels	
Noise range dB re 1 µPa (rms)	Intensity levels
119-127	High
111-119	Medium
103-111	Low

Table 3. Noise categories for measuring relative SPL in whale Mn215_2014.

In order to achieve a better estimation of the contribution of boat noise into the marine ecosystems, boat noise intensities were compared with an ambien tnoise sample. For the control, an example of ambient noise levels (background noise)was measured at 100m and three miles out from the harbour when no boats were present and when weather conditions were preferable. Noise signals were compared in SigPro321 acoustic software and power spectra were developed. Once SPL (dB) was measured for each signal, we calculated relative differences in dB between the signal and the control to estimate the amount of boat noise received by the tag. Signals were standardized as mono files (one channel) compressed twice and with the same sample rate (fs: 2756) for measurements. Thus, signals were compressed twice for better visualization of the low frequencies in the power spectra (from 0 to 1500 Hz). Frequencies at 50 Hz 100 Hz and 300 Hz were selected for calculating differences in amplitude in dB as these octave band frequencies appear to be the most commonly used within the non-song sound productions of humpback whales at their feeding grounds.

One example of each noise intensity range was selected in the tagged whale Mn215_2014 with rms energy values of 109 dB, 118 dB and 121 dB for low, medium and high noise intensity, respectively. The control sample of ambient noise resulted in energies of 97 dB (table 4). Notice that all the samples (including the control) had the same duration to allow the comparison. The characteristics of the original audio files for noise intensity were 1:00.031 duration 48.000 Hz sample rate, 16-bit, Mono channel wav files.

File name	Tag time	rms dB	Intensity
00000555.wav	14:31:48	121	High
00000540.wav	14:16:36	118	Medium
00000517.wav	13:53:59	109	Low
000000Control.wav	-	97	Control

Table 4. Audio file examples chosen for each boat noise intensity in Mn215_2014 and ambient noise (control).

The table shows the original name of each audio file for each noise example, the real time in the tag data, rms values measured in Adobe Audition 3.0 and the correspondent category for noise intensity. All the boat noise examples were retrieved from the same tag attached and during the same day the 25/06/2016 in whale Mn215_2014.

3.4 Behavioural changes due to boat exposure

3.4.1 Experimental design

The aim of this study was to test potential differences in behaviour before, during, and after boat presence or noise exposure. To do so, we isolated noise events from the acoustic data collected with the animal-attached tag. Each noise event contained three phases: before, during, and after noise exposure. The "during" phase of a boat noise event was defined as a period when boat noise was clearly recognized in the sound recording. It was assumed that in most cases, this would be the time duration of an encounter with a whale and a whale watching boat. This assumption is based on the fact that boat noise was recorded during the whale watching peak season in June, when the bay accommodates the highest number of whale watching boats in Skjálfandi Bay. All the tags were attached during the day, when it is very unlikely to find other boat types and the local fishing boats tend to avoid these busy areas during this time. Boats passing (and not stopping and re-approaching the whale) were often registered and they were included as a separate category of noise events for the analysis. The classification of Boat event types as "approaches" or "boat passing events" was mainly based on the noise profile that was recorded in the hydrophone. "Boat approaches," started with a gradual increase in boat noise (boat approaching a whale) followed by a period when noise was very high or very low intermittently for several times (the boat is stopped or slowed down while the whale is diving and speeding up when approaching the whale near the surface). Eventually, the boat approach ended up with a gradual decrease in noise until it disappeared (the boat is leaving the area). Often the highest noise level within an approach event coincided with the last time that the boat approached a whale before it left the area. This is a usual practice often carried out by the operators when they wish to have a closer view of the animal before leaving. In contrast, in “boats passing” events, the noise period was significantly shorter and not spasmodic as previously described for actual “approaches”. The distinction between boats passing and boat approaching events were double-checked with boat Automatic Identification System (AIS) data when this data was available (whales tagged in 2014). Phases in the same block (noise event), always had the same duration (figure 22). However, noise events could differ in duration. The duration of noise events was limited to the boat noise duration in each block (“during” phase duration). Noise events that were less than 5 minutes were excluded from the experiment as we did not expect to see any responses in such a short period of time. We assumed that a boat noise event was finished when the boat noise was below 111 dB re 1 μ Pa in the next two or three surfacing events after the noise presence. The cutoff was set at 111 dB re 1 μ Pa because below this level, boat noise was almost inaudible or difficult to distinguish from the background noise. Thus, we assumed that levels below this threshold were too low to be caused by a whale watching boat approach or a close boat passing and therefore, we did not expect any behavioural responses in the whales. By doing so, we avoided the incidental inclusion of distant boats operating in the bay (e.g., fishing boats) that could disrupt the purpose of this study.

SPL was measured at the maximum noise level heard during the boat event calculated using a one-second rms averaging window and a frequency band of 2-8 kHz. We excluded noise events where boat noise could not be measured accurately due to masking by flow noise.

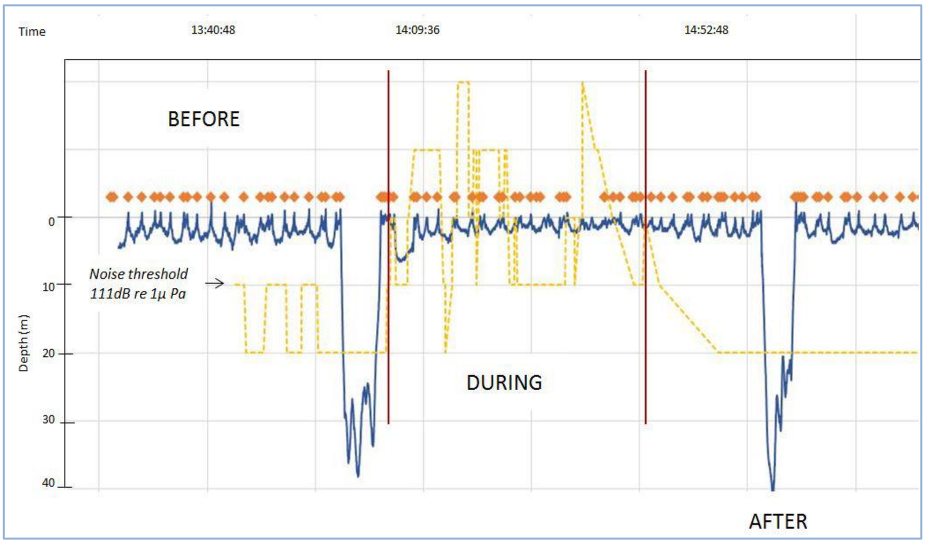

Figure 22. Example of a noise event for the tagged whale Mn215_2014. The figure shows a single noise event of 25 minutes, when each phase last 8.33 minutes. In the example the whale depth is represented in metres in the y-axis and time is shown in the x–axis. The phases before, during and after noise exposure are separated by the vertical red line. The dashed yellow line represents noise intensity along time. Notice that the during phase starts when noise goes up above 111 dB.re 1h Pa based on rms values. The orange dots indicate whale breaths.

The following behavioural parameters were tested in a total of 7 tagged whales to check potential responses caused by whale watching boats (table 5).

Behavioral parameters	***Description***	***Units***
Mean depth	Mean depth within each phase	meters(m)
Jerk rate	Number of times that jerk * signal is given per minute within each phase	counts/min
Breath rate	Number of blows per minute within each phase	blows/min
Mean Vertical speed	Mean vertical speed in each phase	m/s
Dive rate	Number of dives per minute within each phase	dives/min
Mean dive duration	Mean dive duration within each phase	seconds (s)

Table 5: Behavioural parameters tested for potential responses in exposure to boat presence and boat noise.

The table shows the measured behavioural parameters, the description and the correspondent units. These parameters were measured for all the whales in each phase for each noise event (before, during, and after noise exposure).

Mean values, rates, and duration for the behavioural parameters were computed by using R software (Faraway, 2005). Breaths, jerks and dive events were previously computed in Excel as it was described in the section 2.3.

Jerk rate was measured in counts per minute. In this case, a count was the time when a jerk signal was given in the customized built detector. Jerks signals were included in the study as it is often used in whale kinematics studies for recognizing whale lunge feeding events in tag data (e.g., Ware *et al.*, 2011). Generally, a jerk is associated with a lunge feeding, but it can also be indicating lunge attempts. To avoid false assumptions “jerk” as a term and not “lunge” was selected for testing possible changes in feeding behaviour (the construction and functioning of jerk detections is explained in the section 3.2). For dive rate, a dive was defined as any behaviour that occurred when the tag was submerged below 2m. Notice that for the other whales a +-6m depth correction was applied according the individual and tag position.

Differences in whale behaviour (e.g., an increase of breath rate) are likely to occur during and after tagging moment due to stress, hampering the detection of impacts from whale watching boats. In order to determine whether behavioural responses were influenced by the tagging event and not from whale watching boats, potential effect from tagging were analysed. To achieve this, noise events that fell within an hour after the tagging time were treated separately from the other noise events.

Eventually, noise intensity was included as a meaningful covariate. This approach resulted in sample sizes of 26, 27 and 36 for the categories low, medium and high noise intensity respectively (table 6).

Noise categories for measuring boat effects	
Noise range dB re 1 μPa (rms)	Intentisy levels
132-143	High
121-132	Medium
111-121	Low

Table 6. Noise categories for measuring boat effects in all tagged whales (N=7). Average root mean square (rms) pressure level at 1/3 octave band measured in Adobe Audition 3.

3.4.2 General linear models (GLM)

The statistical analyses were performed by using Generalized linear models (GLM) in R (Faraway, 2005). GLM is a type of regression analysis which is useful for modelling data that may not follow a normal distribution. It has been previously applied in similar studies on whale behavioural responses (e.g., Cure *et al.*, 2015; Sivle *et al*., 2016 and Richard, *et al*., 2017).

Since our main interest was to see differences in behaviour between phases (before, during and after) noise exposure and between noise intensity levels (low, medium, high), one model for addressing each objective was developed; one for measuring potential responses due to boat presence using Phase as a main factor and a second one with Noise intensity as a main factor instead, for testing potential changes due to boat noise. Doing this, a more valid way of addressing the objectives was ensured: boat presence and boat noise potential effects, within the limited given data set.

For the first model (differences between phases), we assigned phase (before, during, after) to each observation. Data points that could be assigned to two subsequent noise events, e.g. both the after phase of event 1 and before phase of event 2, were considered only for first event, to avoid pseudo-replication. Due to these overlaps, of the 102 total observations, 89 were considered suitable for the statistical analysis.

Potential candidate covariates, other than Phase and Noise intensity, identified in an exploratory analysis were whale-ID, exposure order (first approach, second approach…), boat event type, and tagging effect. Due to the limited sample size, whale ID and exposure order were excluded from any formal statistical testing and only included two-way interactions that included Phase or Noise intensity (table 7).

Covariate	Description	Factor levels
Phase	Time period before, during or after the noise exposure	Before(0),during(1),after(2)
Boat Event Type	Boat approach or boat passing	Boat approach(0), boat passing(1)
Tagging effect	Start of During within an hour after the animal was tagged	Exposure start after 1 h since tag on(0), exposure start within 1 h since tag on(1)
Noise intensity	Relative maximum noise intensity registered in "during" phase	Low(0),medium(1), high(2)

Table 7. Covariates chose for explaining variation in the data.

Each covariate was a factor covariate (categorical variable) of 2 or 3 factor levels.

For the second model (testing effects of boats noise intensity on behaviour), only observations for “during” phases were included in the analysis while observations for “before” and “after” phases were left out. This is because for before and after phases, boat noise was too low and with high chances to be masked by the background noise. Considering this, it was preferable to not account for them. As a result, the number of observations for this model was N= 34. Choosing the most relevant interactions for a specific study rather than including all the possible interactions is a valid statistical approach especially when dealing with a small data set, as in this case.

When fitting GLM models, it is necessary to assume that our observations from N=7 tagged whales are statistically independent and followed distributions that can be modelled with GLM. In this case, the data were assumed to follow Gaussian or Gamma distributions based upon 1) histograms of the observations for each dependent variable (see Appendix 2) and 2) understanding about the process that generated the observations. For example, Gamma was assumed for the parameter dive duration, as values cannot be negative and very large values are uncommon.

A hypothesis-based model selection was performed using backwards selection on the candidates covariates other than Phase and Noise intensity (Phase and Noise Intensity were always included as it was of prime interest in the first and in the second model respectively). To determine the best-fitting model, the p-values given by ANOVA (sequential Wald test) were used with a significance threshold of 0.05. Plots were previously used as guidance for fitting the model (histograms) (see Appendix 2). Once the best fitted model was determined, p values and parameter coefficients were calculated for each response variable using repeated Wald tests.

Jerk rates violated one of the model assumptions for the GLM for boat noise, meaning that this model was not suitable or detecting effects in this variable. Jerk rate, or the logarithm of jerk rate, did not follow a Gamma distribution, probably because of the excessive quantity of zeros present in the sample. This is caused by natural variation (jerk rate is always zero when the whale is not feeding). As an alternative to GLM, a Wilcoxon Rank Sum Test was applied for measuring differences in jerk rate (counts/min). This non-parametric statistical hypothesis test was used to test for differences in jerk rate between the different levels of the main covariates (Phase and Noise intensity). Non-paired tests and a Bonferroni correction was used to account for the problem of using multiple significance test (i.e. a significance level of 0.025 was used, which was half of the original significance level of 0.05).

3.5 Acoustic behaviour

Vocal sounds were identified manually for the seven tagged whales by using the audio signal and the spectrograms in Adobe Audition 3.0. (Adobe Audition CC, 2014.) Each vocal sound was added in the Excel sheet (explained in the section 2.3) for matching the time of the vocal sound with the tag data, and therefore associate acoustic data with the current whale behaviour. Due to time limitations, specific acoustic measurements of each vocal sound were only conducted for the tagged whale Mn215_2014 (the whale used as a baseline for data analysis), and not for the other whales. However, for the seven whales, the vocal sounds that were considered to be interesting or relevant were described in this section for further discussion.

The vocalizations were reported when flow noise was low enough not to mask the vocal signals. Acoustic measurements were taken by using Raven 64 1.4Ink (Cornell Lab of Ornithology). All the audio signals were low-pass filtered (<4000 Hz) for a better visualization and to reduce considerably flow noise.

The following acoustic measurements were considered (table 8):

Measurement	Notation	Definition
Description	Desc	Word that gives information about vocal sound behavior
Call type	Type	Types of calls (as determined by aural-visual analyses)
Duration (ms)	Dur	Length of the signal
Peak Frequency (Hz)	Peak	Frequency of the spectral peak
Freq 95% (Hz)	Band 95	Frequency range of 95% lenght
Low Frequency	Low	Lowest frequency detected in the signal
Root Mean Square amp (u)	RMS	Relative power measurement based on average of the squared of amplitude values(u)
Max power(dB)	Max (dB)	Relative maximum power detected in the signal

Table 8. Definition of acoustic measurements used for vocal sounds.

4. Results

4.1 Insights into behaviour from acoustic tags

During the whole tag period (12h 32 min) whale Mn215_2014 made a total of 273 dives. The average maximum depth (± s.d) during this time was 11 ± 21m. The majority of the dives occurred at a range between 30-70m. Based on these observations, a distinction between shallow and deep dives was made. Shallow dives were defined as dives where the whale does not go deeper than 10 metres while deep dives were deeper than 10 metres.

4.1.1 Foraging stage

By looking at the tag data combined with the audio signal, whale behaviour could be easily classified as foraging/non-foraging and resting behaviour. At the first hours after tagging, the whale was actively performing vertical excursions indicating foraging behaviour. After feeding, the whale changed behaviour and it remained calm near the surface indicating presumable resting behaviour (stage2). During resting behaviour some deep dives were registered. In this study, foraging stage and resting + possible exploratory dives were examined separately (figure 23).

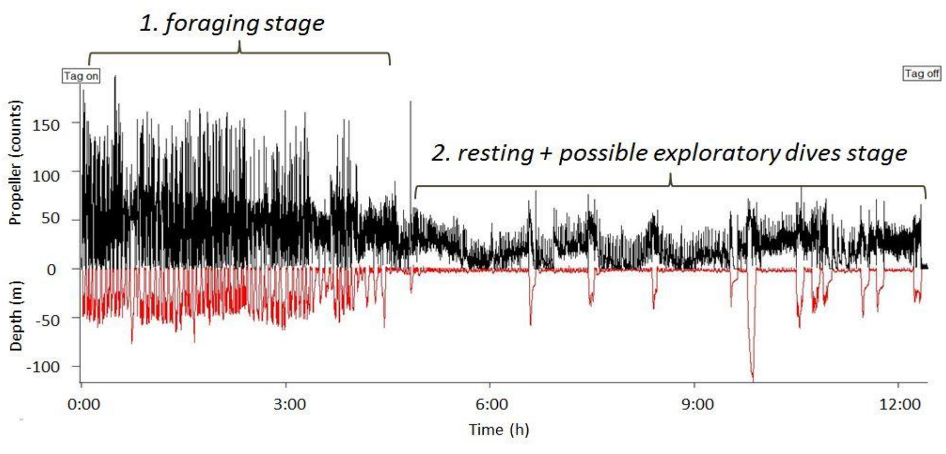

Figure 23. Behavioural stages in the whale Mn215_2014 during tag duration.

The figure shows foraging behaviour (1) and resting + possible exploratory dives. Speed (counts) and depth (m) are represented in the y-axis and tag time is indicated in the x-axis (h).

During the first 5 hours approximately, whale Mn215_2014 was actively making descending and ascending excursions in a nearly vertical position and following a constant dive pattern. This behaviour was associated with lunge feeding attempts. This was supported by the audio signal where high and almost constant flow noise was clearly correlated with the whale movement and speed. These particular near vertical dives are also named (U-shaped) foraging dives. Foraging dives often showed vertical excursions at the maximum depth of a dive (figure 24*)*.

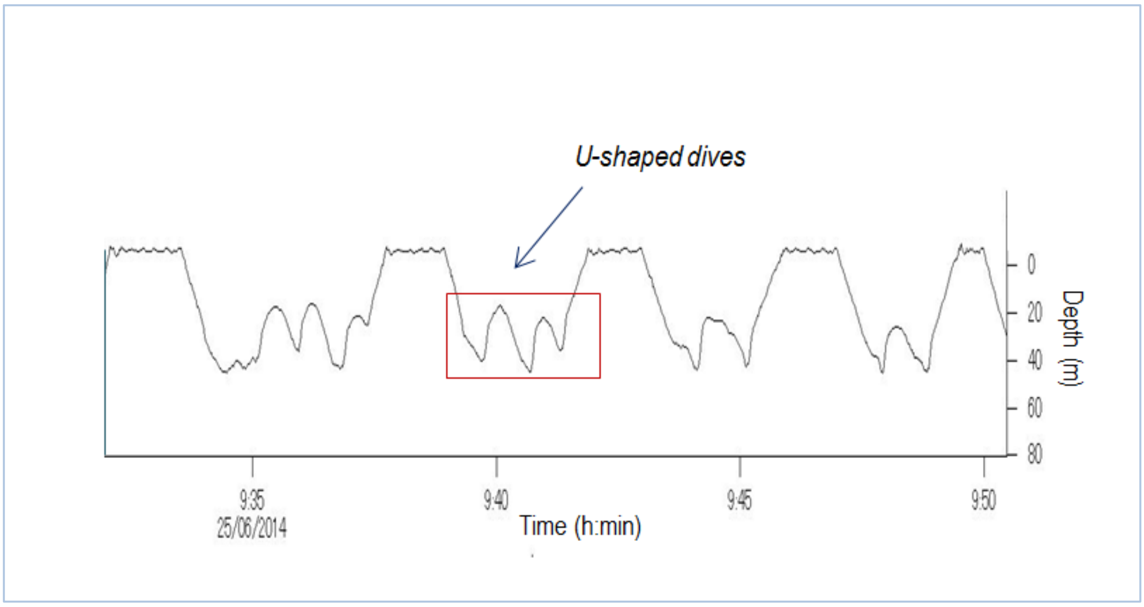

Figure 24. U-shaped foraging dives of a humpback whale (Mn215_2014). The descending and ascending excursions U-shaped dives in each dive are linked to lunge feedings.

Prey availability was confirmed in the tag by the loud Arctic tern *(Sterna paradisaea)* sounds recorded in the hydrophone when the tag crossed the surface. Artic terns are typically found in Iceland during the feeding season, foraging on the small fish and plankton at the surface together with the humpback whales.

From 06:32:21 to 10:27:44 (3h 55 min 23 sec) the whale performed a total of 57 foraging dives with an average of 14 dives per hour (figure 25).

In Mn215_2014, all foraging dives were performed at peak depth ranges of 30m (s.d=10.49) and 70 m (s.d=7.45) (figure 25, left graph), with the highest reaching depth of 45m (figure 25, right graph). This repetitive depth range used by the whale suggests that the prey was congregated mainly among this depth range.

