Whistle variations within the bottlenose dolphin population of Cardigan Bay, Wales

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A thesis submitted for the degree of
M.Sc. Marine Biology
September 2014

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DECLARATION

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This dissertation is being submitted in partial fulfilment of the requirement of the M.Sc. in Marine Biology.

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Whistle variations within the bottlenose dolphin (*Tursiops truncatus*) population of Cardigan Bay, Wales

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Abstract

Bottlenose dolphins (*Tursiops truncatus*) live in fission-fusion societies and constantly use vocal cues to stay in contact with one another. Of all the sounds emitted by this species, whistles are the most studied and observed vocalisation due to their ease of analysing and categorising. Whistle variations have been studied in many different populations and have been observed to change depending on specific environmental and biological factors. Similarities have also been observed between groups of dolphins due to individuals mimicking whistle characteristics. A study was conducted looking at the whistle variations of the bottlenose dolphin population in Cardigan Bay by combining acoustic data that was taken for three consecutive summers. This data was collected from a combination of *ad libitum* and line-transect surveys and multivariate analysis was used to assess if differences did occur between groups of dolphins and if these differences were due to certain environmental or biological factors.

Whistles produced were similar between groups. However, non-parametric testing revealed that each whistle parameter was significantly different from one another between groups. Whistle characteristics such as beginning frequency and minimum frequency increased at greater depths while minimum frequency decreased and duration increased in larger groups. These differences could be due to the fact that high frequency whistles do not travel as far in deeper waters and that whistles have to travel a farther distance when dolphins are more dispersed. The presence of calves also revealed to effect whistle characteristics, especially whistle contour being more complex in lone mother-calf pairs. It can be concluded that whistle variation does occur in the Cardigan Bay bottlenose dolphin population. However, further studies are needed to get a better understanding of what is causing these variations and how other factors such as geographic location and season could effect whistle characteristics.

Acknowledgments

I would like to thank my supervisor Dr. Peter Evans for providing me with the opportunity to conduct this project and for his endless guidance and advice throughout the project. I would also like to thank the staff and interns at the Sea Watch Foundation for making my time there so worthwhile, especially Emilia Benavente Norrman for helping me extract the data I used for analysis. I also would like to thank my supervisor at Bangor University, Irene Martins, for all her support throughout the project.

This project would not have been possible without the constant encouragement and love I received from my parents Ellen and Steve Massey and my sister Caroline Chandler. My peers also played a major role in what I have achieved this past year and have made my time here unforgettable.

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List of Abbreviation

ANOVA: Analysis of Variance

ANOSIM: Analysis of Similarities

dB: Decibels

EU: European Commission

JNCC: Joint Nature Conservation Committee

kHz: Kilohertz

m: Meters

≥: Greater Than or Equal To

>: Greater Than

<: Less Than

MDS: Multi-dimensional Scaling

%: Percent

PRIMER: Plymouth Routines in Multivariate Ecological Research

SAC: Special Area of Conservation

SIMPER: Similarity Percentages

1. Introduction

1.1 Background

Bottlenose dolphins (*Tursiops truncatus*) live in fission-fusion societies in temperate and tropical waters all over the world (Leatherwood & Reeves, 1990; Reynolds *et al.*, 2000). Due to their often coastal habitat and social behaviour resulting in them being easily observed in the wild, bottlenose dolphins are one of the most studied of marine mammals (Connor *et al.*, 2000). The species constantly leaves and re-joins different pods, making communication important between groups and individual dolphins (Wells & Scott, 1999; Connor *et al*., 2000; Tyack & Clark, 2000). Larger pods will split off into smaller groups in order to feed, mate, and socialise, using visual and auditory signals to stay in constant communication with other individuals (Connor, 2007). These smaller groups can remain intact for up to a couple of years and may comprise of individuals of similar sex and age, forming complex bonds between each individual (Shane *et al.*, 1986; Sayigh *et al.*, 1990). These complex bonds allow individuals within a group to communicate with each other during times when the group is loosely dispersed usually during feeding and foraging (Tyack, 1997). However, these animals mainly rely on auditory cues to communicate with each other due to the fact the visibility can be low in certain areas and because visual cues do not travel as far as auditory cues (Janik, 2000). Vocal cues can also carry a larger amount of information by changing the characteristics of each vocalisation produced, which is not possible when using visual cues (Herzing, 1996).

1.2 Types of Vocalisations

There are three different types of vocalisations used by bottlenose dolphins: broad-band short duration clicks, wide-band pulse sounds, and narrow-band frequency whistles (McCowan & Reiss, 1995; Herzing & dos Santos, 2004; Perrin *et al*., 2008). Broad-band clicks are used in echolocation to distinguish small details of different objects such as pelagic fish and squid species (Au, 1993). Clicks are mainly used for hunting, orientation, and navigation, rather than for communication purposes (Overstrom, 1983). Pulse sounds are used in a more social context and are produced in the form of squawks, yelps, and pops (McCowan & Reiss; 1995; Xitco & Roitblat, 1996). Pulse sounds have a frequency range from 2-200 kHz with a low directionality, and can be used to show different types of emotion (Lammers *et al.*, 2003). Due to the fact that whistles are easy to catagorise and analyse, whistles are the most studied vocalisation in bottlenose dolphins. This type of vocalisation is mainly used for communication and individual recognition and can be split into variant and signature whistles (Herman & Tavolga, 1980; Leatherwood & Reeves, 1990; Cook *et al*., 2004; Harley, 2008; May Collado & Wartzok, 2008). Variant whistles are used during times of travel and foraging when constant communication is required. These whistles are highly directional and help keep a group together over large distances. By comparison, signature whistles have discrete characteristics unique to an individual, and are used to help with individual recognition (Tyack, 1986). These whistles can also be mimicked between individuals especially between mother-calf pairs and male-male alliances (Reis *et al.*, 1997; Smolker & Pepper, 1999).

1.3 Whistle Characteristics

Whistles are usually produced in the audible range of humans (1-32 kHz), and can have a source level from 125–140 dB. Whistles have many different contours that can range from constant, ascending, descending, ascending-descending, descending-ascending, and multi-loop whistles and can possess harmonics that are produced in multiple frequencies during a whistle (Azevedo *et al*., 2007; Abbott, 2009). From a whistle recording, different frequency parameters can be calculated such as beginning and ending frequency, start and end time, duration, number of inflection points, minimum and maximum frequency, and contour type (López, 2011; Figure 1). These parameters can change depending on the group or individual producing the sound. Many studies have found that specific factors such as group size, behaviour, water depth, seabed substrate, and presence of mother-calf pairs can affect the type of whistle produced by changes in the structure and frequency parameters of each vocalisation (Cook *et al*., 2004; Quintana-Rizzo *et al*., 2006; Baron *et al*., 2008; Esch *et al*., 2009).

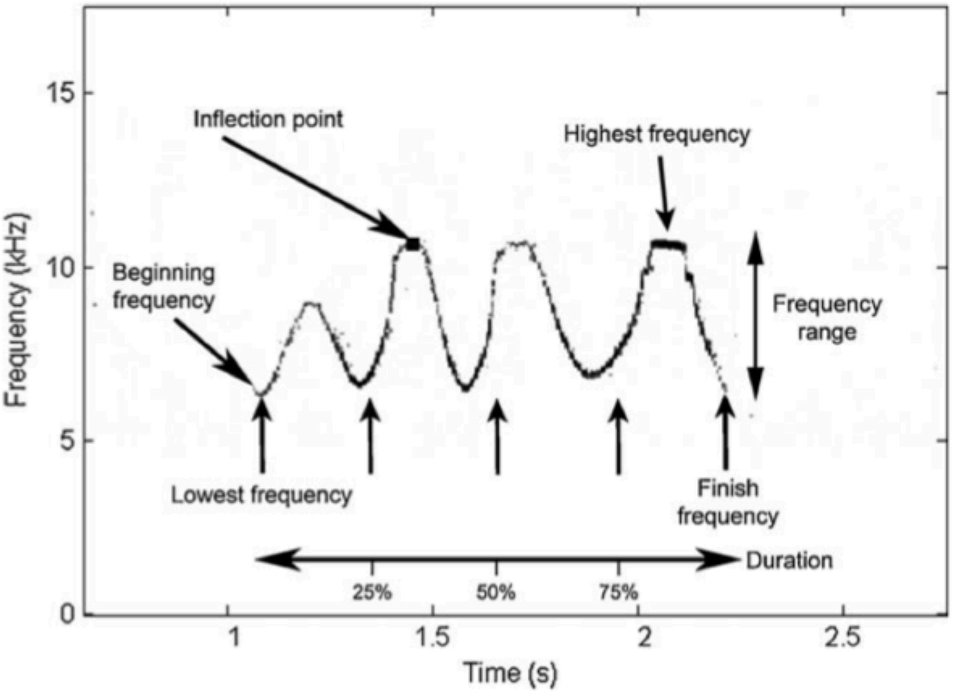


Figure 1. Spectrogram of a bottlenose dolphin whistle and the seven different acoustic variables that can be analysed. Illustration from López, 2011

1.4 Signature Whistles

Similar to other whistles, signature whistles are usually produced between 1-32 kHz and have frequency parameters that vary depending on the individual producing the sound (Caldwell & Caldwell, 1965). Due to the difficulty of distinguishing which signature whistle belongs to a particular individual, most studies of signature whistles have been conducted on captive dolphins or during capture-release events (Smolker *et al.*, 1993; Janik *et al.*, 1994; Sayigh *et al.*, 1995; Janik & Slater, 1998; Fripp *et al.,* 2005; Janik *et al.,* 2006; Esch *et al.*, 2009), with only a handful upon wild individuals (Janik, 2000; Cook *et al.*, 2004; Quick & Janik, 2012; Janik *et al.*, 2013). Many of these studies not only found that signature whistles were produced over 50% of the time, but that different factors such as behaviour, sex, and age could change the rate and structure of the whistle produced (Smolker *et al.*, 1993; Cook *et al.*, 2004; Esch *et al.*, 2009). Some studies have come up with a specific methodology to pinpoint exactly where each whistle is coming from by using a hydrophone array made up of two to four hydrophones (Quick *et al*., 2008; Quick & Janik, 2008; Quick & Janik, 2012; Janik *et al*., 2013). However, even with this methodology, there is still difficulty in recording and analysing signature whistles due to the difficultly of accurately recording whistles of individual dolphins.

1.5 Cardigan Bay Population

Cardigan Bay is home to the largest coastal population of bottlenose dolphins in the United Kingdom for which two Special Areas of Conservation (SAC's) have been established under the EU Habitats Directive (Evans & Pesante, 2008; Pesante *et al.*, 2008; Veneruso & Evans, 2012a, b; Feingold & Evans, 2014). For the purposes of conservation management, many land- and boat-based surveys specifically using photo identification have been conducted in the area since 2001 (Baines *et al*., 2002; Ugarte & Evans, 2006; Pesante *et al*., 2008; Veneruso & Evans, 2012a, b; Feingold & Evans, 2013, 2014). These studies have been conducted not only upon the population that resides within the bay, but also those individuals who pass through the bay during the summer months. From these studies, the population abundance, distribution, structure, and life history have been recorded and analysed. However, only a small number of studies have looked at the vocalisation characteristics of the dolphin population in the bay (Shaw, 2010; Bird, 2012; Thompson, 2012; Nuuttila *et al*., 2013).

Due to their use for communication and individual recognition purposes, it is important to collect acoustic data to gain a better understanding of the dolphin population that resides within Cardigan Bay. Past studies in the region have found whistle characteristics to change due to specific factors such as depth, seabed substrate, group size, behaviour, boat presence, and geographic location (Bird, 2012; Thompson, 2012). From those initial results it is important to continue conducting acoustic studies in the area not only to increase sample sizes so as to better examine how these specific factors are affecting vocalisations, but also to see if other factors that have not been previously investigated could have an effect on whistle characteristics. Due to the high proportion of calf sightings within the bay between April and September, Cardigan Bay is thought to serve at least partially as a nursery area for the dolphin population (Veneruso & Evans, 2012a, b). With a relatively high number of calves in the area, it would be beneficial to see if groups that contain mother-calf pairs have different whistle characteristics than groups with no calves. A study undertaken on bottlenose dolphins in Italy, for example, found groups with mother-calf pairs to whistle significantly more often than groups without mother-calf pairs (Patson, 2008). However, this specific factor has not been extensively studied within the Cardigan Bay bottlenose population and further analysis is important to see if any trends exist. This research can provide a better understanding of how the dolphins utilise the bay and help distinguish certain anthropogenic factors such as boat presence that might be changing the way the species communicates vocally.

1.6 Aims & Objectives

The aim of this study is to determine if bottlenose dolphin whistles for the population residing in Cardigan Bay change structure or rate between groups and if so whether these variations are a result of specific environmental and biological factors. In order to address this specific aim, whistles will be assessed to determine if their frequency parameters vary between groups of bottlenose dolphins within the bay. Also, by using visual observations, dolphin behaviour and a range of environmental factors will be recorded and analysed to see if any of these have an effect on the whistle production within a dolphin group. To achieve these objectives, the following hypotheses will be tested:

H1: Whistles will vary by frequency range, duration, and rate between groups of bottlenose dolphins residing in Cardigan Bay.

H2: Factors such as depth, seabed substrate, group size, behaviour, and presence of mother-calf pairs will result in whistle variations between groups of dolphins within Cardigan Bay.

2. Methods

2.1 Study Area

Cardigan Bay is located along the west coast of Wales (Figure 2, at coordinates 52.4667°N, 004.1500°W) and is the largest bay in the United Kingdom. There is little variation of depth within the bay and the topography of the seabed changes from fine sediments inshore to coarse sediments offshore.

Under the EU Habitats Directive, the bay holds two Special Areas of Conservation (SACs), one called Cardigan Bay in the south and the other being Pen Llyn a'r Sarnau in the north. These two Natura 2000 provide protection for certain species within a special Annex due to their particular vulnerability to human pressures. The species under protection include the bottlenose dolphin (*Tursiops truncatus*), grey seal (*Halichoerus grypus*), harbour porpoise (*Phocoena phocoena*), and two species of lamprey.

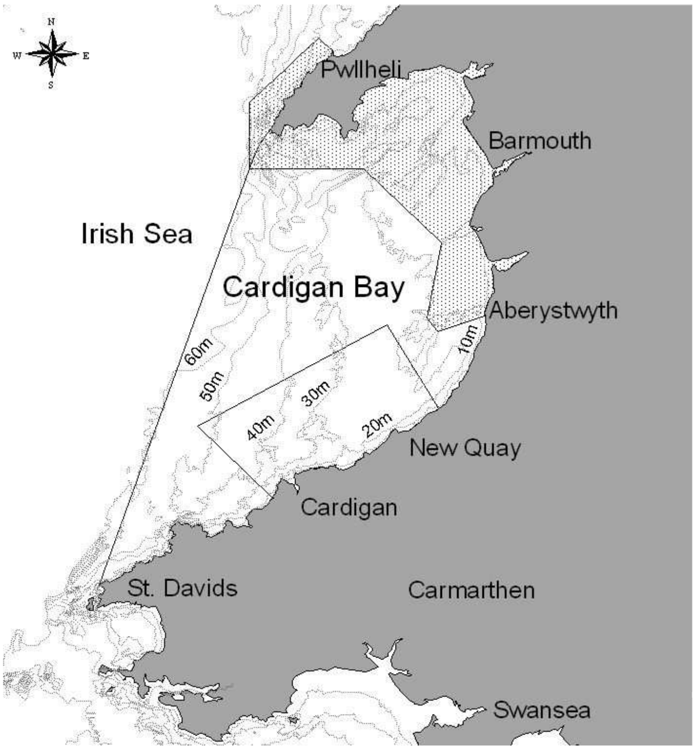


Figure 2. Map for study area within Cardigan Bay. Rectangle represents Cardigan Bay SAC and textured polygon represents Pen Llyn a'r Sarnau SAC (Pesante *et al.*, 2008)

2.2 Data Collection

Whistle recordings were collected using a mixture of line-transect surveys and *ad libitum* surveys while aboard one of three different research vessels chartered by Sea Watch Foundation. Both survey methods required specific weather conditions with a Beaufort sea state of <3 and visibility being >1.5 km. Line transect surveys were conducted either on inner or outer transect lines depending on what line was drawn at random that morning. While on board the vessel, the hydrophone was deployed into the water once dolphins were 100 m away. A C55RS hydrophone was used with a linear frequency range of 0.015 to 50 & 124 to 250+ kHz, a usable frequency range of 0.008 to 77 and 96 to 250+ kHz, and a transducer sensitivity of -200 dB re 1v/µPa. The hydrophone was connected to a NEMA-4X water resistant battery box which was then connected to an Olympus LS-11 EU recorder set to record at a sampling rate of 96 kHz (Figure 3). During an encounter the hydrophone was placed into the water at c. 3m depth while behavioural data such as time, location (latitude and longitude), sea state, group size, behaviour, composition, and distance from boat were recorded every 3 minutes (Appendix C). When possible, the engine was turned off when recordings were being taken. However, due to the fact that the dolphins travelled in varying directions it was difficult to keep the engine off during the entire encounter. During this study, whistles could only be analysed between groups rather than within groups due to the fact that individual whistles could not be recognized with the available equipment.

