Short-beaked Common Dolphin, *Delphinus delphis*, Whistles: Whistle Density, A Reliable Form of Measuring Group Size?

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1. Abstract

‘Conservation biology and management’ has become an ever increasingly used phrase in marine mammal science over the past 20 years; monitoring the changes in cetacean population sizes, distribution, and their anthropogenic causes are key areas of conservation. The Short-beaked common dolphin, *Delphinus delphis*, found in waters around the United Kingdom and Republic of Ireland has come under increasing threat from industrial fishing operations, pollution and vessel disturbance. Current estimates of *D.delphis* population size in the Celtic Deep (UK) range between 23,000 and 249,000 animals, with other estimates suggesting 100,000 animals off the UK and French coasts. Recent acoustic developments have suggested that sound can be used to estimate the number of animals in a dolphin school. Using the Short-beaked common dolphin as an example, this vessel-based study uses acoustic recordings in conjunction with visual sightings data from the Celtic Deep, UK. *D.delphis* whistle density (whistles per minute) was regressed against dolphin group size to produce a mathematical model (Equation 1.1), which was then used to predict the whistle density for dolphin schools containing up to 80 animals. The results presented here are compared with those previously reported for two dolphin species. Suggestions are made as to the future development of this technique into a viable method of assessing dolphin group size acoustically. The 414 whistles recorded for this study were also analysed and classified into 20 distinct whistle categories based on contour shape and duration; three categories comprised 44.2% of all whistles recorded. The descriptive frequency (maximum, minimum, start, end, mean, and median) and duration parameters of the categories are presented, and compared with those of previous *D.delphis* acoustic reviews. Whistles ranged in frequency from 3.37 - 20.982 kHz and lasted between 0.0169 and 2.1482 seconds in duration.

Key words: Short-beaked common dolphins, group size, whistle density, population estimates, acoustics.

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4. Introduction

Since the 11th century cetaceans (whales and dolphins) increasingly became seen as a resource, with whaling operations exploiting these animals for economic growth and recreation (Clapham *et .al*, 2002). As a consequence cetacean populations crashed, and in 1986 the International Whaling Commission effectively brought an end to commercial whaling by imposing a zero catch quota (Clapham *et .al*, 2002). Today the old harvesting risk has been replaced by one of indirect human (anthropogenic) threats such as fisheries bycatch, pollution and tourism disturbance (Taylor, 2002 & Evans *et .al*, 2003). 'Conservation biology and management' has become an ever increasingly used phrase in marine mammal science over the past 20 years; monitoring the changes in cetacean population sizes, distribution, and their anthropogenic causes are key areas of conservation (Evans *et .al*, 2003). However, obtaining accurate year-to-year population estimates for cetacean species is a problem that has long faced scientists. This gap in knowledge restricts our ability to successfully manage cetacean populations (Van Parijs *et .al*, 2002).

4.1 Population Estimates

Photo-identification is one of the most important tools in dolphin research today. It enables scientists to record individually distinct features, such as dorsal fin nicks and colouration, of animals within a population over time (Wells, 2002). This can provide estimates of annual population size while also allowing researchers to study many aspects of cetacean behaviour and ecology. The key to photo-identification is obtaining high- resolution, quality photographs of a dolphin's identifying features (Wells, 2002). As animals spend little time at the waters surface it is important for the observer to be fairly close, and parallel to a dolphin, when it comes up to breathe, in order to take useful pictures clear enough for future recognition (Datta *et .al*, 2002). To accomplish this most researchers use vessel-based surveys (Wells, 2002) which, depending on study area size, are potentially expensive (Evans *et .al*, 2003). There are no guarantees that all the dolphins in a population will be photographed or successfully re-identified in the future. This can bias the population estimates of photo-identification studies (Wursig *et .al*, 1990).

Distance sampling is the most widely used technique when estimating cetacean population size in a region (Buckland *et .al*, 2002). Systematic zig-zag line transects are used to survey a study area, typically by boat although aircraft can be used. Visual observers sight animals from the vessel recording their distance and angle from the transect line. This information is used to standardise animal detection, and produce an estimation of local population size (Buckland *et .al*, 2002). The distance sampling technique has three key assumptions: (1) all animals near the transect line are sighted, (2) prior to detection, animals do not move in response to the survey vessel, and (3) distance and angle measurements are accurate (Evans *et .al*, 2003 & Buckland *et .al*, 2002). Of course animals do move, cetaceans are known to be attracted or actively avoid boats (Evans *et .al*, 2003), and as previously stated they spend most of their time out of sight under the waters surface (Datta *et .al*, 2003). This means that all population estimates derived from distance sampling have some level of bias. Surveys also tend to be conducted over large areas, meaning they are expensive (Evans *et .al*, 2003 & Buckland *et .al*, 2002).

A major problem with any visual survey is the weather, and resulting sea state. As the wind increases so too does the wave height and swell. This makes it increasingly difficult to spot animals, and accurately determine the number of animals within a group (Macleod *et .al*, 2003). Visual surveys are generally not conducted in sea states above Beaufort scale two[1], and not at all during the winter months, because they produce bias population estimates (Evans *et .al*, 2003).

