COMPARATIVE STUDY OF BOTTLENOSE DOLPHIN WHISTLES IN THE SOUTHERN CARDIGAN BAY SAC AND IN THE SHANNON ESTUARY

By

RONAN HICKEY

M.Sc. in MARINE MAMMAL SCIENCE

School of Biological Sciences
University of Wales, Bangor

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1 Introduction

1.1 General Introduction

About 70 million years ago, the terrestrial ancestors of Cetaceans (whales and dolphins) returned to the world oceans. To facilitate their new aquatic life, these mammals had to undergo dramatic evolutionary adaptations in locomotion and respiration. The underwater environment also presented these early cetaceans with a series of obstacles from a sensory perspective. The respiratory adaptations necessary for an aquatic lifestyle have compromised olfaction, which has limited use underwater. Despite the fact that Odontocetes (toothed whales and dolphins) have been shown to have excellent eyesight both over and under the waves (Dawson 1980), light does not propagate great distances in water, as it does in air, limiting visibility to a few tens of meters. However, unlike light, sound travels about four and a half times faster through the dense medium of water than it does through air. With this in mind it is hardly surprising to hear that cetaceans rely predominantly on acoustics to perceive their surroundings, navigate, find prey and communicate. In a comparison of the number of the auditory and optic nerves, Ketten (1997) points out that the auditory/optic ratios in most cetaceans are two to three times that of land mammals. This suggests an increased investment in audition compared to vision. Therefore, it stands to reason that one way to improve on our limited knowledge and understanding of these animals would be to look, or rather listen, to the world as they do.

Perception of sound in cetaceans may be passive, where sounds produced by natural phenomena, conspecifics and other species are heard (Tyack 2000, Au 2000) or active, when an animal is both the source and receiver of the sound. The acoustic range of cetaceans spans from the low-frequency calls, well suited for long-range communication in the large baleen whales, to high-frequency sonar use by odontocetes. Dolphins (family Delphinidae) in particular possess a wide variety of vocalisations that span the auditory spectrum from below 100Hz to more than 100Khz.

1.2 **Dolphin vocalisations**

Dolphin vocalisations can be broadly categorised into two types, pulsed and tonal sounds (Richardson *et al* 1995). Pulsed sounds are stereotypically high frequency, broadband signals the most obvious of which is the click. Clicks are most commonly associated with echolocation, which has been subjected to extensive documentation and study (Au 1993), although in recent years it has been suggested that high-frequency clicks are used for intraspecific communication as well perception (Lammars *et al.* 2003, Herzing 1996). More commonly however, it is the other category of dolphin vocalisation that is associated with communication. These narrowband, tonal sounds are generally referred to as whistles (Caldwell *et al.* 1990, Tyack 2000). Whistles are frequency-modulated sounds with a fundamental frequency usually below 20KHz, harmonics up to 100KHz and durations between 0.05 and 3.2 seconds (Lammers *et al.* 2003). Communication in dolphins is also thought to involve a series of other, less well defined, pulse sounds termed; chirps, grunts, buzzes and barks. (Van Parijs & Cockeron 2001, Caldwell & Caldwell 1968). However, it is the whistle that is most associated with intraspecific communication among dolphins.

The evolutionary origin of dolphin whistles is still unclear. However, in a study examining the vocalisations of the Amazon River dolphin (*Inia geoffrensis*), Podos *et al.* (2002) concluded that the absence of whistles in the vocal repertoire of this closely related sister taxa to the Delphinidae supports the hypothesis that whistles are a uniquely derived vocalisation exclusively used by members of the Delphinidae. The mechanics involved in the production of whistles is still unresolved (Cranford *et al.* 1996), although a correlation between whistle frequency and body size, where larger animals produce whistles of lower frequency, has been noted (Matthews *et al.* 1999).

The earliest studies on dolphin whistles concentrated mainly on assigning meaning to whistles and associating certain whistles to particular contexts. (Lilly 1963, Busnel & Dziedzic 1968). However, with the discovery that each dolphin has an individual whistle (Caldwell and Caldwell 1965) these ideas fell from favour. Later these individual whistles went on to be termed “signature whistles” (Caldwell *et al.* 1990). The function of signature whistles is thought to be involved in group cohesion, i.e. between mother and calf or during co-operative hunting (Herzing 1996). Early studies stated that the signature whistle accounted for over 90% of the whistles produced by a dolphin. However, these statements have been subject to criticism as they depict the vocalisations of animals that are experiencing unnatural and often stressful situations (Tyack 2000). In a study carried out on four captive, undisturbed dolphins, Janik & Slater (1998) concluded that signature whistles are most often used when an animal is isolated. This suggests that the signature whistle may not constitute the overwhelming majority of dolphin vocalisations. McGowan (1995) and McGowan & Reiss (1995) describe a wide range of whistles types, recorded from captive dolphins, that are used by more than one individual, although the categorisation methods used in the analysis have been subject to some criticisms (Janik 1999). These shared whistles, termed "variant whistles" can include a diverse range of rising, falling and flat tones (Janik & Slater 1998). Whistles that are shared by more than one dolphin may be the result of mimicry. In a study on the origins of an individual's signature whistle (Fripp et al. 2005) concludes that calves model their whistles on the whistles of other community members. However, Sayigh *et al.* (1995) looked at the signature whistles of 21 male and 21 female bottlenose dolphin calves (*Tursiops truncatus)* and compared them to the whistles of their mothers. The results suggested that males were more likely to develop signature whistles similar to their mother's, while females showed a greater degree of variance. Female bottlenose dolphins are more likely than males to remain in the same social group as their mother's. Therefore, it would be beneficial to have a degree of distinction between the whistles of mother and daughter. Male bottlenose dolphins on the other hand, tend to form alliances with other males and roam between groups of females. Therefore, a case where a male develops a signature whistles similar to its mother's might not result the same confusion. Similarity between the signature whistles of mothers and male calves might also help to avoid the possibility of inbreeding. Whistle sharing by allied males has been shown to occur, where the signature whistles of the males in an alliance become similar to one another (Watwood 2003). Mimicry of another animal's signature whistle is evidence of the possibility of vocal learning in dolphin society.

1.3 Vocal learning and Dialect

Vocal learning occurs when an animal modifies its vocalisations in some way as a consequence of experiencing the vocalisations others (Janik & Slater 2000). Early studies on vocal learning generally investigated the vocalisations of sub-tropical songbirds (Marler 1970). These birds must learn species-specific songs to attract mates and defend their territory. The conclusion drawn from these early studies was that these animals have only a short sensitive period during development to learn and refine their songs. However, more recently it has been shown that some birds are capable of learning new songs for longer periods of time and even into adulthood (Nordby *et al.* 2001). Vocal learning has also been observed in group living species. Many animals that live in groups produce calls that indicate group membership. Vocal learning in the context of group life has been shown in birds (Farabaugh *et al* 1994), bats (Boughman 1998), primates (Mitani & Gros-louis 1998) and cetaceans (Rendell & Whitehead 2003). It is possible that the process of vocal learning in these group living species could result in regional dialects between isolated groups and populations.

Vocal learning could cause sounds within a groups or populations to change as a consequence of copying errors, environmental factors or other influences. The resulting effect of this could cause dialects to develop between groups. In cetaceans, group dialects have been most commonly observed in killer whales (*Orcinus orca*) (Ford 1991,Deeke *et al.* 2000, Yurk *et al.* 2001). Killer whales around Vancouver Island live in stable pods, each with its own unique, culturally transmitted, vocal dialect, within a hierarchical social structure. Pods that show similarity in their vocalisations are grouped together into clans. In spite of regular interactions and sympatry, the vocalisations of pods and clans remain distinct. In a study examining dialect in sperm whale (*Physeter macrocephalus*) vocalisations (termed codas), Rendell & Whitehead (2003) concluded that variation in vocal behaviour between clans is cultural, based on vocal learning. It was discovered that there were large variations between groups overlaying weaker geographical diversity. Variations in the vocalisations between populations have also been seen in dolphin whistles.

Wang *et al.* (1995) reported variation in the whistles between populations of bottlenose dolphins (*Tursiops truncatus*). However, Morisika *et al.* (2005) points out the possibility that the difference between the populations could be attributed to differences between species, as the study may have included both *T.truncatus* and *T.aduncus.* In an examination of the geographic variations in whistles between three populations of indo-pacific bottlenose dolphins (*T.abuncus*) Morisika *et al.* (2005) found significant differences between all three populations. The whistle variance found correlated with the geographical differences between the populations.

Species that produce group specific vocalisations share several common characteristics (Watwood 2003). As group specific vocalisations tend to develop through interactions with group members, rather than through competitive encounters with rivals, complex stable relationships between individuals are common. The processes of vocal learning take time in most species. Therefore, long life spans are generally required to provide ample opportunity for group distinctive vocalizations to develop. Long lives and complex social relationships with known individuals are common for most species that produce group distinctive vocalisations. The ability for group members to recognize one another's vocalisations allows the group to defend limiting resources from intruding non-group members. Group stability or long term social bonds also ensure that individuals are not constantly adjusting their vocalizations for short-term relationships.

1.4 Bottlenose Dolphins (*Tursiops truncatus*)

Due to their coastal existence and success in captivity, bottlenose dolphins are probably the most familiar and well-studied cetacean species. Bottlenose dolphins are members of the family *Delphinidae* in the sub-order *Odontociti* (toothed Whales) within the order *Cetacea*. They inhabit tropical and temperate zones (60 N – 50 S), with herd sizes that range from 1 to 30 animals in coastal areas and up to hundreds in oceanic waters. Geographical variations in morphology have lead some in the past to divide the genus into as many as 20 different species (Hershkovitz 1966). The North Eastern populations were divided into offshore forms *T.nuuanu* and near *T.gilli.* However, due to considerable overlap in the morphological characteristics used to distinguish these alleged species, most now recognise one species *T.truncatus* (Hoelzel *et al.* 1998) with the exception of Indo Pacific regions, where bottlenose dolphins were once regarded as one species with two types *aduncus* and *truncatus* before morphological and molecular studies revealed that these two types were separate species *T.aduncus* and *T.truncatus* (Wang *et al.* 2000). *T.aduncus* is now referred to as the Indo Pacific bottlenose dolphin. To avoid confusion, *T.truncatus* is the subject of this study.

1.4.1 Morphology

Bottlenose dolphins are a dark grey colour with paler undersides with calves often lighter in shade than adults. They have a robust head with a distinct short beak, often with a white tipped lower jaw. The tall slender dorsal fin, which is usually sickle-shaped, is centrally placed along the back of the animal (Plate 1.1). Adults typically measure between 3 and 4 meters in length, with males growing slightly larger than females (Leatherwood and Reeves 1983). Newborn calves are about one meter in length and remain in close association with their mothers for up to four years, suckling for at least the first 18 months.

(a)

(b)

Plate. 1.1 Bottlenose dolphin (a) leaping and (b) Female and calf pair. Pictures taken in the Shannon Estuary by Simon Berrow: Reproduced here with his concent.

1.4.2 **Behaviour and Society**

Bottlenose dolphins live in a fission-fusion society where regular changes in group composition and structure occur on the order of minutes and hours (Wells 2003). Underlying this ever-changing network of associations, complex, long-term social bonds also exist. Females of the same reproductive status that share a similar home range commonly associate together in groups (Duffield & Wells 2002). These female groups have been termed "bands" (Wells *et al* 1987). The reproductive success of mothers that are members of larger bands is generally greater than that of females in smaller bands or lone individuals. Young females will often recruit into their natal bands (Wells 2003).

The strongest association in bottlenose dolphin society is the alliance formed between adult males (Wells *et al.* 1987). These male-male bonds tend to last the lifetime of the animals. In incidences where one of the males in an alliance dies, the surviving male has been seen to form a new partnership with another single male (Wells 2003). Single males tend to have smaller home ranges than males that are in alliances. Males generally have lager home ranges than females.

Bottlenose Dolphins are long-lived and can survive in the wild for up to 40-50 years (Hohn 1990). Males generally have shorter life spans than females. Females produce a single calf every 2-6 years following a one year gestation period. Bottlenose dolphins have a great deal of variability in the timing of births. Populations have been shown to have seasonality of births or produce young throughout the year. Births are most likely timed to coincide with food abundance and other environmental factors (Urian *et al.* 1996). Therefore, as bottlenose dolphins are found in a range of locations and habitats, variation in the timing of births throughout the species would be expected. Bottlenose dolphins are opportunistic feeders that have been known to eat a wide range of fish, molluscs and crustaceans. This versatility in diet and feeding strategy has lead to the species' success and varied geographical distribution.

1.4.3 **Distribution**

Bottlenose dolphins are a cosmopolitan species that are widely distributed in a range of coastal habitats from tropical to temperate seas. They are known to inhabit both sheltered and exposed areas of estuaries, lagoons, and continental coasts. They also inhabit pelagic waters offshore and around the coasts oceanic island. In Britain and Ireland, bottlenose dolphins have been recorded most frequently in coastal waters.

The waters of Britain and Ireland are home to three known resident populations of bottlenose dolphin: Cardigan Bay in Wales, the Moray Firth in Scotland and the Shannon Estuary in Ireland (fig 1.1). Smaller groups are regularly reported elsewhere in the British and Ireland, including along the Cornish, Devon and Dorset coasts, in the waters around the Hebrides and occasionally in offshore waters of the North-east Atlantic, Irish Sea and St. George’s Channel (Cardigan Bay SAC Management plan). In the cold waters of Britain and Ireland, bottlenose dolphins are amongst the largest examples of the species in the world, growing up to 4m in length.

Figure 1.1 Map of the Britain Isles, showing the locations of the three known resident populations of bottlenose dolphin.

1.5 Study Locations

1.5.1 Cardigan bay

Cardigan Bay is situated off the West coast of Wales, north of Pembrokeshire. Due to the presence of a resident population of bottlenose dolphins, the southern part of the bay from Aberarth to just South of the Tefi Estuary and extending to about 12 miles offshore has been designated a special area of conservation (SAC) (fig 1.2). The bay is generally sloping and relatively shallow throughout, reaching 50m in the outer regions and staying below 30m for the majority of the SAC.

The SAC is subject to frequent human activity with harbours at New Quay, Aberaeron and Aberystwyth. These harbours are mainly used by fishing vessels and recreational craft. In order sustain navigable depths within the harbours, occasional dredging is carried out by the County Council.

As well as bottlenose dolphins a number of other marine mammal species have been sighted in the waters of the SAC. Of these the most frequent is the harbour porpoise, which comprises nearly 30% of the sightings in the SAC (as recorded on the SeaWatch Foundation regional database). Pilot (*Globicephala melas*), killer (*Orcinus orca*) and minke (*Balaenoptera acutorastrata*) whales have also been seen, although infrequently. Shortly after the data collection period for this study a humpback whale (*Megaptera novaengliae*) was sighted in the area. The Cardigan Bay area is also home to a population of grey seals (*Halichoerus Grypus*) with a few pupping sights in the southern part of the SAC.

Bottlenose dolphins are a year round feature in Cardigan Bay, with numbers increasing throughout the summer months and into early autumn, peaking in late September. A trend of increasing group size has also been observed through the same period. Frequency of sightings and group numbers tend to drop during the winter months. However, this could be due to poorer weather conditions and a decrease in survey effort.

A greater understanding of all aspects of this population is crucial to the functional and practical management of the Cardigan Bay SAC. To the author's knowledge there are no published studies on the vocalisations of Cardigan Bay bottlenose dolphins.

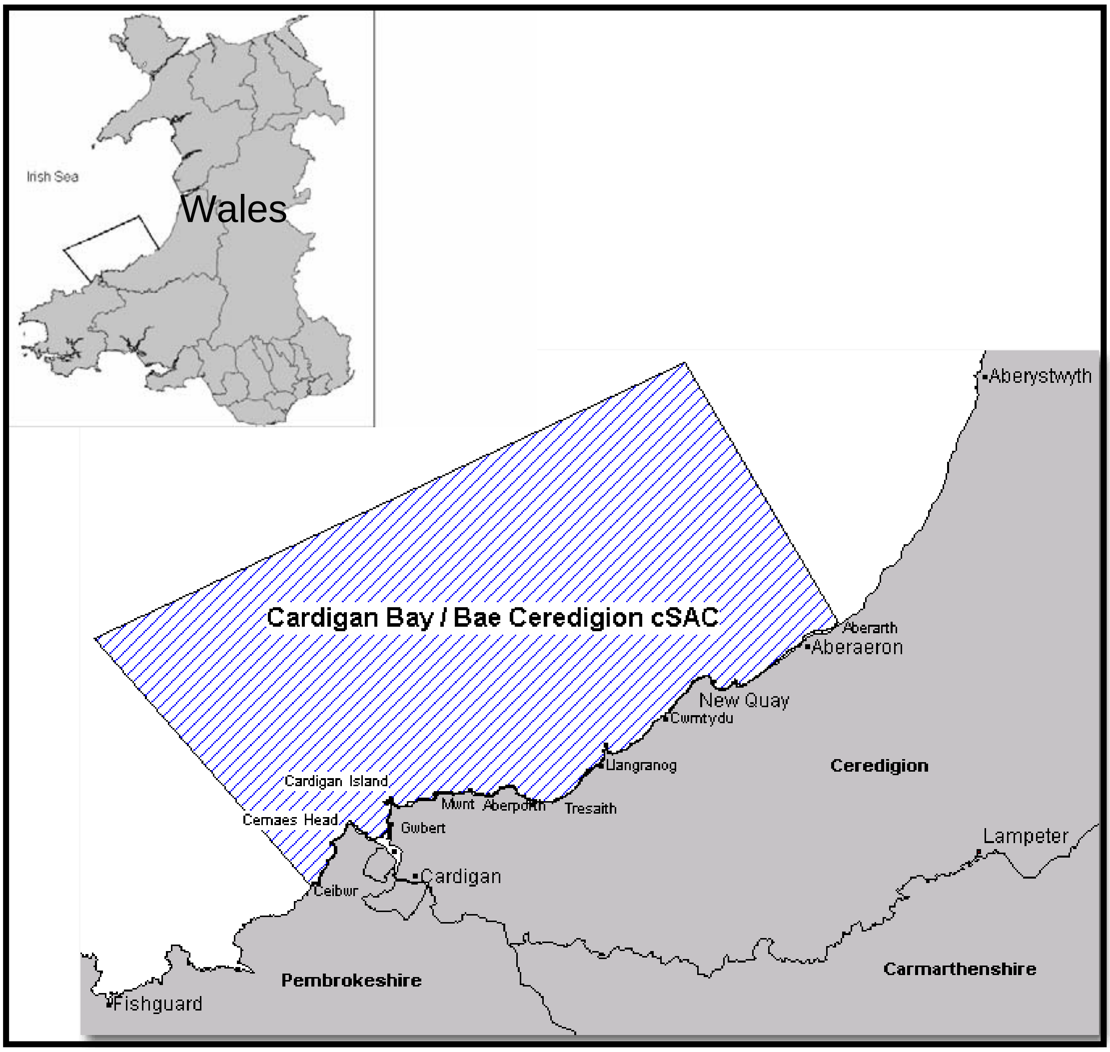


Figure 1.2 map showing Cardigan Bay special area of conservation (SAC). Inset showing location relative to Wales.

1.5.2 <u>Shannon Estuary</u>

At 240km in length, the River Shannon is the longest waterway in Ireland. Opening into the Atlantic between the counties of Clare and Kerry at 52^{o}30’N, 9^{o}50’W, the Shannon is an example of a manipulated river system with a hydroelectric scheme at its lower end. The tidal waters of the Shannon extend 80km inland, with deep water as far up as the port of Foynes on the southern shore. The outer part of the Shannon Estuary is known to be inhabited by a resident population of bottlenose dolphins (Berrow *et al* 1996), see fig. 1.3.

Although the bottlenose dolphins of the Shannon estuary are one of only six known resident populations in Europe, there is relatively little published work on their behaviour and ecology. To date, there have only been two peer-reviewed studies that descried their abundance and behaviour (Berrow *et al*.1996 and Ingram & Rogan

2002). It is not known how long dolphins have inhabited the estuary but anecdotal records date back to 1835 (knott, 1835). Dolphins are present in the estuary throughout the year but seasonal fluctuations in abundance have been observed, with numbers reaching their highest between the months of May and September. Mark recapture models and an existing photo-identification catalogue have estimated a population size of around 113 individuals (Rogan *et al.* 2000). The presence of calves between July and September, suggest that there is a distinct breeding season in this population and that the estuary is an important area for nursing.

The Shannon Estuary is a major shipping route and large vessels (some reaching 180,000 tons, the largest to enter Irish waters) are a regular fixture. The Shannon provides a unique opportunity to study wild dolphins as the strong tidal influence and the enclosed environment of the outer estuary all aid in locating dolphin groups. Currently there are three operators taking tourist out during the summer months to see the dolphins with a 97% success rate of locating animals (Rogan *et al.* 2000).

While some studies have looked at the whistles produced by Shannon Estuary dolphins (Berrow *et al.* unpublished), a catalogue of whistle types has yet to be defined. Thus far the whistles of this population have not been compared with those of any other.