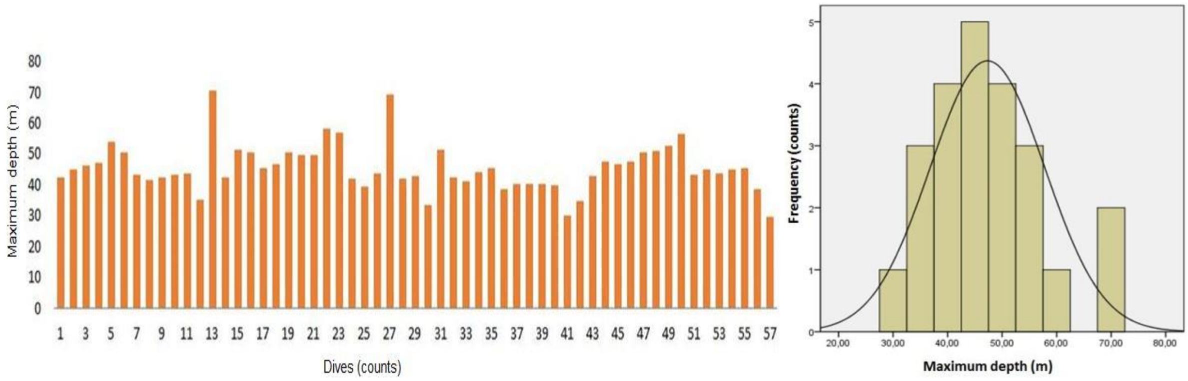

Figure 25. Foraging dives for Mn215_2014.

The graph on the left shows the maximum depth (m) of each dive (counts) in the x-axis (N =57 total foraging dives).The graph in the right part shows the distribution of maximum depth for foraging dives. Frequency (counts) in the y-axis and maximum depth in the x-axis. Notice that the majority of the foraging dives occurred between a maximum depth range of 30 to 70m, with 45m being the most frequent depth used by the whale for foraging.

Dive duration was measured and compared with surface duration. Each foraging dive lasted an average of 3:05 minutes (figure 26).

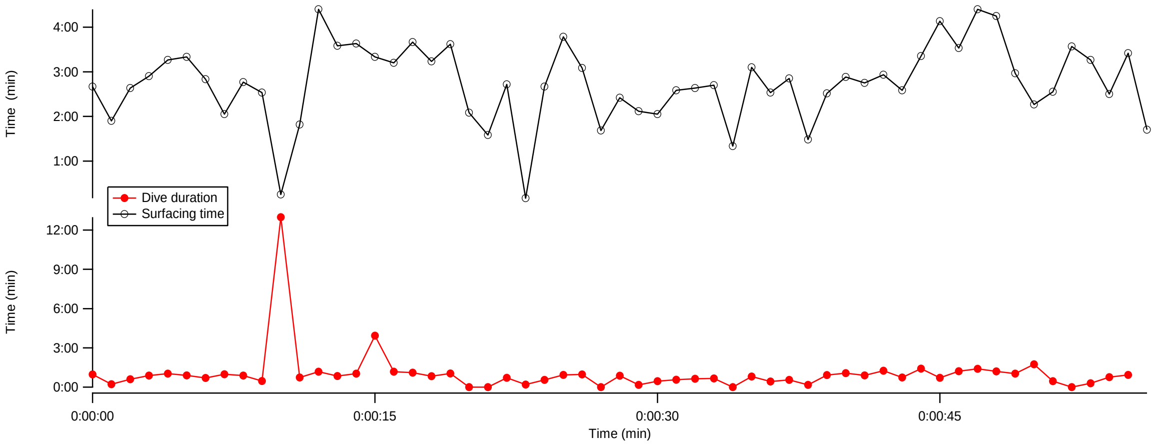

Figure 26. Correlation between dives and surfaces duration within one hour of foraging state for Whale Mn215_2014 in Igor Pro 5.0.

The longest foraging dive (red line) was 12:00 minutes and the shortest only lasted 00:15 minutes. The average foraging dive duration was 3 minutes. Surfacing duration is a complementary measurement of dive duration (black line).

From the audio files, a total of 142 lunge feedings events were recognized which were characterized by periodic large drops in flow noise in the last part of the lunges. The drop in flow noise coincided with the time where there was a drop in speed and acceleration data in the tag (see section 3.2 for further information about lunge detection). High flow noise linked with high speed just before lunging (opening the mouth) suggests that the animal is making strokes with its fluke (strong movements of the caudal tail up and down) towards to propel itself to catch his prey each time that it makes a lunge.

Most of the lunges were performed near vertically and in the ascending portions of foraging dives. The whale descends until it reaches a maximum depth, then it starts ascending fast, gaining speed. The whale reaches the maximum acceleration just before opening the mouth for prey engulfment. On average, 3 lunges were performed per dive ranging from 1 to 5 lunges. The Inter-lunge interval (ILI) was 43 (s.d ± 1.73) seconds. (table 9).

Mn250_2014							
Start tag time	End tag time	Duration (sec)	Total dives	N dives/hour	Lunges Counted per Dive (LCD)	Dives duration (sec)	Inter-lunge Interval (ILI)
6:32:21	10:27:44	3:55:23	57	14.53	3±2.5	3:05	43 ±1.73

Table 9. Scores of foraging stage of a humpback whale (Mn215_2014).

The table shows foraging start time, end time and duration, foraging dive scores and lunge scores. N=142 lunges.

The few seconds during a lunge when the whale reached his maximum speed and the audio signal gets clipped is called the peak of a lunge. Lunges lasted an estimated time of 4.5 seconds since the whale started strongly accelerating and increasing speed until a drop in acceleration speed and flow noise occurred as a consequence of drag generated by opening the mouth. The fact that the whale exhibited vertical or nearly vertical lunges provided detailed information about lunges by using vertical speed and vertical acceleration. How vertical speed was calculated is explained in the section 2.3.

For whale Mn215_2014, the average maximum vertical speed reached when lunging was 2.62 ± 0.41 m/s with the maximum value at 3.90 m/s. The average peak in acceleration was at 0.72 ± 0.31 m/s² and the maximum was at 1.86 m/s². The typical drops in acceleration occurring in the last part of the lunge were at an average of -1.5±-0.42 m/s² in whaleMn215_2014.

Thus, by comparison of the audio files and vertical parameters, it was found that the whale was making two apparently different types of lunges.

When lunging, the whale headed down in the vertical position until it reached a maximum depth (approximately 60m), then the animal suddenly changed orientation, heading up and quickly gaining speed and acceleration for performing a lunge in the depth where the food was presumably located (around 30-40m). After this, the whale went down again reaching nearly the same depth point than before and propelling himself for the next lunge. This lunge type was named type1 lunge and the whale repeats this type of lunge several times in a dive. In every foraging dive, during the last portion of a foraging dive, a lunge before surfacing is performed which slightly differs from type1 lunge. Due to the different characteristics regarding speed and acceleration parameters and noise signature, it was named type2 lunge (figure 27).

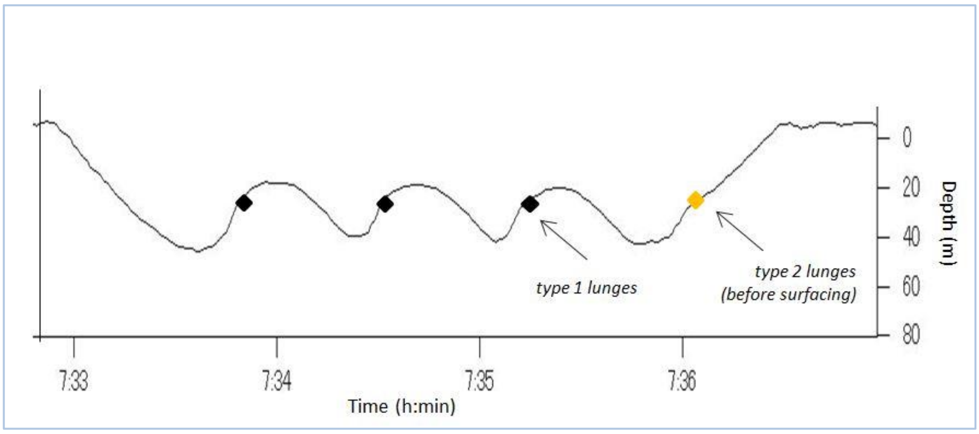

Figure 27. Example of lunge types in a single foraging dive of a humpback whale (Mn215_2014) in Igor Pro 5.05.
It is worth noting the sequence of type1 lunges that ended up with a type 2 lunge (before surfacing). The time window is of 4 minutes. Depth is represented in y-axis (m) and tag time in the x-axis (h: min).

Often, type2 lunges were performed a few metres shallower than type1 lunges. The greatest difference among lunges is the fact that type2 lunges were more powerful than type1 lunges. Overall, lunges type2 showed on average higher levels of speed and acceleration as well as higher drops in the acceleration in comparison with lunge type 1 (table 10 and Figures 28 and 29). For type1 lunges, the average value was of 2.56 ± 0.61m/s for vertical speed with a maximum at 3.9 m/s, values of 0.8 ± 0.4m/s² for vertical acceleration with the maximum value at 1.4 m/s^2 and scores of -1.58 ± 0.6m/s^2 for drop in acceleration with the highest value at -2.6 m/s^2. For type 2 lunges the coefficients were an average of 2.6 ± 0.4 m/s with maximum at 3.4 m/s for vertical speed, 0.9 ±0.3 m/s^2 with maximum at 1.4 m/s^2 for vertical acceleration and -1.70 ± 0.5 m/s^2 with maximum at -2.5 m/s^2 for acceleration drop (table 10).

Mn215_2014			
	X V.speed (m/s)	**X V.acc (m/s^2)**	**Drop acc (m/s^2)**
Type 1	2.56±0.61	0.8±0.4	1.58 ±0.6
Type 2	2.6±0.4	0.9 ±0.3	1.70±0.5
	Max V. speed (m/s)	**Max V.acc (m/s^2)**	**Max drop acc (m/s^2)**
Type 1	3.9	1.4	2.6
Type 2	3.4	1.4	2.5
	Min V.speed (m/s)	**Min V.acc (m/s^2)**	**Min drop acc (m/s^2)**
Type 1	1.6	0.1	2.6
Type 2	1.8	0.3	2.5

Table 10. Comparison between averages for vertical speed and vertical acceleration parameters for type1 lunges and type2 lunges.

For type 1 lunges and type2 lunges, the table shows the average vertical speed (m/s), average vertical acceleration (m/s^2) and drop in acceleration (m/s^2) in the last seconds of the lunge. Notice that although they can be different there are not extreme differences among lunge types. N =142 lunges.

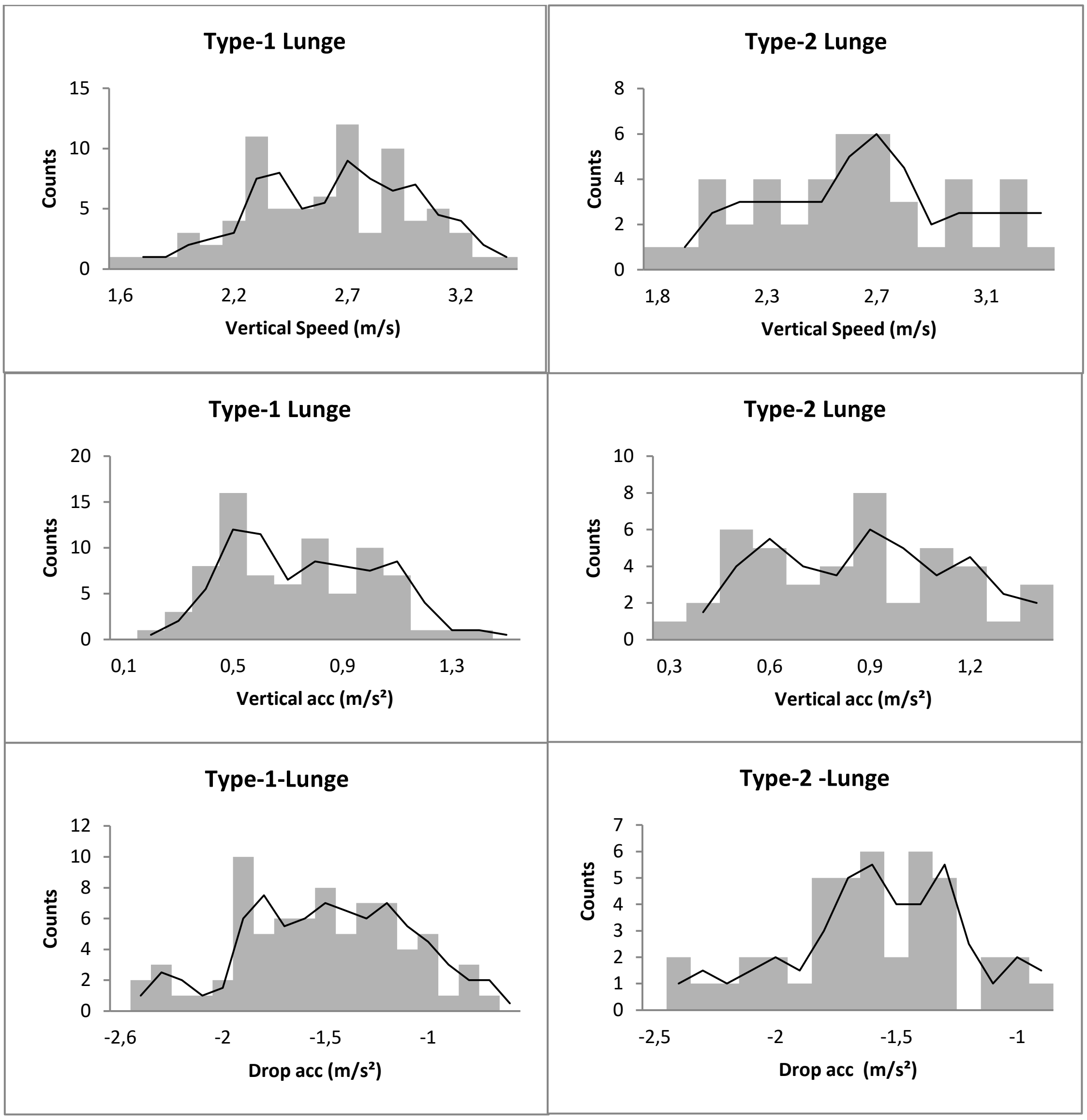

Figure 28. Plot examples for vertical speed, vertical acceleration and drop in acceleration for type1 lunges and type2 lunges.

Differences were also visible in the audio signature where fluctuations in the waveform and the higher flow noise during type2 lunges might be signs of higher fluking rate when the whale was lunging just before surfacing (figure 29). These differences in power indicate that the whales make greater efforts when taking the last lunge and surfacing for breathing, perhaps with the purpose of gaining extra energy needed for diving a longer distance and in a constant upward position towards surfacing.

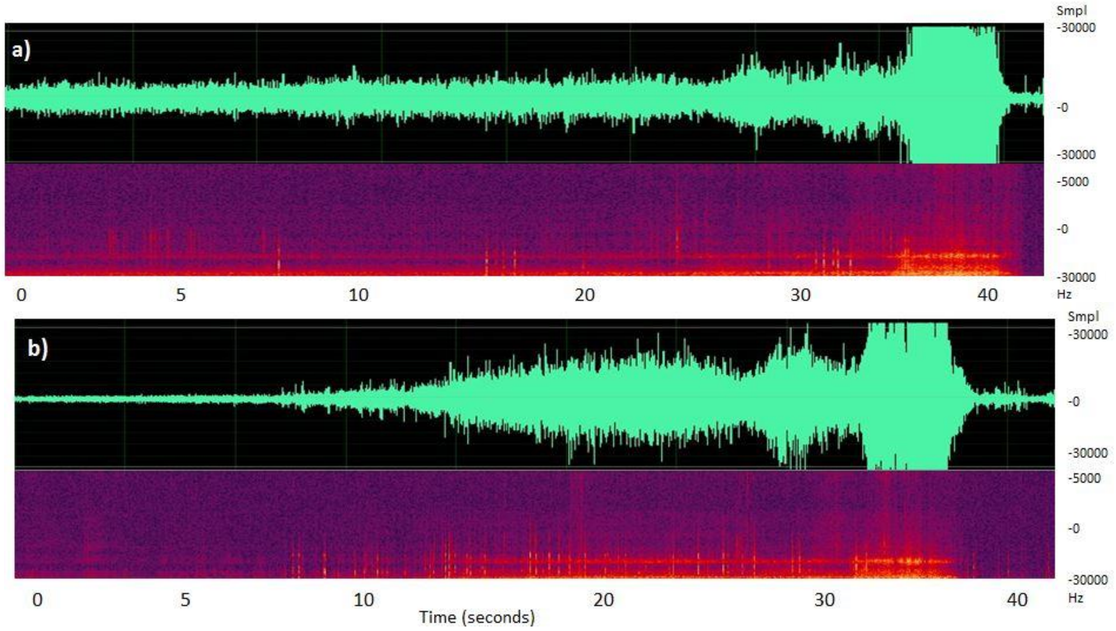

Figure 29. Audio signatures for type1 lunges (a) and for type2 lunges (b).

Slight differences are noticeable in the waveform. Type1 lunges show a more constant waveform than type2 lunges where the signal is bigger and therefore more powerful, but also more fluctuations are present that might be indicating stronger fluking. This occurs in the previous seconds before the actual lunge where the audio signal gets clipped.

4.1.2 Resting behaviour and possible exploratory dives

After actively feeding, the whale Mn215_2014 showed resting behaviour during 1 hour and 45 minutes. During this time (from 11:20:24 to 13:06:20 in the tag time) the whale remained close to the surface and calm (above 5m). When resting, the average depth was of 2.79m and maximum depth reached was 4.75m. In contrast with foraging behaviour, flow noise was very little during this time meaning low or no-whale movement (figure 30).

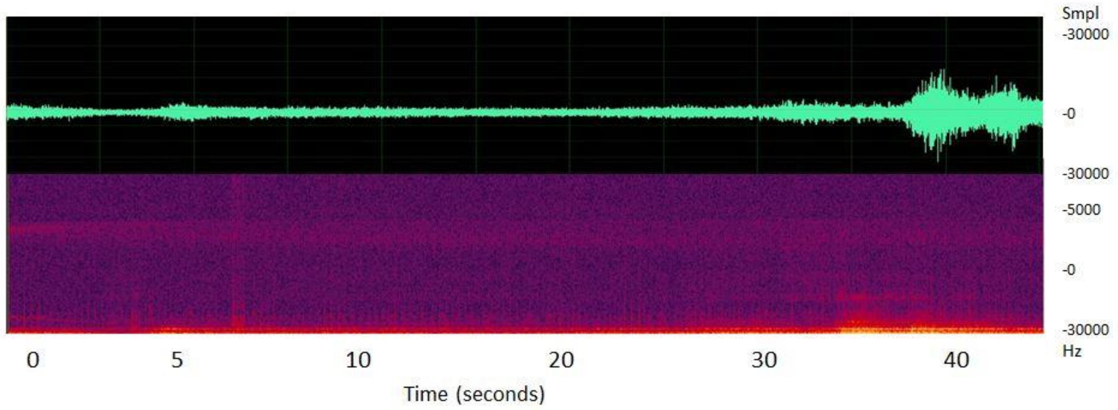

Figure 30. Example of audio signature of resting whale.
The constant line in the waveform shows the little whale movement. This was linked to some low noise fluctuations probably related to slow stroking.

Breathing rate was calculated and compared between foraging and resting behaviour to help for classifying feeding/non-feeding behaviour and resting. The same time window was chosen to measure breathing rate in both behaviour states. For foraging state, data was taken at least one hour after tagging to avoid the possible influence of tagging effects on breathing rate. Results showed that for the same time duration (105 minutes), breathing rate was of 1.19 breaths /min for foraging stages and only 0.78 breaths/min for resting stage. As it was expected, breathing rate was higher during foraging time (125 breaths in total during feeding time while only 82 breaths for resting state). In other words, breathing rate during resting decreased 34.4% in comparison with foraging stage.

After resting stage, from 13:06:20 in the tag time, whale Mn215_2014 was performing surfacing events for around five hours which presented similar characteristics as resting state. Furthermore, some isolated deep dives were found and investigated. Five of these dives showed a scalloped pattern ranging from 60m when descending to 40m when ascending, presenting a similar pattern as it was found in foraging stage (Figure 31b). While these dives also lasted an average of 4 minutes (similar to the average for foraging behaviour), no sign of lunge feeding activity was detected during these dives. The other isolated dives showed an almost equal pattern among each other and they did not show a scalloped pattern. Interestingly, all of these dives presented a particular µ-shape: when performing these particular µ-shaped dives, the whale started quite fast descending close to vertically, until it reached 40-50m (similar to the foraging stage).