In 1995 Clark proposed the use of visual observation techniques in conjunction with acoustic recordings to estimate the relative abundance of Blue, Fin and Minke whales. The idea proved to be successful, allowing Clark to study the seasonal occurrence and abundance of these mysticete (baleen, filter feeding) whales. Clark *et .al* conducted further visual and acoustic

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[1] When the waves have white caps.

studies in 1996 and ‘97, culminating in 2000 when a 16 element hydrophone array was used to survey Fin whales in the Sea of Cortez, Mexico. As in 1995 the results suggested that vocal activity is a reliable means of assessing relative abundance and distribution of mysticetes. In 1999 Van Parijs *et .al* (2002) expanded the technique to odontocetes (toothed whales), namely the Pacific humpback dolphin, *Sousa chinensis*. They used acoustic recordings from a stationary mounted hydrophone, together with visual data from a land based platform on Stradbroke Island, Australia. The mean number of calls in a three-minute period and dolphin group size were analysed in a regression, and were found to have a positive linear relationship. Van Parijs *et .al* (2002) created a mathematical model capable of predicting group size from vocalisation rate. They tested their model with further acoustic samples, and declared it an acceptable technique to assess inshore delphinid group size, ‘within an area’. Wakefield also touched on this subject in 2001. He recorded ten Short-beaked common dolphin vocal samples, a minute in duration, and compared it to the number of dolphins observed at the waters surface. Like Van Parijs *et .al* (2002), Wakefield found a positive linear relationship between group size and vocalisation rate. The success of these studies has the potential to revolutionise how cetacean abundance estimates are achieved. It has been suggested that hydrophone and recorder packages could be deployed in remote coastal areas to determine the presence and abundance of certain cetacean species (Van Parijs *et .al*, 2002). This would have an advantage over visual surveys because cetacean vocalisations are generally independent of sea state (Evans *et .al*, 2003), therefore remote surveying of animal presence and abundance could be conducted all year round.

4.2 The Short-beaked Common Dolphin, *Delphinus delphis*

4.2.1 Classification

As their name suggests Common dolphin (*Delphinus* spp.) are one of the most widely distributed of the dolphin family, *Delphinidae* (Carwardine *et .al*, 1998 & Moore *et .al*, 1995). They are a member of the suborder *Odontoceti* (toothed whales) within the order *Cetacea* (Wurtz *et .al*, 1998). Over the years more than 20 separate species of Common dolphin have been proposed and rejected (Carwardine *et .al*, 1998). In 1994 the genus *Delphinus* was separated into two, the Short-beaked common dolphin (*Delphinus delphis*), and the Long-beaked common dolphin (*Delphinus capensis*) (Perrin, 2002; Reeves *et .al*, 2002 & Carwardine *et .al*, 1998). The split was due to consistent physical and genetic differences worldwide (Carwardine *et .al*, 1998). A third species of Common dolphin, the Very-long-beaked common dolphin (*Delphinius tropicalis*), has been proposed; its taxonomic status is uncertain due to a lack of knowledge (Perrin, 2002). To avoid any confusion, it is the Short-beaked common dolphin found around the United Kingdom and Republic of Ireland that is the subject of this study.

4.2.2 Morphology

Short-beaked common dolphins are slender animals with a tall, slightly falcate, dorsal fin. Their pectoral fins are fairly large and tapered (Perrin, 2002 & Reeves *et .al*, 2002). They can weigh up to 200 Kg and measure between 1.5 - 2.2 metres in length; males are approximately five percent longer than females. At birth individuals can be between 0.7 and a metre long (Perrin, 2002; Reeves *et .al*, 2002; Carwardine *et .al*, 1998 & Martin *et .al*, 1990). Short-beaked common dolphins have between 41 - 54 pairs of teeth, with the upper mandible typically containing one or two more pairs than the lower mandible (Perrin, 2002 & Reeves *et .al*, 2002).

Common dolphins are easily distinguished from other dolphin species by a pale yellow (thoracic) and grey (posterior) hourglass body colouration that runs laterally from the eye to the caudal peduncle. Dorsal of the hourglass is black to dark grey in colour; the ventral surface is white (Perrin, 2002; Reeves *et .al*, 2002 & Carwardine *et .al*, 1998). The beak is separated from the melon by a crease along which a black or dark grey stripe runs to the eye. The dorsal surface of the beak is grey, and both mandibles have a dark tip. From the lower mandible runs a thin black or dark grey stripe that joins to the pectoral fins (Perrin, 2002; Reeves *et .al*, 2002 & Martin *et .al*, 1990). The dorsal fin is black to dark grey; adults often have a small lighter grey triangle within their dorsal. The pectoral fins and fluke are similar in colouration to the dorsal fin (Reeves *et .al*, 2002 & Martin *et .al*, 1990). See Figure 1.

Figure 1. Short-beaked common dolphin, *Delphinus delphis*, in the Mediterranean Sea. Photograph taken by Hanna Nuuttila; reproduced here with her consent.

