UNIVERSITY OF NORDLAND

MASTER THESIS

Distribution and vocal behavior of Atlantic white-sided dolphins (*Lagenorhynchus acutus*) in northern Norway

Ellyne Terese Hamran

BI309F MSc IN MARINE ECOLOGY

Faculty of Biosciences and Aquaculture

October 2014

Table of Contents

Foreword

Journal style: Journal of Applied Ecology. Reports such as the Norwegian Marine Institute and additional were referenced as reports with document numbers and referenced in the text with author(s) and year.

Dolphin Naming: The usage of the common names of Atlantic White-sided Dolphins and White-beaked Dolphins became confusing if detail to the second half of the name were ignored hence the Latin names were more distinctive and preferred.

Maps: Maps were created in ArcGIS (desktop Advanced 10.2.2 by ESRI) utilizing bathymetry layers and data was estimated as close as possible to sighting locations however some data in the database was not defined in exact coordinates.

Student Involvement: The searching effort that I took part in was 75 hrs 32 min for 11 days in June, July, and September of 2013. Trips ranged from 3 hrs to 11 hrs and 57 min depending mostly on weather conditions. This does not reflect the extensive searching efforts of Ocean Sounds and their database from 2007 to 2013. For this study I analyzed all of the photographs to create a new Photo-ID database and re-sightings. I also analyzed all of the sound recordings data and collected additional data from the field during the summer of 2013. I performed the statistical analysis, created graphs, maps, and writing.

Reading Boxplots: The median (divides the range in the middle with 50% of the data below) is the thick middle line. The third quartile (75 percentile) is the top of the rectangle. The first quartile (25 percentile) is the bottom of the rectangle. The thin "T" looking bars on the top are the maximum and the thin "T" looking bars on the bottom are the minimum. Outliers are the circles on the ends and the closely grouped outliers are the suspected outliers.

Abstract

The Atlantic White-sided Dolphin (*Lagenorhynchus acutus*) distribution is understudied in Norway. Vessel based surveys were conducted in the Vestfjorden of northern Norway and sightings occurred during 2005, 2007-2013. A total of 72 annual sightings were observed including 55 Photo-ID individuals of which 29 individuals were re-sighted (2 of the 15 re-sighted individuals were observed on 6 occasions with gaps no greater than 2 years). Sound recording were recorded using a hydrophone and the vocal behavior of clicks, buzzes, whistles, and calls that were compared with activity; foraging, socializing, milling, and traveling. Clicks were the most abundant sound produced and whistles were equally abundant second to clicks. Stereotyped whistles were also observed (eg. 11-20 kHz, length 853 msec). Calls were observed most common during traveling (32.4%) and least common during foraging (18.8%). Buzzes varied (0-14.0%) and were absent during milling. Sound was dependent on activity and sound production increased during socializing. Click production increased in deeper water than shallower water, and was observed during foraging and milling. Two different foraging strategies were observed; group cooperative herding of fish in a shallower narrower fjord, Ingelsfjorden (8-10 m) and herding of fish by dolphin pairs in a deeper wider fjord, Øyhellsundet (52-81 m) in northern Norway on two consecutive dates. Frequent observations in this study of *L. acutus* may indicate a variety of population behaviors and distributions however more research is required to identify and confirm them.

Introduction

Atlantic White-sided Dolphin Distribution and Biology

Atlantic White-sided Dolphins (*Lagenorhynchus acutus*) are part of the order Cetacea (whales, dolphins, and porpoises), sub-order Odontoceti (toothed whales) in the Delphinidae family and part of the a genus *Lagenorhynchus* of which half of the dolphins have northern distribution; Atlantic White-sided Dolphins (*Lagenorhynchus* acutus), White-beaked Dolphins (*L. albirostris*), and Pacific White-sided Dolphin (*L. obliquidens*) and the remaining have southern distribution; Dusky Dolphin (*L. obscurus*), Peale's Dolphin (*L. australis*), and the Hourglass Dolphin (*L. cruciger*). Atlantic White-sided Dolphins (further referred to as *L. acutus*) are endemic to the North Atlantic cool (5-16^{0}C) and low salinity water (Waring et al. 2008) along the continental shelf in 100-500m depths. They are distributed west from the Davies straight to the Norwegian Sea east, and southward in North Carolina (35^o N) in the west, in the Celtic Sea and perhaps the Azores (37-39 ^{o}N) to the east (Reeves et al. 2002; Figure 1). *L. acutus* are oceanic dolphins located near the continental shelf, slope, canyon waters, and concentrate in areas of high seafloor relief, more densely in deeper areas (Reeves et al. 2002) and sometimes near the coast (Cipriano 2009). The continental shelf edge can be used as a navigation aid to travel or simply an area with high prey abundance (Stevick 2002). *L. acutus* are also sighted year round in the deep waters north of Scotland and in the North Sea in summer most likely following prey (Northridge et al. 1997). *L. acutus* tend to move to northern latitudes during warmer months and closer to shore in the summer and offshore during the winter (Reeves et al. 2002). Little is known about the northern limitations which range at least the southern part of Greenland, southern Iceland, and the south coast of Svalbard Island (Reeves et al. 1999). *L. acutus* are considered common in south-western Norway although few sightings were reported (Northridge et al. 1997) and they sometimes enter fjords and inlets (Reid et al. 2003).

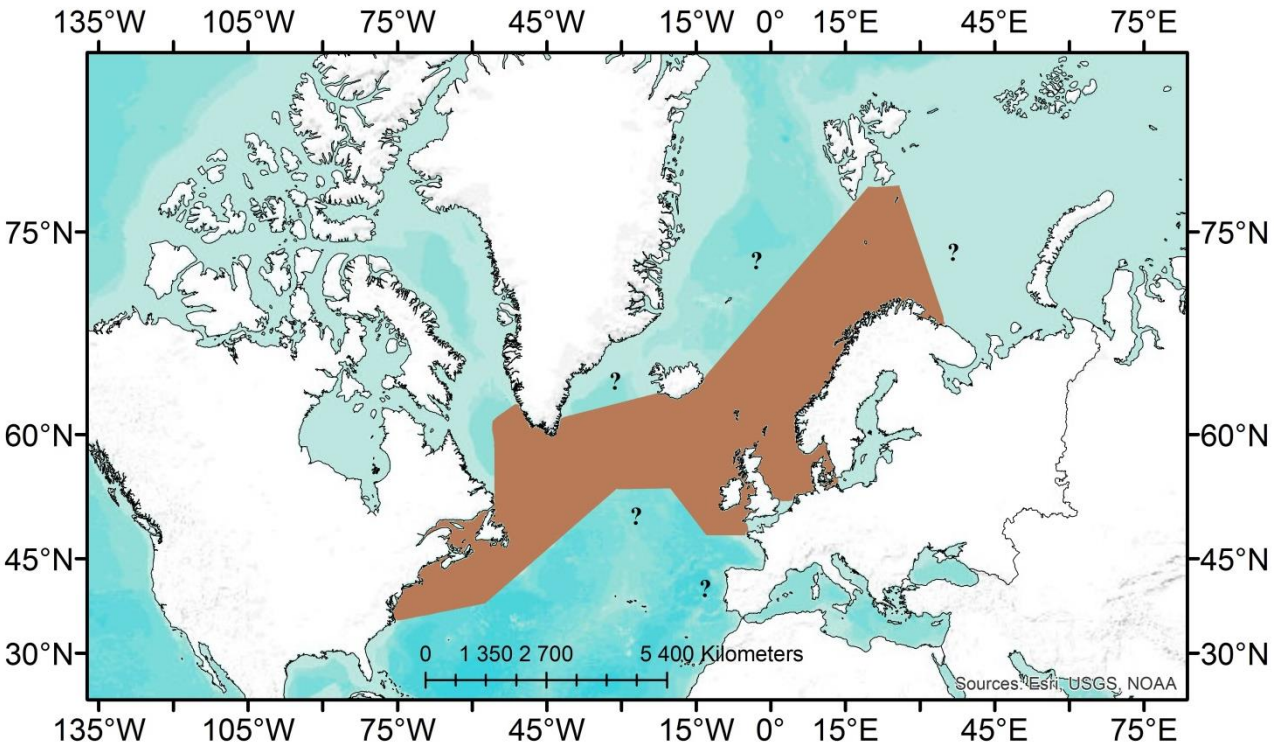


Figure 1. Atlantic White-sided Dolphin (*Lagenorhynchus acutus*) distribution based on Cipriano (2009, Figure 1 pg. 57). The "**?**" refers to areas of uncertainty in distribution.

Seasonal migration occurs in *L. acutus* when various types of prey are dominant at different seasons (Cipriano 2009). Their prey consists of small schooling fish; Atlantic Herring (*Clupea harengus*), Atlantic Mackerel (*Scomber scombrus*), Atlantic Cod (*Gadus morhua)*, Smelts (*Osmeridae spp.*), Sand Lances (*Ammodytidae spp.*), several types of squid (*Teuthida spp.*; Reeves et al. 1999), Silver Hake (*Merluccius bilinearis)*, Red Hake *(Urophycis chuss*), and Cephalopods, mostly Long Fin Squid (*Loligo pealeii*) (Craddock et al. 2009). Sometimes they also follow their prey in their spawning migration of mackerel in Ireland (Couperus, 1997). Seasonal prey and habitat variability occurs with different alternating dominant prey of mackerel and mid-water fish (Cipriano 2002). *L. acutus* feed on herring in Norwegian waters (Nøttestad et al. 2002) however *L. acutus* feeds mainly on mackerel in Vestfjorden (Heike Vester personal communication). An abundance estimate for

L. acutus in the Atlantic Ocean estimate was reported over 100,000 dolphins (Hammond et al. 2008); including 51,640 in the North American shoreline (Waring et al. 2006) and including 96,000 west coast of Scotland (MacLeod 2004) and was reported data deficient in eastern and central Atlantic (Cipriano 2009).

L. acutus males can grow up to 2.82 m and weight 230 kg, females can grow up to 2.43 m and weight 180 kg (Reeves et al. 2002). Females reach sexual maturity at the age of 6 to 12 years and males at the age of 7 to 11 years old (Cipriano 2009). Calving occurs between June and July after 11 months of gestation and the calf is suckled for 18 months, females give birth alternating years (Reeves et al. 2002). Calves are 120 cm long and weigh 25 kg (Perrin and Reilly 1984). In the western Atlantic the mid-summer is the main calving time and a few months longer in the eastern Atlantic (Weinrich et al. 2001). Some strandings of lactating pregnant females suggest that some individuals may breed year round (Sergeant et al. 1980). The *L. acutus* has a reported maximum life span of at least 22 years for males and 27 years for females (Cipriano 2009). *L. acutus* has unique color patterns (Figure 2) that may be easily identified and are suggested to be the most distinct species in their genus due to their unique coloration (Mitchell 1970).

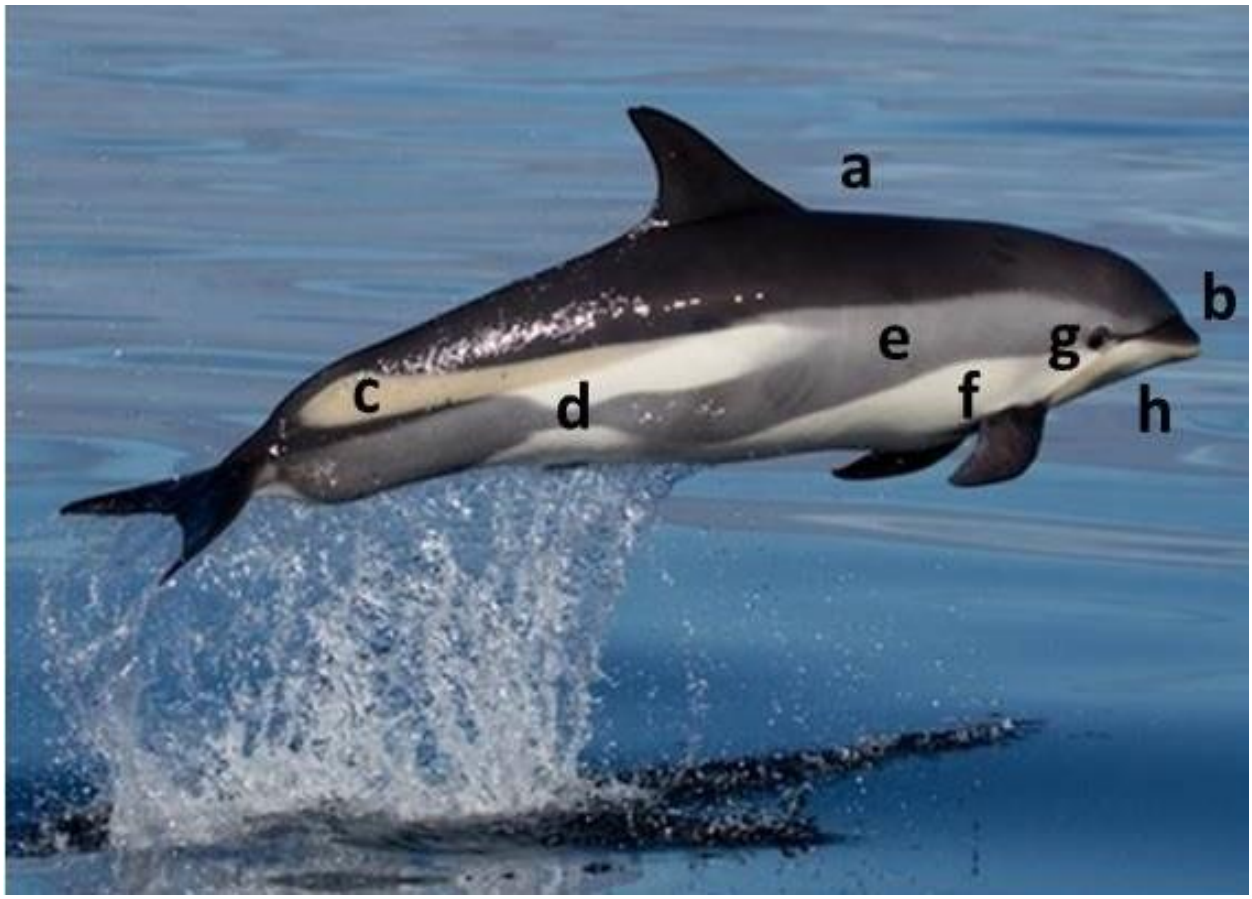


Figure 2. Photograph of an Atlantic White-sided Dolphin (*Lagenorhynchus acutus*) in Vestfjorden, northern Norway 2013. Descriptive features labels with letters; (a) dark gray dorsal side, (b) dark gray rostrum, (c) yellowish patch near the fluke, (d) white patches below the dorsal fin, (e) light gray sides, (f) white ventral side, (g) black eye patch, and (h) white lower rostrum. Photograph kindly provided by Heike Vester.

Social and Acoustic Behavior in Dolphins

Bottlenose Dolphins (*Tursiops truncatus*) are the model specie in the dolphin family and the most studied cetacean. Dolphins live in fission-fusion groups that may alter by the minute or hour (Conner et al. 2000, eg. Würsig and Würsig1977). A small primary group consists of long-term associations (possibly kin) and a secondary large group meets together

to forage (searching for prey), socialize, or mate (Boness et al. 2002). The groups may be separated by sex, age, kinship and reproductive status (Perrin & Reilly 1984). Pelagic dolphins typically form larger groups (Norris and Dohl 1980) however group size may be limited by the amount of prey in the school or single prey (Connor 2002). Behavior states are based on activities and described as foraging (hunting), socializing, milling (resting), and traveling (Shane 1990). Group foraging is more beneficial than solitary foraging, including oceanic dolphins, and dolphins exhibit plasticity in foraging methods (Bowen et al. 2002). The foraging methods are individually chosen by the dolphin and the preferred ones can be transferred from mother to calf (Nowacek 2005). Bottlenose Dolphins push fish towards or onshore and towards other groups of dolphins (Würsig 1986). *L. acutus* display similar foraging strategies to the Dusky Dolphins (*L. obscurus*; Reeves et al. 1999) in Argentina that hunt herds of fish to the surface, surrounding the fish working as a group, and taking turns feeding on the fish (Würsig & Würsig 1979).

Dolphins communicate vocally and non-vocally through signals (Würsig et al. 1990). They produce a variety of sounds; burst-pulse sounds, echolocation clicks and whistles (Popper 1980). Burst-pulsed sounds are broadband discrete groups of clicks that have been described as buzzes, calls, squawks, screams, and barks (Herzing 1996). Calls are between a whistle and clicks and are referred to as pulsed calls. Pulsed calls are tonal signals with a series of harmonics. Buzzes are repeated burst-pulse sequences at a highly repetitive rate (Watkins 1967). Buzzes can be used in socializing and examining close objects. Echolocation clicks are broad bandwidth sounds (30-40 kHz) and contain high frequencies (>100 kHz) and are typically used for orientation, navigation, and prey detection. Whistles are continuous narrow-band signals with harmonic frequencies and can be in the ultrasonic frequency range (Lammers and Au 1996). Whistles are used for intraspecific communication (Herman and Tavolga 1980). Frequency modulated whistles and burst-pulsed sounds are used for social

signals. A stereotyped whistle is a specific characteristic whistle repeated in several different situations. Schevill and Watkins (1962, cited in Reeves et al. 1999) recorded *L. acutus* "squeals" and a few clicks at 1-24 kHz. Steiner (1981) compared differences in five dolphin species whistles in the North Atlantic (including the *L. acutus*) and described that *L. acutus* produced pure tonal whistle dominant frequencies of 6-15 Hz (Nova Scotia, Canada and Massachusetts, USA). Little is known about the vocal communication of *L. acutus* (Reeves et al. 1999).