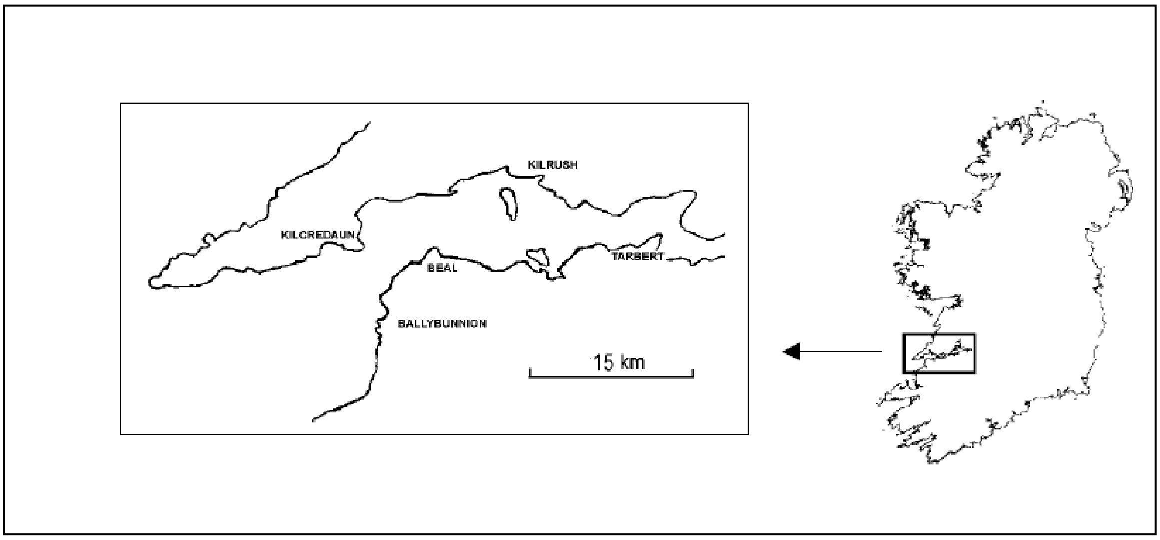


Figure 1.3 The outer Shannon Estuary,

1.6 Analysing Dolphin Vocalisations

In studies that require the analysis of dolphin whistles, such as comparisons of whistle characteristics between populations, it is necessary to describe and measure whistles in an unambiguous way that allows for suitable statistical tests to be preformed. Three approaches have been taken to the task of categorising dolphin whistles, the first of which involves assigning descriptive names to differing whistle types. For example, a whistle that begins with high frequency and decreases continually to end on a low frequency would be termed a "downsweep" (Lilly 1963, Caldwell *et al* 1990, Janik *et al.* 1994). The advantage of this method is that whistles that are common in a population can be described in an easily understood way. However, this qualitative method is open to a large degree of ambiguity and can result in confusion, particularly in describing more complex whistle types. The second technique for examining dolphin whistles is to carry out Fourier transform analyses (FFT) on the data, to create a visual representation of the acoustic signal by plotting it on a spectrogram; usually with time and frequency on the X and Y axes respectively and amplitude represented by greyscale or colour intensity (Lilly 1963, Janik and Slater 1998 and Cockeron & Van Parjis 2001). While this method is easily understood and can be useful for depicting individual whistle types, studies on dolphin whistles often require large data sets with many different whistle types. The process of looking at large amounts of spectrograms could become confusing and may result in error or even bias. One way of eliminating the possibility of human error is to use a range of univariate or parameters (for example whistle duration, maximum and minimum frequencies) to describe the whistle (Janik *et al.* 1994, Morisika *et al.* 2005). However, the lack of a standard set of parameters can make comparisons between studies difficult. Recently the use of artificial neural networks has been used to measure for similarity in killer whale vocalisations (Deeke et al 1999), grade false killer whale *Pseudorca crassidens* (Murray *et al.* 1998) and classify common dolphin whistles. These multivariate statistical methods have the advantage of being objective and repeatable. Despite these advantages however, comparisons between multivariate and subjective methods, by eye, have shown that these new automated techniques are no better (Deeke *et al.* 1999) and in some cases less reliable (Janik 1999) than humans.

1.7 Cyclic Patterns and Tidal Times

Cyclic patterns in behaviour are common throughout the animal kingdom. Due to their presence in coastal habitats, tidal cycle is likely to influence the activities of bottlenose dolphins, particularly in estuarine environments. Tidal currents will influence temperature and salinity, which in turn could influence the movements and distribution of prey species. In a study focusing on the influence of environmental factors in the Shannon Estuary bottlenose dolphins, Ingram (2000) found significant correlation between dolphin behaviour and diurnal and tidal cycles. Ingram (2000) concludes that dolphins were more likely to feed during periods of flowing tide than during slack waters, while resting was more commonly observed during slack water. Ingram (2000) also found that diurnal cycles had an influence on group size. Larger groups were more regularly encountered later in the day, while lone individuals where encountered predominantly in the morning. This relative predictability of behaviour and group size could help in associating conspecific vocalisations to particular scenarios.

1.8 Aims and Hypotheses

The central aim of this project is to examine and compare the repertoire, characteristics and rate of the Cardigan Bay and Shannon Estuary bottlenose whistles. The study also aims to compare between years, groups and group sizes within the Shannon Estuary population. In order to fulfil these objectives, a classification system for categorising bottle dolphin whistles was developed. As a side study, the association between the movements of Shannon Estuary bottlenose dolphins and tidal cycle was also be explored.

The hypotheses are

1. That the whistle repertoire of bottlenose dolphins *T.truncatus* in the Cardigan Bay population is distinct from the repertoire of the Shannon Estuary population.

2. There is no significant variation in whistle repertoire and characteristics between years, groups and groups of different sizes within the Shannon Estuary population.

3. Whistle rates of bottlenose dolphins in the Shannon Estuary increases with increasing group sizes.

4. That bottlenose dolphins in the Shannon Estuary show some behavioural correlation with the tidal cycle.

2 Methods:

2.1 Survey and data collection methods

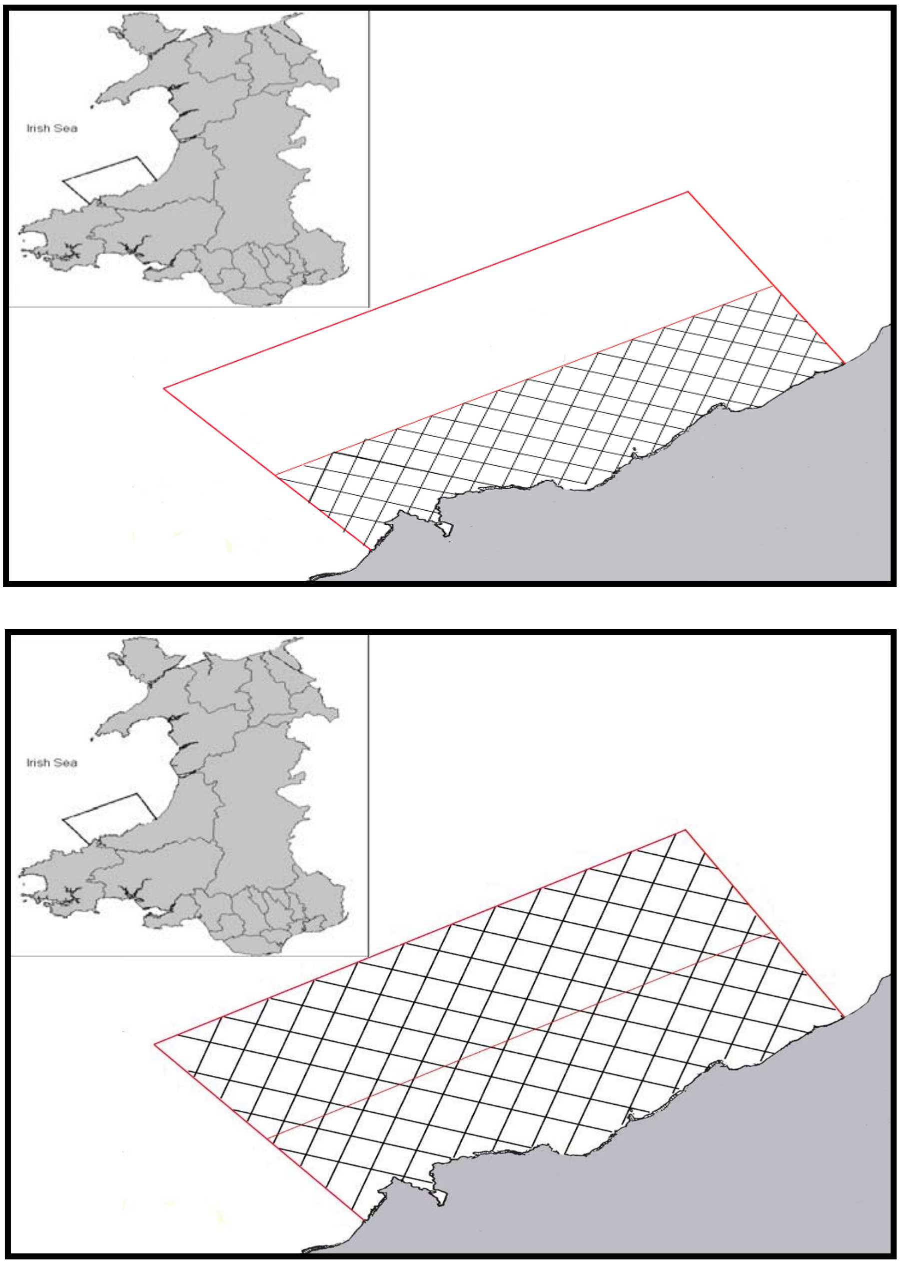
2.1.1 Cardigan Bay

Cardigan Bay data was collected between the months of May and August 2004 and in June 2005. All recordings in 2004 were made from the chartered survey vessel “Sulair” which travelled along specific transect lines (fig 2.1) actively searching for dolphins. An active search consisting of two dedicated observers and one independent observer was preformed at all times while onboard. The 2005 data was collect both from a dedicated survey vessel “Dunbar Castle 2” which used the same transect lines shown in fig 2.1 and from a tourist boat “Ermol 5” that would travel south along the coastline from Newquay to Ynys Lochtyn and back again (fig 2.2). A casual watch for dolphins was carried out at all times on the Ermol 5.

On encountering dolphins the objective was to position the boat up stream of the group, cut the engine, lower the hydrophone into the water and allow the boat to drift through the group, while recording. The engine was cut to eliminate engine noise, which would influence the recording. Surveyors onboard Dunbar castle 2 were licensed to approach a group of dolphins for a maximum of 30 minutes. While onboard the Ermol 5 however, no active approaches to dolphins were undertaken. The vessel held a steady course and encounters only occurred when the dolphins chose to approach the boat.

During dolphin encounters on either vessel, visual recordings were made of group size, distance from boat at the beginning and end of recordings, group formation and some observational notes on behaviour were also taken. Behaviour was simply categorised as either travelling, feeding, suspected feeding or socialising. Additional information such as position using the ship’s GPS (global positioning system) and sea state were also taken.

Dolphin whistles were recorded using an 11m standard mono hydrophone (MAGREC HP30), which was deployed into the water only after dolphins had been sited and the vessel was in position with its engine turned off. Recordings were made onto digital audio tape (DAT) via a 2.5KHz filter to eliminate any low frequency background noise caused by other vessels in the vicinity. DAT recordings were made on a Sony TCD-D8 recorder (sensitivity 20Hz-22KHz). Recordings were coded with time and date from the DAT recorders internal clock, which was set at the beginning of each survey and synchronised with the clock of the visual observers' GPS. This allowed acoustical recordings to be correctly assigned to the visual data, during playback analysis.



a.

b.

Figure 2.1 Cardigan bay SAC showing the (a) inner and (b) outer transect lines used during dedicated cetacean surveys on the sue lair (2004) and the Dunbar Castle 2 (2005). Inset shows position of the map relative to the rest of Wales.

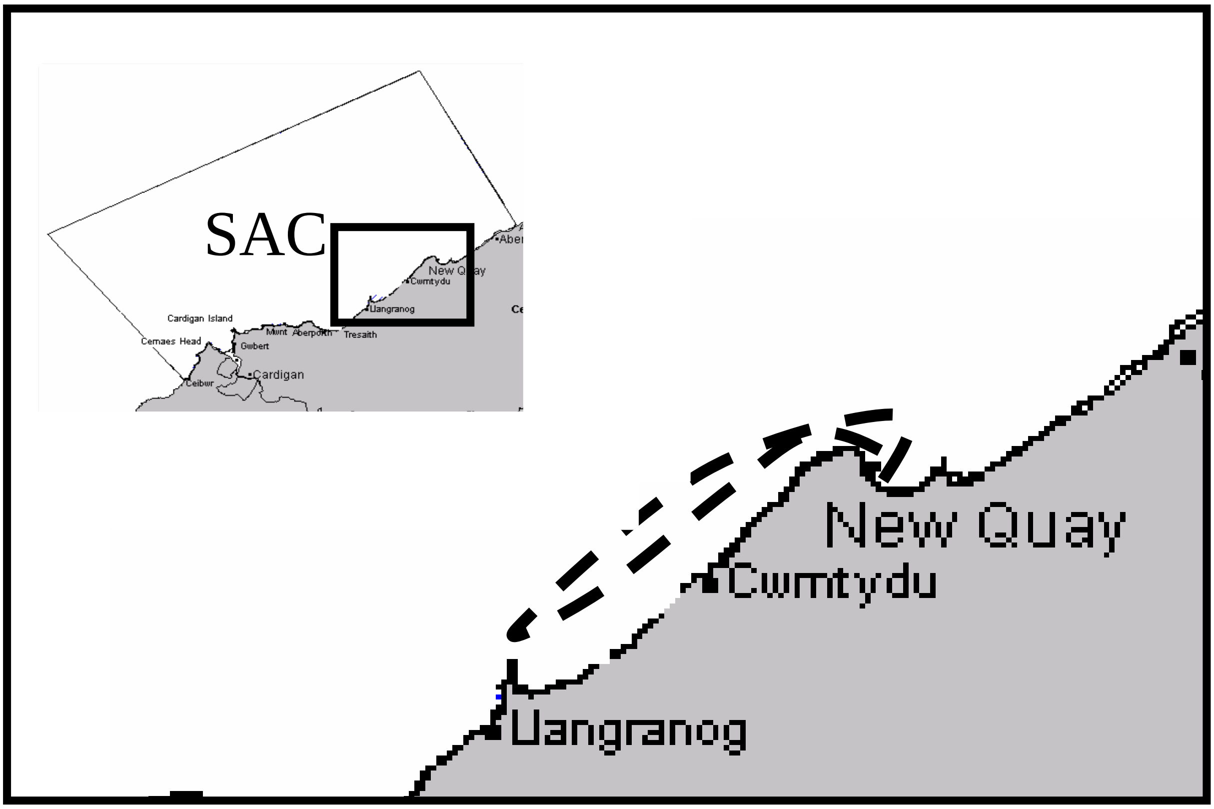


Figure 2.2 Map showing the round trip from New Quay to Ynis Lochtyn taken by the tourist vessel Ermol 5. Inset shows position relative to the entire SAC.

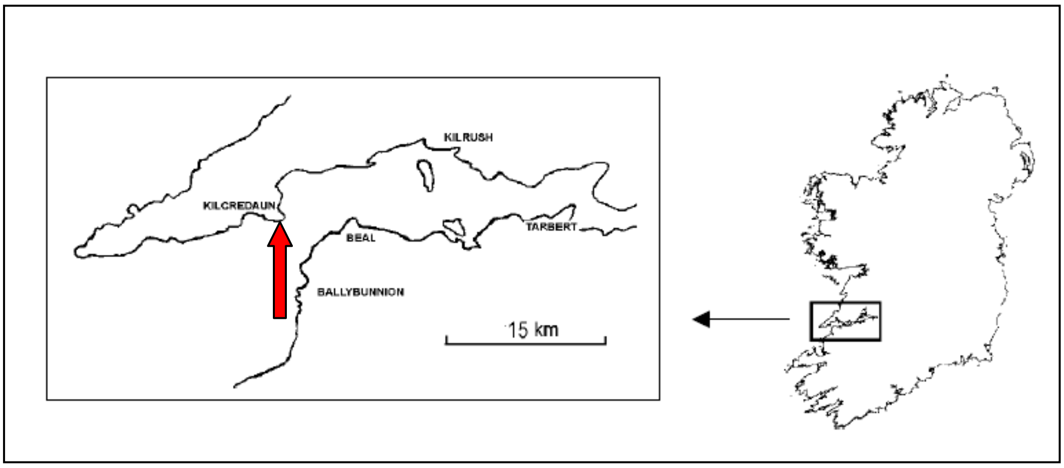
2.1.2 <u>Shannon estuary</u>

Shannon estuary data was collected between May and August 2003, August and September 2004 and July and August 2005. In 2003 and 2004 recordings were made using an underwater hydrophone (MAGREC HP30), which was permanently fixed to a metal frame, approximately 1 meter from the sea bed, at a depth of 10-12 meters and approximately 100m offshore (Berrow et al. unpublished), at Kilcredaun Point, Co Clare (52^{o}34.7’N 9^{o}41.3’W) (see fig 2.3). In July 2005 a replacement hydrophone (also MAGREC HP30) was deployed and fixed in approximately the same location, as the original was swept away in the current during the previous winter (Berrow Pers comm.). The hydrophone cable ran onshore where the signal passed through the same 2.5KHz filter and DAT recorder that was used to collect the Cardigan Bay data. From the recording position on land, visual observations were made noting behaviour, group size, group composition, distance from hydrophone* and any additional information such as surrounding boat traffic etc. Information of sea state and weather conditions were also recorded.

Recordings from 2003 were collected opportunistically with some brief notes on visual observations (Berrow pers. comm.). In 2004 surveys consisted of 7 two-hour sessions at varying states of tide. Recording was continuous throughout the sessions. The 2005 data was collected over 9, six-hour survey sessions in late July and early August. Eight of the sessions were conducted during the ebb tide (the period from high to low tide) with one session (3/08/2005) conducted during the flood tide (from low to high tide). Surveys were carried out predominantly during the ebb tide, as dolphins were more likely to be encountered (Ingram 2000, Berrow pers. com.). The time frame of the study period meant more surveys during flood tides could not be carried out. During the sessions, 10 minute visual scans were conducted once every 30 minutes using binoculars (8 x 40). Passive listening for dolphins, without recording, was continuously carried out throughout each session. Recording started after either the visual or acoustic detection of dolphins. Recordings lasted until the dolphins were determined to have left.

* Distance for the Hydrophone was achieved by estimating the distance between the dolphin group and the buoy that was attach to the hydrophone and could be seen from the observation point.

(a)



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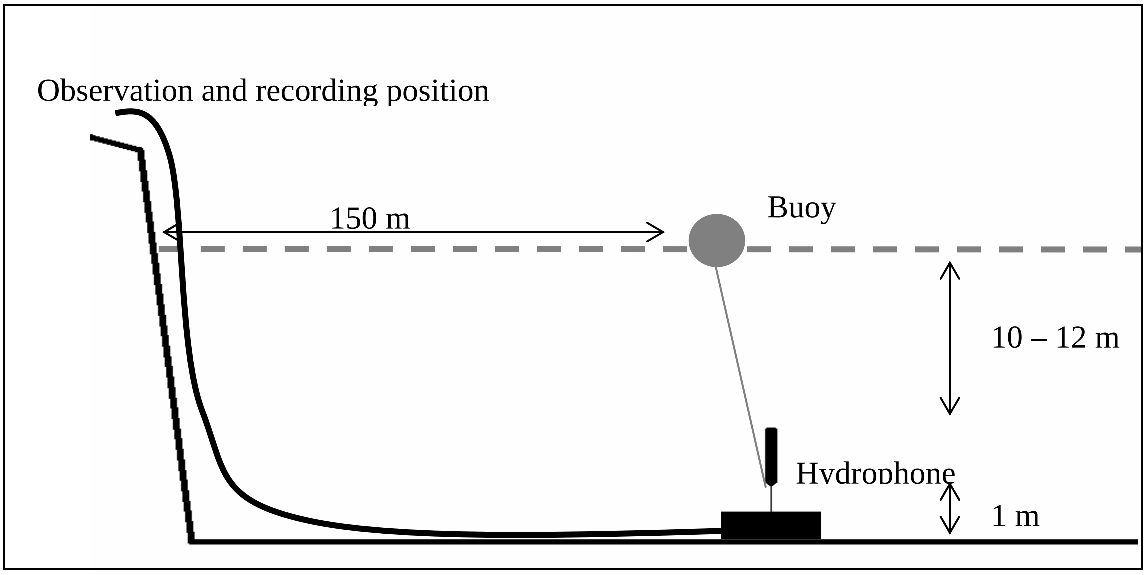

Figure 2.3. (a) Map of the outer Shannon Estuary, arrow showing the location of the study site. **(b)**Underwater hydrophone set up at Kilcredaun Point. Co Clare (52°34.7'N 9°41.3'W).

2.2 Data Analysis

The DAT recordings were played back and whistles were detected by ear. The time of each whistle was noted so that short, 10-second recordings could be downloaded into a computer containing one or few whistles. Whistles were downloaded into a computer using a Marian Marc 2 Digital sound card, with optical Input and output, via a Sony optical digital cable compatible with the DAT recorder. The recordings were then saved as PCM wav files (.wav) using the audio program Cool Edit 2000. Files were named using the date and time when the whistle was recorded. The wav files were then imported into MATLAB (version 5.2) and converted into vector format using "wav2raw" M-file* (copyright 1984-94 by The MathWorks, Inc., modified by Mark Johnson, September 1995). A further M-file called "Delphi", written by Dr. John Goold, was then used to digitise the time/frequency contour of each whistle. The programme creates a spectrogram of the sample period, which can be scrolled forward by the user (fig 2.4). When the whistle has been located by eye, the programme allows the user to trace the contour of the whistle using a crosshair. Each click of the mouse along the contour records the time and frequency at that point.

The matrices of time and frequency for each whistle can then be saved as a text file (.txt) and imported into excel spreadsheets where the shape of each whistle could be graphed and the following parameters were calculated.

- Duration, in seconds of each whistle
- Maximum frequency
- Minimum Frequency
- Starting frequency
- Ending frequency
- Mean frequency
- Gradient from start to end

Once in this graphical format the whistles could be categorised. The X and Y axes of each graph were standardised (1.5 seconds long, with a frequency range of 0Hz to 24Khz) to prevent distortion of whistles caused by axes of differing length effecting the interpretation and categorising process.

* An M-file is a series of MATLAB commands stored as a text file, allowing automatic repetition of operations.

