Geostatistical Analyses of Interactions between Minke Whales (*Balaenoptera acutorostrata*) and Whale-Watching Boats in Skjalfandi Bay, Northeast Iceland

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Abstract

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Abstract

The Icelandic whale-watching industry has experienced rapid growth since its inception in 1991, and today represents the fastest growing economic activity of the country. Skjalfandi Bay in Northeast Iceland has become the epicenter of whale-watching in Iceland, yet little is known about the local effects of the whale-watching industry on cetaceans. I used theodolite techniques and GIS to examine boat effects on the swimming speed, directionality, inter-breath intervals, and surface feeding events of minke whales (*Balaenoptera acutorostrata*) in Skjalfandi Bay. The proximity and number of vessels did not have a statistically significant effect on any aspect of minke behavior. These results contradict a previous study from Faxafloi Bay, suggesting that differences exist between the two locations, and that management strategies may need to be location-specific.

Acknowledgements:

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Acronyms

Húsavík Research Center – HRC

International Whaling Commission – IWC

University of Washington – UW

School of Marine and Environmental Affairs – SMEA

Introduction

In many nations where whale watching is prevalent, restrictions exist over tour-operators intended to reduce disturbances to cetaceans and encourage natural behaviors. These restrictions include limits on the speed with which vessels can approach an animal, the number of boats permitted to be proximate to any one animal at a time, the size of tour boats, and the maximum distance a vessel is allowed to approach a whale before discontinuing or turning off its engines. Currently, Iceland stands out for having no binding regulations regarding the whale watching industry. Although voluntary agreements exist for vessel handling in proximity to cetaceans in Iceland (Martin, 2012), these guidelines are commonly violated, suggesting that binding regulations may be needed (Allan et al., 2007; Duprey et al., 2008; Wiley et al., 2008). In order to develop regulations to mitigate disturbances to whales while promoting sustainable whale watching tourism, it is important to describe the response of whales to vessels. Given that most existing studies of the effects of whale watching vessels on cetacean behavior have focused on odontocetes, which utilize resources differently than mysticetes, most previous studies conducted outside of Iceland cannot be applied with confidence (Jelinski et al, 2002, Christiansen et al., 2013). Consequently, I examined whether whale-watching vessels affect cetacean swimming behavior and activity states in Skjálfandi Bay. I then compared the results to a similar analysis of boat-whale interactions in Faxafloi Bay.

Definition of Whale Watching

The International Whaling Commission (IWC) defines whale watching as "*any enterprise which provides for the public to see cetaceans in their natural habitat* (IWC, 1994, Parsons 2012)." Therefore, activities that allow for people to view cetaceans in an unnatural setting, such as in an oceanarium, are not considered whale watching. While the most common form of whale-watching includes commercial boat tours that takes tourists to areas where cetaceans are present, other forms exist. Residents may opt to captain their own vessels to view whales instead of hiring a commercial company. In some regions where cetaceans venture close to shore, land-based viewing is possible. Some tour operators provide opportunities to see cetaceans aerially from plane. Moreover, "swim-with cetacean" and whale-feeding tourism also are increasing in popularity and allow people to view whales in their natural habitats. The word "whale" in whale watching generally refers to all cetaceans regardless of whether they are a whale, dolphin or porpoise. Many whale-watching companies guarantee their passengers the opportunity to see whales in the wild, and if no whales are encountered, offer another free trip or refund, but many companies will not compensate passengers if dolphins are sighted. For the purposes of this paper, whale watching is restricted to the effects of boat-based operations on minke whales (*Balaenoptera acutorostrata*).

The Rise of Icelandic Whale Watching

Prior to 1991, commercial whale-watching did not exist in Iceland (O'Connor, 2008). Since then, the industry has increased sharply, growing 251% per year since 1994. Now a multimillion dollar industry (Figure 1), commercial whale watching is currently the fastest growing economic activity in the country (Magnusdottir et al., 2011). Commercial whale watching is particularly prevalent in Faxafloi Bay in the greater Reykjavik region (accounting for 51% of whale watch trips in Iceland) and Skjalfandi Bay in northeast Iceland near the town of Húsavík (accounting for 36% of whale watch trips in Iceland), but whale watching is increasing in other regions of the country such as the Vestmann Islands (Figure 2). Because whales are often found near shore, trips generally last around three hours and cost $60 (2013 USD- ISK exchange rate). The Icelandic whale watching industry hires about 104 people and caters mostly to international visitors.

Year	Number of whale watchers	AAGR	Number of operators	Direct expenditure	Indirect expenditure	Total expenditure
1991	100	N/A	1	$17,000	$43,000	$60,000
1994	200	26%	4	$32,000	$114,000	$146,000
1998	30,330	251%	12	$2,958,000	$3,512,000	$6,470,000
2008	114,500	14%	10	$6,618,087	$10,090,900	$16,708,987

Figure 1. The growth of the whale watching industry in Iceland showing the increasing number of tourists and their expenditures in the country. Reproduced from O'Connor, 2008.

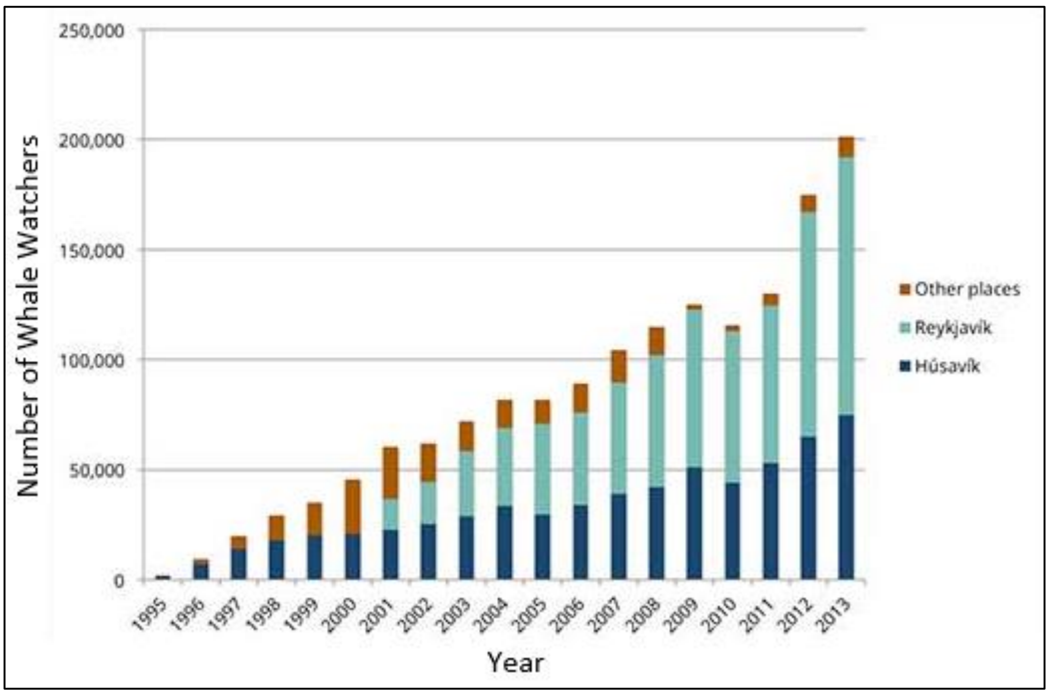

Figure 2. Growth of the Icelandic whale watching industry. Reproduced from Icewhale (2014).

The Rise of Whale Watching in Húsavík

The town of Húsavík in northeast Iceland (population 2,500) has always depended on living marine resources for its economic wellbeing. Historically, its economy has been dependent on fisheries, which remain an important part of the town's economy. The introduction of the individual transferable quota (ITQ) system for cod in 1984 decreased the amount of employment available through fishing. Whale watching began in Húsavík in the 1990s, and by the next decade Húsavík had proclaimed itself to be the "Whale Watching Capital of Europe." In 2008, 41,500 visitors engaged in whale watching in Húsavík out of 114,500 whale-watching visitors nationwide (O'Connor, 2009). There are currently two commercial whale watch operators in Húsavík (North Sailing and Gentle Giants), which provided up to 18 tours a day in 2011 (Magnúsdóttir et al., 2011, Martin 2012).

Negative Impacts of Whale Watching

As a result of this increase in commercial whale watching, cetacean-human interactions occur more frequently and over a larger extent of Icelandic coastal waters than previously. Many conservationists support whale watching because it provides an alternative activity to whale hunting, which is also culturally important for many Icelandic citizens. While many environmental groups tout whale watching as an ecologically sound way to benefit the economy, whale watching can also negatively impact cetacean populations. There is mounting evidence that whale watching can affect a large variety of behaviors as described below and summarizes in Figure 3.

Surfacing/Diving Behavior

Boat traffic has been shown to affect surfacing and diving behavior in cetaceans. Among the species with documented changes in blow intervals and dive times when in the presence of vessels are humpback whales (Baker and Herman, 1989, Corkeron, 1995), Indo-Pacific bottlenose dolphins (Stensland and Berggren, 2007) and costero (*Sotalia guianensis*). Valle and

Cunha Melo (2006) found that costero dolphins remained submerged for longer periods of time when approached.

Active Behavior

Interactions between vessel traffic and cetaceans can lead to altered active behaviors. Lusseau (2006) found that the occurrence of side flops in New Zealand populations of bottlenose dolphins was higher when interacting with power boats. Noren et al. (2009) suggests that boats elicit behavioral response in Salish Sea orca (*Orcinus orca)* populations including breaching, spy hopping and tail slapping.