4.2.3 Behaviour and Life History

Short-beaked common dolphin groups generally consist of 30 or fewer individuals; thought to be closely related. However groups of hundreds or thousands have been seen gathered together, with possible segregations by age and sex (Perrin, 2002 & Reeves *et .al*, 2002). Recent research has suggested that *D.delphis* have a fluid fission-fusion social structure, similar to coastal Bottlenose dolphin (*Tursiops truncatus*) (Bruno *et .al*, 2004). Common dolphin are known for their acrobatic breaching and boisterous behaviour, acoustically detectable from miles away. They often come from distance to bow ride vessels, a behaviour thought to have originated from mysticete bow riding (Perrin, 2002; Reeves *et .al*, 2002; Carwardine *et .al*, 1998 & Martin *et .al*, 1990). *D.delphis* have been seen in association with many species including Pilot whales (*Globicephala* spp.), Risso's, *Grampus griseus*, and *Lagenorhynchus* dolphin species (Macleod *et .al*, 2003; Perrin, 2002 & Martin *et .al*, 1990).

Short-beaked common dolphin feed on epipelagic and mesopelagic squid or small schooling fish from the deep scattering layer (Ohizumi *et .al*, 1998). Stomach contents analysis in European waters on stranded or incidental fishing by-catch suggests that the main prey species of *D.delphis* are herring (*Clupea harengus*), mackerel (*Scomber scombrus*), sand eel (*Ammodytes* spp.), sprat (*Sprattus sprattus*), and long-finned squid (*Loligo* spp.) (Overholtz, 1991 & Santos *et .al*, 1994). Common dolphin time their foraging effort with the vertical movement of prey items during the night (Reeves *et .al*, 2002 & Goold, 2000); dives to 200 metres have been recorded (Perrin, 2002). During the daylight hours the animals spend most of their time resting and socialising before, in late afternoon, breaking up into smaller groups in anticipation of prey (Reeves *et .al*, 2002 & Martin *et .al*, 1990).

The reproductive behaviour of the Short-beaked common dolphin seems to vary with its distribution. Calving is thought to occur all year round, especially in tropical waters. At high latitudes it tends to peak in late spring and early summer (Reeves *et .al*, 2002; Gill *et .al*, 1997 & Martin *et .al*, 1990). Gestation lasts for ten to eleven months, with a calving interval of one to three years depending on geographic location (Perrin, 2002; Reeves *et .al*, 2002 & Martin *et .al*, 1990). Males are estimated to reach sexual maturity from three years old in the Black Sea, and between seven and twelve years in the Eastern Pacific. Female sexual maturity is estimated between two and three years in the Black Sea, and six to seven years in the Eastern Pacific (Perrin, 2002 & Martin *et .al*, 1990). It is thought that this difference is due to animal density. Maximum age is estimated at 22 years in the Black Sea (Perrin, 2002).

4.2.4 Distribution

D.delphis can be found between approximately 60 degrees North and 40 degrees South. They are the most numerous delphinid species found in the offshore temperate and tropical waters of the Atlantic and Pacific Oceans (Perrin, 2002; Reeves *et .al*, 2002; Carwardine *et .al*, 1998; Wurtz *et al*, 1998 & Moore *et .al*, 1995). Short-beaked common dolphins can be found in the eastern Atlantic from southern Norway to Gabon in West Africa, including the

Mediterranean and Black Seas; and from Newfoundland to Florida in the western Atlantic. In the eastern Pacific they can be found from southern Canada to central Chile; and in the western Pacific around New Caledonia, New Zealand, Tasmania, southern Japan, and Southeast Australia (Perrin, 2002 & Reeves *et .al*, 2002). Common dolphin population estimates in the Celtic Deep (UK) range between 23,000 and 249,000 (Anonymous, 1999). Other estimates suggest 100,000 animals off the British Isles and France, tens of thousands in the Western Atlantic. Hundreds of thousands in the Northeast Pacific, and three populations estimated to total three million in the eastern tropical Pacific (Reeves *et .al*, 2002).

Many studies have looked at their distribution in relation to oceanographic features such as bottom topography, and sea surface temperature (SST). *D.delphis* distribution has often been linked with areas of upwelling along continental drop-offs and underwater banks (Perrin, 2002; Reeves *et .al*, 2002; Hui, 1979 & Dohl *et .al*, 1986). It has been suggested that Common dolphin use offshore ridges as migration channels (Dohl *et .al*, 1986). Very little is known about their movements, although offshore migrations have been reported during the autumn and winter months in the California Bight (USA), North-west Bay of Plenty (New Zealand) and Irish/ Celtic Sea (UK) (Dohl *et .al*, 1986; Neumann, 2001 & Goold, 1998).

Sea surface temperature (SST) studies have presented mixed results. Dohl *et .al* (1986) reported Common dolphin movements related to SST. As SST rose in late spring/ early summer they observed an increase in animal sightings, no animals were sighted in waters cooler than 14°C (Dohl *et .al*, 1986). More recent studies by Goold (1998) and Neumann (2001) suggest that although *D.delphis* prefer warmer surface waters, it is not the driving force behind their movements. They both suggest that the availability and movement of prey are more likely to be the primary factor influencing Common dolphin distribution. This theory is backed up by commercial fishermen in Neumann's New Zealand study area as, like the dolphins, they too move further offshore in pursuit of fish (Neumann, 2001).

