Spatio-Temporal Comparisons between Acoustic and Visual Detections of the Short-Beaked Common Dolphin (*Delphinus delphis*) in the St George's Channel, in Relation to Environmental Features

By

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Abstract

The Short-beaked common dolphin, *Delphinus delphis*, is frequently observed off the south-west coast of England and Wales during spring and summer. Two-day acoustic and visual (line-transect) surveys were conducted once a month from May to August 2004-2006 in the St. George’s Channel. The aim was to determine any significant differences between the two survey techniques in relation to environmental features. During 2004-2006, a total of 142 acoustic and 220 visual encounters were detected. Data collected from acoustic and visual encounters were separately analysed and then later compared. 57.8% of all acoustic encounters were not associated with a visual sighting within the same timescale; however within this, 28.9% of acoustic contact occurred within less than five minutes of a sighting. Vocalisation strength was categorised into weak, medium and strong signals which significantly differed in accordance with whether a sighting was detected. Significant positive correlations were observed between group size and acoustic encounter duration, and acoustic encounter duration and the number of sightings per acoustic encounter. A Geographical Information System and remotely-sensed satellite data were used as tools to investigate spatio-temporal distribution of the common dolphin in relation to fixed variables, i.e. depth, and non-fixed variables, i.e. sea surface temperature, surface chlorophyll-a concentration and frontal systems. A significant positive correlation with depth and a significant negative correlation with chlorophyll-a concentration were identified in relation to the distribution of *D. delphis*. In 2006, *D. delphis* were thought to be associated with the highly productive Celtic Sea front, an oceanographic feature which forms at the boundary between the Celtic and Irish Seas. Dolphins appeared to be distributed in waters south of the front where the sea surface temperature was warmer. Depth and chlorophyll-a were considered as variables which influenced the dolphins’ prey which subsequently influenced the distribution of *D. delphis*.

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1.0 Introduction

1.0 Introduction

1.1 The Short-Beaked Common Dolphin, *Delphinus delphis*, Linnaeus (1758)

The common dolphin is, as its name suggests, the most numerous dolphin inhabiting offshore warm temperate and tropical regions of the Pacific and Atlantic Oceans (Perrin, 2002; Reeves *et al.,* 2002). Various stocks of common dolphin exist, each exhibiting different characteristics. Over previous years this has led to the proposal and rejection of an estimated twenty species. As of 1994 two species of common dolphin are recognised, the short-beaked common dolphin (*Delphinus delphis)* and the genetically distinct long-beaked common dolphin (*D. capensis*) (Bearzi *et al.*, 2003; Carwardine *et al*., 1998). A third variety, the very-long-beaked common dolphin (*D. tropicalis*) endemic to the Indian Ocean exists, however its taxonomic status is uncertain (Perrin, 2002).

1.1.1 Morphology

One distinguishable feature of the short-beaked common dolphin, that separates it from many other dolphin species, is its elaborate hourglass pattern (**fig 1.1**).

Figure 1.1 Short-Beaked Common Dolphin of the Azores, with typical hourglass pattern (Source: Author)

The complex pattern consists of a dark grey or black dorsal surface which extends low on the sides into a 'V' shaped or saddle pattern below the dorsal fin. The yellow-tan coloured 'thoracic patch' lies anterior to the 'V' shaped pattern, with the posterior 'flank patch' light to medium grey. The under and lower sides are white in colour. A dark stripe connects the predominantly dark flipper to the lower jaw with a second dark coloured stripe running from the eye to the beak. Along with slight variation in pattern, the colourisation of *D. delphis* is generally crisper than that of *D. capensis* (Carwardine, 2002; Perrin, 2002; Reeves *et al.*, 2002). The colourisation of the short-beaked common dolphin makes the species easy to identify both above and beneath the surface of the water (**fig 1.2**).

Figure 1.2 The Short-beaked common dolphin in St. George's Channel, showing hourglass pattern underwater (Source: author)

The short-beaked common dolphin is a small, slender species with adult males measuring up to 2.7 metres in length. Adult females are slightly smaller in length, measuring up to 2.6 metres (Reeves *et al.*, 2002). Sexual dimorphism between males and females is recognised at birth with male calves born measuring 0.9 metres, slightly longer than females at 0.8 metres (Viallelle, 2002). Small conical pairs of teeth are present in both upper and lower jaw with the number of teeth ranging from 40 to 55 pairs. The lower jaw usually contains one or two pairs less than the upper jaw (Reeves *et al*., 2002; Viallelle, 2002). Females become sexually mature at 5-12 years of age, with males becoming sexually mature slightly earlier at 3-12 years of age. The gestation period lasts 10-11 months with the female giving birth, usually to a single calf, every one to two years. The lifespan of a common dolphin is estimated to be between twenty-five and thirty years (Boness, 2002; Viallelle, 2002).

1.1.2 Distribution

The common dolphin inhabits temperate, tropical and subtropical seas worldwide. *D. delphis'* distribution ranges from the eastern Atlantic (Southern Norway to west Africa including the Mediterranean and Black seas) to the western Atlantic (Newfoundland to Florida), the eastern Pacific (southern Canada to Chile), the central northern Pacific (Central Japan to Taiwan, excluding Hawaii) and the western Pacific (around New Caledonia, New Zealand and Tasmania), making it one of the world's most widely distributed cetaceans. It is thought to be absent from the Indian and South Atlantic Oceans (Perrin, 2002) (**fig 1.3**).

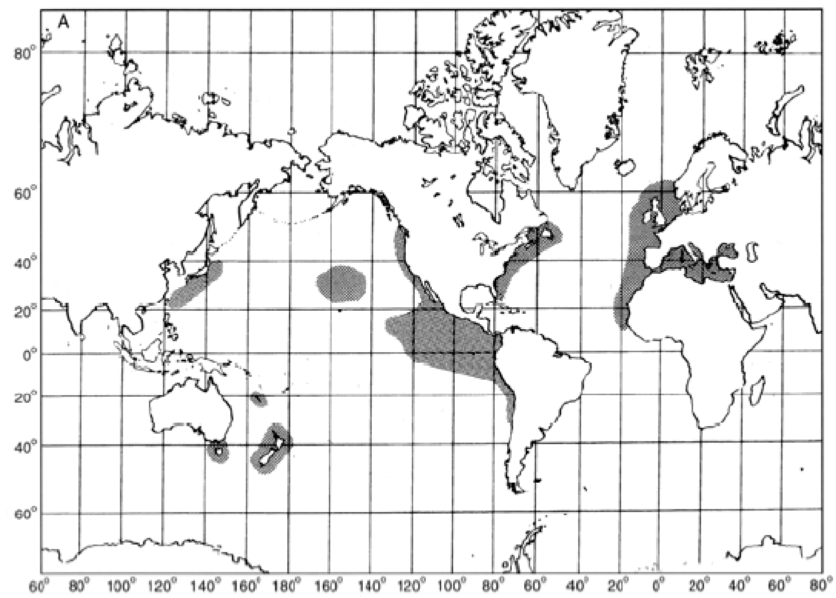


Figure 1.3. Worldwide distribution of the Short-beaked common dolphin as indicated by shaded areas (Perrin, 2002).