Acoustic Behavior

Cetacean associated tourism has been documented to affect vocalizations produced by marine mammals. Scarpaci et al. (2000) found that bottlenose dolphins increased whistling behavior when swim-with dolphin operators were present. Noise produced from whale-watching boats can also influence vocalizations, as Sousa-Lima and Clark (2008) found that boat traffic in Northeast Brazil negatively affected humpback whale singing.

Group size or Cohesion

In a few documented cases, vessel traffic has been demonstrated to influence cetacean group size and cohesion. A study from South Carolina, USA found that bottlenose dolphins had a larger mean group size when a boat was present (Mattson et al, 2005). Bejder et al. (2006) found that the cohesion of Indo-Pacific dolphins in Western Australia became more compact when they were approached by boats. Valle and Cunha Melo (2006) concluded that costero dolphins in Brazil formed more cohesive groups when approached.

Swimming Speed and Direction

Vessel approach has been shown to elicit changes in cetacean swimming speeds. Timmel et al. (2008) found that Hawaiian spinner dolphins (*Stenella longirostris*) increased speeds when boats approached, including kayaks. Similar results have been documented in other species. Timmel et al. (2008) also documented increased re-orientation in Hawaiian spinner dolphins.

Altered Feeding and Resting

Constantine et al. (2004) assessed how dolphin-watching company vessels affect the behavior of bottlenose dolphins in New Zealand, and concluded that the amount of time dolphins spent resting was negatively correlated with the number of boats in proximity to individuals. Similar results were found for Tanzanian Indo-Pacific bottlenose dolphins, where Christiansen, et al. (2010) noted a decrease in foraging activity.

Behaviour change	Species
Surfacing/diving	Common bottlenose dolphin, *Tursiops truncatus* Indo-Pacific bottlenose dolphin, *Tursiops aduncus* Indo-Pacific humpback dolphin, *Sousa chinensis* Costero, *Sotalia guianensis* Killer whale, *Orcinus orca* Humpback whale, *Megaptera novaeangliae* Fin whale, *Balaenoptera physalus* Sperm whale, *Physeter macrocephalus*
"Active" behavior (e.g., tail slapping and beaching)	Common bottlenose dolphin, *Tursiops truncatus* Commerson's dolphin, *Cephalorhynchus commersonii* Killer whale, *Orcinus orca* Humpback whale, *Megaptera novaeangliae*
Acoustic	Common bottlenose dolphin, *Tursiops truncatus* Killer whale, *Orcinus orca* Humpback whale, *Megaptera novaeangliae* Sperm whale, *Physeter macrocephalus*
Group size or cohesion	Common bottlenose dolphin, *Tursiops truncatus* Costero, *Sotalia guianensis*
Swimming speed	Indo-Pacific bottlenose dolphin, *Tursiops aduncus* Spinner dolphin, *Stenella longirostris* Killer whale Humpback whale, *Megaptera novaeangliae*
Swimming direction	Common bottlenose dolphin, *Tursiops truncatus* Indo-Pacific bottlenose dolphin, *Tursiops aduncus* Indo-Pacific humpback dolphin, *Sousa chinensis* Spinner dolphin, *Stenella longirostris* Costero, *Sotalia guianensis* Killer whale, *Orcinus orca* Humpback whale, *Megaptera novaeangliae*
Altered feeding or resting	Common bottlenose dolphin, *Tursiops truncatus* Indo-Pacific bottlenose dolphin, Tursiops aduncus Short-beaked common dolphin, *Delphinus delphis* Costero, *Sotalia guianensis* Dusky dolphin, *Lagenorhynchus obscurus* Commerson's dolphin, *Cephalorhynchus comersonii* Risso's dolphin, *Grampus griseus* Killer whale, *Orcinus orca* Humpback whale, *Megaptera novaeangliae*

Figure 3. Summary of documented behavior changes associated with whale watching activity. Taken from Parsons, 2012.

Odontocetes versus Mysticetes

The order Cetacea, which include whales, dolphins and porpoises, can be classified into two suborders, the Odontoceti and Mysticeti. Odontocetes contain teeth, and use echolocation to find prey. Most odontocetes need to eat constantly and maintain high speeds when feeding. Unlike odontocetes, mysticetes do not have teeth. Instead, their mouths contain plates of long, filamentous keratin bristles called baleen, which they use to filter food from the water.

While many studies have examined the effect of boat activity on cetacean behavior, most of these studies have focused on odontocetes, and limited research exists on the effect on mysticetes. This is important because the life-strategies of odontocetes and mysticetes differ. Unlike toothed whales, baleen whales only eat for a few months every year. In Iceland, baleen whales come to the productive waters of Skjalfandi Bay to feed before migrating to tropical latitudes in the winter to reproduce. Because baleen whales do not feed within their reproductive range, all of the energy they use for a year comes from their feeding grounds in Iceland. This is important in the context of disturbance from boats. For example, a previous study from Faxafloi Bay found that whale watching disrupts minke whale feeding activities by altering swimming behavior, directionality, and inter-breath intervals (Christiansen et al., 2013). That study is the only examination of the effects of whale-watching vessels on cetaceans in Iceland, one of the only study on mysticetes worldwide, and the only study on minke whales. I performed a similar study of the effects of boat disturbance on minke whales in Skalfandi Bay to determine whether the results reported by Christiansen et al. (2013) were observable in a second location in Iceland.

Research Methods

The Study Area

Skjálfandi Bay is located in the northeast of Iceland, with the town of Húsavík lying in the southeast corner of the bay (Figure 4). The mouth of the bay is 51 km across, and extends for 10 km to the base (Martin, 2012). Several cetacean species occur within the bay, presumably due to the bay's high productivity. In Skjalfandi Bay odontocete species include the white-beaked dolphin (*Lagenorhynchus albirostrus)* and the harbor porpoise (*Phoceana phoceana*). Other toothed whales and dolphins that periodically visit the bay include the killer whale (*Orcinus orca)*, the long-finned pilot whale (*Globicelphala melas)* and the northern bottlenose whale (*Hyperoodon ampullatus*). Mysticete species present on a seasonal basis include minkes, the fin whale (*Balaenoptera physalus)* the blue whale *(Balaenoptera musculus)*, the sei whale *(Balaenoptera borealis)* and the humpback whale *(Megaptera novaeangliae)*.

Figure 4. Location of Skjalfandi Bay in Iceland. Reproduced from Magnusdottir, et al. 2011

Data Collection

Just north of the town (66°3.100'N and 17°21.800'W) is a lighthouse on a cliff overlooking the sea, from which the entirety of the bay can be observed. From this vantage point, cetaceans within the bay are observable when they surface. Thus, from the lighthouse it is possible to observe cetacean behavior when whale watching boats are present and when they are absent. Theodolite model Geodimeter 640 was mounted on the observation platform of the Húsavík lighthouse and used to determine and track the exact location of boats and cetaceans in the bay in real time. A theodolite can measure vertical angles relative to its position and adjust for height-altering phenomena such as the curvature of the earth or tidal forces. Additionally, using a horizontal landmark in which the distance is known, a theodolite can be calibrated using trigometric functions to determine the exact coordinates of an object (Figure 5). For this study the horizontal landmarks were Lundey and Flatey, two small islets in Skjalfandi Bay (Figure 6).

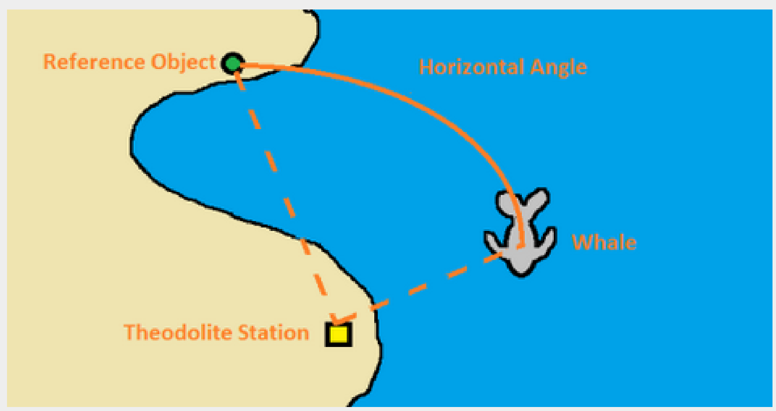

Figure 1 - Calculating the whale's horizontal position in relation to a known reference object

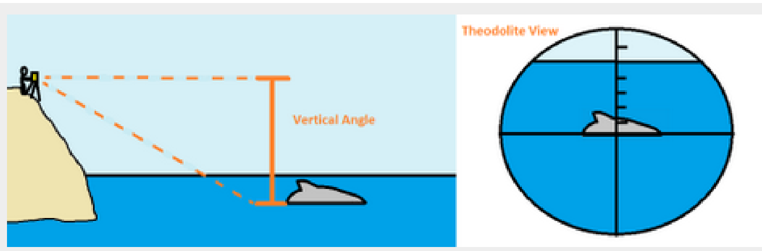

Figure 2 - Calculating the vertical angle to the whale

(Southwest Whale Ecology Study, http://souwest.org/research/research-methods/theodolite-tracking/)

Figure 5. Calculating the location of an object using a land-based theodolite. Taken from the Southwest Whale Ecology Study.