Where the Celtic and Irish Sea meet an oceanographic front is known to seasonally occur during spring and summer. This is the boundary where tidal mixed, nutrient rich, water from the Irish Sea meets thermally stratified water from the Celtic Sea, creating a thermal front (Simpson *et .al*, 1979 & Simpson *et .al*, 1974). The stratified water on the Celtic Sea side holds planktonic organisms at the surface of the water, where sunlight enables them to photosynthesise. While tidal water from the Irish Sea provides the plankton with nutrients, enabling the front to persist (Goold, 1998). Thermal fronts are usually associated with areas of high primary productivity, capable of supporting top-level predators, such as dolphins (Goold, 1998). The Celtic Sea front may be one of the most important areas in British waters for predators such as the Short-beaked common dolphin. This makes it a good area to encounter *D.delphis*.

4.2.5 Conservation

The global population of *D.delphis* is considered by the IUCN[2] to be 'lower risk, least concern' meaning it is under little threat of extinction (CITES, 2004 & IUCN, 2003). However in 2003 the Mediterranean subpopulation of Short-beaked common dolphin was placed on the IUCN red list as 'endangered' due to a 50 percent reduction in numbers over the last 30-45 years; reported to be because of over fishing and habitat degradation (IUCN, 2003).

In the UK all cetaceans are protected by section nine of the Wildlife and Countryside Act 1981, and Wildlife Order 1985. These acts prohibit the intentional killing, injuring of an animal, and destruction of its habitat (JNCC, 2004). All cetaceans are also listed on Annex IV of the EC Habitats Directive, and Annex A of the EU Council Regulation 338/97 prohibiting commercial trade in the species (Anonymous, 1999). Despite this legislation the future of *D.delphis* in British waters is still uncertain. There are four main threats affecting the population; interaction with commercial fisheries, boat activity, pollution, and over exploitation of marine resources leading to changes in the ecosystem (Anonymous, 1999).

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[2] International Union for Conservation of Nature and Natural Resources

Each year vast numbers of *D.delphis* are caught in the fishing nets of industrial trawlers around the Celtic Sea and English Channel. Between 1975 and 1998 a total of 593 Common dolphins were reported dead off the Portuguese coast, of which 44% were reported to be as a result of fisheries bycatch and interaction (Silva *et .al*, 2003). French drift-net fisheries reported 400 Common dolphin accidentally caught in their nets between 1992 and '93. In 1995 a small UK drift net fleet operating in the Bay of Biscay reported a total bycatch of 60 Common dolphin (Anonymous, 1999). Between 1990 and 1995 a total of 138 Common dolphin washed up along the British coast line. Post mortems took place and concluded that at least 62% were as a result of fisheries interaction (Anonymous, 1999). These are potentially sizable chunks of a Common dolphin population with no accurate estimation of size.

The English Channel and Irish Sea are some of the most intensively used stretches of water in the world. Ships can potentially cause physical harm to cetaceans via collisions, and indirectly by underwater noise pollution resulting in auditory damage at close range. If prolonged this can affect a dolphins' ability to navigate, communicate with conspecifics and find prey (Anonymous, 1999 & Ford *et .al*, 2000). Seismic surveys of the sea bed have recently taken place in the southern Irish and Celtic Seas in pursuit of oil and gas. No relationship was found between the presences of *D.delphis* in the area of seismic surveying (Goold, 1998). However Short-beaked common dolphin have been found to significantly increase both the frequency and rate of their vocalisations during a survey (Wakefield, 2001).

Pollution of the marine environment with man-made pollutants, like PCB's and DDT, are hidden dangers affecting cetaceans. As top-level predators, dolphins consume a large variety of man-made industrial pollutants through their prey. These contaminates bind with fats and accumulate in their blubber layer. Organochlorines have been shown to cause suppression of the immune system and reduce reproductive potential (Ford *et .al*, 2000 & Anonymous, 1999).

4.3 Dolphin Communication

Dolphins are highly social animals often needing to coordinate their activities with other members of a group. It is communication that enables successful interaction to occur between animals, and hence maintain social bonds (Dudzinski *et .al*, 2002). Dolphins have good vision both below and above the water line, but visual communication is not ideal for the marine environment. Light levels and organic matter limit the distance that an animal can see underwater to a few metres. Where light fails sound succeeds. In water sound travels approximately four and a half times faster than it does in air; allowing dolphins to communicate over distances of metres to kilometres (Dudzinski *et .al*, 2002).

The study of cetacean acoustics started in 1949 when Schevill and Lawrence made the first underwater recordings of Beluga whale, *Delphinapterus leucas* vocalisations. Over the years researchers have advanced our understanding of dolphin communication, however we still have much to learn. What we do know is that their vocalisation can be split into three distinct categories; tonal whistles, pulsed sounds (clicks) for echolocation, and burst pulse sounds such as squawks, barks and yelps (Van Parijs *et .al*, 2001[a]; Caldwell *et .al*, 1968; Caldwell *et .al*, 1965 & Lilly *et .al*, 1961). Dolphins use these sounds to communicate with each other, and to perceive the environment around them (Caldwell *et .al*, 1965 & Richardson *et .al*, 1995). Research suggests whistles are the primary form of social communication between dolphins, but there are some exceptions (Dudzinski *et .al*, 2002). The highly social Killer whale, *Orcinus orca*, communicates mainly using pulsed calls (70- 95%), as well as producing whistles. Harbour porpoise, *Phocoena phocoena*, are known to be a non-whistling species, but they are normally found alone or in a small group (Richardson *et .al*, 1995).