Atlantic White-sided Dolphin and White-beaked Dolphin Distribution

The White-beaked Dolphin (*L. albirostris*) has a more northern distribution and a slightly less southern distribution than the *L. acutus* (Føyn et al. 2002, Table 1). Both dolphin species have a similar latitudinal range that differs by water depth (Reid et al. 2003). Mixed groups of *L. acutus* and *L. albirostris* have been observed in groups in the North Sea (Haase 1987). However *L. acutus* and the *L. albirostris* distribution overlap significantly and *L. acutus* are more pelagic occurring in lower latitudes than the *L. albirostris* (Reeves et al. 2002). A shift in species occurred when the *L. acutus* became dominant and the *L. albirostris* became scarce during reduction of herring and mackerel by fishing in the Gulf of Maine (Kenney et al. 1996). The total abundance for both the *L. acutus* and *L. albirostris* in Norwegian waters is 131,500 individuals (including 50,000 individuals in the Barents Sea) (Føyn et al. 2002). The *L. albirostris* are the most common in the North Sea and a total of both dolphin species combined was 20,000 individuals in the North Sea (Ottersen et al. 2010). Group size for both dolphin species was estimated to be 30 individuals (mostly sighted with less) and sometimes found in large groups of several hundred dolphins, and in Norway *L. acutus* and *L. albirostris* primary prey consists of herring, cod, and possibly capelin and squid (Føyn et al. 2002).

Table 1. The distribution and occurrence of the Atlantic White-sided Dolphin (*Lagenorhynchus acutus*) and White-beaked Dolphin (*Lagenorhynchus albirostris*).

Location	***L. acutus***	***L. albirostris***	**Source**
Norway, Iceland, Greenland, Canada, North-East United States, Ireland, and the United Kingdom	common	common	Waring et al. 2009
Faroe Islands	common	rare	Waring et al. 2009
Netherlands and Denmark (Kattegat/ Baltic)	rare	common	Waring et al. 2009
Northern Greenland, Greenland Sea, Svalbard	absent	common	Føyn et al. 2002
English Channel	absent	common	Føyn et al. 2002
Bear Island (near ice edge)	rare	common	Føyn et al. 2002

Aim of Study

This study was the first reporting of *L. acutus* (a) vocal behavioral spectrograms and descriptions of clicks, buzzes, calls, whistles, and stereotyped whistles, (b) relationship between vocal communication and behavior, and (c) variability of foraging strategies observed. In Norway this is the first reporting of a *L. acutus* Photo-ID study with reoccurring identified individuals and distribution of *L. acutus* in Norway, specifically in the Vestfjorden (northern Norway). The objectives of this study were to study (1) the distribution and occurrence of the Atlantic White-sided Dolphins in Norway through sightings and Photo-ID, (2) describe the vocal behavior; sound categories (clicks, buzzes, whistles, and calls), (3)

determine if sound production was dependent on activity (foraging, socializing, milling, and traveling), depth (shallow and deep), and/or group affiliation, and (4) describe the presence or absence of stereotyped whistles.

Methods

Study Area and Survey Platform

Photo-ID, behavioral notes, sounds (clicks, whistles, buzzes, and calls) from *L. acutus* were collected in Norway from Vestfjorden (68.0500° N, 14.7667° E) during 2005, 2007-2013 (Figure 3). Daily *L. acutus* sighting research trips were conducted on an open rubber Zodiac boat (7.3 m long with 250 HP outboard engine). Routes were determined based on recent sightings, current sightings from other boats, listening underwater for *L. acutus*, and areas not surveyed yet. A GPS track (Raymarine & GPS Widget for Android phones) of each day's entire trip was recorded with waypoint coordinates at the location of the first dolphin sighted until the end of the encounter. Only the first location of a sighting was used in this analysis in order to avoid recounting the same sighting although all locations were recorded.

Additional sightings were reported by Arctic Whale Tours and local media sources [Norwegian Broadcasting Corporation (NRK), Aftenbladet, Lofotposten, Avisa Nordland (AN), and Bladet Vesterålen]. Media sources were confirmed by visual inspection of photographs to confirm the specie, unconfirmed dolphin species were classified as unknown.

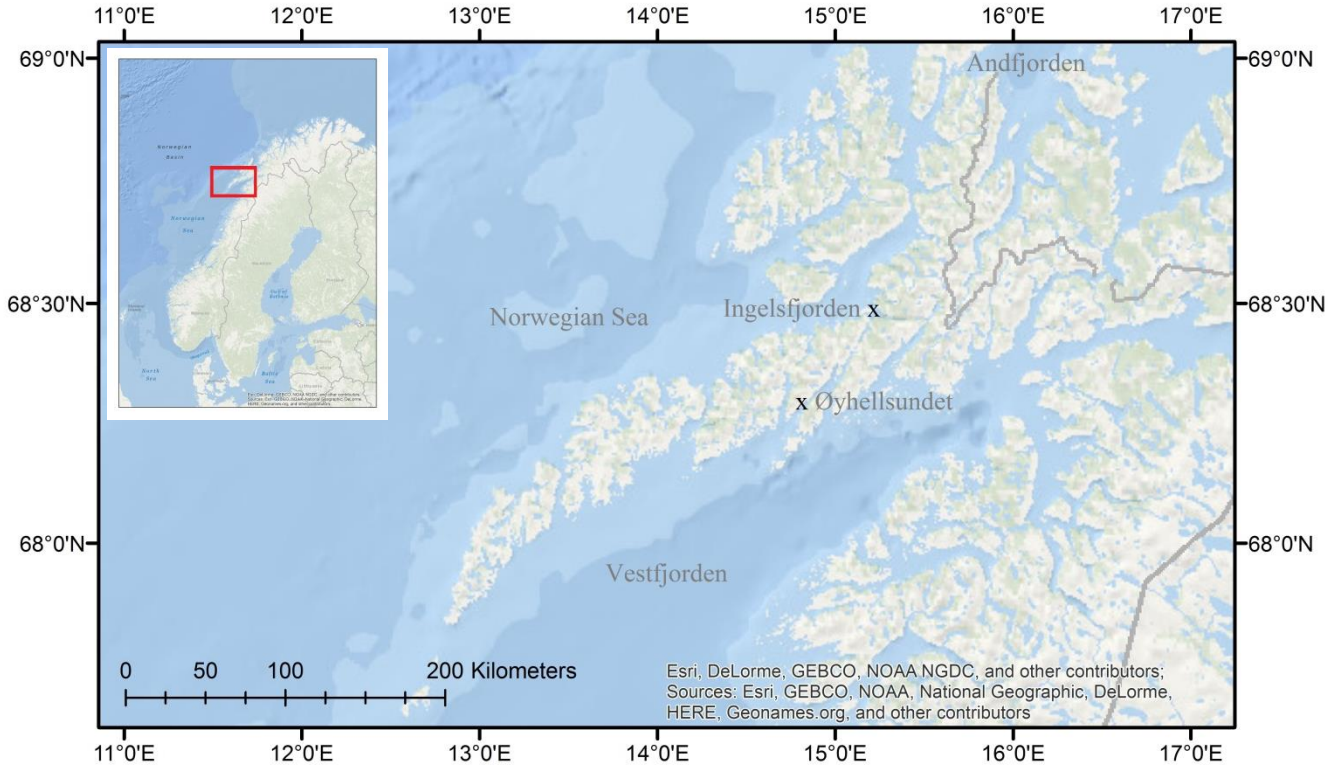


Figure 3. Map of study area Vestfjorden (68.0500° N, 14.7667° E) in northern Norway. "X" indicate the locations of the depth observations occurring in the shallow narrow straight Øyhellsundet (52-81 m) and the deep wide area of Ingelsfjorden (8-10 m), Lofoten Norway.

Sightings and Photo-ID

6479 photographs (only good quality photos could be used for ID) of *L. acutus* were collected and taken during 2007-2013. The photographs were taken by Heike Vester Photographs were taken using a Canon EOS 1D Mark IV with a 100-400 mm zoom lens. (additional photographs were collected from Arctic Whale Tours, Louise Normann Jensen, Isabelle Dupre, Angelica and Maria Morell). The photographs were analyzed using the methods of Photo-ID, identifying individuals based on natural markings (nicks, scars and scratches) on the dorsal fins and the body of odontocetes following the protocol of Bigg et al. (1982). Photo-ID was used to track individuals by date encountered and to enable identifying

re-sightings of individuals. Natural markings assist in long-term and reliable details to be studied in the field over time in movement patterns, population size, dynamics, and social structure. Subtle or small markings require maximum resolution to identify individuals. Some natural markings are present at birth but many new natural markings will be added during their lifetime (Whitehead et al. 2000).

Behavioral Sampling

L. acutus were observed underwater and surfacing from the boat. Behavioral notes were written down on notebooks following methods of focal group sampling (recording the behavior of all or most of the individuals in the group), continuous behavioral sampling and event sampling (recording of all changes in the group behavior) (Altman 1974). Behavior was categorized by the group's activity; traveling, foraging, milling, and socializing (Shane 1990, Table 2). All behavior was recorded with details on foraging methods in shallow and deep water fjords.

Table 2. Description of dolphin behavior activities. Based on Henderson et al. (2012; Table 1 pg. 444) and behavior methods of Shane (1990).

Behavior	**Description**
Foraging	Variable movement of individuals and the group in a similar area that visibly are chasing fish or rapid swimming (possibly jumps and dives).
Socializing	The group being close together (possibly touching) and active movement behavior of jumps, tail slaps, and various movements of individuals.
Milling	Resting with the group closely together slowly swimming and lacking fast movements but staying close to the surface.
Traveling	Grouped together for slow, moderate, and fast speed. The group move together in the same direction at a steady or rapid rate with surfacing (possibly synchronized).

Acoustic Sampling

437 minutes of underwater sounds of *L. acutus* were recorded with hydrophones during 2008 and 2011-2013. Recordings of underwater sounds included clicks, whistles, buzzes, and calls from *L. acutus* (only good quality sounds with less background noise could be used for analysis). Two hydrophones [Reson TC 4032 Hydrophone (20 m cable) with a custom built Etec amplifier and a Sound Devices 744T audio-recorder] were suspended on two parallel sides of the boat. The depth of the hydrophone ranged 2-18 m depending on the depth of the fjord.

This study investigated if the sounds produced were dependent on the context of depth. The comparison of depth; shallow and deep were conducted on 22.07.2013 (shallow data) & 23.07.2013 (both shallow & deep data) in the same shallow narrow straight Øyhellsundet (52-81 m), Lofoten Norway and the deep wide area of Ingelsfjorden (8-10 m), Lofoten Norway (Figure 3). The depth analysis considered the group to be the same both dates and was re-sighted in the same location and identified using Photo-ID.

Analysis

Photographs were analyzed based on the quality and distinctive features of the individuals. Photographs of poor quality were excluded from the database. The collected photographs were enlarged on a PC monitor for detailed analysis using FastStone Image Viewer 4.8 by FastStone. The best photograph of each *L. acutus* displaying identifiable markings was magnified and named to be used as a primary identifiable photograph (Figure 4). The unidentified photographs were manually compared to the database for natural markings to identify re-sighted individuals.

Figure 4. Example of Atlantic White-sided Dolphins (*Lagenorhynchus acutus*) Photo-ID (22/07/2013) natural markings such as the large lower nick on the dorsal fin (indicated by a red circle) and small top nicks (indicated by a red arrow). Norwegian Atlantic White-sided Dolphin Photo-ID (Appendix 1).

A spectrogram is a visual representation of the frequencies of sound and amplitude which consists of frequency (kHz) on the y axis and time (seconds) on the x axis. Spectrograms of *L. acutus* whistles, call, clicks, and buzzes were created using Avisoft SAS Lab Pro 5.2.07 software by Avisoft Bioacoustics on a PC. Audio visual inspection was used to classify the four types of sound categories; clicks, buzzes, calls, and whistles and each sound category amount were counted per 10 seconds. Not all calls could be analyzed due to the background noise mostly from boats. Only good quality sound files were used for analysis. The recordings were analyzed using a sampling frequency of 48 kHz, resulting in 24 kHz maximum spectrograms, ultrasonic sounds above 24 kHz were excluded. Stereotyped whistles were identified visually using a spectrogram and an on-screen harmonic cursor (in

Avisoft SAS Lab Pro) to measure the frequency at the beginning, lowest point, highest point, and inflection points and at the end of the whistle. Connections were investigated with behavioral stages and the context of the water depth.

Organization of data and a histogram was created in Microsoft Excel with Windows 7. Boxplot graphs were made using a statistical computer software "R" version 3.0.2 (The R foundation for statically computing). Map bathymetry layers were acquired from a geographic information system (GIS), ArcGIS for Desktop Advanced 10.2.2 by ESRI.

The sound recording data was changed manually from 10 second intervals to 1 minute intervals and the remaining seconds at the end of the file were removed. The zeroes were removed from the sound data set to extract more information from the data. Unfortunately it is not possible to identify which individual produces which call. This impedes the statistical analysis which requires independence of observation. Therefore it is not possible to tell if the calls are produced by one or by different individuals. The limitation of statistics hinders the depth of analysis.

Results

Sightings and Photo-ID

A total of 72 *L. acutus* encounters were sighted during 2005, 2007-2013 in Norway and were mostly concentrated within the vessel based survey study area of Vestfjorden in northern Norway (Figure 4). Sightings varied by year with the highest amounts in 2011 (17 sightings), 2012 (17 sightings), and 2013 (18 sightings) (Figure 4). 10 sightings of White-beaked Dolphins (*L. albirostris*) during 2009-2014 in Norway and 6 unidentified dolphin specie sightings during 2008-2010, 2012, and 2014 were recorded (Figure 5). More sightings of *L. acutus* (Figure 4) were observed than *L. albirostris* (Figure 5) with few sightings of *L. albirostris* within the study area (no sightings of *L. albirostris* were recorded during vessel surveys in the Vestfjorden).

55 individual dolphins during 25 boat surveys dates (2007-2009 and 2011-2013) were identified using the method of Photo-ID (Bigg et al. 1982) (Appendix 1). Identifications from the Photo-ID resulted in 29 re-sightings (Table 3). The re-sightings were recorded per year; 2 in 2008 (# 3, 6), 1 in 2009 (#8), 8 in 2011 (#3, 6, 8, 9 three times, 10, 15), 2 in 2012 (# 3, 20), and 12 in 2013 (# 1, 2 twice, 3 twice, 9 twice, 14 twice, 17 twice, 23) (Table 3). 2 dolphins (# 3 and 9) were re-sighted on 5 occasions, 6 dolphins (# 2, 8, 14, 17, 32) were re-sighted twice, and 7 dolphins (# 1, 10, 15, 20, 23, 27, 38) were re-sighted once (Table 3). Sightings of # 3 occurred yearly during 2007-2008 and 2011- 2013 however # 9 sightings varied; once in 2008, three occurrences in 2011, and twice in 2013 (Table 3).

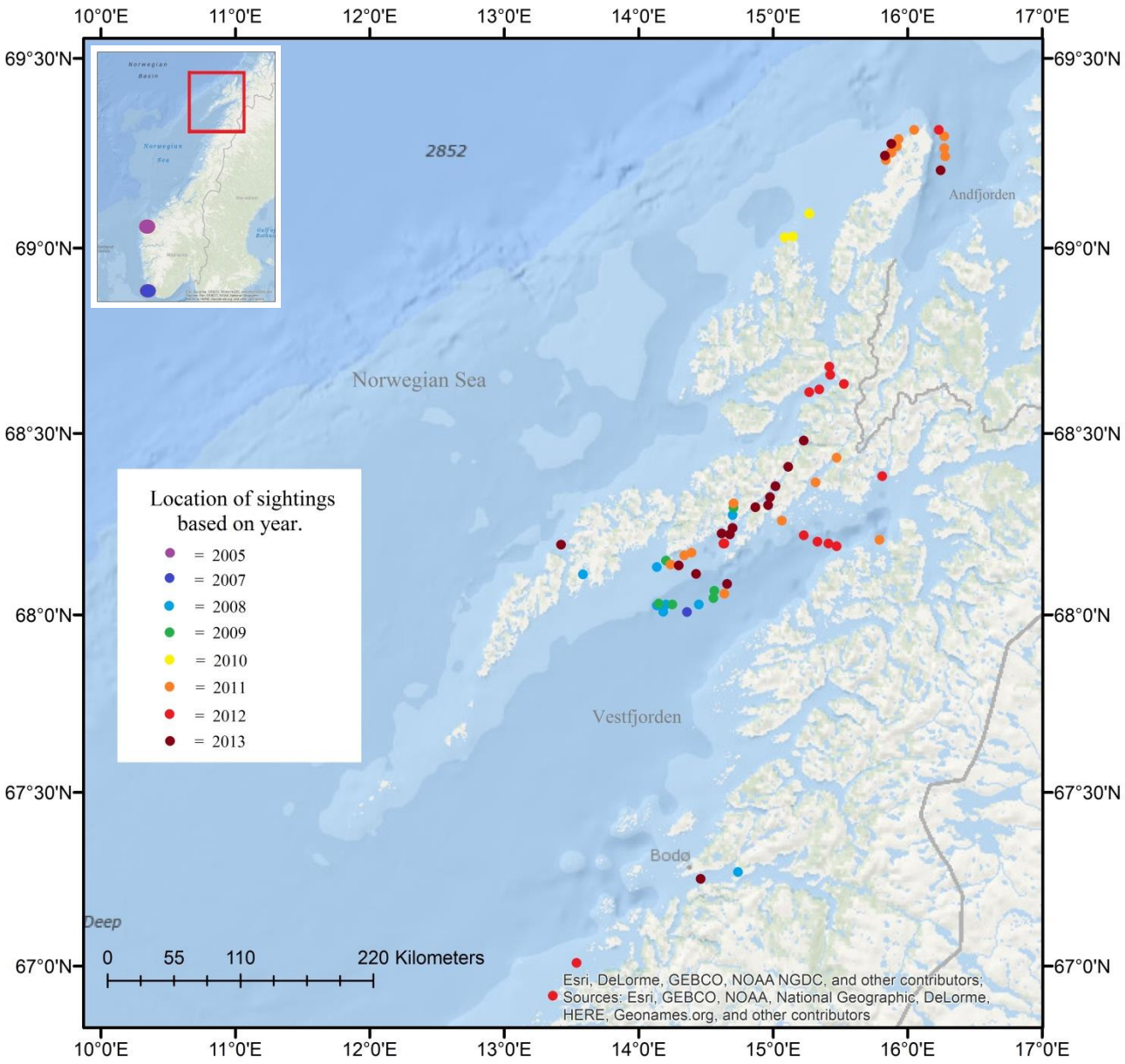


Figure 4. Sighting map of all Atlantic White-sided Dolphin (*Lagenorhynchus acutus*) encounters observed during 2005, 2007-2013 in Norway. Sightings come from vessel surveys and media sources. Each dot indicates a sighting and is coded by year observed. The dots do not reflect the group size or individuals sighted.