Effort

Observations of minke whales were collected as tracks. A track is determined as the geographical location of minke surfacing events, as measured with a theodolite, in a fifteen minute period. The 2009 field season extended from May 31 – September 2, during which minke whale tracks were observed on 15 days. The 2010 field season extended from June 13 – August 8, over which time minke whale tracks were observed on an additional 15 days. In total, 57 tracks were recorded in each year (2009 and 2010), for a total of 114 tracks over the study period.

Figure 6. Map of Skjalfandi Bay indicating the location of the Húsavík Lighthouse, where the theodolite was mounted, and the islet Lundey, which was used to calibrate the theodolite since its true distance from the tracking station was known

Observations were taken by a three-person team at the Húsavík Lighthouse every day throughout the summers of 2009 and 2010, except on days with poor visibility or rough seas when the Beaufort scale was 3 or higher. Observations began at 7:00 AM and continued for 8 hours into the afternoon. Data collectors rotated between three positions which included a theodolite operator, a data recorder, and a binocular scanner. The theodolite recorded the geographical coordinates of whales and boats in the bay. The binocular scanner was responsible for locating whales. In the event a whale did not resurface after five minutes, subsequent appearances counted as new tracks if it could not be determined that the whale was the same individual.

Data Analysis

The computer tracking program Cyclops Tracker (Version 1.3.1), developed at the University of Newcastle, was used to transfer and view data. This data, in .CSV format, was then exported for analysis in Microsoft Excel and to ArcGIS 10.2 where spatial and temporal analyses were conducted. The projected coordinate system was WGS 1984 Complex UTM Zone 28N. For each track, if a surface feeding event was observed, it was recorded for that track in the comments section of the data sheet. Surface feeding events consist of direct observations when a whale surfaces and engulfs prey. An inter-breath interval (IBI) is the time elapsed between two consecutive surfacing events. The deviation index (DEV) is the relative angle between two adjacent dives. To calculate DEV, the angle is measured between the direction after the first two surfaces (P_{t-1} and P_{t-2}) and the segment formed by the second two dives (Figure 7). It can have a value between 0° (no deviation) and 180° (erratic movement).

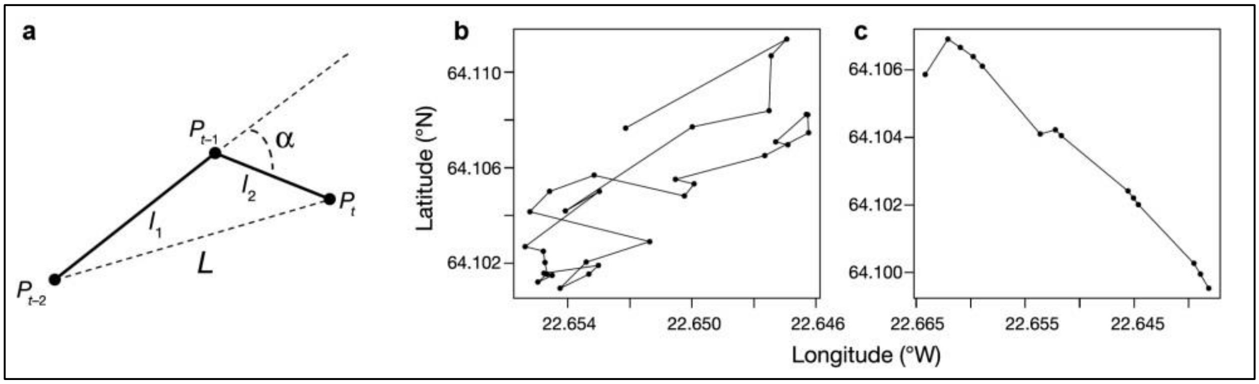

Figure 7. *Balaentopera acutorostrata*. (a) Example of a movement track of a minke whale with three surfacing (P_t, P_{t-1} and P_{t-2}) and two inter-breath intervals (I_1 and I_2); P is the present position, P_{t-1} the previous position, etc. and L is the net distance traveled between P_t and P_{t-2}. Example of a minke whale movement tracks during (b) foraging and (c) non-feeding activity. Adapted from Christiansen et al., 2013).

The speed, deviation, inter-breath intervals and surface feeding events derived from each track were used to determine whether the activity state of each organism represents surface feeding, foraging, or non-feeding activity, in conjunction with determining the distance each animal is from a vessel and the size, speed, directionality and numbers of those vessels in proximity to the whales. Comparing these variables of minke whales under conditions where whale-watching vessels are not present with conditions in which they are was used to infer the effects of the whale watching industry on minke whale energy states (Figure 8; Christiansen et al., 2013).

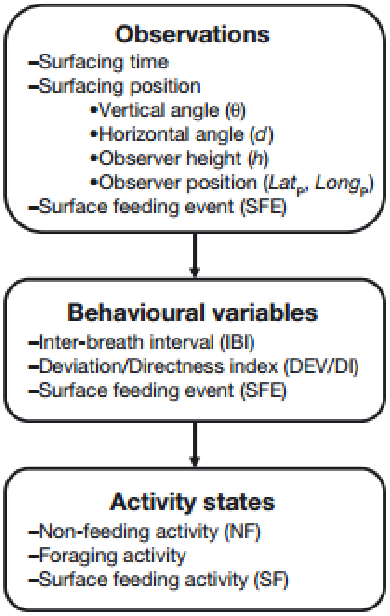

Figure 8. The behaviors of minke whales can be calculated using different behavioral variables such as Inter-breath Intervals, Re-orientation, and surface feeding events, and these variables can be used to infer minke activity states. Reproduced from Christiansen et al., 2013.

Table 1. *Balaenoptera acutorostrata*. Definitions of minke whale activity states on a feeding ground in terms of movement metrics and the associated bioenergetic function (energy acquisition or expenditure) of each state. DEV = deviation index, DI = directness index, IBI = inter-breath interval, SFE = surface feeding event. Sources—a: Lynas & Sylvestre (1988), b: Bertulli (2010), c: Curnier (2005), d: Bailey & Thompson (2006), e: Bailey et al. (2009), f: Stelle et al. (2008)

Activity state	DI low and DEV high		DI high and DEV low		SFE	Bioenergetic functions		Source
	IBI short	IBI long	IBI short	IBI long		E. acquisition	E. expenditure	
Surface feeding (SF)	✓	–	–	–	✓	✓	✓	a, b
Foraging	–	✓	–	–	–	✓	✓	c, d, e, f
Non-feeding (NF)	✓	–	✓	✓	–	–	✓	c, d, e, f

Furthermore, the geographical distribution and habitat use of minke whales within Skjalfandi Bay can be mapped and compared for habitat distribution with and without the presence of vessels. Because theodolite observations occur from early morning to afternoon for a few months each year, changes in habitat use, activity state or swimming behavior throughout the course of a day or summer can be documented, which can shed light on minke behavioral ecology.

Limitations of the Methodology

Although theodolite tracking of cetaceans is a commonly utilized technique for determining cetacean behavior in their natural environments, it can be prone to errors. The accuracy of geographic coordinates collected through theodolite tracking depends on 1) the technological intricacies of the theodolite and 2) the altitude of the theodolite. The altitude of the theodolite station changes throughout the day as the tide ebbs and flows, which could be particularly problematic in regions that experience extreme changes between low and high tide, or extreme swells (Bailey and Lusseau, 2004). However, Würsig et al, 1991 demonstrated the greater the theodolite altitude, the more accurate the distances from the tracking station and the speed of the objects being tracked regardless of the tide (Figure 9).

Theodolite height (m)	Error in height (%)	Actual distance (m)	Distance underestimate		Estimated speed (m/sec)	Speed underestimate	
			(m)	(%)		(m/sec)	(%)
15	6.7	500	30	6.0	1.88	0.12	6.0
		2,500	172	6.9	1.86	0.14	6.9
		5,000	379	7.6	1.85	0.15	7.6
30	3.3	500	17	3.4	1.93	0.07	3.4
		2,500	85	3.4	1.93	0.07	3.4
		5,000	177	3.5	1.93	0.07	3.4
45	2.2	500	11	2.2	1.96	0.04	2.2
		2,500	56	2.2	1.96	0.04	2.2
		5,000	116	2.3	1.95	0.05	2.3
100	1	500	5	1.0	1.98	0.02	1.0
		2,500	25	1.0	1.98	0.02	1.0
		5,000	21	1.0	1.98	0.02	1.0

Figure 9. Theodolite errors in distance and speed of tracked objects as a result of inaccurate theodolite height measurements. Reproduced from Würsig et al, 1991.

Results

Range of Swimming Speeds

Swimming speed was calculated for whales in close proximity to boats (< 100 m) and far from boats (> 1000 m). The percentage of minkes swimming less than 6 km.hr decreased when boats were present (Figure 10a). The percentage of whales traveling 6-8 km/hr when boats were present was about the same frequency regardless of boat presence. Conversely, the frequency of tracks with animals moving between 8-12 km/hr was higher when boats were present. The percent of animals traveling greater than 12 km/hr was higher when vessels were not present. Despite these observation, a χ^2 analysis indicated no statistical difference in swimming for minkes near versus far from boats (Figure 10b).