Once the whale reached this threshold, it went straight up again making a temporally U-shaped dive. When the whale was near the 20m depth line, it remained at an almost horizontal position, slowly fluking for about 4 minutes. Eventually, the animal significantly increased acceleration, gaining speed towards the surface and take few breaths. Based on this fact, these dives were named µ-shape dives (figure 31c).This dive pattern is repeated for four times during the monitoring stage.

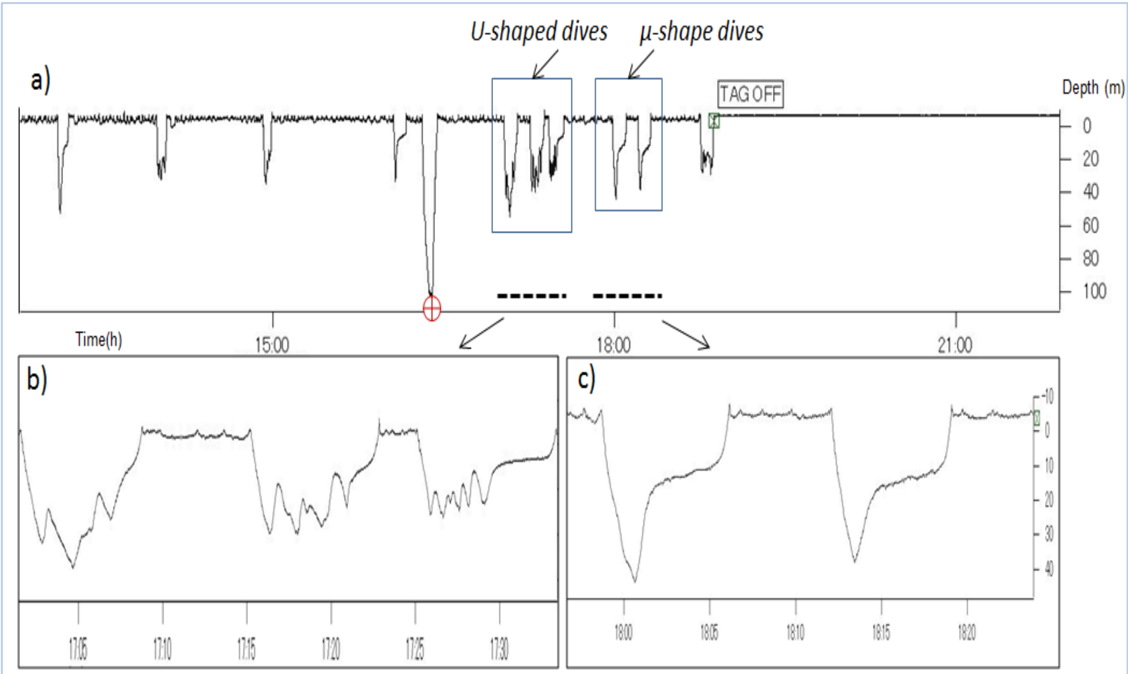

Figure 31. Resting + possible exploratory dives stage

The figure a) shows U-shaped dives and µ-shape dives. During the stage duration (5h 30 minutes) N = 6 scalloped dives and N= 4 µ-shape dives. The small square indicates tag off time. Both dive types appear as exploratory dives for checking prey availability. The red dot indicates the deepest dive found in the whole tag, which reached 110m.
The figure b) represents zoomed scalloped dives. The figure c) is a zoomed representation of two µ-shape dives. Notice the equal pattern among them by looking at in the depth profile. In both figures depth is represented in metres in the y-axis and tag time in the x-axis.

4.2 Testing lunge feedings and breath detectors

- **Lunge feeding detector**

The accuracy of the lunge feeding detector was tested for Mn215_2014 (3h 55 min of foraging). Of a total of 142 lunges registered by listening 111 of the cases were identified to be correct detections (true positives), while 31 of the cases were false detections of false positives. Nine of those 31 cases were registered by the detector but not by listening (true negatives) (see figure 30) and 22 were false negatives (lunges missed by the detector). The absolute number and percentage of false positives out of all automatic detections was 31 out of 111 (27.92%) according to the formula:

*False positives rate (%): False positives/ True positives*100*

For false negatives, the absolute number and percentage out of all manual detections (assuming that all the lunges were correctly identified by listening) is 22 of 142 (15.5%) according to the formula:

*False negatives rate (%): False negatives/True positives*100*

The sensitivity for the lunge detector (ability to correctly detect lunges automatically out of those detected manually) is of 78.16% according to the formula:

*Sensitivity (%)= True positives/(True positives+ False negatives)*100*

It seems that the test present relative high sensitivity considering the data limitations and software constrictions.

The specificity of the lunge detector (test ability to detected events where no lunges occurred) is 22.5% according to the formula:

Specificity(%): True negatives/ True negatives + False positives

- **Breath detector**

The sensitivity of the detector was tested in Mn215_2014 in a window time of 3h 55 min when foraging, because the flow was low enough during the whole tag duration for attesting the presumed breaths with the audio signal. The automatic detector identified 722 blows out of 604 breaths manually detected. A total of 591 out of 722 were identified to be correct detections (correct hits), meaning that 131 were false detections or false positives (18.49%). A total of 118 of those 131 cases were registered by the detector but not by listening (true negatives) (figure 32).

The absolute value of false detections (false positives) out of all automatic detections was 131 of 722 (18.1%).The absolute value for false negatives out of all the manual breaths detected was 13 out of 604 (2.1%). The sensitivity for breath detector was of 82%.1· Eventually, the specificity of the breath detector was 47%.

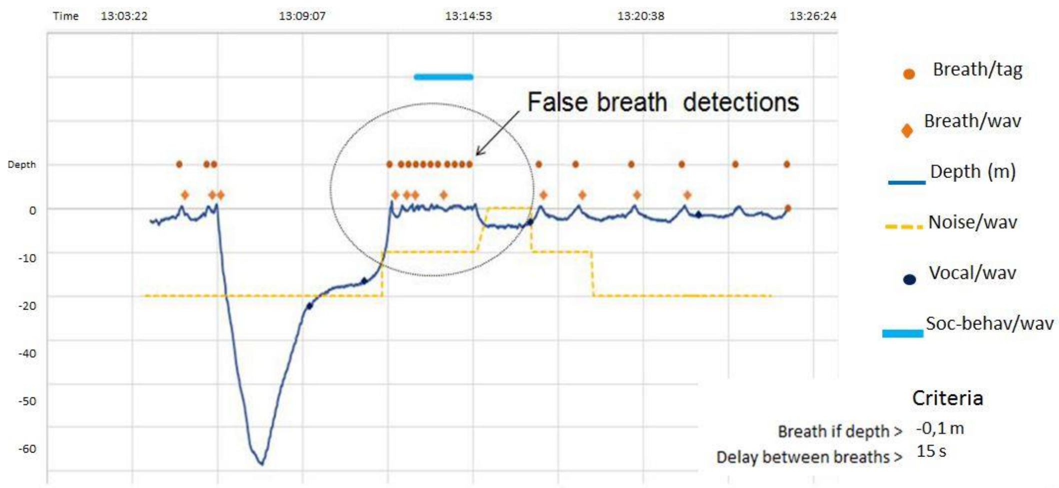

Figure 32. Example of breath detector functioning for whale Mn215_2014 (within 23 minutes).

Time (h: min: sec) is represented on the x-axis and depth (m) on y-axis. The orange dots are the blows automatically detected, the orange squares are the ones detected by listening. In the figure, false positives and true positives are indicated. At the bottom right specific criteria for breath detector in this whale is shown (depth threshold of 0.1m and interval between breaths of 15 seconds). Besides the breaths, the graph shows other data (aurally and visually detected in the recordings) and computed in the Excel. Blue dots indicate whale vocal sounds. Yellow lines indicate boat noise levels and blue line is associated to social behaviour (tail/flipper slapping or breaching).

4.3 Boat noise levels

According to the sound power spectrograms of Mn215_2014, all the signals showed similar energies across frequency with rather low fluctuations among the measured low frequencies range (up to 1500 Hz) (see figure 32,33,34). The power spectra show clear differences between high noise-control and low noise –control (see figures 33 and 35) but similar energies for medium-control and low-control.

- High noise intensity & Control

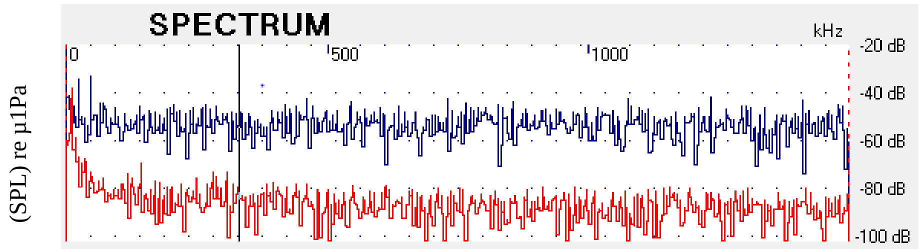

Figure 33. Sound power spectra for high intensity boat noise signal 121 dB re1 µ Pa (blue line) and the control 97 dB re1 µ Pa (red line).

- Medium noise intensity & Control

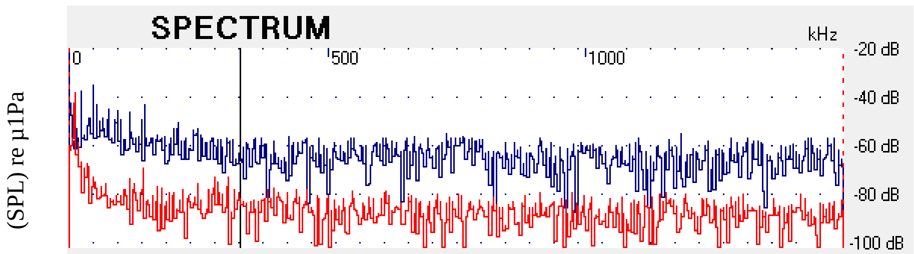

Figure 34. Sound power spectra for medium intensity boat noise signal 118 dB re1 µ Pa (blue line) and the control 97 dB re1 µ Pa (red line).

- Low noise intensity & Control

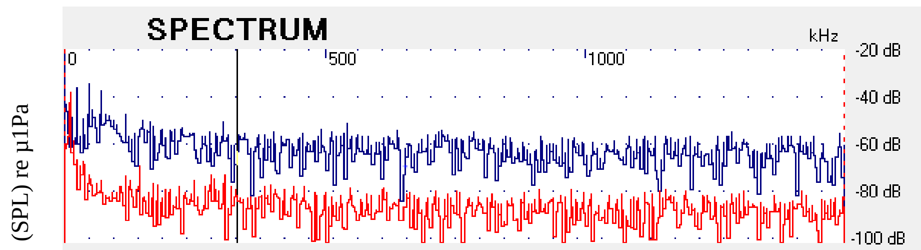

Figure 35. Sound power spectra for low intensity boat signal 109 dB re1 µ Pa (blue line) and the control 97 dB re1 µ Pa (red line).

SPL (rms) values were measured for the low, medium, high noise and control samples at 50, 100 and 300 Hz frequencies. The obtained scores were summarized in the table 11. The results evidence that relative noise levels drop when noise intensity decreases (the highest levels correspond to high noise and the lowest levels for the control sample). For high noise, the results show that rms values stay relatively constant across frequency (around 50 dB), specifically -51 dB at 300 Hz and -50 Hz, and --50 dB at 100 Hz. For medium sample, the highest value was -55 dB at 300 Hz, followed by -58 dB at 100 Hz and the lowest value was registered at 50 Hz with -62 dB. The energy range of medium noise intensity considering all the measured frequencies was from -55 to -62 dB. For low noise, the lowest rms value peaked at 300 Hz with -69 dB, followed by -63 dB at 50 Hz and -60 dB for 100 Hz. In this case, the range value is from -60 to -69 dB.The rms values for the control were -82 dB for 50 Hz, -78 dB for 100 Hz and -80 dB for 300 Hz with a range of -78 to -82 dB (table 11).

	Amplitude (dB)			
f-Hz	High	Medium	Low	Control
300	51	55	69	80
100	50	58	60	78
50	51	62	63	82

Table 11. Relative (uncalibrated) measurements for noise intensity and the control (ambient noise) at the targeted frequencies (300,100 and 50 Hz) by SigPro

Overall,the highest energies registered reached 31 dB above the ambient noise for high noise at 50 Hz. This was followed by the high values at 300 Hz with 29 dB and 28 dB at 100 Hz. For medium boat energies, the maximum power energy peaked at 300 Hz with a 25 dB followed by 20 dB for both 100 Hz and 50 Hz. Finally, for low noise level, at 100 and 50 Hz the values were very similar to each other (18 dB and 19 dB respectively) and very similar to the medium values measured at the same frequency (table 12).

	Amplitude (dB)		
f-Hz	High	Medium	Low
300	29	25	11
100	28	20	18
50	31	20	19

Table 12. Relative differences between noise levels and the ambient noise. The table shows the differences in dB between each noise intensity levels and the control (high noise - control; medium noise - control and low noise - control) for each specific frequency (300 Hz, 100 Hz and 50 Hz.) by SigPro.

4.4 Behavioural changes due to boat exposure

The study was conducted on a total of 7 tagged whales: Mn240_2013, Mn270_2013, Mn255_2013, MnNI_2013, Mn215_2014, Mn200_2014 and MnNI_2014.

- **Effects of boat presence on whale behaviour**

Overall, "Phase" (before, during and after noise exposure) did not seem to influence behavioural changes in any of the parameters analysed. For mean depth, results did not show significant differences for phase 1 or phase 2 compared with the before phase (phase 0). The interactions Phase1:TaggingEffect1 and Phase2:TaggingEffect1 did not show significant differences compared to their reference level Phase0:TaggingEffect0. In contrast, tagging Effect1 appears to be significant at $p<0.001$ showing an increase in the average (±s.e.) values of 18.5 ±5.0 m for mean depth) in comparison with the intercept (9.8 ± 1.3 m) (see table 13).

Regarding jerk rate, values for phase1 and phase 2 did not remain significant compared to the reference level (Phase0). However, BoatEventType1 was significant at $p < 0.05$, showing that in exposure of "passing boats" jerk rate is higher (±s.e.) values of 0.21 ± 0.09 jerks/min) if we compare with approaching boats (BoatEventType0) with scores at 0.25 ± 0.06 jerks/min. In other words, boat approaches were associated with a significant reduction of jerk rate (fewer feeding lunges attempts) compared to boat passes. Breath rate (number of blows/min) showed non-significant changes among phases and changes in breath rate were not explained by the type of boat event or tagging.

Mean vertical speed did not present any significant differences for any of the measured covariates. The results indicate that the whales kept their vertical velocity independent of the phase (before during and after noise exposure), and boats passing or boat approaches. Tagging effect appeared not to have any influence on this parameter.

No significant differences were found for dive rate in the study, providing no evidence of influences of a number of dives /min for phase, boat event type and tagging exposure.

Mean duration did change significantly according to tagging exposure ($p<0.001$). Specifically, an increase of (±s.e.) 265 ± 57 seconds was found under tagging exposure (Tagging Effect1) in comparison with non-tagging exposure with average values of (±s.e.) 92.8 ± 29.4 seconds for dive duration (see table 13)

Behavioural parameter	***Factor level or interactions***	***Estimate***	***s.em.***	***t-valu***	***Pr(>|t|)***
Mean depth (m)	(Intercept)	9.8731	1.3455	7.338	1.33e-10 ***
	Phase1	0.7653	1.8384	0.416	0.678287
	Phase2	0.7813	1.9218	0.407	0.685383
	TaggingEffect1	18.5019	5.0346	3.675	0.000421 ***
	Phase1:TaggingEffect1	1.3431	6.5274	0.206	0.837482
	Phase2:TaggingEffect1	-12.0630	6.5514	-1.841	0.069152
Jerk rate (counts/min)	(Intercept)	0.25683	0.06646	3.864	0.000217 ***
	Phase1	-0.01683	0.08844	-0.190	0.849485
	Phase2	-0.09677	0.09197	-1.052	0.295678
	BoatEventType1	0.21370	0.09748	2.192	0.031097 *
Breath rate (blows/min)	(Intercept)	1.0870	0.0835	13.017	<2e-16 ***
	Phase1	-0.1257	0.1077	-1.167	0.246
	Phase2	-0.0515	0.1153	-0.447	0.656
Mean Vertical speed (m/s)	(Intercept)	1.62278	0.12965	12.516	<2e-16 ***
	Phase1	0.22666	0.176280	1.286	0.202
	Phase2	0.00113	0.183363	0.006	0.995
Dive rate (dives/min)	(Intercept)	0.7441	0.3281	2.268	0.0259 *
	Phase1	0.1861	0.4366	0.426	0.6709
	Phase2	0.2490	0.4540	0.548	0.5849
	BoatEventType1	-0.7810	0.4812	-1.623	0.1083
Dive Duration (s)	(Intercept)	92.88	29.45	3.154	0.00223 **
	Phase1	11.25	39.66	0.284	0.77729
	Phase2	27.81	41.29	0.674	0.50240
	TaggingEffect1	265.22	57.26	4.632	1.29e-05 ***

Table 13. GLM statistical analysis for boat presence effects on whale behaviour.

The table shows the scores reported from the fitted model summary. It includes estimated coefficients, standard error (s.e.m), t values and p-values (Pr(>|t|) based on Walt tests. Values are given for each factor level or/and interaction of the measured behavioural parameters. An interval confident of 95% was applied. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

- **Effects of boat noise intensity on whale behaviour**

Results for mean depth also suggest tagging effects, same as the first model, showing that mean depth increases significantly under tagging exposure ($p<0.001$) at estimate coefficients of (±s.e.) 19.8±4.4 m differences in comparison with non-tagging exposure (±s.e.) 3.5 ± 3.5 m. Interestingly, noise intensity seems to have a clear influence as well regarding mean depth values ($p<0.05$). The results indicate that the whales tend to dive deeper with estimated average values of (±s.e.) 9.4 ± 3.9 m differences when they are exposed to high noise intensity in comparison with low noise intensity (±s.e.) 3.5 ± 3.5 m.In addition,, for medium noise intensity there was a non-significant difference in mean depth compared to low noise intensity.

Non-significance was found for breath rate regarding Boat Event Type, Noise Intensity and the interactions between the two. However, the interaction NoiseIntensity1:BoatEventType1 are very close to being significant (marginally significant), with $p=0.057$, suggesting that there is a tendency in the data for increase of breath rate for Noise.intensity1:BoatEventType1 (medium noise:passing boats) with average values of (±s.e.) 0.8 ± 0.4 blows/min when compared with Noise.intensity0:BoatEventType0 (low noise:approaching boats) (±s.e.) 1.2 ± 0.2 blows/min. Although, it cannot be confirmed, the existence of an effect for this interaction based on this model, but a bigger sample size would truly help for confirming potential effects.

Mean vertical speed and dive rate did not change with Noise Intensity or interactions with BoatEventType in the output.

Results for dive duration support the findings of the first model (effects on boat presence), indicating that whale dives are significantly longer ($p<0.001$) under tagging effect (312 ± 104 seconds) (TaggingEffect1) in comparison with control levels or non-tagging exposure (46 ± 84 seconds). Noise Intensity did not show any influence in the variation of this parameter (table 14).

Behavioural parameters	Factor levels or interactions	Estimate	s.em.	t-value	r(>|t|)
Mean depth (m)	(Intercept)	3.550	3.534	1.005	0.3234
	Noise.intensity1	5.867	4.204	1.396	0.1734
	Noise.intensity2	9.403	3.915	2.402	0.0229 *
	TaggingEffect1	19.888	4.400	4.520	9.6e-05 ***
Breath rate (blows/min)	(Intercept)	1.2710	0.2419	5.255	1.54e-05 ***
	Noise.intensity1	-0.5264	0.2704	-1.947	0.0621 .
	Noise.intensity2	-0.2314	0.2557	-0.905	0.3735
	BoatEventType1	-0.4375	0.3420	-1.279	0.2118
	Noise.intensity1:BoatEventType1	0.8205	0.4131	1.987	0.0572
	Noise.intensity2:BoatEventType1	-0.1021	0.4908	-0.208	0.8368
Mean vertical speed (m/s)	(Intercept)	2.3409	0.3632	6.445	4.04e-07 ***
	Noise.intensity1	-0.6378	0.4241	-1.504	0.143
	Noise.intensity2	-0.5113	0.4015	-1.273	0.213
Dive rate (dives/min)	(Intercept)	0.1188	0.8493	0.140	0.890
	Noise.intensity1	0.2540	0.9918	0.256	0.800
	Noise.intensity2	1.0722	0.9389	1.142	0.263
Dive duration (s)	(Intercept)	46.25	83.67	0.553	0.58465
	Noise.intensity1	107.17	99.52	1.077	0.29041
	Noise.intensity2	32.88	92.68	0.355	0.72534
	TaggingEffect1	311.68	104.16	2.992	0.00561 **

Table 14. GLM statistical analysis for noise intensity effects on whale behaviour.