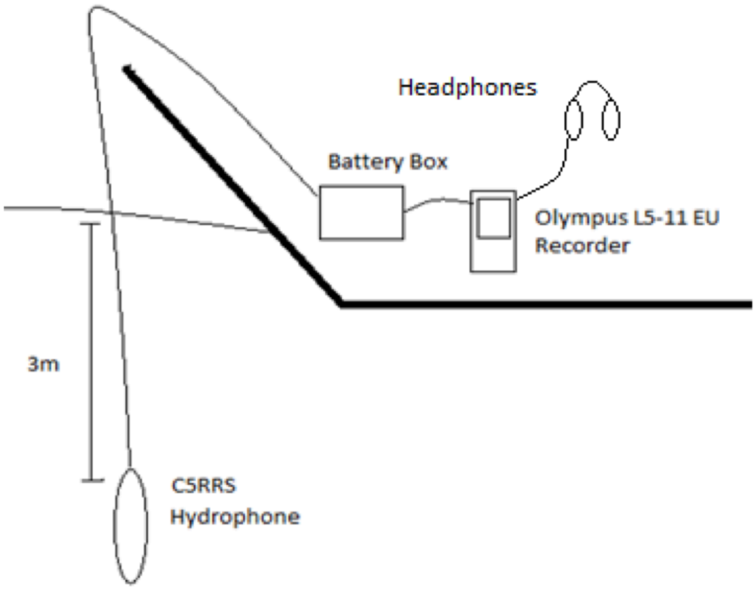


Figure 3. Diagram extracted from Thompson, 2012 of equipment set-up while onboard research vessel

2.3 Data Analysis

2.3.1 Whistle Classification

Whistles were classified using the software Raven Lite 1.0. Sound files were displayed as a spectrogram with a frequency range of 0-22 kHz. Parameters such as beginning frequency (kHz), ending frequency (kHz), minimum frequency (kHz), maximum frequency (kHz), duration (s), number of inflection points, and contour type were identified by visual observation. Five different contour types were recorded categorized by Azevedo *et al*. (2007) as constant (where beginning and ending frequency were the same), ascending (rising in frequency), descending (falling in frequency), ascending-descending (first rising in frequency with one inflection point and then falling in frequency), descending-ascending (first falling in frequency with one inflection point and then rising in frequency), and multi-loop (more than two inflection points within a whistle) (Figure 4).

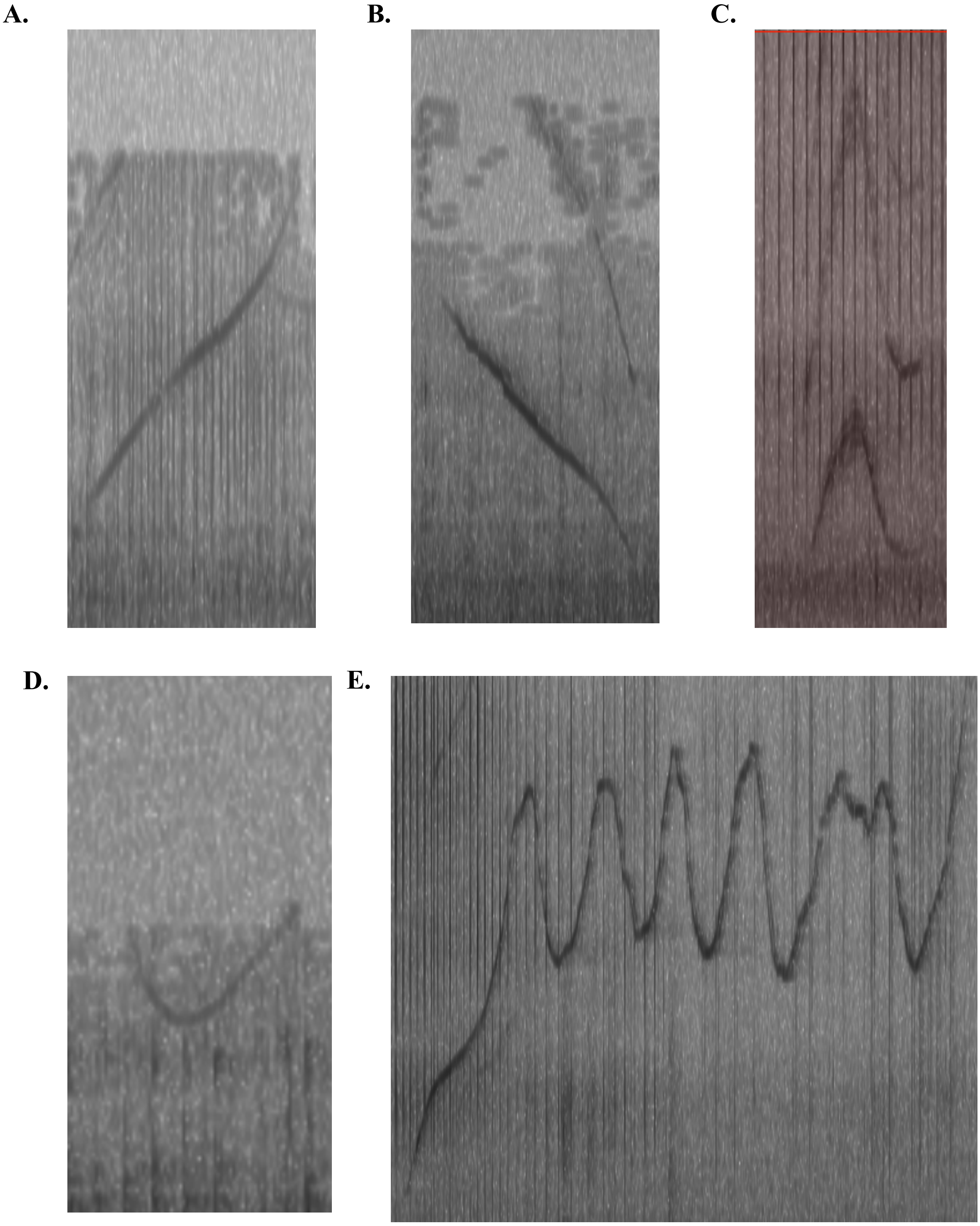


Figure 4. Spectrogram of different whistle contours extracted from Raven Lite 1.0 software and used for analysis. (A.) ascending, (B.) descending, (C.) ascending-descending, (D.) descending-ascending, and (E.) multi-loop

2.3.2 Statistical Analysis

Statistical analyses were carried out using PRIMER v.6 and IBM SPSS version 22 software. Due to a varying number of whistles collected per encounter, only encounters containing five or more whistles were used for analysis. From these encounters five whistles were selected at random for each encounter using a random number generator through Microsoft Excel.

2.3.2.1 Variation between groups

Different analyses using PRIMER v.6 were undertaken to assess if there were any similarities between whistle characteristics collected during each encounter. Data were first transformed using square-root transformation in order to normalize the data. A Bray-Curtis resemblance matrix was then used to help determine the differences between the whistles collected at each encounter. ANOISM (analysis of similarities) and MDS (multidimensional scaling) plots were used to determine if there were any similarities or differences between encounters. A SIMPER test was then run to assess where the dissimilarities were occurring and what frequency parameters were contributing the most to the average dissimilarities. Whistle parameters were then tested for homogeneity using Levene's test with a significance value of $p < 0.05$. Parameters that passed the Levene's test were then run through a one-way ANOVA (Analysis of Variance) test to determine significance. Frequency parameters that did not pass the Levene's test were put through non-parametric testing via a Kruskal-Wallis test.

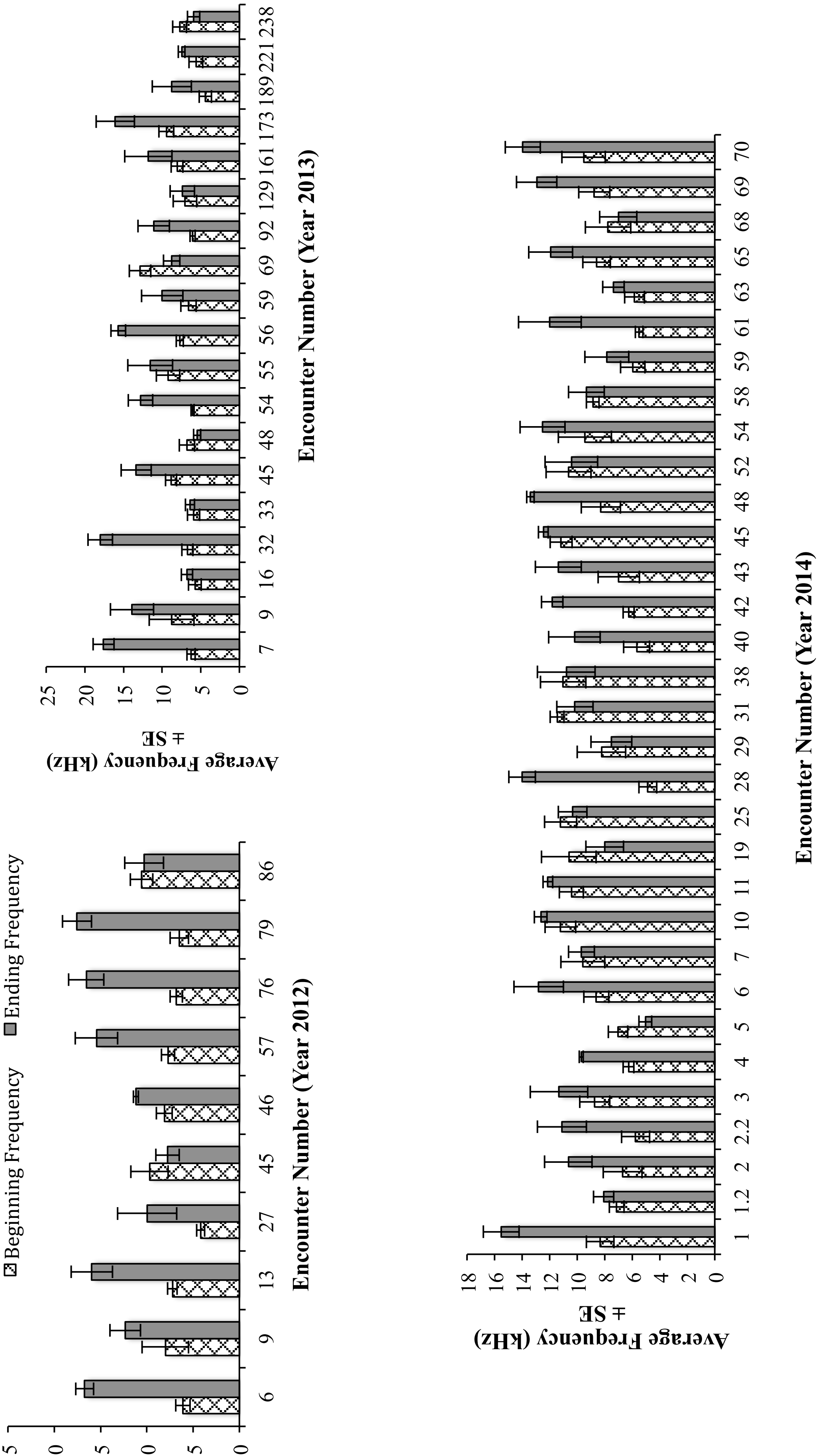
2.3.2.2 Variation between different environmental and biological factors

Group size was separated into five groups: 1-3 individuals, 4-6 individuals, 7-9 individuals, and ≥10 individuals. Depth and seabed substrate were separated into three different categories: 0.1-10.0 m, 10.1-20.0 m, 20.1-50.0 m, infralittoral fine sand/muddy sand, infralittoral rock, and infralittoral mixed sediments, respectively. Types of dolphin behaviours were separated into travel, feeding, and socializing. The presence of calves within a group was categorised by groups (3+ individuals) with calves present, groups (3+ individuals) without calves present, lone individual, single mother and calf pairs, and pairs of dolphins without a calf. In order to determine which environmental variables were contributing to the changing whistle parameters, chi-squared tests were first run between the different environmental and biological factors being tested. Due to a small sample size within each of the categorisations, the *p* value obtained from Fisher's exact test was used to determine if factors were significantly independent from one another. Fisher's exact test has been used in other studies on whistles and pulsed calls of narwhals (*Mondon monoceros*) in Koluktoo Bay, Canada and on signature whistles of different species of bottlenose dolphins in Western Australia (Marcoux *et al*., 2012; Mann & Sargeant, 2003; respectively). Factors found to be independent were then run through a Levene's test for homogeneity followed by a one-way ANOVA or a non-parametric Kruskal-Wallis test depending on whether or not they passed the Levene's test. ANOVA was used to determine if there were significant differences between whistle parameters such as beginning frequency, end frequency, minimum frequency, maximum frequency, and duration when compared with different environmental or biological factors such as group size, depth, seabed substrate, behaviour, and presence of calves. Environmental and biological factors found to be dependent on one another were not statistically tested due to the fact that they could be masking the effect that another factor might be having on the different frequency parameters of each whistle. When two or more factors were found to be dependent on one another, only one factor was selected for statistical analysis in order to establish whether these specific factors are affecting the frequency parameters.

3. Results

A total of 110 encounters were recorded for the three-year period from 2012-2014, with 29 encounters in 2012, 33 encounters in 2013, and 48 encounters in 2014. The number of whistles recorded for each encounter varied from none to 387 whistles. Of the 110 encounters, 61 had five or more recorded whistles and were used for analysis (Appendix A & B). From these encounters, 2,357 whistles were recorded with an average number of whistles per encounter being 38.6. The total recording time was 1,367 minutes with an average of 0.58 whistles produced per minute. The average whistle characteristics and standard errors for the 61 encounters were as follows: beginning frequency 7.89 ± 0.18 kHz, ending frequency 11.25 ± 0.26 kHz, minimum frequency 6.45 ± 0.10 kHz, maximum frequency 13.25 ± 0.21 kHz, duration 0.67 ± 0.02 sec, and number of inflection points 2.01 ± 0.09. These specific frequency parameters seem to vary not only between encounters, but also between years (Figure 5, A-D). For the majority of whistles recorded, the average ending frequency was higher than the average beginning frequency (69%), mainly producing whistles with an ascending contour type (35%). Whistles with a contour type of descending-ascending were the second most recorded, contributing 22% of the total data set, followed by multi-loop 19%, ascending-descending 18%, descending 6%, and constant 0.3% (Figure 6). These contour types were significantly different between encounters (Kruskal-Wallis; df = 60, $X^2 = 85.62$, $p = 0.017$). When comparing whistles that were collected in the Pen Llyn a'r Sarnau SAC to whistles collected within the Cardigan Bay SAC, frequency parameters did not vary significantly (Figure 7). Whistles with an ascending contour type were also found to dominate within both SAC's (Figure 7).

A.