D. delphis inhabit waters around the British Isles and frequently occur in waters off the south-west coast of England and Wales (**fig 1.4**). *D. delphis* are recorded in all months of the year, although they are recorded more frequently in British waters from July to October (www.seawatchfoundation.org.uk). Goold (1998) identified them to be particularly abundant off south-west Wales in May-September. The SCANS (Small Cetaceans in European Atlantic and North Sea) survey of 1994 estimated common dolphin abundance for the Celtic sea region to be 75,540 (CV = 0.67; 95% C.I.: 23,000 – 249,000) (Hammond *et al.*, 2002)

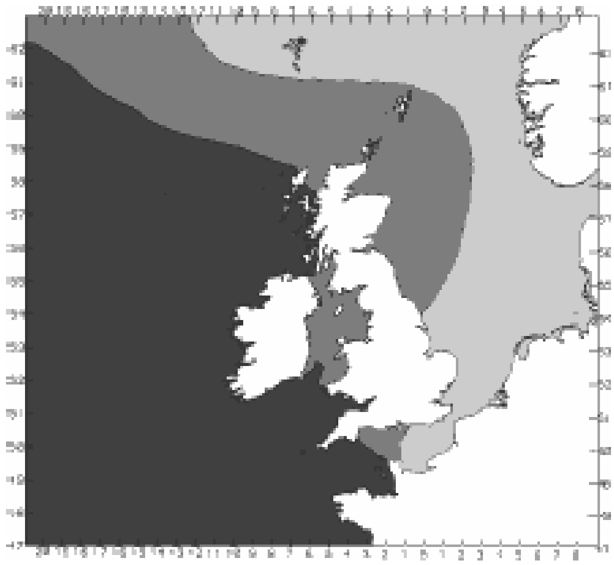
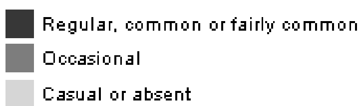


Figure 1.4 Distribution of short-beaked common dolphins around British waters



Source: www.seawatchfoundation.org.uk

Although abundant throughout the world, several regions have observed a decline in population of the short-beaked common dolphins, in particular the Mediterranean which has seen a marked decline in number. Once the most abundant cetacean species in the Mediterranean they are now absent or rare in certain areas, in particular around the island of Kalamos in the eastern Ionian Sea (Bearzi *et al.,* 2003). Observations in this region made from 1993-2002 identified a significant decrease in group size after

1996 and in sighting frequency after 2000. No single cause had been attributed to the decline but anthropogenic impacts such as prey depletion, due to over-fishing and habitat degradation, and contamination, leading to immunosuppression and reproductive impairments, were thought to be contributing factors (Bearzi *et al.*, 2003).

1.1.3. Behaviour

D. delphis are energetic, active swimmers (Carwardine, 2002) and, as observed by Caldwell (1955), will often approach vessels to bow ride (Goold, 1996). They are gregarious, gathering in large groups that can range from hundreds (Viallelle, 2002) to thousands (Hui, 1979) of individuals. Though large groups are observed, typical group size consists of up to thirty individuals (Reeves *et al.*, 2002). Group size can also vary according to season and time of day (Carwardine, 2002). The formation of groups can provide mutual protection, whilst factors such as breeding and calving can influence group composition (Hui, 1979) and create age and sex segregation, as identified by stranding and by-catch records (Waring *et al.*, 1990, Silva & Sequeira, 2003).

The short-beaked common dolphin has been observed swimming at speeds of four to five knots when feeding, although it can reach speeds of up to thirty knots (60 km/hour) (Viallelle, 2002). It can travel over 500 km in four days without feeding although the speed it travels may be reflected by its metabolic energy requirements (Hui, 1987).

1.1.4 Feeding Ecology

Common dolphins, in particular those which inhabit continental shelves, feed on squid and epipelagic shoaling fish such as sardines and anchovies (Ohizumi *et al.*, 1998). Feeding habits of cetaceans that inhabit offshore waters are often determined by examining stomach contents (Southern California Bight: Evans, 1975, western North Pacific: Ohizumi *et al.*, 1998: Portuguese waters: Silva, 1999). Data collected by this method can be limiting as obtaining the stomachs is often dependent and reliant on incidentally caught or stranded animals.

Common dolphins are opportunistic feeders (Young & Cockcroft, 1994; Canadas *et al*., 2002). Diet can vary according to geographical location and seasonal fluctuations in prey distribution and prey abundance (Silva, 1999). In the southern California Bight, Evans (1975) identified that anchovies constituted 62% of the diet of *D. delphis* following a time when anchovies were abundant, and only constituted 2% when anchovies were scarce. Around the United Kingdom, Atlantic Mackerel (*Scomber scombrus)* and Herring (*Clupea harengus*) are important prey species and common dolphins are often distributed near concentrations of these species (Evans, 1980). Other prey consumed by common dolphins around the U.K. include: sprat (*Sprattus sprattus*), lanternfish (*Myctophidae* spp) and squid (*Todaropsis eblanae*) (Ohizumi *et al.,* 1998).

Variation in diet can be affected, not only by distribution, but by the sex and age of the individual dolphin (Young & Cockcroft, 1994). By examining the stomach contents of common dolphins stranded and incidentally caught off the Portuguese coast, mature females were found to consume higher volumes of squid (67%) than mature males (20%). Immature females were found to consume a higher percentage, by weight, of cephalopods (13.5%) than mature females (9.1%) (Silva, 1999).

Common dolphins are thought to be surface predators (Ohizumi *et al.,* 1998), feeding primarily in the evening. In the afternoon, large aggregations of *D. delphis* disperse into smaller groups to await the ascent of their prey (Reeves *et al.,* 2002). Prey species consumed by *D. delphis* in the western North Pacific vertically migrate to shallower water at night (Ohizumi *et al*., 1998), a behaviour observed by Goold (2000) with *D. delphis* off the coast of west Wales. He observed nocturnal feeding in response to the diel vertical migration of their prey. Major (1986) observed *D. delphis* feeding in the western North Atlantic on short-finned squid (*Illex illecebrousus*) during the hours of 22.20 and 23.10 at depths of 0-8 metres, with large groups breaking into smaller groups to feed until individual dolphins were chasing individual squids. Hui (1979) speculated, but did not determine, that *delphinus* group size reflected prey density, with larger feeding aggregations at times when anchovy density was at its peak, and smaller aggregations when anchovy density was sparse and other prey species had to be consumed. The small feeding groups may have increased efficiency in detecting and capturing other prey.

1.2 Survey Techniques

Animal populations can change, both spatially and temporally, in distribution and size. Conservation research involves monitoring these changes and identifying the causes (Evans & Hammond, 2004). Obtaining information on cetacean abundance and distribution will help in assessing how at risk a species is, especially from human activities at sea (Macleod *et al.*, 2003) such as the use of air-gun arrays (e.g. Goold & Fish, 1998).