*The table shows the scores exported from the summary of the final model. It includes estimated coefficients, standard errors and p-values based on Walt tests. Values are given for each factor level or/and interaction of the measured behavioural parameters. An interval confident of 95% was applied. *p < 0.05, **p < 0.01, ***p < 0.001.*

When analysing changes for jerk rate for noise intensity effects, the Wilcoxon test indicated that under the Bonferroni correction, none of the tested comparisons were significant, suggesting that jerk rate is not strongly related to the main covariates Phase and Noise Intensity. However, it is important to consider that the Bonferroni correction is a conservative approach and that before this correction of the significance level, Noise Intensity1 was marginally significant or very close to significant (p=0.09) with differences of 0.33 jerks/min and Noise Intensity2 was significant (p=0.041), compared to Noise Intensity0 showing differences of 0.32 jerks/min. These trends indicate that Noise Intensity might still have an influence on jerk rate if more whales would have been sampled (table 15).

Level 1	***Level 2***	***W***	***p=value***
NoiseIntensity0 (low)	NoiseIntensity1 (medium)	10	0.090
NoiseIntensity0 (low)	NoiseIntensity2 (high)	14	0.041
Phase0 (before)	Phase1 (during)	443	0.772
Phase0 (before)	Phase2 (after)	414	0.692

Table 15. Results of Wilcoxon Rank Sum test for jerk rate.

The table shows W (t =statistic values) and p-values, considering a confident interval of 0.025 after Bonferroni correction for comparison of jerk rate between noise intensity levels and phase levels. H0: Jerk rate and the levels are not related.

4.4.1 Checking for GLM assumptions

GLM model assumptions were tested in order to validate the model by checking for normality in the residuals (figure 36).

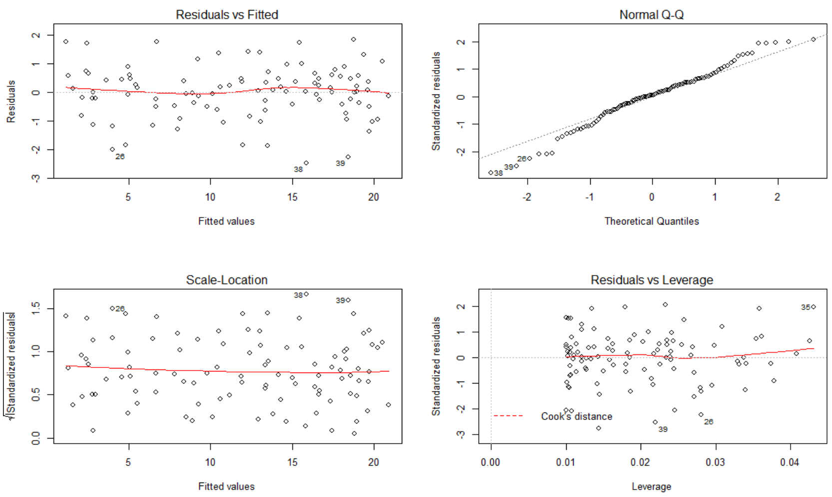

Figure 36. Example of residual plots for dive duration.
The plots show that the residuals follow a normal distribution and therefore, the model can be validated for testing differences in scores for dive duration. It was interesting to check for error distributions in "dive duration" as it was the variable with the highest chances of not following random or unpredictable patterns in the residuals due to high standard error in the GLM results.

The first figure in the upper left part shows the residuals versus the fitted values. The random distribution of the errors confirms that the residuals are normally distributed. The figure in the lower left part (Scale-Location) gives similar information than the upper-left graph but it uses the standardized version of the residuals. Here it is evident that the residuals have a constant spread throughout the range. In the downright graph (residuals vs Leverage) the fact that the residuals fall in a symmetrical pattern indicating normal distribution of the residuals

All the variables showed similar residual plots so that GLM models can definitely be validated (see appendix 3). Overall, after checking for normality in the residuals, it can be assumed that all the variation showed in the results can be explained by the predictor variables in the model.

4.5 Acoustic behaviour

A total of 188 vocal sounds were recorded in the audio files among the 7 deployed tags. Most of the vocalizations were found in Mn200_2014. (N=87). In this study the majority of the vocalizations were non-songs social sounds (low-frequency sounds below 1000 Hz) (table 16).

ID	*N Vocals*	*Tagging duration*
Mn215_2014	47	12.53h
Mn200_2014	87	13.08h
MnNI_2014	0	6.55h
Mn240_2013	20	110.08h
Mn270_2013	2	10.78h
Mn255_2013	1	41.17h
Mn11_2013	29	19.94h

Table 16. Total of vocal sounds found for the seven tagged whales and tag time duration of each tag. N=188 vocal sounds within 214.13 hours of listening.

4.5.1 Low frequency social sounds

Among the seven tags, often low-frequency non-song social sounds such as moans, grunts and pulse trains were found. In many cases, these low-frequency sounds (moans, grunts) were associated with surfacing events (occurring just few seconds before surfacing below 5m depth). In several cases the vocalizations were associated with foraging behaviour (detection of foraging behaviour is explained in the sections 3.1 and 3.2). Furthermore, sometimes these vocal sounds during foraging were accompanied by presumable bubble sounds (audible in the recordings). This was particularly noticeable on the tag attached in the whale Mn240_2013.

The analysis of acoustic properties of each vocalization was conducted only for whale Mn215_2014 during the tag duration (table 17).

Date Time	Description	Duration (ms)	Min freq (Hz)	Peak (Hz)	Call type	Comments
2014/06/25 06:31:47	Upsweep (1/1)	0.373	103	567	swop?	just after tagging
2014/06/25 06:31:47	Upsweep (1/2)	0.267	103	824	swop?	just after tagging
2014/06/25 06:53:03	Upsweep	0.732	188	1430	whup	before breathing
2014/06/25 07:08:14	Upsweep	0.425	73	478	whup	
2014/06/25 07:08:14	Upsweep	0.352	73	496	whup	
2014/06/25 07:09:15	Upsweep	0.296	64	419	whup	
2014/06/25 07:11:17	Upsweep	0.328	117	261	whup	after breathing
2014/06/25 07:12:17	Upsweep	0.405	71	534	whup	
2014/06/25 07:13:18	Upsweep	0.373	54	462	whup	
2014/06/25 07:14:19	Upsweep	0.264	64	463	whup	after breathing
2014/06/25 07:18:22	Upsweep	0.267	50	549	whup	
2014/06/25 07:37:36	Upsweep	0.699	158	251	swop?	
2014/06/25 08:37:21	Downsweep	0.251	100	451	swop?	after breathing
2014/06/25 08:42:25	Upsweep	0.413	143	274	whup	
2014/06/25 09:08:45	Upsweep	0.267	68	377	whup	before breathing
2014/06/25 09:29:00	Upsweep	0.293	61	411	whup	
2014/06/25 09:56:21	Upsweep	0.829	79	385	whup	
2014/06/25 10:30:47	Upsweep	0.373	49	396	whup	
2014/06/25 10:31:47	Upsweep	0.317	61	446	whup	
2014/06/25 10:32:48	Upsweep	0.453	45	360	whup	before breathing
2014/06/25 10:36:51	Upsweep	0.259	150	443	whup	between breaths
2014/06/25 10:57:06	Upsweep	0.283	17	499	whup	
2014/06/25 10:57:06	Upsweep	0.571	79	595	whup	
2014/06/25 11:01:09	Upsweep (1/2)	0.091	80	724	whup	
2014/06/25 11:01:09	Upsweep (2/2)	0.293	62	1268	whup	before breathing
2014/06/25 11:01:09	Upsweep (1/2)	0.085	557	93	whup	
2014/06/25 11:01:09	Upsweep (2/2)	0.291	118	563	whup	
2014/06/25 11:01:09	Upsweep	0.043	133	538	whup	
2014/06/25 11:01:09	Upsweep	0.048	145	625	whup	
2014/06/25 11:05:12	Upsweep	0.109	143	805	whup	after breathing
2014/06/25 11:05:12	Upsweep	0.347	156	351	whup	after breathing
2014/06/25 11:09:16	Upsweep	0.04	198	990	whup	after breathing
2014/06/25 11:10:16	Upsweep	0.053	122	469	whup	after breathing
2014/06/25 11:12:18	Upsweep	0.069	88	847	whup	after breathing
2014/06/25 12:42:26	Upsweep	0.147	129	395	whup	
2014/06/25 13:10:47	Downsweep	0.323	122	367	Und	
2014/06/25 13:15:51	Downsweep	0.176	113	1052	Und	
2014/06/25 13:21:55	Downsweep	0.469	148	322	Und	
2014/06/25 13:45:13	Downsweep	0.483	113	1246	Und	
2014/06/25 13:55:20	Downsweep	0.464	130	290	growl ?	
2014/06/25 13:59:23	Upsweep	0.349	53	467	whup	
2014/06/25 14:16:36	Stable	0.435	137	579	growl?	after breathing
2014/06/25 14:33:49	Downsweep	0.173	118	466	growl?	
2014/06/25 14:58:08	Blow-like	0.387	692	3949	Und	
2014/06/25 16:18:08	Und	1.917	149	836	Und	
2014/06/25 17:23:57	Upsweep	0.541	65	724	whup	after breathing
2014/06/25 17:45:13	Und	6.331	79	262	Und	

Table 17. Acoustic measurements taken for vocal sounds in whale Mn215_2014 (N=47).

*The table contains the real date and time when the vocal sounds were recorded, sound description, duration (sec), peak frequency, frequencies at 95% and suggested call type. The vocal sounds within the yellow square were produced when the whale was feeding. The other vocalizations were reported when the whale was not foragin.. The grey colour in the table represents "whups" call types described in the table as "upsweeps" (N =33 whups).Upsweep ½ means that there were two following vocal sounds. Other sounds types remained unknown, and they are marked by a (?). "Stable" sound means that they do not show any significant upsweep or down sweep components. They could be "swop" according to Fournet, M. E et al., (*2015*) description. Und= undefined sound. Blow-like could be not whale related.*

"Whups" were easily recognized and were the most common found vocal sounds in the seven tagged whales. In Mn215_2014 a total of 33 "whups" were registered within 12:53 hours of tagging. These harmonic upsweeps "Whups" consisted of a low-frequency "growl" with a fundamental pulse followed by a sudden upsweep, according to the first description given by Dunlop *et al*., (2007) (figure 37).

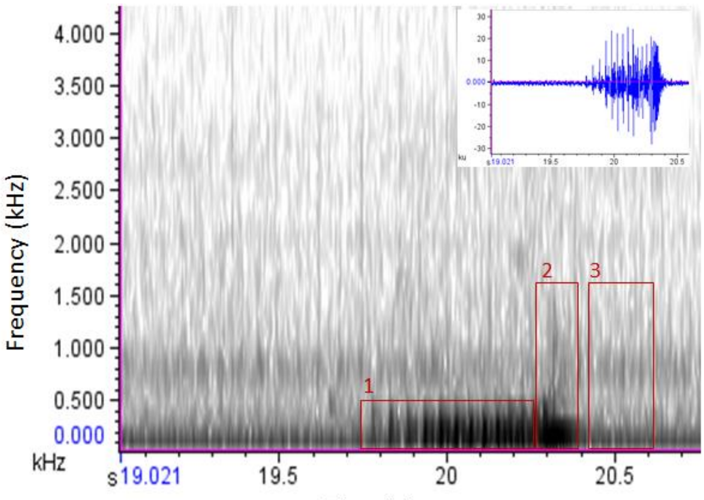

Figure 37 . View of a spectrogram *showing a "Whup" signal example for Mn215_2014.*

(1) growl (2) upsweep, (3) indicates background noise. Hanning window.334 samples, DFT 512, 50% overlap. The growl component lasted 0.43 sec within a 47-270 Hz frequency range with peak frequency at 180 Hz. The upsweep component lasted 0.09 sec in duration and it ranged from 30 to 550 Hz with a peak frequency at 187 Hz.

“Whups” occurred in both situations during feeding and non-feeding behaviour.

The following vocalizations were described and fselected for further discussion as examples of the most relevant information found within the recordings.

Non-social vocal sound 1: this vocalization consisted of two components: the first component lasted for 8.5 seconds. The second component of the vocal sound had a similar structure lasting for three seconds (see white squares). The lowest frequency was at 80 Hz and the peak frequency at 1709 Hz. At this time, the whale was not foraging, but resting near the surface.

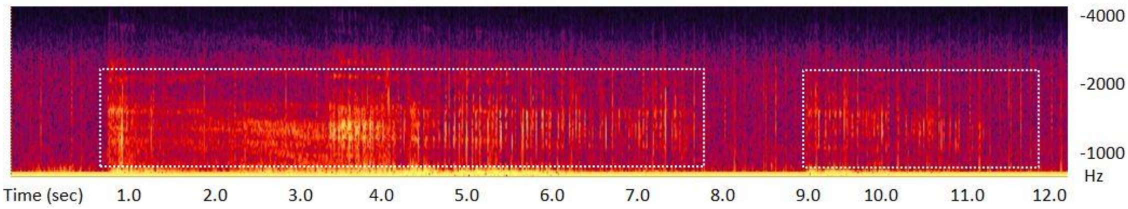

Figure 38. Acoustic signature for non-social vocal sound 1 (recorded on the 25/06/2014 at 17:45:27 on the tagged whale Mn215_2014). Sample rate 48000 Hz, 16-bit. Signal low pass filtered at 3000 Hz.

Non-social vocal sound 2: this sound last 0.47 seconds. The lowest frequency is at 400 Hz and the highest frequency is at 804 Hz. During this time the whale was foraging. Bubble sounds (probably produced by the whale to enable prey capture) were also audible. This vocal sound is followed by a blow (figure 39).

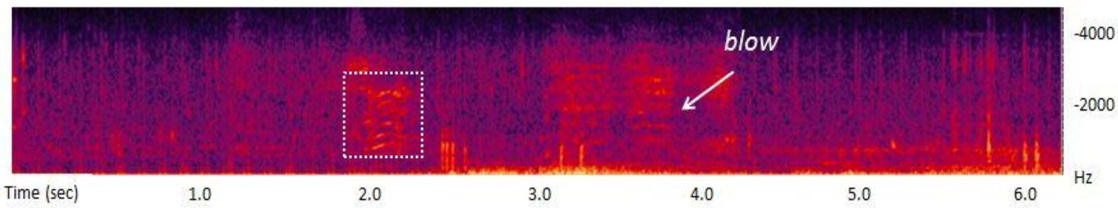

Figure 39. Acoustic signature for non-social vocal sound 2 (before breathing) (recorded at 08/06/2013 at 16:36:06 on tagged whale Mn240_2013). Sample rate 48000 Hz, 16-bit, Mono. Low pass filtered at 4000 Hz.

Non-social vocal sound 3: it contains two components; the first component was shorter (0.5 seconds) than the second one (1.5 seconds). The second or main component reached the lowest frequency of 403 Hz and the highest frequency of 1982 Hz (figure

40). During this vocal sound, the whale was moving fast, as is visible in the flow noise, because it was actively feeding at the moment. This sound could be a “grumble”, name given by Dunlop *et al.*, (2008).

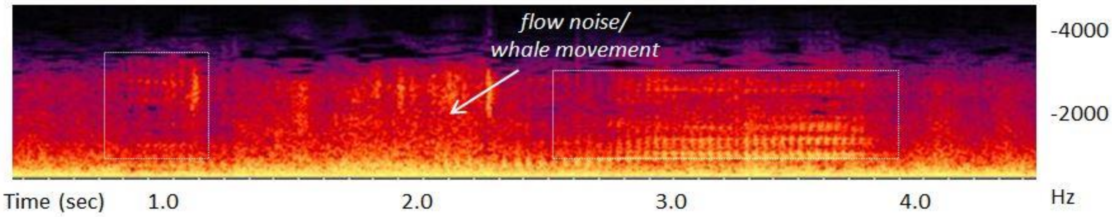

Figure 40. Acoustic signature for non-social vocal sound 3 (recorded on the 08/06/2013 at 22:09:22 on the tagged whale Mn240_2013). Sample rate 48000 Hz, 16-bit, Mono. Low pass filtered at 3000 Hz.

Non-social vocal sound 4: this sound type duration consists of a single component of 1.27 seconds duration. The frequencies ranged from the lowest at 67.5 Hz to the highest at 945 Hz (figure 41). According to the consulted experts, this sound type is commonly associated with surfacing events in humpback whales, although the signal is not clear due to high flow noise. During this sound event the whale showed feeding and fast movement for lunging.

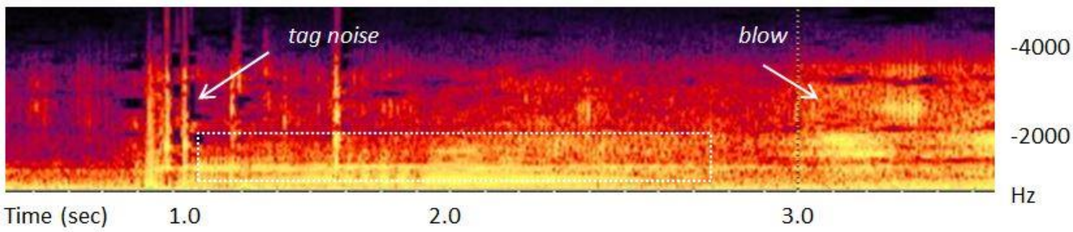

Figure 41. Acoustic signature for non-social vocal sound 4 (before breathing example) (recorded on the 08/06/2013 at 22:12:26 on the tagged whale Mn240_2013). Sample rate 48000 Hz, 16-bit, Mono. Low pass filtered at 4000 Hz.

Non-song social vocal sound 5: This sound type lasted for 2.8 seconds. The lowest frequency was registered at 95 Hz and the highest frequency was at 1282 Hz. This vocal type is associated with foraging behaviour and bubbles sound and occurred before breathing (figure 42).

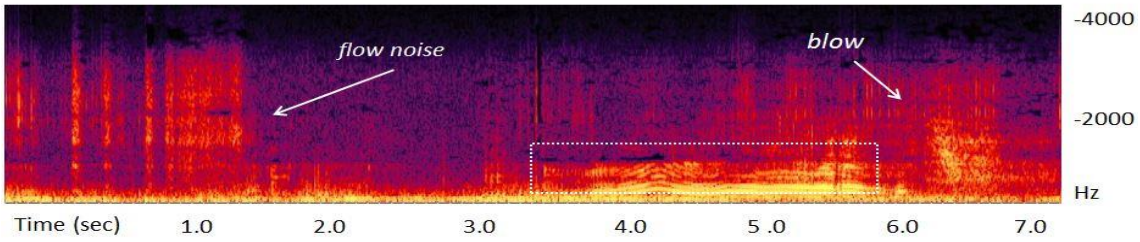

Figure 42. Acoustic signature for non-song social vocal sound 5 (before breathing example) (recorded on the 08/06/2013 at 22:12:50 on the tagged whale Mn240_2013). Sample rate 48000 Hz, 16-bit, Mono. Low pass filtered 3000 Hz.

Non-song social vocal sound 6 (grunts): grunts usually occurred in bouts or series containing several units or similar following grunts. The sounds lasted an average of 0.25 seconds with the lowest frequencies at 47.5 Hz and the highest at 332 Hz. In this case the whale was not showing feeding behaviour and was moving slowly (figure 43 and 44).

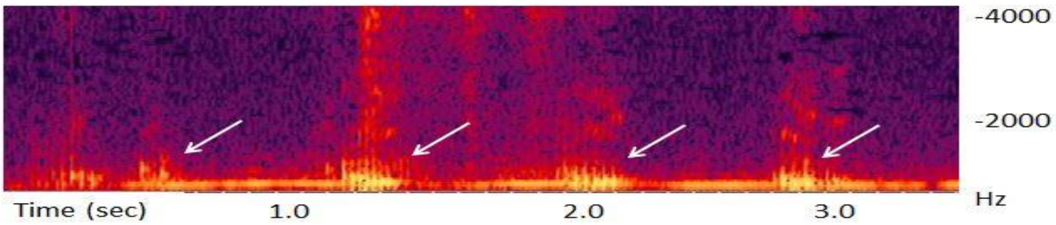

Figure 43. Acoustic signature for non-song social vocal sound 6 (grunts series example 1) (recorded on the 07/06/2013 at 07:08:39 on the tagged whale Mn11_2013).Sample rate 48000Hz, 16-bit, Mono. Low pass filtered at 4000 Hz.