Beginning Frequency
Ending Frequency
Average Frequency (kHz) ±SE
25
20
15
10
5
0
6
9
13
27
45
46
57
76
79
86
Encounter Number (Year 2012)
Average Frequency (kHz) ± SE
7
9
16
32
33
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48
54
55
56
59
69
92
129
161
173
189
221
238
Encounter Number (Year 2013)
Average Frequency (kHz) ± SE
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14
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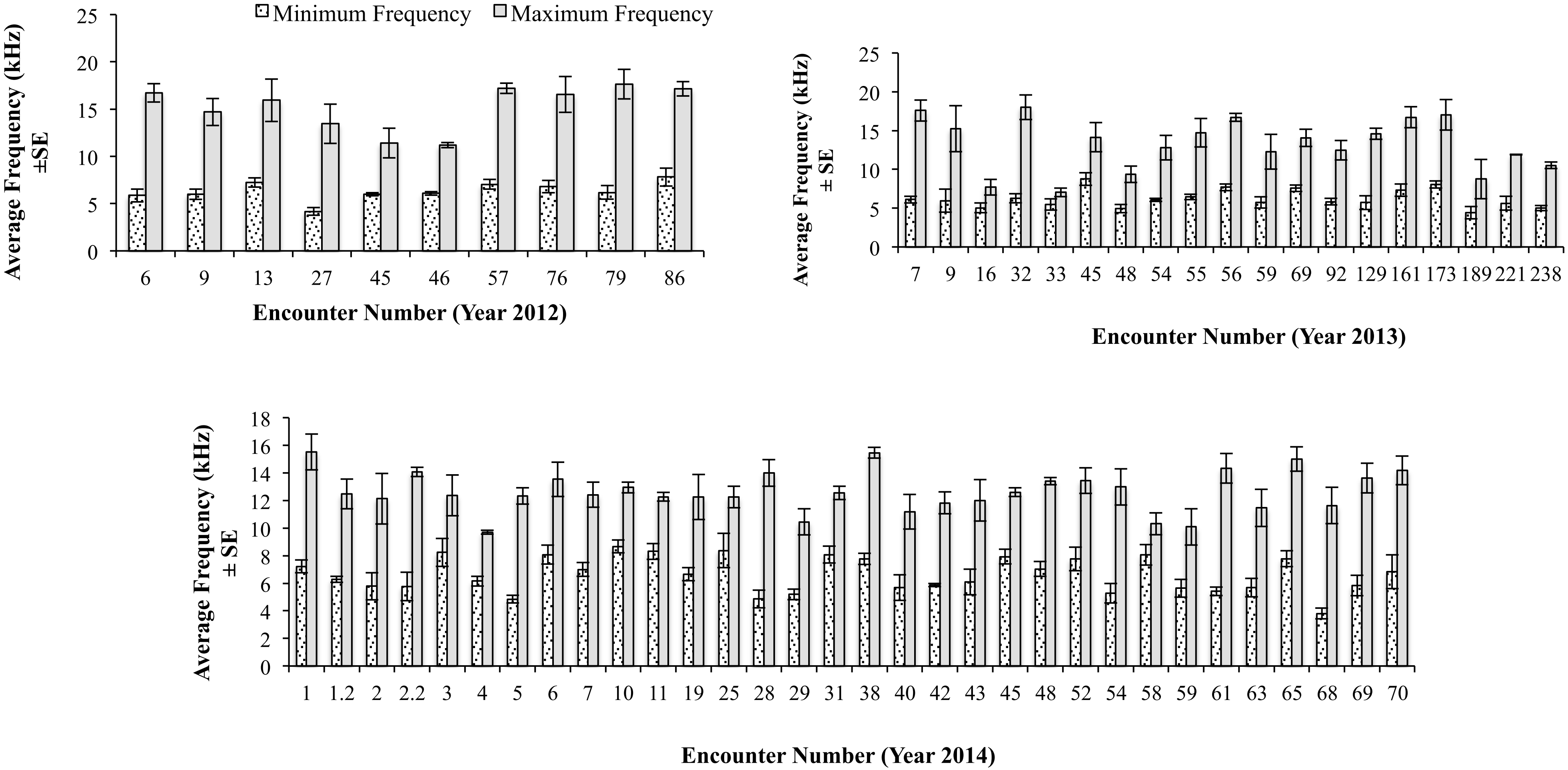
Encounter Number (Year 2014)

B.


Minimum Frequency
Maximum Frequency
Average Frequency (kHz) ±SE
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Encounter Number (Year 2012)
Average Frequency (kHz) ± SE
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Encounter Number (Year 2013)
Average Frequency (kHz) ± SE
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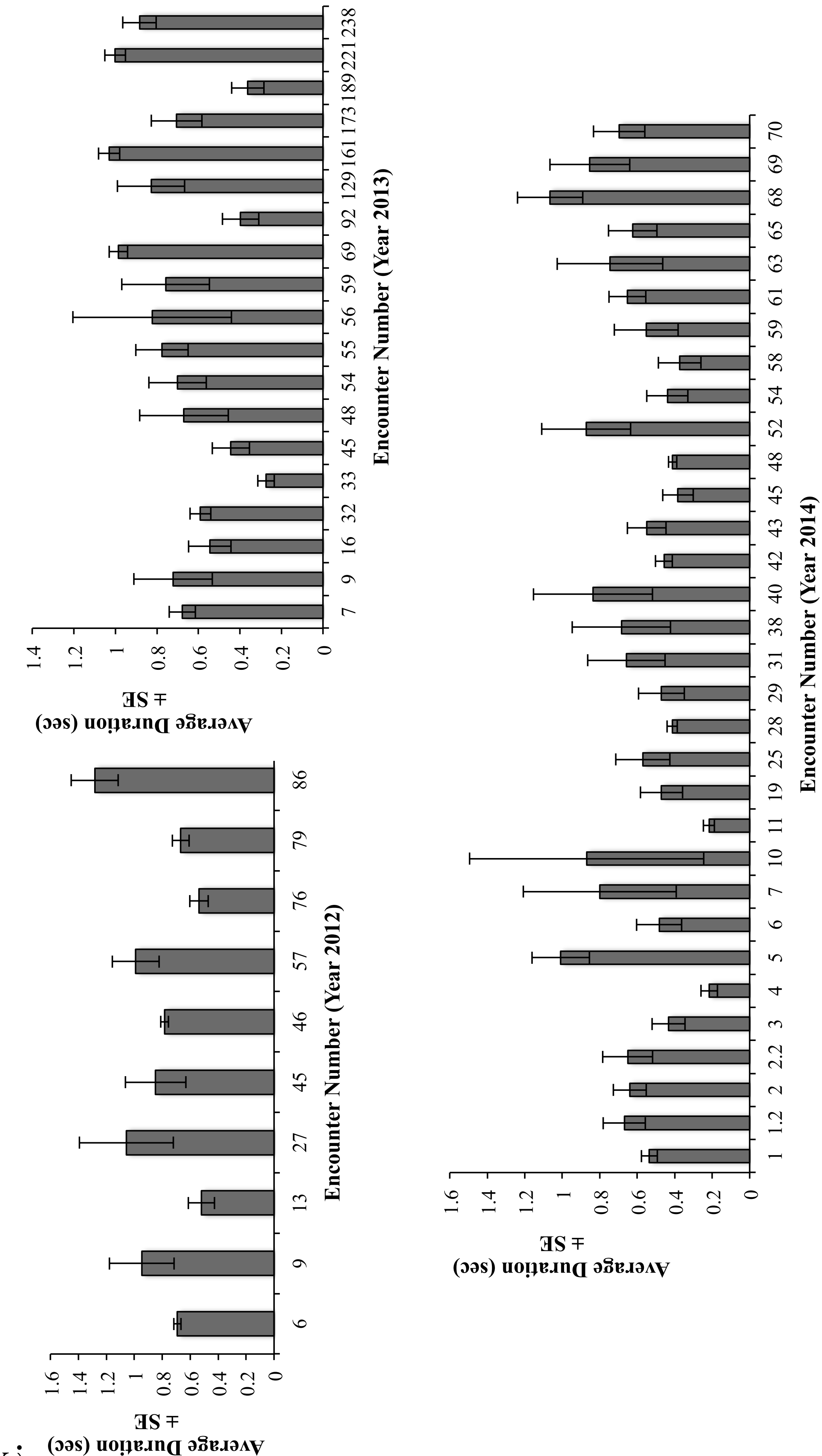
C.
Average Duration (sec) ± SE
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Encounter Number (Year 2012)
Average Duration (sec) ± SE
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Encounter Number (Year 2013)
Average Duration (sec) ± SE
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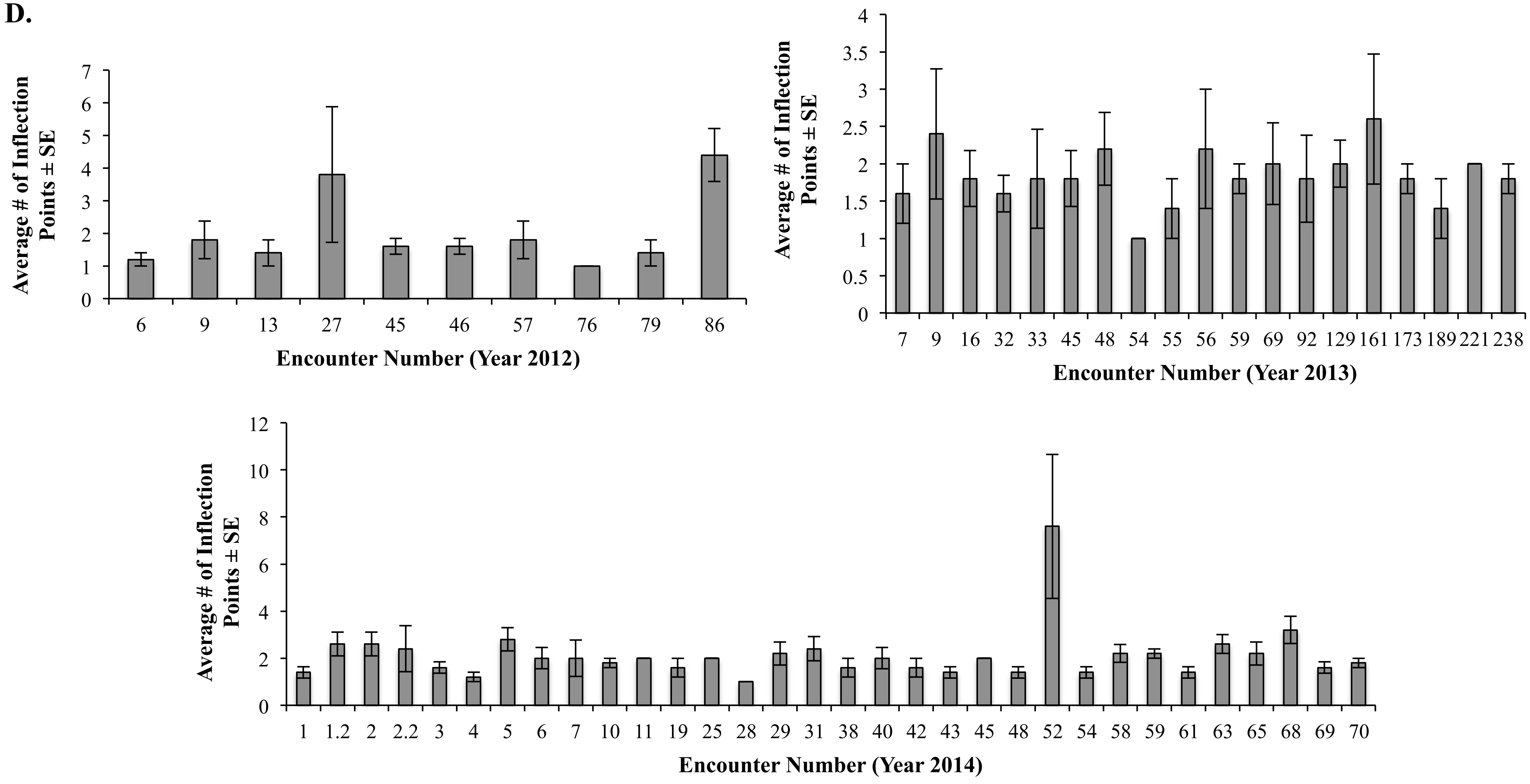


Figure 5. Average beginning and ending frequency (A), average minimum and maximum frequency (B), average duration (C), and average # of inflection points (D) with standard errors for each encounter between 2012 – 2014

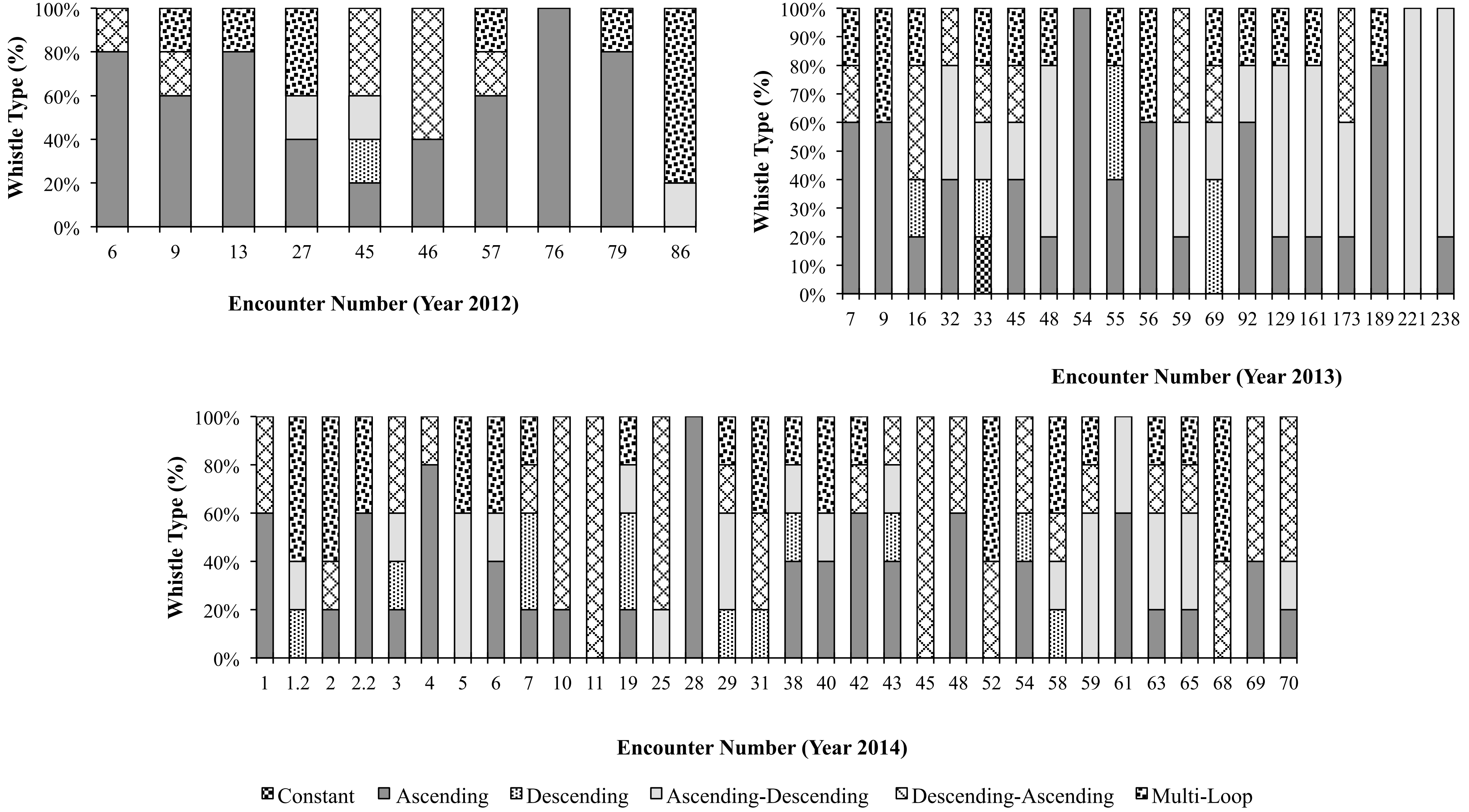


Figure 6. Percentage of different whistle contours; constant, ascending, descending, ascending-descending, descending-ascending, and multi-loop occurring during each encounter from 2012 – 2014

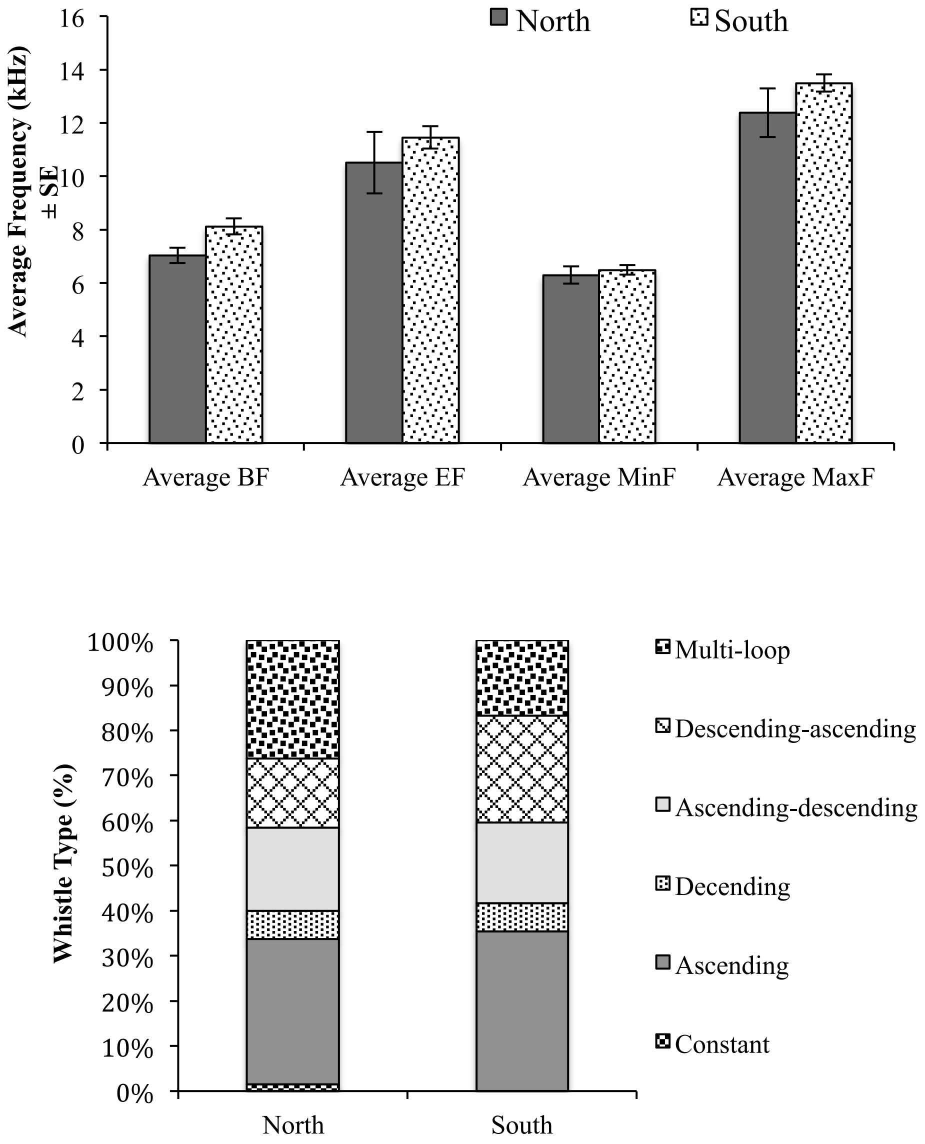


Figure 7. Average frequency parameters with standard errors (BF = beginning frequency, EF = ending frequency, MinF = minimum Frequency, & MaxF = maximum frequency) and contour types of whistles collected from Pen Llyn a'r Sarnau (North) and Cardigan Bay (South) SACs

3.1 Whistle variation between groups

Multivariate analysis showed that similarities were present between the whistle characteristics for each group (ANOSIM; $R^2 = 0.268$, $p = 0.001$). These similarities are supported by the MDS plot in Figure 8, where there is no specified grouping observed between encounters.