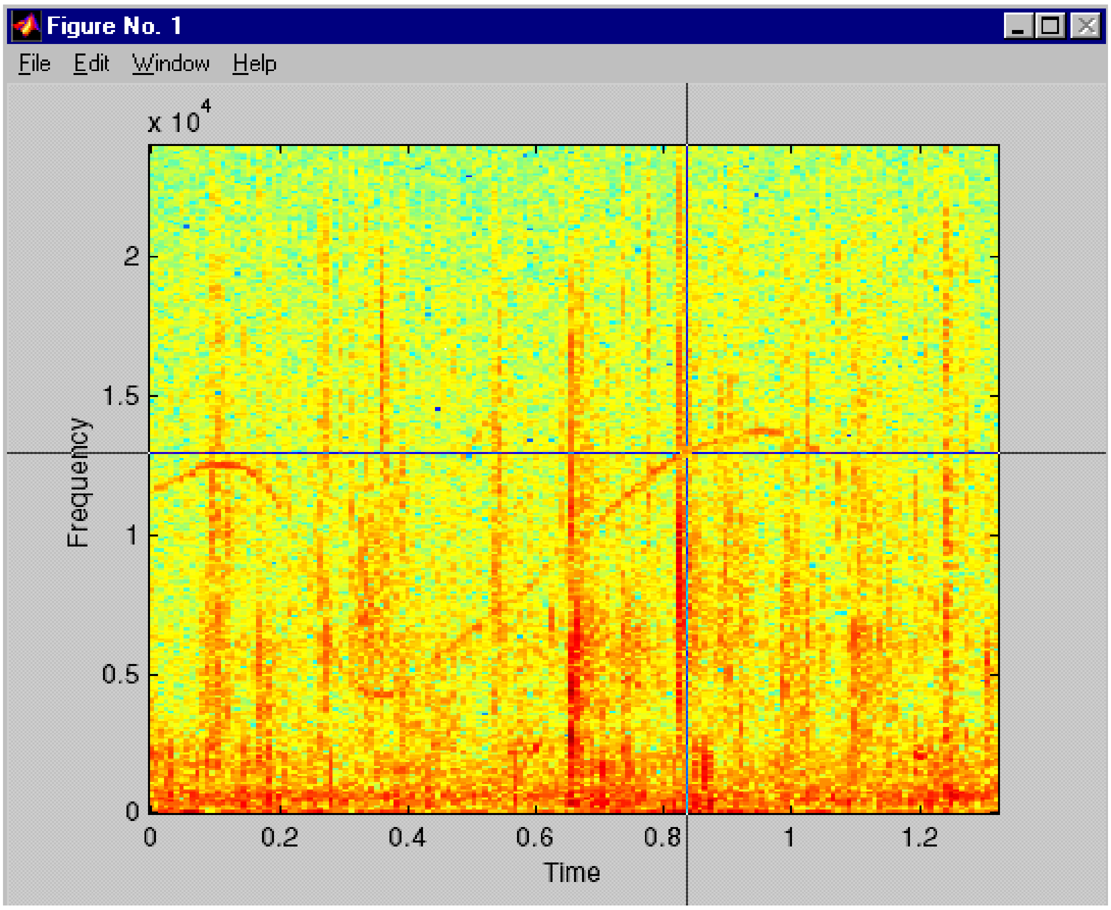

Figure 2.4 Example of the spectrogram created by the Delphi programme enabling the user to trace the whistle contour using the crosshairs.

2.3 Statistical Analysis

Statistical tests were used to test for variance in whistle parameters and the frequency of occurrence of the most common whistle types. Due to a small sample size obtained from Cardigan Bay tests for variation within populations were only performed on the Shannon Estuary data. The tests used in this study to determine the presence or absence of any significant differences or correlations, included Anderson-Darling normality tests, t-tests for use in analysis of variance, Kruskal-Wallis ANOVA, Chi squared test and Spearman's rank order coefficient.

Unfortunately one issue that is unavoidable in this study is that of the non-independence of data (Wakefield 2001). As it is often impossible to determine vocalizing individuals in studies on wild dolphins at sea, the possibility of whistles produced by the same individual being treated independently is a strong one. Some of the statistical tests used in this study (i.e. Chi square test for independence) are based on assumptions of independence of data. This assumption may have been violated in the course of this study. Whistles produced by the same individual or whistles in direct response to another individual's vocalisation could skew the data and result in pseudoreplication (Hurlbert 1984). Previous studies have combated the possibility of pseudoreplication by deleting whistles that come in close temporal succession (Janik *et al*. 1994). However, the small sample size from Cardigan Bay meant that the deletion of any whistles could not be afforded. The possibility of pseudoreplication is particularly high in the Shannon Estuary as the fixed hydrophone, did not allow for studies to be taken from a range of locations. Although, it is a requirement of the test, the Kruskal-Wallis ANOVA is particularly robust to violations of independence of data (Kramer and Schmidhammer,1992). Nonetheless, the results of this study should be considered with a degree of caution. The topic of non-independence of data in relation to the results of this study is explored further in the discussion section.

3. Results

3.1 Survey effort and encounter rate

3.1.1 Cardigan Bay

In total 69 hours of effort were spent over 19 different dates, searching for bottlenose dolphins in Cardigan Bay, June 2005. Forty-three of these hours were spent on onboard a dedicated survey vessel over five different dates. Twenty-six hours were spent on thirteen, 2-hour tourist trips. Dolphins were encountered and recordings were made on 11 of the 19 days. A total of 2 hours 13 minutes of recordings were made over the 11 encounters. No more than one group was encountered and recorded in the same day. Whistles were detected in the recordings of three of the eleven encounter dates (fig 3.1a).

In 2004 whistles were successfully recorded in nine different encounters between 22nd May 2004 and 31st August 2004. The degree of survey effort for the 2004 is not known.

3.1.2 Shannon Estuary

Dolphins were seen on eight of the nine survey sessions in the Shannon Estuary in July and August 2005. The session on the 3rd August 2005 was the only session where dolphins were not detected. This was also the only session to be carried out during the flow tide. While dolphins were seen on the 8th August 2005, they were too far away from the hydrophone and no recordings were made. Of the seven remaining dates, a total of 15 hours 13 minutes of recording were collectively made. Whistles were successfully recorded during encounters on all seven days (fig 3.1b).

Whistles were recorded on six of the seven 2-hour surveys conducted in August and September 2004. The 2003 data came from two separate dates, 29th May 2003 and 18th August. Effort for 2003 is not known.

(a) (b)

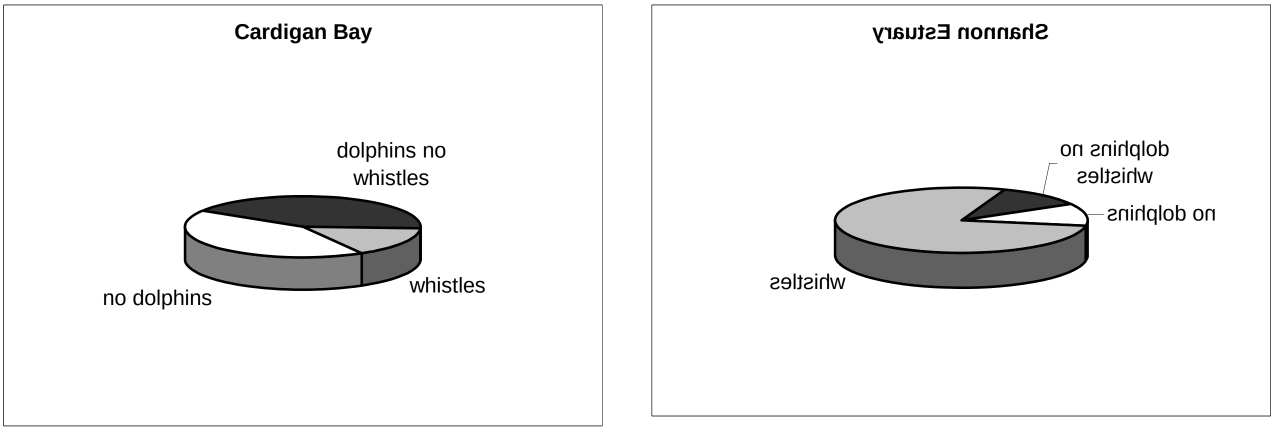

Figure 3.1 Proportions of survey dates where dolphins were not encountered, encountered with no whistles recorded and encountered with whistles successfully recorded, for **(a)** Cardigan Bay and **(b)** The Shannon Estuary in 2005.

3.2 <u>Whistles types.</u>

A total of 1882 whistles were digitised and analysed. The majority of these whistles were collected from the Shannon Estuary. There were 167 whistles collected in Cardigan Bay (39 from 2005 and 128 from 2004) and 1715 from the Shannon Estuary (971 from 2005, 116 from 2004 and 628 from 2003). Whistles were categorised into one of six fundamental shapes: rising, falling, flat, convex, concave or continually modulated. Once in these general categories, whistles were then subcategorised further according to the combinations of shapes that comprised the whistle contour, i.e. a whistle that started with a rise and levelled off into a flat section was categorised as "AC". Whistles were sorted into 32 different categories based upon the 6 general types (fig 3.2). Of these, 1 category was observed exclusively in recordings from Cardigan Bay, 8 were found to be exclusive to the Shannon Estuary and 23 where recorded at both sites. Examples and statistical descriptions of each category are given in the appendix.

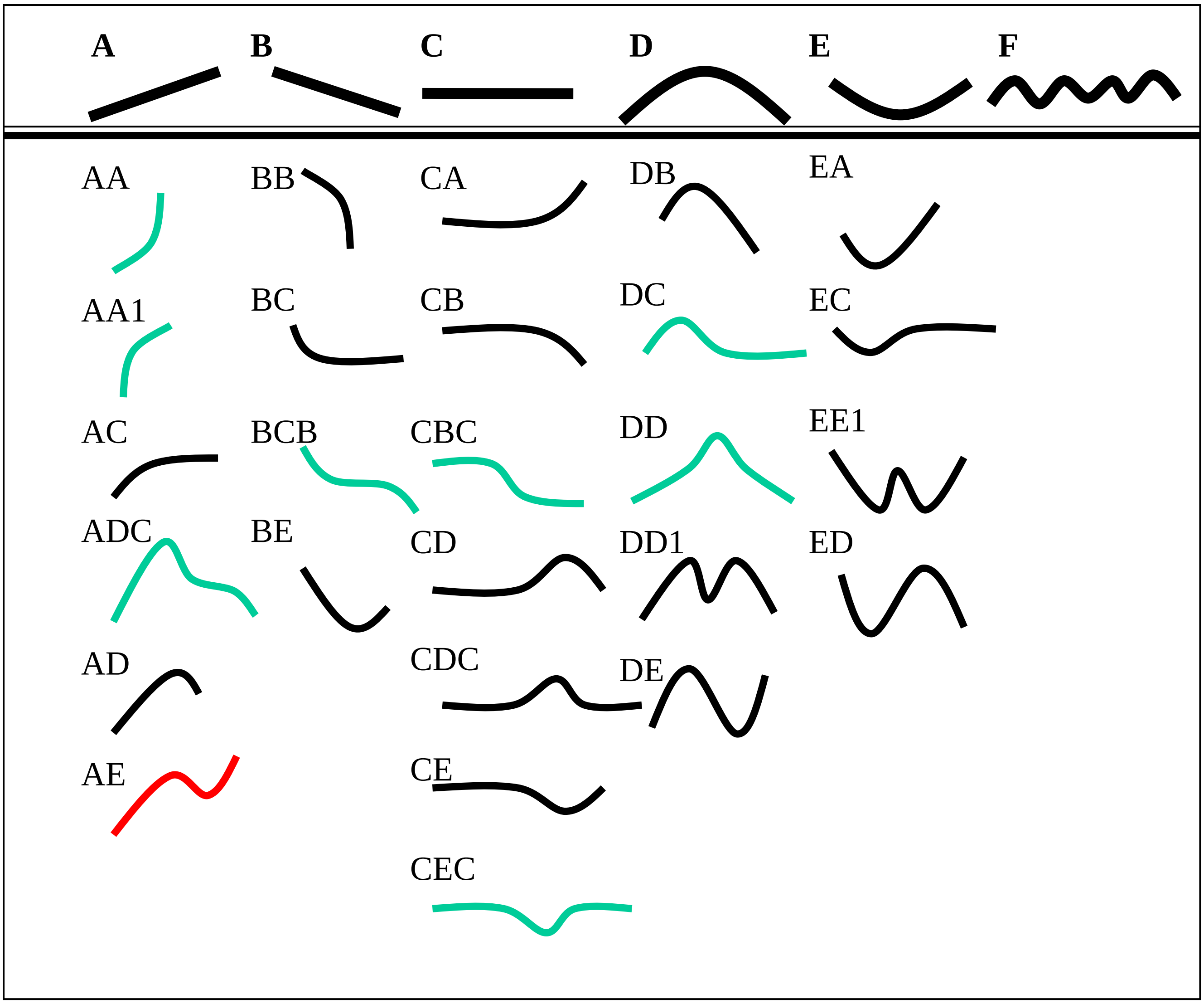

Figure 3.2 Contour shapes of the 32 whistle categories described in this study. Categories that were exclusive to the Shannon Estuary are given in green. The category exclusive to Cardigan Bay is in red. All others were recorded in both study sites.

The most common whistle type encountered in the analysis was a simple rising tone (category A), which accounted for 15.3% of all whistles. The next most common was a pure un-modulated tone (category C), which made up 11.6 % of whistles. 9.5% of whistles had a falling tone (category B) with whistles comprising of a convex shape (category D) making 9.4%. 3.4% showed a concave shape (category E) and 1.8% had a continually modulated shape (category F). The proportions of all categories are given on table 3.1.

Whistles ranged in duration from 0.08 to 1.61 seconds. Category F whistles were found to have the longest mean duration (0.98 sec.), while the category BB had the shortest (0.254). Average frequency means ranged between 13.21KHz, which belonged to category EE1 whistles and 7.712 KHz, of category DBC. The highest mean frequency for any whistles was 23.048 KHz. This was the mean frequency of a category E whistle. The lowest mean Frequency was of a category C whistle (0.769KHz). The categorisation process was intended to reflect the time and frequency fluctuations of each whistle, however, there was a great deal of variability found between the whistles within each category.

Table 3.1. Number and percentage of whistles in each category in Cardigan Bay and Shannon Estuary.

Category	Cardigan Bay		Shannon estuary		Total	
	N	%	N	%	N	%
A	30	18.1	257	15.0	287	15.3
AC	3	1.8	125	7.3	128	6.8
AD	7	4.2	73	4.3	80	4.3
B	28	16.2	161	9.4	178	9.5
BB	2	1.2	6	0.3	8	0.4
BC	4	2.4	53	3.1	57	3.0
BE	1	0.6	5	0.3	6	0.3
C	11	6.4	200	11.7	218	11.6
CA	4	2.4	79	4.6	83	4.4
CB	4	2.4	57	3.3	61	3.2
CD	1	0.6	32	1.9	33	1.8
CDC	1	0.6	8	0.5	8	0.4
CE	1	0.6	3	0.2	4	0.2
D	18	10.8	158	9.2	176	9.4
DB	13	7.8	63	3.7	76	4.0
DD1	5	3.0	67	3.9	72	3.8
DE	1	0.6	43	2.5	44	2.3
E	12	7.2	52	3.0	64	3.4
EA	5	3.0	31	1.8	36	1.9
EC	2	1.2	11	0.6	13	0.7
EE1	3	1.8	8	0.5	11	0.6
ED	6	3.6	38	2.2	44	2.3
F	6	3.6	28	1.6	34	1.8
AA			13	0.8		
AA1			2	0.1		
ACD			22	1.3		
BCB			20	1.2		
CBC			39	2.3		
CEC			5	0.3		
DC			42	2.4		
DD			14	0.8		
AE	3	1.8				

3.3 Comparison of whistle types and parameters

The following results are presented in two sections: interpopulation comparisons of whistle categories, univariate parameters and whistle rates and intrapopulation comparisons between groups, group size and years in the Shannon Estuary. Due to the small data set, Intrapopulation comparisons were not carried out for Cardigan Bay.

3.3.1 Comparisons between Cardigan Bay and Shannon Estuary populations

Frequency of occurrence of whistles types between populations

The results of the Chi squared test for independence showed a significant difference between the frequencies of occurrence of categories A, B and C between whistles from Cardigan Bay and the Shannon Estuary (Pearson chi-square test: P = 0.03, d.f. = 3). The proportion of category B whistles was found to be considerably lower in samples from the Shannon Estuary than those from Cardigan Bay. 9.4% of whistles recorded in the Shannon Estuary had the falling shape of category B whistles, while 16.4% of Cardigan Bay whistles were of this type. The opposite was found with category C. 11.7% of Shannon Estuary whistles were categorised as C type whistles. This percentage was 6.4% for the Cardigan Bay data. There was less variance found between the two populations on the Frequency of occurrence category A whistles and all other categories. Proportions of whistles in each of the three most common categories are given on Table 3.2

Table 3.2 Percentages and frequency of occurrence of whistles in each of the three most common categories (A, B, and C) and all others between Cardigan Bay (C. B.) and Shannon Estuary (Sh. E.) popiulations.

	A	B	C	Others	Total
% within Cardigan Bay	15.0	9.4	11.7	63.8	100.0
N	257	161	200	1097	1715
% within Shannon Estuary	18.1	16.4	6.4	59.6	100.0
N	30	28	11	98	167
% within Populations	15.3	10.1	11.3	63.3	100.0
N	287	189	211	1195	1882

Comparison of time and frequency parameters between populations

The average duration of whistles from the Shannon Estuary population were found to be significantly longer than the average duration of whistles recorded in Cardigan Bay (P = 0.00). Whistles from the Shannon Estuary averaged at 0.48 sec long (std. err. 0.011 sec) while Cardigan Bay whistles were on average 0.32 secs in length (std. err. 0.019 sec).

For all of the frequency parameters tested there was a significant difference between populations ($P < 0.05$). The start, end, max, min and mean frequencies were all higher in the Cardigan Bay population than in the Shannon Estuary. The average maximum frequency for whistles from Cardigan Bay was 16.575 kHz (std. err. 0.501 kHz) compared to the Shannon Estuary average maximum (12.219 kHz std. err. 0.077 kHz). The average mean frequency of Cardigan Bay whistles was found to be 4.209 kHz higher than Shannon Estuary whistles. The mean and standard error of all parameters tested between populations are presented in table 3.3.

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Table 3.3 The average and standard errors of start, end, maximum, minimum, mean and gradient of frequencies of bottlenose dolphin whistles from the Shannon Estuary and Cardigan Bay.

	Cardigan Bay		Shannon Estuary	
	Average	Sdt err	Average	Std err
Time	0.3175	0.0198	0.4829	0.0116
Start Frequency	14187	518	8515	101
End Frequency	14007	473	10112	91
Max	16575	502	11752	92
Min	11942	466	7420	77
Mean	14299	463	10090	63
Gradient	-858	1947	3820	422

Comparison of whistle rates between populations

Whistle rates were defined as the mean numbers of whistles in five minutes of recording. A non-parametric, Mann-Whitney U test was used to test for significance between the average amounts of whistles in five minutes of recording between Cardigan Bay and Shannon Estuary recordings. The results of the test show that there was no statistical difference between the two populations (P = 0.83). The average amount of whistles recorded in five minutes of recording from Cardigan Bay was 1.4 with a std. Err. of . 06. The Shannon Estuary average was 4.9 (std. err. 0.9).

3.3.2 Intrapopulation comparisons between years, groups and group sizes in the Shannon Estuary.

Variance between years (Shannon Estuary population)

Frequency of occurrence of whistle types between years

There was significant difference found in the frequency of occurrences of the three most common whistle categories (A, B and C) and all others, between years (Pearson chi-squared test: X^2 = 0.197, P = 0.00, d.f. = 6). No significant difference was found between frequency of occurrences of 2004 and 2005 whistles (P = .205, d.f. = 3). While category A whistles accounted for 18.1% and 18.2% for the 2004 and 2005 whistles respectively, only 9.9% of whistles from 2003 were of this type. Similarly 77.1% of the 2003 whistles were not categorised as A, B or C. These percentages were 54.3% and 55.9% for 2004 and 2005 respectively. This inter annual variability was also seen in some of the less common whistle types. For example, 7.8% of the whistles recorded in 2003 were of the type DB. However, only 1.5% of the 2005 whistles were categorised as this and there were no DB whistles found from 2004. The frequency of occurrence of each of the three main whistle categories within each year is presented on table 3.4.

Comparisons of time and frequency parameters between years

The durations of 2003 whistles were found to be significantly longer than those of 2004 or 2005 (P = 0.00). Whistles from 2003 had a mean duration of 0.573 secs. (Std. err. 0.01219), compared to means of 0.454sec (Std. Err. 0.03123) for 2004 and 0.478 sec (Std. err 0.00958) for 2005. There was no significant different in the durations of whistles from 2005 and 2004.

In comparisons of frequency parameters between years, the results showed significant different for all parameters tested. In the case of start, max, min and mean frequencies, each year was separate from the other two. Over all whistles from 2004 had the highest mean frequency (11.667 KHz, Std. err 0.328 KHz) and those from 2005 had the lowest (9.674 KHz, Std. err 0.07 KHz) (fig 3.3).

Table 3.4 Percentages and frequency of occurrence of bottlenose dolphin whistles in each of the three most common categories (A, B, and C) and all others between years.