Whistles are pure tone, narrow band frequency modulated sounds. The majority of their energy is below 20 kHz, typically rising and falling in a frequency band of seven to 15 kHz. They normally average less than a second in duration, but can continue for up to three seconds (Berta *et .al*, 1999 & Richardson *et .al*, 1995). Highly vocal, Common dolphins produce a wide range of whistles (Moore *et .al*, 1995). Previous studies have suggested they lie between 4.8 and 23.8 kHz, lasting 0.026 to 1.622 seconds in duration (Wakefield, 2001; Moore *et .al*, 1995 & Caldwell *et .al*, 1968). Caldwell and Caldwell (1968) did not describe the frequency parameters of the whistles they recorded; however the published spectrograms show a whistle type with a frequency of just over 20 kHz. Goold (1996) estimated that *D.delphis* whistles can be acoustically detected from about 500 metres away.

Dolphin whistles were originally thought to be context specific. Lilly and Miller (1961) reported that a confined and distressed Bottlenose dolphin (*Tursiops truncatus*) would repeatedly emit two specific whistles. Over the years context specific whistles have lost acceptance, however papers are still being published on this subject. McCowan and Reiss (2001) suggested that *T. truncatus* have a shared group contact call; individual variation in the production of this call is how animals differentiate between each other (McCowan *et .al*, 2001). The theory of context specific whistles was replaced in 1965 by what became known as the signature whistle hypothesis. While working with recently captured Bottlenose dolphins, Caldwell *et .al* (1965) discovered that isolated animals produce a unique individualised whistle that makes up more than 90% of their communication. These whistles are believed to be learned (Sayigh, 2002) and have been shown to remain stable for up to 12 years (Sayigh *et .al*, 1990). The signature whistle hypothesis has become widely accepted and vast amounts of work has been conducted. The majority of work has focused on the Bottlenose, *T.truncatus*, however signature whistles have also been reported for Atlantic spotted dolphins, *Stenella frontalis* (Caldwell *et .al*, 1973), Common dolphin, *D.delphis* (Caldwell *et .al*, 1968), and Pacific white-sided dolphin, *Lagenorhynchus obliquidens* (Caldwell *et .al*, 1971).

In 1998 Janik and Slater looked at signature whistles in relation to captive Bottlenose dolphin group cohesion. They conducted their study across two connected indoor pools. Their results showed that when a dolphin is separated from its group, the primary vocalisation is an animal's signature whistle (31.8 - 91.7%). They also found that when an animal is absent from a group, the majority (56%) of vocalisations produced by the remaining dolphins were their signature whistles. When the group was reunited again nonsignature whistles became the main communication, 2.4% of whistles were still signature whistles. They also reported signature whistle copying by members of the group. Copied whistles did not act to reunite the group or provoke specific vocal responses (Janik *et .al*, 1998). Signature whistle copying or imitation has been reported in many studies, and has previously been found to act as a cohesion call in males (Sayigh, 2002).

4.4 Describing and Classifying Whistles

Early descriptions of dolphin whistles took the form of text, such as 'downsweep' or 'falling inflection' (e.g. Caldwell *et .al*, 1965). This provides the reader with the general shape of a whistle but prevents them from seeing or understanding the fluctuations in frequency and variations in whistle duration. Although some papers still describe category names in text (e.g. Moore *et .al*, 1995), it is more common to show whistles graphically as time (x-axis) frequency (y-axis) plots called 'specrograms' (e.g. Bazua-Duran *et .al*, 2002; Corkeron *et .al*, 2001 & Janik, 2000). This provides detailed information about the properties of a whistle, but is unable to show the variations of many whistles in a large dataset. Most papers therefore display a few specrograms of key whistle shapes along with tables of descriptive information regarding whistle variation. Whistle parameters like start, end, maximum, minimum, and mean frequency along with whistle duration and standard deviation are commonly shown (e.g. Corkeron *et .al*, 2001 & Moore *et .al*, 1995).

For almost as long as researchers have been describing whistles, they have also been trying to classify them into groups. Many qualitative (human) and quantitative (statistical) methods have been used to do this. To begin with whistles were classified by ear. In 1965 Caldwell and Caldwell were one of the first to play Bottlenose dolphin vocalisations at 1/8th speed in order to distinguish between different types of whistle. Over the years the methodology evolved to classification by eye. Spectrograms were used to classify whistles by their frequency/ time contour shape (e.g. Bazua-Duran *et .al*, 2002; Janik, 1999; Janik *et .al*, 1998). Recently multivariate statistics have been used to categorise whistles. In 2001 McCowan *et .al* marked 60 frequency/ time points along the contours of Bottlenose dolphin whistles. They used statistics to compare their similarity with one another. This method has been criticised by studies comparing qualitative and quantitative techniques for not classifying whistles as successfully as human observers (Janik, 1999). In return McCowan *et .al* (2001) have argued that quantitative methods are an unbiased way of categorising whistles, unlike human observers. Neural networks are the latest method of classifying whistles. Deeke *et .al* (1999) tested a neural network against human classification of Killer whale, *Orcinus orca*, vocalisations. They concluded that neural networks are no better at classifying *O.orca* calls than humans.