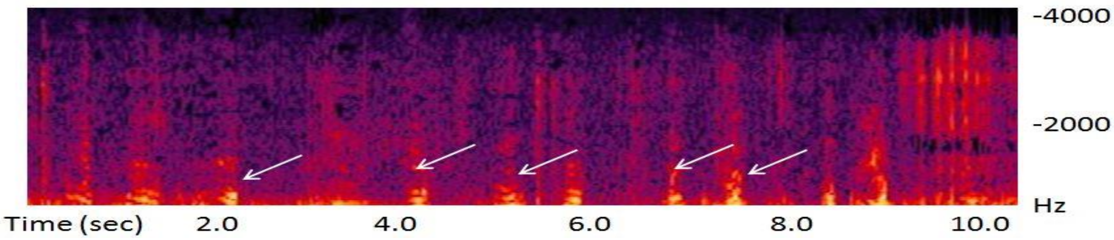

Figure 44. Acoustic signature for non-song social vocal sound 7 (grunts series example 2) (recorded on the 07/06/2013 at 07:26:09 on the tagged whale Mn11_2013). Each arrow indicates a grunt. Sample rate 48000 Hz, 16-bit, Mono. Low pass filtered at 3000 Hz.

Non-song vocal sound 8: in this example, the whale makes several vocal sounds, some less than 400 ms (grunts) and some slightly longer in duration (moans). The minimum frequency was at 95 Hz and the peak frequency at 453 Hz (figure 45).

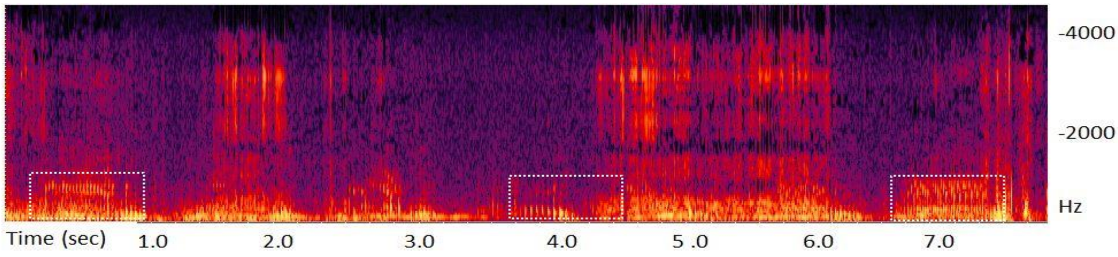

Figure 45. Acoustic signature for non-song vocal sound 8 (moans and grunts serie) (recorded at 04.50.30 on MnNI_2013.) Pulse train of vocal sounds. Sample rate 48000 Hz, 16-bit, Mono. Low pass filtered at 4000 Hz.

4.5.2 High frequency vocal sounds

Interestingly, some high frequency vocal sounds or "calls",were recorded in the tag attached to Mn240_2013.

In total, four similar "calls" were recorded and all of them were found in the same tag (whale Mn240_2013) within a short period of time (20 minutes). During this time the tagged whale was actively foraging during the night. The first call (produced at 04:10:36) was clearly audible and relatively loud so that it is very likely that it was produced by the tagged whale. The call contains four separated harmonic units produced by the whale just after acceleration (see high flow noise in the figure 46). The frequency ranges from 90 Hz up to approximately 8000 Hz with maximum intensity of 110 dB. The call last for 15 seconds. There are clear oscillations in frequency (figure 46).

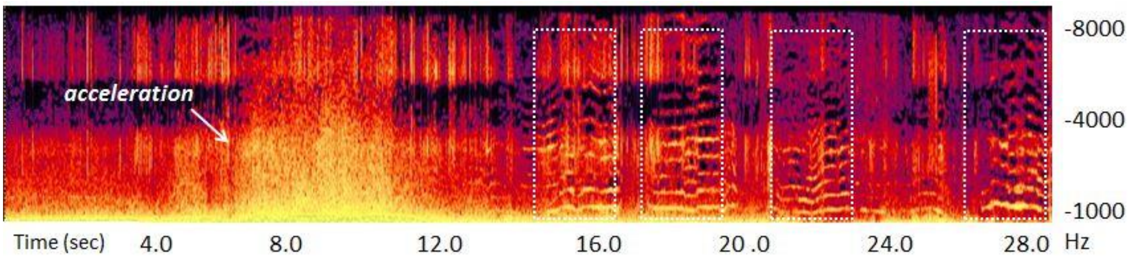

Figure 46. Spectrogram for vocal sound (call).
(recorded on the 13/06/2013 at 04:10:36 on the tagged whale Mn240_2013). Low pass filtered at 8000 Hz. Sample rate 48000 Hz, 16-bit, Mono. with 127 dB re 1 µ Pa energy

This call was followed by three following similar calls occurring within the next 15 minutes. These calls showed a similar pattern than the first registered call. However, it was not clear whether or not the sounds were produced by the same individual. When listening to the audio it sounded more like a background call in comparison with the first one.

The first call is produced at 04:10:36 just at the moment that the whale reaches his maximum depth in the foraging dive (25m). The first background call is produced 5 minutes and 5 seconds after the first call (04:15:41 tag time) and it is heard when the tagged whale was at 27m, just a few seconds after reaching maxim depth of the dive at 30m, following a similar pattern as the first call. This call contains two units lasting 4.0 and 5.0 seconds respectively, with a maximum power of 95.6 dB. No lunge feedings are performed by the tagged whale during this particular dive (figure 47;48)

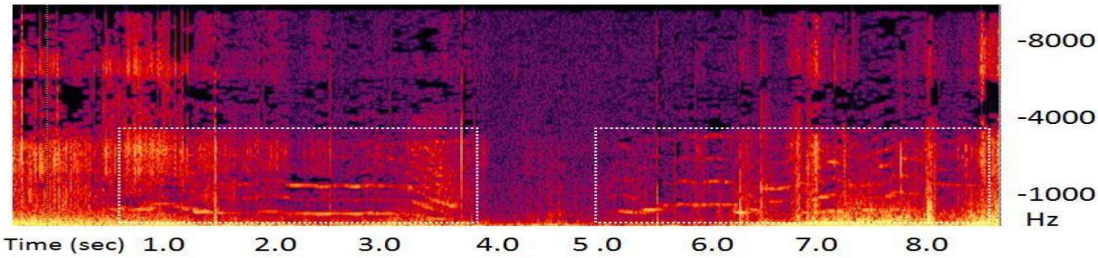

Figure 47. Spectrogram of the first background call (recorded on the 13/06/2013 at 04:15:41). The call contains two separated harmonic units with high frequencies up to 4000 Hz,

The second background call is heard one minute after the previous one (04:17:24) and at this time the tagged whale was diving at 17m depth, but no lunge events were registered in this dive. The third background call occurred at 8 minutes and 25 seconds after at 04:25:49. In this case, the call was heard when the tagged whale was at 4 metres coming up for breathing after making a few lunge feedings (figure 48).

The third and fourth background calls were difficult to interpret in the spectrograms due to flow noise, although it was still possible to hear them in the audio files. In these cases, it felt like they were produced far away from the tagged whale as the sound was much less audible.

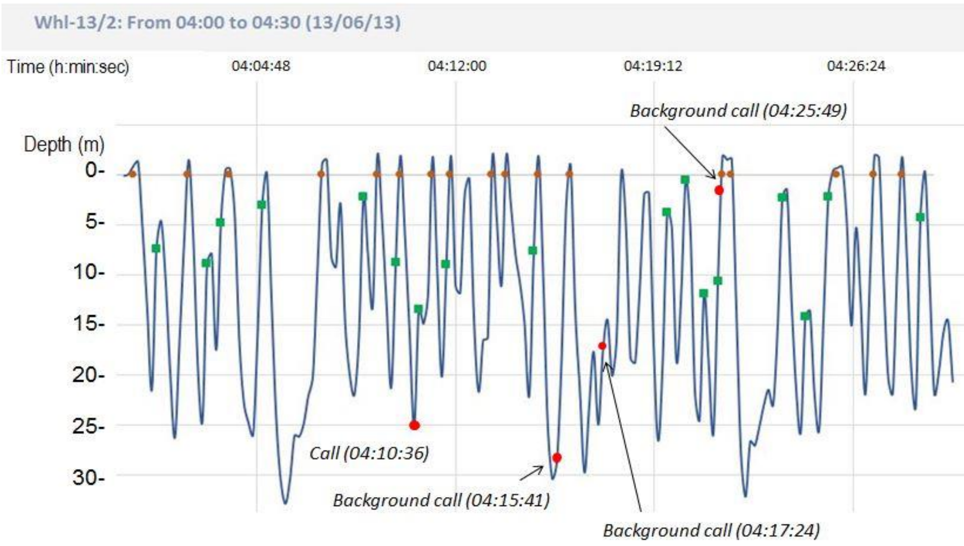

Figure 48. Calls sequence during foraging at night.
The green squares represent lunges. The orange dots indicate breaths. The red dots show calls during feeding stage.

5. Discussion

5.1 Gaining knowledge into humpback whale behaviour

The results of this project provide novel knowledge regarding the foraging behaviour of humpback whales in Icelandic feeding grounds. Foraging dives showed constant U-shaped dive types and often had a scalloped pattern near the maximum depth of the dive (i.e. several consecutive ascents and descents near the maximum depth before the steep ascent to the surface). This trend has been also reported for other baleen whales (blue, fin and humpback whales) when studying kinematic patterns associated with lunges (Croll *et al*., 2001, Acevedo-Guitierrez *et al*., 2002, Goldbgen *et al*., 2006, Goldbogen *et al*., 2008; Goldbogen *et al*., 2011, Ware *et al*., 2011). This makes sense as these baleen whales similarities in body physiology and the similar prey target indicate that they must use similar ways of catching prey.

In addition, a new dive type was reported on the tagged whale Mn215_2014 at resting stage: µ-shape dives (U-shaped pattern plus a linear pattern at the horizontal line before breathing) (figure 31c). The periodicity of these constant µ-shape dive types during five hours after foraging, suggest that these dives may play a specific role in humpback whale behaviour. In addition, the presence of µ-shape dive types linked to isolate scalloped dives during the same period might indicate that these particular dives may have an exploratory function where the whale might be testing for food availability. Alternatively, for µ-shape dives, the whale might be going to a deeper depth to listen to its environment. However, these conjectures are not enough to conclude the function of these dive patterns and further research needs to be done. The fact that no information was found in the literature regarding this dive pattern suggests that this type of µ-shape has likely not been described before.

5.2 Validation of lunge and breath detectors

Determining with certainty when whales are attempting to feed is essential for answering deeper questions about foraging ecology (e.g., energetic costs, prey selection). Considering the time constrictions and the fact that the lunge detection was developed exclusively in Excel, the resulted sensitivity (ability to correctly detect lunges automatically out of those detected manually) of 78% (based on 3h 55 min of foraging of validation data) was considered satisfactory. This approach for detecting lunges based on preliminary exploration of whale behaviour and the usage of thresholds for drop in vertical speed, vertical acceleration and depth at the precise moment of lunge is definitely a worthy tool for helping lunge event identification with relatively high accuracy in tag data.

It could be concluded that using vertical speed and acceleration parameters and flow noise (whale movement) could give similar results than using the speed calculated from the propeller, at least for near vertical (upwards or downwards) lunge identification (figure 14).

It is unlikely that the whales performed horizontal lunges at foraging as a correlation between a linear depth (or close to linearity) and the typical acoustic signature of a lunge was never found in any of the tagged whales. This may suggest a trend for humpback whales for using vertical foraging techniques in this particular feeding ground where they could benefit from productive cold and depth waters. Adding an additional layer looking for seasonal prey distribution could have helped understanding humpback whales foraging skills in Skjálfandi Bay.

Similarities were found when comparing the results from this project with existent literature regarding whales foraging kinematics. For instance, for whale Mn215_2014, the average maximum vertical speed reached when lunging was 2.62±0.41 m/s with the maximum value at 3.90 m/s. The average peak in acceleration was at 0.72±0.31 m/s^2 and the maximum was at 1.86 m/s. The typical drops in acceleration occurring in the lunge peak were at an average of -1.5±-0.42 m/s^2 (see section 3.2). Such results match with previous studies made by Ware *et al*., (2011) who also studied the kinematics of near vertical lunge feedings and other lunge types in humpback whales. This new approach enhanced our understanding of whales foraging behaviour. Here it is demonstrated that humpback whales use drag based feeding techniques for foraging and vertical lunge feeding in the highly productive Icelandic feeding grounds. For future research, further development of the lunge detection algorithm is recommended to determine the efficiency of this detector and optimize its accuracy. The incorporation of a video camera (when visibility is reasonable) to capture prey during feeding attempts could bring broader knowledge regarding prey preferences. The inclusion of 3-axis acceleration/ magnetometer data (to estimate whale orientation) would be a valuable approach to achieve a more detailed exploration of whale kinematics and foraging abilities as it was carried previously for studying large baleen whale´s foraging (Cade *et al*., 2016).

Overall the automatic breath detector greatly helped to recognize breath events. The detector worked with a high sensitivity of 82% (ability to detect breaths manually detected), it maximized breath detections previously made manually (aurally and visually) and helped for identifying and excluding false detections made accidentally by listening, especially in the presence of high flow noise. The high relative specificity (true negatives rate) for breath detectors was generated by the fact that even if it is known that the whale is at the surface for breathing by looking at the depth data, it was not possible to determine the exact moment when a blow occurred, unless the audio data would have been integrated for signal detection. Eventually, an additional algorithm is recommendable for avoiding these false detections and it would improve the results.

In this thesis, it is demonstrated that by using sample parameters and basic software tools (Excel) is it possible to describe and monitor respiratory rates and foraging behaviour of humpback whales (and probably of other baleen whales as well) in a relatively easy manner. Nonetheless, it was proved that tag location on the whale has an influence on the automatic detectors and that the capability for detections can be enhanced by simply adjusting the values. The inclusion of the acoustic data for feeding lunges (based on flow noise) or breaths into the detectors may have saved time as it would have facilitated automatic detection. It may have been possible to achieve the same goals in a easier manner and perhaps with more accuracity by having more time and extended knowledge of a more adapted and programming language; however, the current detectors implemented in Excel were sufficient to address the objectives of this project and provided meaningful biological results.

5.3 Boat noise levels

In this study, it was found that the highest boat-related noise received by the whales was measured at 143 dB re 1 µ Pa. Since boat noise was exclusively gathered by the acoustic tag, it was not possible to define the exact geometry at that moment (e.g., distance from the boat to the whale, speed, way of approaching). Nevertheless, the source level (SL) produced by the boats is obviously higher than the received level shown in this study. Sound is attenuated with distance due to both; transmission loss and absorption. Taking into account absorption properties it is likely that the reported boat noise levels fall within the source levels (SL) generally produced by small whale watching boats (e.g., 115–127 dB re 1 µPa at 1 m for one-third-octave bands (Au and Green, 2000) and 145–169 dB re 1 µPa at 1 m for one twelfth-octave bands), assuming that noise intensity increases considerably with speed (Erbe, 2002). Boat noise was compared with the ambient noise (97 dB re 1 µPa when no boats were present and adequate weather conditions). Assuming an accurate measurement for ambient noise, the highest relative boat noise introduced in the marine environment within 214.13 hours of recordings was reported as a range from 28 to 31 dB at the dominant frequency range used by vocalizing humpback whales on the feeding grounds (50 Hz to 300 Hz) (Erbe, 2002).

These values overlap in low frequencies between boat noise and whale vocalization suggest that it is likely that noise levels from whale watching boats cause masking in whale communication. These results are preliminary as underwater noise research in the wild involves many different variables for addressing potential effects, but it is a good starting point for further research regarding noise and impacts of cetaceans. A recent study carried out by Dunlop, R. A. (2016), demonstrates that groups of humpback whales showed an increase of the number of vocal sounds and surface behaviour (e.g., tail slapping) in exposure to wind-related noise. However, the whales remained silent during high noise generated by a passing vessel, suggesting a masking effect and that the whales might not be able to cope with boat noise boat Dunlop, R. A. (2016).

Determining whale behavioural and masking thresholds, or even harmful levels (e.g., from passing cruise ships) due to boat noise levels, would involve a more detailed study including more variables (e.g., distance between the noise source (boat) to the target (whale), boat speed, number of vessels) and boat AIS data. For example, the application of adequate sound propagation models as it was done in other locations (e.g., the study carried by Erbe, C. 2002 in British Columbia and northwestern Washington State) would allow for the prediction of noise levels and take into account the bathymetry and acoustic properties in the water column. These types of noise predicting projects could greatly help stakeholders for enforcing the existent "soft" guidelines in the study area.

5.4 Potential effects of whale watching boats on humpback whales

The choice of separating the analysis by using two different GLM models (one for impacts of boat presence (before, during, and after) and one for impacts of boat noise level) provided a better understanding of the relative contribution of each aspect of boat exposure on the measured behavioural parameters.

The results indicated that whale watching activities in Skjálfandi Bay may cause changes in humpback whale dive patterns (mean dive depth in particular) and possible disruption of foraging behaviour (as indicated by changes in jerk rate). These responses are clear in this specific situation when boat noise is high and boats are probably relatively close to the whale. Further, the observed increase in breath rate during boats approaching might be indicating stress but these results are not clear enough for confirming an effect as they seem quite limited based on the few number of analyzed whales. Regarding the analysis of boat presence, the absence of effects on Phase covariate (before, during and after boat presence) was an unexpected result, as it was hypothesized that the behaviour of the whales during and after exposure to boats would differ from the behaviour of the whales before the exposure. The lack of effects of Phase can be driven by the definition of the "during" phase. Probably, the way that "during" was defined may did not correspond to the perception of the whales and they may have heard/been aware of the presence of the boats much sooner than the start of the defined "during" phase.

It was expected that the whales reacted to boats more strongly within the first hour after the tag was attached, as indicated by the Tagging effect variable, specially considering that the used tags were invasive and attached to the animal using a small pin. These initial behavioural reactions (making deeper and longer dives) due to tagging, highlighted the fact that the behaviour of tagged whales can be temporarily disturbed at first and that those initial observations should not be considered natural behaviour. Furthermore, it is important to highlight that these immediate responses also served as a guide to understand how the whales might react to other disturbances (including whale watching boat disturbance). Similar behavioural reactions have been reported for humpback whales in other regions, which suggest that performing longer dives might be a sign of whale disturbance. For example, Schaffar, A, 2009 and her team found that the whales performed significantly longer dives from 2.7 (±2.4) to 3.1 (±1.9) mins and a considerable decrease in their path linearity when they compared whale behaviour with and without boat presence (Schaffar, A., Madon, B., Garrigue, C., Constantine, R., 2009.) These whale reactions are likely to be associated with avoidance strategies as cetaceans and other marine mammals show these reactions to elude predators (Howland, H. C., 1974; Weihs, D., and Webb, P.W. 1984).

The reduction in jerk rate (associated with foraging lunge events) (from 0.25 ± 0.06 to 0.21 ± 0.09 jerks/min) during boat approaches in comparison with boats passing indicate a decrease of lunge feedings during approaches (when they were exposed to more aggressive boat manouvering) and it may suggest disruption of foraging behaviour (or at least less foraging attempts). Aditionally, the fact that the results for jerk rate were marginally significant when exploring changes in noise intensity may support the previous findings (jerk rate decreases during boat approaches) as generally higher noise is associated with boat approaches,but additional statistical analyses are needed to evidence the effects. The temporal disruption of foraging behaviour can significantly reduce foraging success. Short-term implications such as the increase of energetic costs due to stress may, imply long-term consequences affecting the energy availability for subsequent migration and breeding season. These short-term responses have been previously demostrated (e.g., Schaffar, A *et al.*, 2009). More recently, evidences of impacts on humpback whales foraging behaviour due to shipping noise and the implications have been widely described by Blair H.B, Merchant N.D, Friedlaender AS, Wiley D.N, Parks S.E. (2016).

It is worth noting that the difference in jerk rate found in this study might also depend upon other factors not included here (e.g., angle of approach, speed, number of boats) as exclusively tag data was used for the analysis. More generally, the natural variation in whale behaviour (due to, for example, behavioural state before noise exposure, age and gender of the individuals, previous experiences of boat exposure, habituation or sensitization) (Ellison, W. T *et al*.,2012), may also mask the detection of effects when analysing tagging data sets with relatively small sample sizes.

The model for boat noise effects demonstrated that the whales started diving significantly deeper when noise was more intense (from 3.5±3.5m to 9.40±3.9m) between low and high noise intensity, suggesting vertical avoidance behaviour. Generally, whale avoidance behaviour or disturbance signs are likely to be the same as the reactions that whales would show for avoiding predation and this is useful for understanding potential impacts due to anthropogenic disturbance (Frid and Dill, 2002).