	A	B	C	Other
2003 (%)	19.0	9.3	17.7	54.0
Count	173	85	161	492
2004 (%)	18.1	14.7	12.9	54.3
Count	21	17	15	63
2005 (%)	8.9	8.2	3.5	79.3
Count	63	58	25	560
Total (%)	14.8	9.2	11.6	64.3
Total Count	257	160	201	1115

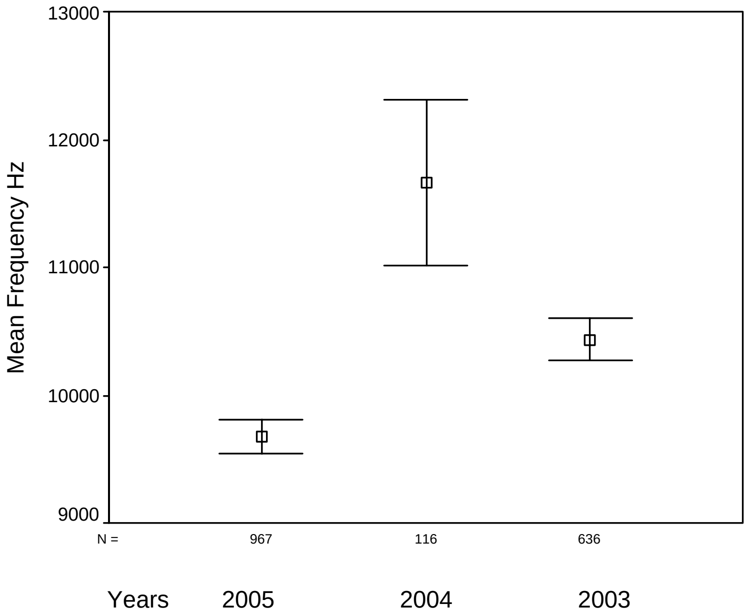

Figure 3.3 Error Bar plot showing the mean frequencies (Hz) and 95% confidence intervals of bottlenose dolphin whistles in the Shannon estuary in 2003 (1.00) ,2004(2.00) and 2005(3.00).

Variance between groups (Shannon Estuary population 2005)

No more than one group was encountered during each of the survey sessions. For the purpose of this test, each new day's data was treated as a different group*. In total seven groups were encountered over the survey period. Due to the small amount of whistles collected on the 10th August 2005 (n = 6) that data was omitted from this analysis.

Comparison of frequency of occurrence of whistle types between groups

The results of the Pearson chi-squared test for independence of the three main whistle categories (A, B and C) and all others between different groups showed no significant difference ($X^2 = 0.095$, P. = 0.00 d.f. = 15). Unlike the inter-annual comparison of frequency of occurrence of whistle types, where the 2003 data was significantly different from the other two years, this significant difference cannot be attributed to one outlying data set. The frequency of occurrence of each of the three main whistle categories within each group is presented on table 3.5.

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* See methods section for a note on the independence of data.

Comparison of time and frequency parameters between groups

Significant difference was found in the durations of whistles between groups (P. = 0.00). Whistles collected on the 28th July 2005 had the longest mean duration (0.7435 sec, Std err 0.0993) while whistles collected on the 26th July 2005 had the shortest (0.3625 sec, Std err 0.04968).

Significant variance was also found in all but one of the frequency parameters (P. = < 0.05). No variance was found in the starting frequencies between groups (P = .319). Mean frequencies ranged from 10.108 KHz (std err .119KHz) for the 27th July 2005 to 9.143 KHz (std err .295KHz) for the 26th July 2005 (fig 3.3)

Table 3.5 Percentages and frequency of occurrence of whistles in each of the three most common categories (A, B, and C) and all others within groups of dolphin in the Shannon Estuary 2005.

	A	B	C	Other	Total
% within 26th July		36.1	5.6	58.3	100.0
Count		13	2	21	36
% within 27th July	14.6	4.9	15.2	65.2	100.0
Count	24	8	25	107	164
% within 28th July	15.0	15.0	5.0	65.0	100.0
Count	3	3	1	13	20
% within 29th July	16.3	9.4	8.3	66.0	100.0
Count	47	27	24	190	288
% within 9th August	10.4	11.5	39.6	38.5	100.0
Count	19	21	72	70	182
% within 11th August	29.7	5.4	12.7	52.1	100.0
Count	77	14	33	135	259

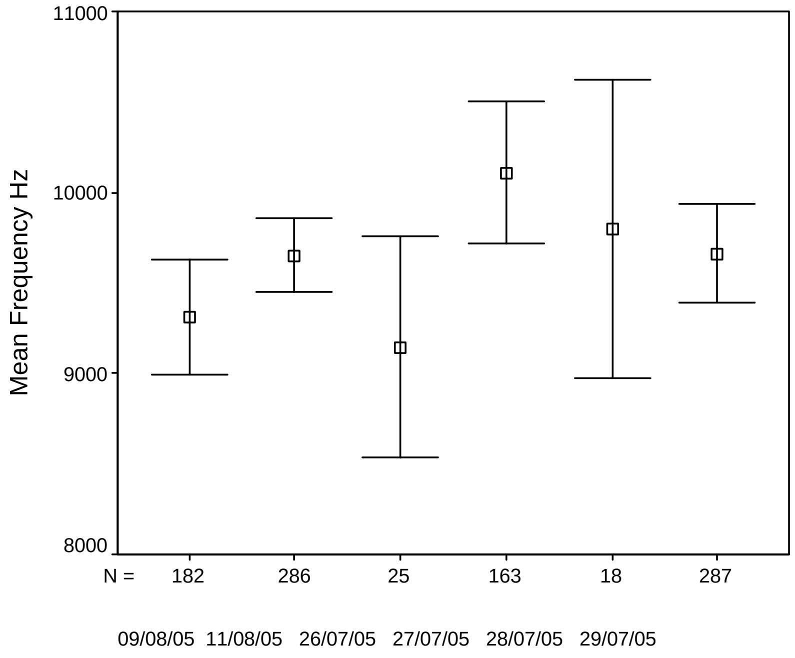

Figure 3.4 Error Bar plot showing the mean frequencies (Hz) and 95% confidence intervals of bottlenose dolphin whistles in the Shannon estuary between groups.

3.4 <u>Whistle Rates (Shannon Estuary 2005)</u>

Whistle rates were defined as the mean numbers of whistles in five minutes of recording. On average 4.95 whistles were recorded every five minutes during dolphin encounters in the Shannon estuary. There was however a large amount of variation between five minute sections (std dev 12.29). The most whistles recorded in five minutes, was on the 29/07/05 (n = 91). Of the 948 whistles recorded in 2005, only 10 whistles were not preceded by another whistle within the following five minutes. Whistle rates could not be calculated for 2004 and 2003 date. Therefore no inter-annual comparison of whistle rates was made.

Correlation between group size and whistle rate

Group size varied from 17 animals to one individual. The largest group was seen on the 27th July 2005 where 17 animals (3 mother and calf pairs among them) stayed around the hydrophone for one hour. In this time 139 whistles were recorded. Whistles from a lone individual were recorded on one occasion: between 12.00 and 12.25 on 09th August 2005: a total of 9 whistles were recorded, six of which came in the same five minutes.

Spearman's Rank order coefficient was used to test for a correlation between group sizes and whistle rate. The results of the test show that here was a positive relationship between average whistle per five minutes recording and group size (P. 0.212)(fig 3.5).

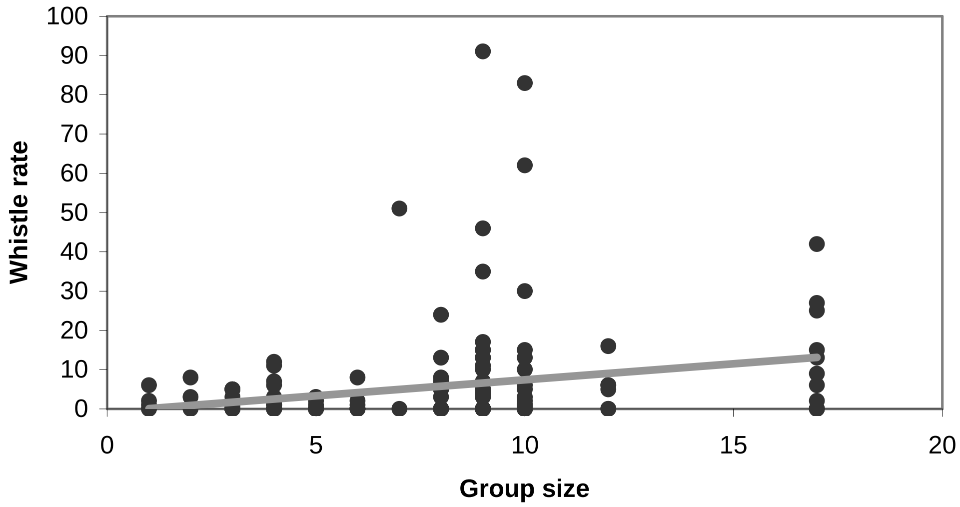

Figure 3.5 Plot of whistle rate against group size for the Shannon Estuary 2005. Whistle rate was defined as the mean amount of whistles recorded in a five-minute period. Trend line shows correlation between rate and group size (Spearmen's rank order Coefficient P = 0.212).

3.5 Dolphin Encounters and Tidal Times (Shannon Estuary)

Of the 7 visual encounters where dolphin activity and behaviour was recorded in the Shannon Estuary in 2005, all observations were on feeding animals. With the absence of any other behavioural data, any investigation attempting to associate behaviour with either whistle types or tidal and diurnal cycles was not possible. Instead a simple comparison was made looking for a correlation between the tidal cycle and the presence or absence of dolphins. Dolphins were encountered 7 times during the ebb tide at varying times of day. Figure 3.6 shows the ebb cycle and the amount of times the dolphins were seen at those times. Dolphins were most likely to be seen in the mid ebb tide rather than during the slack waters of either low or high tide. Dolphins were most often encountered 2 hours after high tide. Only on one of the survey days were dolphins not seen at this time.

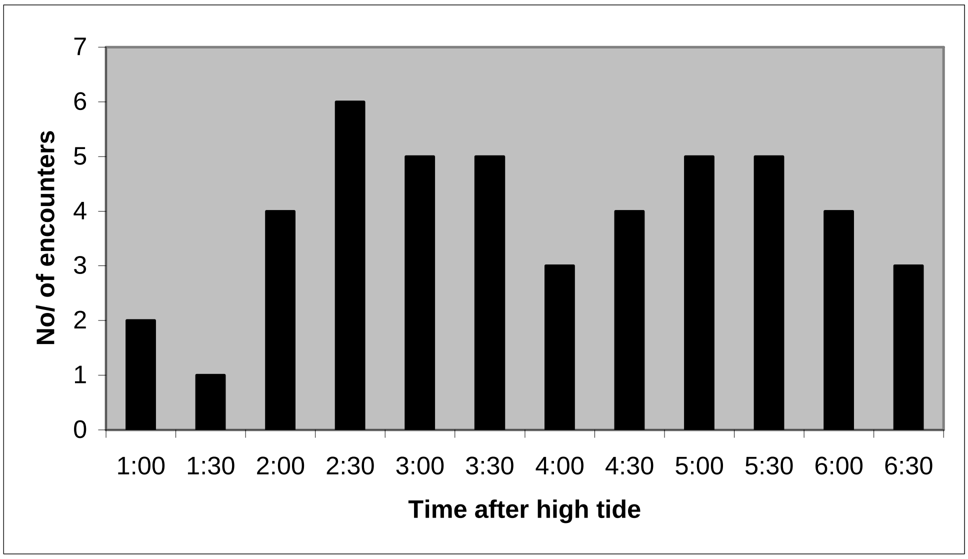

Figure 3.6. Ebb tide divided into half hour sections showing the number of bottlenose dolphin encounters within that tidal period, over the 7 survey days in the Shannon Estuary.

4. Discussion

4.1 Active and Passive acoustic survey methods.

The most obvious result in this study is the ratio of whistles collected from Cardigan Bay to whistles from Shannon Estuary. The Shannon Estuary accounts for the overwhelming majority of the whistles collected in this study. Field methods differ greatly between the study sites and it would seem that one was far more successful at collecting whistles than the other. In attempts to understand the natural behaviour of any animal, the use of passive techniques is generally preferable to active methods as the impact of active observation might influence the behaviour of the animal. The fixed hydrophone in the Shannon Estuary enabled surveys to be carried out over long periods of time at relatively little expense. Also when dolphins were present, the passive nature of this method allowed for recording over long time frames without impacting the dolphins. However, it is extremely difficult and often impossible to design passive acoustic methods for studying wild cetaceans. Encounter rates, locations, group size, behavioural context and number of individuals phonating cannot be controlled. None the less, passive acoustics have been used to identify and monitor cetaceans (Stafford & Moore 2005, Moore *et al.* 2002, Stafford *et al.* 1999). At first glance it would seem that the passive recording methods used in Shannon Estuary were far more successful at recording dolphin whistles than the active approach used in Cardigan Bay. It should be noted however, that no two locations are the same and the apparent success of the fixed hydrophone in the Shannon Estuary might not be the case if a hydrophone was fixed off the coast of Cardigan Bay. Although abundance estimates for the two populations are relatively similar (Rogan *et al.* 2002, Seawatch foundation sightings list), the Shannon Estuary is far more enclosed than Cardigan Bay resulting in a high encounter rate.

It should be noted that the larger number of whistles recorded in Shannon Estuary comes at a price. While the Methods used in the Shannon Estuary succeeded in collecting the greater number of whistles, the immobility of the hydrophone and the cyclic habits of the animals (see section 4.4) means that there is a strong possibility that the same individuals were recorded in more than one encounter and all encounters were of feeding animals. The lack of variety in behavioural data collected in the Shannon Estuary limited its use in this study. For the reasons stated above, the potential for pseudoreplication in this study was high (particularly in the comparison between groups) and must be carefully considered during interpretation of the results.

Two possible solutions to this problem would be to fix a number of other hydrophones in areas where other behavioural activities are observed or to periodically move the fixed hydrophone to other areas in order to gain samples from a range of locations. From a practical perspective, neither of these solutions are very feasible. As is often the case with scientific design, there is a conflict between ideal scientific method and the practical and financial implications of those methods. In the author's opinion, one course of action would be to investigate the true extent of the limitations of a fixed hydrophone. Comparisons between whistles collected using the fixed hydrophone with whistles collect actively over a range of locations and behavioural states would reveal the degree of limitation that comes with immobility.

4.2 Comparisons Between Cardigan Bay and Shannon Estuary Populations

Whistle types between populations.

Of the 32 different whistles categories that are described in this study, 21 were recorded in both the Shannon Estuary and Cardigan Bay. Of the 9 remaining whistle types, 8 were found to be exclusive to the Shannon Estuary and one was unique to Cardigan Bay. While the three most common whistle types for each population were the same, there was significant difference in the proportions that they were used. For example, category B whistles (falling) were the second most common whistle type in the Cardigan Bay data, followed by category C whistles (un-modulated). However, in the Shannon Estuary population category C whistles were second most common followed by category B.

The variation of proportion of whistle types used between the populations could be an example of a potential dialect between groups, as seen in killer (Yurk *et al.* 2002) and sperm whales (Whitehead *et al*. 1998). Dolphins have been observed to model their whistles on surrounding conspecifics (Fripp et al. 2005, Sayigh *et al.* 1995). Mimicry of whistles could result in a population developing its own dialect through vocal learning. Variation in dolphin whistles has been shown to occur between geographically isolated populations (Bazúa-Dúran 2004, Wang *et al.* 1995, Morisika *et al* 2005). However, in studies on the vocal dialects of killer and sperm whales, it has been suggested that dialects are the result of cultural transmission rather than geographic isolation (Randell and Whitehead 2002, Deeke *at el* 2000). Killer and sperm whales both live in stable matrilineal groups and although there may be some degree of transfer and interaction between groups (Christal *et al.* 1998), this is nowhere near on the same scale as seen in dolphin society. Bazúa-Dúran and Au (2004) point out that the fisson-fussion society, observed in bottlenose dolphins, would render vocal dialects less distinct then those of killer and sperm whales. Therefore, the variation observed in the proportion of common whistle types between populations could be due one or more of a range of environmental, ecological or behavioural factors.

The context in which whistles were recorded might have a part to play in the variability between populations. In the Shannon Estuary, all recordings were of foraging animals. The Cardigan Bay recordings however, were of feeling, socialising and travelling dolphins (although the majority of whistles came from 28th June 2005, where animals were observed to be foraging). In a study examining bottlenose dolphins off the coast of Costa Rica, Acevedo-Gutiérrez and Stienessen (2004) conclude that, bottlenose dolphins produce more whistles while feeding than during resting periods. It was suggested that, the increase in whistles during feeding periods was related with increasing group numbers. An increase in group numbers would benefit these animals by increasing both feeding efficiency and defence from other competing species (Acevedo-Gutiérrez 2002). The former might be more relevant to this study as there seems to be no other top predator competing with either of the study populations. The hypothesis that an increase in whistles during periods of feeding is a strategy to increase group size is supported by the idea that dolphin whistles (specifically signature whistles) are cohesion calls (Janik and Slater 1998). Although Acevedo-Gutiérrez and Stienessen (2004) describe an increase in whistle rate during periods for feeding without making reference to the whistle types used, dolphins have been found to produce different sounds relative to their behavioural context (Herzing 1996). If dolphins do exhibit different vocalisation characteristics in different contexts, then the over representation of feeding dolphins in the Shannon Estuary could skew the data in some way. Due to the lack of recording during different behavioural states, a comparison of vocalisations in different behavioural contexts was not possible in this study

It should be noted that, while there was variation found in the frequency of occurrence of common whistle types between species, 66% of the whistles described in this study were common to both populations irrespective of how often they were used. In a comparison of the whistles of spinner dolphins (*Stenella longirostris*) in the Hawaiian Islands, Bazúa-Dúran and Au (2004) found that populations had common characteristics in approximately 48% of their whistles. Similarity between the whistle repertoires of the two populations could be attributed to fluidity and transition between the populations. Bottlenose dolphins have been reported along the southern and eastern coasts of Ireland and in the Irish Sea (Irish whale and dolphin group sighting list). Hence, there may be some interaction between individuals of both populations. Alternatively, similarity in the vocalisations of the two populations could be a cultural throwback to divergence. If both populations arose relatively recently from the same origins than degree of similarity in the vocalisations may be attributable to this. Dolphins have been reported in the Shannon since 1835 (Knott 1835) but it is unknown when dolphins first began to inhabit the estuary. It is also unknown when bottlenose dolphins first began to colonise the Cardigan Bay. Dialects in dolphin whistles could be the result of vocal learning from mimicry of conspecifics. Although bottlenose dolphin society is a great deal more fluid than that of killer and sperm whales, the mimicry of dolphin whistles (descried in Fripp et al. 2005, Janik 2000 Sayigh *et al.* 1995, Tyack 1986) could result in dialects and specific whistle types being culturally transmitted between matrilineal lines. While the influence of these potential maternal lineages might not be as pronounced as in killer whale clans (Deeke *et al* 2000), a potential dialect hierarchy may exist at some level. Therefore, if the two populations share some common lineage, they may also share some vocal characteristics in their respective whistle repertoires. This could explain why 66% of the whistles categories described in this study were common to both populations. To further investigate the possibility of this divergence theory it would be beneficial to examine the whistle repertoire of the bottlenose dolphin population in the Moray Firth, Scotland and compare them to the populations examined in this study.

Of the remaining 9 whistle types that were unique to one or other of the populations, 8 were found in the Shannon Estuary data. This is most probably the result of the small sample size of Cardigan Bay whistles analysed in this study. It is possible that a higher sample size could yield either a greater number of whistles that were unique to Cardigan Bay or examples of the whistles that have only been seen in the Shannon Estuary. Another possible explanation for the presence of unique whistles within the populations is that they are examples of signature whistles. This is most likely the case for categories CDC and DD from the Shannon Estuary as these whistles were generally seen in close succession in repeated cycles as described by Janik (1994). This is of particular interest in the case of category CDC as examples of this whistle have been recorded in 2003, 2004 and 2005. Detection of the signature whistles of wild dolphins in this way could provide researchers with a new technique of monitoring population dynamics. By recognising individual's signature whistles it would be possible to identify individuals from acoustic recordings. This would be of particular use for resident populations of bottlenose dolphins, as their coastal fidelity and relatively low group sizes would make monitoring in this way easier than for larger offshore populations.

Time and Frequency parameters between populations.

The average duration of whistles from Cardigan Bay was found to be significantly shorter than those from the Shannon Estuary. A possible explanation for the difference in whistle length between populations could be environmental. In a comparison of the whistles of bottlenose dolphins from different geographic areas, Ding *et al.* (1995) concluded that longer whistle durations could be linked with areas of high background noise. No measurements of background noise levels were taken in either of the study areas. Both Cardigan Bay and the Shannon Estuary experience regular boat traffic from tourist and fishing vessels. While no comparison of the boat traffic between the sites was made, the Shannon Estuary is a major shipping route with 10 million tons of boat traffic per annum (Rogan *et al* 2000). Personal observations during the 2005 study period would conclude that boat traffic in the Shannon Estuary is considerably heavier than in Cardigan Bay. The Shannon Estuary is also a far more enclosed area than Cardigan Bay. This could cause low frequency noise, produced by heavy boat traffic, to reflect off the land on either side of the estuary and contribute to increasing the background noise levels. Due to the heavier boat traffic and geographical conditions it would seem that the Shannon Estuary is a noisier environment than Cardigan Bay. The link between whistle duration and background noise described in Ding *et al.* (1995) would provide an explanation to why whistles in he Shannon Estuary were found to be significantly longer than those of Cardigan Bay.

The comparisons of frequency parameters of whistles between the two populations revealed that whistles from Cardigan Bay had significantly higher frequencies for all parameters tested. This variance in frequency between the populations would suggest that the whistles of bottlenose dolphins in Cardigan Bay are significantly higher in frequency than whistles of dolphins in the Shannon Estuary. The average maximum frequency for the Shannon Estuary population (11.754 KHz) was found to be lower than the average minimum frequency for the Cardigan Bay population (11.942KHz). This variation in the whistle characteristics between the two populations could be the result of genetic or cultural isolation.