5. Aims and Hypotheses

The Short-beaked common dolphin found in waters around the United Kingdom is an ideal species to test the group size and whistle density (whistles per minute) hypothesis. It is a highly vocal, group living species that has no definitive population estimate, and is under threat from anthropogenic activities (Moore *et .al*, 1995; Perrin, 2002 and Anonymous, 1999). This study was run in conjunction with a cetacean distribution and abundance survey being conducted by the Sea Watch Foundation in the Celtic Deep, specifically targeting the Short-beaked common dolphin. It aims to …

- Validate previously reported positive linear relationships between dolphin group size and vocalisation rate. This builds on previous work by Wakefield (2001) who was the first to expand Van Parijs and Corkeron's (2002) technique to the Short-beaked common dolphin (*Delphinus delphis*).

- Classify and compare the whistles of Short-beaked common dolphin in the Celtic Deep with those previously recorded in the surrounding area (Wakefield, 2001), as well as those reported by Moore and Ridgway (1995) in the Southern California Bight.

To test these aims the following hypotheses were generated:

1. Vocalisation rate (whistles per minute) is correlated to dolphin group size.

2. Vocalisation rate (whistle per minute) is significantly different with increased distance between a dolphin group and the survey vessel.

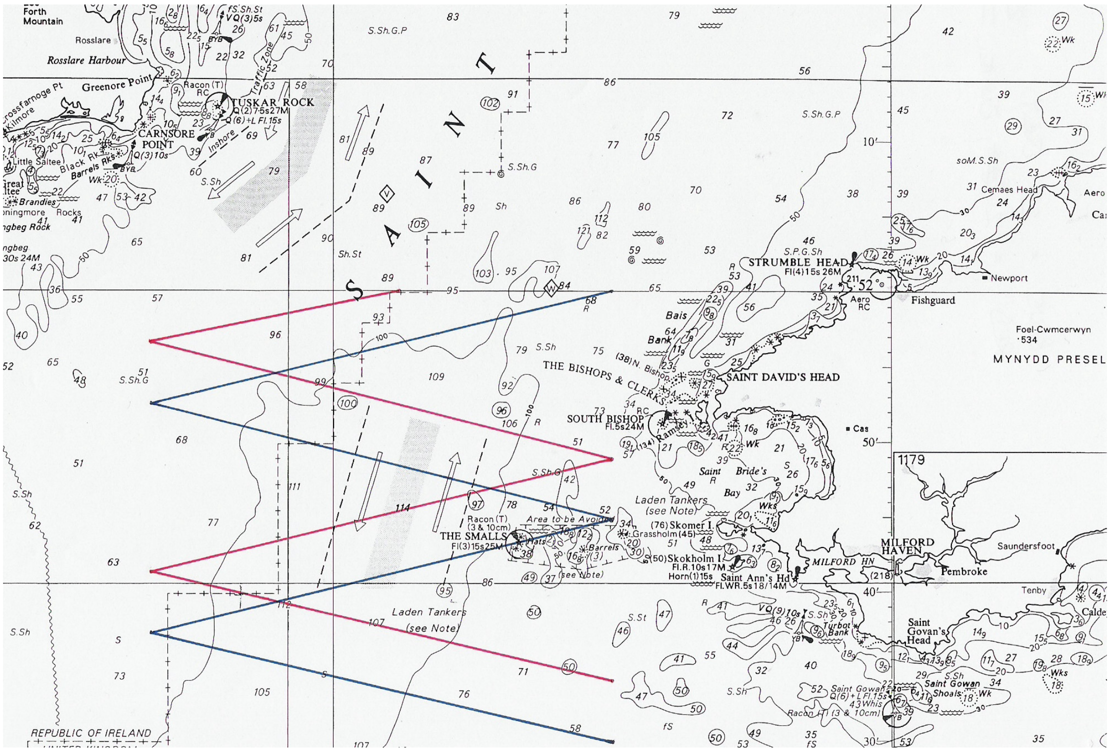
6. Methodology

6.1 Dolphin Surveys and Study Area

The surveys took place in the Celtic Deep between Pembrokeshire, Wales (UK) and the Republic of Ireland; encompassed by 51 30 North to 52 00 North latitude and 05 30 West to 06 20 West longitude (see Map. 1.). Two days of dedicated line transect surveys, 21 June and 23 July 2004, were conducted aboard a chartered boat 'Liberty of White'. Liberty is a 11.28 metre long offshore going vessel, 'Ocean Ranger' class, with twin Volvo 300 engines, driving twin propellers. The beginning and end points of each survey transect leg were programmed into Liberty's GPS (Global Positioning System) as waypoints, this provided accurate navigational information regarding the completion of each transect leg. Both surveys were predominantly conducted in 'passing mode'; where the vessel stays on the transect line making no attempt to close on a detected group of animals (Buckland *et .al*, 2002). Survey one (21/6/2004) was conducted in sea states ranging from zero to two, the second survey (23/7/2004) was conducted in between two and four, averaging sea state three.