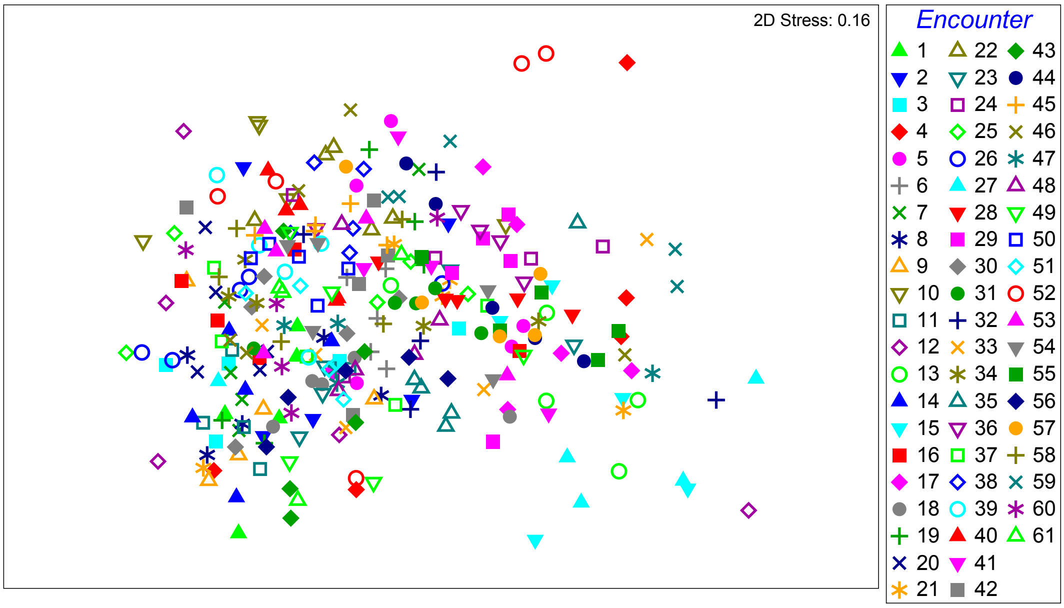


Figure 8. MDS plot of individual whistles collected from 2012-2014 based on whistle characteristics from each encounter. Each marker represents a specific encounter/group

Non-parametric testing revealed that each whistle parameter was significantly different between groups (Table 1). SIMPER analysis also revealed that maximum frequency and beginning frequency contributed the most to the average dissimilarity between groups (25% and 21%, respectively), while minimum frequency contributed the least (13%).

Table 1. Results from non-parametric testing of each whistle characteristic between encounters.

Kruskal-Wallis	*df*	*Chi-Squared*	*p*
Beginning Frequency	60	131.168	<0.001
Ending Frequency	60	148.437	<0.001
Minimum Frequency	60	139.165	<0.001
Maximum Frequency	60	146.263	<0.001
Duration	60	121.106	<0.001
Number of Inflection Points	60	89.073	0.009

3.2 Whistle variation due to varying environmental and biological factors

Throughout the three-year period, dolphin groups were observed in varying habitats. However, the majority of encounters were from near New Quay headland with a shallow depth range (10-20 m) and a seabed consisting of infralittoral fine sand/muddy sand and infralittoral mixed sediments (Figure 9 & 10, respectively). Many different social structures such as group size, behaviour, and presence of calves were also recorded. The majority of groups recorded comprised 4-6 individuals usually with calves present, and were either traveling or feeding. Chi-squared tests showed that group size and the presence of calves were inter-correlated as were also depth, behaviour, and seabed (Table 2). The inter-relationship between group size and presence of mothe-calf pairs is expected due to the categorisation of the mother-calf pairs. When looking at the relationship between depth and seabed, shallower depths of 0.1-10.0 m had a rocky substrate while deeper areas (10.1-50.0 m) had substrates of infralittoral fine sand/muddy sand and infralittoral mixed sediments. It was also observed that at shallower depths (0.1-20.0 m), the main behaviour was feeding while at deeper depths (20.1-50.0 m) traveling and socialising were observed more often. When observing seabed and behaviour, traveling occurred the most at substrates of fine sand/muddy sand and mixed sediments whereas feeding was observed mainly in rocky substrates.

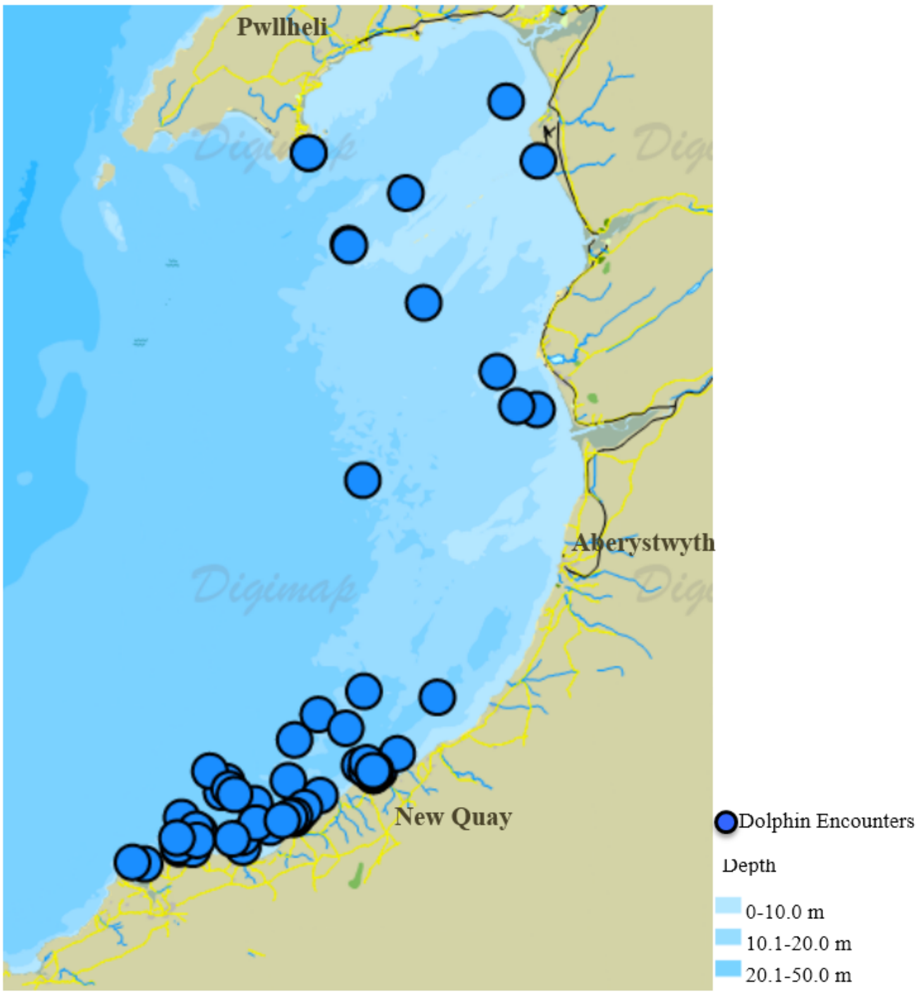


Figure 9. A map of the different depths within Cardigan Bay including the 61 dolphin encounters from 2012-2014 (Marine Digimaps)

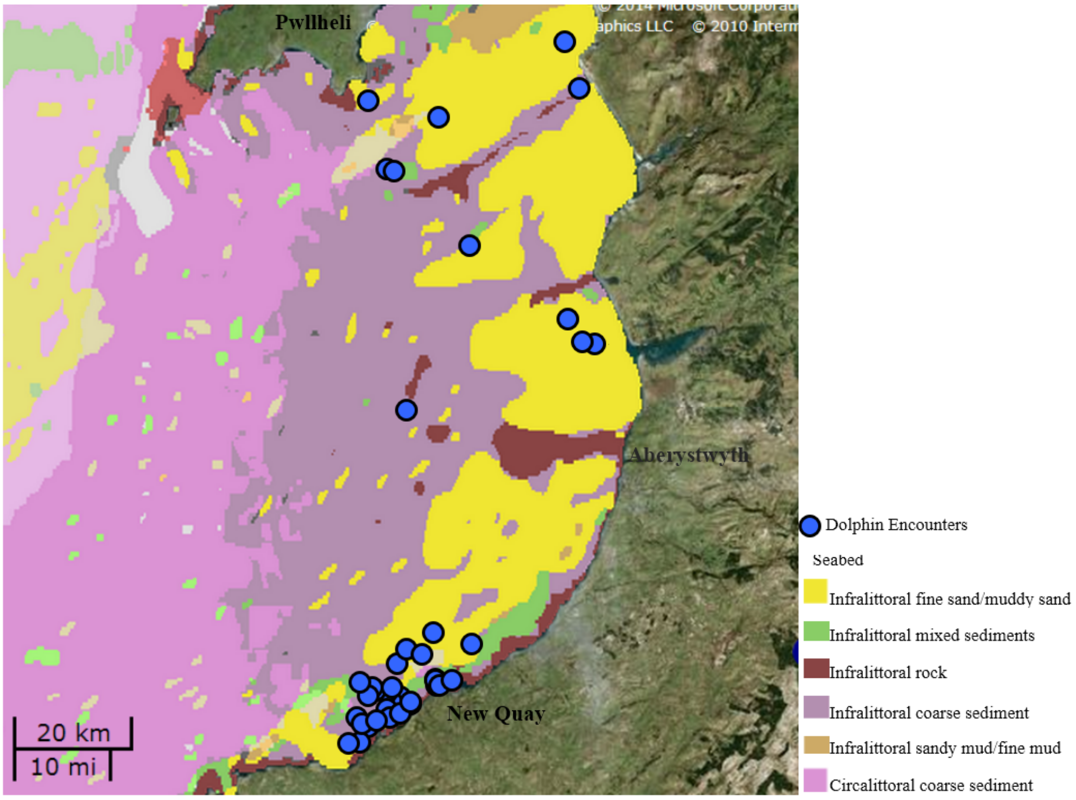


Figure 10. Habitat map of the different seabed substrates present in Cardigan Bay including the 61 dolphin encounters from 2012-2014 (JNCC Joint Nature Conservation Committee)

Table 2. Chi-squared results looking at dependence of different social factors

	Fisher's Exact Value	*p*
Group Size vs. Depth	4.15	0.68
Group Size vs. Seabed	3.797	0.735
Group Size vs. Behaviour	6.728	0.334
Group Size vs. Mother/Calf Pairs	26.628	<0.001
Depth vs. Seabed	15.93	0.002
Depth vs. Behaviour	22.676	<0.001
Depth vs. Mother/Calf Pairs	7.69	0.376
Seabed vs. Behaviour	9.634	0.041
Seabed vs. Mother/Calf Pairs	6.424	0.607
Behaviour vs. Mother/Calf Pairs	6.541	0.58

3.2.1 Group Size

The average minimum frequency between differing group sizes was significantly higher in groups comprising 1-3 individuals compared to groups of 4-6 individuals (Post-hoc LSD test; $p = 0.02$, Figure 11). Groups comprising 7-9 individuals also produced whistles with a longer average duration than groups of 1-3 individuals (Post-hoc LSD test; $p = 0.015$, Figure 11). The average number of inflection points stayed constant between the different group sizes, at between 1.8 and 2.3 (Figure 11). Ascending whistle types were observed the most in all four group categories being recorded over 30% of the time (Figure 12). However, ascending contour type was not significantly different from other contour types in relation to group size (ANOVA; $F_{3,301} = 0.198$, $p = 0.898$).

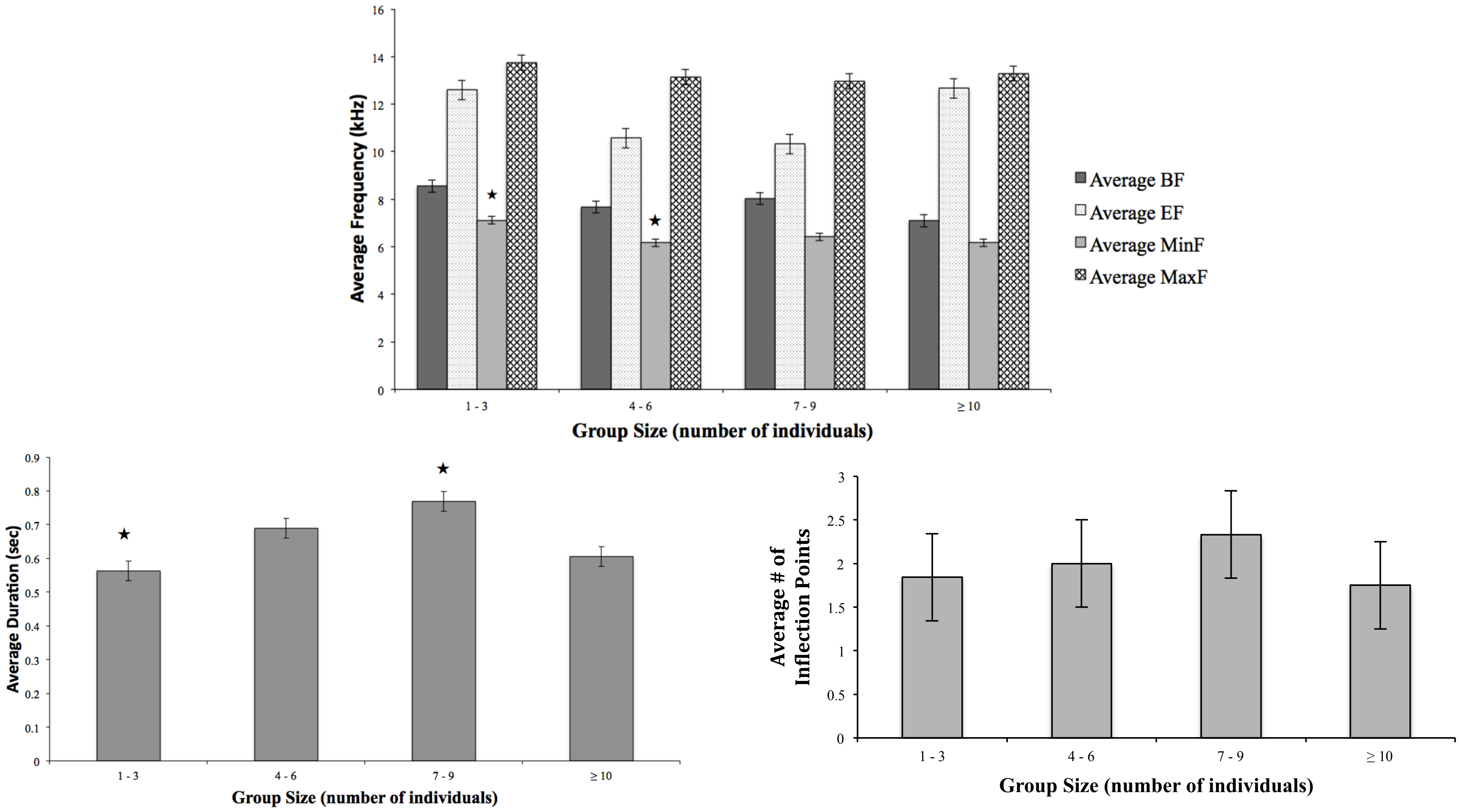


Figure 11. Average frequency parameters ±standard error (BF = beginning frequency, EF = ending frequency, MinF = minimum Frequency, & MaxF = maximum frequency), duration, and number of inflection points between differing group sizes