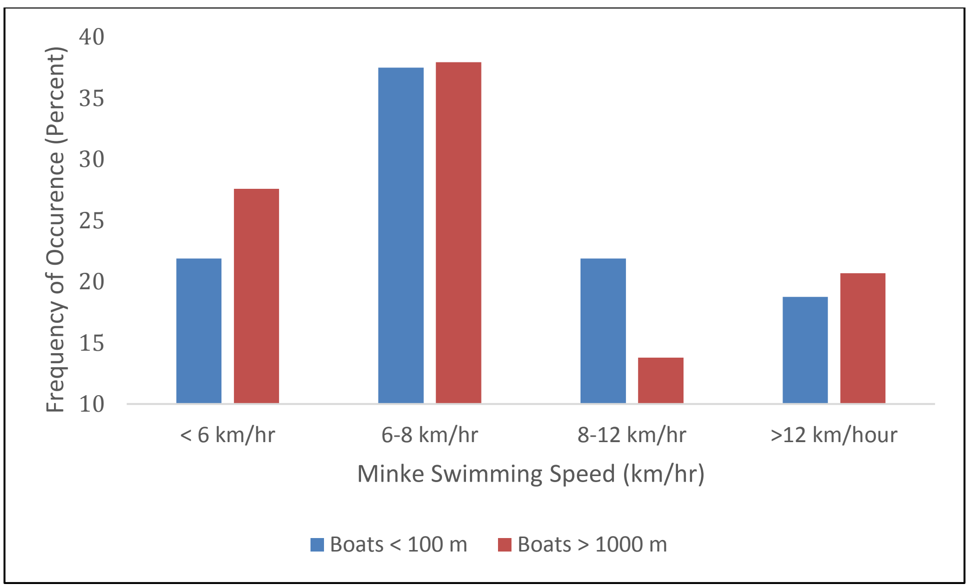

Figure 10a: Frequency of minke whale swimming speeds in the presence and absence of boats

Observed

Categories	< 6 km/hr	6-8 km/hr	8-12 km/hr	>12 km/hr	Row totals
Boats < 100 m	7	12	7	6	32
Boats > 1000 m	16	22	8	12	58
Column totals	23	34	15	18	90

Expected

Categories	< 6 km/hr	6-8 km/hr	8-12 km/hr	>12 km/hour
Boats < 100 m	8.17778	12.0889	5.33333	6.4
Boats > 1000 m	14.8222	21.9111	9.66667	11.6
Column totals	23	34	15	18

Computing Chi-squared

Categories	< 6 km/hr	6-8 km/hr	8-12 km/hr	>12 km/hour
Boats < 100 m	0.16963	0.00065	0.52083	0.025
Boats > 1000 m	0.09359	0.00036	0.28736	0.01379

Sum:	1.11121
df:	3
P-value	0.77437

Figure 10b. Results of χ^2 analysis showing that minke swimming speeds were not statistically different for tracks within 100 m and greater than 1000 m

Minke Swimming Speed and Proximity to Boats

The average swimming speed for minke whales in tracks less than 100 m from boats in a five minute period was 10.56 km/hr, compared with 9.82 km/hr for whales farther than 1000 m from any boats, although this difference was not statistically significant (Figure 11).

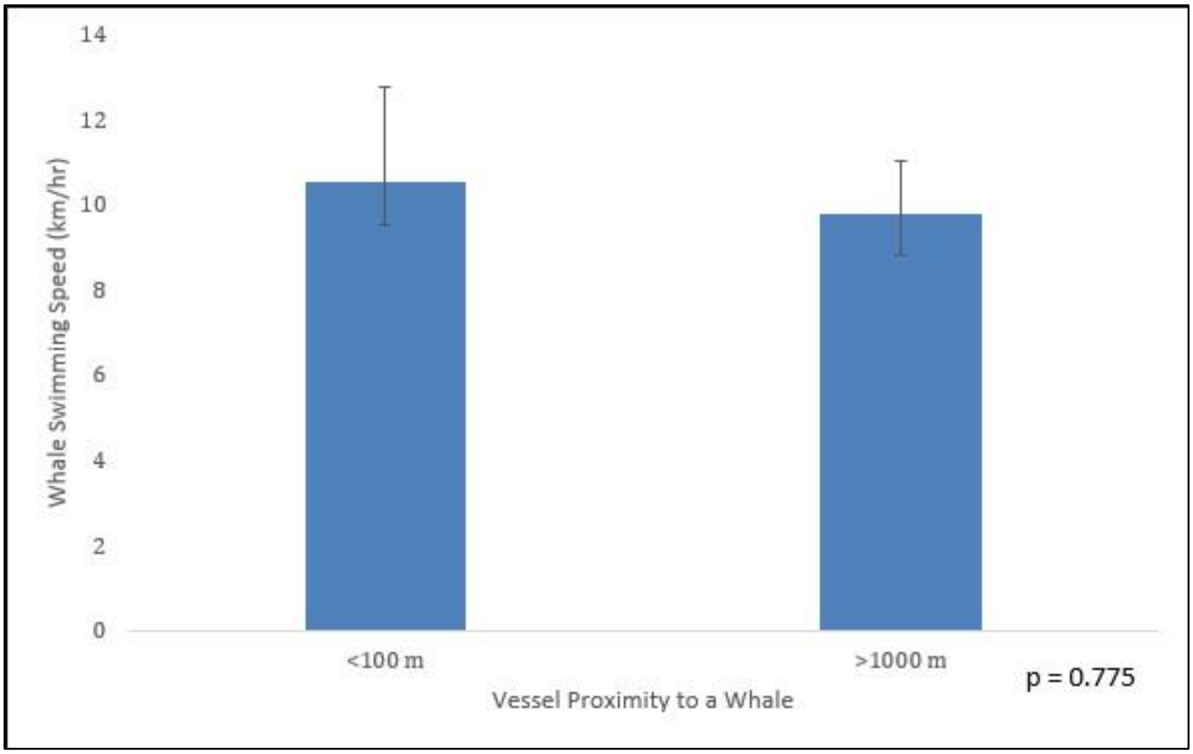

Figure 11: Minke whale swimming speed within differing proximities to vessels

Minke Swimming Speed and Boat Number

As the number of boats within 1000 m of a whale increased, the average minke swimming speed did not show any detectable trend. Interestingly, variation in swimming speed was greatest in the absence of boats and appeared to decline with the number of boats (Figure 12).

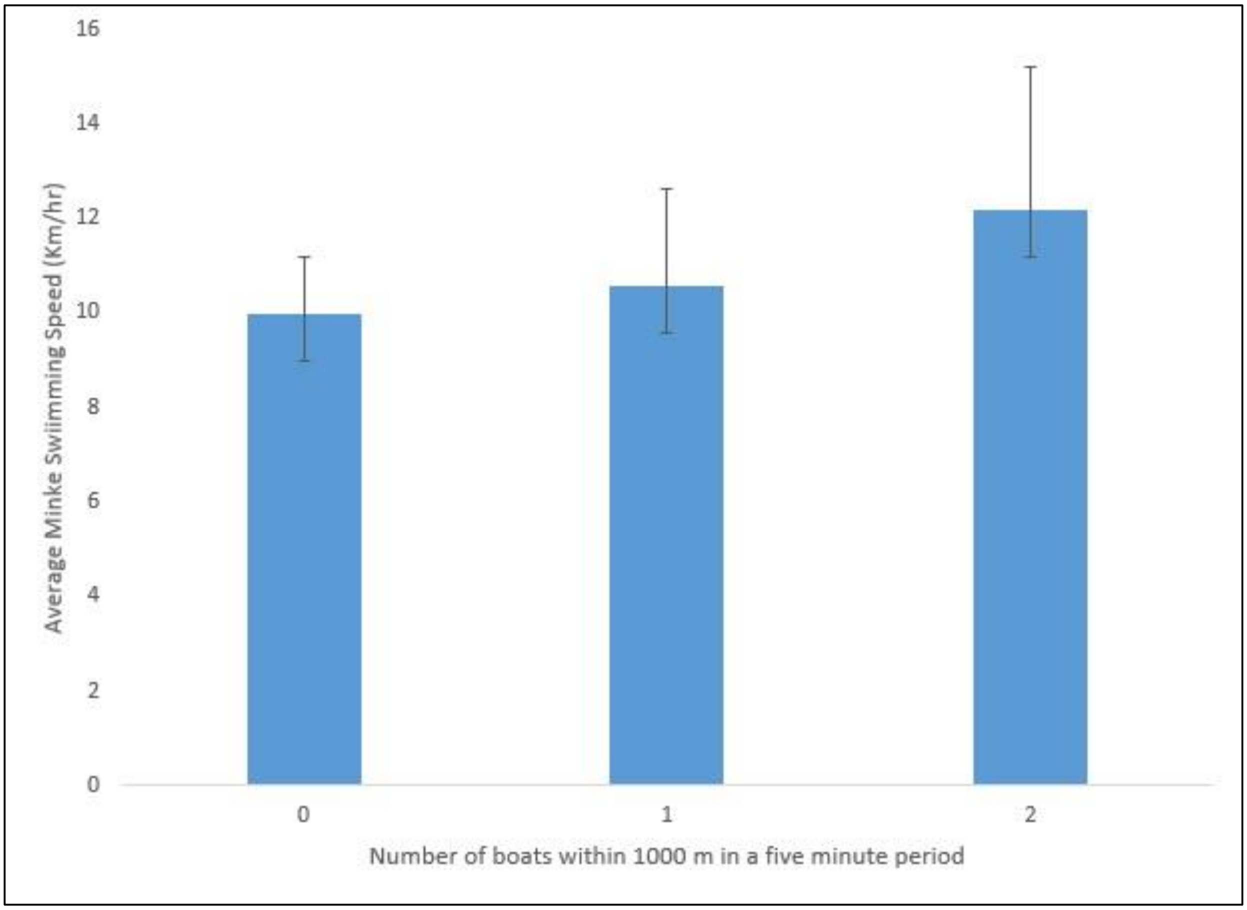

Figure 12 Relationship between the number of boats within 1000 m and average minke swimming speed

Minke Linearity and Proximity to Boats

The mean angle created between three minke surfacing events was 53.71 º when whales were within 500 m and 42.27 º when boats were greater than 500 m away, although this difference was not statistically significant (Figure 13).