Interestingly, mean depth also increased due to tagging in both the boat presence and boat noise models, suggesting a similar level of disturbance between boat events with high noise levels and boat events that occurred early in the tag record. In addition, the fact that only high intensity noise was significantly different from low intensity noise might indicate that whale behaviour only changed when boats were relatively close. In other words, low or medium noise intensity may not have been loud enough for the whale to have a response in terms of changing mean dive depth.

It is likely that whales responded to noise from whale watching vessels by increasing their breath rate (0.8 ± 0.4 blows/min differences and p=0.057) due to a higher energetic cost that could be generated by stress. Nonetheless, more analysis is needed for detecting clearer responses in this parameter. Increase of breath rate has been reported in humpback whales previously (Baker C. S *et al*., 1989). The study carried by Baker C. S demonstrated that in presence of medium-large size vessels, at a distance less than 4000m, humpback whales responded by increasing blow rate and dive duration. Further, they showed avoidance behaviour by moving away from the approaching vessels (Baker C. S *et al*., 1989).

Testing stress hormons levels present in the blood samples or skin biopsies samples of the tagged whales would have helped to interpret negative effects from boat pressure from a different perspective and it is something to take in account for future projects.

Despite the given small amount of data, GLM seemed to be a good approach for detecting potential effects. At least mean depth and dive duration seems to be sensitive to behavioural changes, suggesting they are good indicators for measuring whales short-term reactions in exposure to boats.

Moreover, it is likely that short term behavioural changes are correlated with speed, distance and number of boats (e.g., Erbe *et al.*, 2001; Baker C. S *et al.*, 1989). These context-dependent variables (e.g., distance, speed, number of boats, size) could not be included in this analysis for a more complete understanding of the behavioural changes during boat encounters. A combination of methodologies including boat AIS data, visual observations and tag data (including 3-axis acceleration for estimating whale orientation) would be a more comprehensive approach for detecting impacts in cetaceans and monitoring further risks. The study of short term reactions is important for developing the "zone of responsiveness"; this zone predicts over what range animals are likely to react to a boat. This valuable assessment can be applied for further development of whale watching guidelines.

Finally, considering that humpback whales present relatively strong site fidelity for particular feeding grounds (Palsbøll *et al.*, 1997; Stevick *et al.*, 2006) in Skjálfandi Bay (Basran, pers.comm., 2017 February), some whales are likely to be repeatedly exposed to whale-watching activities over the years, meaning that the potential impacts due to boat presence/noise may be cumulative and that there would be differences in the tolerance levels of different whales.

5.5 Contributions for humpback whale vocal sounds in Icelandic feeding grounds

Typical humpback whale´s low frequency vocal sounds (below 2 Hz) during feeding grounds were also reported in this study, evidencing that humpback whales in Icelandic waters produce the same sound types as in other feeding grounds.

The preliminary results show a relation between low-frequency sounds (e.g., moans, grunts, pulse trains) associated with surfacing events (based on observations/listening) and some cases linked to bubble sounds (feeding behaviour). Interestingly, these sounds types and other low-frequency sounds (e.g., trumpeting) have been already reported in humpback whales during the feeding season in southeast Alaskan waters linked to surfacing behaviour (e.g., flipper slaps, fluke slaps) (Thompson *et al.*, 1986) and in the Northwest part of the Atlantic Ocean (Stimpert *et al*., 2011). It is suggested that they might play a significant role in whale communication (Thompson *et al.*, 1986). However, further qualitative and quantitative analysis would be required to support the manual findings on the data, that was not possible to perform in this case due to time constrictions.

Harmonic upsweeps "Whups" (Wild and Gabriele, 2014), or originally "Wops" (Dunlop *et al.*, 2008) was the only vocal sound type call that could be precisely categorized as a "type" and they were the most common vocal sound in the acoustic data. The existent non-songs vocal sounds "whups" in this study matched in acoustic properties (the growl component duration was 0.43 sec within a 47-270 Hz frequency range and peak at 180 Hz; the upsweep component lasted 0.09 sec in duration and it ranged from 30 to 550 Hz with a peak frequency at 187 Hz*)* with the previous studies for "whups" found in Iceland (Björnsson. A *et al*., 2014), and also in other feeding grounds and migratory routes (e.g., Erbe, C., & Gustavus, A. 2003; Stimpert *et al*., 2011).

According to the study carried out by Dunlop *et al*., 2008, "Whups" were heard more frequently in groups of more than one humpback whale. The function of "whups" is still

unclear but the authors suggest that it is a fundamental component for inter group communication and mediates social interactions (Dunlop *et al*., 2008).
The study reveals that humpback whales in Icelandic feeding grounds produce relatively high-frequency sounds up to 8000 Hz.

In addition, the rhythmic high frequency vocal sound types found in Mn_240_2013 suggests that the North Atlantic population of humpback whales (particularly in Icelandic feeding hot spots) share vocal types with the populations in Alaskan feeding grounds and migratory paths of Australian waters. The four calls within 20 minutes of foraging behaviour suggests that those calls could be Atlantic Humpback whales feeding calls. These "rhythmic" feeding calls have been reported and described by (Cerchio *et al.*, 2001) in South East Alaskan feeding grounds. It was not possible to confirm whether or not the calls were produced by the tagged whale or nearby whales in the area. Thus, the clear differences in loudness between the first call (maximum power at 110 dB) and the other following three calls (below 96 dB) suggest that the calls might have been produced by different individuals. Bubble sounds when foraging (perceptible in the audio) could be a sign of "bubble net" feeding technique, a behaviour that has been reported in Skjálfandi Bay (Rasmussen M .H., 2016 June) but not scientifically proved yet.

Nonetheless, the separated units of the reported calls, appear to be similar to parts of the songs reported for the South East Alaskan feeding grounds, reported by McSweeney, *et al.*,(1989). Interestingly, these Alaskan summering songs also share song fragments in common with the songs heard off Mexico and in Hawaiian waters during winter.
Further, Humpback whale songs have been previously recorded on feeding grounds of the North-West Atlantic Ocean (Mattila *et al*., 1987; Vu, 2012) and precisely in the area of study Skjálfandi Bay, Iceland (Magnúsdóttir, *et al.*, 2014)**.**

5.6 The usage of Excel as a data management tool

Excel was chosen for preliminary data exploration and management in this thesis as it is a well-known, easy to start with and rather flexible tool.The usage of customized Excel sheets for processing the tag data was a useful tool for preliminary visualization and management when using these big data sets. This tool not only allowed the exploratory analysis of the tag data, to accurately match the time between tag data and the acoustic information (added manually to the Excel sheet) and make complex graphs with those data, but also it served for developing the automated lunge and breath detectors. While the development of the first worksheet (as a baseline for the other whales) was a tedious and time-consuming task (including maintenance and update work), once the first sheet was designed it was relatively easy to create the others for the following whales. However, the usage of Excel was sometimes prone to errors. It is important to mention that Excel is not considered to be powerful enough for managing these data set types as a unique tool and that other sophisticated programming software would have facilitated the analysis and saved time.

5.7 Implications

5.7.1 Regulatory framework for noise pollution

Although there is a total absence of laws regarding marine noise pollution, Iceland does use the United Nations Convention on the Law of the Sea as a fundamental pillar of Iceland's oceans policy (The Permanent Mission of Iceland to the United Nations, 2014, Statement of Iceland reg. Oceans and the law of the sea). According to this Convention, noise pollution is defined as "introduction by humans" which results or is likely to result in deleterious effects are considered as pollution. This definition is poor and vague for law enforcement. Human-made noise introduced in the ocean must result in "deleterious effects" to constitute marine pollution (e.g., being harmful, disruptive and non-wanted effects) (LOS Convention, Article1 (1) (4)). However there still is a big space for interpretation of what is considered "deleterious effects" in this definition.

In the official policy document published by the Ministry of the environment, fisheries and foreign affairs called "the Ocean" it is noticeable that the Icelandic government's first concerns are problems involving pollution (waste management) and overfishing of the coastal zones (Ministry for the Environment, 2004), while the noise pollution issue remains without any acknowledgment.

Nevertheless, according to this policy paper, it is noticeable the intention of the government to protect nature from the human impact. The problem of noise pollution is a relatively recent problem at the global scale and especially in Iceland due to rapid increase tourism and development. Considering this particular case, extended research regarding noise pollution is essential for showing the evidences of those impacts to the government stakeholders towards starting to manage noisy activities.

Hence, even under the current vague regulation framework (particularly the acts No. 32/1996, No. 44/2002, No. 44/1999, 7/1998 of "The Ocean" document) it is still possible to pressure the government for the implementation of new laws if enough proof of environmental damage from current human development is provided.

As possible efficient regulation measurements, Iceland could simply follow the example of other nations where underwater noise is already successfully managed. For example, in Germany they set limits for marine noise pollution during constructions to a maximum of 160 dB measured at a distance of 750m to the construction site. (Elmer, K. H., Gerasch, W. J., Neumann, T., Gabriel, J., Betke, K., & SCHULTZ V GLAHN, M., 2006). These limitations can apply for development and boat noise.

The European Commission together with the International Whaling Commission launched in 2013 a Marine Strategy in order to establish Good Environmental Status (GES) for 2020. In order to achieve this target, the Technical Sub-Group on Underwater Noise is in charge of providing recommendations based on noise pressure indicators. Other regional bodies such as OSPAR and HELCOM are responsible for suggesting adequate pressure indicators to the upper stakeholders.

Considering this policy frame, Iceland is part of OSPAR region and therefore, having access to get sucessfully involved with other nations for the implementation of a noise regulation.

Iceland could also follow the guidelines published by the "International Maritime Organizations" in 2013, to provide guidance for designing quieter ships and for reducing noise from existing ships, especially from propeller cavitation" (International

Maritime Organization, 2014, S. 1). These guidelines are not mandatory but it can help Icelandic stakeholders to compromise with responsible development.

Nonetheless, as a recommendation, the easiest way of reducing noise and pressure from whale watching boats in Skjálfandi Bay, would be by simply enforcing the existent voluntary guidelines, making it official and mandatory for the operators (e.g., controlling boat manoeuvring practices, putting penalties in case of non-compliance of the code of conduct). These regulations would enhance the development of new techniques (Mark P. Simmonds, 2014), and more eco-friendly boat designs from the operators to reduce noise pollution could benefit the economy, attracting more visitors by making Iceland a pioneer in silent and responsible whale watching.

5.7.2 Further risks and recommendations for Skjálfandi Bay

This thesis provides novel knowledge regarding potential effects of whale watching development in Iceland on one of the most valuable species from the whale watching perspective in Skjálfandi Bay: the humpback whales. The rapid development of whale watching can maximize the opportunities the local economic expansion and diversification of income sources in the area, but it is of primary concern to detect potential negative effects on whales and minimize risks to promote responsible development. Future projects regarding underwater noise monitoring in Skjálfandi Bay could involve more specific measurements of whale watching boats noise (e.g., taking into account type of vessel, design, and other specific characteristics) in order to identify the main origin of high noise within the operating boats. Further, quieter boats could be proposed to the companies. In addition, studies of short-term behavioural responses in the target species could include ideally, a combination of bio-logging tags and direct observations of whale behaviour to achieve a more comprehensive approach.

In regards of the current development of the new silica factory next to Skjálfandi Bay, it is critical to follow the "precautionary principle" in a rapid development situation like this. This can be achieved by arranging research monitoring projects for studying short and long-term implications in the targeted cetaceans that are facing the upcoming high traffic and noise levels generated by the construction and operation of the factory. The assessment of this particular development is relevant for avoiding temporal effects (e.g., displacement of certain species to other quieter areas previously reported (e.g., Culloch, *et al*., 2016), that could cause the alteration of their seasonal migration patterns, but also the consequent socio-economic impacts in the long term (e.g., "loss of marine resources" from the whale watching sector).

5.7.3 Research limitations and considerations

- Lack of homogeneous data and small data sets: even though without any doubt these bio–logging devices have a high potential for giving sophisticated information for this project, the tags were not deployed with the same purpose and they did not have the same properties (e.g., tag resolution, sample rate of the hydrophone). The information gathered by the tags was not the same among the whales and the common data streams (variables) collected for analysis was rather small for multifaceted analysis. Similarly, AIS data was available only for summer 2014, but not for 2013. Furthermore, the different acoustic properties of the audio signal in the tags limited the comparison of boat noise levels in SigPro software so that the analysis was restricted to the acoustic data of a single tagged whale. For the future, tags must be deployed for the same purposes in order to achieve common analysis and the usage of statistical tests. The availability of 3-axis acceleration and magnetometer data for all the whales would have enhanced the detection of short-term behavioural responses by including extra interesting behavioural variables such as track linearity and heading (direction where the whale is moving to). Information regarding whale orientation and body alignment (pitch angle, roll), speed and acceleration not only would have given more detailed explanation of the animal behaviour when studying dive patterns of the animals, but it would have enhanced detector efficiency and the possibility of detecting other possible lunge types (e.g., horizontal lunge feedings). Additionally, to obtain a more accurate boat measurement it is highly recommended to compare the boat noise recorded in the tags with previous taken standardized boat noise (e.g., to standardize boat speed, distance to the noise source). Finally, a bigger data set (more tagged whales) would have given more capacity for replicating the experiment giving more powerful statistic results.

It is worth mentioning that some pseudo-replication was created when accounting for changes in whale behaviour due to boat exposure by including multiple boat events per whale in order to get enough samples, meaning that boat events were not fully independent events. The use of GEE or mixed models would have accounted for that level of dependence/correlation, but this was not possible to be applied due to the small sample size.

- Time limitation: A major drawback within this research was the time limitations. Adittional tests applied in all tagged whales for improving the customized breaths and lunge detectors would have served for optimizing the functionality and reduce the error rate of these methods. Nevertheless, the inclusion of the acoustic signals for feeding lunges (based on flow noise) or breaths into the detectors, may have saved time as it would have facilitated automatic detection. This was not possible due to time constrictions and limited knowledge for dealing with high-tech software for data programming.

  During this thesis, basically depth data and acoustic data was used, being enough for achieving the objectives of the project. However, the amount of information obtained and its accurateness that can be highly enhanced by combining tag data with other data types and this is important take in account for future similar projects.

An additional alternative for detecting effects from whale watching boat noise in this study could have been to use the acustic data for measuring potential changes in whale social sounds repertory (e.g., frequency of the vocal sounds and acoustic properties) in response to boat noise presence/ absence, or for comparing the acoustic behaviour between boat noise and in exposed to a natural noise source (wind) as it was already applied by Dunlop *et al*., (2016) giving proper results for detecting masking effect.

The following table reviews the limitations found in the provided data set for arranging this project and emphasizes the advantages of including different data types for optimizing the research (table 18).

Data recorder	Data	Availability	Used in this thesis	Comments
Tag GPS	Animal position and time	No	No	Can be used to compute the distance animal/boat
AIS	Boat position, time & name, type, route, speed of boats	Partially (not all the boats recorded). Only for 3 whales (2014)	Used only for checking boat presence	Can be used to compute the distance animal/boat, number of boats and to obtain a more accurate boat noise measurements : to correlate noise received by the tag RL with boat activity (e.g., speed and number of boats during at the moment)
Tag data	Depth (from pressure) => Vertical speed and acceleration	For all tagged whales (N= 12)	Yes	Vertical speed and acceleration are computed from the depth.
	Speed (from tag propeller)	Only for 3 whales (2014)	Only in one whale for testing feasibility of using vertical speed and acceleration	Give the animal longitudinal speed. Using the vertical speed allows computing the pitch of the animal (angle between its direction and vertical).
	3-axis magnetometer	Only for 3 whales (2014)	No	To compute the animal orientation in the space. (heading) To compute the animal track between 2 GPS position.
	3-axis accelerometer	Only for 5 whales 2013 and 2014	No	To compute the animal orientation in the space. (pitch angle and roll) To compute the animal track between 2 GPS position.
	Temperature	Only for 3 whales (2014)	No	
	Pressure		No	Used to compute the depth (see Depth)
	Others (e.g., drone, video camera incorporate in the tag)	No	No	To study whale behaviour related to boats, social interactions, feeding technics and prey selection underwater.
Audio recorder		Only for 7 whales (2013 and 2014)	Yes	Audio files can be synchronized with the GPS/AIS and Tag data.

Table 18. Data types usage during this thesis and limitations. The used data types are shown in grey colour. The other tag data was not used in this thesis.

6. Conclusion

In this thesis, it was demonstrated that by using simple parameters and basic software tools it is possible to describe and monitor respiratory rates and foraging behaviour of humpback whales (and other baleen whales as well) in a relatively easy manner. The current detectors implemented in Excel were sufficient to address the objectives of this project and provided meaningful biological results.

It was relevant to address potential changes in whale behaviour using multisensory tags, as this approach can bring new insights into the underwater whale behaviour. Therefore, the usage of acoustic tags in this project resulted in a successful approach for investigating short-term reactions due to whale watching activity. The outcomes of this study enhance the essential role of engagement towards addressing whale watching development. The provided scientific recommendations can extraordinarily help the stakeholders and for optimizing their resources (whales) for sustainable management. Monitoring boat noise from the acoustic tag, not only brought novel estimations regarding current whale watching boat noise levels, but this measurements can be was useful for monitoring the gradual increase of noise in Skálfandi Bay due to the rapid development of noisy activities in Húsavík while supporting further noise research in the area.

The vocal sounds reported in this study provide new information on the little existent humpback whale acoustics in Icelandic foraging grounds. The study of whale sound production is essential for understanding whale ecology and determining its functions in whale hot spots will inform future studies.

Húsavík, "the capital of whale watching" of Europe, seems the ideal place for innovation on bioturism development, embracing a tremendous capacity building towards whale conservation: the presence of the Whale Museum and the Research Centre have a great potential and generate new opportunities for research and education. Finally, the recent initiatives from some of the whale watching operators for development of quieter boats (less noisy) are becoming a key point for attracting greater numbers of tourists, who are willing to choice more eco-friendly through the years.

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Appendix 1. Work sheets in Excel for managing data

1. Sheet 1. Raw tag data plotted in Excel

7	Time attached:	12,35 h											6,0 m	correction on depth:
8	Actual sheet data size:	50990		max=	4091,0	2923,0	3585,0	2617,0	2518,0	2710,0		110,0	198,0	5,5
9	Sheet capacity:	14,16 h		min=	1392,0	565,0	719,0	1414,0	1529,0	1563,0		-11,5	0,0	-116,0
10	Whale name:	Whl-1												
11														
12	Lost time at begining:	01:42:59	recommended											
13	o remove at begining:	0 h	1 h											
14	Sheet starting time:	04:48:01										depth is negative=>		-1,0
15	25/06/14 04:48:01													
16					Compass	ompass	ompass-Z				Pressur	Dpth-src	Propeller	Dpth-cor
17	Date/time	Rec-type	Rec-name	Comment	npass-X	pass-Y	ompass	Accel-X	Accel-Y	Accel-Z	Dpth.ba	Dpth-src	Propeller	
18	14/06/25 04:48:01	tag	Whl-1		2690,0	1192,0	2486,0	2349,0	2275,0	2201,0		-6,0	22,0	0,00
19	14/06/25 04:48:02	tag	Whl-1		2756,0	1180,0	2454,0	2247,0	2249,0	1900,0		-6,0	0,0	0,00
20	14/06/25 04:48:03	tag	Whl-1		1842,0	1699,0	1931,0	1824,0	2285,0	1686,0		-6,0	0,0	0,00
21	14/06/25 04:48:04	tag	Whl-1		1994,0	1310,0	1734,0	1919,0	2321,0	1670,0		-6,0	0,0	0,00
22	14/06/25 04:48:05	tag	Whl-1		1920,0	1343,0	1824,0	1939,0	2345,0	1711,0		-6,0	0,0	0,00
23	14/06/25 04:48:06	tag	Whl-1		2080,0	1272,0	1644,0	1930,0	2284,0	1659,0		-6,0	0,0	0,00
24	14/06/25 04:48:07	tag	Whl-1		1683,0		1968,0	1824,0	2357,0	2228,0		-6,0	1,0	0,00
25	14/06/25 04:48:08	tag	Whl-1		2239,0	1340,0	2649,0	1907,0	2335,0	2356,0		-6,0	0,0	0,00
26	14/06/25 04:48:09	tag	Whl-1		2195,0	1263,0	2789,0	1917,0	2262,0	2418,0		-6,5	0,0	0,50
27	14/06/25 04:48:10	tag	Whl-1		2140,0	1247,0	2781,0	2055,0	2269,0	2408,0		-6,0	0,0	0,00
28	14/06/25 04:48:11	tag	Whl-1		2157,0	2567,0	2585,0	2097,0	2319,0	2370,0		-6,0	0,0	0,00
29	14/06/25 04:48:12	tag	Whl-1		2159,0	2621,0	2499,0	1788,0	2180,0	2402,0		-6,0	0,0	0,00
30	14/06/25 04:48:13	tag	Whl-1		1829,0	1451,0	2545,0	1845,0	1849,0	2314,0		-5,8	0,0	-0,25
31	14/06/25 04:48:14	tag	Whl-1		1624,0	1867,0	2693,0	1641,0	2045,0	2338,0		-5,8	0,0	-0,25
32	14/06/25 04:48:15	tag	Whl-1		1494,0	1870,0	2547,0	1651,0	2014,0	2351,0		-6,0	0,0	0,00
33	14/06/25 04:48:16	tag	Whl-1		1710,0	1864,0	2771,0	1716,0	2010,0	2412,0		-5,8	0,0	-0,25
34	14/06/25 04:48:17	tag	Whl-1		1712,0	1872,0	2782,0	1715,0	2009,0	2412,0		-6,0	0,0	0,00
35	14/06/25 04:48:18	tag	Whl-1		1718,0	1858,0	2772,0	1715,0	2010,0	2412,0		-6,0	0,0	0,00
36	14/06/25 04:48:19	tag	Whl-1		1710,0	1862,0	2785,0	1717,0	2011,0	2412,0		-5,8	0,0	-0,25
37	14/06/25 04:48:20	tag	Whl-1		1718,0	1875,0	2775,0	1717,0	2011,0	2413,0		-5,8	0,0	-0,25
38	14/06/25 04:48:21	tag	Whl-1		1716,0	1857,0	2774,0	1716,0	2011,0	2412,0		-5,8	0,0	-0,25
39	14/06/25 04:48:22	tag	Whl-1		1716,0	1876,0	2771,0	1717,0	2011,0	2412,0		-5,8	0,0	-0,25
40	14/06/25 04:48:23	tag	Whl-1		1712,0	1868,0	2779,0	1717,0	2011,0	2412,0		-5,8	0,0	-0,25
41	14/06/25 04:48:24	tag	Whl-1		1713,0	1866,0	2770,0	1718,0	2012,0	2412,0		-6,0	0,0	0,00
42	14/06/25 04:48:25	tag	Whl-1		1703,0	1859,0	2764,0	1717,0	2010,0	2411,0		-6,0	0,0	0,00
43	14/06/25 04:48:26	tag	Whl-1		1713,0	1865,0	2772,0	1716,0	2010,0	2412,0		-6,0	0,0	0,00

Example of work sheets in Excel for plotting tag data: the table shows the 3-axis acceleration data, depth (m) and propeller data (counts), and corrected depth. All the data are matched in time with the audio files. Notice that data point is given at each second (tag´s resolution is 1 second for this particular whale Mn215_2014).