There are various techniques used to estimate abundance, techniques which can vary depending on the objective (Buckland & York, 2002). Estimating cetacean abundance is derived primarily from visual techniques such as mark-recapture studies using photography to identify individual animals (e.g. Wilson *et al.*, 1999), and distance sampling methods (Van Parijs *et al.*, 2002). One method of distance sampling is line transect sampling which is a popular technique to use (e.g. Hammond *et al.*, 2002) as it is suited to populations of animals that are readily detectable and sparsely distributed over a large area. Line transect sampling follows several assumptions (Buckland & York, 2002; Evans & Hammond, 2004):-

1) every animal on the transect line is detected
2) animals do not move prior to detection
3) distances are accurately measured
4) animals and the number of animals present are correctly identified

A different form of animal detection, other than visual, is through the use of passive acoustic techniques. Acoustic techniques involve the use of a hydrophone or hydrophone arrays which are used to detect underwater vocalisations emitted from the animal. Used alone or in combination with distance sampling methods, these techniques provide an independent source of detection and can improve estimates of the probability of visual detection (Van Parijs *et al.,* 2002).

1.3. Cetacean communication

Social cetaceans, such as the short-beaked common dolphin, need mechanisms for continuously interacting and maintaining group cohesion (Janik & Slater, 1998). For many cetacean species, visual detection is a good way of communicating both above and below the water, yet a number of factors can limit its usefulness underwater (Dudzinski *et al.,* 2002). The attenuation of light in the sea (i.e. how far the light penetrates) is dependant on the dissolved and suspended matter in the water, as well as the water itself. Both the suspended particular matter and dissolved constituents are highly variable, especially in coastal waters. This is particularly relevant in areas with poor weather and sea conditions, such as around the coast of the United Kingdom (Goold, 1996). Acoustic communication travels 4.5 times faster underwater than above it and is not limited by the same factors as that of visual communication. This makes it an excellent form of underwater communication, especially over long distances (Dudzinski *et al.,* 2002).

Delphinids are known to produce at least four different types of sounds: burst pulse sounds, low-frequency narrow band sounds, broad band clicks and frequency modulated whistles. Clicks, used mainly for echolocation (Van Parijs & Corkeron, 2001), allow the dolphins to explore their surroundings and locate food (Goold, 1996). Clicks emitted from dolphins contain peak energy at frequencies up to 120 kHz (Au, 1980). At this frequency echolocation is directional, with a narrow beam emitted from the dolphin and concentrated in a forward direction. The beam width emitted can vary depending on species, but as a general rule, the higher the frequency, the narrower the beam width, the greater the directionality.

Frequency modulated whistles are used for communication and can serve many functions within this role such as communicating position both within a group or as individuals, to co-ordinate with each other during hunting and to identify individuals through signal whistles (Jacobs *et al*., 1993). As well as describing the types of whistles produced, Caldwell & Caldwell (1965) observed that of the whistles produced by a single individual bottlenose dolphin, one distinctive whistle, the signature whistle, was produced over 90% of the time. Caldwell & Caldwell (1968) indicated that individual common dolphins may also have the mechanism to produce a signature whistle of their own. Dolphin whistles are poorly directional (Goold, 1996). The majority of their energy is below the frequency of 20 kHz (Richardson *et al.,* 1995), making them audible to the human ear which has an upper frequency limit of 20 kHz. *D. delphis* whistles have frequently been detected without the aid of a hydrophone, especially during bow riding (Author's personal observation). Studies have shown that *D. delphis* produce whistles which range in frequency from 4 to 16 kHz (Viallelle, 2002) and 3.37 to 23.51 kHz, for those short-beaked common dolphins found in the Celtic Sea (Scullion, 2004; Ansmann, 2005). Caldwell & Caldwell (1968) published spectograms indicating frequencies range from an estimated 2 to 20 kHz.

To the author's knowledge, no audiogram has been generated for *D. delphis.* However audiograms produced for other odontocete species have shown vocalisations to range in frequency from 0.5 to 160 kHz for the striped dolphin (Kastelein *et al.,* 2003), 2 to 115 kHz for the false killer whale (Thomas *et al.*, 1998) and 0.25 to 180 kHz for the harbour porpoise (Kastelein *et al.*, 2002).

1.4 Cetaceans and Environmental Variables

The effects of environmental variables such as Sea Surface Temperature (SST), chlorophyll, depth and sea floor profile have been the focus of a number of studies investigating the distribution of cetaceans (Neumann, 2001). A fundamental necessity for any marine mammal in order to maintain itself, grow and reproduce is the consumption of food (Costa, 2002). Studies on energetic requirements show that most cetaceans have to feed every day (Baumgartner *et al.,* 2000). Insufficient food can reduce reproductive potential and may lead to a reduction in a species' population (Bearzi *et al.*, 2003).

Fixed variables, i.e. depth, and non-fixed variables, i.e. sea surface temperature and chlorophyll concentration, often play major roles in determining the spatial and temporal distribution of marine mammals, especially around frontal regions where non-fixed variables are thought to be of great importance (Hooker *et al.,* 1999). Cetaceans are often found feeding in areas of high primary production, which are areas rich in phytoplankton (Perry, 1986). Chlorophyll, which is the photosynthetic pigment of phytoplankton, is related to primary productivity of the water column and can be used to estimate the quantity and distribution of productivity (Baumgartner *et al.,* 2000). Using satellite data, Smith *et al.,* (1986) compared chlorophyll concentrations with cetacean distribution off the coast of California, USA. Sightings showed cetaceans to be distributed non-randomly in regions where chlorophyll concentrations were high and rich in productivity. During their study, out of all cetacean species present, *D. delphis* was the most abundant species identified.

As a pelagic species, *D. delphis* are generally distributed over the continental shelf at depths of 100-200 metres, or over areas with prominent bottom topographic features (Seizer & Payne, 1988; Silva, 1999, Perrin, 2002). They can however inhabit all depth ranges (Forcunda & Hammond, 1998; Canadas *et al*, 2002; Macleod *et al.*, 2003). Whilst surveying in the north-eastern Alboran Sea, Canadas *et al.,* (2002) investigated the distribution of cetaceans in relation to depth and slope. During 1992 to 2001 (excluding 1999), depth was identified as the variable with the strongest influence, with *D. delphis* showing a preference for depths of ≤400 metres, in particular inhabiting regions ≤200 metres. During 1999, *D. delphis* showed a preference for depths of >600 metres. The significant difference in depth was considered to be the result of a sudden 8 to 10 ºC drop in SST, from the norm, down to 15 to 16 ºC which had major effects on the dolphins' prey distribution.

Although correlations between cetacean distribution and environmental features have been identified, it is the effect on prey distribution and abundance which is believed to primarily influence cetacean distribution (e.g. Seizer & Payne, 1988; e.g. Cockcroft & Peddemors, 1990; Bearzi *et al* 2003)**.** In the southern Californian Bight, Hui (1979) reported that *delphinus* were associated with areas rich in upwellings and where mixing of nutrients occurred, areas of high topographic relief. The nutrients stimulated primary production so increasing the abundance of prey. The dolphins were found in these regions year-round and changed their diet according to prey availability/abundance.

1.5. St. George's Channel

Situated on the continental shelf, St George's Channel lies between the coast of Wales in the United Kingdom and the east coast of Ireland (**fig 1.5**) (http://en.wikipedia.org).