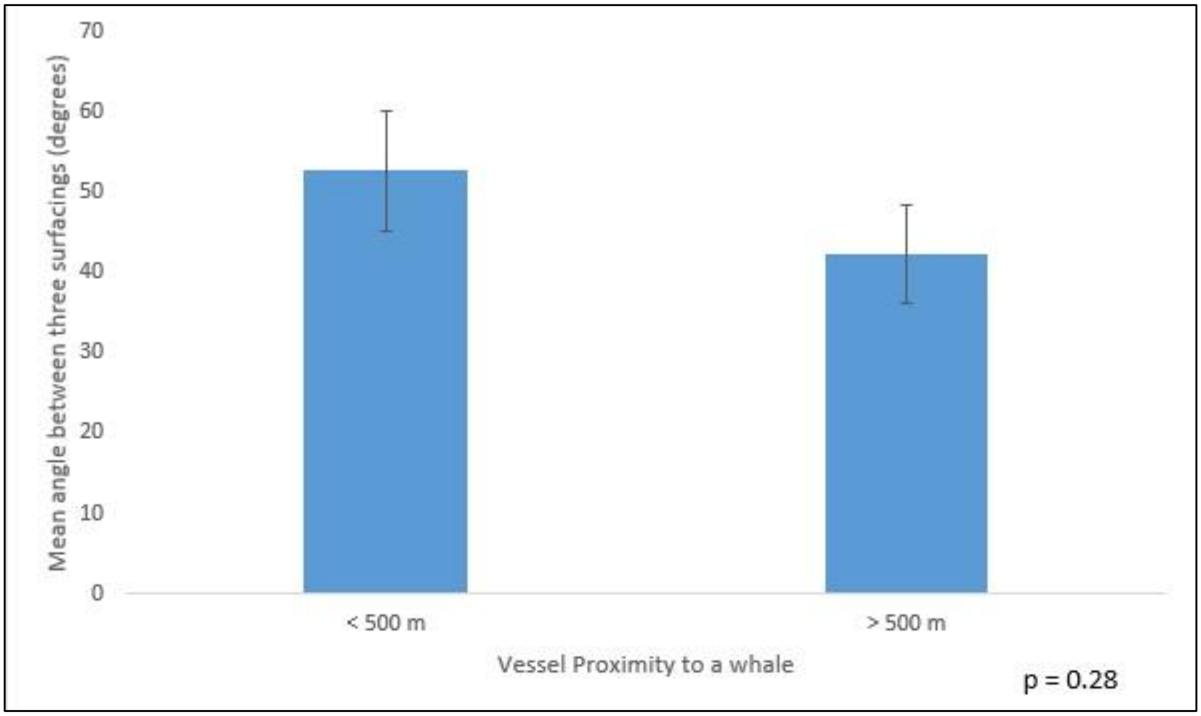

Figure 13: Minke linearity within differing proximities to vessels

Minke Linearity and Boat Number

As the number of boats within 1000 m of a whale increased, minke linearity did not show any detectable trend. The mean angle created between three minke surfacing events was 40.37 ° for no boats, 56.05 ° for one boat, and 56.20 ° for two boats (Figure 14).

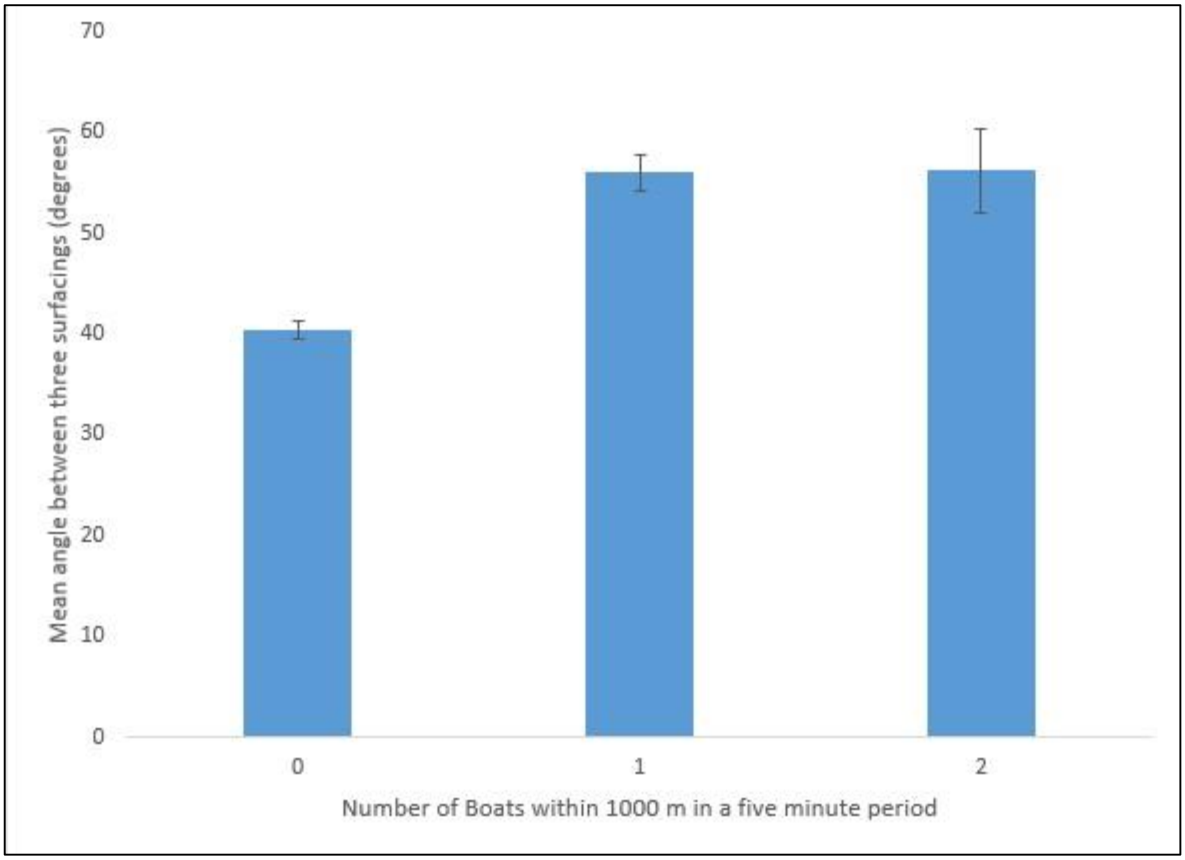

Figure 14 Relationship between the number of boats within 1000 m and minke linearity

Inter-breath Interval vs Boat Proximity

The average inter-breath interval for whales within 100 m was 118 seconds, 88 seconds for dives when the closest boats were 100 – 500 m away from minkes, and 115 seconds for boats greater than 1000 m away (Figure 15).

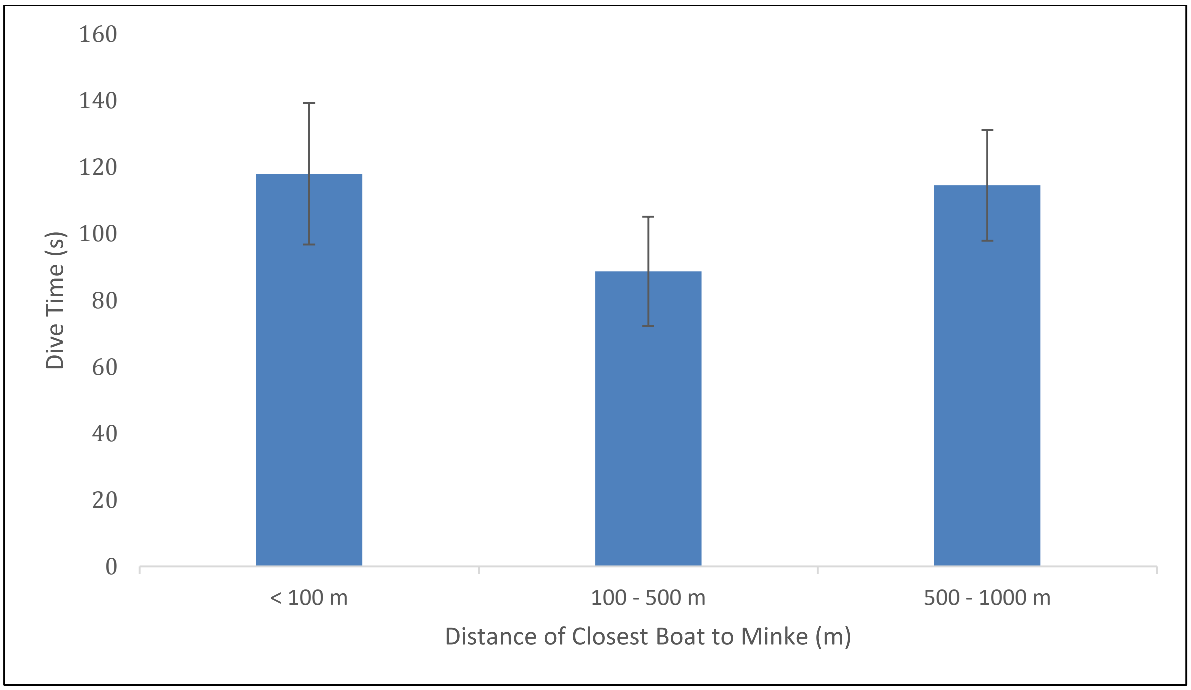

Figure 15: Average inter-breath intervals of minke whales with closest boat at different distances.