Although the physiological mechanisms of dolphin whistles are still unclear, some authors have suggested that variation in the vocal characteristics of dolphins could arise from genetic differences in vocal tract morphology (Janik and Slater 1998). A difference in morphology between groups is not uncommon among delphinid cetaceans. Morphotypic diversity is seen to occur in killer whales (*O.orca*) (Visser & Makelainen 2000) spinner dolphins (*S.longirostris*) (Perrin *et al.* 1991) and common dolphins (*D.delphus*) (Jefferson & Van Waerebeek 2002). In an examination into the genetic diversity between populations of bottlenose dolphins, Natoli *et al.* (2004) found significant differentiation among all regional populations tested suggesting restricted gene flow for both males and females. However, in their study, *Natoli et al.* (2004) obtained samples of the eastern north Atlantic population from stranded animals in Scotland and southern England. It is therefore possible that the genetic diversity found between populations in their study was primarily on a global scale and does not incorporate populations in as close proximity as the Shannon estuary and Cardigan Bay. To the author’s knowledge, no studies have investigated the mating behaviour or population genetics of dolphins in either the Shannon Estuary or Cardigan Bay. It is far beyond the scope of this study to speculate whether the two populations are genetically or reproductively isolated. The cultural transmission of vocal characteristics in bottlenose dolphins has already been discussed in this section. As well as causing variance in whistle types between the populations, cultural isolation could be responsible for whistle characteristics, such as frequency, to differ between populations. Many studies have found that parameters focusing on the frequency of dolphin whistles when comparing between species and populations provide the most definitive results (Bazúa-Dúran 2004, Bazúa-Dúran and Au 2004, Morisaka *et al.* 2005). This would suggest that variations in frequency between populations of dolphins are not uncommon.

The difference observed in the frequencies of whistles between the populations could be a result of the different conditions in which whistles were recorded in the two study sites. Due to the immobility of the hydrophone used in the Shannon Estuary, there was a great deal of variation in how far the animals were from the hydrophone between encounters. Although the exact location of a vocalising individual was impossible to obtain, groups of dolphins were anywhere from 2 km to a few meters from the hydrophone while whistles were being recorded. In Cardigan Bay, the distance of dolphins from the hydrophone was between 100 and 400 meters for all encounters. Tyack (1985) reported that the underwater intensity of bottlenose dolphin whistles recorded 1m from the hydrophone, could vary by at least 15 dB, from 125 to 140 dB re 1mPa. The lower frequency elements of bottlenose dolphin whistles are usually of a higher intensity than the higher frequency elements (Caldwell *et al*., 1990). Attenuation, of underwater sound is proportional to frequency. Sounds with higher frequencies travel less distance before being absorbed than sounds with lower frequencies. Attenuation therefore leads to the higher frequency components of loops being lost before the lower frequency components. Hence, the high frequency components of whistles are lost if the vocalizing animals are farther from the hydrophone. A greater average distance of dolphins from the hydrophone in the Shannon estuary could explain why the frequency of recorded whistles was significantly lower than whistles from Cardigan Bay.

<u>Whistle rates between populations</u>

There was no statistical difference in the whistle rates of the two populations. This came as a surprise, as from personal observations the mean rate from Shannon Estuary was expected to be higher than Cardigan Bay. Lesage *et al.* (1999) observed that increased vessel noise cause belugas (*Delphinapterus leucas*) to modify their calling rates. The degree of modification was dependant on the size of the vessel. Therefore, it was hypothesised that the high background noise levels caused by heavy boat traffic in the Shannon Estuary (discussed above) would result in a higher vocalisation rate. This however, was not the case. Due to the different survey techniques used at both sites and the limited sample size of whistles collected in

Cardigan Bay, the results of this comparison are far from definitive. More data is required before the results of this study can be confidently confirmed or denied.

4.3 Inrtapopulation comparisons in the Shannon Estuary.

Variance between groups in the Shannon Estuary.

Interpretation of the results of the comparisons between groups should be treated with a degree of caution. Groups were defined as animals that were encountered on different days. However, location, tidal state and observed behaviour did not differ between days. It is very possible that different groups consisted of some or even all of the same individuals. The variation found between groups could be attributed to differences in group composition. Individual bottlenose dolphins in Sarasota Bay vary their vocalisations relative to their surrounding conspecifics (Watwood *et al.* 2005). Males that were voluntarily separated from their alliance partners where most likely to use their signature whistles while the majority of whistles produced by a pair of allied males in a courtship with a female were variant whistles. Group dynamics during encounters in the Shannon Estuary were ever-changing, with groups frequently separating and rejoining. The variation in whistle characteristics between groups of the same population is most likely representative of the fluidity of bottlenose dolphin society. Intrapopulation variations in dolphin whistles were found in Indo-Pacific bottlenose dolphins (Morisaka *et al.* 2005) and spinner dolphins (Bazúa-Dúran and Au 2004). Variation with groups of dolphins should be accounted for in studies examining larger scale comparisons between populations.

Variance between years in the Shannon Estuary.

The frequency of occurrence of the three most common whistle categories was found to be significantly different between years. Whistles recorded in 2003 were separate from the other two. Comparisons of the whistle parameters showed a significant difference between each year and the other two. Temporal variation in delphinid vocalisations has been described in killer whales (Deeke *et al* 2000) and Indo-Pacific bottlenose dolphins (Morisaka *et al.* 2005). Annual differences in the vocalisation characteristics of a population, is strong evidence for the possibility of vocal learning. The fact that whistles from 2005 were more closely related to whistles from 2004 than 2003 further supports the theory of continual change over time. If whistles characteristics do continually change, then the accumulation of changes over time would result in geographic variations between isolated populations. Unfortunately the possibility of bias caused by recording of the same individuals over successive years cannot be excluded. Also the influence of immigration of new members into the population is unknown. However, regardless of the process, variation of dolphin whistles over time is an important consideration when studying geographic variations of population.

Whistle rate and group size in the Shannon Estuary.

Common sense dictates that in increase in group number would correlate with an increase in the overall whistle rate; as was found to be the case in this study. Correlations between group number and vocalisation rate have been found in other dolphin species (Wakefield 2001, Van Parjis *et al.* 2002). In the case of the common dolphin *D.delphus* however, Scullion (2004) found a curved relationship where the whistle rate of a single individual was found to be higher than the rate of a small group of animals. Scullion (2004) also observed an exponential relationship between whistle rate and group size. The relevance of this may not be applicable to studies of inshore bottlenose dolphins, as group sizes of common dolphins range into the hundreds and the maximum group size recorded in this study was 17. Pacific humpback dolphins *Sousa chinensis* usually occur in groups of no more than 10 animals (Van Parjis *et al.* 2002). In a comparison of group size and vocalisation rate, Van Parjis *et al.* (2002) found that the size of most humpback dolphin schools could be estimated accurately using acoustic techniques. In their study however, Van Parjis *et al* . (2002) examined all vocalisations of humpback dolphins; i.e whistles, clicks and pulse sounds. Variables such as behavioural state were also ignored. The use of whistle rate to estimate group size could provide researchers with a new technique to monitor bottlenose dolphin populations. Unlike visual survey techniques, acoustic methods have the advantage of independence from observer bias and weather conditions. Although, a situation where dolphins were present and were not vocalising is possible. Acoustic survey methods should be used to supplement visual techniques rather than replace them.

4.4 <u>Dolphin encounters and tidal times in the Shannon Estuary.</u>

The results show that the activity of bottlenose dolphins is closely correlated with tidal times. Dolphins were most often seen during the mid ebb tide. This result corresponds with the findings of Ingram (2000). Dolphins were most frequently observed swimming against the current during these periods. Swimming against the current has been described in a number of cases (Shane 1980, Shane 1990). Some studies however have reported dolphins frequently swimming with the current (Harzen 1998), while others show no preference (Felix 1994). Groups travelling into strong tides often remained stationary or were even swept downstream by the current. In general dolphins would swim against the current as far as the hydrophone and remain stationary in that vicinity. While swimming into the current is clearly energetically expensive, dolphins were observed tossing salmon on a number of occasions. Swimming against the tide may be a behavioural strategy to maximise the number of prey encountered (Ingram 2000). The presence of the hydrophone seemed to have little impact in the dolphins. It is more likely that dolphins remained stationary in that particular area, as Kilcredaun pt. is a headland. It is possible that the bottleneck effect caused by the headland would further increase the number of prey fish encountered. Dolphins remained close to the shore where currents are weaker than in the middle of the estuary. The findings of this study and Ingram (2000) indicate that dolphins in the Shannon Estuary follow cyclic patterns of behaviour that are influenced by the tide and time of day. By understanding these patterns in this and other populations, researchers could greatly increase their proficiency in studying resident dolphin populations.

4.5 <u>Further work</u>

While results of the statistical analysis showed variance between the two populations, this project provides nothing more than a base point from which further study is required before the variation in vocal characteristics of bottlenose dolphins in Cardigan Bay and the Shannon Estuary can be fully described. The two most obvious limitations in this study were the small sample size from Cardigan Bay and the limitations associated with the fixed hydrophone in the Shannon Estuary. Future studies that could overcome these and other limitations and improve techniques and methods are listed below.

- More survey effort in Cardigan Bay to increase the sample size and insure an even representation of the whistle repertoire of the population.
- Samples of whistles from dolphins in other behavioural states in the Shannon Estuary to insure an even representation of the full whistle repertoire of the population.
- Exploration into the extent of bias introduced by the fixed hydrophone. Comparisons of whistles over a range of behavioural states. Incorporation of photo identification methods to identify group members and discriminate between groups.
- Inclusion of whistles from bottlenose dolphins in the Moray Firth could provide further insight into the relationship between the three populations. The results of this study would have conservation implications for bottlenose dolphins throughout Britain and Ireland.
- Comparison of passive and active monitoring methods in the same location and during the same behavioural state could provide valuable insight into the influence of active survey methods on bottlenose dolphins.
- An investigation into the genetic variation of the two populations would provide evidence of any interbreeding between Cardigan Bay and the Shannon Estuary. This would provide a solid background to hypothesis possible functions causing variation in the whistle characteristics between the populations.

5. Conclusion

Bottlenose dolphin whistles recorded in the Shannon Estuary were significantly shorter and lower in frequency than whistles recorded in Cardigan Bay. The frequency of occurrence of the three most common whistle categories was also different between the populations. Therefore, the first hypothesis of this study can be accepted. The mechanism driving this observed variation remains unclear. Differences in geographical, ecological, behavioural and genetic factors between the populations cannot be ruled out. Another element that may have contributed to the variation observed is that of differing methods between the sites. It would seem that while the passive methods used in the Shannon Estuary resulted in a far greater number of whistles being recorded, the quality of the data was compromised.

Variance between whistles within the Shannon Estuary was also found. Frequency of occurrence of whistle types and univariate parameters were seen to differ between years and groups. For this reason the second hypothesis must be rejected. Intrapopulation variation must be considered when comparing dolphin whistles between populations.

The third hypothesis of this study can be accepted as a linear correlation between group size and whistle rate was found. Whistle rate was shown to increase with group size. Group numbers ranged from 1 individual to 17 animals.

Dolphins were most often seen at the study site during the middle two hours of the ebb tide. All observations were of feeding animals. It would seem that Kilcreadaun pt is a regularly used feeding ground and is visited periodically by bottlenose dolphins. The absence of data from other locations and other tidal states limits the conclusions that can be made from this result.

In summary the results of this study have provided a starting point from which the relationship between bottlenose dolphins whistle in Cardigan Bay and the Shannon Estuary can be fully understood. The information obtained and further questions raised from interpopulation comparisons of dolphin whistles could provide insight into the social behaviour, distribution and ecology between populations of bottlenose dolphins in Britain and Ireland. This insight could be applied to improve upon conservational methods currently employed to protect this species within our waters.

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Appendix 1. Sighting Forms used in a) Cardigan Bay and b) the Shannon Estuary in 2005.

A) Cardigan Bay sightings form

Date	Time	Recording Volume	GPS	Group Size	Dist Start	Dist End	Observed Behaviour
			N 52^0 W 004^0				
			N 52^0 W 004^0				
			N 52^0 W 004^0				
			N 52^0 W 004^0				
			N 52^0 W 004^0				
			N 52^0 W 004^0				
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			N 52^0 W 004^0				
			N 52^0 W 004^0				
			N 52^0 W 004^0				
			N 52^0 W 004^0				
			N 52^0 W 004^0				
			N 52^0 W 004^0				

Behaviour
FF= feeding
FS= suspected feeing
T= travelling

B) Shannon Estuary Survey form.

Date	Tape No	Sea State	High tide	Wind direction	Wind Speed
				Location	
Recording Level		Cloud Cover			
Time	Distance	Group No	Group Size	Group Structure	Behaviour

Behaviour:
Surfacing mode:

Quite . Slow or normal surfacing with no foam
Peppy . Energetic surfacing
Arial. Leaps breaches etc.
Stationary. Logging or finning

Overall Behaviour:
Travelling. Clearly directional movement and fast or normal speed
Foraging. Tosses, surface rushes.
Ariel. Leaps

Other Tail slaps, side slaps, surface rolls, bow riding, socialising behaviour.

Appendix 2.

Statistical information of whistle categories of bottlenose dolphins recorded in Cardigan Bay and the Shannon Estuary.

Information on the 32 whistle categories are presented as follows:

Title.

Name

The sites in which the whistle was recorded.

Verbal description of the contour.

Number of examples of the category in each sites and overall.

Descriptive statistics
Table of the mean whistle parameters (described in Materials and Methods) and standard deviation in each site and overall.

Contour Shape
Idealised contour shape (not to scale) used to distinguish the category

Example
Spectrogram showing an example of the whistle category from the data used in this study. Note that natural whistle contours could differ from idealised representations of contour shape.

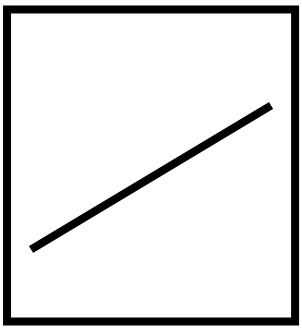
Category A. (Both sites)

Continually rising tone with little or no modulation.

Cardigan Bay	30 whistles 18.1%
Shannon Estuary	257 whistles 15.0%
Total	287 whistles 15.3%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.27888	0.26766	0.41610	0.28000	0.39100	0.23408
Start	8092.63	5446.82	8689.80	3327.05	8627.16	3599.52
End	10705.48	6263.69	10547.56	2928.93	10564.13	3416.16
Max	11050.52	6257.91	12341.21	2912.47	12205.82	3425.11
Min	7533.25	5522.27	7615.42	2503.00	7606.80	2951.14
Mean	9513.53	5699.26	10029.28	2283.64	9975.18	2827.77
Gradient	17138.72	30864.03	5367.05	19228.34	6610.54	21006.86

Contour Shape



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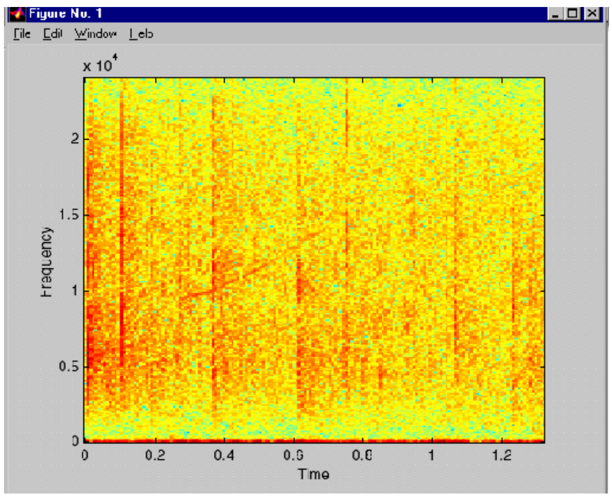


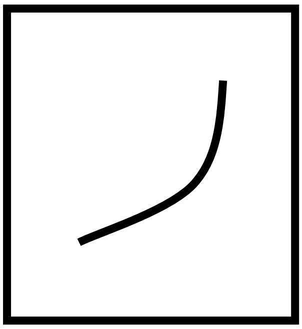
Category AA. (Shannon Estuary only)

Continually rising tone with an un-sweeping positive modulation.

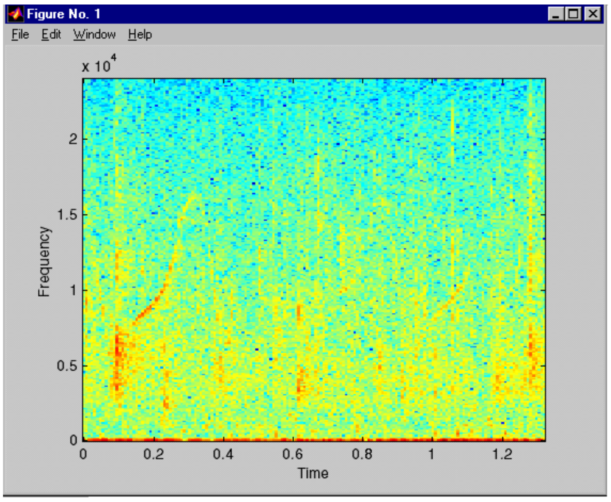
Cardigan Bay	0 whistles	0%
Shannon Estuary	13 whistles	0.8%
Total	13 whistles	0.8%

Parameter	Cardigan Bay	Shannon Estuary		Total
		0.27	0.20	
Duration		9332.92	3316.34	
Start		11107.13	2288.78	
End		12320.21	1344.20	
Max		7999.87	2649.01	
Min		10301.59	1707.12	
Mean		9466.321	22908.69	
Gradient				

Contour Shape



Example



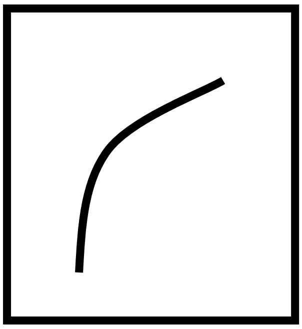
Category AA1. (Shannon Estuary only)

Continually rising tone, levelling off towards the end. Recorded at both sites.

Cardigan Bay	0 whistles 0%
Shannon Estuary	2 whistles 0.1%
Total	2 whistles 0.1%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration			0.07993	0.06521		
Start			5819.09	723.79		
End			11370.10	779.46		
Max			11370.10	779.46		
Min			5819.09	723.79		
Mean			8508.28	518.21		
Gradient			11216.77	211.02		

Contour Shape



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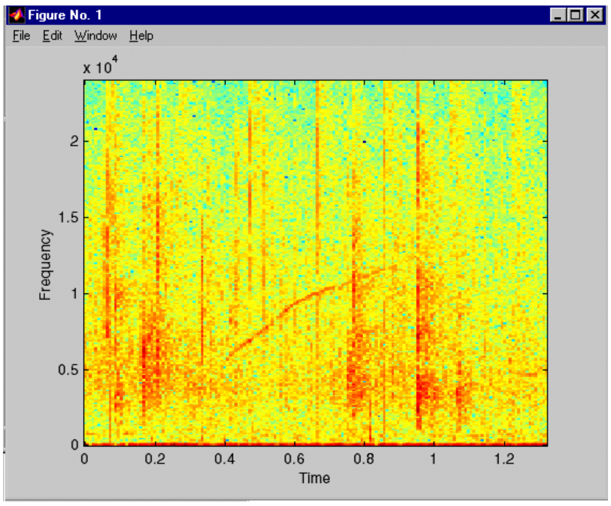


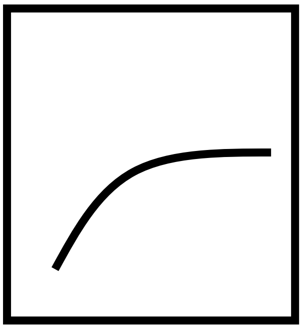
Category AC. (Both sites)

Initially rising tone with no inflection followed by a level modulated section.

Cardigan Bay	3 whistles 1.8%
Shannon Estuary	125 whistles 7.3%
Total	128 whistles 6.8%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration	0.30899	0.20617	0.45913	0.25179	0.45558	0.25117
Start	11234.21	8313.14	8616.45	3396.97	8678.78	3539.59
End	16079.00	8135.70	10121.87	2757.73	10263.70	3051.72
Max	16640.00	8680.87	11672.00	2576.44	11790.29	2874.49
Min	11234.21	8313.14	7203.77	2404.17	7299.73	2669.76
Mean	14219.67	8357.78	9567.25	2073.06	9678.02	2412.30
Gradient	25681.49	22519.55	3708.59	13037.75	4231.75	13613.55

Contour Shape



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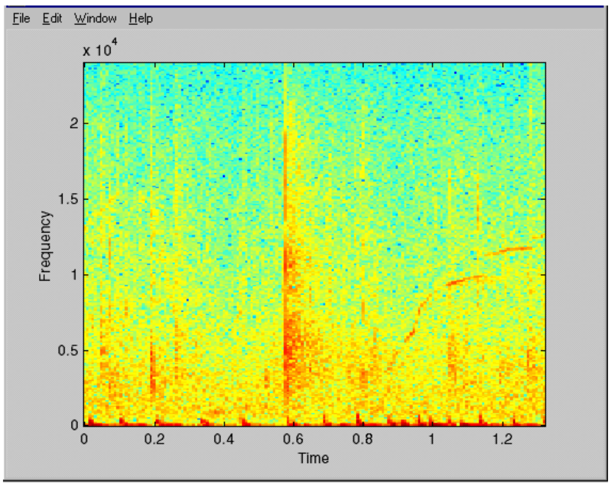


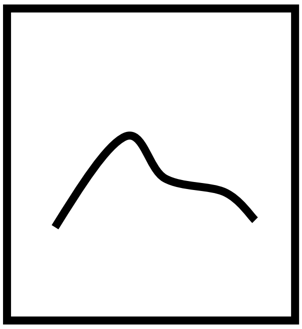
Category ADC. (Shannon Estuary only)

Continually rising section with little or no modulation followed by a negative inflection and a falling tone with a single modulation.