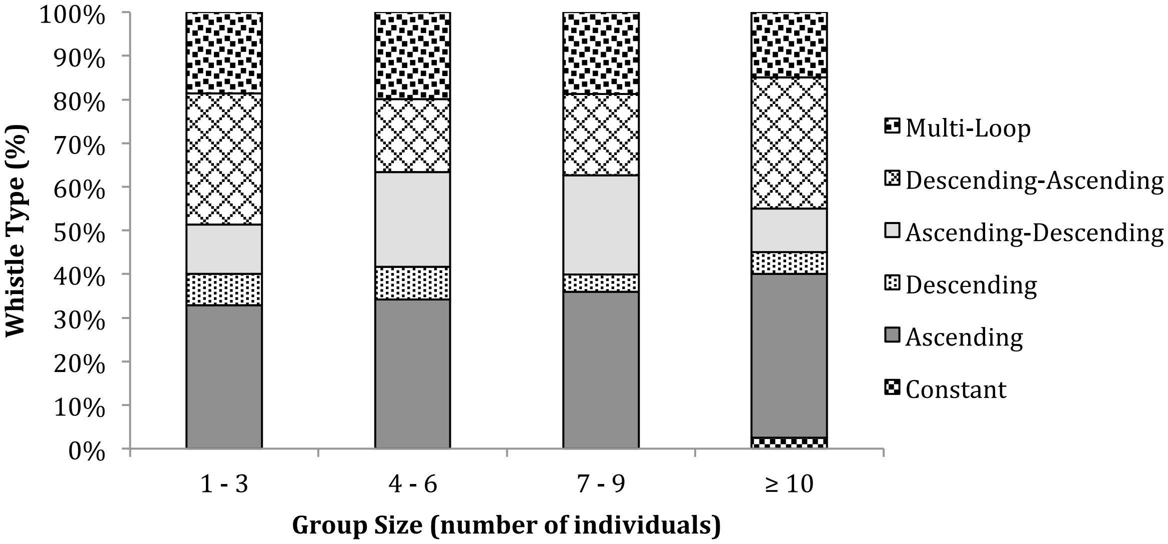


Figure 12. Percentage of different whistle types between differing group sizes

3.2.2 Depth

The average beginning frequency was significantly lower at depth ranges from 0.1-10.0 m than at 20.1-50.0 m and from 10.1-20.0 m compared to 20.1-50.0 m (Post-hoc LSD test; 0.1-10.0 m to 20.1-50.0 m, p = 0.017, 10.1-20.0 m to 20.1-50.0 m, p = 0.011). The average minimum frequency recorded for each whistle was also observed to be lower at shallower depth ranges (10.1-20.0 m) compared to deeper areas (20.1-50.0 m) (Post-hoc LSD test; p = 0.035). Average duration stayed constant between shallow and deeper depths, while a higher average number of inflection points were observed at depths 20.1-50.0 m (Figure 13). Whistles recorded at shallower depths ranging from 0.1 – 20.0 m mostly consisted of ascending whistle types. However, at deeper depths ranging from 20.1 – 50.0 m, more whistles had a descending-ascending contour type (Figure 14). Post-hoc testing revealed that at depths from 10.1-20.0 m to 20.1-50.0 m, there was a significant difference between the contour types recorded (p = 0.030).

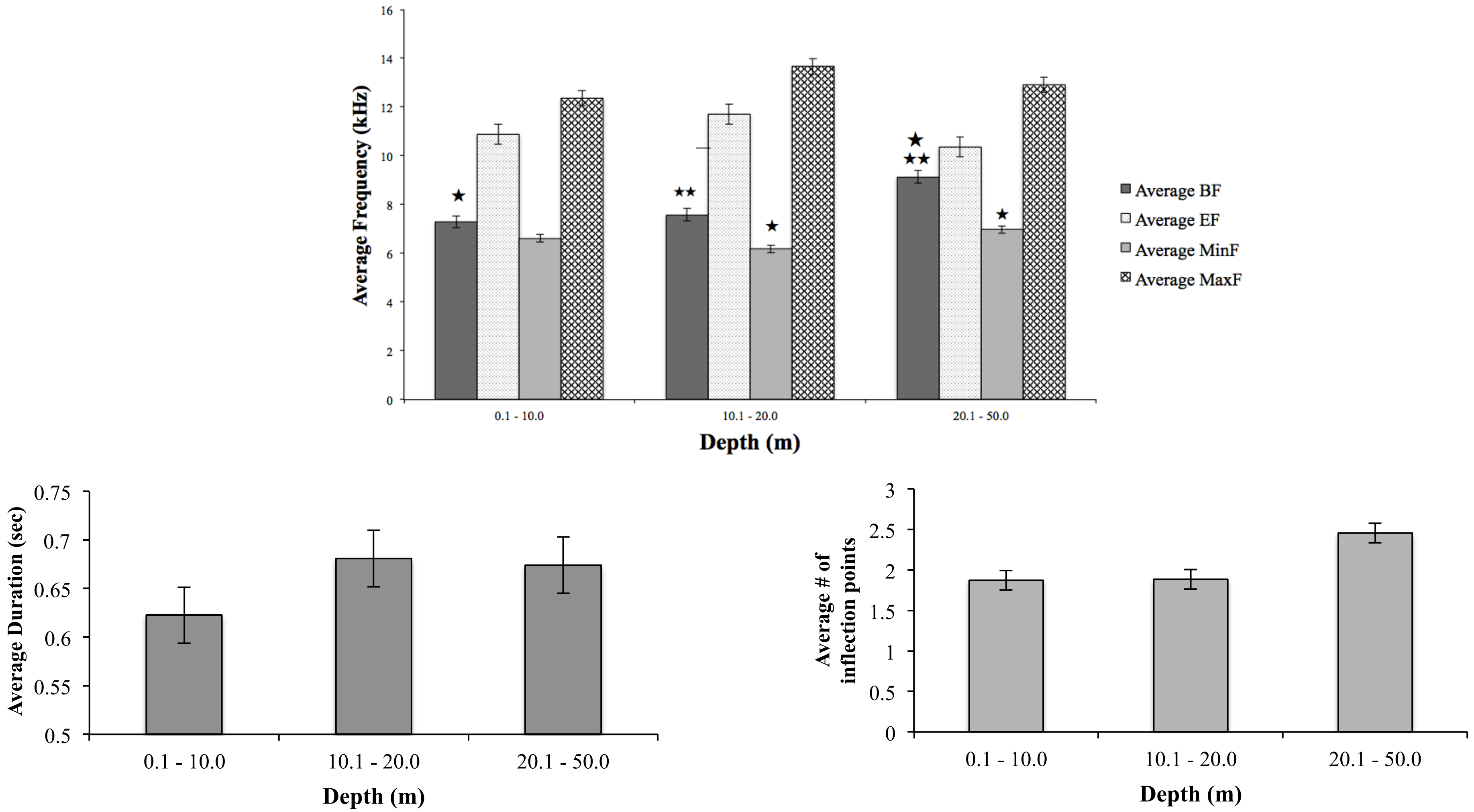


Figure 13. Average frequency parameters ±standard error (BF = beginning frequency, EF = ending frequency, MinF = minimum Frequency, & MaxF = maximum frequency) duration, and number of inflection points at different depth ranges

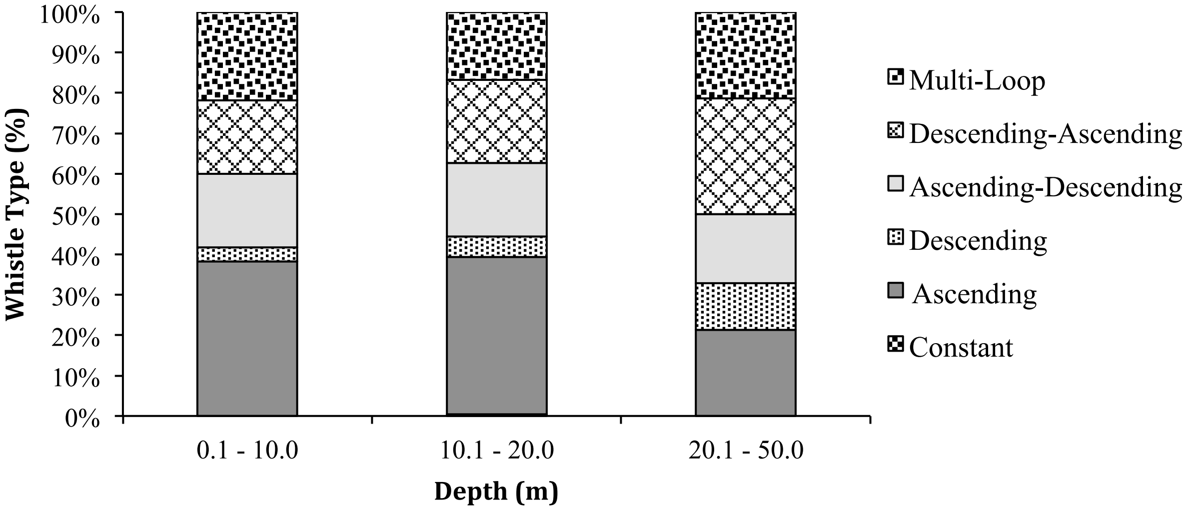


Figure 14. Percentage of different whistle types between different depth ranges

3.2.3 Behaviour

Throughout the three-year survey period, traveling, feeding, and socialising were the main behaviours observed during an encounter, whereas resting and aerial behaviours were uncommon. Whistle characteristics stayed constant between times when dolphins were either traveling, feeding, or socialising, with the average beginning frequency being higher when dolphins were observed to be traveling (Figure 15). The average duration of whistles did increase from animals that were traveling compared to ones that were feeding and socialising while the average number of inflection points decreased between those behaviours (Figure 16). Whistles collected mainly had an ascending contour between the different behaviours (Figure 17).

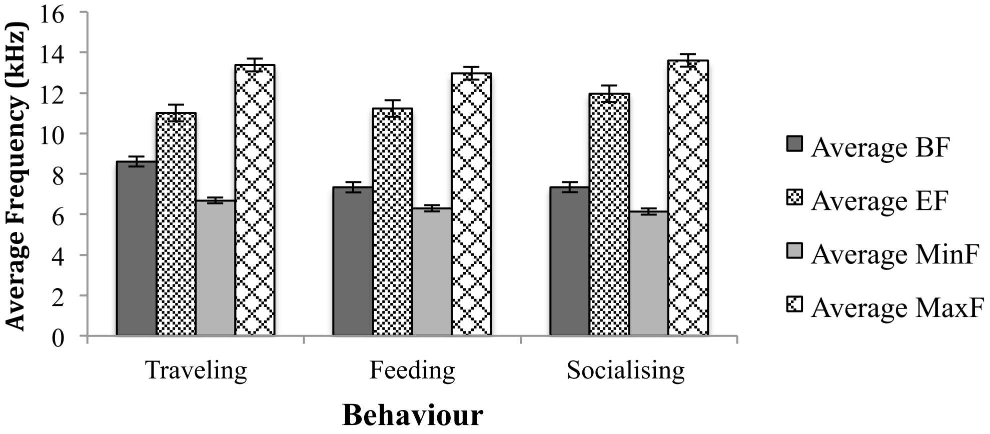


Figure 15. The average frequency parameters ±standard error (BF = beginning frequency, EF = ending frequency, MinF = minimum Frequency, & MaxF = maximum frequency) between different dolphin behaviours

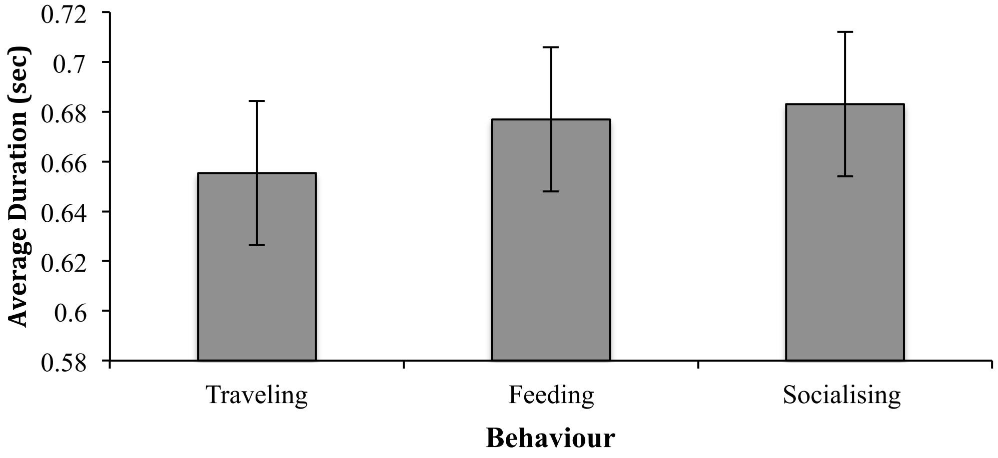


Figure 16. The average duration and number of inflection points ±standard error between different dolphin behaviours

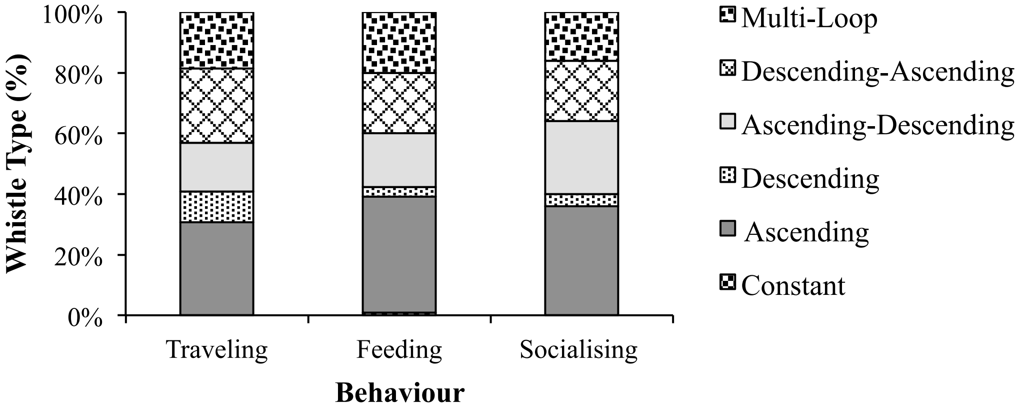


Figure 17. Percentage of different contour types occurring during different dolphin behaviours

3.2.4 Seabed

There are three main types of seabed substrate found within Cardigan Bay: infralittoral fine sand/muddy sand, infralittoral rock, and infralittoral mixed sediments. The average beginning frequency and minimum frequency of the whistles collected remained relatively constant between the three substrates, while the average maximum frequency increased slightly when the seabed was made up of infralittoral rock and infralittoral mixed sediments (Figure 18). Both the average duration and number of inflection points of each whistle also increased when seabed comprised infralittoral mixed sediments (Figure 19). As seen with other environmental factors, the main contour type observed for each whistle was ascending. However, whistles collected over an infralittoral rock seabed had the highest percentage of whistles with an ascending contour type while whistles collected over an infralittoral mixed sediment seabed had almost the same percentage of ascending and descending-ascending contour types (Figure 20).