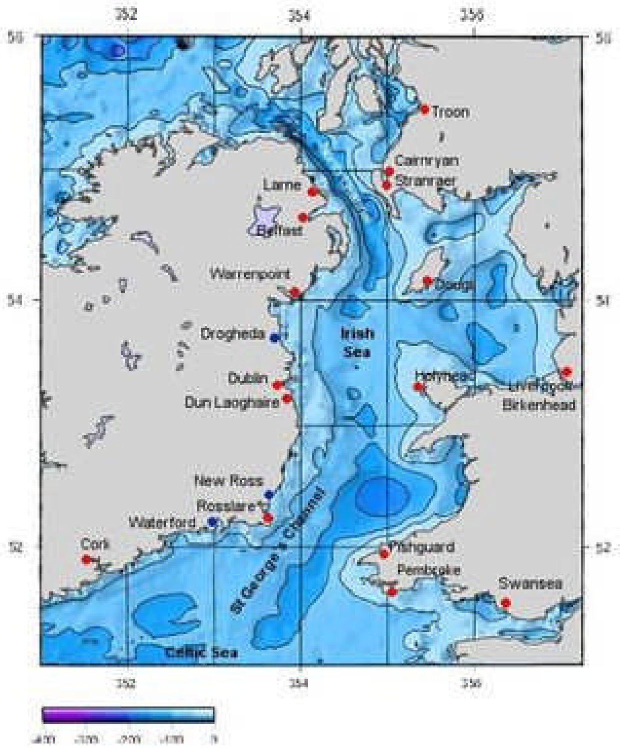


Figure 1.5 Relief map showing the location of the St. George's Channel
(Source: http://en.wikipedia.org)

Extending 100 miles in length with a minimum distance of 47 miles at its narrowest point (http://www.answers.com), St. George's Channel connects the Irish Sea to the north with the Celtic Sea to the south. During the spring and summer (May to October) each year the Celtic Sea front is present in this region (Horsburgh *et al.*, 1998). The Celtic Sea front is an oceanographic feature which forms at the boundary (Goold, 1998) between the cooler tidally mixed Irish Sea and the thermally stratified Celtic Sea (Horsburgh *et al.*, 1998). Studies surrounding the Celtic Sea front, such as that conducted by Pemberton *et al.* (2004), have shown that both well mixed and stratified water vary in hydrographic factors that will effect primary production. Stratified water, where no mixing of water occurs between top and bottom layers, is often nutrient limited. The nutrients locked in the cooler bottom water cannot surface to replenish the nutrients required by the phytoplankton, therefore the quantity phytoplankton declines. Phytoplankton in well mixed waters on the other hand, are continually supplied with nutrients but can become limited by the availability of light. The continuous mixing of the water, limits the amount of time phytoplankton spends in the euphotic zone, hence reduces photosynthesis (Goold, 1998; Pemberton *et al.*, 2004). At the front itself, mixed water could leak nutrients into the stratified water creating an area rich in biological activity.

1.6 Aims and Objectives of this study

The fundamental aim of this project is to investigate any significant differences between the acoustic and visual distribution of the short-beaked common dolphin, and determine any significant findings in relation to environmental factors. This will be achieved though the combined use of a Geographic Information System (GIS), remote sensing and statistical analysis.

To help investigate the main aim, the results are broken down into the following sections, each section containing their own objectives:

1) Visual encounters

* Investigate encounter frequency in relation to group size and sighting distance
* Identify the effect of sea state on group size and sighting distance
* Look at the relationship between group size and sighting distance

2) Acoustic encounters

* Investigate encounter frequency in relation to signal strength and encounter duration
* Identify the effect of sea state on signal strength and encounter duration
* Look at the relationship between signal strength and encounter duration

3) Visual and acoustic encounters

* Investigate acoustic contact with visual detection
* Identify the effect of signal strength on sighting ability
* Look at the relationships between visual (group size and sighting distance) and acoustic (signal strength and encounter duration) data sets

4) Environmental variables

* Investigate and describe the presence of significant patterns and correlations between the distribution of *D. delphis* in the St. George's Channel and depth, sea surface temperature and chlorophyll-a concentration
* Describe *D. delphis* distribution in relation to the Celtic Sea front

2.0 Methods

2.0 Methods

2.1. Fieldwork – Surveys

Four two-day line-transect surveys were carried out during the summer of 2006 (**fig 2.1**). Each survey was conducted once a month, with way points randomly selected before the start of the 2006 surveys (appendix A). The survey due to be conducted in May was postponed until June due to bad weather conditions at the end of May.

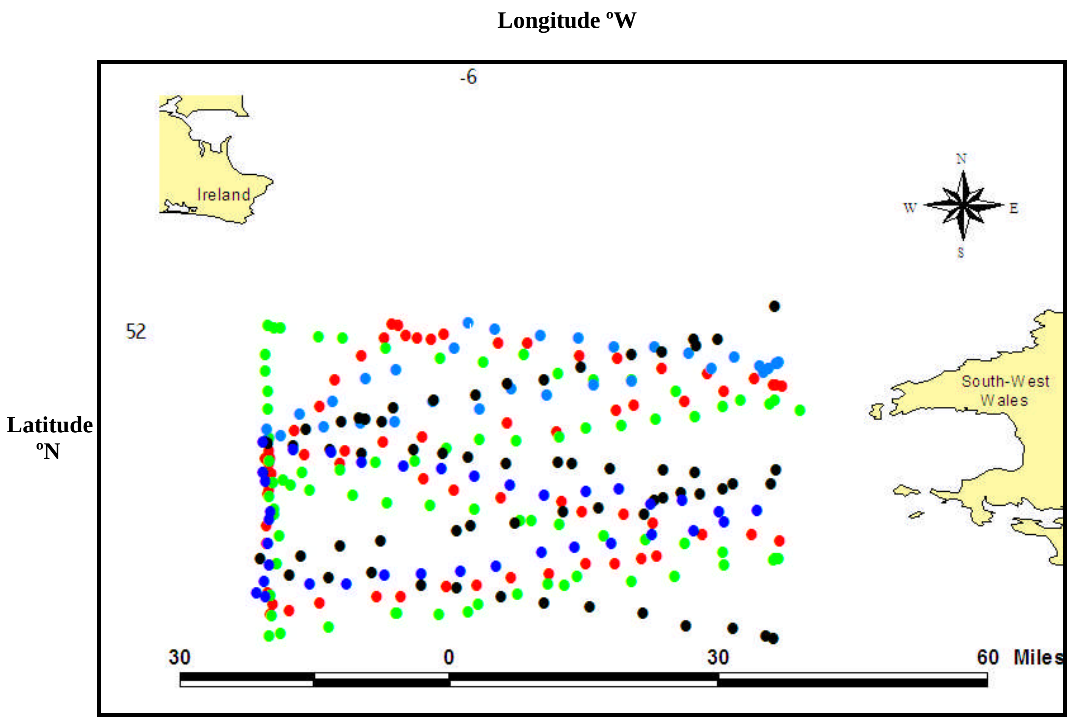


Figure 2.1 Line-transects during the 2006 surveys● June 01-02; ● June 26-27; ● July 23-24 ● August 22-23

All surveys were conducted aboard the vessel *Liberty of Wight* (**fig 2.2**), a 38 foot ocean ranger with twin Volvo 42v engines (www.pdcgo.co.uk) hired from Pembrokeshire Dive Charters. The four surveys departed from Neyland marina in south-west Wales and were conducted in St. George's Channel over the Celtic Deep, between latitudes 51°50' N and 52°03' N and longitudes 005°49' W and 006°34' W.