Cardigan Bay	0 whistles	0%
Shannon Estuary	22 whistles	1.3%
Total	22 whistles	1.3%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration			0.87239	0.24668		
Start			8402.11	2313.95		
End			10309.01	3025.86		
Max			12080.04	2526.94		
Min			7154.97	1440.15		
Mean			9821.57	1723.38		
Gradient			2451.92	8865.80		

Contour Shape



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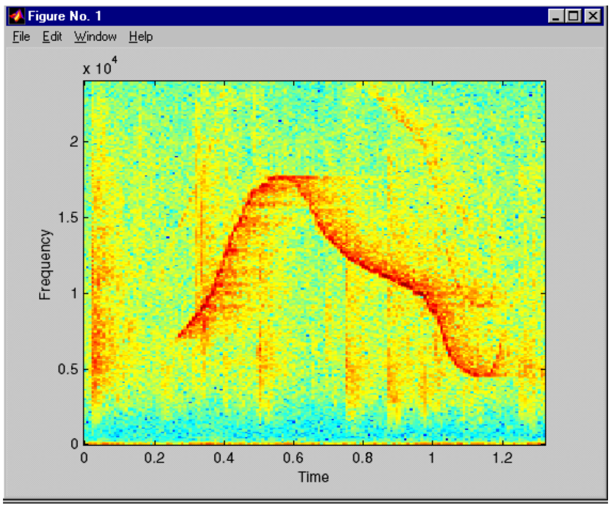


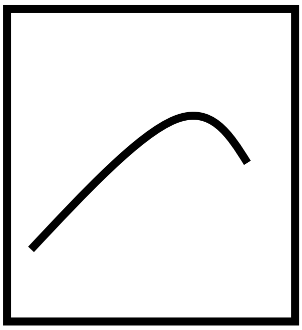
Category AD. (Both sites)

Continually rising tone ending with a negative inflection, Starting frequency always lower than ending frequency.

Cardigan Bay	7 whistles 4.2%
Shannon Estuary	73 whistles 4.3%
Total	80 whistles 4.3%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.42343	0.18339	0.47829	0.21598	0.47343	0.21283
Start	8796.66	4363.11	8787.78	3091.67	8788.57	3188.26
End	12462.35	5815.46	10271.00	2711.45	10465.17	3112.31
Max	14560.44	6606.28	12607.56	1790.88	12780.60	2566.81
Min	7667.96	4228.24	7266.90	2203.57	7302.43	2410.05
Mean	11462.42	5257.22	10051.92	1605.58	10176.90	2152.98
Gradient	12541.50	14081.96	3914.42	10758.43	4678.85	11256.02

Contour Shape



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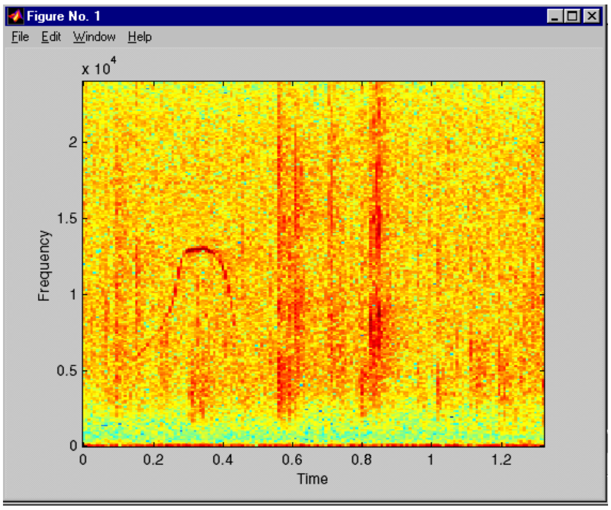


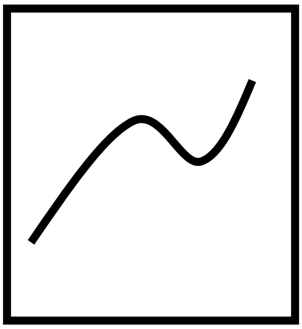
Category AE. (Cardigan Bay only)

Continually rising tone ending with a negative inflection followed by a positive inflection. Starting frequency always lower than ending frequency.

Cardigan Bay	3 whistles	1.8%
Shannon Estuary	0 whistles	0%
Total	0 whistles	1.8%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.86310	0.15224				
Start	6185.17	3265.27				
End	8662.34	4383.71				
Max	9966.11	3252.75				
Min	5741.88	3125.14				
Mean	7454.80	2695.00				
Gradient	3070.63	2081.52				

Contour Shape



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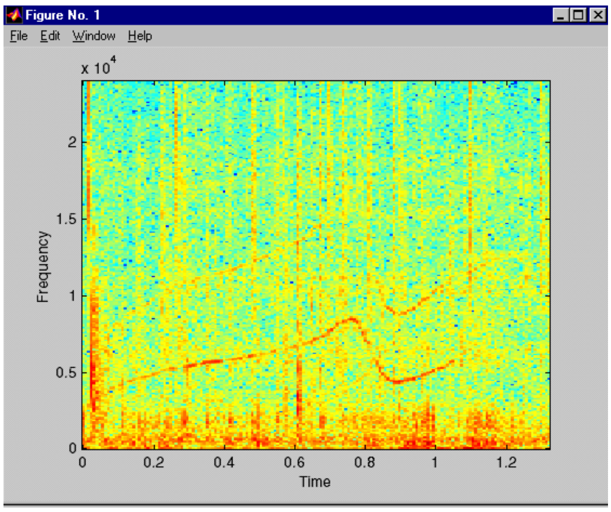


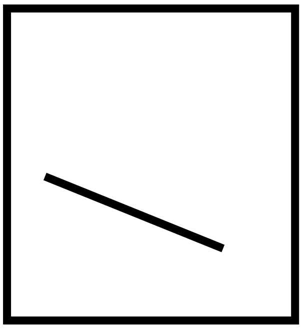
Category B. (Both sites)

Continually falling tone with little or no modulation.

Cardigan Bay	28 whistles	16.2%
Shannon Estuary	161 whistles	9.4%
Total	178 whistles	9.5%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.20460	0.12196	0.38065	0.25233	0.35457	0.24547
Start	19456.63	5672.07	9691.14	3836.54	11137.88	5408.00
End	15320.23	4830.08	10132.36	3054.69	10900.94	3834.91
Max	19737.54	5061.21	12831.48	2814.59	13854.60	4058.56
Min	15095.62	5293.60	7756.77	2659.53	8844.01	4108.19
Mean	17355.08	4851.99	10363.48	2360.03	11399.27	3784.57
Gradient	-23977.84	33450.55	-240.02	10717.36	-3756.73	18164.35

Contour Shape



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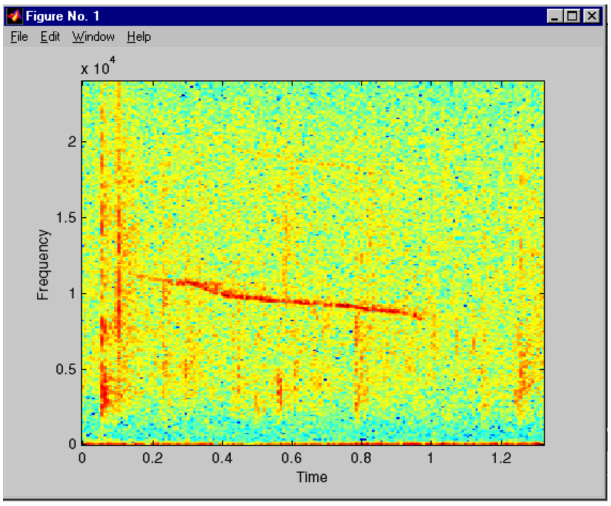


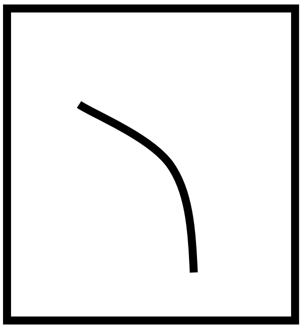
Category BB. (Both sites)

Falling tone with levelling gradient but remaining negative throughout.

Cardigan Bay	2 whistles 1.2%
Shannon Estuary	6 whistles 0.3%
Total	8 whistles 0.4%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration	0.10404	0.03029	0.30431	0.21343	0.25424	0.20313
Start	12872.36	1351.20	7597.85	1863.07	8916.48	2949.86
End	9133.67	881.22	11008.96	2993.15	10540.14	2695.14
Max	12872.36	1351.20	12156.87	3299.13	12335.74	2853.94
Min	9133.67	881.22	7361.64	1422.81	7804.65	1493.25
Mean	10459.52	807.78	10315.85	2116.78	10351.77	1816.09
Gradient	-36840.06	6208.95	3941.25	4517.24	-6254.08	19402.69

Contour Shape



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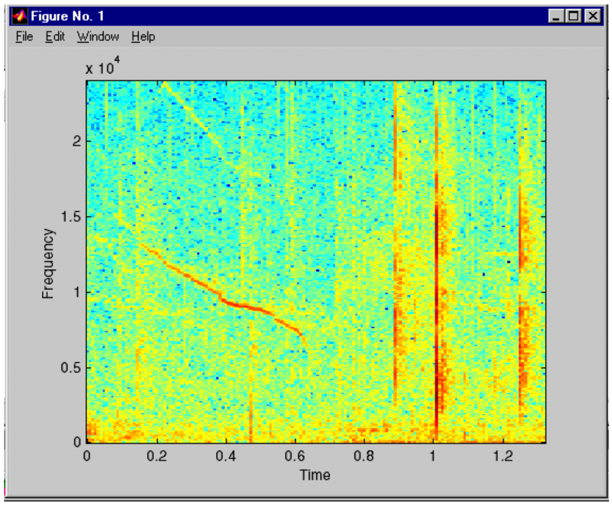


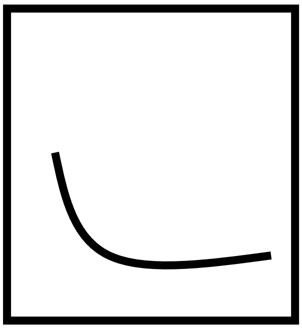
Category BC. (Both sites)

Initially falling levelling of to a flat section.

Cardigan Bay	4 whistles 2.4%
Shannon Estuary	53 whistles 3.1%
Total	57 whistles 3.0%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration	0.2600	0.1349	0.3757	0.2215	0.3673	0.2177
Start	16908.68	4451.83	9135.31	3059.42	9700.65	3730.71
End	12645.96	4156.95	10044.94	3031.82	10234.11	3152.10
Max	16926.29	4421.14	12047.96	2794.88	12402.75	3154.88
Min	12420.50	4181.25	7715.66	2034.31	8057.83	2514.67
Mean	14103.64	4328.88	9863.96	2039.50	10172.30	2475.31
Gradient	-18889.39	9463.23	1770.69	17608.01	268.14	17926.78

Contour Shape



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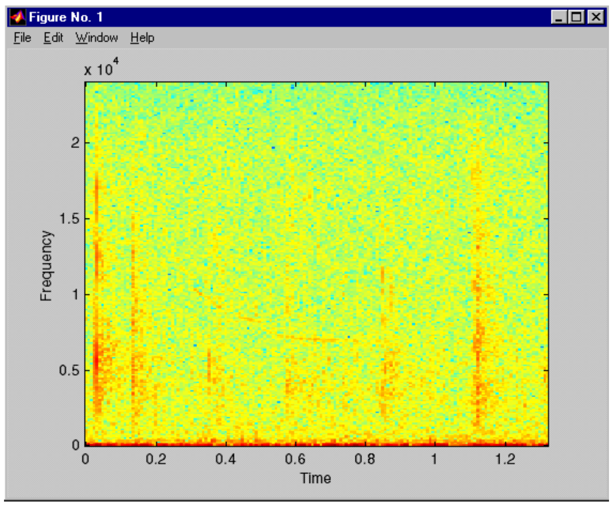


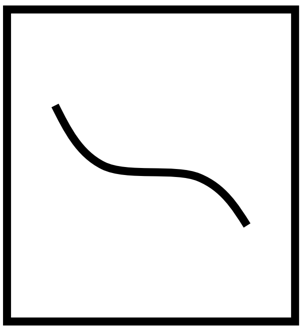
Category BCB. (Shannon Estuary only)

Initially falling section levelling off and a falling again.

Cardigan Bay	0 whistles	0%
Shannon Estuary	20 whistles	1.2%
Total	20 whistles	1.2%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration			0.43017	0.21356		
Start			10184.51	3102.05		
End			10438.68	2634.24		
Max			12798.48	2572.54		
Min			8418.01	2507.59		
Mean			10662.29	2082.40		
Gradient			-1070.24	13996.73		

Contour Shape



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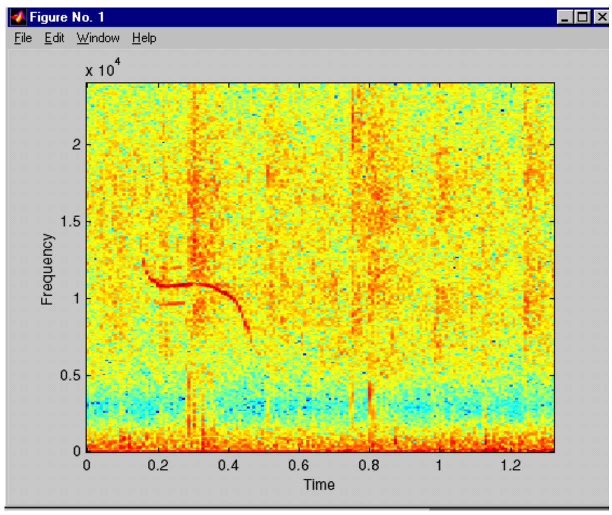


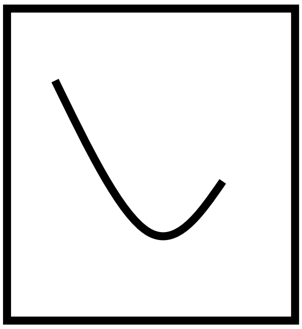
Category BE. (Both sites)

Falling section with a positive inflection at the end, starting frequency always higher than ending frequency.

Cardigan Bay	1 whistles	0.6%
Shannon Estuary	5 whistles	0.3%
Total	6 whistles	0.3%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.28941		0.47076	0.24649	0.54983	0.43970
Start	21035.16		11310.26	1929.77	10492.07	3023.35
End	19706.46		10410.15	3938.08	10101.49	1125.97
Max	21035.16		11980.42	2499.36	11518.77	3130.31
Min	15011.72		9669.55	3322.10	7657.51	985.32
Mean	18250.87		10688.30	2995.18	9968.82	1519.16
Gradient	-4591.07		-1123.49	10878.97	862.67	3749.85

Contour Shape



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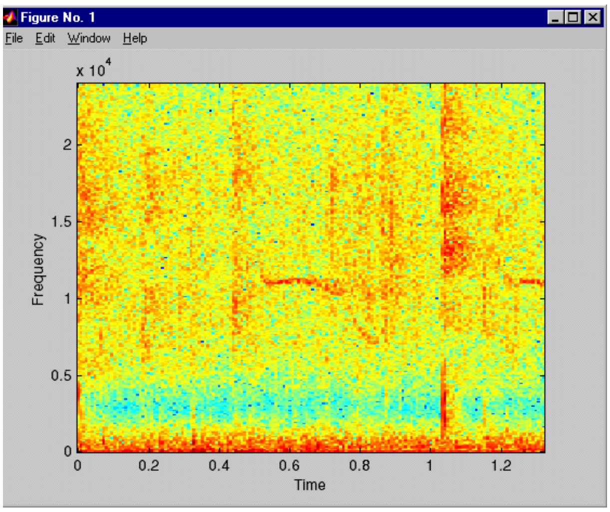


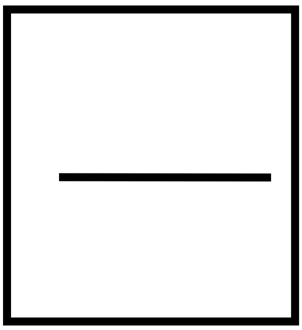
Category C. (Both sites)

Flat tone with no or only slight gradient.

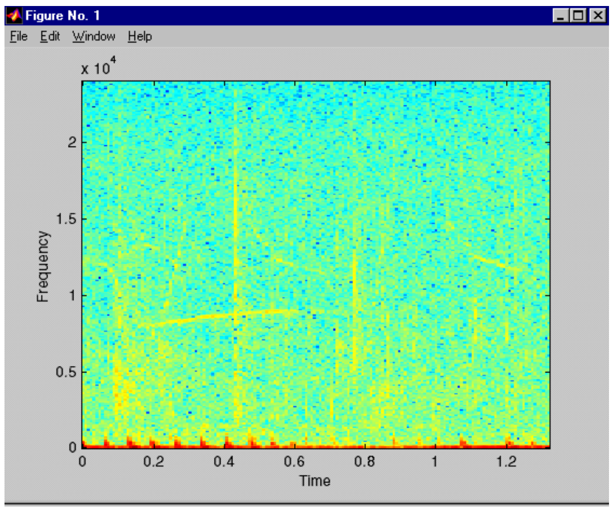
Cardigan Bay	11 whistles	6.4%
Shannon Estuary	200 whistles	11.7%
Total	218 whistles	11.6%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration	0.27957	0.12649	0.40910	0.24850	0.40235	0.24518
Start	11720.17	7401.48	9180.26	3390.70	9312.67	3718.01
End	11582.67	7242.26	9645.10	2893.32	9746.12	3258.35
Max	12181.36	7288.01	11495.54	3520.82	11531.30	3781.47
Min	11330.48	7356.27	8025.25	2575.59	8197.56	3066.84
Mean	11810.13	7283.28	9799.79	2652.84	9904.60	3065.23
Gradient	-1376.17	2878.77	528.35	11015.66	429.07	10750.04

Contour Shape



Example



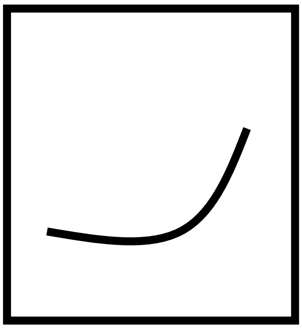
Category CA. (Both sites)

Initially flat section followed by an up-sweep.

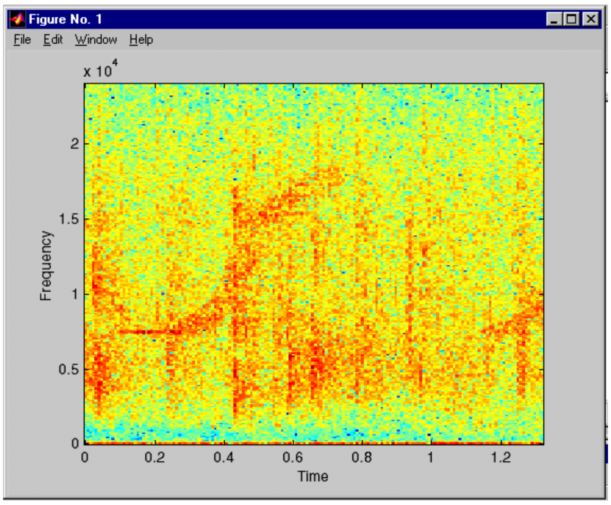
Cardigan Bay	4 whistles	2.4%
Shannon Estuary	79 whistles	4.6%
Total	83 whistles	4.4%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration	0.31491	0.27793	0.44046	0.75480	0.35615	0.19404
Start	8728.01	2636.23	9375.47	3791.26	9343.10	3732.29
End	13556.48	2445.06	10467.04	3152.15	10621.51	3181.05
Max	13556.48	2445.06	12288.07	3215.77	12351.49	3181.51
Min	7791.30	2720.95	8068.42	3274.21	8054.56	3234.58
Mean	10346.95	2104.66	10185.66	2943.07	10193.73	2896.99
Gradient	23993.84	11874.35	3455.88	10020.49	4482.78	10998.64

Contour Shape



Example



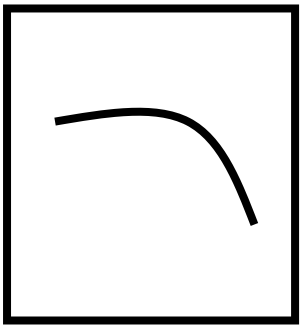
Category CB. (Both sites)

Flat section followed by a down-sweep.

Cardigan Bay	4 whistles	2.4%
Shannon Estuary	57 whistles	3.3%
Total	61 whistles	3.2%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration	0.26897	0.19257	0.36073	0.22730	0.35406	0.22467
Start	14726.04	4088.24	9789.20	3757.34	10148.24	3959.10
End	10904.02	5948.18	10832.02	3436.74	10837.26	3591.97
Max	14866.93	4252.65	12885.77	3299.45	13029.86	3369.61
Min	10904.02	5948.18	8622.26	3395.57	8788.20	3605.42
Mean	12941.16	5030.50	10901.46	2936.34	11049.80	3110.48
Gradient	-16591.91	8941.24	1834.26	7660.37	494.17	9060.73

Contour Shape



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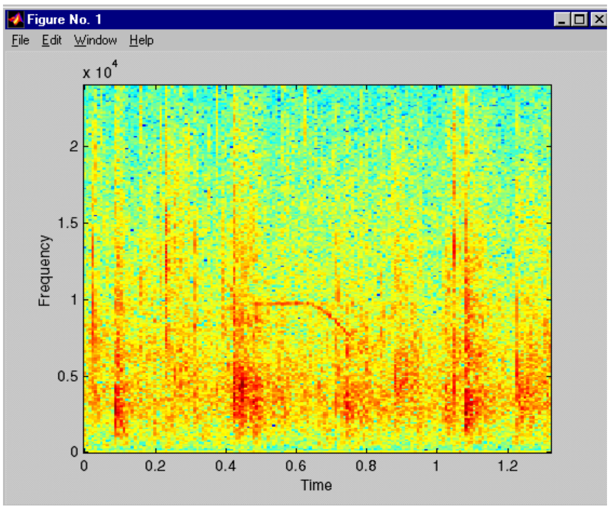


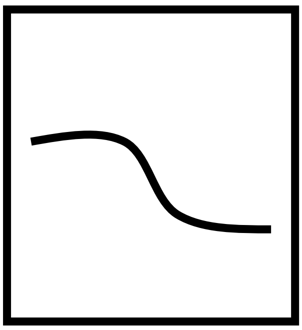
Category CBC. (Shannon Estuary only)

Flat section followed by a down-sweep and levelling off again.