6.2 Data Collection

A team of five observers participated in each survey, working on a rotation basis. Two collected visual data, one acted as an independent observer, and another logged the survey effort. The final observer monitored hydrophone output using Panasonic RP-HT379 stereo headphones plugged into a DAT recorder. This enabled the listener to determine when dolphins were present, and warn the visual observers. All observations were made from Liberty's flying bridge, two metres above sea level, allowing a 360^{o} view. Cetacean sightings were recorded on Sea Watch Foundation 'cetacean encounter summary' or 'simple sightings' check sheets (see 12.1.1 and 12.1.2). Data was collected on location (GPS), group size and estimated life-phase, distance from boat, sightings angle from track-line, boat heading, and behaviour. Anthropogenic and seabird associations were also collected along with environmental data. Survey effort was logged approximately every 15 minutes, with latitude and longitude readings taken from hand held portable GPS. Ships course and speed, water depth, sea state, swell, visibility (distance), and any other boat activity in the area were also recorded (see 12.1.3.).



Map 1. Shows the study area, in St. Georges Channel, and the survey line transects. The red line represents the first survey waypoints (51 34 N, 05 30 W to 51 415 N, 06 20 W to 51 49 N, 05 30 W to 51 565 N, 06 20 W to 52 00 N, 05 53 W), conducted on 21/6/2004. The blue line represents the second survey waypoints (51 30 N, 05 30 W to 51 375 N, 06 20 W to 51 45 N, 05 30 W to 51 525 N, 06 20 W to 52 00 N, 05 30 W), conducted on 23/7/2004.
(Haslam, 1980)

The acoustics in this study were recorded using a custom-built hydrophone array made up of screen cable and two Benthos AQ4 transducers (separated by 40 metres) with built in preamplifiers. The twin-element array was towed 200 - 250 metres aft the vessel (see Figure 2.). At the end of the assembly a rope ‘tattletale’, approximately one metre long and one centimetre thick, was attached to create drag keeping the array taut. The hydrophone was deployed from a dustbin at approximately 4 Knots, and towed at a survey speed of between 10 - 12 Knots. When towed the hydrophone elements were estimated to be between five and ten metres below the waters surface. Continuous stereo underwater recordings were made onto digital audio tape (DAT) via a 3kHz high pass filter to remove excessive low frequency ship noise. The signal from the rear element passed into the left channel of the DAT recorder, and the front element into the right channel. All DAT recordings, made using a Sony TCD-D8 recorder (sensitivity: 20Hz to 22kHz), were continuously data-coded with both time and date from the DAT recorder's internal clock. Before each survey the DAT recorder's internal clock was synchronised with that of the visual observer's portable GPS (Global Positioning System), allowing acoustic recordings to be correctly assigned to visual data during future playback analysis.

Figure 2. Photograph showing the fully deployed hydrophone, and central towrope attached to Liberty of Whites' port and starboard stern cleats.

6.3 Data Analysis

Following each survey the hydrophone recordings were played back in the laboratory, where dolphin whistles were detected by ear. The dolphin vocalisations were downloaded onto a Sony PCG-FR285M laptop using a Creative Sound Blaster Extigy (24bit, 96kHz, 100dB SNR) external Dolby Digital sound card, via a Sony optical digital cable compatible with the DAT recorder. The audio programme Cool Edit 2000 was used to create windows PCM wave files (.wav) of one-minute duration. The start of each acoustic sample is associated with the first visual sighting of a dolphin group, and was labelled with the data, time, duration of recording, and species recorded (e.g. 210604_1923_60_D.delphis.wav). The wave files were then imported into MATLAB 6.1, release 12.1, for whistle analysis. Each whistle contour was manually marked (see Figure 4) and later graphically represented. To minimise background contamination of the samples by Liberty's engines, only whistles recorded on the rear hydrophone were marked.