Figure 2.2.: The survey vessel, *Liberty of Wight*

A team of three observers from the Sea Watch Foundation (SWF) were used during each survey, one independent observer on the deck of the boat, and two primary observers covering waters both port and starboard. Upon sighting a marine mammal the following fields were completed on the SWF sighting sheet (appendix B): time, date, boat position (latitude and longitude, using the ship's Global Positioning System (GPS)), species, group size including number of adults/young, behaviour and associated birds. Every fifteen minutes, or when a new way point was reached, effort data including: date, time, boat position (GPS), course and speed, sea state (Beaufort scale), swell height, visibility and boat activity were recorded using vessel based effort forms (appendix C).

Using a hydrophone, 130 metres in length, recordings were continuously made whilst the boat was on transect. The hydrophone was deployed at a point when the water depth reached and remained at a safe depth, usually greater than 60 metres. If the vessel stopped for photo identification of cetaceans and the water was at a shallow depth, the hydrophone was brought aboard to prevent damage by hitting the seabed. The mono hydrophone, consisting of one channel, was towed behind the vessel (**fig. 2.3**).

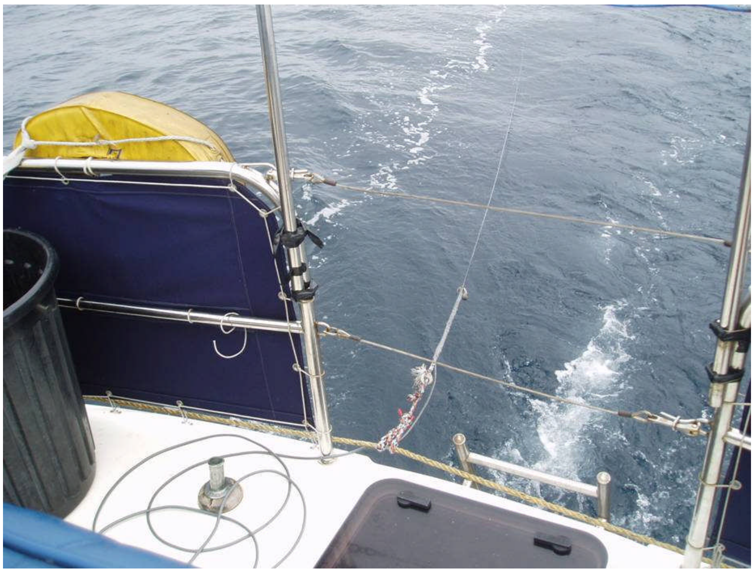


Figure 2.3 Photograph showing the towed hydrophone behind the boat

Digital Audio Tape (DAT) was used to record vocalisations via a Sony TDK-D7 DAT recorder which had a sensitivity range of 20 Hz to 22 kHz. Low frequency engine and turbulence noise was reduced by connecting the hydrophone to a 3 kHz high pass filter (**fig 2.4**).

a) b)

Figure 2.4 Figure; a) Hydrophone cables connected to the recording equipment. Figure; b) DAT recorder (left) and high pass filter (right)

All recordings were continually date and time coded using the DAT recorder's internal clock, which was synchronised with the portable GPS' used by the primary and independent observers. The author acted as acoustic observer, continuously monitoring acoustic activity, via headphones, to ensure settings were maintained at a consistent recording level and at a sampling rate of 48000 Hz, so not miss any of the higher frequency whistles.

2.2 Data

Recordings were replayed, through headphones, by the author and vocalisations detected by ear. To ensure consistency the same headphones and volume settings were used and maintained whilst listening to recordings from all four surveys. When a dolphin vocalisation was heard it was logged onto a spreadsheet. The author recorded start and end times of each vocalisation event to the nearest second, along with the signal strength of the event. Signal strength was categorised as either 0 (weak), 1 (medium) or 2 (strong) and relied upon the author's judgement. A new vocalisation event would be logged after a silence of more than ten seconds.

Vocalisations were grouped into 'acoustic' encounters, each encounter defined by a silence of five or more minutes between any vocalisation. In order to maintain consistency with SWF sightings data, the acoustic encounters were rounded to the nearest minute. Encounters lasting less than one minute were rounded up to one minute. Sea state at the start of each acoustic encounter was obtained from SWF vessel based effort sheets. Visual encounters or 'sightings' data were obtained from SWF sighting and independent observer sighting sheets. With group size data, the largest number of individuals logged was used, and the shortest distance when calculating sighting distance to the animal.

With the exception of the non-whistling harbour porpoise (Dudzinski *et al*., 2002), any whistles detected during sightings other than *D. delphis*, or at the same time as *D. delphis* sightings, were excluded from the data as whistle identification could not be verified as belonging to the short-beaked common dolphin. In order for further data analysis and to enable comparisons to be made, sightings occurring before deployment of the hydrophone and after the hydrophone was brought in were excluded from the data. Sightings occurring whilst the DAT recorder was inoperable, due to equipment malfunction/tape change, were also excluded.

2004 and 2005 data were provided by the SWF for use in statistical analyses. The data from both years were obtained from line-transect surveys conducted in the same region and same time of year as the 2006 surveys.

2.3. Visual Encounters

Using the data obtained from the visual surveys, group size and sighting distance to the dolphins, two histograms were produced in Microsoft Excel. The first identifying *D. delphis* group size against encounter frequency and the second the sighting distance against encounter frequency. After separately arranging group size and sighting distance data by sea state, two further histograms were produced. The first showing group size at sea states 0 to 2.5 and sea states 3 to 4, and the second showing sighting distance at corresponding sea states. Differences between the two classes of sea state were statistically tested using the non-parametric Mann-Whitney U test (for data not normally distributed). Pearson correlations were used to investigate relationships between sea state and sighting distance and sea state and group size. Although a parametric test, the data were not measured on a scale that could be meaningfully ranked, as required for a Spearman rank correlation. The non-parametric Spearman rank correlation was used to investigate the relationship between group size and sighting distance as these data could be sorted into rank order.

2.4. Acoustic Encounters

Following the same methods of visual analysis, histograms were created, showing both general encounter frequency and the effects of sea state upon signal strength of vocalisations and encounter duration, the data obtained from the acoustic surveys. Differences between sea state classes and variables were investigated (Mann-Whitney U tests), as were tests to look at relationships between variables. All relationships were investigated using Pearson correlations due to the non meaningful rank ability of the data.

2.5. Visual and Acoustic Encounters

For each acoustic encounter, it was noted whether a sighting had occurred within the same time period. This was achieved by looking at the start and end times of each acoustic encounter and at the start time of each visual encounter for the corresponding survey date. An acoustic encounter was marked as having a sighting if a visual encounter fell within its start and end time. Acoustic encounters not containing any visual sightings were investigated further to try to determine why no sightings were recorded. A stacked bar chart was created in Excel showing whether or not a sighting was present (yes/no) at the three different signal strengths heard during playback. After exporting the data into MINITAB, a non-parametric Kruskal-Wallis test for difference was applied.