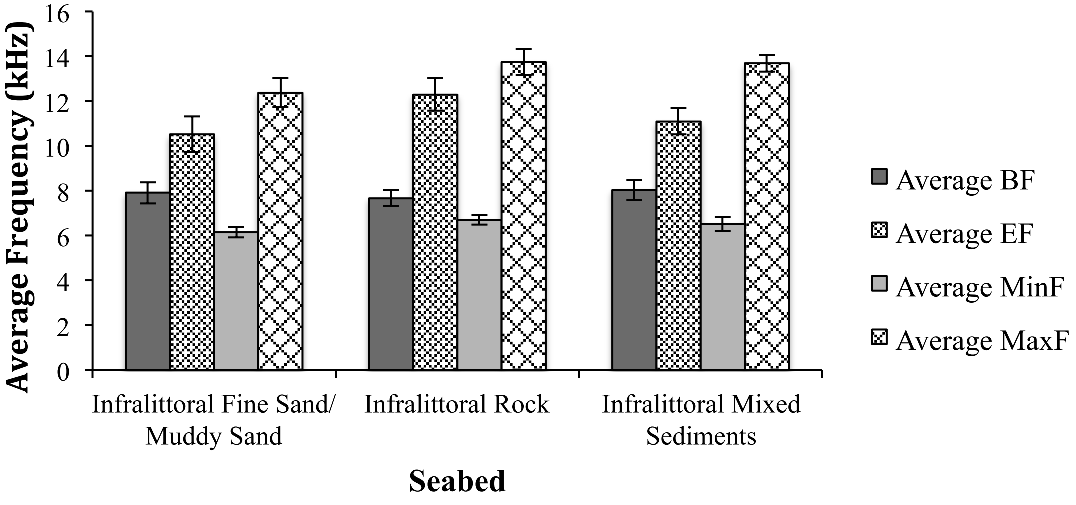
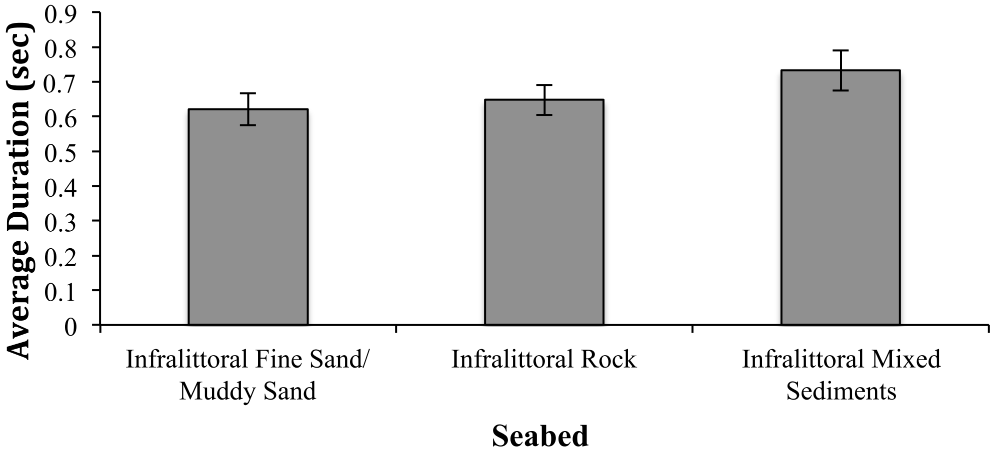


Figure 18. The average frequency parameters ±standard error (BF = beginning frequency, EF = ending frequency, MinF = minimum Frequency, & MaxF = maximum frequency) between different seabed substrates



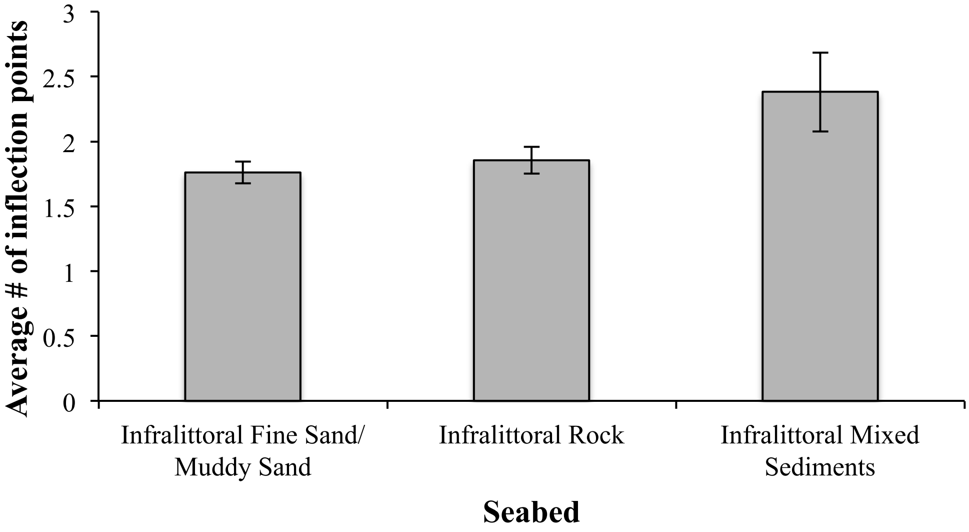


Figure 19. The average duration and number of inflection points ±standard error between different seabed substrates

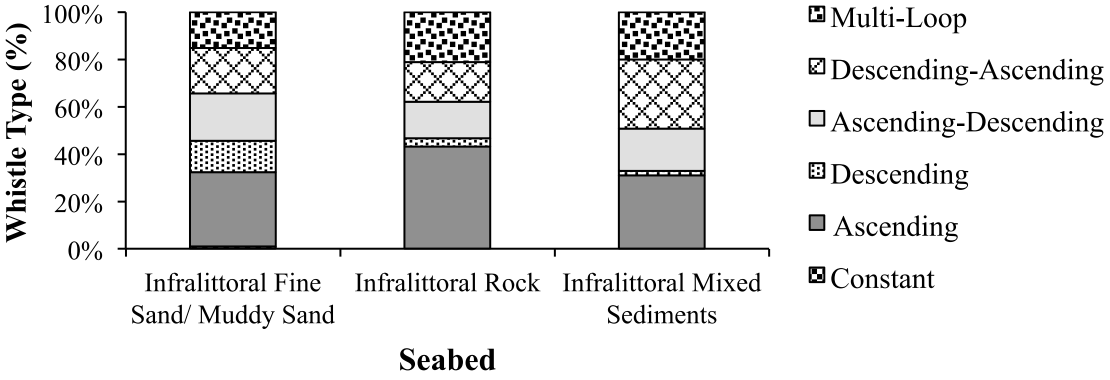


Figure 20. Percentage of different contour types occurring between different seabed substrate

3.2.5 Mother-Calf Pairs

From the whistles collected between 2012 and 2014, the presence of calves seemed to affect the characteristics of the whistles produced between dolphins. Groups were split up into five different categories: groups of three or more individuals where calves were present, groups of three or more individuals where no calves were present, individual dolphins, mother and calf pairs, and pairs of dolphins where no calf was present. Frequency parameters such as average ending frequency and maximum frequency were highest when lone individuals were observed while the average beginning frequency and minimum frequency was the highest when a mother and calf pair were observed on their own (Figure 21). The average duration of whistles and number of inflection points collected stayed relatively constant between groupings with lone individuals producing the longest whistles on average (Figure 22). Comparing groups with and without calves present along with lone individuals, the most common contour type observed was ascending. However, when mother and calf pairs were observed on their own there was a higher percentage of descending-ascending whistle types recorded. When pairs of dolphins were observed without a calf present, more whistles were recorded that took on a multi-loop contour (Figure 23).

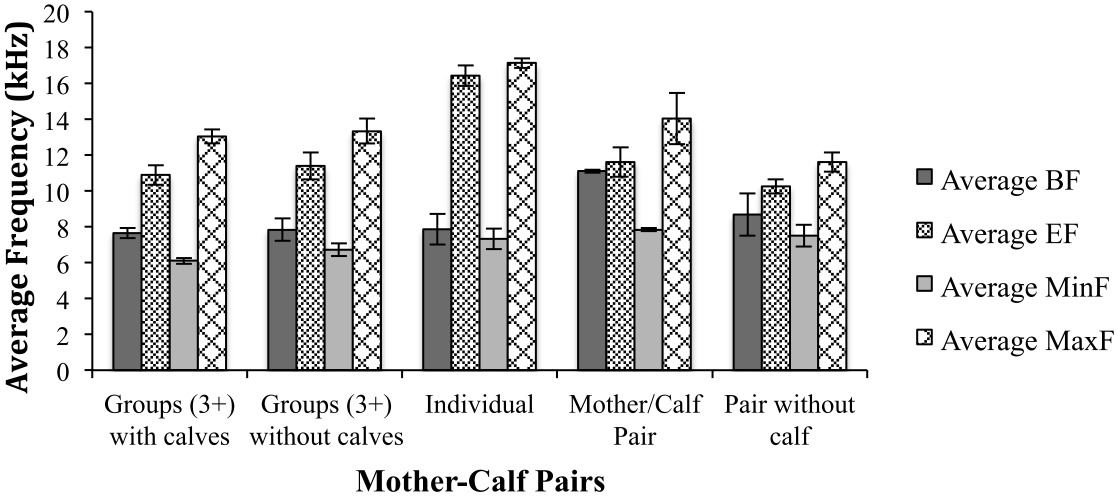
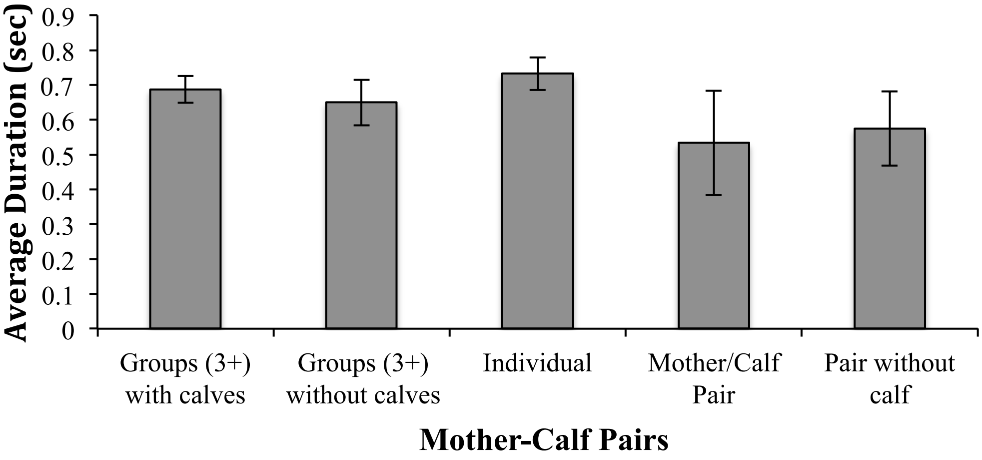


Figure 21. The average frequency parameters ±standard error (BF = beginning frequency, EF = ending frequency, MinF = minimum Frequency, & MaxF = maximum frequency) between groups with and without calves present



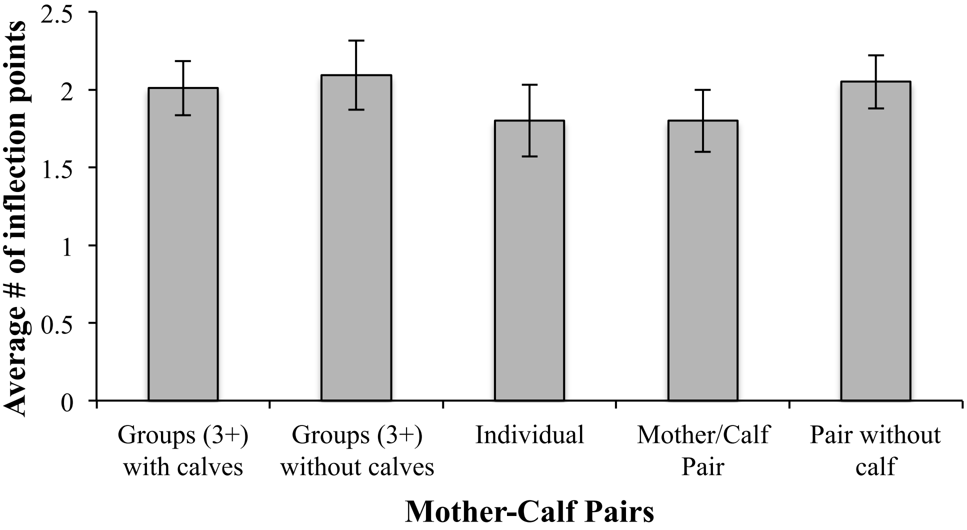


Figure 22. The average duration and number of inflection points ±standard error between groups with and without calves present

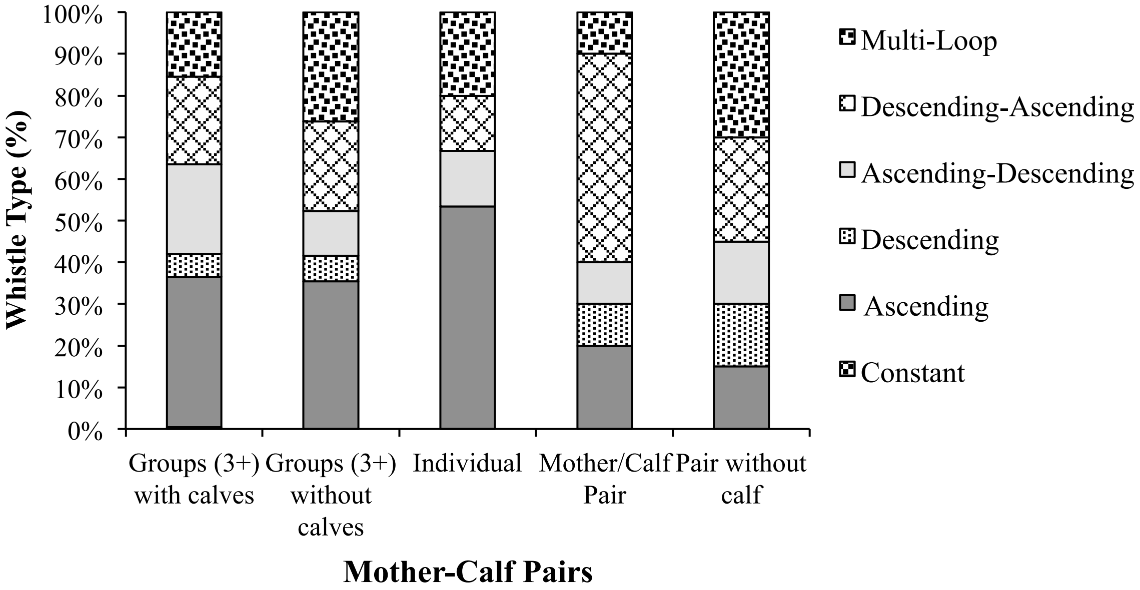


Figure 23. Percentage of different contour types occurring between groups with and without calves present

4. Discussion

From this study it can be seen that whistle characteristics do vary within the Cardigan Bay bottlenose dolphin population. Statistical analyses also revealed that a number of whistle characteristics significantly differ from one group to the next along with changes in certain environmental and biological factors.

4.1 Variations in Whistles Between Groups

Different dolphin groups were recorded every time a new encounter started. This classification was due to the fact that around 60% of the dolphin population in Cardigan Bay have distinct fin markings and therefore it is easy to determine from photo-identification if a group has already been encountered that day. However, when it comes to whistle recordings, it is difficult to know from which individual(s) whistles are coming, and therefore each encounter was treated as a separate group when analysing recordings. Groups have been found to produce similar whistle characteristics and contours over the three years that whistles have been collected. The MDS plot showed no specified grouping between the 61 different encounters that were analysed. Similar results were also found in a study conducted two years earlier within Cardigan Bay, with similarities between the frequency parameters for whistles recorded between each group (Thompson, 2012). The present study found that all seven frequency parameters recorded for each whistle were significantly different from one another when compared between groups. However, the present results differed slightly from what was found in 2012, where beginning frequency and number of inflection points were not found to be significantly different (Thompson, 2012). These differences could be due to there being smaller sample sizes in 2012, which could have been the cause of the differences in whistle parameters reported. Also, the studies conducted on the population in 2012 used Ishmael software rather than Raven Lite 1.0 to extract whistles (Bird, 2012; Thompson, 2012). By using different software to extract whistles, this could have resulted in different whistles from 2012 being used for analysis, and in turn yielding different results observed from the present study. Many studies have found whistles to be used by dolphins for individual recognition, and so it is not surprising that frequency parameters in this study were observed to be significantly different between groups (Herman & Tavolga, 1980; Cook *et al.*, 2004; Harley, 2008; Leatherwood & Reeves, 1990). By changing the frequency parameters of the whistles produced, groups are able to distinguish and recognise one another. However, many of the individuals that reside in Cardigan Bay during the summer months have been observed in the area more than once, some for many years (Feingold & Evans, 2014). The reoccurrence of individuals from one year to the next would suggest that individual recognition is not as vital compared to other dolphin populations that do not interact with each other on a regular basis due to their geographic locations. A study conducted in Australia on three male dolphins found that the more time the individuals spent together, the more difficult it was to fully distinguish between the whistles being produced (Smolker & Pepper, 1999). Smolker & Pepper (1999) suggested that the similarities in whistle parameters were due to an alliance being formed between the three males. However, in the present study, sex was difficult to determine without animals either leaving the water or turning on their side, making it unclear if male-male alliances were the result of the similarities in whistle characteristics observed. The differences in whistle characteristics could also be due to the fact that a higher number of calves are present within Cardigan Bay during the summer months (Feingold & Evans, 2014).

As stated before, signature whistles are whistles with unique frequency parameters that individuals use for group cohesion and individual recognition (Janik *et al.*, 1994; Janik & Slater, 1998). Many studies have found that calves will start developing signature whistles in their first four months, with the signature whistle being completely developed by year one (Sayigh *et al.*, 1990; Sayigh, 1992; Smolker & Pepper, 1999; Fripp *et al.*, 2005). The higher number of calves present in Cardigan Bay during the summer months could be the reason why differences in frequency parameters were observed. However, recordings of whistles from identified individuals could not be collected, meaning that a solid conclusion cannot be made on whether or not the development of signature whistles in calves were causing these differences in frequency characteristics.

Although the duration of whistles collected throughout the study were found to be similar to what was observed in 2012, these were of longer duration when compared to other bottlenose dolphin populations (Ding *et al.*, 1995; Baron *et al.*, 2008; Bird, 2012). One reason for this could be because Cardigan Bay has a high amount of boat activity during the summer months resulting in dolphins increasing the average duration of whistles in order to avoid masking (Morisaka *et al.*, 2005). An increase in the number of inflection points was also found throughout this study compared to the study conducted two years earlier (Bird, 2012). This might be expected due to an increase in boat activity from 2012 to 2014 resulting in a greater chance of whistles being masked by high ambient noise levels (Feingold & Evans, 2014; Sea Watch Foundation, unpublished data).

It is difficult to say what might be causing the changes in frequency parameters between the whistles collected from different dolphin groups in Cardigan Bay. However, certain environmental and biological factors could be causing groups to produce whistles at different frequencies.