2. Sheet 2. Computation of required parameters

ep/l	Speed	MaxSpd5	MinSpd5	DifSpd5	Accel	MaxAcc5	MinAcc5	DifAcc5	V.speed	V.accel	V.acc.dro	H.speed
			b= 0,0194		0,0933	0,0194						
	18,49	18,49 m/s	16,72 m/s	16,33 m/s^2	13,81 m/s^2	13,81 m/s	1,40 m/s	17,54 m/s^2	6,50 m/s^2	0,4 m/s^2		
	0,02	0,02 m/s	0,00 m/s	-8,40 m/s^2	-8,77 m/s^2	-1,96 m/s	-8,77 m/s	-1,77 m/s^2	-6,25 m/s^2			
	0,00				0							
ep/l	Speed	MaxSpd5	MinSpd5	DifSpd5	Accel	MaxAcc5	MinAcc5	DifAcc5	V.speed	V.accel	V.acc.dro	H.speed
ep/l	2,07				0,00 m/s^2							
0	2,07	2,07 m/s	0,02 m/s	2,05 m/s	0,00 m/s^2	0,00 m/s	-2,05 m/s	2,05 m/s	0,0	0,0	0,0	2,1
0	0,02	2,07 m/s	0,02 m/s	2,05 m/s	-2,05 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,0	0,0	0,0	0,0
0	0,02	2,07 m/s	0,02 m/s	2,05 m/s	0,00 m/s^2	0,00 m/s	-0,09 m/s	0,09 m/s	0,0	0,0	0,0	0,0
0	0,02	2,07 m/s	0,02 m/s	2,05 m/s	0,00 m/s^2	0,00 m/s	-0,09 m/s	0,09 m/s	0,0	0,0	0,0	0,0
0	0,02	2,07 m/s	0,02 m/s	2,05 m/s	0,00 m/s^2	0,00 m/s	-0,09 m/s	0,09 m/s	0,0	0,0	0,0	0,0
0	0,02	2,07 m/s	0,02 m/s	2,05 m/s	0,00 m/s^2	0,00 m/s	-0,09 m/s	0,09 m/s	0,0	0,0	0,0	0,0
0	0,11	0,02 m/s	0,02 m/s	0,00 m/s	0,09 m/s^2	0,00 m/s	-0,09 m/s	0,09 m/s	0,0	0,0	1,0	0,1
0	0,02	0,11 m/s	0,02 m/s	0,09 m/s	-0,09 m/s^2	0,09 m/s	0,00 m/s	0,09 m/s	0,0	0,0	1,0	0,0
0	0,02	0,11 m/s	0,02 m/s	0,09 m/s	0,00 m/s^2	0,09 m/s	0,00 m/s	0,09 m/s	0,5	0,5	1,5	0,0
0	0,02	0,11 m/s	0,02 m/s	0,09 m/s	0,00 m/s^2	0,09 m/s	0,00 m/s	0,09 m/s	-0,5	-1,0	1,5	0,0
0	0,02	0,11 m/s	0,02 m/s	0,09 m/s	0,00 m/s^2	0,09 m/s	0,00 m/s	0,09 m/s	0,0	0,5	0,8	0,0
0	0,02	0,11 m/s	0,02 m/s	0,09 m/s	0,00 m/s^2	0,09 m/s	0,00 m/s	0,09 m/s	0,0	0,0	0,8	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	-0,3	-0,3	1,0	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,0	0,3	1,0	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,3	0,3	0,8	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	-0,3	-0,5	0,8	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,3	0,5	0,8	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,0	-0,3	0,8	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	-0,3	-0,3	0,8	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,0	0,3	0,5	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,0	0,0	0,3	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,0	0,0	0,5	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,0	0,0	0,5	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,3	0,3	0,5	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,0	-0,3	0,5	0,0
0	0,02	0,02 m/s	0,02 m/s	0,00 m/s	0,00 m/s^2	0,00 m/s	0,00 m/s	0,00 m/s	0,0	0,0	0,5	0,0

Example of work sheets in Excel for computing data

Extra columns were added for computing vertical parameters required for lunge feedings and breath detection. The green row in the upper part shows the equation coefficients for computing the speed (m/s) from the propeller (counts) provided by the tag. In the upper part it is shown the max/min values for each parameter along the tag duration (white colour).

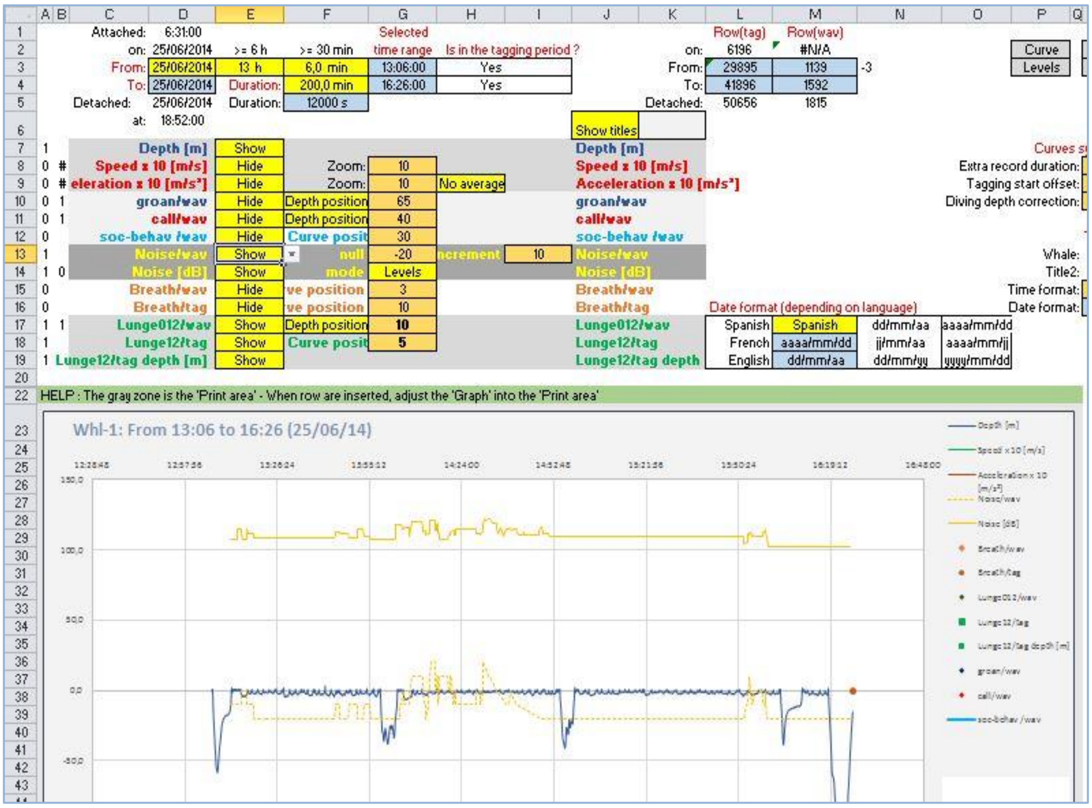
3. Sheet 3. Inclusion of acoustic data in the Excel sheet

925	W	2014/06/25 11:24:28	breath	Whl-1				breath	1,0			
926	W	2014/06/25 11:25:08	x-engine	Whl-1				x-engine	41,0	medit	high	119,4
927	W	2014/06/25 11:25:26	x-engine	Whl-1				x-engine	59,0	low	medium	116,7
928	W	2014/06/25 11:25:28	sound	Whl-1	short dives low speed	2014-06-25-00000371.wav	Link					DO NOT modify/delete this row
929	W	2014/06/25 11:25:28	x-engine	Whl-1				x-engine	0,0	null	high	120,2
930	W	2014/06/25 11:25:34	breath	Whl-1				breath	6,0			
931	W	2014/06/25 11:26:28	sound	Whl-1	short dives low speed	2014-06-25-00000372.wav	Link					DO NOT modify/delete this row
932	W	2014/06/25 11:27:08	x-engine	Whl-1				x-engine	40,0	null	medium	117,0
933	W	2014/06/25 11:26:41	breath	Whl-1				breath	13,0			
934	W	2014/06/25 11:27:29	sound	Whl-1	short dives low speed	2014-06-25-00000373.wav	Link					DO NOT modify/delete this row
935	W	2014/06/25 11:27:43	breath	Whl-1				breath	14,0			
936	W	2014/06/25 11:27:58	x-engine	Whl-1				x-engine	29,0	null	low	112,0
937	W	2014/06/25 11:27:59	x-engine	Whl-1				x-engine	30,0	null	null	112,0
938	W	2014/06/25 11:28:30	sound	Whl-1	short dives low speed	2014-06-25-00000374.wav	Link					DO NOT modify/delete this row
939	W	2014/06/25 11:28:32	breath	Whl-1				breath	2,0			
940	W	2014/06/25 11:29:31	sound	Whl-1	Short dive Different background noise (diving hc	2014-06-25-00000375.wav	Link					DO NOT modify/delete this row
941	W	2014/06/25 11:30:31	sound	Whl-1	short dives low speed	2014-06-25-00000376.wav	Link					DO NOT modify/delete this row
942	W	2014/06/25 11:30:50	breath	Whl-1				breath	19,0			
943	W	2014/06/25 11:31:26	call	Whl-1				call	55,0			
944	W	2014/06/25 11:31:32	sound	Whl-1	short dives low speed	2014-06-25-00000377.wav	Link					DO NOT modify/delete this row
945	W	2014/06/25 11:32:33	sound	Whl-1	short dives low speed	2014-06-25-00000378.wav	Link					DO NOT modify/delete this row
946	W	2014/06/25 11:33:02	breath	Whl-1				breath	29,0			
947	W	2014/06/25 11:33:34	sound	Whl-1	short dives low speed	2014-06-25-00000379.wav	Link					DO NOT modify/delete this row
948	W	2014/06/25 11:33:57	breath	Whl-1				breath	23,0			
949	W	2014/06/25 11:34:35	sound	Whl-1	short dives low speed BOAT PASSING (2)	2014-06-25-00000380.wav	Link					DO NOT modify/delete this row
950	W	2014/06/25 11:34:51	x-engine	Whl-1				x-engine	16,0	null	low	111,0
951	W	2014/06/25 11:35:35	sound	Whl-1		2014-06-25-00000381.wav	Link					DO NOT modify/delete this row
952	W	2014/06/25 11:35:45	breath	Whl-1				breath	10,0			
953	W	2014/06/25 11:36:36	sound	Whl-1	. The whale does not move and it is close to surf	2014-06-25-00000382.wav	Link					DO NOT modify/delete this row
954	W	2014/06/25 11:36:36	x-engine	Whl-1				x-engine	0,0	low	medium	117,7

Example of Excel sheets for inclusion of acoustic data

Each acoustic data found in the recordings (e.g., boats, whale breaths, whale calls, lunges) was added as an "event" and matched in time with the tag data *(e.g., speed, depth). Furthermore, this sheet can be used for creating categories to characterize the events (e.g., intensity for boat noise, type of vocal sound, type of lunge) and comments can be easily added in each cell for helping data interpretation.*

4. Sheet 4. Tag and acoustic data plotted in graphs

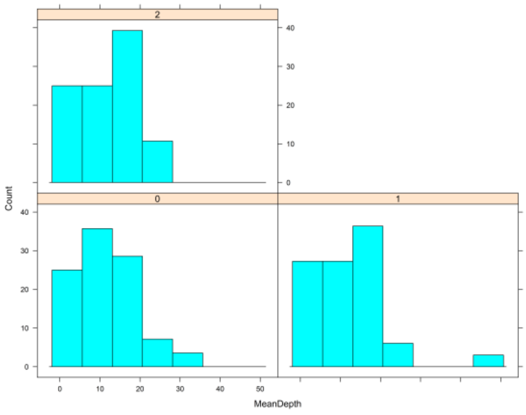


Example of Excel sheet for graphs display by using combined tag and acoustic data

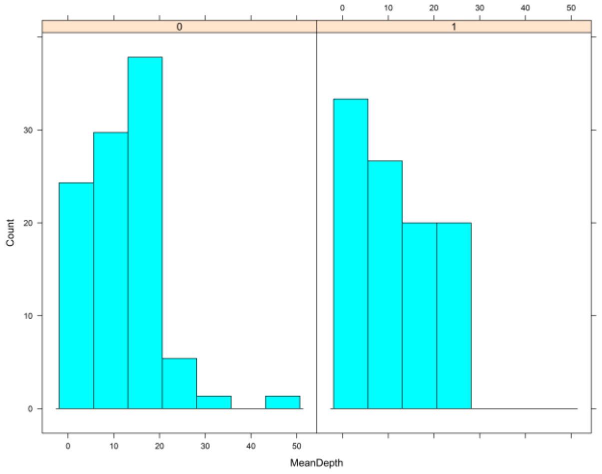
In the upper part is possible to choose a window time, and the desired parameters. In the sheet it is possible to combine the parameters computed by the breath and lunge detectors and compare them with the acoustic data. The language can be changed for avoiding possible errors given by using different format linked to the language type.