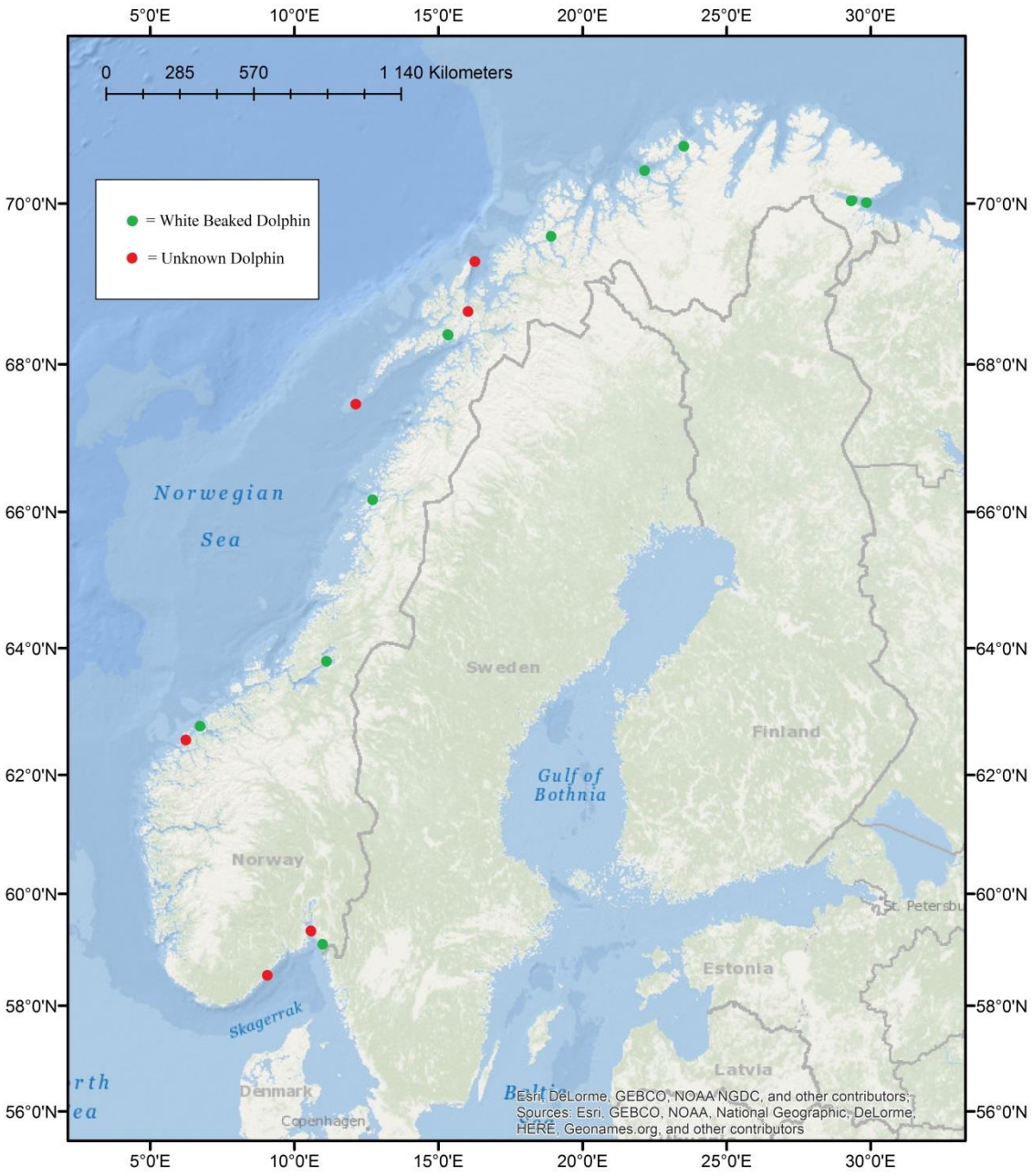


Figure 5. Sighting map of White-beaked Dolphins (*Lagenorhynchus albirostris*) during 2009-2014 and unidentified dolphin specie sightings during 2008-2010, 2012, and 2014. All sightings were based on media data with no observations of *L. albirostris* on the vessel surveys. Each dot indicates a sighting and does not reflect the group size or individuals sited.

Table 3. Photo-ID re-sightings from 55 individuals from during 2007-2009 and 2011-2013 resulted in 29 re-sightings. Individual number refers to the Photo-ID database (Appendix 1) of individuals identified by natural markings and is numbered based on the first sighting of an individual with older sighting assigned with lower numbers.

Individual Number #	First Sighting Date	Re-sighting(s) Dates
1	10/06/2007	23/07/2013
2	10/06/2007	22/07/2013, 23/07/2013
3	10/06/2007	05/09/2008, 25/08/2011, 05/07/2012, 01/07/2013,09/08/2013
6	10/06/2007	05/09/2008, 29/07/2011
8	05/09/2008	11/08/2009, 19/06/2011
9	05/09/2008	25/06/2011, 29/07/2011, 02/08/2011, 22/07/2013, 23/07/2013
10	05/09/2008	24/06/2011
14	22/06/2009	22/07/2013, 23/07/2013
15	22/06/2009	19/06/2011
17	19/06/2011	22/07/2013, 23/07/2013
20	25/06/2011	11/01/2012
23	02/08/2011	22/07/2013
27	02/08/2011	22/07/2013
32	02/08/2011	05/07/2012, 09/08/2013
38	22/07/2013	23/07/2013

Sightings were evaluated based on month to test for seasonal occurrence (Figure 7). The sightings were highest during summer months however this coincides with the main search effort in the vessel surveys.

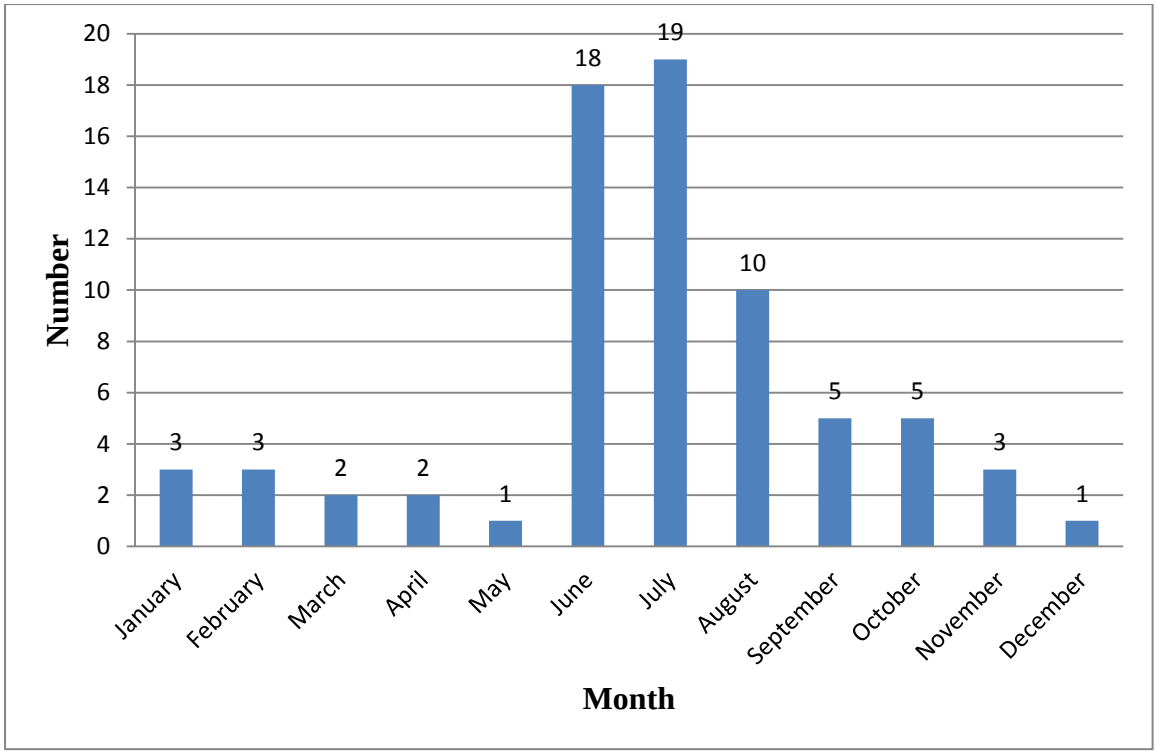


Figure 6. Encounters of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*) by month during 2005, 2007-2013 in Norway. Each sighting was counted as a single sighting and not as an individual.

Behavioral Observations

L. acutus were observed on two occasions (22/07/2013 & 23/07/2013) displaying variation in their foraging strategies. *L. acutus* were observed feeding on mackerel in a narrow (0.2-0.3 nautical miles) and shallow (2.2-30 m, mainly concentrated in the 8-10 m range) straight, Øyhellsundet (Lofoten, Norway) (Figure 6 a.). *L. acutus* moved as a group in a large circular pattern chasing and rounding up fish. They pushed the fish towards the shallower bays near land, this occurred within an estimated 0.5 km area. Visual behaviors displayed during shallow water foraging included chasing fish, jumping, 180° turns, and underwater slaps (most likely from fluke). During this time the dolphins had no interest in the boat and focused solely on foraging.

L. acutus were also observed feeding on mackerel in a different location on one occasion in a wide (1.1-1.4 nautical miles) and deeper area (52-141 m, mainly concentrated in the 52-81 m range), Ingelsfjorden on 23.07.2013 (Figure 6 b.). The foraging method differed from the shallow observations; the group separated far apart into pairs and spread out to the far end perimeters of the shores to scan for fish. They chased the fish and herded the fish as a dolphin pair (instead as a group) and pushed the fish towards the shallow areas. Visual behaviors displayed during deep water foraging included chasing fish and jumping. The dolphins continued to express no interest in the boat and focused solely on foraging.

L. acutus were observed traveling between the shallow straight and the deeper area on 23/07/2013. During traveling on 23/07/2013 part of the group of 12 adults and 3 calves *L. acutus* performed aerial displays of synchronized jumping; 2 pairs, 1 trio, and 2 quads were observed. Unfortunately the sex was unable to be determined; some of the pairs appeared to contain calves (possible mother-calf synchronization). *L. acutus* traveled at 10 knots with occasional bow riding behavior observed. Upon arrival in the deeper area, the dolphins were observed socializing and milling. Socializing consisted of the group approaching closer together and aerial displays of jumps, rubbing or touching could not be determined. Milling consisted of slow swimming and resting.

Acoustic Behavior

L. acutus produced clicks, buzzes, calls (Figure 7) and whistles (Figure 8). The rate of clicks varied and spanned the entire frame of frequency range analyzed 1-24 kHz (Figure 7 a). The buzzes and calls observed were concave; frequency modulated with an instantaneous frequency increasing with time in the beginning and ending with the instantaneous frequency decreasing with time (Figure 7).

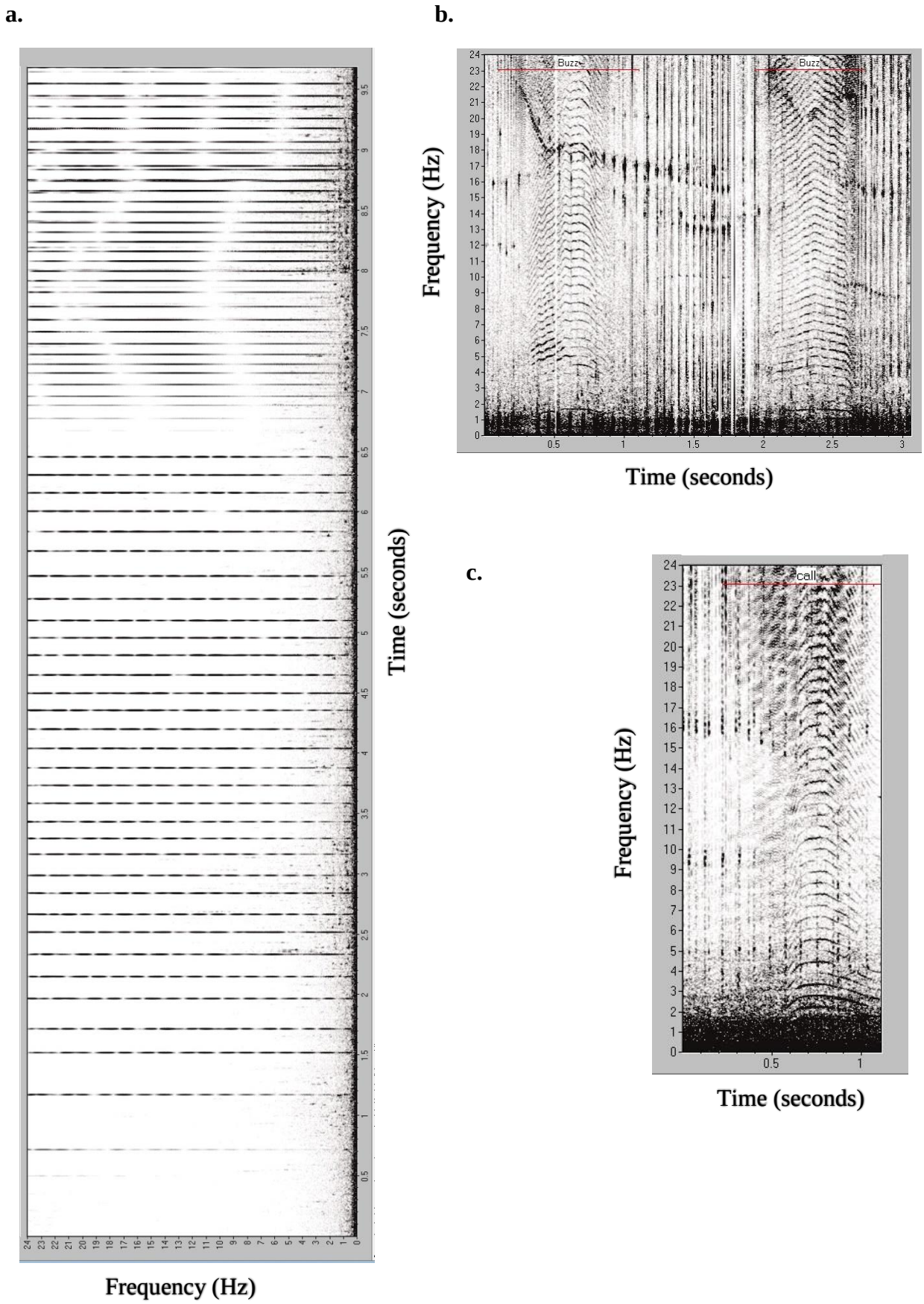


Figure 7. Spectrogram of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*) sounds observed; (a) clicks, (b) buzzes, and (c) call.

Whistles & Stereotyped Whistles

898 whistles were recorded. A downsweep (a flat tone of higher frequency tone changes to a falling tone of lower frequency) followed by an upsweep (the opposite of downsweep) after the inflection point results in convex shaped whistles recorded. The repeated whistle with the same pattern and close to or the same frequency contour is an example of a stereotyped whistle observed (Figure 8). The beginning frequency of a whistle was 19968 Hz and the end frequency was 16734 Hz (length 853 msec, highest frequency 19969 Hz and lowest frequency 10828 Hz) and the whistle has four parts with inflection points (Figure 8). Many sterotyped whistled were observed in the data and repeated several times in a row or repeated later in time.

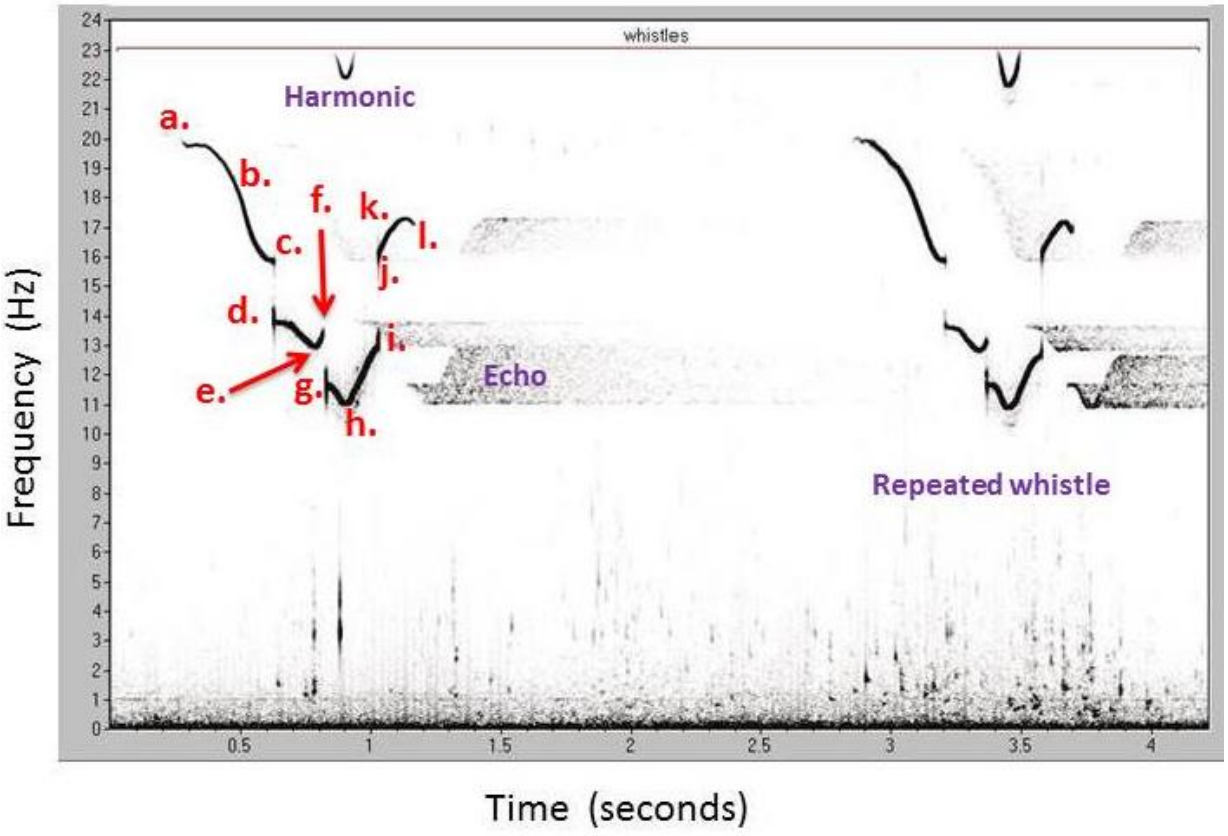


Figure 8. Spectrogram of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*) whistles. The letters refer to the frequency measurements (Hz) of beginning, low, high, inflection points and end frequency of the whistle contours; a. 19968 Hz, b. 18316 Hz, c. 15656 Hz, d.