To enable the investigation of relationships between visual variables (group size and sighting distance) and acoustic variables (signal strength and encounter duration), data were arranged accordingly in Excel. In some cases acoustic encounters contained more than one visual encounter, resulting in 'N' number of group sizes and sighting distances for a single encounter time. For the acoustic encounters where this was relevant, where more than one visual encounter occurred in a single acoustic encounter, the mean of those variables were calculated and correlations carried out using the mean. As with both acoustic and visual analysis, tests of relationship were carried out using Pearson correlations. The strength of relationships between the number of visual sightings per acoustic encounter duration were also investigated.

2.6. Environmental Variables and *D. delphis* Distribution

2.6.1 Depth

A Geographical Information System (GIS) was used to investigate depth in relation to short-beaked common dolphin distribution in the St. George's Channel. Depth data at a 2-minute x 2-minute resolution was obtained from SWF for the study area. The data were saved into a Dbase IV file and imported into the programme ArcGIS, version 3.3 (Arc 3). Arc 3 was used to convert the depth data from an event theme into an interpolated grid. Land was added showing the survey area in relation to the coast of south-west Wales. By overlaying a grid, consisting of 100 squares, over the survey region in Arc 3, the depth of each square was obtained using Arc 3 'identify' function. A pie chart representing the percentage of each depth range for the whole survey area was created (appendix D). *D. delphis* encounter data obtained from the visual and acoustic surveys were imported into Arc 3, to enable distribution plots and further comparisons between the two survey techniques to be made.

2.6.2 Remote Sensing

Remotely-sensed sea surface temperature (SST), chlorophyll-a (CHL-a) and front maps for the study area coinciding with the 2004, 2005 and 2006 surveys, were acquired from the NERC Remote Sensing Data Analysis Service (RSDAS), based in Plymouth Marine Laboratory, UK. RSDAS carried out all the image processing prior to delivery. All SST, CHL-a and front data were obtained from satellites, no in-situ readings or measurements were made at the time of the survey.

2.6.2a Sea Surface Temperature

Sea Surface Temperature (SST) used in this study was derived from the Advanced Very High Resolution Radiometer (AVHRR) carried aboard the National Oceanic and Atmospheric Administration (NOAA) satellites. Data were obtained at a spatial resolution of 1.1 km². Daily composites coinciding with the 2004, 2005 and 2006 survey days were obtained. Due to the nature of the infrared sensor, no data could be obtained through cloud cover, resulting in no useful daily composites for June 26-27, August 22-23 2006, and May 16-17 2005. Images for all other survey dates were used. Any cloud present in images resulted in a value of 0, therefore any encounters occurring in regions of cloud cover, were excluded from statistical analysis. All images were supplied as geo-referenced GeoTIFF (Georeferenced Tag Image File Format) 8-bit files. All SST images to be used in analysis were imported into Arc 3 and converted from a theme into a grid format for further analysis. Encounters corresponding to the date of the image were imported and SST values for each encounter extracted, with SST as the Z variable. The SST for each encounter was converted from digital number (DN) into 'real world' values (ºC) using the following equation supplied by RSDAS:

$$SST = DN \times (0.1 + 5)$$

where

DN = Digital number or the value of each pixel

Using the same grid method as with depth, the overall SST range for the study area was calculated (appendix E). With SST however, values were extracted from each available satellite image corresponding to the dates of each survey.

2.6.2b Chlorophyll-a

Concentrations of near surface Chlorophyll-a for the survey area were obtained from both the Sea-viewing Wide Field of view Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) with resolutions of 1.1 km² and 250 m² respectively. SeaWiFS provided daily CHL-a composites for all surveys taking place in 2004. Excluding images for May 16-17 2005 due to cloud cover, daily composites for all 2005 surveys, and seven-day composites for 2006 surveys were obtained from

MODIS. Although seven-day composites are lower in spatial and temporal resolution, no cloud free daily composites were available for any of the dates corresponding with when the surveys took place. As with SST, any cloud present in images resulted in a value of 0, therefore any encounters occurring in regions of cloud cover, were also excluded from statistical analysis. The GeoTIFF images were imported into Arc 3 and converted from a theme into a grid format for further analysis. Encounters corresponding to the date(s) of the image(s) were imported and CHL-a values for each encounter extracted, with CHL-a as the Z variable. Chlorophyll-a concentration for each encounter was converted from digital number into 'real world' values (mg/m^3) using the following equation supplied by RSDAS:

$$Chl = 10 \wedge (DN \times 0.015 - 2)$$

where

Chl = Chlorophyll-a (mg/m^3)

DN = Digital number or the value of each pixel

As with sea surface temperature, the overall chlorophyll-a concentrations for the survey area (appendix F) were calculated using data extracted from the satellite images.

2.6.2c Front Maps

Three-day composite front maps, derived from the AVHRR SST, were obtained for dates corresponding to the four surveys conducted in 2006. The front maps used in the present study, showed the presence and location of the Celtic Sea front, the oceanographic feature observed annually within the region. The composites were used in visual analysis to ascertain if the presence of fronts had an effect on the distribution of the short-beaked common dolphin.

2.7. Environmental Variable Analysis

Acoustic and visual encounters were graphed showing their distribution in relation to the maximum depth, SST and CHL-a concentration for the survey region. The non parametric Mann-Whitney U test was used to determine any significant differences between acoustic and visual encounters in relation to depth, SST and CHL-a. Using the data obtained from the visual encounters only (as visual data gave a greater sample size than that obtained from acoustic encounters), Pearson correlations were used to identify the degree of correlation between the environmental variables and encounters. Although not normally distributed, the continuous data sets allowed the Pearson correlation to be used. Scattergraphs were created showing the relationships between encounters and depth, SST and CHL-a. The mean SST and CHL-a concentration by survey month was calculated using the data extracted from the available satellite imagery. The month of May was not included to due lack of data availability.

2.8. Statistical Analysis

All statistical analyses were conducted using the statistical package MINITAB version 13. A variety of statistical tests were carried out to determine any significant differences or correlations in the data. Normality was tested using the Anderson-Darling test, and both the non parametric Mann-Whitney U and Kruskal-Wallis tests were used to study variance between variables. Relationships were detected using both Pearson correlation and Spearman rank correlation.

3.0 Results

3.0. Results

During 2006, four two-day surveys were conducted in the St. George’s Channel. Out of the four surveys, data were collected for all days with the exception of 23 June when technical problems with the recording equipment resulted in no acoustic data being collected for that day. Analyses of data did not include any sightings data from 23 June 2006. A total of 43 hours and 43 minutes of recordings were made during the 2006 surveys. Of those, 10 hours, 57 minutes were recorded during Survey 1 (June 01-02), 13 hours, 10 minutes during Survey 2 (June 26-27), 7 hours, 19 minutes during Survey 3 (July 24) and 12 hours, 26 minutes during Survey 4 (August 22-23).

During the four 2006 surveys 79 short-beaked common dolphin acoustic encounters were recorded and 131 visual encounters. Of the 131 visual encounters, 24 were excluded from further analysis as they were sighted whilst the hydrophone was not deployed or at times when the hydrophone was inoperable. Combined data from 2004, 2005 and 2006 recorded a total of 142 acoustic encounters and 220 visual encounters. Seven acoustic encounters and eight visual encounters were disregarded from statistical analysis due to incomplete data sets.