Inter-breath Interval vs Boat Number

The average inter-breath interval for minke tracks with no boats within 1000 m was 115 seconds, 98 seconds for tracks with one boat present, and 102 seconds for tracks with two boats within 1000 m of a minke (Figure 16).

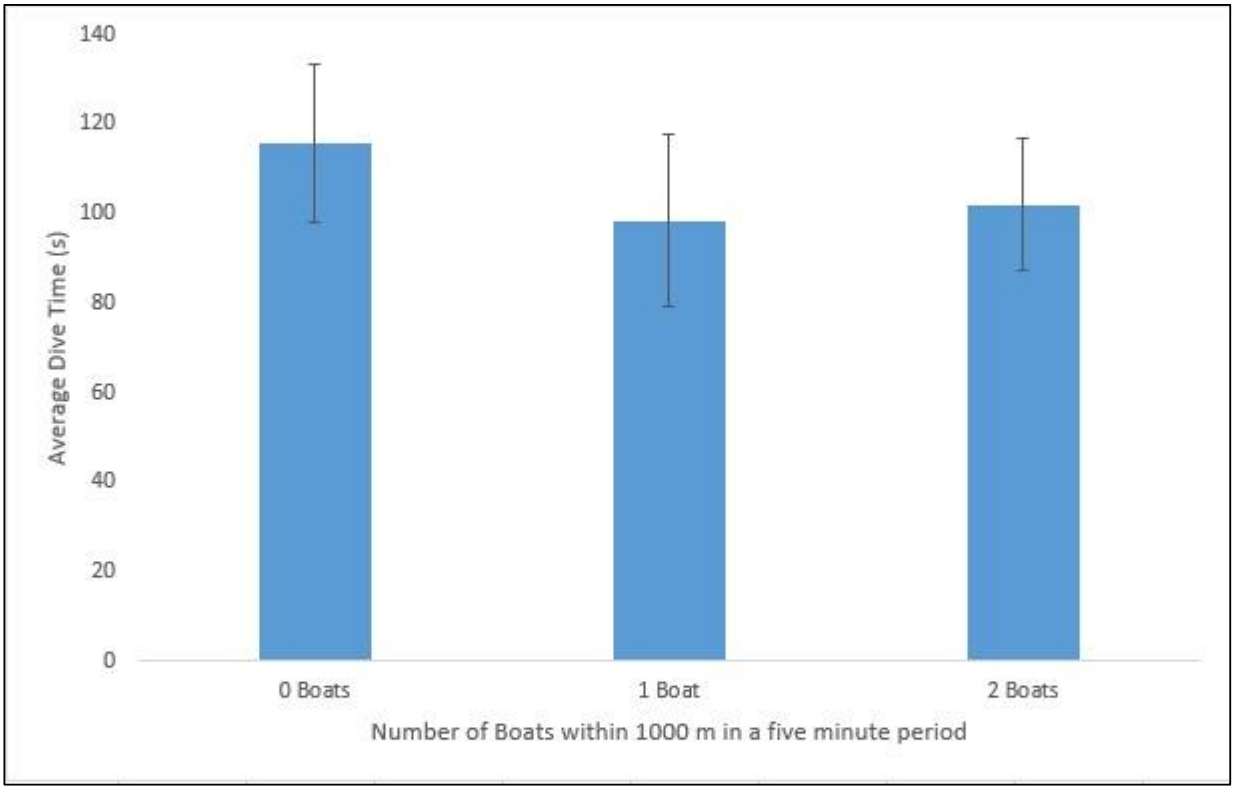

Figure 16: Relationship between average minke track interbreath interval and boat number

Proximity vs Surface Feeding Events

A total of 22 surface feeding events were recorded during the study period. Sixty-three percent of surface feeding events were observed when boats were greater than 500 m from whales, 14% of surface feeding events occurred when a vessel was 100 – 500 m from a whale, and 23% of feeding activity was observed when boats were within 100 m (Figure 17).

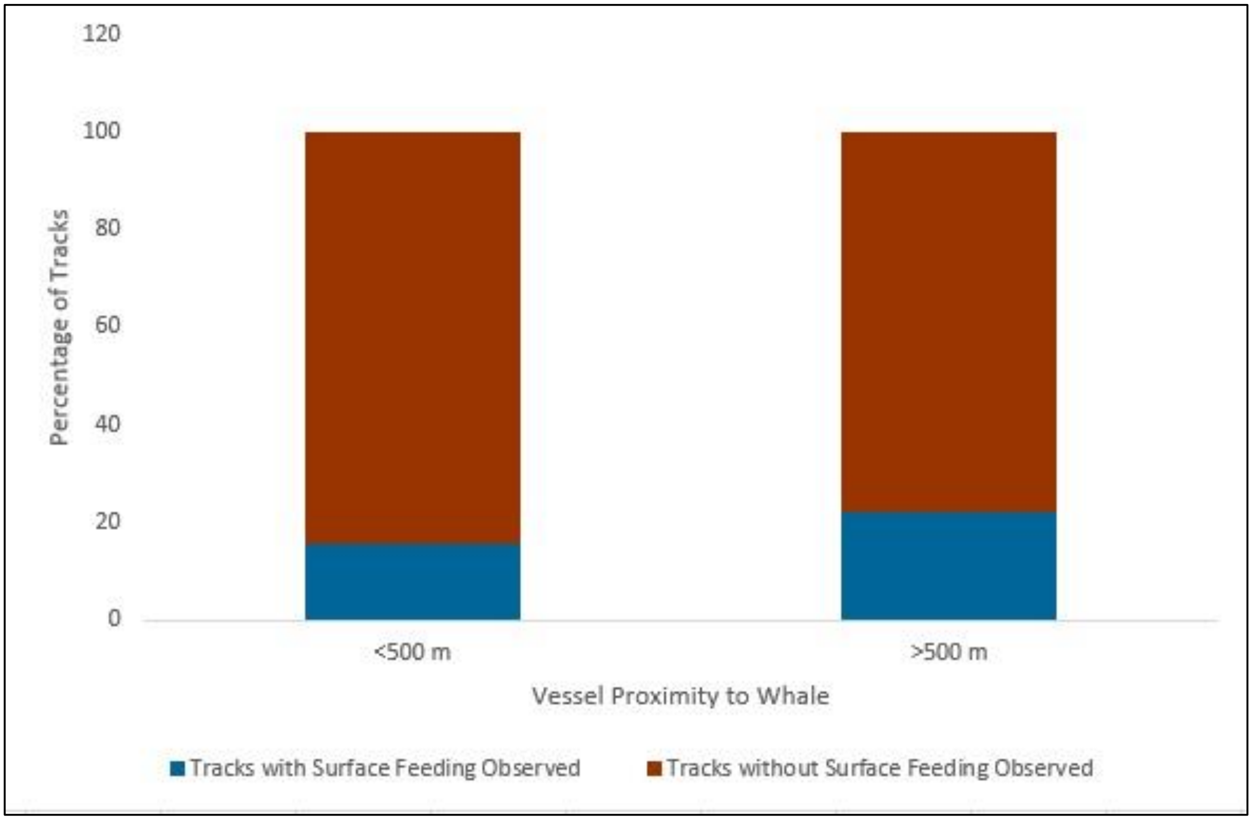

Figure 17: Surface feeding event prevalence and minke distance to nearest boat

Relationship between Boat Number and Surface Feeding Events

Surface feeding events were observed in 20% of tracks when no boats were within 1000 m of a whale, 11% of tracks when one vessel was within 1000 m from a whale, and 15 % of tracks for two vessels (Figure 18).