13734 Hz, e. 12703 Hz, f. 13406 Hz, g. 11856, h. 10828 Hz, i. 12609 Hz, j. 15844 Hz, k.17203 Hz and l. 16734 Hz. The second repeated whistles is an example of a sterotyped whistle. An example of an echo and harmonic are labeled.

Hydrophone Recordings

The sound categories included; calls, whistles, buzzes, and clicks and the activities included; milling, traveling, foraging, and socializing. 443 minutes from 8 recording dates were used in the sound analysis of the *L. acutus* (Table 3). Each observation varied in activity and group size. The main activity observed was foraging (233 min), milling (80 min), socializing (77 min), and traveling (53 min); the group size ranged from 4 to 50 individuals (Table 3). The group size was visually counted and estimated from the boat and photos taken.

Table 3. Overview of the 8 recording dates with group size and activities of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*). The activities are in minutes recorded.

Date	**Group Size**	**Milling (sound/min)**	**Traveling (sound/min)**	**Foraging (sound/min)**	**Socializing (sound/min)**
10/08/2008	20-30	19	0	0	29
05/09/2008	4	0	0	48	0
02/08/2011	50	0	24	9	19
25/08/2011	10	9	0	7	0
05/07/2012	n/a	0	14	0	0
22/07/2013	20	0	0	92	0
23/07/2013	15	52	0	77	0
09/08/2013	40	0	15	0	29
Total		**80**	**53**	**233**	**77**

Sound Production and Activity

Clicks were the most abundant sound produced overall; during foraging/milling (99%) and during socializing/traveling (98%) (Table 4). Whistles were the second most observed sound; socializing (1.2 %), traveling (1.3%), foraging (0.55%), and milling (0.61%), followed by calls; socializing (0.41%), traveling (0.63%), foraging (0.15%), and milling (0.19%). Buzzes were the least observed sound and absent during milling. Every activity resulted in a dominant presence of clicks followed by whistles, calls, and a low amount of buzzes (Table 4).

Table 4. Total sounds in each category depending on the activity of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*).

Sounds	**Socializing (sound/min)**	**Traveling (sound/min)**	**Foraging (sound/min)**	**Milling (sound/min)**
Calls	123	59	102	18
Percentage of total sounds	**0.41%**	**0.63%**	**0.15%**	**0.19%**
Whistles	358	119	364	57
Percentage of total sounds	**1.2%**	**1.3%**	**0.55%**	**0.61%**
Buzzes	29	4	76	0
Percentage of total sounds	**0.096%**	**0.043%**	**0.11%**	**0%**
Clicks	29612	9177	66132	9206
Percentage of total sounds	**98%**	**98%**	**99%**	**99%**
Total Sounds	**30122**	**9359**	**66674**	**9281**

Due to the dominant presence of clicks, clicks were excluded for further analysis of the remaining sound categories. Whistling was 65.4%-76.0% of the sounds produced and whistling was approximately equally abundant during all four activity categories after

excluding the clicks, which dominated the sounds (Table 5). Calls were most common during traveling (32.4%) and the least common during foraging (18.8%) (Table 5). Buzzes greatly varied from 0-14% however the amount of buzzes was much less than the other sound categories recorded and absent during milling. Every activity resulted in the abundance of whistles followed by calls and buzzes (Table 5).

Table 5. The percentage of the sound categories (excluding clicks) during each activity of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*).

Sounds	**Socializing (sound/min)**	**Traveling (sound/min)**	**Foraging (sound/min)**	**Milling (sound/min)**
Calls	123	59	102	18
Percentage of total sounds	**24.1%**	**32.4%**	**18.8%**	**24.0%**
Whistles	358	119	364	57
Percentage of total sounds	**70.2%**	**65.4%**	**67.2%**	**76.0%**
Buzzes	29	4	76	0
Percentage of total sounds	**5.69%**	**2.20%**	**14.0%**	**0%**
Total Sounds	**510**	**182**	**542**	**75**

An overview of all *L. acutus* sound categories occurrences were placed in histograms (with zeros included) (Appendix 2). Further analysis excluded the zeros in the data to investigate the presence of the sound categories observed. The total sounds (calls, whistles, clicks and buzzes) of each activity (foraging, milling, socializing and traveling) were compared (excluding zeros, Figure 9). The socializing medians vary, although there is a trend that socializing produces more vocal behavior (Figure 9). The buzzes had too few data points to determine a difference in the variables.

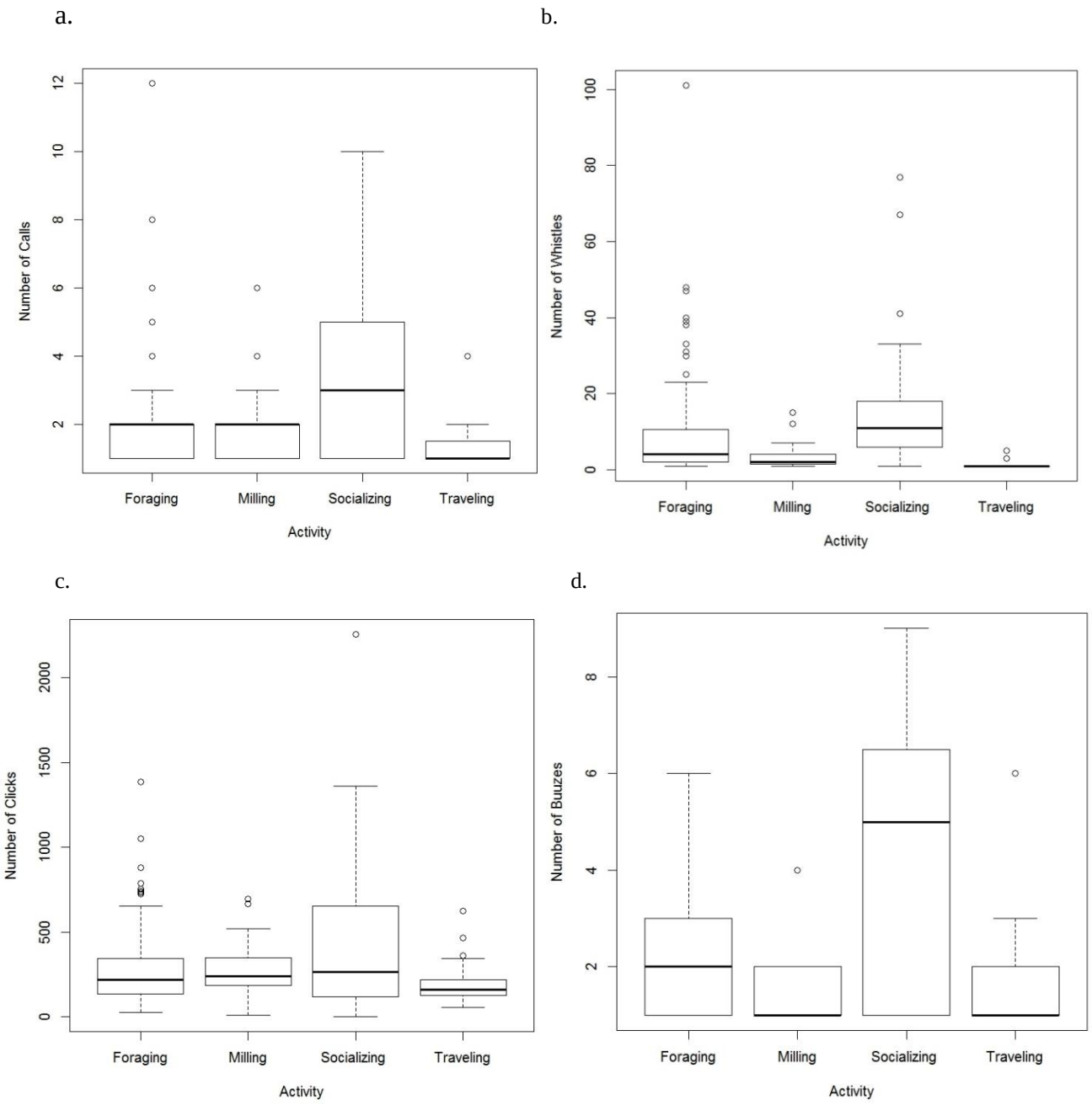


Figure 9. Total sounds of each category compared to activity of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*); (a) calls, (b) whistles, (c) clicks and (d) buzzes (zeroes removed in figure). The x-axis is the activities and the y-axis is the amount of the respective sound category.

Sound Production and Depth

In the depth analysis, the groups observed had estimated group sizes of 20 dolphins (22/07/2013) and 15 dolphin (23/07/2013) individuals. On 22/07/2013, 11 dolphins were identified using Photo-ID (including 7 re-sightings) and on 23/07/2013, 11 dolphins were identified (including 6 re-sighted) (Appendix 1; Table 3). A total of 5 dolphins were re-sighted and present on both consecutive dates (Appendix 1). The groups were concluded to be the same group of individuals based on the re-sightings, same location two consecutive dates and the same observed shallow water foraging strategy both dates. A comparison of depth and activity included two occasions of foraging observations in shallow waters and one occasion of deep water foraging however milling was only observed in deep waters (Table 6). Clicks were the dominant sound produced in both shallow and deep water (Table 6). More clicks were observed per minute in deep foraging than shallow foraging when compared to total recording time of each observation (Table 6).

The sounds categories were compared to depth resulting in a trend of more clicks produced in deeper water than in shallow water (Figure 10c.). The medians were very close for the call and whistle depth comparison therefore no difference could be determined (Figure 10). The buzzes had too few data points to determine a difference in the variables. Foraging and milling were compared with depth, shallow milling was not observed during the depth comparison dates (Figure 11). However there is a trend that more clicks are produced in deep water than in shallow water (Figure 10c) and the trend is more clear during foraging and milling (Figure 11c). Whistles are produced more during deeper foraging (Figure 11 b) however there is no trend in overall whistles production and depth (Figure 10b). Buzzes were not observed frequently.

Table 6. Depth comparison of activity and the sound categories of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*). Day 1 (22/07/2013) and day 2 (23/07/2013). Percentages of sounds are in parentheses. Sound units are sounds per minute.

Activity	**Day**	**Recorded (min)**	**Calls**	**Whistles**	**Buzzes**	**Clicks**	**Total Sounds**
Shallow Foraging	**1**	88	18 **(0.12%)**	21 **(0.14%)**	9 **(0.06%)**	15443 **(99%)**	**15491**
Shallow Foraging	**2**	32	0 **(0%)**	45 **(0.84%)**	2 **(0.04%)**	5285 **(99%)**	**5332**
Deep Foraging	**2**	40	35 **(0.26%)**	378 **(2.8%)**	19 **(0.14%)**	13065 **(97%)**	**13497**
Deep Milling	**2**	31	15 **(0.17%)**	61 **(0.68%)**	4 **(0.04%)**	8944 **(99%)**	**9024**

Group Affiliation

Low variation was observed in the comparison of all sighting date groups and activity (Appendices 3-6), however there is a trend that more clicks are produced during foraging (Appendix 5c) which could be related to foraging depth. The buzzes had too few data points to determine a difference in traveling and no buzzes were observed during milling (Appendix 6).

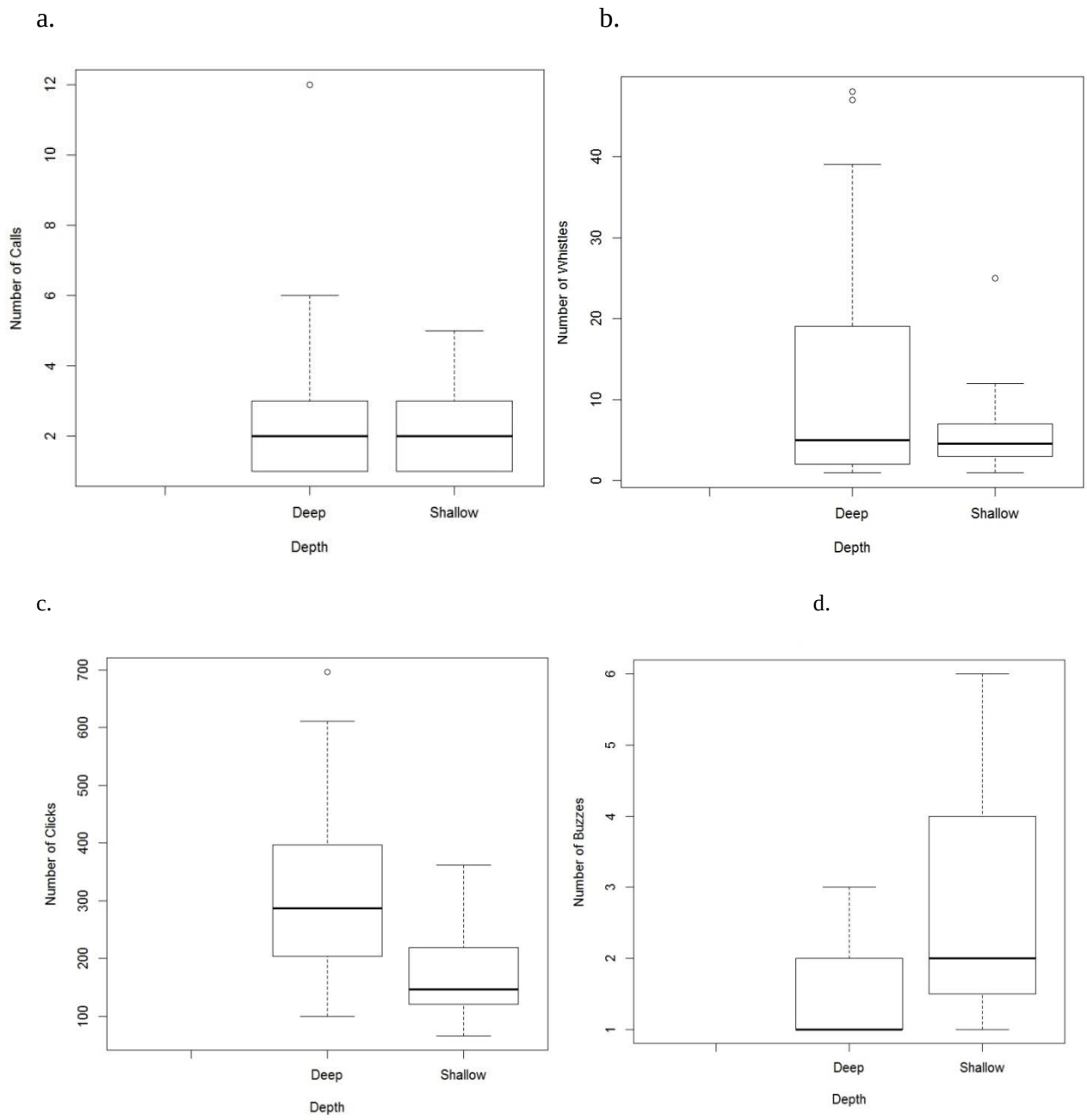


Figure 10. Sound categories compared to depth of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*); deep and shallow (sighting encounters from 22/07/2013 & 23/07/2013); (a) calls, (b) whistles, (c) clicks and (d) buzzes (zeroes removed in figure). The x-axis is the depth and the y-axis is the amount of the respective sound category.