3.1. Visual Encounters

During the 212 visual encounters, 1641 individuals were recorded over the three survey years. The greatest distance an animal was detected from the vessel was 3000 metres, whilst the maximum group size encountered consisted of 56 individuals. The surveys were conducted in sea states ranging from 0 to 4, with the mean sea state as 1.5. Using the Anderson-Darling test, data obtained from visual surveys did not follow the normal distribution curve. **Table 3.1** shows the descriptive statistics, including the results for normality tests, for data obtained from visual surveys.

	Group size	Distance to animal	Sea state
Minimum	1	4	0
Maximum	56	3000	4
Mean	8	391.19	1.5
Standard Deviation	8.97	401.74	0.95
Number	212	212	212
A-Squared	20.416	10.151	7.273
P-Value	<0.001	<0.001	<0.001

Table 3.1. Descriptive statistics for data obtained from visual surveys, including group size, distance to animal (metres) and sea state (Beaufort scale). P. Value = probability; A-Squared = test result

Figure 3.1 shows the group size of the short-beaked common dolphin and the frequency at which that group size was sighted. As group size increased the number of sightings decreased. With 139 sightings, the most frequent encounters occurred with a group size consisting of 1 to 6 individuals. No sightings with a group size greater than 56 individuals were observed.

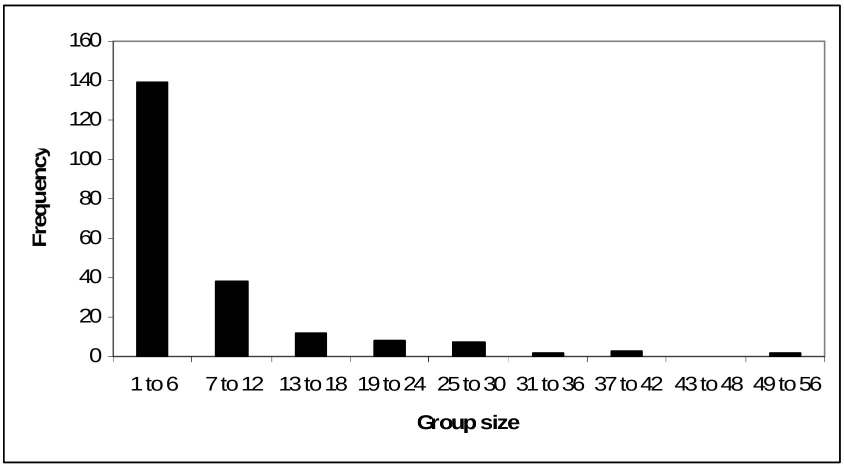


Figure 3.1. Frequency histogram showing the group size of *D. delphis* during the 2004, 2005 and 2006 surveys

Figure 3.2 shows the sighting distance to the short-beaked common dolphins that were visually detected. The general trend shows the greater the distance from the vessel, the lower the frequency at which they were sighted. The greatest number of sightings occurred when the *D. delphis* were within 1 to 100 metres and 300 to 599 metres of the boat, in which 55 encounters were detected. Dolphins observed 101 to 299 metres away only differed by 4 encounters, with 51 encounters being detected at that distance. Only 1 encounter was detected between distances of 2000 to 3000 metres. No short-beaked common dolphin encounters were detected greater than 3000 metres.

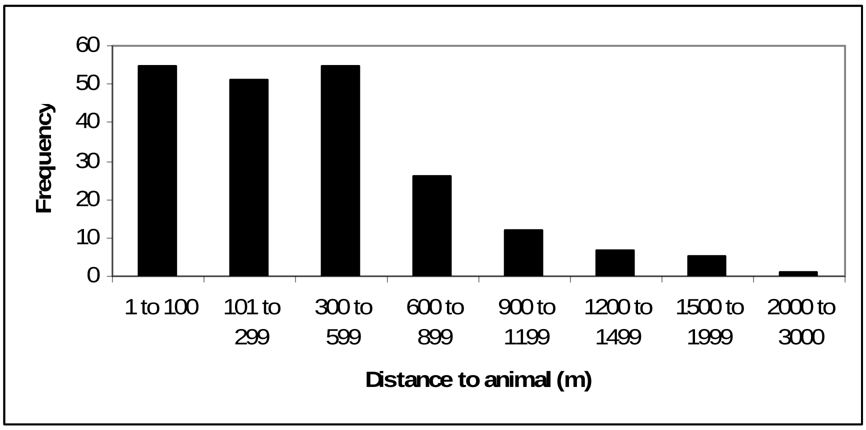


Figure 3.2. Frequency histogram showing the sighting distance (metres) of *D. delphis* during the 2004, 2005 and 2006 surveys.

Figure 3.3 shows the group size and the frequency at which dolphins were encountered at sea states 0-2.5 and sea states 3-4. The distribution of data generally follows that of figure 3.1, with the highest encounter frequency observed with a group size of 1 to 6 individuals. For groups consisting of 1 to 24 individuals, the figure generally shows a greater encounter frequency during sea states 3 to 4 (n =74) than during sea states 0 to 2.5 (n = 65). As group size increased to above 25 individual, encounters were more frequently detected in sea states 0 to 2.5.

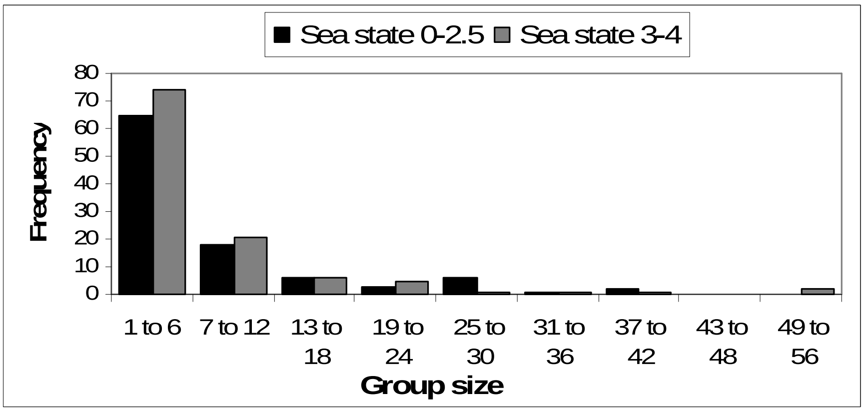


Figure 3.3 Frequency histogram showing the group size of *D. delphis* in varying sea states

Figure 3.4 shows the sighting distance and the frequency at which dolphins were encountered at that distance during sea states 0-2.5 and sea states 3-4. The sighting distances observed during sea states 0 to 2.5 follow the same general trend as that in figure 3.1 with the lowest sighting frequency the farther away the dolphins were from the boat. One obvious difference between the two sea state classes is in the number of encounters. The highest number of encounters observed during sea states 0-2.5 (n = 51) occurred at a distance of 300 to 599 metres, with encounters observed at all distances up to a maximum distance of 3000 metres. In sea states 3 to 4, the maximum number of *D. delphis* encountered was 16, and were observed closer to the boat at a distance no greater than 100 metres. The maximum sighting distance was 1,999 metres from the boat, however only 1 encounter was observed at this distance.