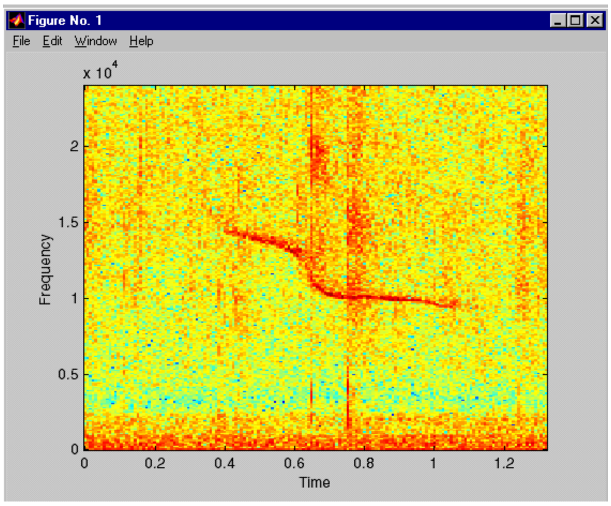
Cardigan Bay	0 whistles	0%
Shannon Estuary	20 whistles	1.2%
Total	20 whistles	1.2%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration			0.59932	0.30500		
Start			9758.93	3636.17		
End			10633.49	3034.28		
Max			12423.52	2615.93		
Min			8104.00	2854.19		
Mean			10369.81	2268.69		
Gradient			1142.37	9500.72		

Contour Shape



Example



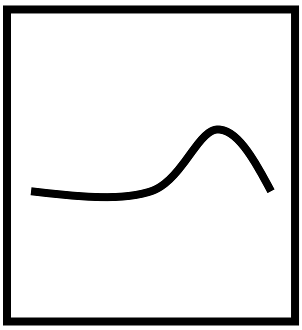
Category CD. (Both sites)

Flat section followed by a convex modulation.

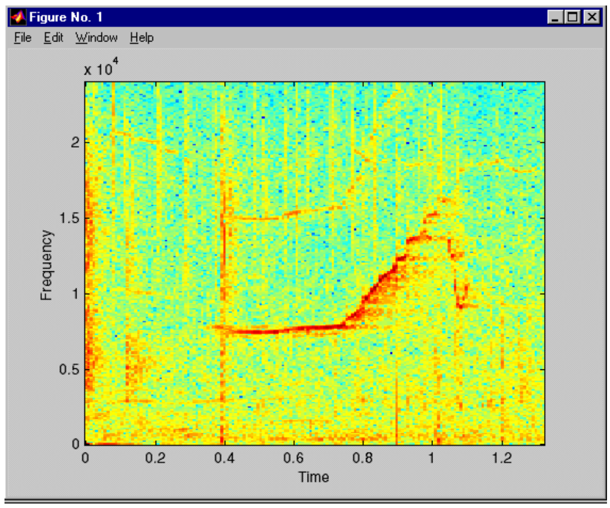
Cardigan Bay	1 whistles	0.6%
Shannon Estuary	32 whistles	1.9%
Total	33 whistles	1.8%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration	0.53242		0.70890	0.20971	0.70355	0.20868
Start	5448.19		8103.60	2889.14	8023.13	2880.97
End	7913.93		9865.62	2672.61	9806.48	2652.37
Max	11225.06		11455.29	2826.34	11448.32	2782.12
Min	5448.19		7335.68	2381.75	7278.48	2367.15
Mean	8043.70		9532.36	2195.79	9487.25	2176.69
Gradient	4631.15		5160.94	10316.34	5144.89	10154.29

Contour Shape



Example



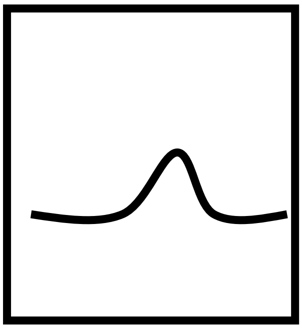
Category CDC. (Both sites)

Flat section followed by a convex modulation ending with another flat section.

Cardigan Bay	1 whistles	0.6%
Shannon Estuary	8 whistles	0.5%
Total	8 whistles	0.4%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration	0.83626		0.75302	0.25557	0.75302	0.25557
Start	12951.07		9756.20	3163.51	9756.20	3163.51
End	11128.19		9944.17	4197.15	9944.17	4197.15
Max	12951.07		12793.26	2481.61	12793.26	2481.61
Min	11128.19		8214.01	3353.00	8214.01	3353.00
Mean	11722.60		10862.58	1822.60	10862.58	1822.60
Gradient	-8451.62		259.83	8324.25	259.83	8324.25

Contour Shape



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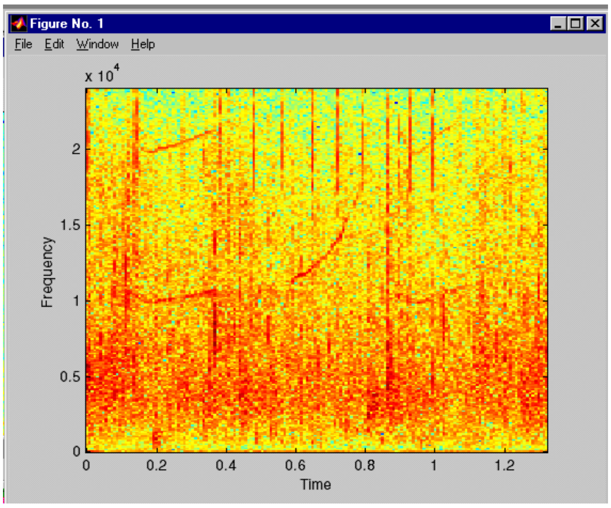


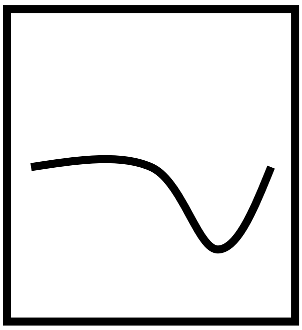
Category CE. (Both sites)

Flat section followed by a concave modulation.

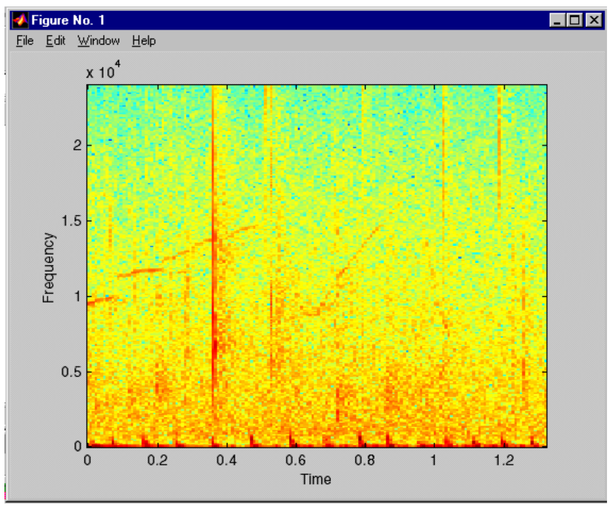
Cardigan Bay	1 whistles	0.6%
Shannon Estuary	3 whistles	0.2%
Total	4 whistles	0.2%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.24559		0.71352	0.32204	0.59653	0.35196
Start	9105.62		9497.58	3843.41	9399.59	3144.24
End	8792.72		10395.95	3231.79	9995.14	2757.82
Max	9105.62		12496.06	1087.36	11648.45	1913.63
Min	8245.13		8552.30	3942.24	8475.51	3222.49
Mean	8698.02		10765.22	2220.14	10248.42	2086.71
Gradient	-1274.10		579.40	6222.82	116.02	5164.74

Contour Shape



Example



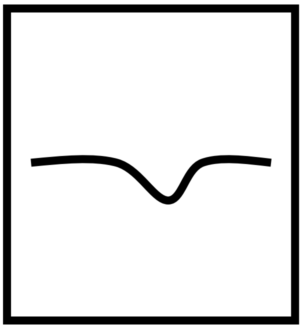
Category CEC. (Shannon Estuary only)

Flat section followed by a concave modulation ending with another flat section.

Cardigan Bay	0 whistles	0%
Shannon Estuary	5 whistles	0.3%
Total	5 whistles	0.3%

Parameter	Cardigan Bay		Shannon Estuary		Total
	Mean	Sd	Mean	sd	
Duration			0.42003	0.22617	
Start			8188.15	4094.67	
End			9220.02	3584.62	
Max			10875.10	4424.10	
Min			7087.55	2839.04	
Mean			9440.74	3510.66	
Gradient			3310.57	7594.04	

Contour Shape



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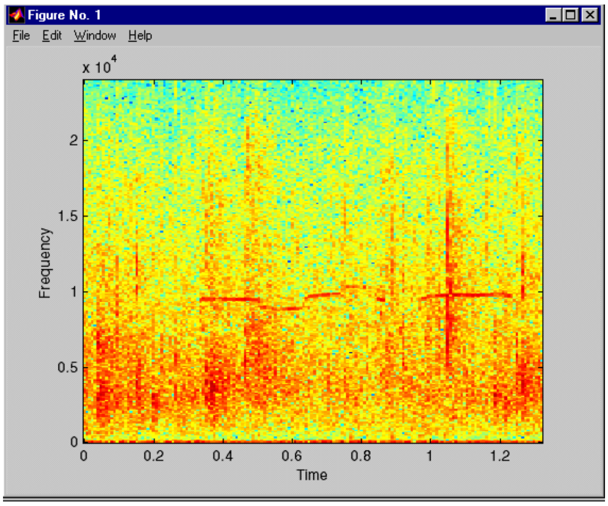


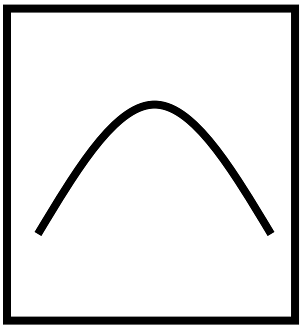
Category D. (Both sites)

Convex modulation with similar start and end frequencies.

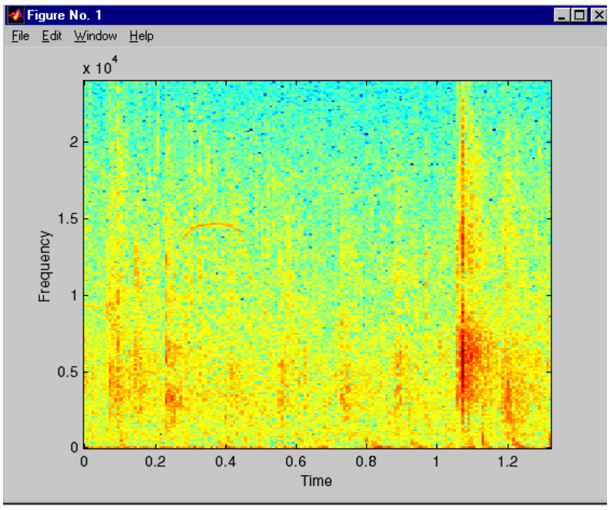
Cardigan Bay	18 whistles	10.8%
Shannon Estuary	158 whistles	9.2%
Total	176 whistles	9.4%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.32120	0.33184	0.46338	0.27911	0.43644	0.29332
Start	14800.82	6725.61	9036.25	3225.61	10128.49	4663.73
End	14957.26	6889.22	8972.39	2901.87	10106.36	4577.24
Max	18034.14	6698.95	11893.49	2739.07	13056.98	4475.96
Min	14157.79	7025.68	7254.77	2296.48	8562.71	4537.25
Mean	16203.68	6840.73	9617.84	2115.72	10865.68	4337.51
Gradient	1477.63	8757.62	230.64	8656.66	466.92	8642.91

Contour Shape



Example



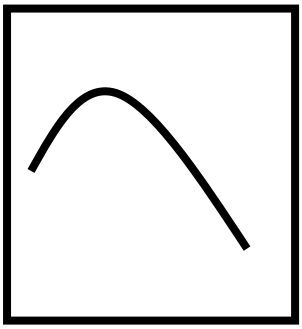
Category DB. (Both sites)

Convex modulation with lower higher starting frequency than ending frequency.

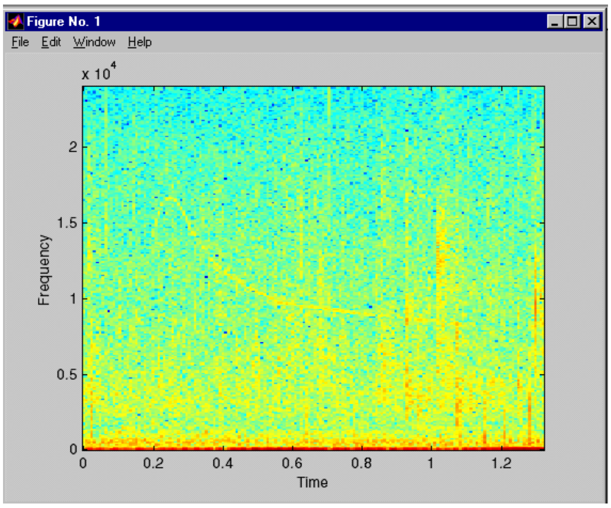
Cardigan Bay	13 whistles	7.8%
Shannon Estuary	63 whistles	3.7%
Total	76 whistles	4.0%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	Sd	Mean	sd	Mean	sd
Duration	0.27827	0.09285	0.60019	0.24290	0.54512	0.25504
Start	17997.54	2144.78	9772.67	3259.46	11179.56	4386.18
End	14966.73	3854.27	10326.83	3148.92	11120.50	3696.92
Max	20896.49	2310.77	12990.13	2658.32	14342.54	3959.53
Min	14562.12	3735.61	8238.36	2546.36	9320.06	3652.23
Mean	17733.39	2104.65	10686.27	2264.77	11891.70	3476.27
Gradient	-10725.89	12237.84	1046.23	10813.52	-994.27	11866.00

Contour Shape



Example



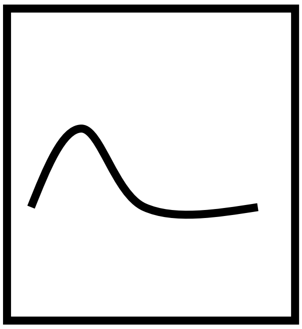
Category DC. (Shannon Estuary only)

Convex modulation followed by a flat un-modulated section.

Cardigan Bay	0 whistles	0%
Shannon Estuary	42 whistles	2.4%
Total	42 whistles	2.4%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration			0.60495	0.23995		
Start			10339.69	3774.67		
End			9720.32	2996.46		
Max			12105.33	3107.53		
Min			8236.75	3142.73		
Mean			10121.53	2726.60		
Gradient			-4790.02	20934.25		

Contour Shape



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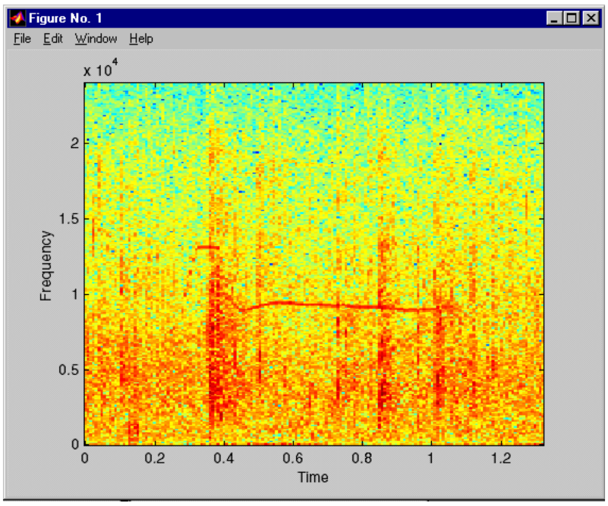


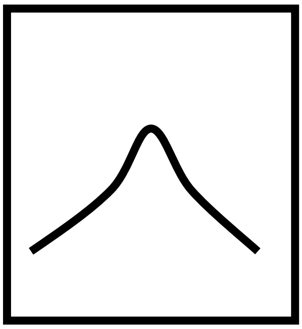
Category DD. (Shannon Estuary only)

Continually rising tone followed by a convex modulation followed by a falling section.

Cardigan Bay	0 whistles	0%
Shannon Estuary	14 whistles	0.8%
Total	14 whistles	0.8%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration			0.95903	0.15376		
Start			9019.25	3773.38		
End			9534.98	2993.90		
Max			13060.35	2165.51		
Min			7838.20	2714.35		
Mean			10468.73	2003.48		
Gradient			-412.36	8001.58		

Contour Shape



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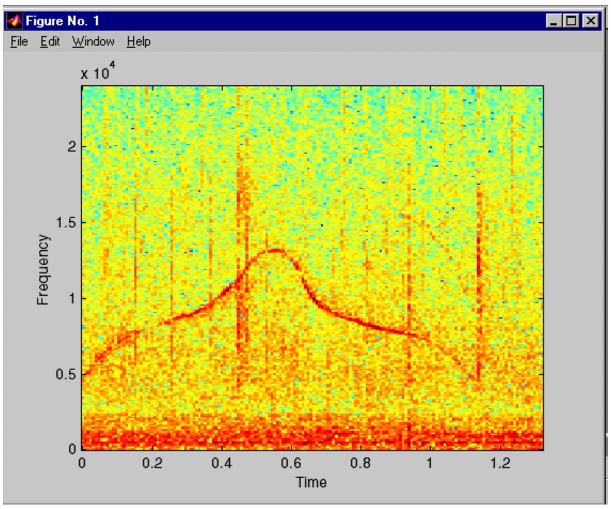


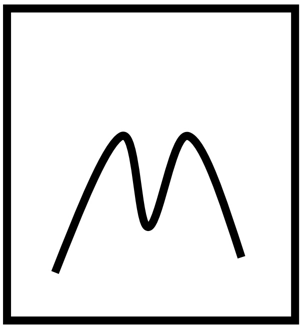
Category DD1. (Both sites)

Two consecutive convex modulations.

Cardigan Bay	5 whistles	3.0%
Shannon Estuary	67 whistles	3.9%
Total	72 whistles	3.8%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration			0.36084	0.05921		
Start			19529.30	2398.21		
End			14330.23	8679.29		
Max			22718.18	1271.36		
Min			15808.94	2002.38		
Mean			19432.65	1340.39		
Gradient			-12780.74	17772.08		

Contour Shape



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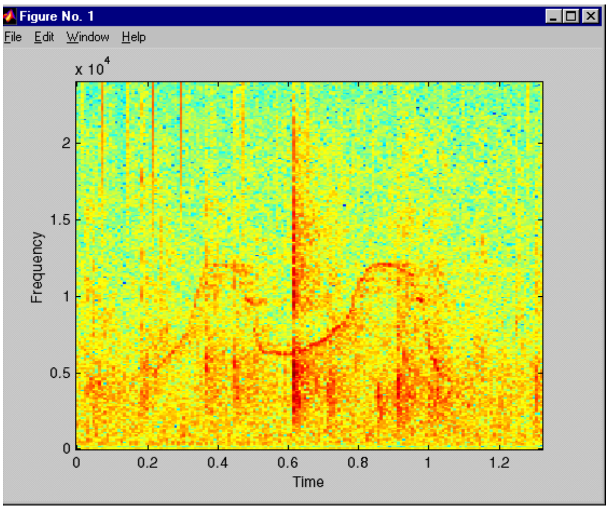


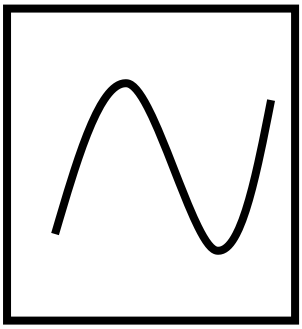
Category DE. (Both sites)

Convex modulation followed by a positive inflection.

Cardigan Bay	1 whistles	0.6%
Shannon Estuary	43 whistles	2.5%
Total	44 whistles	2.3%

Parameter	Cardigan Bay	Shannon Estuary		Total	
	0.44335	0.80336	0.30178	0.79499	0.30318
Duration	17580.54	8444.06	2993.02	8651.71	3262.97
Start	18554.92	10881.78	2996.10	11056.17	3178.99
End	20503.68	12871.83	2504.03	13045.29	2729.12
Max	12620.06	7323.22	2521.66	7443.60	2616.97
Min	17626.17	10321.61	1890.48	10487.62	2168.75
Mean	973.94	5124.73	11227.64	5030.40	11113.94
Gradient	0.44335	0.80336	0.30178	0.79499	0.30318

Contour Shape



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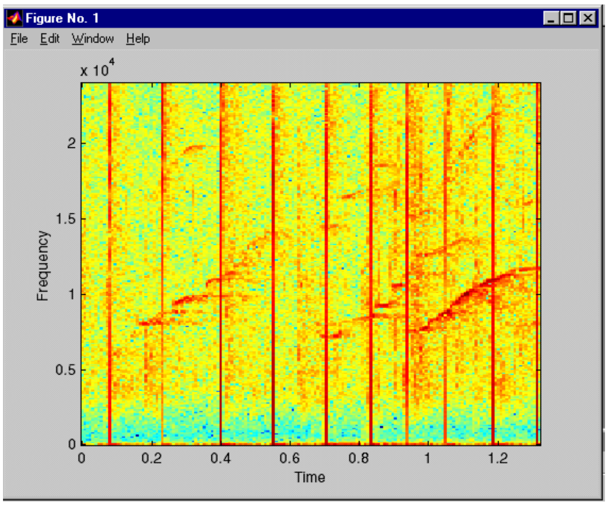


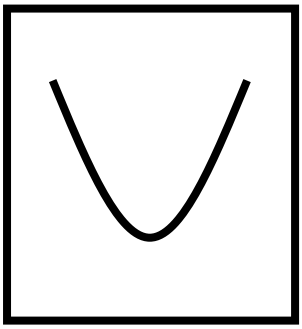
Category E. (Both sites)

Concave modulation with similar start and end frequencies.