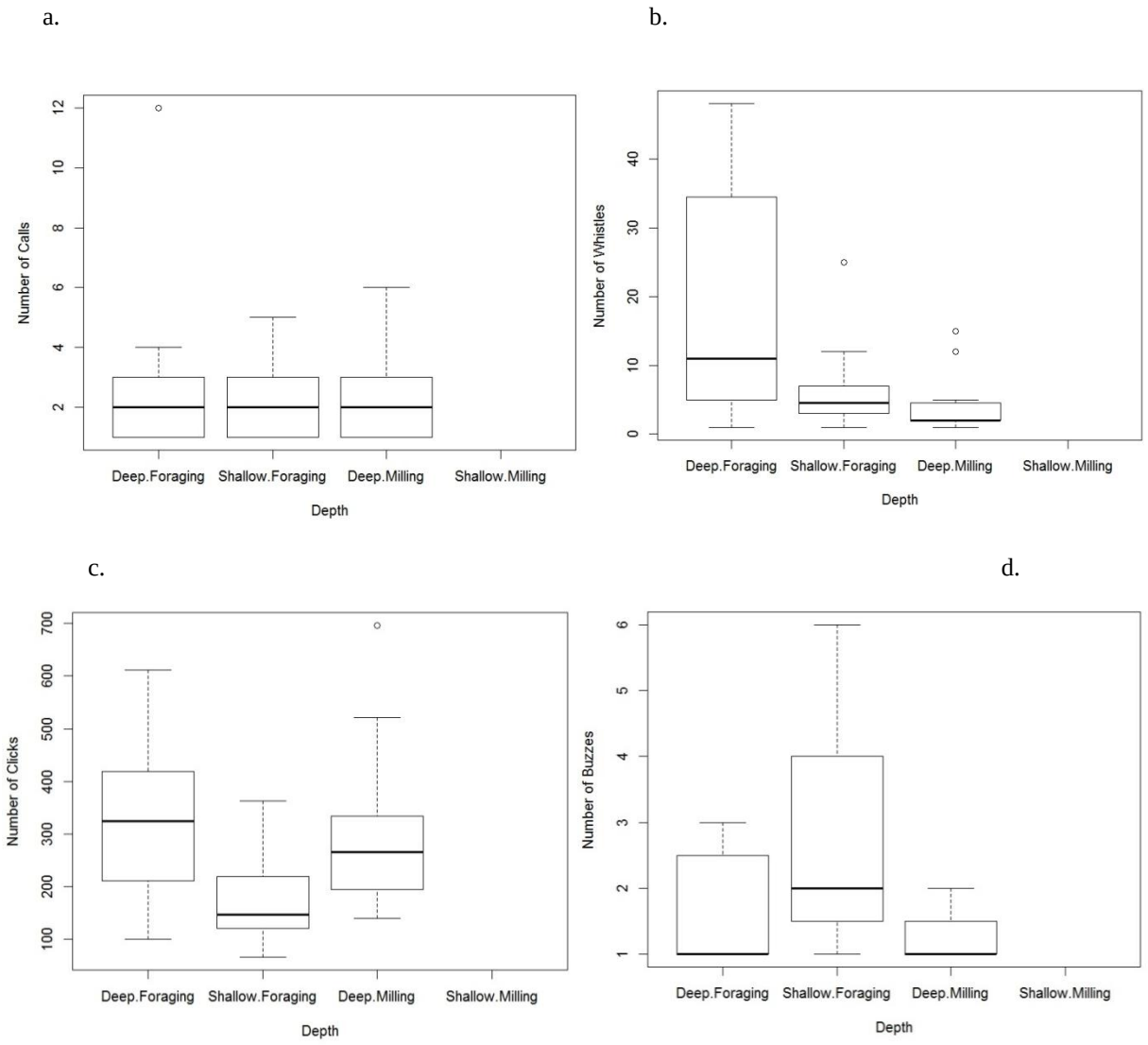


Figure 11. Foraging and milling compared to depth and the sound categories (sighting encounters from 22/07/2013 & 23/07/2013) of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*); (a) calls, (b) whistles, (c) clicks and (d) buzzes (zeroes removed in figure).The x-axis is the depth including activity and the y-axis is the amount of the respective sound category. No shallow water foraging was observed on the depth comparison dates.

Discussion

A total of 72 of Atlantic White-sided Dolphins (*Lagenorhynchus acutus*) were observed during an eight year study (2005, 2007-2013) in northern Norway. Clicks were the most abundant sound produced and had frequencies of at least 24 kHz. Whistles were equally abundant after clicks and an example of a whistle had a frequency of 11-20 kHz. Calls were observed most common during traveling and least common during foraging. Buzzes varied and were absent during milling. Sound production increased during socializing. Click production increased in deeper water than shallower water and was observed during foraging and milling. Foraging was the most observed behavior during hydrophone recordings. Two different foraging strategies were observed in the shallow (8-10 m range, group cooperation of herding fish) and deep waters (52-81 m range, herding fish in dolphin pairs) on two consecutive days.

Sightings and Photo-ID

72 total sightings of *L. acutus* (Figure 4) during 2005, 2007-2013 were observed. *L. acutus* resulted in more sightings than *L. albirostris.* 10 sightings of White-beaked Dolphins (*L. albirostris*) during 2009-2014 in Norway and 6 unidentified dolphin specie sightings during 2008-2010, 2012, and 2014 were sighted (Figure 5). Most sightings of *L. acutus* (Figure 4) were within the vessel survey area of northern Norway. In Norway this is the first reporting of a *L. acutus* Photo-ID study with reoccurring identified individuals and distribution of *L. acutus* in Norway, specifically in the Vestfjorden area (northern Norway). 55 individual dolphins during 25 boat surveys dates (2007-2009 and 2011-2013) were identified using the method of Photo-ID (Bigg et al. 1982) (Appendix 1) and 29 re-sightings that were also identified (Table 3). Creating a photographic database based on natural markings enabled a tracking system for individuals sighted and individuals present during the sound recordings and to be re-sighted. Most Photo-ID markings in this study were on the

dorsal fins in the form of nicks and scars. In the Gulf of Maine *L. acutus* has been identified by scars and nicks on dorsal fins and unique pigment patterns (Weinrich et al. 2001). The subtle markings and scraps on dolphins (Würsig and Würsig 1977) can be difficult to identify and re-sight. Weinrich et al. (2001) studied the behavior and ecology of *L. acutus* in the New England waters using Photo-Id and concluded that Photo-ID was a limited technique for this specie due to the lack of distinctive markings and the difficulty of re-sighting them. However no substantial pigmentations were observed in this study and in some cases dorsal fins can remain constant over 12 years (eg bottlenose dolphins, Würsig and Harris 1990). Distinctive markings can give rise to determining a home range (Caldwell 1955) therefore re-sightings may indicate that *L. acutus* may have a home range (Wells et al. 1999) or possibly are part of a resident population similar to the bottlenose dolphin (eg. Argentina, Würsig and Harris 1990), although further studies are needed to confirm this. However the sightings and re-sightings observed could be of residents and nonresidents that have overlapping ranges (Rossbach and Herzing 1999) or based on prey migration (Selzer and Payne 1988).

Distribution in Norway

Separate populations of *L. acutus* has been debated. Palka et al. (1997) suggested that three separate populations in the Western North Atlantic (Gulf of Maine, Gulf of St. Lawrence, and the Labrador Sea) based on stranding, by-catch, and sightings however Mikkelsen and Lund (1994) compared the skulls characteristics of 228 *L. acutus* and concluded that there existed no separate populations based on phenotypic differences. Recently Banguera-Hinestroza et al. (2014) suggested connectivity across the North Atlantic across the Western and Eastern North Atlantic; these findings were based on nuclear and mitochondrial genetics and agree with the Mikkelsen and Lund (1994) theory of no separate populations of *L. acutus*.

L. acutus may also be underrepresented in stranding reports due to their offshore distribution (Evans 1980). Strandings have risen in recent years and mass strandings have been reported (Bogomolni et al. 2010). *L. acutus* has been greatly impacted through by-catch (Reeves et al. 1999). Hunting still occurs in Canada, Greenland, and the Faroe Islands (Hammond et al. 2008) which could affect the abundance. The Faroe Islands can take more than 500 dolphins per year (Bloch and Mikkelsen 2009, cited in Banguera-Hinestroza et al. 2014) however the hunting impact on population is unknown (Banguera-Hinestroza et al. 2014).

L. acutus are described to have a pelagic distribution (Evans 1980) preferring cold (5-16^{0}C) and low salinity water (Waring et al. 2008) with high bottom relief (100-500m) along deep water canyons and troughs (Selzer and Payne 1988) however in this study *L. acutus* were sighted near the coast (Cipriano 2009) close to shore and in various sized fjords (Reid et al. 2003) in Norway. *L. acutus* are considered common in south-western Norway, south of Norway (Northridge et al. 1997), west coast of Norway (Jonsgård and Nordli 1952), northern Norway (Føyn et al. 2002) including sighted offshore in northern Norway (Nøttestad et al. 2002), and north up to Spitzbergen (77^{0}N) (Øien 1996).

An indication of year round distribution may be present in Norway based on sightings and Photo-ID (Figure 6) however this study conducted most of the vessel surveys in June-September, more year round data would need to be acquired to confirm. Sightings of individual # 3 occurred yearly during 2007-2008 and 2011- 2013 (Table 3) although most individuals were not sighted as frequently. *L. acutus* could be moving to northern latitudes during warmer months and closer to shore in the summer (Reeves et al. 2002). Seasonal distribution of *L. acutus* has been reported in New England, USA with more sightings occurring in August to October than April to June (Weinrich et al. 2001) however in Newfoundland, Canada the sightings were highest in July to October (Reeves et al. 1999).

Seasonal distribution of *L. acutus* occurs on the shelf waters from the Gulf of Maine to the Middle Atlantic (Selzer and Paine 1988) and in the North Sea and northern Gulf of Maine (Northridge 1997). The sighting distribution could be influenced by avoidance of survey vessels (Wall et al. 2006) or avoidance of seismic activity (Stone, 2003). Seismic activity was observed and recorded during the summer of 2013 in Vestfjorden. *Lagenoryhnchus* species are exceptionally affected by seismic activity and display the most avoidance of all the cetaceans altering their behavior to swim rapidly and as a result sightings are reduced during air guns firing (Stone, 2003).

Foraging and Social Behavior

In the west North Atlantic *L. acutus* prey on sand lance near the continental shelf (100-500 m) and in the east North Atlantic *L. acutus* prey on herring and mackerel (Weinrich et al. 2001) including our observed feeding of mackerel in the Vestfjorden, Norway. The foraging strategies varied greatly from the shallower (8-10 m range) narrow area in Øyhellsundet, (northern Norway) and the deeper (52-81 m range) wide area in Ingelsfjorden (northern Norway). *L. acutus* cooperate to herd and feed on schools of fish and are described to use the same foraging strategies as the Dusky dolphins (*L. obscurus*, Reeves et al. 1999). The shallower foraging strategy may be comparable to the Dusky Dolphin foraging strategy in Argentina.

Würsig & Würsig (1979, 1980) described the dusky dolphin foraging in Argentina as small groups of 6-15 animals herding anchovy to the surface and the dolphins swam closely around and under the school of fish to herd them, taking turns swimming through the ball of fish to feed and herded strays. Other surrounding dolphins up to 8 km have been observed joining the foraging and reported aerial displays of jumping towards the dolphin foraging group. Socializing occurs after foraging and Würsig & Würsig (1979, 1980) suggest it may strengthen social bonds that are essential for foraging cooperation.

The deeper water foraging strategy was similar to the foraging strategies of bottlenose dolphins, searching for prey in dolphin paired formations, up to hundreds of meters wide in open waters, communicating and cooperating together (Norris and Dohl 1980) and chasing fish into the shallows (Tayler & Saayman 1972). Weinrich et al. (2001) observed only a single occurrence of *L. acutus* foraging in Stellwagen Bank (New England, USA, depth 18-37m), part of the group 10-12 dolphins, (N= 35-50 dolphins) cooperated to herd sand lance (*Ammodytes spp*.) into a ball and the dolphins alternated feeding. The ability to switch foraging strategies to the environment is essential for survival. More possible foraging strategies may be used that were not observed. This study is the first report of *L. acutus* displaying flexibility in their foraging behavior (Bowen et al. 2002).

Behavioral observations during traveling included aerial displays of synchronized jumps of 2 pairs, 1 trio, and 2 quads (included calves) *L. acutus* are highly acrobatic. Synchronous movements are relationship based and displayed by mother and calf (Mann and Smuts 1999) and male-male alliances that touch during surfacing and diving (Connor et al. 2000). Unfortunately the sex could not be determined to indicate male-male or female-female pairs. Socializing occurred with possible touching and solitary jumping. Therefore the indication of alliances could be present in this population however further studies are needed to confirm. Würsig & Würsig (1979, 1980) describes aerial jump displays of dusky dolphins as communication, with distinctive splashes that most likely convey information about the individuals or location. Dusky dolphins perform various aerial jumps; during foraging with sharper and longer splash (possibly to frighten fish), towards other dolphin foraging groups, and after foraging, that are more acrobatic with small splashes (Würsig & Würsig 1979, 1980).

Acoustic Behavior

Little is known about *L. acutus* acoustic behavior (Reeves et al. 1999). Echolocation

clicks are broad bandwidth sounds (30-40 kHz) and contain high frequencies (>100 kHz) and are typically used for orientation, navigation, and prey detection. The interclick interval (rate of clicks) changes in reference of the dolphin to its target (Au 1993).The rate of clicks varied and spanned the entire frame of frequency range analyzed 1-24 kHz which contain ultrasonic components (Figure 7 a). The frequency of the clicks in this study are consistent with Schevill and Watkins (1962, cited in Reeves et al. 1999) which reported that *L. acutus* produces clicks at 1-24 kHz. Dolphins produce short broadband clicks with frequencies up to 120 kHz in bottlenose dolphins (Au 1980) and up to 120 kHz with some maximum peaks of 250 kHz (ultrasonic) in *L. albirostris* (Rasmussen and Miller 2004). In this study the clicks were however only analyzed up to 24 kHz; further analysis at higher frequencies should be evaluated to test for click peak frequency which is unknown in *L. acutus*.

The buzzes and calls observed consisted of concave contours (Figure 7). Burst-pulsed sounds such as calls and buzzes are not heavily studied (Lammers et al. 2004). High repetition click trains and burst-pulsed echolocation sounds contain prey and social information (Herzing 2004). Low frequency buzzing may occur during courtship, discipline, play, aggression, and exploration (Herzing 1996).

Convex shaped whistles were recorded and described as downsweep, inflection point, and upsweep contours (Figure 8). Steiner (1981) described *L. acutus* producing pure tonal whistle dominant frequencies of 6-15 Hz in Nova Scotia and Massachusetts and compared five different Atlantic dolphin species including *L. acutus*, bottlenose dolphins, long-finned pilot whales (*Globicephala melaena*), Atlantic spotted dolphins (*Stenella plagiodon*), and spinner dolphins (*Stenella longirostris*) whistles resulting in frequencies up to 20 kHz. Steiner (1981) deduced that the differences in the whistles were greater in overlapping ranges than in non-overlapping ranges of dolphin species. One selected convex shaped whistle had a frequency of 11-20 kHz (Figure 8) which falls within the frequency range described by Steiner (1981). *L. albirostris* whistles have been recorded with a larger range of frequency of

3-35 kHz with various whistle contours (Rasmussen and Miller 2004). Whistles are long distance social signals used for communication and have localized frequency modulation (Norris and Dohl 1980). Some of the whistles observed indicated stereotyped whistles (a specific characteristic whistle repeated in several different situations).

Signature whistles are a learned unique whistle type that tells the identity of the owner (Janik and Sayigh 2013, Caldwell 1990) and is copied in order to address another individual (Janik and Slater 1998). Signature whistles in bottlenose dolphins aids in group cohesion (Janik and Slater 1998) and individual identity (Sayigh et al. 1999). Additionally they are observed when meeting other dolphins (Quick and Janik 2012), stress (Caldwell et al. 1990), socializing (Quick and Janik 2008), when a dolphin is isolated (Caldwell et al. 1990), and mother-calf reuniting (Smolker et al. 1993). Signature whistles have been suggested in *L. acutus* (Steiner 1981) however this has not been studied and in order to recognize signature whistles further extensive long term research is required including creating the first vocal repertoire of *L. acutus.* This study was the first reporting of *L. acutus* vocal behavior spectrograms and descriptions of clicks, buzzes, calls, whistles, and stereotyped whistles (Figure 7, Figure 8).

Sound Production and Behavior

Sound production was compared with behavior to test for dependency on activity; foraging, socializing, milling, and traveling (Shane 1990). Foraging was the most common activity of the sound recorded dates, group size ranged from 4-50 dolphins (Table 3) although overall sightings group size was 1-200 individuals (Figure 4). Echolocation clicks are produced during foraging and consist of short pulses of high frequency and directionality to detect prey (Zimmer 2011) and were the most abundant sound produced (Table 4). Social signals such as whistles are used for communication and have localized frequency modulation (Norris and Dohl 1980) and were equally abundant when clicks were excluded

(Table 5). Dolphins produce pulsed sounds below 5-10 kHz for communication (Caldwell 1967) and during foraging in bottlenose dolphins and Killer Whales (*Orcinus orca*, Marten et al. 1988). However the calls were most common during traveling (32.4%) and the least common during foraging (18.8%) (excluding the clicks, Table 5). Dolphin communication signals are emitted in whistles or complex calls (Zimmer 2011). Buzzes varied in the observations (0-14%) and were absent during milling when (excluding the clicks, Table 5). Buzzes have been reported during foraging in wild bottlenose dolphins (Herzing 1996) and foraging resulted in the highest amount of buzzes (14%) (clicks were excluded, Table 5). Sound production increased during socializing in all sound categories (Figure 9). Whistles are used for communication and produced more during foraging and socializing and less during traveling or milling (eg. bottlenose dolphin, dos Santos 1990). However whistles were produced similarly during all activities with the highest during milling (76.0%) and socializing (70.2%, Table 5) most likely due to the low amount of milling observed.

Burst-pulse sounds are mainly produced during socializing (Schultz et al. 1995) and foraging (dos Santos et al. 1990) in bottlenose dolphins however calls were produced most during traveling (32.4%, Table 5). Buzzes are produced during foraging and playing in bottlenose dolphins (Herzing 1996) and this agrees with our results of most buzzes during foraging (14%) and socializing (5.69%, Table 5). Whistles are mainly produced during traveling, milling, and socializing in Spinner Dolphins (*Stenella longirostris*, Norris et al. 1994). Whistle production occurred most during milling (76%) and socializing (70.2%) however traveling (65.4%) and foraging (67.2%) whistles were similar (Table 5). Echolocation clicks are the predominant sound produced during foraging (Herzing 2000) and used for scanning prey in bottlenose dolphins (dos Santos et al. 1990) and the observations agrees with the dominance of clicks produced (Table 4), however the percentage of clicks did not greatly vary with activity (98%-99%, Table 4). This study was the first reporting of *L. acutus* relationship between vocal communication and behavior.

Dolphins live in fission-fusion groups that may alter by the minute or hour (Conner et al. 2000, eg. Wursig and Wursig1977) that are not maternally linked groups (Bigg et al. 1990) without group-specific dialects (Ford 1991), therefore dolphin groups should not express group-specific dialects and should express low vocal variation between the groups. The analysis of group affiliation resulted in low variation of sounds produced per sighting group date when compared with activity (Appendices 3-6), this agrees with the fission-fusion society (Conner et al. 2000) of dolphins lacking group-specific dialects (Ford 1991). A trend was present with higher click production during foraging (Appendix 5c) however this trend may relate to the depth, foraging strategy, or prey scanning effort.