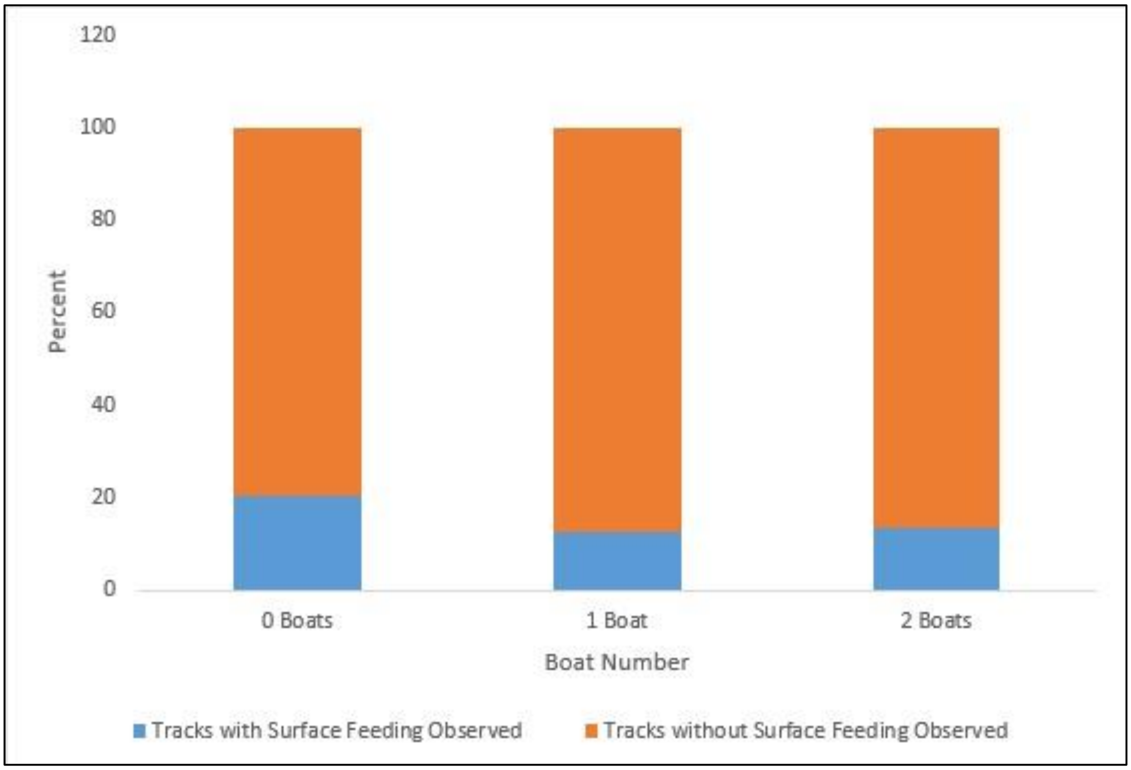

Figure 18. Surface feeding event frequency in relation to boat number proximate to minke

Boat number frequency per minke

Of the minke tracks where boats were present within 1000 m, about half (52%) did not have any boat nearby, 31% had two boats within 1000 m, 11% of whales had 3 boats, 3% had four boats, and 3% had five boats within 1000 m (Figure 19).

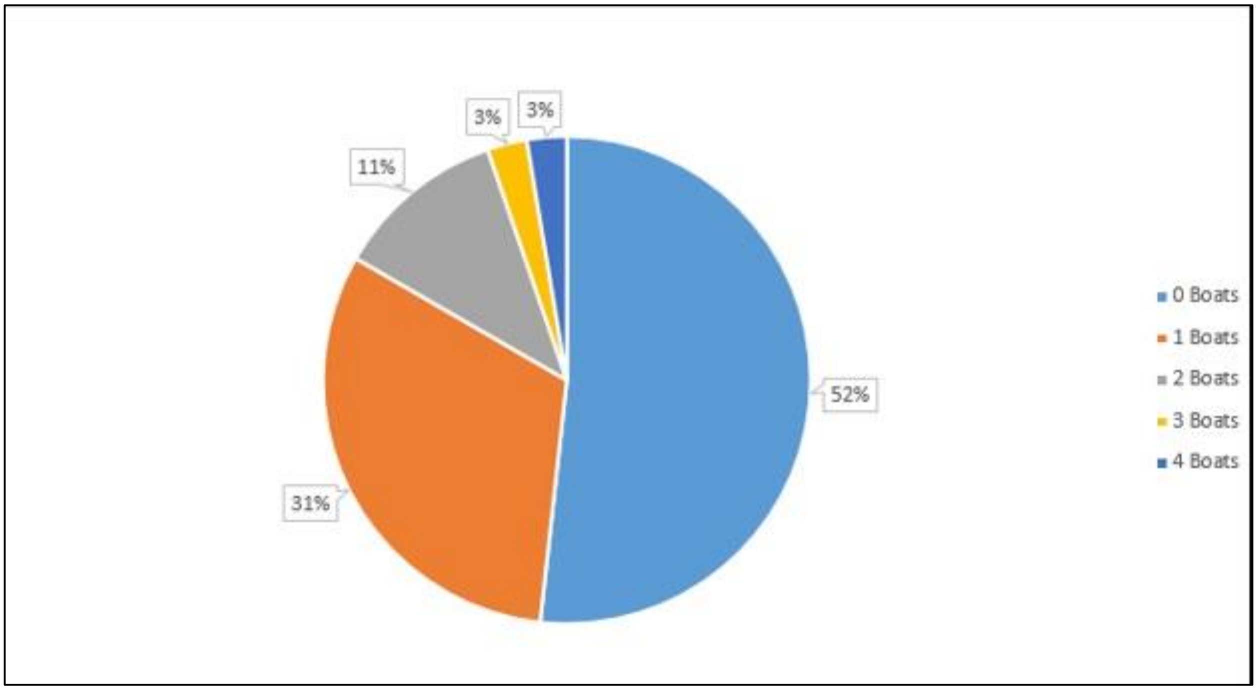

Figure 19: Boat number frequency for minke whale tracks within 1000 m of boats

Discussion

The results of this study differed from those reported for minke whale-boat interactions in Faxafloi Bay. In Faxafloi Bay, boat activity altered the deviation of minke whales and dive times. Conversely, the results reported here for Skjalfandi Bay do not show any relationship between boat proximity and the deviation and inter-breath intervals of minkes, nor do they show any correlation between boat proximity and whale swimming speed (a variable not examined by Christiansen et al (2013). Although no relationship was detected between boat proximity and dive times, swimming speed, or re-orientation, there does appear to be a relationship between boat proximity and active surface feeding behavior. Minke whales appeared more likely to surface feed when in the same area as boats. However, the difference is not significant. Some error may have resulted in some tracks erroneously being coded as minke whales when they were in fact white-beaked dolphins. Some tracks labeled as minkes did not behave as typical minkes, but there tracks were included in the study to avoid bias.

While many studies have shown that boat activity can influence cetacean behavior, little data exists on the long-term impacts of such changes. When imposed over long periods, short term changes in energy use and behavior could negatively influence vital metabolic processes (Figure 20, Lusseau and Bedjer, 2007). If boat activity diminishes surface feeding events, as demonstrated for Faxafloi Bay but not supported for Skjalfandi Bay, repeated disturbance over the course of a foraging season could result in whales obtaining less food than they would be able to obtain in the absence of vessels. Because boat disturbances may influence bioenergetics of minke whales, disruption of foraging behavior could have a negative effect on an adult's ability to produce healthy offspring, ultimately resulting in population decline. This hypothesis remains to be tested.

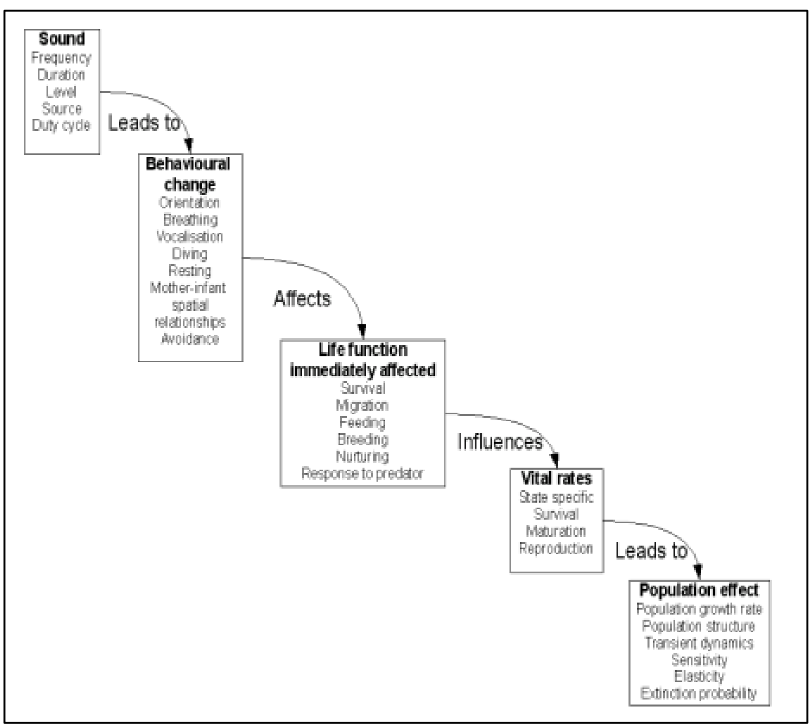

Figure 20. A framework hypothesizing how short-term changes to whale behavior can impact populations over a long-term period. Taken from Lusseau and Bedjer, 2007

Fewer cetacean species are found in Faxafloi Bay compared with Skjalfandi Bay. Many tourists would prefer to see certain species of whales including blue whales, fin whales and humpbacks compared to minke whales. Hence, in Skjalfandi Bay, where a greater diversity of whales is present, whale-watch boats may focus more intensively on viewing species other than minkes, whereas minkes may be more targeted by whale watching boats Faxafloi Bay. A higher rate of interactions between minkes and boats may occur in Faxafloi Bay, potentially resulting in more disturbances to minkes in that foraging ground than in Skalfandi Bay, contributing to differences observed in the two locations, and leading to the possibility that observed effects are dependent on the species composition of the location under study. Alternatively, or in addition, other physical or biological differences between the two bays could account for the differences observed.