4.2 Whistle Variation due to Environmental and Biological Factors

4.2.1 Group Size & Presence of Calves

Chi-squared tests revealed that group size and presence of calves were inter-correlated. This is to be expected since the presence of calves was categorised between groups of three or more individuals with and without calves, lone individuals, and pairs of dolphins with and without calves. In groups of 4-6 individuals, the average minimum frequency recorded was significantly lower than in groups of 1-3 individuals. This corresponds with the fact that the lowest minimum frequency recorded for mother-calf pairs was found in groups (3+) where calves were present. The decrease in frequency within larger groups could be due to the fact that individuals are more dispersed from one another. It has been found that low frequency whistles travel further than high frequency whistles making it easier for individuals to communicate when in larger groups (Quintana-Rizzo *et al.*, 2006). A lower minimum frequency when calves are present could also be due to mothers keeping in contact with their dependent calf if they were to stray too far from the group.

Whistle duration was also found to be significantly higher in groups comprising 7-9 individuals compared to 1-3 individuals, with duration being highest in lone individuals when comparing groupings of mother-calf pairs. Studies have found that individuals will produce whistles that are longer and at a higher rate during times when they have either been separated from the group or when they have found a food source (Nowacek, 2005). By producing longer whistles, individuals have a better chance of communicating with other groups of individuals who are nearby. The current study also found duration to decrease when calves were present. This may be because it not only provides individuals with a better chance of communicating, but also lowers the chance of being detected by predators (Jones & Sayigh, 2002). However, other studies have reported that once a group reaches a size of 15 individuals, whistle production will stop increasing and start to level out (Jones & Sayigh, 2002; Cook *et al.*, 2004; Quick & Janik, 2008; Lopez & Shirai, 2009). Quick & Janik (2008) believed that the leveling out of whistle production was not only to avoid masking, but might also be the result of different noise conditions due to the fact that noise caused by whistles is still higher in larger groups despite decreased whistle production. This could explain why whistle duration and the number of inflection points were observed to be decreasing with groups comprising 10 or more individuals. On the other hand, the number of samples collected for this specific group category was very small, possibly skewing the results that were recorded.

Whistle types also changed with group size as well as whether or not calves were present in a group. Between the different group sizes, whistles recorded mainly had an ascending contour type which was similar to what was found in 2012 (Bird, 2012; Thompson, 2012). However, when looking at the types of whistles emitted between mother and calf pairs compared to groups (3+) with and without calves and lone individuals, contour type changed from mainly ascending in the groups and individuals to descending-ascending in mother and calf pairs. Mothers and calves could be producing more complex whistle types in order to keep in constant contact with each other causing and producing unique whistle structures in order to recognise one another if they become separated.

Due to a small sample size both in larger groups and between individuals and mother-calf pairs, it is difficult to assess whether group size and presence of calves are affecting the whistles produced. Further analyses should be undertaken with a larger sample size in order to fully understand why these variations are occurring.

4.2.2 Depth, Seabed, and Behaviour

Results from the present study revealed that depth, seabed type, and behaviour were inter-correlated. Cardigan Bay's seabed changes from fine to coarse sediment when depths become greater. Studies have also found that bottlenose dolphins will change their behaviour depending on the type of seabed substrate and whether they are swimming at shallower or deeper depths (Nowacek, 2005; Quintana-Rizzo *et al.*, 2006). In turn, dolphins have changed the structure and rate of whistle production when performing different behaviours (Jones & Sayigh, 2002; Santos *et al.*, 2005; López & Shirai, 2009). Beginning frequency was significantly higher at greater depths compared to more shallow depths. This result was opposite to that which Forrest *et al.* (1993) suggested in that lower frequency sounds do not travel as far in shallow waters and therefore whistles produced in shallow waters would be expected to have a higher frequency. However, one has to keep in mind that increasing temperature and pressure can also have a big effect on the speed that sound travels. Due to the fact that the speed of sound will increase with increasing depths, means that both low and high frequency whistles will not travel as far in shallower waters (Evans & Raga, 2001). The increase in beginning frequency could be due to the fact that at shallower depths the main substrate found was rocky. With a rocky seabed whistles produced have a higher chance of bouncing off the rocks back to the individual who produced the whistle. It could be that when the animals were observed at shallower depths they were close enough to each other that they did not need whistles to travel very far in order to communicate with another individual.

The duration of whistles produced was also shorter when animals were at shallower depths. Similar to beginning frequency, animals could be producing shorter whistles so that there is not a problem of the sound bouncing off the rocky bottom. A study of a resident bottlenose dolphin population in Sarasota, Florida, found that animals would produce whistles at a higher frequency and shorter duration in shallow seagrass areas (Quintana-Rizzo *et al.*, 2005). As with rocky bottom substrates, shallow seagrass areas were thought to cause whistles to bounce off thick vegetation and therefore not travel as far. Duration was also found to increase during times when animals were socialising and feeding compared to when they were traveling. This increase in duration could be a result of animals needing to communicate more during social and feeding activities compared with times when they are traveling. Studies have found similar results where animals will whistle more often during times of excitement as when socialising or times when group cohesion is essential such as feeding (Acevedo-Gutierrez & Stienessen, 2004; Quick & Janik, 2008).

The number of inflection points also increased at greater depths. This corresponds with the main whistle types found at shallower depths having an ascending contour type while whistles produced at greater depths have a descending-ascending contour type. These specific contour types could be due to the fact that at greater depths, animals were found to be socialising and had to stay in constant contact with each other by emitting more complex whistle types in order to recognise one another (Quick & Janik, 2008).

4.3 Limitations

Due to the fact that only encounters with five or more whistles extracted were used for analysis, this significantly reduced the amount of data analysis, which could have had an effect on the results that were produced and therefore may not be representative of the whistle variations recorded within the population. Furthermore, although Raven Lite 1.0 software was used to produce spectrograms of the recordings, whistles were extracted by hand rather than by using the software to extract all the whistles and their parameters. By extracting whistles by hand, this increases the chance of human error and could have had an effect on the results.

Another limitation was the amount of boat surveys that were carried out each week. Due to limited funds and access to boats, surveys were only conducted once a week, with some weeks having no surveys due to poor weather conditions. With the combination of the study only being conducted for two months and the restricted number of surveys carried out per week, this reduced the amount of data that could be collected over the three seasons. Collection of whistles from specific individuals was also very difficult due to the difficulty in pinpointing individual vocalisations. A parabolic reflector consisting of a metal bowl, into which the hydrophone was placed and connected to an adjustable pole, was constructed for the purpose of recording whistles from certain individuals. However, during most encounters the boat had to be in constant movement in order to maintain close contact with the dolphins. This made it difficult to use the parabolic reflector due to the drag it caused when placed in the water, resulting in very little control of the device. By having a smaller boat available that could be stopped when dolphins were present, the parabolic reflector might be able to collect more precise data from specific individuals. This type of data collection will also be beneficial when it comes to analysing signature whistle production within the Cardigan Bay population.

With only one hydrophone available, it was not possible to analysis signature whistles of individual dolphins due to the fact that with only one hydrophone it is not clear which individual is vocalising. Studies have investigated the use of hydrophones arrays to triangulate where the source of the whistle is coming from in order to isolate whistles from certain individuals (Quick *et al.*, 2008; Quick & Janik, 2008; Quick & Janik, 2012; Janik *et al.*, 2013). With more hydrophones available, signature whistles could be extracted from recordings and analysed not only for variations between groups, but also between individuals.

4.4 Future research recommendations

Although much information was obtained from this study, future research is still needed to gain a better understanding of the whistles produced by the bottlenose dolphin population residing in Cardigan Bay. One recommendation is to start conducting acoustic surveys during the winter months as well as during the summer season. By extending acoustic surveys to the winter, a better understanding of the whistles being produced by the population can be observed, along with determining whether temperature changes can affect the whistles produced. A study conducted in North Carolina found that bottlenose dolphins would produce more whistles during the autumn compared to the summer months (Jacobs *et al.*, 1993). Jacobs *et al.* (1993) believed that the increased whistle production during the autumn was due to animals traveling in search for food and feeding during these months compared to summer months where they were mainly seen socialising. It would be beneficial to see if similar results occur within the population residing in Cardigan Bay due to the fact that many of the animals will move up north off the coast of Isle of Anglesey during the winter months to forage for more pelagic prey (Feingold & Evans, 2014). Also, surveying for a longer amount of time each year, would help produce a larger sample size making future studies statistically more robust.

Finally, it would also be valuable to examine the production and characteristics of signature whistles produced since this has yet to be studied in the Cardigan Bay population. By using an array of hydrophones, Quick *et al.* (2008) showed that signature whistles could be recorded and analysed to determine whether these types of whistles vary in their structure from one individual to the next. The collection of such data would also help when comparing whistle rates and structures to other bottlenose dolphin populations so as to assess whether geographic location can have an effect on whistle characteristics.

4.5 Conclusions

This study has shown that similarities do occur between whistles produced by different groups of bottlenose dolphins within Cardigan Bay. These similarities could be due to the fact that many of these individuals return to the bay every summer and are constantly moving in and out of different groups resulting in individuals mimicking one another's whistles (Smolker & Pepper, 1999). On the other hand, variations were present when observing the different frequency parameters that were produced between groups. With a high number of calves present during the summer months, the production of a calf's signature whistle could be causing these variations (Sayigh *et al.*, 1990; Sayigh, 1992). However, certain environmental and biological factors have been known to cause variation in the whistle parameters produced (Cook *et al.*, 2004; Quintana-Rizzo *et al.*, 2006; Akiyama & Ohta, 2007; Baron *et al.*, 2008).

With significant differences being observed between certain whistle characteristics with varying group sizes and depths, it is clear that certain environmental factors do have an effect on the types of whistles produced. By observing that whistle parameters also change depending on seabed type, behaviour, and presence of calves, it is clear that bottlenose dolphins within Cardigan Bay are changing and modifying whistles produced depending on these specific factors. Although further research and more data are needed in this area, it is clear that the whistles in this bottlenose dolphin population are affected by the changing environment it experiences.

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Appendices

Appendix A: Average and standard error for each whistle parameter from each encounter

Date (Encounter) Boat Name	Beginning Freq.	Ending Freq.	Minimum Freq.	Maximum Freq.	Duration	# of Inflection Points
12/05/28 (006) Gallois	6.08 ±0.77	16.72 ±0.97	5.86 ±0.67	16.72 ±0.97	0.69 ±0.03	1.2 ±0.2
12/06/13 (009) Gallois	7.99 ±2.51	12.33 ±1.64	6 ±0.57	14.69 ±1.42	0.95 ±0.23	1.8 ±0.58
12/07/09 (013) Gallois	7.23 ±0.5	15.95 ±2.25	7.23 ±0.5	15.95 ±2.25	0.52 ±0.09	1.4 ±0.4
12/07/26 (027) Gallois	4.18 ±0.42	9.98 ±3.2	4.18 ±0.42	13.46 ±2.09	1.06 ±0.34	3.8 ±2.08
12/06/12 (045) Dunbar	9.71 ±2.01	7.76 ±1.25	5.99 ±0.18	11.42 ±1.57	0.85 ±0.22	1.6 ±0.24
12/06/18 (046) Dunbar	8.1 ±0.85	11.19 ±0.28	6.08 ±0.19	11.19 ±0.28	0.78 ±0.03	1.6 ±0.24
12/06/ 18 (057) Dunbar	7.7 ±0.7	15.43 ±2.28	7.03 ±0.52	17.2 ±0.55	0.99 ±0.17	1.8 ±0.58
12/07/12 (076) Dunbar	6.8 ±0.65	16.54 ±1.89	6.8 ±0.65	16.54 ±1.89	0.54 ±0.07	1 ±0
12/07/12 (079) Dunbar	6.48 ±1	17.54 ±1.56	6.18 ±0.71	17.66 ±1.57	0.67 ±0.06	1.4 ±0.4
12/08/05 (086) Dunbar	10.57 ±1.23	10.28 ±2.09	7.81 ±0.95	17.14 ±0.75	1.28 ±0.17	4.4 ±0.81
13/09/23 (007) Islander	6.24 ±0.52	17.59 ±1.37	6.1 ±0.43	17.59 ±1.37	0.68 ±0.06	1.6 ±0.4
13/09/23 (009) Islander	8.77 ±2.89	13.91 ±2.8	5.97 ±1.49	15.25 ±2.97	0.72 ±0.19	2.4 ±0.87
13/07/05 (016) Machipe	5.76 ±0.82	6.78 ±0.75	5.04 ±0.65	7.71 ±1.01	0.55 ±0.1	1.8 ±0.37
13/07/12 (032) Machipe	6.72 ±0.7	18 ±1.59	6.28 ±0.59	18 ±1.59	0.59 ±0.05	1.6 ±0.24
13/07/12 (033) Machipe	5.95 ±0.8	6.41 ±0.6	5.48 ±0.75	7.04 ±0.55	0.27 ±0.04	1.8 ±0.66
13/05/26 (045) Dunbar	8.86 ±0.72	13.37 ±1.95	8.75 ±0.8	14.15 ±1.87	0.44 ±0.09	1.8 ±0.37
13/09/25 (048) Machipe	6.78 ±1.01	5.47 ±0.46	4.94 ±0.52	9.36 ±1.06	0.67 ±0.21	2.2 ±0.49
13/06/03 (054) Dunbar	6.06 ±0.2	12.82 ±1.59	6.06 ±0.2	12.82 ±1.59	0.7 ±0.14	1 ±0
13/06/03 (055) Dunbar	9.25 ±1.52	11.55 ±2.9	6.44 ±0.34	14.73 ±1.84	0.78 ±0.13	1.4 ±0.4
13/09/26 (056) Pedryn	7.7 ±0.44	15.67 ±0.94	7.7 ±0.44	16.72 ±0.53	0.82 ±0.38	2.2 ±0.8
13/06/10 (059) Dunbar	6.58 ±1.01	9.99 ±2.7	5.73 ±0.74	12.29 ±2.26	0.76 ±0.21	1.8 ±0.2
13/06/18 (069) Dunbar	12.86 ±1.39	8.74 ±1.05	7.58 ±0.43	14.07 ±1.11	0.99 ±0.04	2 ±0.55
13/06/25 (092) Dunbar	6.06 ±0.35	11.1 ±2.04	5.84 ±0.42	12.47 ±1.27	0.4 ±0.09	1.8 ±0.58

Appendix A (cont.)

13/07/06 (129) Dunbar	7.05 ±1.54	7.41 ±1.59	5.72 ±0.89	14.59 ±0.71	0.83 ±0.16	2 ±0.32
13/07/18 (161) Dunbar	8.06 ±0.77	11.8 ±3.07	7.3 ±0.79	16.72 ±1.37	1.03 ±0.05	2.6 ±0.87
13/08/07 (173) Dunbar	9.43 ±0.95	16.07 ±2.5	8.06 ±0.47	17.04 ±1.97	0.7 ±0.12	1.8 ±0.2
13/08/22 (189) Dunbar	4.4 ±0.8	8.74 ±2.53	4.4 ±0.8	8.74 ±2.53	0.36 ±0.08	1.4 ±0.4
13/09/12 (221) Dunbar	5.63 ±0.88	7.47 ±0.44	5.63 ±0.88	11.91 ±0.04	1 ±0.05	2 ±0
13/10/05 (238) Dunbar	7.74 ±0.91	5.91 ±0.8	5 ±0.34	10.52 ±0.41	0.88 ±0.08	1.8 ±0.2
14/07/07 (001) Pedryn	8.32 ±0.99	15.51 ±1.3	7.22 ±0.46	15.51 ±1.3	0.54 ±0.04	1.4 ±0.24
14/07/08 (001) Pedryn	7.13 ±0.53	8.09 ±0.74	6.29 ±0.22	12.47 ±1.09	0.67 ±0.11	2.6 ±0.51
14/07/07 (002) Pedryn	6.7 ±1.42	10.64 ±1.72	5.79 ±0.99	12.13 ±1.84	0.64 ±0.09	2.6 ±0.51
14/07/11 (002) Pedryn	5.76 ±1.03	11.1 ±1.78	5.76 ±1.03	14.07 ±0.34	0.65 ±0.13	2.4 ±0.98
14/07/11 (003) Pedryn	8.72 ±1.09	11.32 ±2.09	8.24 ±1.01	12.38 ±1.48	0.43 ±0.09	1.6 ±0.24
14/07/07 (004) Pedryn	6.26 ±0.39	9.71 ±0.14	6.15 ±0.35	9.71 ±0.14	0.22 ±0.04	1.2 ±0.2
14/07/07 (005) Pedryn	7.02 ±0.7	5.05 ±0.47	4.84 ±0.27	12.33 ±0.59	1.01 ±0.15	2.8 ±0.49
14/07/11 (006) Pedryn	8.61 ±0.9	12.8 ±1.8	8.07 ±0.7	13.54 ±1.26	0.48 ±0.12	2 ±0.45
14/06/12 (007) Dunbar	9.59 ±1.6	9.69 ±0.94	7 ±0.5	12.42 ±0.91	0.8 ±0.41	2 ±0.77
14/06/12 (010) Dunbar	11.22 ±1.11	12.65 ±0.45	8.67 ±0.48	12.95 ±0.4	0.87 ±0.62	1.8 ±0.2
14/06/12 (011) Dunbar	10.42 ±0.87	12.13 ±0.35	8.31 ±0.57	12.26 ±0.31	0.22 ±0.03	2 ±0
14/06/13 (019) Dunbar	10.61 ±1.99	8 ±1.37	6.66 ±0.47	12.25 ±1.64	0.47 ±0.11	1.6 ±0.4
14/06/18 (025) Dunbar	11.21 ±1.17	10.32 ±1.04	8.37 ±1.25	12.25 ±0.79	0.57 ±0.14	2 ±0
14/06/18 (028) Dunbar	4.86 ±0.64	13.99 ±0.96	4.86 ±0.64	13.99 ±0.96	0.41 ±0.03	1 ±0
14/06/18 (029) Dunbar	8.23 ±1.75	7.52 ±1.49	5.19 ±0.38	10.45 ±0.95	0.47 ±0.12	2.2 ±0.49
14/06/25 (031) Dunbar	11.46 ±0.51	10.17 ±1.33	8.08 ±0.61	12.55 ±0.48	0.66 ±0.21	2.4 ±0.51
14/06/25 (038) Dunbar	11.02 ±1.65	10.79 ±2.1	7.76 ±0.4	15.46 ±0.39	0.68 ±0.26	1.6 ±0.4
14/07/01 (040) Dunbar	5.67 ±0.93	10.2 ±1.87	5.67 ±0.93	11.19 ±1.26	0.84 ±0.32	2 ±0.45

Appendix A (cont.)