Cardigan Bay	12 whistles	7.2%
Shannon Estuary	52 whistles	3.0%
Total	64 whistles	3.4%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.22971	0.16454	0.29756	0.25393	0.28484	0.24008
Start	14063.82	6701.87	8401.01	2848.64	9462.79	4401.62
End	15100.97	7158.17	9557.73	2591.84	10597.09	4374.94
Max	15628.78	6894.59	11853.17	2138.54	12561.10	3769.38
Min	12399.76	6735.86	6917.62	1911.81	7945.53	3941.08
Mean	14261.94	6821.30	9435.80	1654.21	10340.70	3734.19
Gradient	4136.73	9671.31	5935.53	24052.14	5598.25	22026.03

Contour Shape



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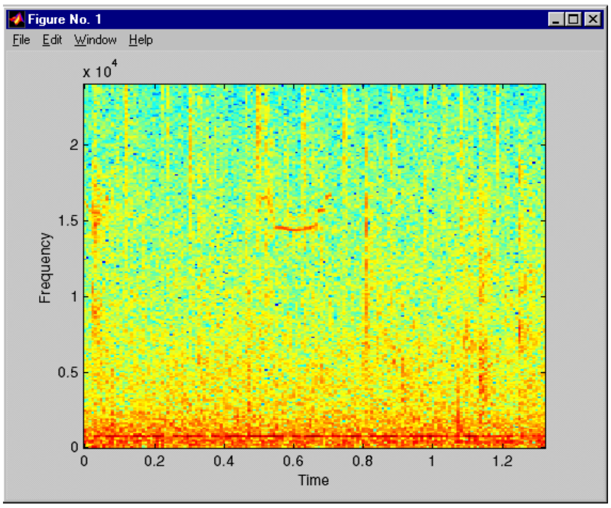


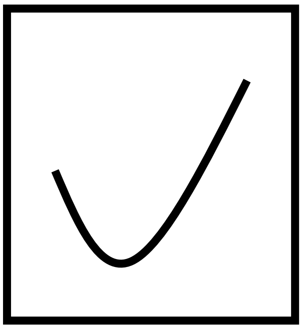
Category EA. (Both sites)

Concave modulation with lower starting frequency than ending frequency.

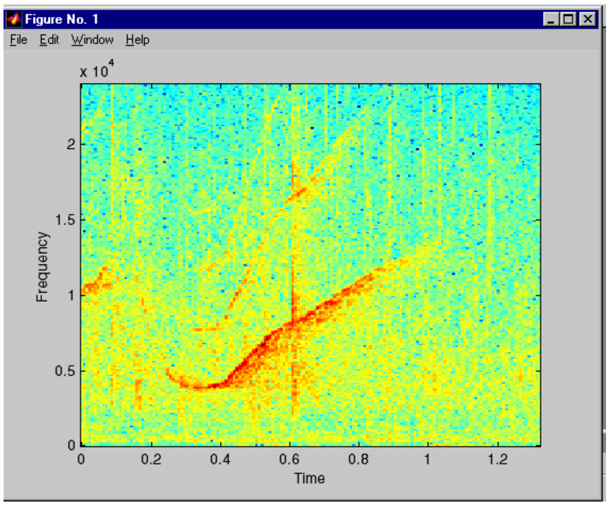
Cardigan Bay	5 whistles	3.0%
Shannon Estuary	31 whistles	1.8%
Total	36 whistles	1.9%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.43431	0.26823	0.41625	0.21845	0.41876	0.22174
Start	15518.62	6875.99	10457.48	3864.18	11160.41	4620.95
End	18301.82	7117.69	11388.43	4085.78	12348.62	5096.88
Max	19523.81	7366.03	13196.64	3654.52	14075.41	4751.13
Min	13760.49	5673.91	8913.66	3654.37	9586.83	4244.49
Mean	15848.09	6021.42	11166.15	3509.99	11816.42	4171.37
Gradient	14116.95	25467.94	4654.03	13971.55	5968.33	15889.03

Contour Shape



Example



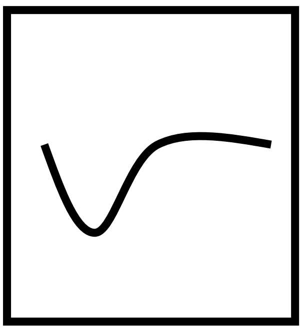
Category EC. (Both sites)

Concave modulation followed by a level section.

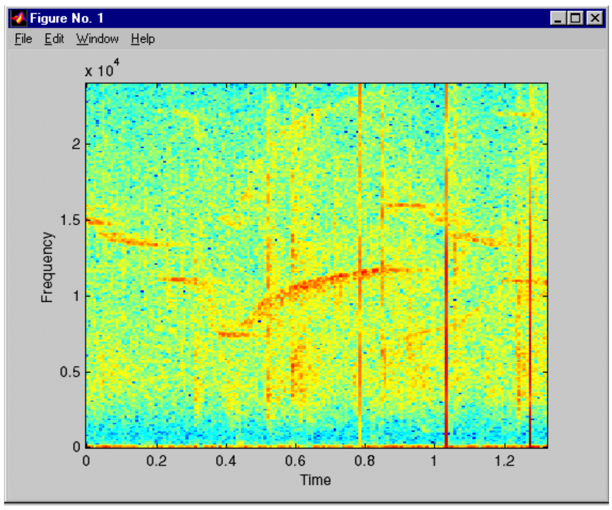
Cardigan Bay	2 whistles 1.6%
Shannon Estuary	11 whistles 0.6%
Total	12 whistles 0.7%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.41051	0.00581	0.43899	0.21393	0.43461	0.19559
Start	19972.20	1503.25	9835.31	4271.19	11394.83	5466.46
End	20326.52	1628.52	10600.21	4065.92	12096.56	5228.63
Max	21300.90	1628.52	12543.18	3490.56	13890.52	4603.33
Min	15277.46	1503.25	8912.56	4444.75	9891.78	4729.13
Mean	18850.87	1664.09	10903.58	3653.62	12126.24	4501.33
Gradient	865.37	317.40	1421.45	7146.50	1335.89	6527.82

Contour Shape



Example



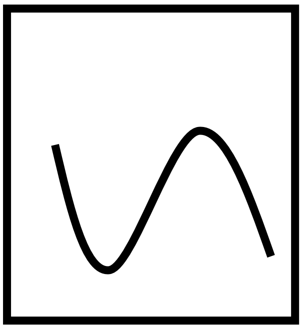
Category ED. (Both sites)

Convex modulation followed by a positive inflection.

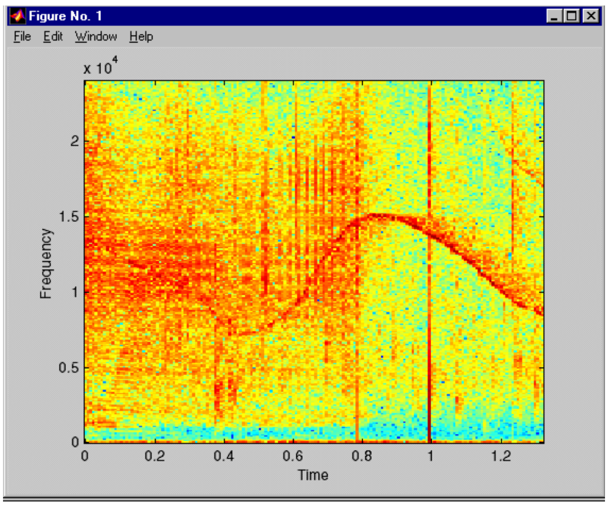
Cardigan Bay	6 whistles	3.6%
Shannon Estuary	38 whistles	2.2%
Total	44 whistles	2.3%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.23023	0.07336	0.69296	0.30140	0.62685	0.33492
Start	18702.55	2900.59	9624.45	4052.64	10921.32	5062.89
End	17949.62	5497.50	10684.10	2318.73	11722.03	4011.67
Max	21241.84	3919.47	13040.31	2502.22	14211.96	3899.53
Min	14554.06	4143.20	7869.08	2656.10	8824.08	3716.46
Mean	17655.36	3946.97	10723.10	2172.63	11713.42	3417.61
Gradient	-3409.15	15729.91	1408.28	9991.20	720.07	10623.03

Contour Shape



Example



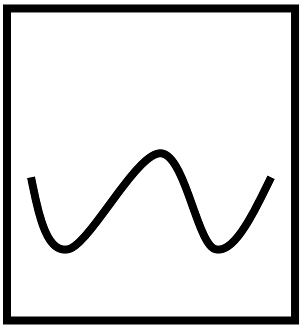
Category EE1. (Both sites)

Two consecutive concave modulations.

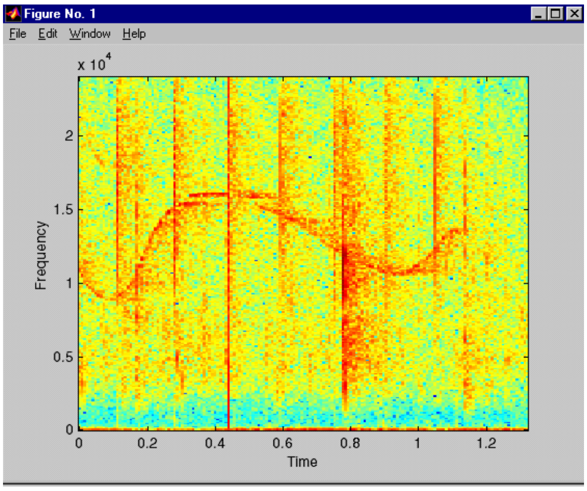
Cardigan Bay	3 whistles	1.8%
Shannon Estuary	8 whistles	0.5%
Total	11 whistles	0.6%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.46987	0.38121	1.02678	0.21357	0.87490	0.35870
Start	20693.27	2610.85	10999.41	3321.88	13643.19	5439.71
End	21849.99	1213.74	10314.46	3475.34	13460.51	6146.74
Max	23226.86	409.19	12233.46	3217.32	15231.66	5800.66
Min	17341.39	726.49	9018.72	3025.64	11288.54	4650.43
Mean	20014.80	969.52	10659.64	3234.11	13211.04	5157.97
Gradient	1565.47	3289.87	-1833.24	17501.10	-906.32	14801.58

Contour Shape



Example



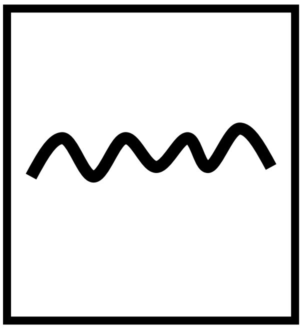
Category F. (Both sites)

Continually modulating tone with similar starting and ending frequencies.

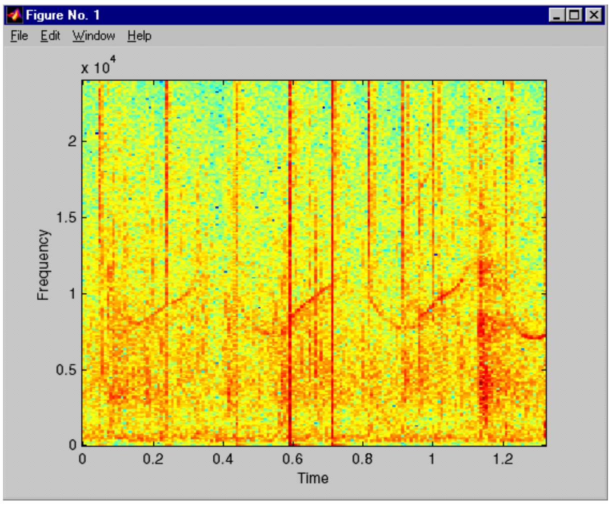
Cardigan Bay	6 whistles	3.6%
Shannon Estuary	38 whistles	1.6%
Total	34 whistles	1.8%

Parameter	Cardigan Bay		Shannon Estuary		Total	
	Mean	sd	Mean	sd	Mean	sd
Duration	0.90324	0.48054	0.99117	0.22635	0.97830	0.27093
Start	12887.44	4839.46	9265.93	2797.51	9795.91	3355.46
End	15001.45	4739.63	9037.49	2244.12	9910.27	3412.22
Max	17934.51	4245.48	12572.89	2150.72	13357.52	3140.99
Min	9177.10	3570.46	7661.80	2058.42	7883.55	2342.87
Mean	13774.90	3643.93	10093.14	1637.35	10631.94	2382.08
Gradient	5639.28	10021.11	-1502.52	7715.28	-457.38	8347.49

Contour Shape



Example



<u>Appendix 3</u>. Statistical tests

Test 1. Pearson's Chi Squared test. Frequency of occurrence of whistle categories A, B, C and all others in Cardigan Bay and Shannon Estuary populations.

Population * Whistle type Crosstabulation

		Type				Total
		A	B	C	Other	
Shannon	Count	257	161	200	1097	1715
	Expected Count	259.8	171.7	191.7	1095.7	1715.0
Cardigan	Count	30	28	11	98	167
	Expected Count	26.2	17.3	19.3	104.3	167.0
Total	Count	287	189	211	1195	1882
	Expected Count	287.0	189.0	211.0	1195.0	1882.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.262	3	.007
Likelihood Ratio	11.853	3	.008
Linear-by-Linear Association	3.026	1	.082
N of Valid Cases	1870		

a 0 cells (.0%) have expected count less than 5. The minimum expected count is 17.28.

Test 2. Pearson's Chi Squared test. Frequency of occurrence of whistle categories A, B, C and all others in 2003, 2004 and 2005 data from the Shannon Estuary.

Years * Whistle type Crosstabulation

		Type				Total
		A	B	C	Other	
2005.	Count	173	85	161	492	911
	Expected Count	135.1	84.1	105.7	586.1	911.0
2004	Count	21	17	15	63	116
	Expected Count	17.2	10.7	13.5	74.6	116.0
2003	Count	63	58	25	560	706
	Expected Count	104.7	65.2	81.9	454.2	706.0
Total	Count	257	160	201	1115	1733
	Expected Count	257.0	160.0	201.0	1115.0	1733.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	142.808	6	.000
Likelihood Ratio	154.278	6	.000
Linear-by-Linear Association	66.916	1	.000
N of Valid Cases	1733		

a 0 cells (.0%) have expected count less than 5. The minimum expected count is 10.71.

Test 3. Pearson's Chi Squared test. Frequency of occurrence of whistle categories A, B, C and all others in Groups in the Shannon Estuary.

Groups* Whistle type Crosstabulation

		Type				Total
		A	B	C	Other	
26 Jul	Count	0	13	2	21	36
	Expected Count	6.4	3.2	6.0	20.3	36.0
27 Jul	Count	24	8	25	107	164
	Expected Count	29.4	14.8	27.3	92.6	164.0
28 Jul	Count	3	3	1	13	20
	Expected Count	3.6	1.8	3.3	11.3	20.0
29 Jul	Count	47	27	24	190	288
	Expected Count	51.6	25.9	47.9	162.5	288.0
09 Aug	Count	19	21	72	70	182
	Expected Count	32.6	16.4	30.3	102.7	182.0
11 Augl	Count	77	14	33	135	259
	Expected Count	46.4	23.3	43.1	146.2	259.0
Total	Count	171	86	159	539	955
	Expected Count	171.0	86.0	159.0	539.0	955.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	168.402	18	.000
Likelihood Ratio	150.427	18	.000
Linear-by-Linear Association	8.652	1	.003
N of Valid Cases	955		

a 8 cells (28.6%) have expected count less than 5. The minimum expected count is .54.

Test 4. Mann-Whitney U test of whistle duration, start, end, maximum, minimum, mean frequencies and whistle gradient between Cardigan Bay and Shannon Estuary populations.

Ranks

	POP	N	Mean Rank	Sum of Ranks
Time	Shannon	171	385.10	65852.00
	Cardigan	966	601.55	581101.00
	Total	1137		
Start	Shannon	171	793.56	135698.50
	Cardigan	966	529.25	511254.50
	Total	1137		
End	Shannon	171	747.22	127775.00
	Cardigan	966	537.45	519178.01
	Total	1137		
Maximum	Shannon	171	777.70	132987.00
	Cardigan	966	532.06	513966.01
	Total	1137		
Minimum	Shannon	171	759.75	129917.50
	Cardigan	966	535.23	517035.52
	Total	1137		
Mean	Shannon	171	770.36	131731.49
	Cardigan	966	533.36	515221.50
	Total	1137		
Gradient	Shannon	171	472.03	80716.50
	Cardigan	962	583.88	561694.50
	Total	1133		

Test Statistics

	Time	Start	End	Maximum	Minimum	Mean	Gradient
Mann-Whitney U	51146.000	44193.500	52117.000	46905.000	49974.500	48160.500	66010.500
Wilcoxon W	65852.000	511254.500	519178.000	513966.000	517035.500	515221.500	80716.500
Z	-7.945	-9.702	-7.700	-9.017	-8.241	-8.700	-4.119
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000

a Grouping Variable: Population

Test 5. Kruskal-Wallis non-parametric ANOVA of whistle duration, start, end, maximum, minimum, mean frequencies and whistle gradient between 2003, 2004 and 2005 data from the Shannon Estuary.

Ranks

	YEARS	N	Mean Rank
Times	2005	967	804.78
	2004	116	728.97
	2003	636	967.86
	Total	1719	
Start	2005	967	771.02
	2004	116	1196.91
	2003	636	933.84
	Total	1719	
End	2005	967	867.21
	2004	116	1032.29
	2003	636	817.62
	Total	1719	
Maximum	2005	967	767.71
	2004	116	1005.37
	2003	636	973.81
	Total	1719	
Minimum	2005	967	809.92
	2004	116	1149.19
	2003	636	883.40
	Total	1719	
Mean	2005	967	777.48
	2004	116	1083.08
	2003	636	944.78
	Total	1719	
Gradient	2005	965	947.37
	2004	116	765.42
	2003	636	741.99
	Total	1717	

Test Statistics

	Time	Start	End	Maximum	Minimum	Mean	Gradient
Chi-Square	50.081	98.590	18.816	76.807	50.631	68.703	70.215
Df	2	2	2	2	2	2	2
Asymp. Sig.	.000	.000	.000	.000	.000	.000	.000

a. Kruskal Wallis Test,

b. Grouping Variable: Years

Test 6. Kruskal-Wallis non-parametric ANOVA of whistle duration, start, end, maximum, minimum, mean frequencies and whistle gradient between groups encountered in the Shannon Estuary.

Ranks

	Groups	N	Mean Rank
Duration	26 Jul	25	352.94
	27 Jul	163	555.97
	28 Jul	18	655.81
	29 Jul	287	480.77
	09 Aug	182	421.50
	11 Aug	286	476.56
	Total	961	
Start	26 Jul	25	546.82
	27 Jul	163	500.21
	28 Jul	18	441.64
	29 Jul	287	462.75
	09 Aug	182	506.49
	11 Aug	286	468.87
	Total	961	
End	26 Jul	25	305.24
	27 Jul	163	474.95
	28 Jul	18	448.69
	29 Jul	287	507.12
	09 Aug	182	418.22
	11 Aug	286	515.59
	Total	961	
Maximum	26 Jul	25	483.08
	27 Jul	163	544.90
	28 Jul	18	559.61
	29 Jul	287	496.83
	09 Aug	182	371.31
	11 Aug	286	493.37
	Total	961	
Minimum	26 Jul	25	404.62
	27 Jul	163	500.12
	28 Jul	18	391.14
	29 Jul	287	454.73
	09 Aug	182	525.19
	11 Aug	286	480.67
	Total	961	
Mean	26 Jul	25	398.72
	27 Jul	163	536.46
	28 Jul	18	506.06
	29 Jul	287	483.95
	09 Aug	182	437.33
	11 Aug	286	479.83
	Total	961	
Gradient	26 Jul	25	279.96
	27 Jul	163	426.43
	28 Jul	18	474.33
	29 Jul	286	524.08
	09 Aug	181	392.23
	11 Aug	284	536.89
	Total	957	

Test Statistics

	Time	Start	End	Maximum	Minimum	Mean	Gradient
Chi-Square	32.790	5.871	26.639	40.008	11.737	13.394	56.772
df	5	5	5	5	5	5	5
Asymp. Sig.	.000	.319	.000	.000	.039	.020	.000

a Kruskal Wallis Test
b Grouping Variable: GROUP

Test 7. Mann-Whitney U test of whistle rates between Cardigan Bay and Shannon Estuary populations.

Ranks

Population	N	Mean Rank	Sum of Ranks
Shannon	27	92.81	2506.00
Cardigan	193	112.97	21804.00
Total	220		

Test Statistics

	POPS
Mann-Whitney U	2128.000
Wilcoxon W	2506.000
Z	-1.736
Asymp. Sig. (2-tailed)	.083

a Grouping Variable: Population

Test 8. Spearman's rank order correlation of group size and whistle rate in the 2005 Shannon Estuary population.

Correlations

			Rate	Group Size
Spearman's rho	Rate	Correlation Coefficient	1.000	.212
		Sig. (2-tailed)	.	.005
		N	171	171
	Group Size	Correlation Coefficient	.212	1.000
		Sig. (2-tailed)	.005	.
		N	171	171

** Correlation is significant at the .01 level (2-tailed).