Sound Production and Depth

Shallow water differs from deep water environments since shallow water consists of more deflected sounds, echoes, and bottom absorption in relationship to the physical environment (Katsnelson and Petnikov 2002). In shallower areas sound distorts communication and is used in short distances or with very high frequency (Bradbury & Vehrencamp, 1998). Sound production was compared with depth in two sand/mud bottom fjords in northern Norway; the shallower fjord (8-10 m range), Øyhellsundet and the deeper fjord (52-81 m range), Ingelsfjorden. More clicks were produced in deeper water than in shallower water (Figure 10c) and during foraging (Figure 11c). Shallower water sound should reflect back more sound than in the deeper areas and fish schools can greatly absorb and scatter sound in shallow water (Makris et al. 2006). Therefore production of sound would need to be altered in frequency or volume to accommodate and this agrees with the increase of clicks observed. The sound categories were context dependent in shallower and deeper water foraging clicks and greatly abundant in the deeper water (Figure 11). The variation in the amount of clicks may be related to the depth and the foraging strategy used. Whistles were produced more during deeper foraging (Figure 11 b) however there is no relationship in

overall whistles produced and depth (Figure 10b). Burst-pulsed sounds of calls and buzzes were independent of depth and buzzes were rarely observed (Table 6).).

Comparison of White-beaked Dolphins and Atlantic White-sided Dolphins

L. acutus are considered more pelagic than the *L. albirostris* (Evans 1980) and have allopatric distributions (Waring et al. 2008). *L. albirostris* are considered more coastal in the east North Atlantic (Evans 1992) and more pelagic in the west North Atlantic (Northridge 1997) and *L. acutus* was suggested to be the most abundant cetacean on the Atlantic Frontier (Hardwood and Wilson 2001). The abundance for both *L. acutus* and *L. albirostris* in Norwegian waters was estimated at 131,500 individuals (including 50,000 in the Barents Sea) (Føyn et al. 2002). In Norway *L. albirostris* have been reported as more common of the two species (Ottersen et al. 2010) however in this study *L. acutus* were sighted more frequently than *L. albirostris.* The increase in frequency of sightings *L. acutus* and the decline of *L. albirostris* in Norway could indicate a species shift or a normal occurring population that has been understudied. A species shift was based on local climate interactions in Scotland with an increase of common dolphins (*Delphinus delphis*) and a decrease in *L. albirostris* most likely due to changes in sea temperature and specie temperature preference (MacLeod et al. 2005). The possible shift in *L. acutus* and *L. albirostris* abundance could indicate a relationship to temperature due to the close temperature preference of each specie with the division around 12^0C (MacLeod et al. 2007). MacLeod et al. (2007) reported the distribution differences based on habitat; *L acutus* preferring warmer deeper water and *L. albirostris* preferring colder shelf waters in Scotland. However they suggested that habitat division may be more dependent on prey than temperature. Prey preference has been suggested by Gaskin (1982) that *L. albirostris* prefer benthic fish (cod, whiting and capelin) and *L. acutus* prefer nekton fish (mackerel, herring and salmonids). In Vestfjorden, Norway *L. acutus* were observed

foraging on mackerel, *L. albirostris* was absent in sightings. Another shift in species has been reported in the Gulf of Maine with an increasing presence of *L. acutus* and scarce *L. albirostris* change due to reductions in fishing of herring and mackerel (Kenny et al. 1996) however the abundance of fish has not become an issue in Norway.

Fewer sightings of *L. albirostris* may be hindered by the main search effort for *L. acutus* however vessel surveys were opportunistic and an absence of *L. albirostris* still resulted in Vestfjorden, Norway. *L. albirostris* could also be present outside the study areas which were indicated in sightings reported by the media sources. Further studies are needed to confirm the presence or absence of a species shift and sightings of *L. albirostris* in Norway. However this study indicates a stronger presence of *L. acutus* and an indication of an absence of *L. albirostris* in the Vestfjorden, Norway.

Conclusions

The coastal occurrence of *L. acutus* has not been well studied as the majority of reports are pelagic based distributions. Many sightings of *L. acutus* including Photo-ID individuals and re-sightings indicate a stronger presence of *L. acutus* than previous reported in Norway. Vocal communication of *L. acutus* was tested and resulted in being dependent on activity. Clicks were the most abundant sound produced and abundant during foraging. Whistle production was the second abundant sound produced and more abundant during milling and socializing. Sound production increased during socializing. Sound production of clicks was dependent on depth and greatly abundant in deeper water more than in shallow water. The flexibility of *L. acutus* foraging strategies in shallower and deeper waters was observed. The known range of *L. acutus* includes the coast of Norway although the reduction of sightings in the literature and the abundant counts are combination with *L. albirostris* creates uncertainty in the abundance and distribution of *L. acutus* in Norway. A comparison

of *L. acutus* and *L. albirostris* resulted in a stronger presence of *L. acutus* observed in the Vestfjorden area, northern Norway based on vessel surveys. Frequent observations in this study of *L. acutus* may indicate a variety of population behaviors and distributions however more research is required to identify and confirm them.

Acknowledgements

I'd like to greatly thank both of my supervisors Heike Vester and Jarle Tryti Nordeide for their guidance in my master thesis. Thanks to both of you for creating this project and making this all possible!

Jarle Tryti Nordeide, I am so grateful for his courageousness that expands past his main research field to create and coordinate a project that interests me. He has incorporated marine mammals into the master program expanding the options for all students. Thank you for your teaching, knowledge, hard work and help with this project.

Heike Vester, I am so grateful for her ideas for the project and her essential past research experience and data. Thank you for truly teaching me about marine mammals and sharing your passion. I am so grateful for her dedication, teaching, hospitality, and hard work on this project. Thank you for all of your support and inspiration to follow my dreams.

The FBA, thanks for all of your help in my education, funding this project, and all of the wonderful professors and staff that have taught and helped me along the way. The University of Nordland, thanks for the opportunity to change my career and facilitating my bachelor and master degree.

The Lofotrådet, thanks for their stipend to make this project happen and for seeing the value in local research and youth.

Thank you for contributing; Ocean Sounds, Felipe Matos, Arctic Whale Tours, Louise Normann Jensen, Isabelle Dupre, Angelica and Maria Morell. Thanks to my family and friends for your support and love. Norway, thanks for giving me the opportunity to continue my education and explore a new part of the world that I now call home. Bjørn Hamran, thank you for your motivation and believing in me.

References

Altman, J. (1974) Observational study of behavior: Sampling methods. *Behavior*, **49**, 227-267.

Au, W.W. L. (1980) Echolocation signals of the Atlantic bottlenose dolphin (*Tursiops truncatus*) in open waters. *Animal Sonar Systems* (eds. R.G. Busnel and J.F. Fish), pp 251–282, Plenum, New York.

Banguera-Hinestroza, E., Hayano, A., Crespo, E., & Rus Hoelzel, A. (2014) Delphinid systematics and biogeography with a focus on the current genus (*Lagenorhynchus*): Multiple pathways for antitropical and trans-oceanic radiation. *Molecular phylogenetics and evolution*, DOI 10.1007/s10592-014-0578-z.

Bigg M.A., (1982) An assessment of killer whale (*Orcinus orca*) stocks of Vancouver Island, British Colombia. *Report International Whaling Commission*, **32**, 655–666.

Bigg, M.A., Olesiuk, P.F., Ellis, G.M., Ford, J.K.B., & Balcomb, K.C. (1990) Social organization and genealogy of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. *Report of the International Whaling Commission, Special Issue*, **12**, 383-405.

Bogomolni, A.L., Pugliares, K.R., Patchett, K., Herzig, S.M., Harry, C.T., LaRocque, J.M., Touhey, K.M., & Moore, M.J. (2010) Mortality trends of stranded marine mammals on Cape Cod and southeastern Massachusetts between 2000–2006. *Diseases of Aquatic Organisms*, **88**, 143–155.

Bowen, W.D., Read, A.J., & Estes, J.A. (2002) Feeding Ecology. *Marine mammal biology; an evolutionary approach* (ed. R. Hoelzel), pp 217-246, Blackwell Science Ltd, Malden.

Bradbury, J,W., & Vehrencamp, S.L. (1998) *Principles of animal communication*. Sinauer Associates Inc, Sunnderland.

Caldwell, D.K. (1955) Evidence of home range of an Atlantic bottlenose dolphin. *J. Mammal*, **36**(2), 304-305.

Caldwell, M.C., & Caldwell, D.K. (1967) Dolphin community life. *Los Ang. Cty. Mus. Nat. Hist. Contrib. Sci*, ***5***, 12-15.

Caldwell, M.C., Caldwell, D.K., & Tyack, P.L. (1990) A review of the signature whistle hypothesis for the Atlantic bottlenose dolphin, *Tursiops truncatus*. *The bottlenose dolphin* (eds. S. Leatherwood & R.R. Reeves), Academic Press, San Diego.

Cipriano, F. (2009). Atlantic white-sided dolphin, *Lagenorhynchus acutus. Encyclopedia of marine mammals, second edition* (eds, W.F. Perrin, B. Würsig, & J.G.M. Thewissen), 56-58. Academic Press, Burlington.

Connor, R.C., Wells, R., Mann, J., & Read, A. (2000) The bottlenose dolphin: Social relationships in a fission-fusion society. *Cetacean societies: Field studies of whales and dolphins* (eds. J. Mann, R.C. Connor, P. Tyack, & H. Whitehead), pp 91–126, University of Chicago Press, Chicago.

Couperus, A.S. (1997) By-catch of marine mammals and discards in pelagic fisheries. *Report of the Netherlands Institute for Fisheries Research RIVO-DLO to the European Commission*, Document CFP 94/018.

Craddock, J.E., Polloni, P.T., Hayward, B., & Wenzel, F.W. (2009) Food habits of Atlantic white-sided dolphins (*Lagenorhynchus acutus*) off the coast of New England. *Fishery Bulletin,* **107**, 384–394.

dos Santos, M.E., Caporin, G., Moreira, H.O., Ferreira, A.J., & Coelho, J.B. (1990) Acoustic behavior in a local population of bottlenose dolphins. *Sensory abilities of cetaceans,* pp. 585-598, Springer, New York.

Evans, P.G.H. (1980). Cetaceans in British waters. *Mammal Review*, **10**(1), 1-52.

Evans, P.G.H., (1992) *Status review of cetaceans in British and Irish waters*. Sea Watch Foundation, Oxford.

Ford, J. K. (1991). Vocal traditions among resident killer whales (*Orcinus orca*) in coastal waters of British Columbia. *Canadian Journal of Zoology*, **69**(6), 1454-1483.

Gaskin, D.E. (1982) *Ecology of whales and dolphins*, pp 459, Heinemann, London.

Haase, B.J.M. (1987) A mixed herd of white-beaked dolphins *Lagenorhynchus albirostris* and white-sided dolphins *L. acutus* in the southern North Sea. *Lutra,* **30**,105-106.

Hammond, P.S. (2008) Small cetaceans in the European Atlantic and North Sea (SCANS II). Final report to the European Commission under contract LIFE04NAT/GB/000245.

Harwood, J. (2001) Marine mammals and their environment in the twenty-first century. *Journal of Mammalogy*, **82**, 630–640.

Henderson, E.E., Hildebrand, J.A., Smith, M.H., & Falcone, E.A. (2012) The behavioral context of common dolphin (*Delphinus sp*.) vocalizations. *Marine Mammal Science*, **28**(3), 439-460.

Herman, L.M., & Tavolga, W.N. (1980) The communication systems of cetaceans. *Cetacean behavior: Mechanisms and functions*, pp 149-209.

Herzing, D.L. (1996) Vocalizations and associated underwater behavior of free-ranging Atlantic spotted dolphins, *Stenell frontalis* and bottlenose dolphins, *Tursiops truncatus*. *Aquatic Mammals*, **22(**2), 61-79.

Herzing, D.L. (2000) Acoustics and social behavior of wild dolphins: implications for a sound society. *Hearing by whales and dolphins.* pp. 225-272, Springer, New York.

Herzing, D.L. (2004) Social and nonsocial use of echolocation in free-ranging *Stenella frontalis* and *Tursiops truncatus*. *Echolocation in bats and dolphins*. pp 404-410, University of Chicago, Chicago.

Janik, V.M., & Sayigh, L.S. (2013). Communication in bottlenose dolphins: 50 years of signature whistle research. *Journal of Comparative Physiology A*, **199**(6), 479-489.

Janik, V.M., Slater, P.J.B. (1998) Context-specific use suggests that bottlenose dolphin signature whistles are cohesion calls. *Anim Behav*, **56**, 829–838.

Jonsgård, A. & Nordli, O. (1952) Concerning a catch of white-sided dolphins (*Lagenorhynchus acutus*) on the west coast of Norway, winter 1952. *Norwegian Marine Ocean Institute*, **41**, 229-232.

Katsnelson, B.G., & Petnikov, V.G. (2002) *Shallow water acoustics*. Springer, New York.

Kenney, R.D., Payne, P.M., Heinemann, D.W., & Winn, H.E. (1996) Shifts in Northeast Shelf cetacean distributions relative to trends in Gulf of Maine/Georges Bank finfish abundance. *The Northeast Shelf Ecosystem: Assessment, Sustainability, and Management*. (eds. K. Sherman, N.A. Jaworski, & T.J. Smayda), pp 169–196, Blackwell Scientific Publications, Cambridge, MA.

Lammers, M.O., & Au, W.W.I. (1996) Broadband recording of social acoustic signals of the Hawaiian spinner and spotted dolphins. *J Acoust Soc Am*, **100**, 2609.

Lammers, M.O., Au, W.W.L., Aubauer, R., & Nachtigall, P.E. (2004) A comparative analysis of the pulsed emissions of free-ranging Hawaiian spinner dolphins (*Stenella longirostris*). *Echolocation in bats and dolphins*, pp 414-419, University of Chicago Press, Chicago.

MacLeod, C.D., Bannon, S.M., Pierce, G.J., Schweder, C., Learmonth, J.A., Herman, J.S. & Reid, R.J., (2005) Climate change and the cetacean community of north-west Scotland. *Biological Conservation*, 124, 477–483.

MacLeod, C. D., Weir, C. R., Pierpoint, C., & Harland, E. J. (2007). The habitat preferences of marine mammals west of Scotland (UK). *Journal of the Marine Biological Association of the United Kingdom*, **87**(01), 157-164.

Makris, N.C., Ratilal, P., Symonds, D., Jagannathan, S., Lee, S., & Nero, R.W. (2006) Fish population and behavior revealed by instantaneous shelf-scale imaging. *Science*, **311**, 661-663.

Mann, J., & Smuts, B. (1999) Behavioral development in wild bottlenose dolphin newborns (*Tursiops sp.*). *Behaviour*, **136**, 529-566.

Marten, K., Norris, K.S., Moore, P.W.B. & Englund, K.A. (1988) Loud impulse sounds in odontocetes predation and social behavior. *Animal Sonar: Processes and Performance* (eds. P.E. Nachtigall & P.W.B. Moore), pp 567–579. Plenum Press, New York.

Mikkelsen, A.M.H., Lund, A. (1994) Intraspecific variation in the dolphins *Lagenorhynchus albirostris* and *L. acutus* (Mammalia, cetacean) in metrical and nonmetrical skull characters, with remarks on occurrence. *J Zool*, **234**, 289–299.

Mitchell, E. (1970). Pigmentation pattern evolution in delphinid cetaceans: an essay in adaptive coloration. *Can. J. Zool*. **48**, 717-740.

Norris, K.S., & Dohl, T.P. (1980) Behavior of the Hawaiian spinner dolphin. *Fishery Bulletin*, **77**, 821-849.

Norris, K. S., Würsig, B., Wells, R. S., & Würsig, M. (1994) *The Hawaiian spinner dolphin*. University of California Press, California.

Northridge, S., Tasker, M., Webb, A., Camphuysen, K. & Leopold, M. (1997) White-beaked *Lagenorhynchus albirostris* and Atlantic white-sided dolphin *L. acutus* distributions in northwest European and US North Atlantic waters. *Report International Whaling Commission,* **47**, 797-805.

Nowacek, D.P. (2005) Acoustic ecology of foraging bottlenose dolphins (*Tursiops truncatus*), Habitat-specific use of three sound types. *Marine Mammal Science,* **21**, 587–602.

Nøttestad, L. Fernö, A., Mackinson, S., Pitcher, T., & Misund, O.A. (2002) How whales influence herring school dynamics in a cold-front area of the Norwegian Sea. *ICES Journal of Marine Science,* **59**, 393-400.

Ottersen, G., Postmyr, E., & Irgens, M. (2010) Faglig grunnlag for en forvaltningsplan for Nordsjøen og Skagerrak: Arealrapport miljø- og naturressursbeskrivelse forurensningssituasjon særlig verdifulle og sårbare områder viktige områder for næringer. Report by Norwegian Marine Research Institute and Director for Nature Management, Document TA-2681/2010, *Fisken og Havet*, **6**, Bergen, Norway.

Palka, D., Read, A., Potter, C. (1997) Summary of knowledge of white-sided dolphins (*Lagenorhynchus acutus*) from the U.S. and Canadian North Atlantic waters. *Report International Whaling Commission*, **47**, 729–734.

Perrin, W.F., & Reilly, S.B. (1984) Reproductive parameters of dolphins and small whales of the family Delphinidae. *Reproduction of Whales, Dolphins and porpoise* (eds. W.F. Perrin, R.L.J. Brownell and D.P. DeMaster), *International Whaling Commission, Special Issue*, **6**, 97-133,

Popper, A.N. (1980) Sound emission and detection by delphinids. *Cetacean Behavior*, (ed. L.M. Herman), pp. 1–52, John Wiley & Sons, New York.

Quick, N.J., Janik, V.M. (2008) Whistle rates of wild bottlenose dolphins: influences of group size and behavior. *J Comp Psychol*, **122**, 305–311.

Quick, N.J., Janik, V.M. (2012) Bottlenose dolphins exchange signature whistles when meeting at sea. *Proc R Soc Lond B*, **279**, 2539-2545.

R Development Core Team. (2006) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.Rproject.org.

Rasmussen, M.H., Wahlberg, M., & Miller, L.A. (2004) Estimated transmission beam pattern of clicks recorded from free-ranging white-beaked dolphins (*Lagenorhynchus albirostris*). *The Journal of the Acoustical Society of America*, **116**(3), 1826-1831.

Reeves, R.R., Smeenk, C, Brownell, R.L., Jr., & Kinze, C.C. (1999) Atlantic white-sided dolphin *Lagenorhynchus acutus* (Gray, 1828). *Handbook of Marine Mammals, Vol 6: the second book of dolphins and porpoises*, (eds. S.H. Ridgway and Sir R. Harrison), pp 31-56, Academic Press, London.