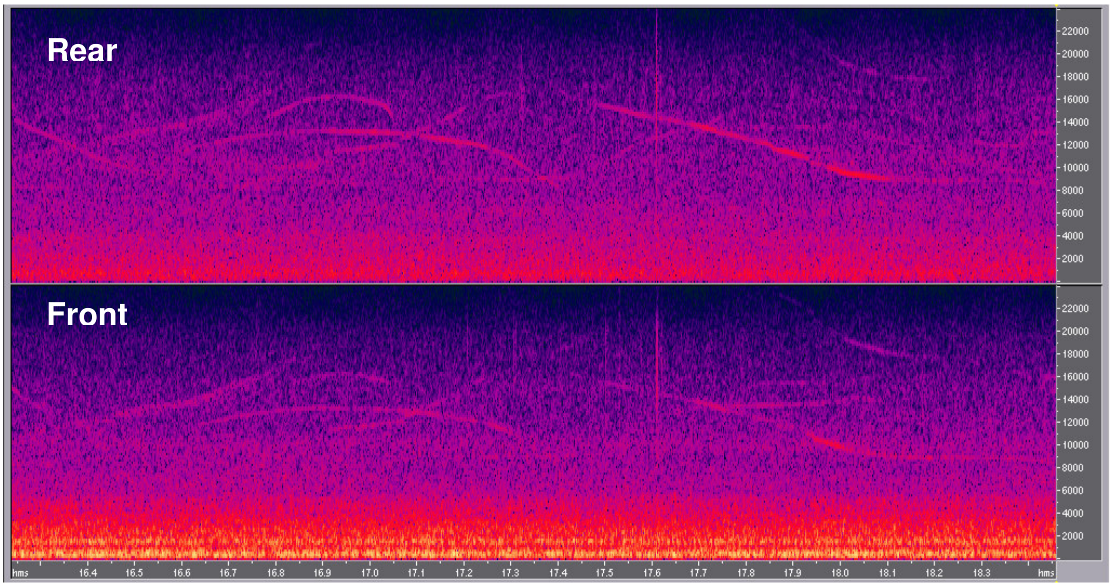


Figure 3. (Above) Example of a Cool Edit 2000 spectrogram used as an aid to mark the whistles in MATLAB 6.1. This example shows the output of the front and rear hydrophone elements from sample 210604_1923_60_D.delphis.wav, with time (16.25- 18.45 seconds) along the x-axis and frequency (0- 24 kHz) along the y-axis. Spectrogram settings: sample rate 48kHz, 16 bit, hanning window, and 128 band resolution.

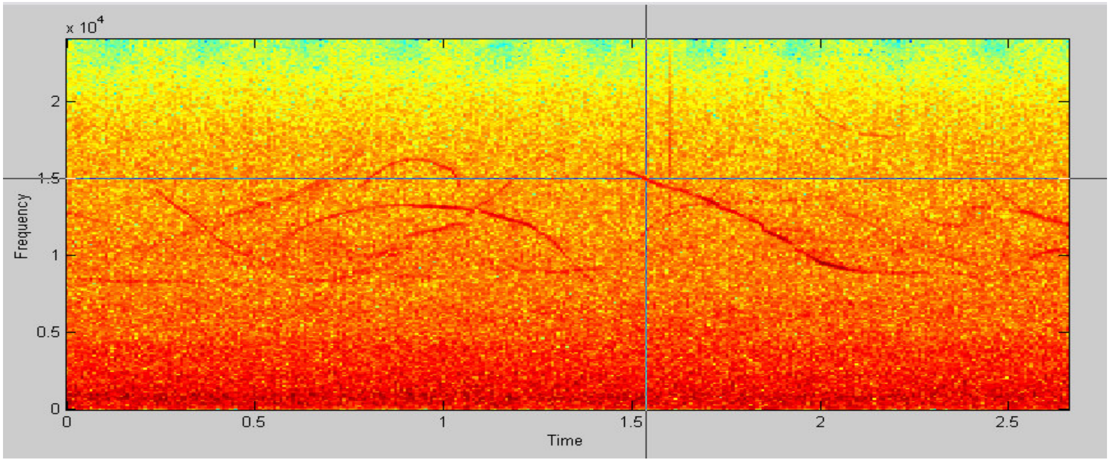


Figure 4. (Above) Example of a MATLAB 6.1 spectrogram, with whistle marking crosshair. This example shows the isolated output of the rear hydrohpone element from sample 210604_1923_60_D.delphis.wav. Time (seconds) is shown along the x-axis, and frequency (kHz x10) along the y-axis.
Spectrogram settings: sample rate 48kHz, 16 bit, FFT-length 250, hanning window.

6.3.1 Dolphin Group Size and Whistle Density

The frequency and time data extracted from the whistles in MATLAB were copied into Windows Excel worksheets and matched by visual encounter time to *D.delphis* groups recorded on the survey check sheets. The number of whistles produced per group were counted, and the results plotted in a scatter graph. It is important to note that groups of dolphin sighted within 10 minutes of one another were aggregated together into a single group. This was done to prevent cross contamination of whistles across groups. Where this occurred a mean acoustic sample, half way between the visual sighting of the first and last dolphin group, was used. It should also be noted that where ranges of group size were reported on the sightings check sheets, an average group size was taken for ease of analysis.

The group size and whistle density data was imported into the statistical package SPSS v11.0 where a Spearman rank correlation was conducted to test for any linear relationship. Following this a regression was used to create a mathematical model, capable of predicting whistle density from group size. Finally, a Kruskall-Wallis test of difference was used to analyse whistle density at varying dolphin group distances from the survey vessel. A 0.05 significance level was set for all statistical analysis. All statistical tests used are non-parametric due to the small sample size.

6.3.2 Whistle Classification

In Excel frequency measurements (start, end, maximum, minimum, mean and median) and duration were taken from all the whistles. This data was then exported to another Excel workbook and segregated into 20 different whistle categories. Previous studies have suggested that Bottlenose dolphins are capable of recognising whistle types even if they lie in a variation of different frequency bands (Ralston *et .al*, 1995 & Richards *et .al*, 1984). Therefore the classification in this study is by variations in whistle contour shape and duration. The whistle contour classifications are primarily based on those previously reported for *D.delphis* in the Southern California Bight, and Spinner dolphin from Hawaii. In 1995 Moore and Ridgway looked at Common dolphin whistles, and classified eight whistle contours; down-up (Dd_1), short-up (Dd_2), up-down (Dd_3), Long-up (Dd_4), down-up-down (Dd_5), down (Dd_6), Level-piece (Dd_7), and up-piece (Dd_8). Bazua-Duran *et .al*, 2002, classified six spinner dolphin whistles categories, three of which are used in this study; concave (a ‘u’ shaped contour), convex (a ‘n’ shaped contour), and sine (a ‘m’ shaped contour). Additional categories created by the author are variations on the theme of those already described.