Appendix 2. Histograms for measured behavioural parameters

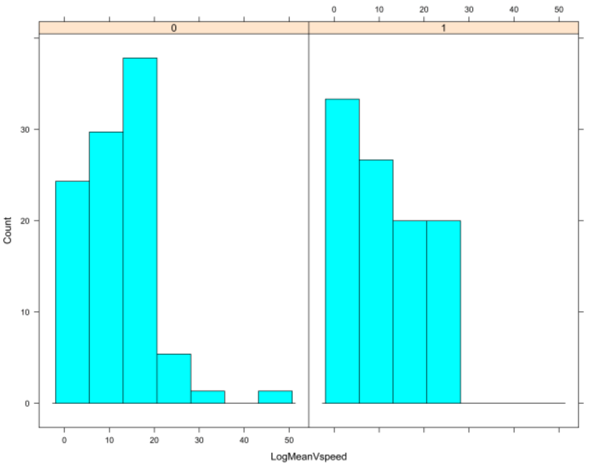
Mean Depth vs Phase



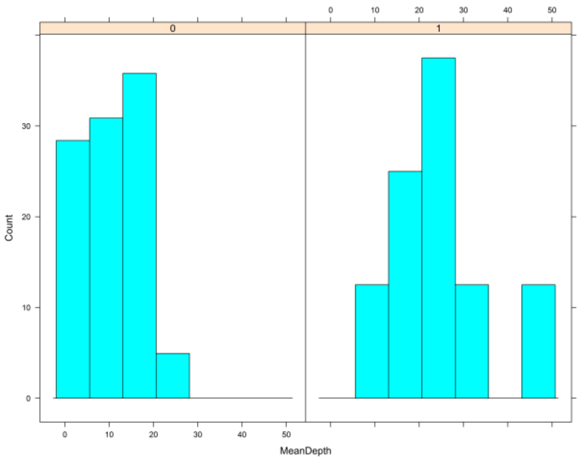
Mean Depth vs Noise Intensity



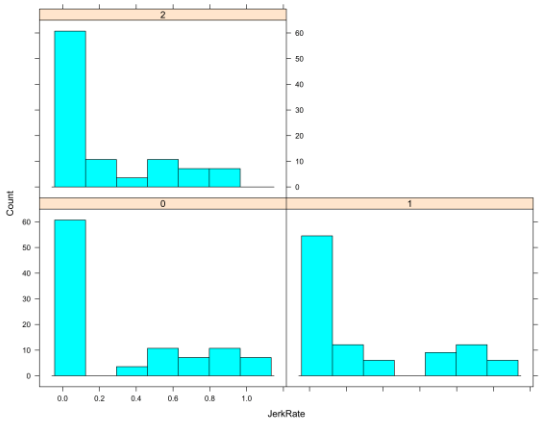
Mean Depth vs Boat Event Type



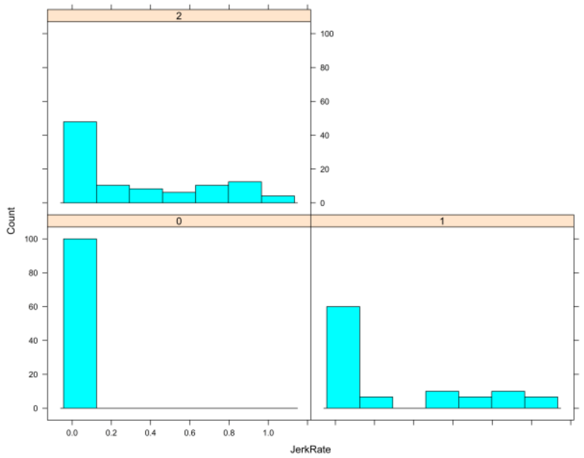
Mean Depth vs Tagging Effect



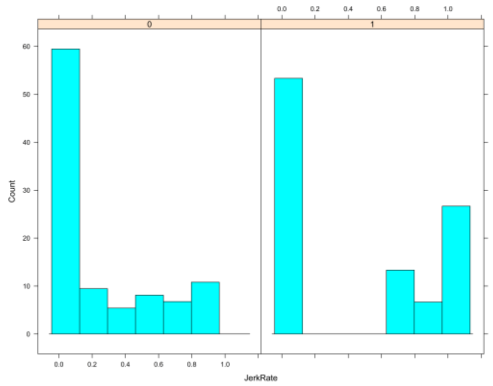
Jerk Rate vs Phase



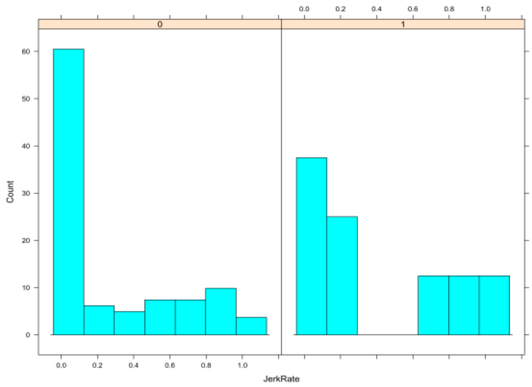
Jerk Rate vs Noise Intensity



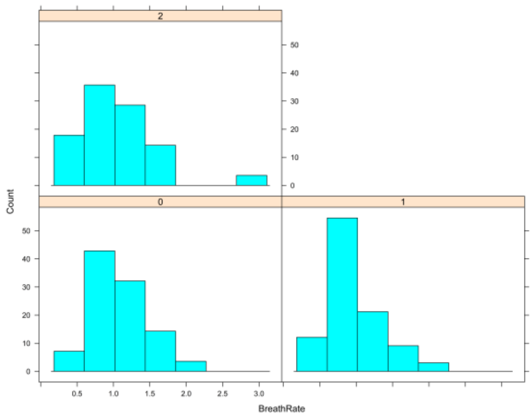
Jerk Rate vs Boat Event Type



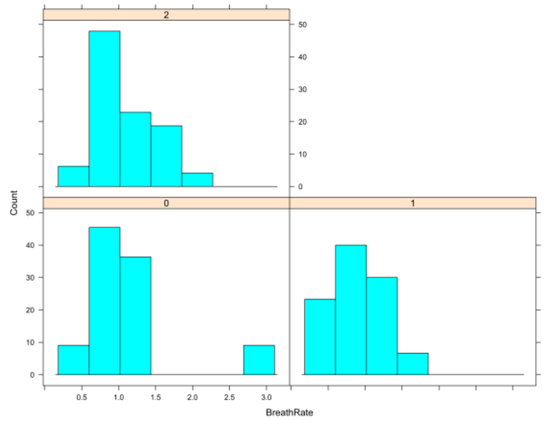
Jerk Rate vs Tagging Effect



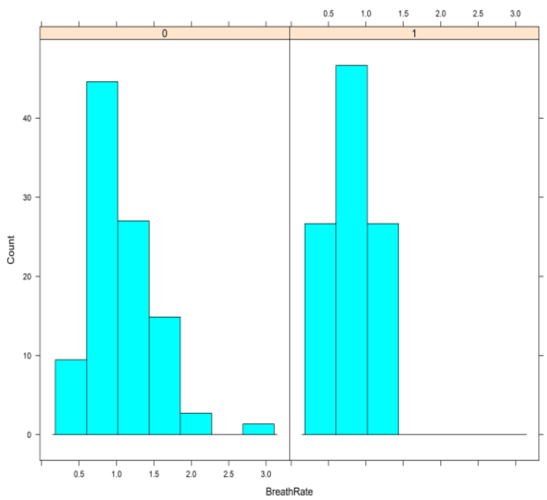
Breath Rate vs Phase



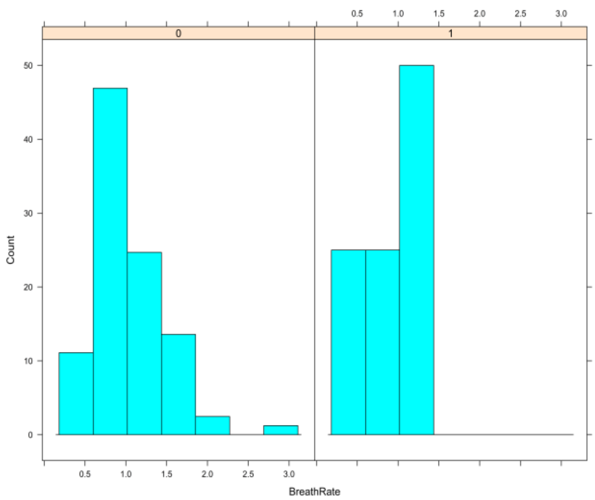
Breath Rate vs Noise Intensity



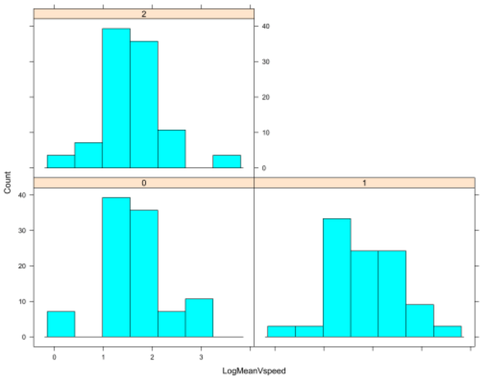
Breath Rate vs Boat Event Type



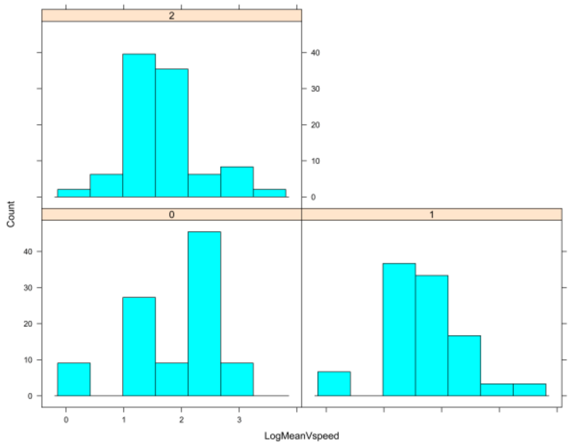
Breath Rate vs Tagging Effect



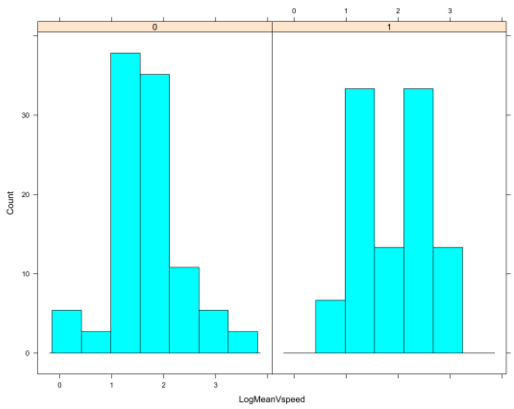
Mean vertical speed vs Phase



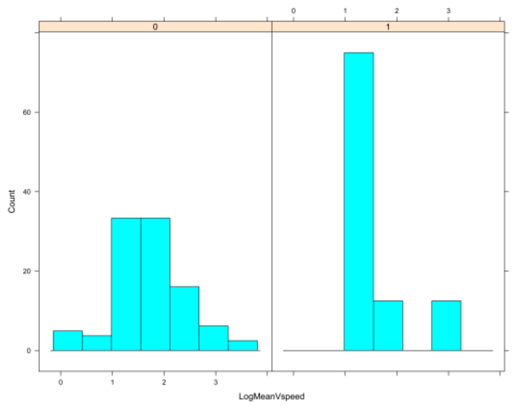
Mean vertical speed vs Noise Intensity



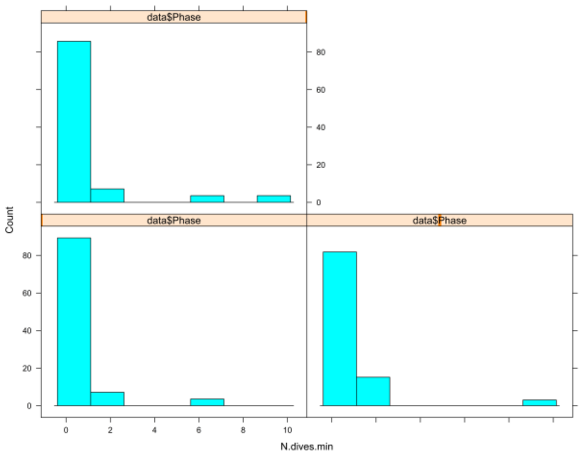
Mean vertical speed vs Boat Event Type



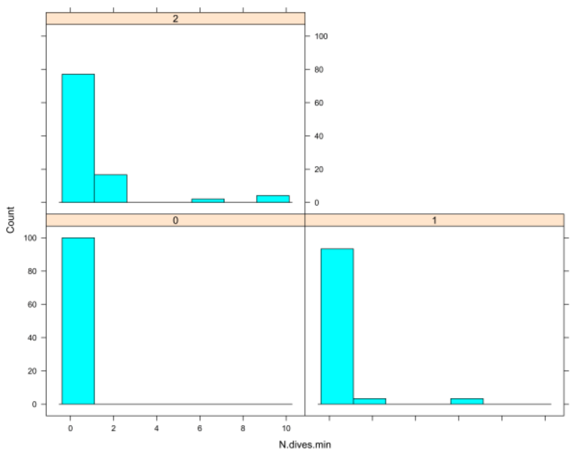
Mean vertical speed vs Tagging Effect



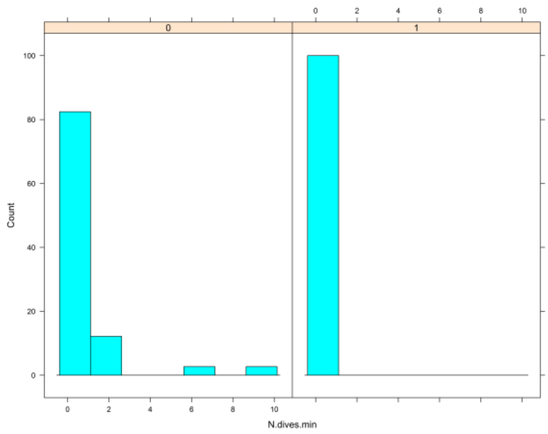
N dives vs Phase



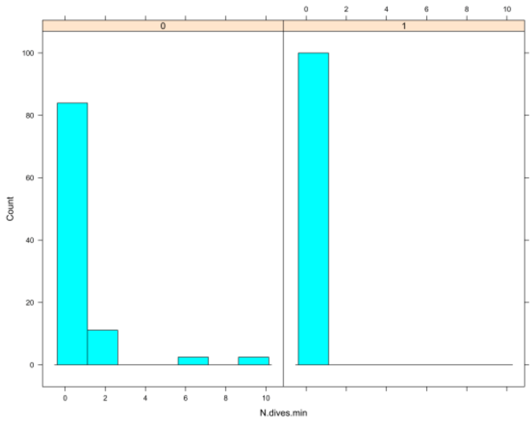
N dives vs Noise Intensity



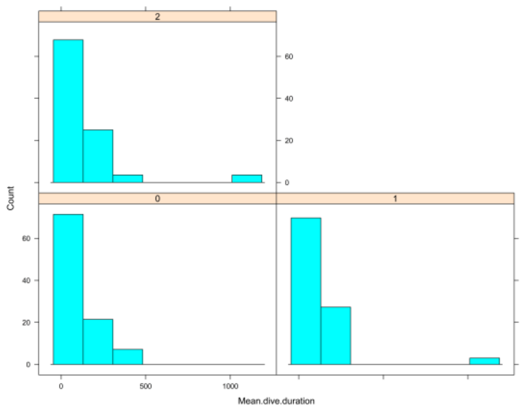
N dives vs Boat Event Type



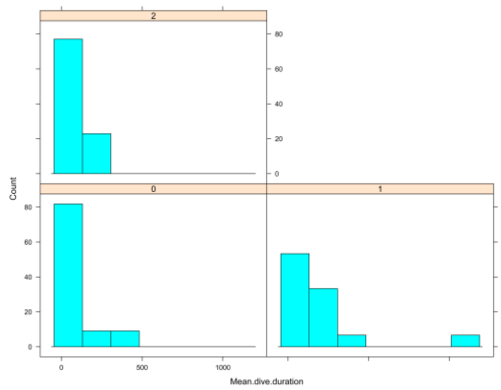
N dives vs Tagging Effect



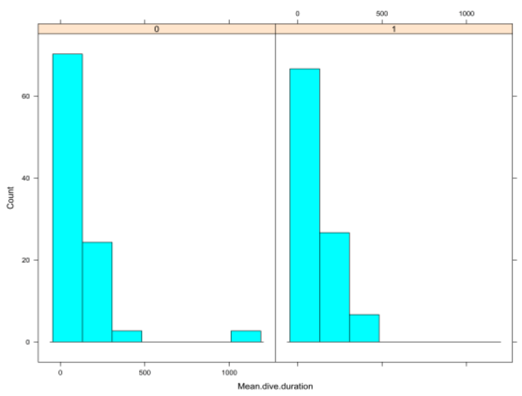
Dives duration vs Phase



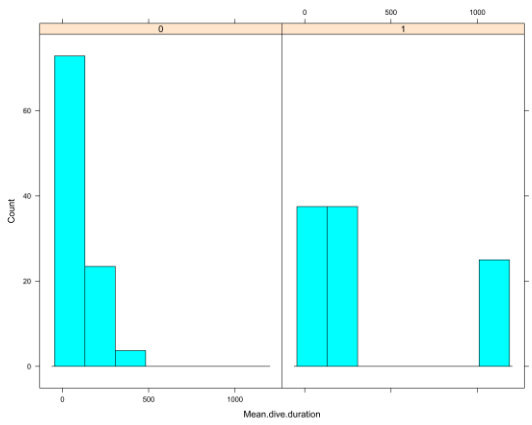
Dives duration vs Noise Intensity



Dives duration vs Boat Event Type

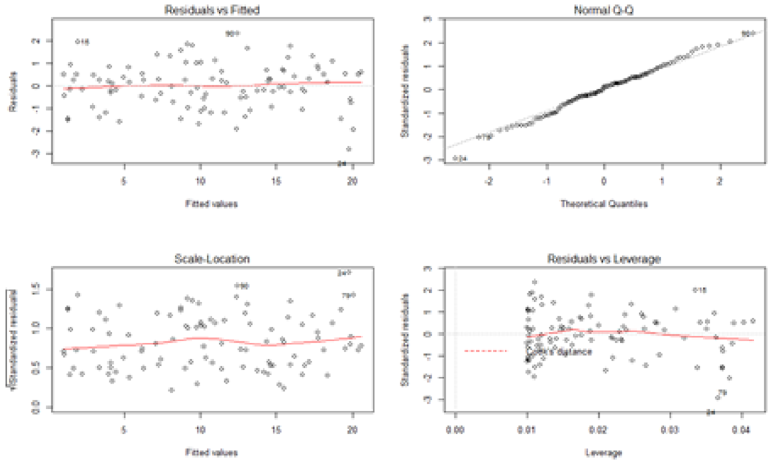


Dives duration vs Tagging Effect

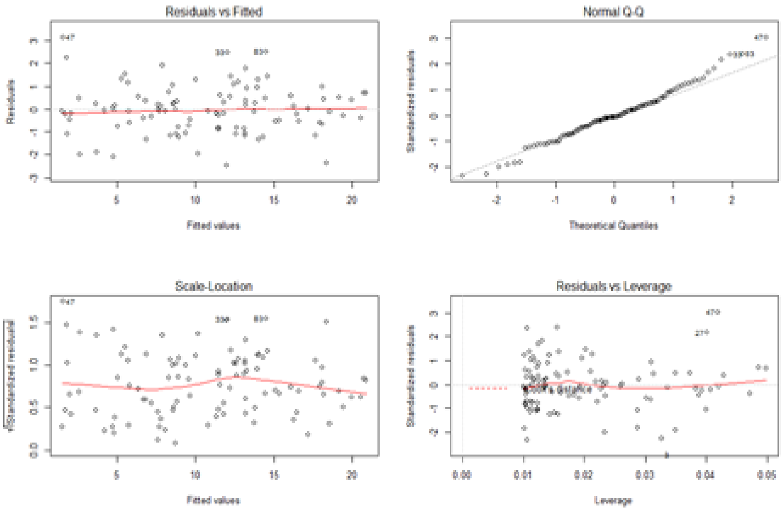


Appendix 3. Residual plots for measured behavioural parameters

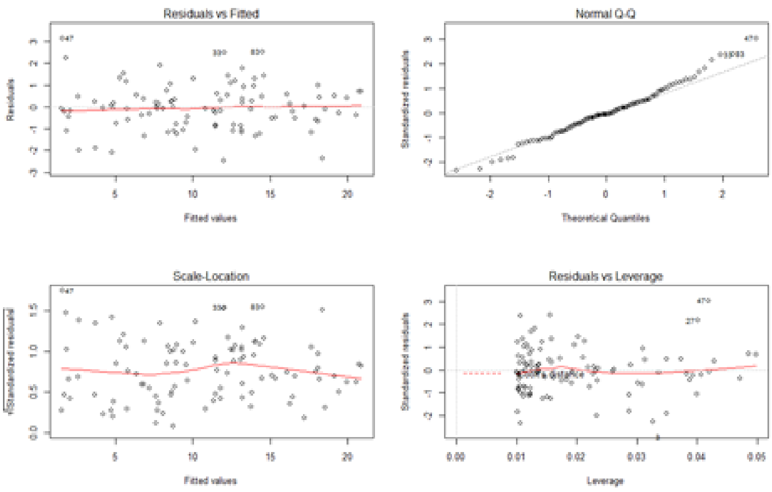
1. Mean depth residuals (m)



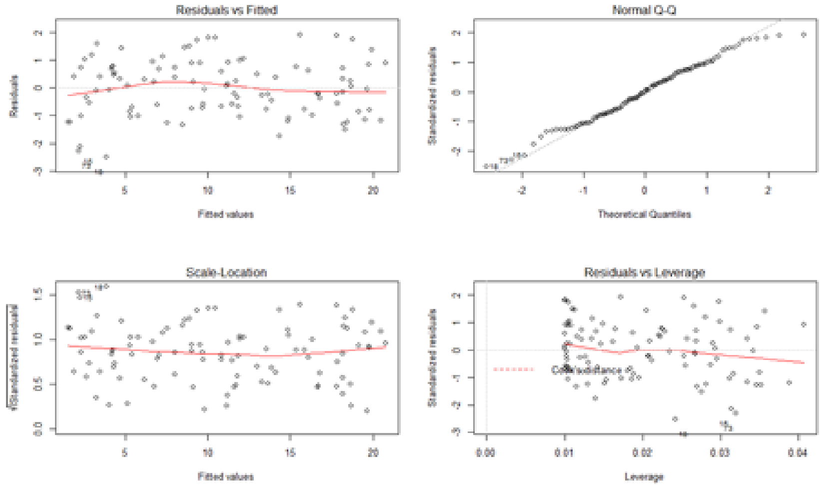
2. Jerk rate (counts)



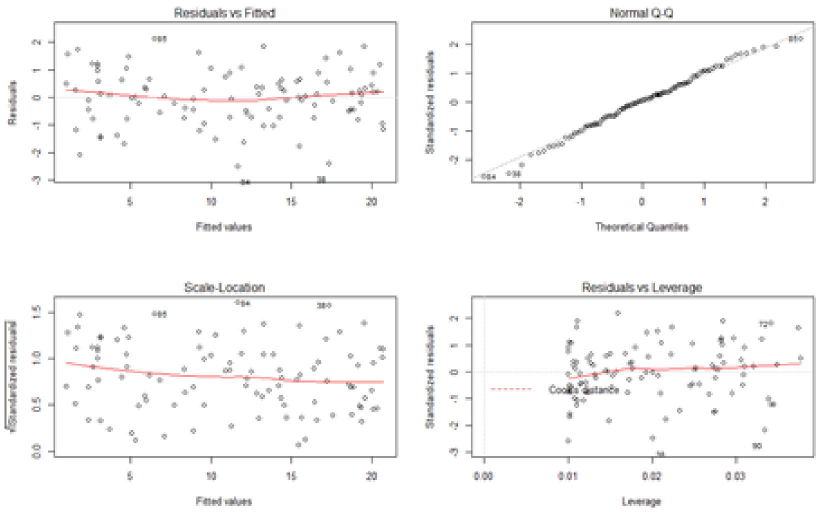
3. Breath rate (blows/min)



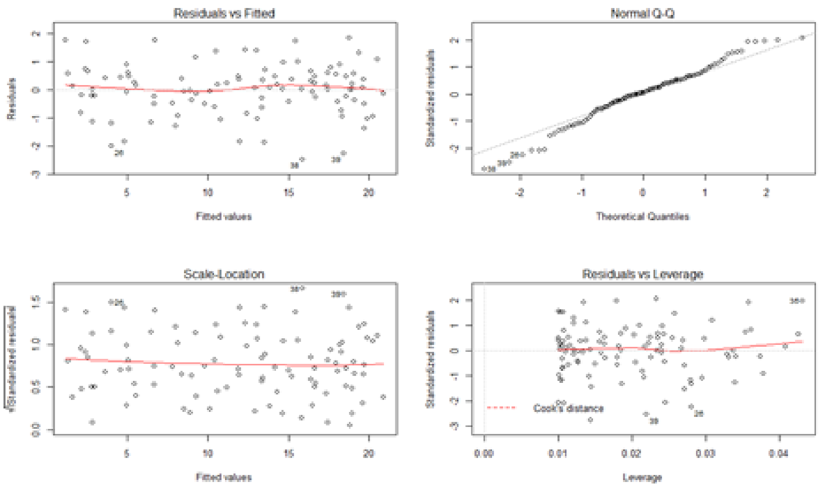
4. Mean (log) vertical speed



5. Dive rate (n dives/min)



6. Mean dive duration (seconds)



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