Reeves, R.R., Stewart, B.S., Clapham, P.J., & Powell, J.A. (2002) Atlantic white-sided dolphin. *Guide to Marine Mammals of the World*, pp 398-401, Chanticleer Press Inc., New York.

Rossbach, K.A., & Herzing, D.L. (1999). Inshore and offshore bottlenose dolphin (*Tursiops truncatus*) communities distinguished by association patterns near Grand Bahama Island, Bahamas. *Canadian Journal of Zoology*, **77**(4), 581-592.

Sayigh, L.S., Tyack, P.L., Wells, R.S., Solow, A., Scott, M.D., & Irvine, A.B. (1999) Individual recognition in wild bottlenose dolphins: A field test using playback experiments. *Animal Behavior*, **56**, 41-50.

Schultz, K.W., Cato, D.H., Corkeron, P.J., Bryden, M.M. (1995) Low frequency narrow-band sounds produced by bottlenose dolphins. *Marine Mammal Science*, **11**, 503-509.

Selzer, L.A., Payne, P.M. (1988) The distribution of white-sided (*Lagenorhynchus acutus*) and common dolphins (*Delphinus delphis*) vs environmental features of the continental-shelf of the northeastern United States. *Mar Mamm Sci*, **4**, 141-153.

Sergeant, D.E., Saint Aubin, D.J., & Geraci, J.R. (1980) Life history and northwest Atlantic status of the Atlantic white-sided dolphin, *Lagenorhynchus acutus*. *Cetology*, **37**, 1-12.

Shane, S.H. (1990) Comparison of bottlenose dolphin behavior in Texas and Florida, with a critique of methods for studying dolphin behavior. *The Bottlenose Dolphin*, (eds. S. Leatherwood & R.R. Reeves) pp 541–558. Academic Press, Inc., San Diego, CA.

Smolker, R.A., Mann, J., Smuts, B.B. (1993) Use of signature whistles during separations and reunions by wild bottlenose dolphin mothers and infants. *Behav Ecol Sociobiol*, **33**, 393–402.

Steiner, W.W. (1981) Species-specific differences in pure tonal whistle vocalizations of five western North Atlantic dolphin species. *Behavioral Ecology and Sociobiology*, **9**(4), 241-246.

Stone, C.J. (2003) The effects of seismic activity on marine mammals in UK waters, 1998-2000. *Report Joint Nature Conservation Committee*, **323**, Peterborough, UK.

Tayler, C.K. & Saayman, G.S. (1972) The social organization and behavior of dolphins (*Tursiops aduncus*) and baboons (*Papio ursinus*): Some comparisons and assessments. *Ann Cape Prov Mus Nat Hist*, **9**, 11-49.

Stevick, P.T., McConnell, B.J., & Hammond, P.S. (2002) Patterns of Movement. *Marine mammal biology; an evolutionary approach*, (ed. R. Hoelzel), pp 185-216, Blackwell Science Ltd, Malden.

Wall, D., O'Brien, J., Meade, J. & Allen, B. (2006) Summer distribution and relative abundance of cetaceans off the west coast of Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy*, **106**B, 135–142.

Waring, G.T., Josephson, E., Fairfield, C.P., & Maze-Foley, K., (2006) U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments 2005. *Report NOAA Technical Memorandum,* Document NMFS-NE-194.

Waring, G.T., Nøttestad, L., Olsen, E., Skov, H., & Vikingsson, G. (2008) Distribution and density estimates of cetaceans along the mid-Atlantic Ridge during summer 2004. *Journal of Cetacean Research and Management,* **10**(2), 137-146.

Waring, G.T., Palka, D.L., & Evans, P.G.H. (2009). North Atlantic Marine Mammals. *Encyclopedia of marine mammals, second edition*, (eds. W. F. Perrin, B. Würsig, & J.G.M. Thewissen), pp 773-781, Academic Press, Burlington.

Watkins, W.A. (1967) The harmonic interval: fact or artifact in special analysis of pulse trains. *Marine bioacoustics*, (ed. W.N. Tavolga), pp 15, **2**, Pergamon Press, New York.

Weinrich, M.T., Belt, C.R., & Morin, D. (2001) Behavior and ecology of the Atlantic white-sided dolphin (*lagenorhynchus acutus*) in coastal New England waters. *Marine Mammal Science*, **17**(2), 231-248.

Wells, R. S., & Scott, M.D. (1999) Bottlenose dolphin *Tursiops truncatus* (Montagu, 1821). *Handbook of marine mammals*, **6**, 137-182.

Whitehead, H., Christal, J., & Tyack, P.L. (2000) Studying cetaceans social structure in space and time. *Cetacean societies, field studies of dolphins and whales*. (eds J. Mann, R.C. Connor, P.L. Tyack, & H. Whitehead), pp 65-87, University of Chicago Press, Chicago.

Würsig, B. (1986) Delphinid foraging strategies. *Dolphin cognition and behavior: A comparative approach*. (eds. R.J. Schusterman, J.A. Thomas, & F.G. Wood), pp 347-359, Lawerence Erlbaum Associates, Hillsdale, New Jersey.

Würsig, B. & Harris, G. (1990) Site and association fidelity in bottlenose dolphins off Argentina. *The Bottlenose Dolphins* (eds. S. Leatherwood & R.R. Reeves), pp. 361-365, Academic Press, San Diego.

Würsig, B., Kieckhefer, T.R., & Jefferson, T.A. (1990) Visual displays for communication in cetaceans. *Sensory abilities of cetaceans*, (ed. J. Thomas & R. Kastelein), Plenum, New York.

Würsig, B., & Würsig, M. (1977) The photographic determination of group size, composition and stability of coastal porpoises (*Tursiops truncatus*). *Science,* **198**, 755-56.

Würsig, B., & Würsig, M. (1979) Behavior and ecology of the bottlenose dolphin, *Tursiops truncatus*, in the South Atlantic. *Fishery Bulletin*, **77**(2), 399-412.

Würsig, B., & Würsig, M. (1980) Behavior and ecology of dusky porpoises, *Lagenorhynchus obscurus*, in the south Atlantic. *Fishery Bulletin*, **77**, 871– 890.

Zimmer, W.M. (2011). *Passive acoustic monitoring of cetaceans*. Cambridge University, Press New York.

Øien, N. (1996) *Lagenorhynchus* species in Norwegian waters as revealed from incidental observations and recent sighting surveys. Document SC/48/SM15, *International Whaling Commission*, Scientific Committee, Cambridge.

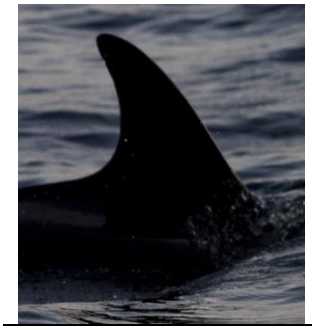
Appendix 1

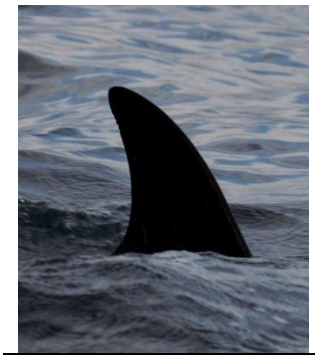
Photo-ID of Norwegian Atlantic White-sided Dolphins

Photo-ID of Norwegian Atlantic White-sided Dolphin (*Lagenorhynchus acutus*). Labels: eg. NAWSD-01-A-2007-06-10; NAWSD (Norwegian Atlantic White-sided Dolphins), 01 (Individual animal number), A [Group letter (date sighted for each group observed)], 2007-06-10 (date first sighted).

Name	**Natural Marking(s)**	**First Sighting**	**Re-sighting(s)**
NAWSD-01-A-2007-06-10 	big middle nick	10/06/2007	23/07/2013
NAWSD-02-A-2007-06-10 	no nicks, scars on dorsal	10/06/2007	22/07/2013 23/07/2013
NAWSD-03-A-2007-06-10 	Plenty nicks (2 low)	10/06/2007	05/09/2008 25/08/2011 05/07/2012 01/07/2013 09/08/2013

NAWSD-04-A-2007-06-10 	scars on back	10/06/2007	none
NAWSD-05-A-2007-06-10 	Plenty nicks (2 high)	10/06/2007	none
NAWSD-06-A-2007-06-10 	low nick (small)	10/06/2007	05/09/2008 29/07/2011
NAWSD-07-B-2008-08-10 	high nick, scar on front of dorsal	10/08/2008	none
NAWSD-08-C-2008-09-05 	plenty of nick (front top + middle), scars on dorsal + back	05/09/2008	11/08/2009 19/06/2011

NAWSD-09-C-2008-09-05 	low nick, top small nicks	05/09/2008	25/06/2011 29/07/2011 02/08/2011 22/07/2013 23/07/2013
NAWSD-10-C-2008-09-05 	high nick	05/09/2008	24/06/2011
NAWSD-11-D-2009-06-22 	plenty of nicks (2 high + middle), scars on dorsal	22/06/2009	none
NAWSD-12-D-2009-06-22 	top nick, scars on dorsal + back	22/06/2009	none
NAWSD-13-D-2009-06-22 	plenty of nick (2 high)	22/06/2009	none

NAWSD-14-D-2009-06-22 	plenty of nicks (2 middle)	22/06/2009	22/07/2013 23/07/2013
AWSD-15-D-2009-06-22 	plenty of nicks (high + long + 2 low)	22/06/2009	19/06/2011
NAWSD-16-F-2011-06-19 	plenty of nicks (2 high nicks)	19/06/2011	none
NAWSD-17-F-2011-06-19 	high nick, scar right side	19/06/2011	22/07/2013 23/07/2013
NAWSD-18-F-2011-06-19 	plenty of nicks (4 high nicks)	19/06/2011	none

NAWSD-19-G-2011-06-24 	plenty of nicks (large middle + large low)	24/06/2011	none
NAWSD-20-H-2011-06-25 	plenty of nicks (2 high + low)	25/06/2011	11/01/2012
NAWSD-21-I-2011-07-29 	scars on right side	29/07/2011	none
NAWSD-22-J-2011-08-02 	plenty of nicks (2 high + low)	02/08/2011	none
NAWSD-23-J-2011-08-02 	plenty of nicks (high + 2 middle + 4 low)	02/08/2011	22/07/2013

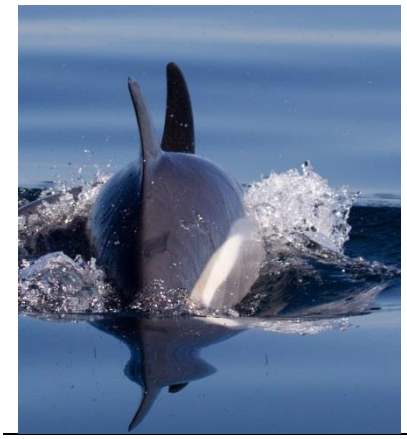
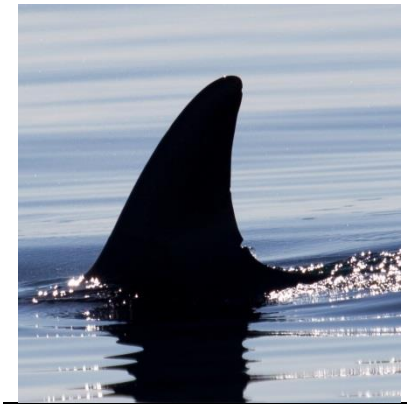
NAWSD-24-J-2011-08-02 	plenty of nicks (high + middle + low)	02/08/2011	none
NAWSD-25-J-2011-08-02 	plenty of nicks (front of dorsal + 2 high + 2 middle + low), scar on left yellow stripe	02/08/2011	none
NAWSD-26-J-2011-08-02 	plenty of nicks (2 high + low)	02/08/2011	none
NAWSD-27-J-2011-08-02 	plenty of nicks (3 high)	02/08/2011	22/07/2013
NAWSD-28-J-2011-08-02 	plenty of nicks (high + middle + low)	02/08/2011	none

NAWSD-29-J-2011-08-02 	bent dorsal	02/08/2011	none
NAWSD-30-J-2011-08-02 	scars on left side back + left side dot on yellow stripe	02/08/2011	none
NAWSD-31-L-2012-01-11 	scars on right side	01/11/2012	none
NAWSD-32-M-2012-06-30 	middle nick	30/06/2012	05/07/2012 09/08/2013
NAWSD-33-M-2012-06-30 	big middle nick	30/06/2012	none

NAWSD-34-N-2012-07-05 	plenty of nicks (2 middle + 2 low)	05/07/2012	none
NAWSD-35-N-2012-07-05 	plenty of nicks (3 high)	05/07/2012	none
NAWSD-36-N-2012-07-05 	plenty of nicks (2 high + 2 low)	05/07/2012	none
NAWSD-37-P-2013-07-16 	plenty of nicks (4 high)	16/07/2013	none
NAWSD-38-Q-2013-07-22 	plenty of nicks (2 top + big middle + 2 low)	22/07/2013	23/07/2013

NAWSD-39-Q-2013-07-22 	plenty of nicks (high + middle), calf dorsal scars, scar on head, side	22/07/2013	none
NAWSD-40-Q-2013-07-22 	calf middle nick, scars on left side	22/07/2013	none
NAWSD-41-Q-2013-07-22 	plenty of nicks (2 high)	22/07/2013	none
NAWSD-42-Q-2013-07-22 	plenty of nicks (high + middle), dorsal scar	22/07/2013	none
NAWSD-43-R-2013-07-23 	calf high nick, back scar	23/07/2013	none

NAWSD-44-R-2013-07-23 	plenty of nicks (middle + low), scars on right side	23/07/2013	none
NAWSD-45-R-2013-07-23 	calf scar on back	23/07/2013	none
NAWSD-46-R-2013-07-23 	dorsal scratches (base), 2 back scars	23/07/2013	none
NAWSD-47-R-2013-07-23 	plenty of nicks (high + big middle + 2 low)	23/07/2013	none
NAWSD-48-S-2013-08-09 	plenty of nicks (4 high + 2 low)	09/08/2013	none

NAWSD-49-S-2013-08-09 	right side scar	09/08/2013	none
NAWSD-50-S-2013-08-09 	plenty of nicks (top + middle + low)	09/08/2013	none
NAWSD-51-S-2013-08-09 	plenty of nicks (3 top + 2 big middle + 2 low)	09/08/2013	none
NAWSD-52-S-2013-08-09 	plenty of nicks (high + big middle), scars	09/08/2013	none

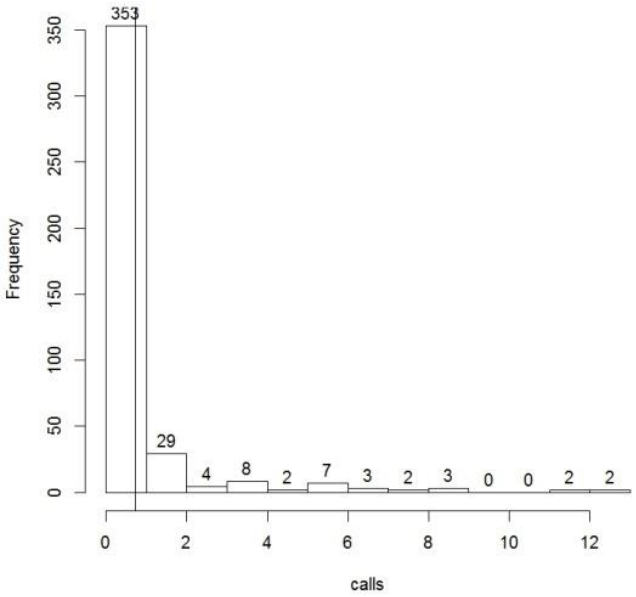
NAWSD-53-S-2013-08-09 	plenty of nicks (big middle + 3 low)	09/08/2013	none
NAWSD-54-S-2013-08-09 	plenty of nicks (big middle + low)	09/08/2013	none
NAWSD-55-S-2013-08-09 	plenty of nicks (2 high + 2 low)	09/08/2013	none

Appendix 2

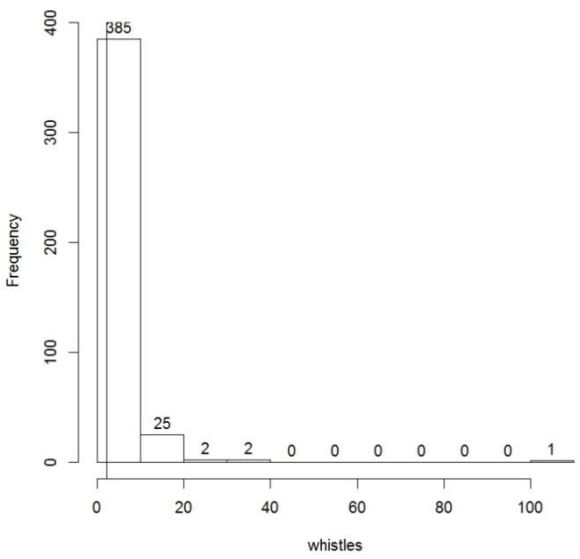
Histogram frequency distributions of sounds produced

Overall data histograms of sounds and the amount observed with zeros included.

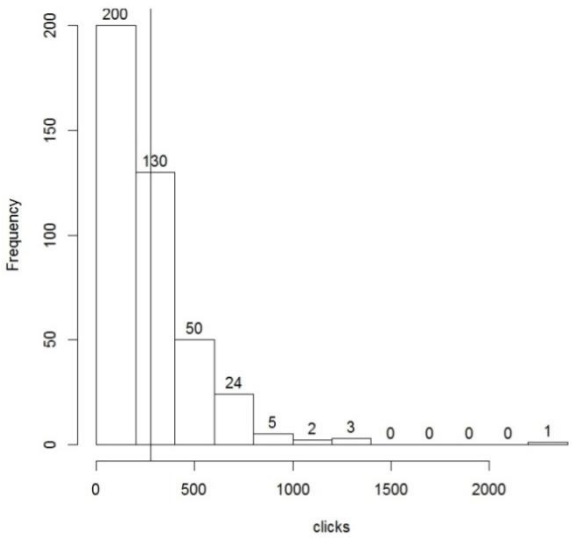
a.