Implications for Management

Long term-sustainability of whale-watch tourism in Iceland requires that whales continue to occupy bays and other near shore areas in numbers sufficient to attract tourists. Evidence from other systems worldwide suggest that management actions that reduce the negative influences of boats on whale behavior can help to assure sustainability of the industry. In Iceland, over-development of whale-watching could have negative consequences for the local community. If whales are harassed to a sufficient degree, they may reduce time spent foraging in Skjalfandi Bay in exchange for neighboring fjords outside the Húsavík region or further offshore. Alternatively, whale watching over a long term may cause a decline in the health of a cetacean population. In such a situation, socio-economic gains from whale watching could disappear. During one year of this study (2010), humpbacks, blue whales, finbacks, and northern bottlenose whales were suddenly very scarce, whereas they are normally quite common in the bay and returned the following year. When these more "desirable" species were not present, demand for minke whale viewing increased. Had minke whales not been present in the bay, the economic outcome could have been highly negative for the whale watching companies operating there, and Húsavík's reputation as the whale watching capital of Europe could have been tarnished. Effective management with binding regulations on whale-watch companies may be needed to preserve the newfound fortune of the whale watching industry in Faxafloi Bay. However, for Skjalfandi Bay, industry imposed voluntary whale watching guidelines as described by Martin (2012) may be sufficient for striking a balance between economic prosperity and sustainability and cetacean health, as well as making sure the passenger experience aboard remains enjoyable.

A high degree of variation was observed in most metric used in this study, obscuring effects that might exist. Study designs that reduce this variation and provide more statistical power could help to confirm or refute the results obtained in this study , and could help in interpretation of differences obtained between this study and that of Christiansen et al. (2013). Determination of specific sensitivities and interspecific differences in sensitivity to boat disturbance among whales in Icelandic waters will help in determining whether regulations are needed, and if so, how regulations should be crafted to optimize the whale-watching experience while reducing the effects on whales. To achieve this, studies similar to this one need to be conducted on other cetacean species in Iceland targeted by the wildlife-viewing industry. Additionally, studies on the effects of whale-watching vessels on other behaviors not examined in this study will provide a more comprehensive view of their impacts, as will on whether boats can behave in certain ways that minimize cetacean disturbance.\

Conclusion

Whale watching activity in Skjalfandi Bay does not appear to affect minke swimming speed, direction or dive times or how often minke whales engage in surface feeding. Revision to management of the rapidly expanding Icelandic whale watching industry may not currently be needed in Skjalfandi Bay to protect both whale populations and the sustainability of the industry. However, further expansion of the industry may potentially impose more disturbance on whales, and more effective management may be needed in the future. While cetacean viewing tourism has diversified and expanded the economy of some Icelandic towns such as Húsavík, such economic gains are only sustainable as long as the whales that tourists flock to see persist in these regions.

Literature Cited

Allen, S., Smith, H., Waples, K. & Harcourt, R. (2007). The voluntary code of conduct for dolphin watching in Port Stephens, Australia: is self-regulation an effective management tool? Journal of Cetacean Research and Management, 9(2), 159-166.

Bailey, H., & Lusseau, D. (2004). Increasing the precision of theodolite tracking: Modified technique to calculate the altitude of land-based observation sites. Marine Mammal Science. 20, 880-885.

Baker, C.S. and Herman, L.M. (1989). Behavioral responses of summering humpback whales to vessel traffic: Experimental and opportunistic observations. Technical Report NPS-NR-TRS-89-01. National Park Service, Alaska Regional Office, Anchorage, AK

Bejder, L., Samuels, A., Whitehead, H., & Gales, N. (2006). Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. Animal Behavior -London- Bailliere Tindall Then Academic Press-. 72, 1149-1158.

Christiansen, F. Lusseau, D. Stensland, E. and Berggren, P. (2010) “Effects of tourist boats on the behaviour of Indo-Pacific bottlenose dolphins off the south coast of Zanzibar,” Endangered Species Research, vol. 11, no. 1, pp. 91–99

Christiansen F, Rasmussen M, Lusseu D (2013) Whale Watching disrupts feeding activities of minke whales on a feeding ground. Mar. Ecol Prog Ser 478:239-251

Constantine R, Brunton D, & Dennis T. (2004). Dolphin-watching tour boats change bottlenose dolphin (Tursiops truncatus) behavior. Biological Conservation, 117, 229-307.

Davidson, Ana D. ; Boyer, Alison G. ; Kim, Hwahwan ; Pompa - Mansilla, Sandra ; Hamilton, Marcus J. ; Costa, Daniel P. ; Ceballos, Gerardo ; Brown, James H. Proceedings of the National Academy of Sciences of the United States, Feb 28, 2012, Vol.109(9), p.3395(6)

Duprey, N., Weir, J. & Würsig, B. (2008) Effectiveness of voluntary code of conduct in reducing vessel traffic around dolphins. Ocean and Coastal Management, 51, 632-637.

IceWhale (2014), "Whale Watching in Iceland"

International Whaling Commission, "Chairman's report of the forty-fifth annual meeting. Appendix 9. IWC resolution on whale watching," Reports of the International Whaling Commission, vol. 44, pp. 33–34, 1994.

Jelinski, D.E, C.C Krueger, and D.A Duffus. "Geostatistical Analyses of Interactions between Killer Whales (Orcinus Orca) and Recreational Whale-Watching Boats." Applied Geography. 22.4 (2002): 393-411. Print.

Lusseau,D., "The short-term behavioral reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand," Marine Mammal Science, vol. 22, no.4, pp. 802–818, 2006.

Lusseau, D. & Bejder, L. (2007). The long-term consequences of short-term responses to disturbance experiences from whale watching impact assessment. International Journal of Comparative Psychology, *20*, 228-236

Magnúsdóttir, E. (2011). Theodolite: Theory and Methods. Presented at the University of Iceland's Marine Mammal Field Course in Húsavik, Iceland, July 2011. Presentation available at the Húsavik Research Centre.

Magnúsdóttir, E., Cummings, J. & Rasmussen. M. (2011). Effects of boat traffic on the minke whale's (Balaenoptera acutorostrata) swimming behaviour in Skjálfandi Bay, NE-Iceland. Poster available at the University of Iceland's Research Centre in Húsavik.

Martin, 2012 Whale Watching in Iceland: An Assessment of Whale Watching Activities on Skjálfandi Bay, University Centre of the Westfjords, Ísafjörður, Iceland

Mattson, M. C., Thomas, J. A., & Staubin, D. (2005). Effects of Boat Activity on the Behavior of Bottlenose Dolphins (Tursiops truncatus) in Waters Surrounding Hilton Head Island, South Carolina. Aquatic Mammals. 31, 133-140.

Noren, D. P., Johnson, A. H., Rehder, D. and Larson, A. (2009) “Close approaches by vessels elicit surface active behaviors by southern resident killer whales,” Endangered Species Research,vol. 8, no. 3, pp. 179–192

O’Connor, S., Campbell, R., Cortez, H. & Knowles, T. (2009). Whale Watching Worldwide: tourism numbers, expenditures and expanding economic benefits. A special report from the International Fund for Animal Welfare, Yarmouth MA, USA, prepared by Economists at Large. Retrieved online February 4, 2014 from: http://www.ifaw.org/sites/default/files/whale_watching_worldwide.pdf

Parsons, E. C. M. “The Negative Impacts of Whale-Watching,” Journal of Marine Biology, vol. 2012, Article ID 807294, 9 pages, 2012. doi:10.1155/2012/807294

Scarpaci, C., Bigger, S. W., Corkeron, P. J, and Nugegoda, D. (2000) “Bottlenose dolphins, Tursiops truncatus, increase whistling in the presence of “swim-with-dolphin” tour operations,” Journal of Cetacean Research and Management, vol. 2, pp. 183–185

Sousa-Lima, R. S. and Clark, C. W. (2008) “Modeling the effect of boat traffic on the fluctuation of humpback whale singing activity in the Abrolhos National Marine Park, Brazil,” Canadian Acoustics, vol. 36, no. 1, pp. 174–181

Stensland, E. and Berggren, P. (2007) “Behavioural changes in femaleIndo-Pacific bottlenose dolphins in response to boat-based tourism,” Marine Ecology Progress Series, vol. 332, pp. 225–234

Timmel, G., Courbis, S., Sargeant-Green, H., & Markowitz, H. (2008). Effects of Human Traffic on the Movement Patterns of Hawaiian Spinner Dolphins (Stenella longirostris) in Kealakekua Bay, Hawaii. Aquatic Mammals. 34, 402-411.

Valle, L. do and Cunha Melo, F.C. (2006), “Behavioral alterations in the gray dolphin Sotalia guianensis (Gervais, 1953) caused by sea traffic,” Biotemas, vol. 19, no. 1, pp. 75–80.

Wiley, D., Moller, J., Pace III, R. & Carlson, C. (2008). Effectiveness of voluntary conservation agreements: Case study of endangered whales and commercial whale watching. Conservation Biology, 22(2), 450-457.

Würsig, B., Cipriano, F. & Würsig, M. (1991). Dolphin movement patterns: information from radio and theodolite tracking studies. In K. Pryor & K. Norris, (Eds). Dolphin societies: discoveries and puzzles (pp, 79-112). University of California Press, Berkeley and Loss Angeles, California.