14/07/01 (042) Dunbar	6.26 ±0.4	11.82 ±0.78	5.88 ±0.12	11.82 ±0.78	0.46 ±0.04	1.6 ±0.4
14/07/01 (043) Dunbar	6.98 ±1.5	11.36 ±1.66	6.1 ±0.94	12.01 ±1.5	0.55 ±0.1	1.4 ±0.24
14/07/01 (045) Dunbar	11.17 ±0.8	12.45 ±0.35	7.93 ±0.52	12.6 ±0.32	0.38 ±0.08	2 ±0
14/07/01 (048) Dunbar	8.28 ±1.42	13.4 ±0.27	7.03 ±0.54	13.4 ±0.27	0.41 ±0.02	1.4 ±0.24
14/07/17 (052) Dunbar	10.63 ±1.65	10.42 ±1.92	7.77 ±0.87	13.44 ±0.93	0.87 ±0.24	7.6 ±3.06
14/07/17 (054) Dunbar	9.44 ±1.94	12.51 ±1.63	5.27 ±0.71	12.98 ±1.31	0.44 ±0.11	1.4 ±0.24
14/07/22 (058) Dunbar	8.87 ±0.45	9.33 ±1.3	8.06 ±0.74	10.31 ±0.79	0.37 ±0.11	2.2 ±0.37
14/07/22 (059) Dunbar	5.96 ±0.88	7.84 ±1.6	5.64 ±0.65	10.08 ±1.31	0.55 ±0.17	2.2 ±0.2
14/07/22 (061) Dunbar	5.5 ±0.28	11.98 ±2.27	5.42 ±0.31	14.33 ±1.07	0.65 ±0.1	1.4 ±0.24
14/07/22 (063) Dunbar	5.84 ±0.73	7.36 ±0.79	5.68 ±0.67	11.47 ±1.35	0.75 ±0.28	2.6 ±0.4
14/07/22 (065) Dunbar	8.59 ±1	11.93 ±1.59	7.78 ±0.59	15.02 ±0.89	0.62 ±0.13	2.2 ±0.49
14/07/22 (068) Dunbar	7.76 ±1.65	7.01 ±1.35	3.8 ±0.39	11.63 ±1.32	1.07 ±0.17	3.2 ±0.58
14/07/22 (069) Dunbar	8.76 ±1.13	12.93 ±1.47	5.84 ±0.74	13.62 ±1.07	0.85 ±0.21	1.6 ±0.24
14/07/22 (070) Dunbar	9.53 ±1.58	13.96 ±1.28	6.83 ±1.23	14.18 ±1.05	0.7 ±0.14	1.8 ±0.2

Appendix B: Latitude and longitude of the recordings from each encounter

Date (encounter) Boat Name	Latitude (degrees, mins, secs)	Latitude (decimal degrees)	Longitude (degrees, mins, secs)	Longitude (decimal degrees)
12/05/28 (006) Gallois	52° 9' 52.2606"	52.16452	-4° 30' 23.5188"	-4.50653
12/06/13 (009) Gallois	52° 10' 22.6806"	52.17297	-4° 28' 19.74"	-4.47215
12/07/09 (013) Gallois	52° 8' 43.1988"	52.14533	-4° 32' 46.86"	-4.54635
12/07/26 (027) Gallois	52° 13' 27.0012"	52.22417	-4° 21' 28.1988"	-4.35783
12/06/12 (045) Dunbar	52° 10' 23.1594"	52.1731	-4° 28' 13.1988"	-4.47033
12/06/18 (046) Dunbar	52° 13' 11.3406"	52.21982	-4° 21' 10.1988"	-4.35283
12/06/ 18 (057) Dunbar	52° 8' 30.2388"	52.14173	-4° 38' 28.5"	-4.64125
12/07/12 (076) Dunbar	52° 12' 54.8382"	52.21523	-4° 21' 18.54"	-4.35515
12/07/12 (079) Dunbar	52° 13' 26.6988"	52.22408	-4° 22' 34.9782"	-4.37638
12/08/05 (086) Dunbar	52° 12' 17.7012"	52.20492	-4° 34' 25.68"	-4.5738
13/09/23 (007) Islander	52° 9' 15.7212"	52.15437	-4° 32' 51.36"	-4.5476
13/09/23 (009) Islander	52° 8' 30.7206"	52.14187	-4° 37' 15.0594"	-4.62085
13/07/05 (016) Machipe	52° 50' 15.18"	52.83755	-4° 11' 14.1612"	-4.18727
13/07/12 (032) Machipe	52° 35' 21.2994"	52.58925	-4° 11' 17.8188"	-4.18828
13/07/12 (033) Machipe	52° 33' 19.9794"	52.55555	-4° 7' 36.3612"	-4.12677
13/05/26 (045) Dunbar	52° 13' 9.0588"	52.21918	-4° 20' 48.3"	-4.34675
13/09/25 (048) Machipe	52° 33' 29.5806"	52.55822	-4° 9' 26.6394"	4.1574
13/06/03 (054) Dunbar	52° 12' 58.2588"	52.21618	-4° 21' 15.9588"	-4.35443

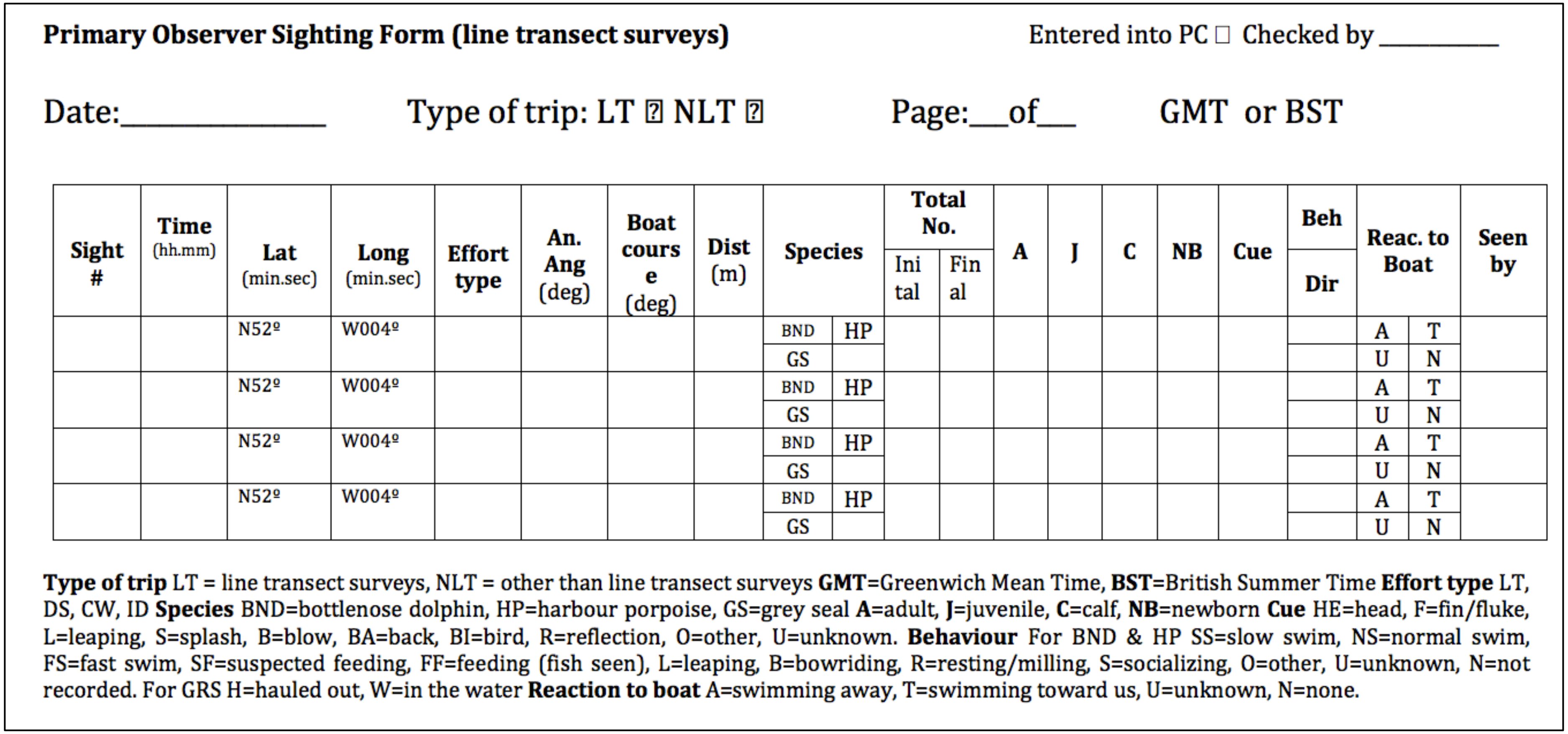
Appendix B (cont.)

13/06/03 (055) Dunbar	52° 10' 44.9394"	52.17915	-4° 27' 46.9794"	-4.46305
13/09/26 (056) Pedryn	52° 12' 55.98"	52.21555	-4° 21' 19.8606"	-4.35552
13/06/10 (059) Dunbar	52° 14' 8.7"	52.23575	-4° 19' 13.1412"	-4.32032
13/06/18 (069) Dunbar	52° 11' 1.3812"	52.18372	-4° 27' 23.6988"	-4.45658
13/06/25 (092) Dunbar	52° 7' 35.58"	52.12655	-4° 41' 30.1194"	-4.6917
13/07/06 (129) Dunbar	52° 10' 4.3212"	52.16787	-4° 31' 40.9182"	-4.52803
13/07/18 (161) Dunbar	52° 7' 38.8812"	52.12747	-4° 42' 36.0606"	-4.71002
13/08/07 (173) Dunbar	52° 17' 31.6782"	52.29213	-4° 22' 24.7188"	-4.37353
13/08/22 (189) Dunbar	52° 10' 33.4806"	52.17597	-4° 28' 16.0788"	-4.47113
13/09/12 (221) Dunbar	52° 14' 43.3212"	52.24537	-4° 28' 28.7394"	-4.47465
13/10/05 (238) Dunbar	52° 17' 19.6188"	52.28878	-4° 15' 47.5812"	-4.26322
14/07/07 (001) Pedryn	52° 42' 8.8194"	52.70245	-4° 25' 7.4604"	-4.41874
14/07/08 (001) Pedryn	52° 45' 2.6208"	52.75073	-4° 20' 5.2116"	-4.33478
14/07/07 (002) Pedryn	52° 29' 9.009"	52.48584	-4° 23' 7.4898"	-4.38541
14/07/11 (002) Pedryn	52° 47' 3.789"	52.78439	-4° 29' 1.8816"	-4.48386
14/07/11 (003) Pedryn	52° 47' 4.3512"	52.78454	-4° 29' 1.2294"	-4.48368
14/07/07 (004) Pedryn	52° 39' 1.1016"	52.65031	-4° 18' 9.2016"	-4.30256
14/07/07 (005) Pedryn	52° 47' 2.3202"	52.78398	-4° 8' 8.8794"	-4.1358
14/07/11 (006) Pedryn	52° 42' 3.3186"	52.70092	-4° 25' 2.841"	-4.41746
14/06/12 (007) Dunbar	52° 11' 41.7006"	52.19492	-4° 34' 51.6"	-4.581
14/06/12 (010) Dunbar	52° 12' 50.3994"	52.214	-4° 35' 58.6782"	-4.59963
14/06/12 (011) Dunbar	52° 12' 26.8812"	52.20747	-4° 28' 55.02"	-4.48195
14/06/13 (019) Dunbar	52° 16' 10.0194"	52.26945	-4° 26' 25.8606"	-4.44052
14/06/18 (025) Dunbar	52° 13' 0.9012"	52.21692	-4° 21' 8.46"	-4.35235

Appendix B (cont.)

14/06/18 (028) Dunbar	52° 11' 8.6382"	52.18573	-4° 31' 51.3588"	-4.53093
14/06/18 (029) Dunbar	52° 11' 53.7612"	52.19827	-4° 34' 11.1606"	-4.56977
14/06/25 (031) Dunbar	52° 11' 36.4194"	52.19345	-4° 33' 41.2812"	-4.56147
14/06/25 (038) Dunbar	52° 9' 28.98"	52.15805	-4° 36' 43.02"	-4.61195
14/07/01 (040) Dunbar	52° 13' 12.7194"	52.2202	-4° 21' 8.46"	-4.35235
14/07/01 (042) Dunbar	52° 13' 12.5394"	52.22015	-4° 21' 58.4994"	-4.36625
14/07/01 (043) Dunbar	52° 15' 27.2982"	52.25758	-4° 23' 55.2588"	-4.39868
14/07/01 (045) Dunbar	52° 11' 42.7806"	52.19522	-4° 26' 1.7982"	-4.43383
14/07/01 (048) Dunbar	52° 13' 35.6982"	52.22658	-4° 21' 56.52"	-4.3657
14/07/17 (052) Dunbar	52° 10' 13.6812"	52.17047	-4° 38' 20.76"	-4.6391
14/07/17 (054) Dunbar	52° 9' 9.2982"	52.15258	-4° 33' 45.72"	-4.5627
14/07/22 (058) Dunbar	52° 13' 3.399"	52.21761	-4° 21' 18.1002"	-4.35503
14/07/22 (059) Dunbar	52° 13' 10.4988"	52.21958	-4° 21' 20.4978"	-4.35569
14/07/22 (061) Dunbar	52° 10' 28.599"	52.17461	-4° 28' 39.6978"	-4.47769
14/07/22 (063) Dunbar	52° 10' 15.4986"	52.17097	-4° 29' 19.899"	-4.48886
14/07/22 (065) Dunbar	52° 8' 39.6996"	52.14436	-4° 38' 34.5978"	-4.64294
14/07/22 (068) Dunbar	52° 9' 36.7986"	52.16022	-4° 37' 0.5016"	-4.61681
14/07/22 (069) Dunbar	52° 9' 0.1002"	52.15003	-4° 36' 53.7012"	-4.61492
14/07/22 (070) Dunbar	52° 9' 6.0012"	52.15167	-4° 38' 42.2016"	-4.64506

Appendix C: Primary observer sighting form for line transect surveys



Primary Observer Sighting Form (line transect surveys) Entered into PC ☐ Checked by __________

Date:______________ Type of trip: LT ☐ NLT ☐ Page:___of___ GMT or BST

Sight #	Time (hh.mm)	Lat (min.sec)	Long (min.sec)	Effort type	An. Ang (deg)	Boat course (deg)	Dist (m)	Species		Total No.		A	J	C	NB	Cue	Beh	Reac. to Boat		Seen by
										Inital	Final						Dir			
		N52º	W004º					BND	HP									A	T	
								GS										U	N	
		N52º	W004º					BND	HP									A	T	
								GS										U	N	
		N52º	W004º					BND	HP									A	T	
								GS										U	N	
		N52º	W004º					BND	HP									A	T	
								GS										U	N	

Type of trip LT = line transect surveys, NLT = other than line transect surveys **GMT**=Greenwich Mean Time, **BST**=British Summer Time **Effort type** LT, DS, CW, ID **Species** BND=bottlenose dolphin, HP=harbour porpoise, GS=grey seal **A**=adult, **J**=juvenile, **C**=calf, **NB**=newborn **Cue** HE=head, F=fin/fluke, L=leaping, S=splash, B=blow, BA=back, BI=bird, R=reflection, O=other, U=unknown. **Behaviour** For BND & HP SS=slow swim, NS=normal swim, FS=fast swim, SF=suspected feeding, FF=feeding (fish seen), L=leaping, B=bowriding, R=resting/milling, S=socializing, O=other, U=unknown, N=not recorded. For GRS H=hauled out, W=in the water **Reaction to boat** A=swimming away, T=swimming toward us, U=unknown, N=none.