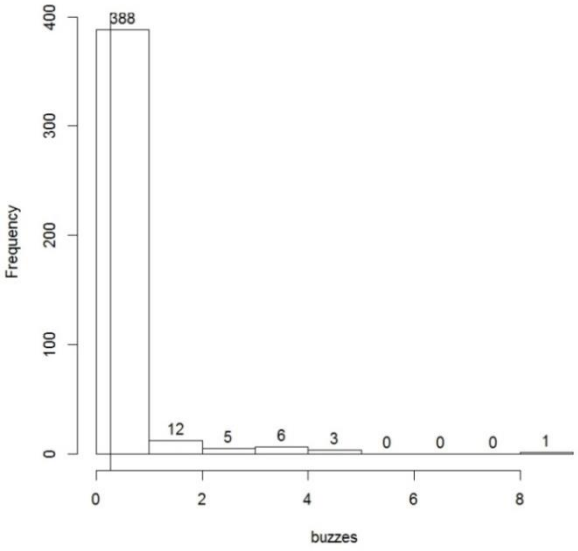
b.



c.



d.



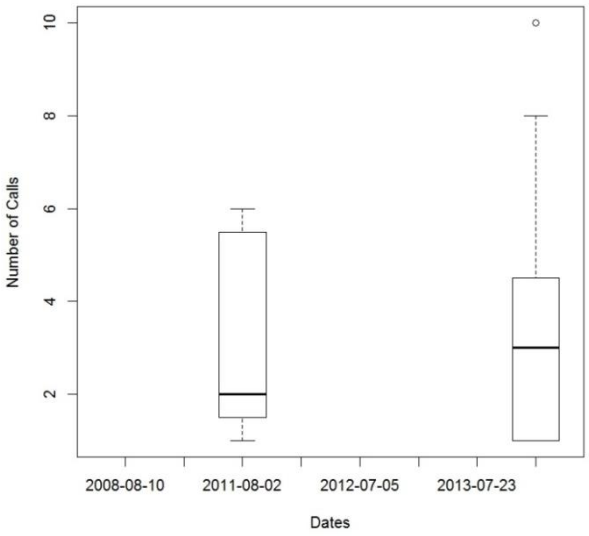
Histogram frequency distributions of sounds produced in Atlantic White-sided Dolphin (*Lagenorhynchus acutus*): (a) number of calls per minute observed, (b) number of whistles per minute observed, (c) number of clicks per minute observed and (d) number of buzzes per

minute observed (zeros removed). The x-axis is the number of sounds in a one minute interval for all observations. The y-axis is the frequency, or occurrence of sounds produced in a one minute interval of all data. The numbers on top of the columns is the occurrence and the vertical bar is the mean; (a) 0.6182 calls, (b) 3.990 whistles, (c) 271.8 clicks and (d) 0.5049 buzzes.

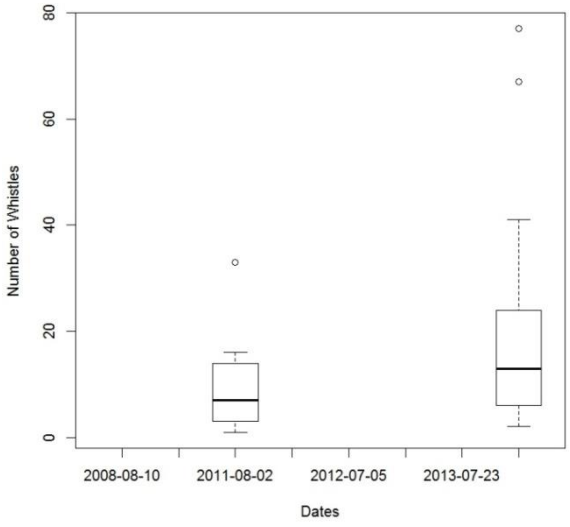
Appendix 3
Boxplots of sounds produced and socializing per sighting date

Boxplots of socializing sounds observed with the zeros removed.

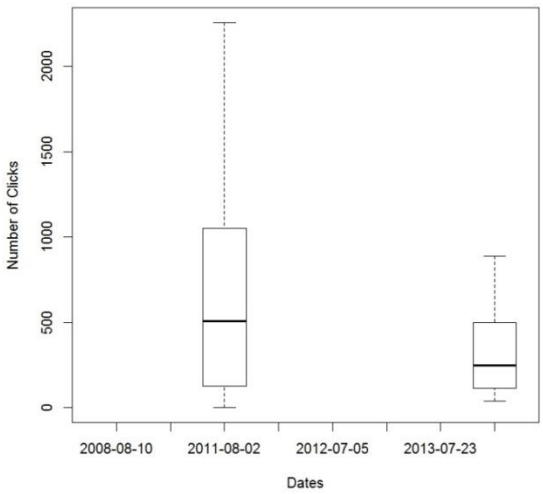
a.



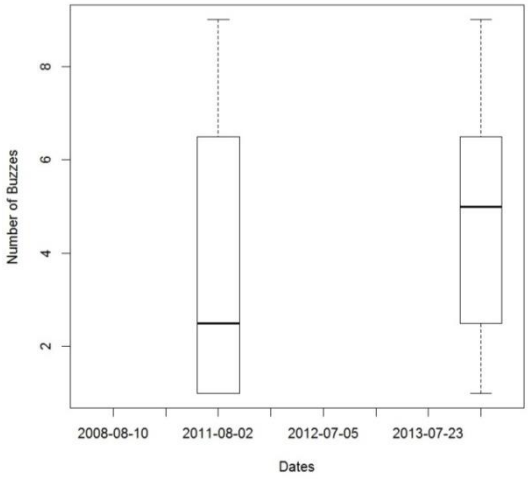
b.



c.



d.

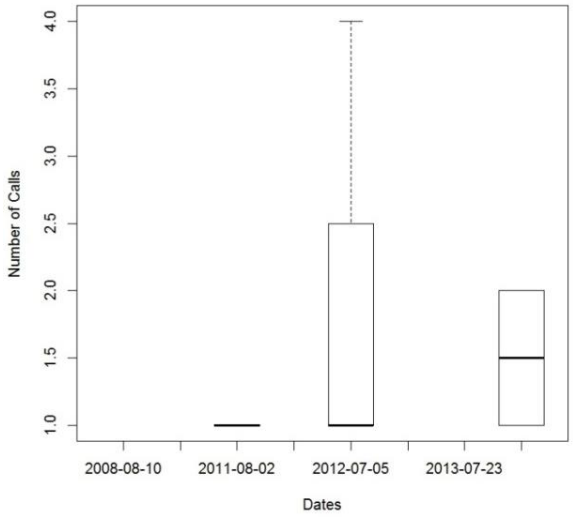


Socializing sounds compared to all recording dates of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*); (a) calls, (b) whistles, (c) clicks and (d) buzzes (zeroes removed in figure). The x-axis is the sighting dates of all recorded socializing observed and the y-axis is the amount of the respective sound category.

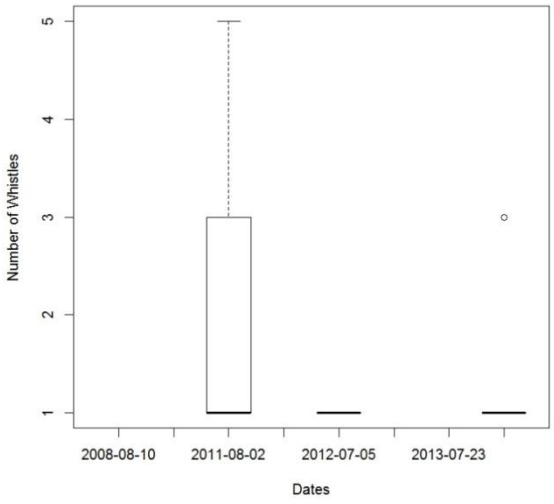
Appendix 4
Boxplots of sounds produced and traveling per sighting date

Boxplots of traveling sounds observed with the zeros removed.

a.

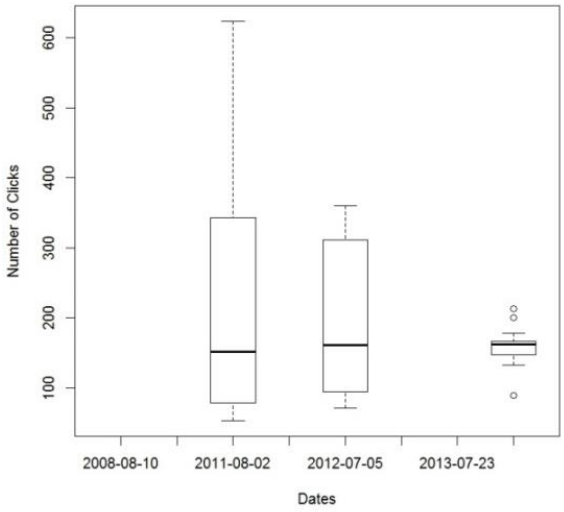


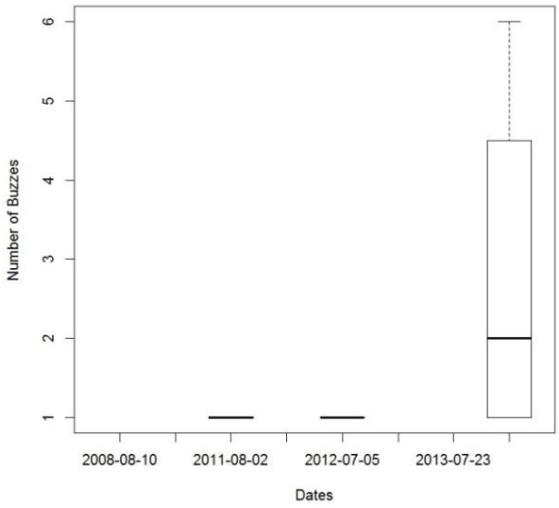
b.



d.

c.



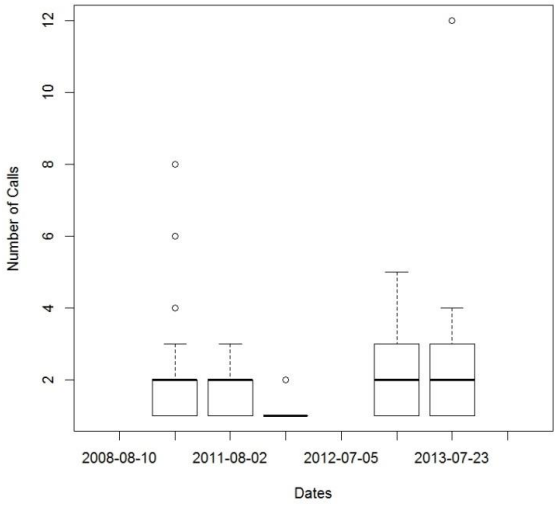


Traveling sounds compared to all recording dates of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*);(a) calls, (b) whistles, (c) clicks and (d) buzzes (zeroes removed in figure). The x-axis is the sighting dates of all recorded traveling observed and the y-axis is the amount of the respective sound category.

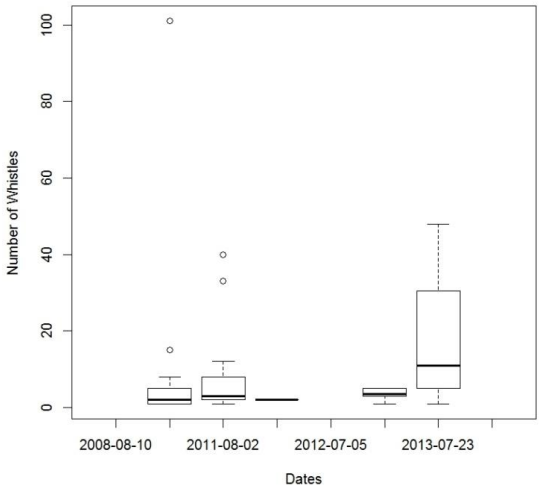
Appendix 5
Boxplots of sounds produced and foraging per sighting date

Boxplots of foraging sounds observed with the zeros removed.

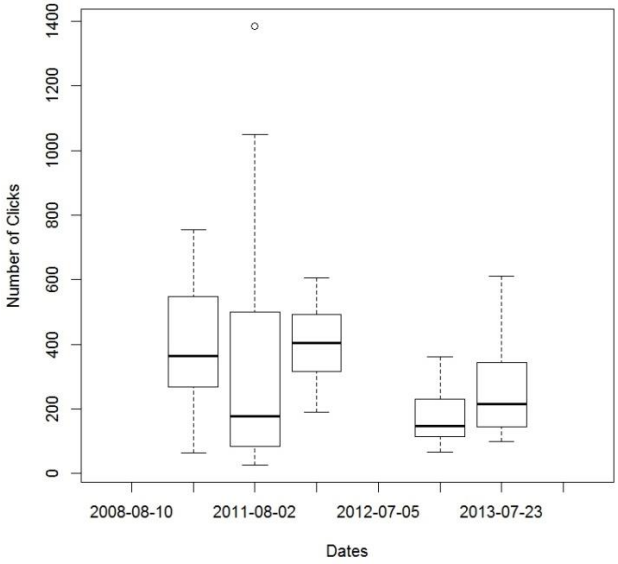
a.



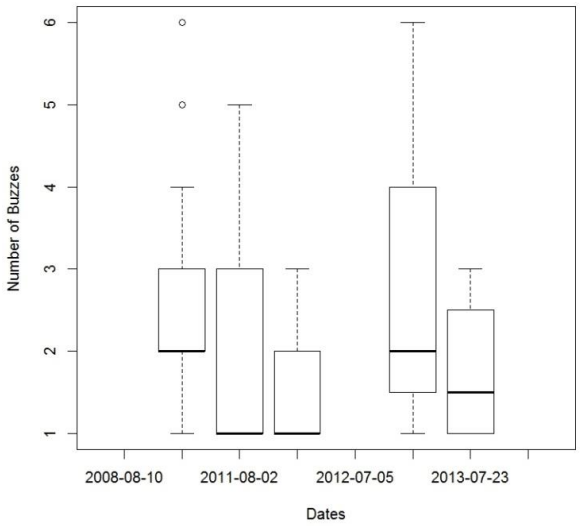
b.



c.



d.

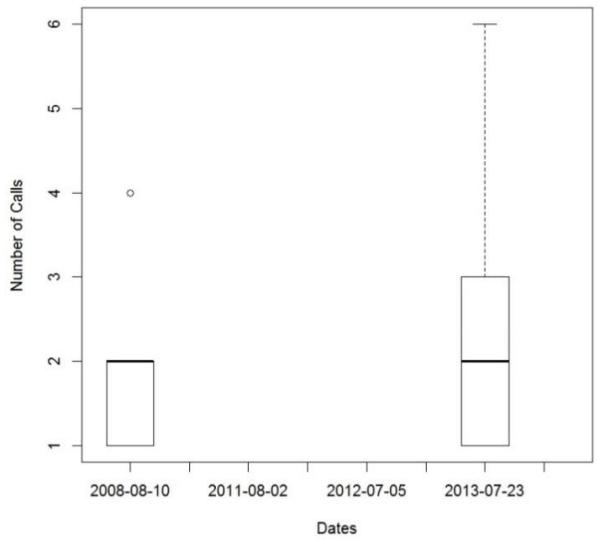


Foraging sounds compared to all recording dates of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*); (a) calls, (b) whistles, (c) clicks and (d) buzzes (zeroes removed in figure). The x-axis is the sighting dates of all recorded foraging observed and the y-axis is the amount of the respective sound category.

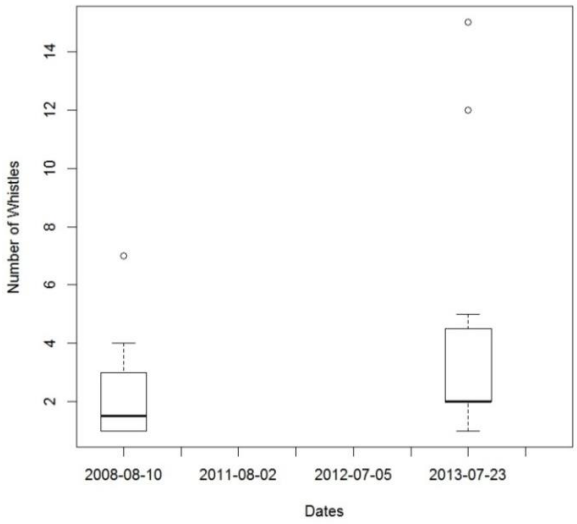
Appendix 6
Boxplots of sounds produced and milling per sighting date

Boxplots of milling sounds observed with the zeros removed.

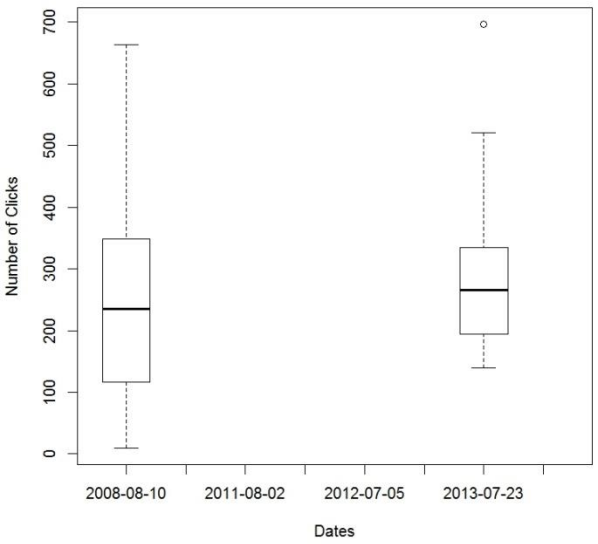
a.



b.



c.



Milling sounds compared to all recording dates of Atlantic White-sided Dolphin (*Lagenorhynchus acutus*); (a) calls, (b) whistles, (c) clicks (zeroes removed in figure). The x-axis is the sighting dates of all recorded milling observed and the y-axis is the amount of the respective sound category. No buzzes were observed.