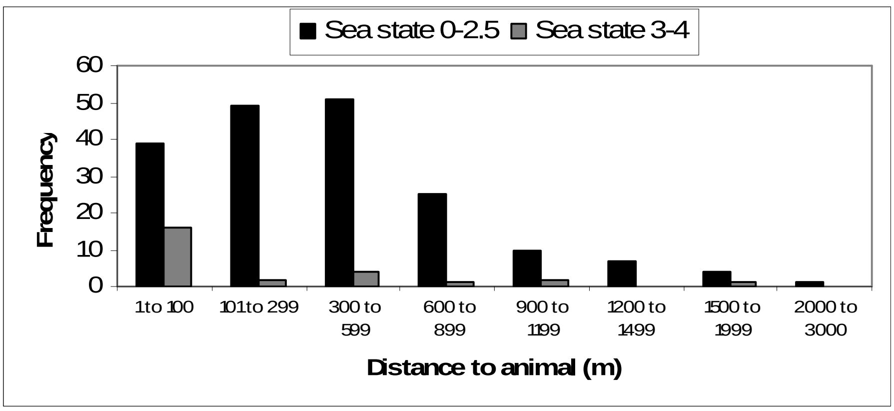


Figure 3.4 Frequency histogram showing the sighting distance of *D. delphis* in varying sea states

No significant difference (Mann-Whitney U test: W=10275; P=0.2782) was identified between group size at the two sea state classes, however a significant difference (Mann-Whitney U test: W=20724.5; P=0.0018) was identified between sighting distance and the two sea state classes. Testing the strength of relationships (**table 3.2**) between the three variables obtained from visual surveys identified no significant relationship between either sea state and group size or sea state and sighting distance. **Figure 3.5** does show a significant relationship (Spearman rank, P=<0.001) between group size and sighting distance, with larger groups being detected at greater distances. The test statistic (Spearman rank, R=0.301;-1 = perfect negative correlation; 0 = no correlation; 1 = perfect positive correlation) does however indicates, although significant, group size and sighting distance to the animal have a relatively weak correlation.

	Distance to animal		**Group size**	
	R	P	R	P
Sea state	-0.074	0.281	-0.047	0.496
Distance to animal	-	-	0.301	<0.001*

Table 3.2 Results of correlation tests (statistic and probability values) between sea state, distance to animal (metres) and group size. Pearson correlation test for Group size/sea state & distance to animal/sea state. Spearman rank for group size/distance to animal * very significant result (<0.01)

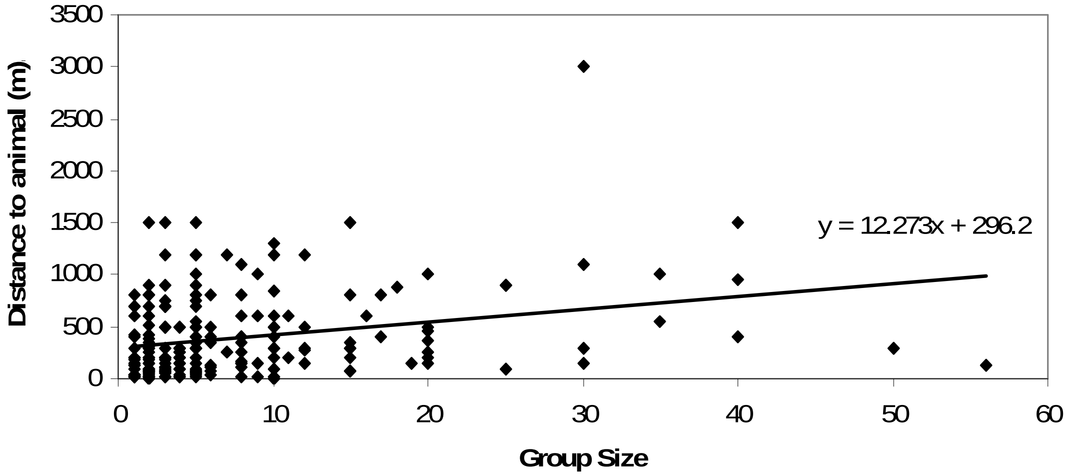


Figure 3.5. Scattergraph with trendline showing relationship between group size and sighting distance (metres) to *D. delphis*

3.2. Acoustic Encounters

The total encounter duration of surveys conducted during 2004, 2005 and 2006 was 2,860 minutes, with the shortest encounter lasting one minute and the longest encounter 300 minutes. Acoustic encounters were detected in sea states ranging from 0 to 4, with a mean sea state of 1.8. Normality tests (Anderson-Darling test) showed data obtained from acoustic surveys were not normally distributed. **Table 3.3** shows the descriptive statistics, including the results for normality tests, for data obtained from acoustic surveys.

	Signal strength	**Encounter duration**	**Sea state**
Minimum	0	1	0
Maximum	2	300	4
Mean	1	21.19	1.8
Standard Deviation	0.828	37.55	0.86
Number	135	135	135
A-Squared	11.210	17.951	6.013
P-Value	<0.001	<0.001	<0.001

Table 3.3 Descriptive statistics for data obtained from acoustic surveys, including signal strength, encounter duration (minutes) and sea state (Beaufort scale). P. Value = probability; A-Squared = test result

Figure 3.6 shows the signal strength detected from the short-beaked common dolphin and the frequency at which that signal strength was detected. Out of the 135 encounters, the greatest number of encounters occurred when the signal strength was strong (n=48), with the lowest number of encounters occurring when the signal was at a medium strength (n=43). Vocalisations which were weak in strength only differed from encounters at a medium strength by one encounter (n=44). A Kruskal-Wallis test for variation revealed no significant difference between signal strengths (H=2.00; DF=2; P= 0.368). **Figure 3.7** shows the encounter duration or how long each acoustic encounter lasted. As encounter time increased, encounter frequency decreased. Encounters lasting between 1 and 10 minutes were most frequently detected (n=74), whilst encounters lasting longer than 100 minutes in duration were detected less frequently (n=1). No encounter lasted between 141 and 160 minutes, nor lasted longer than 300 minutes.

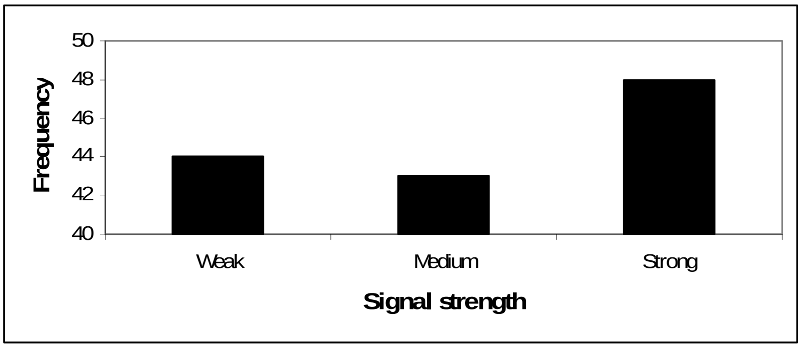


Figure 3.6 Frequency histogram showing the signal strength of *D. delphis* during the 2004, 2005 and 2006 surveys

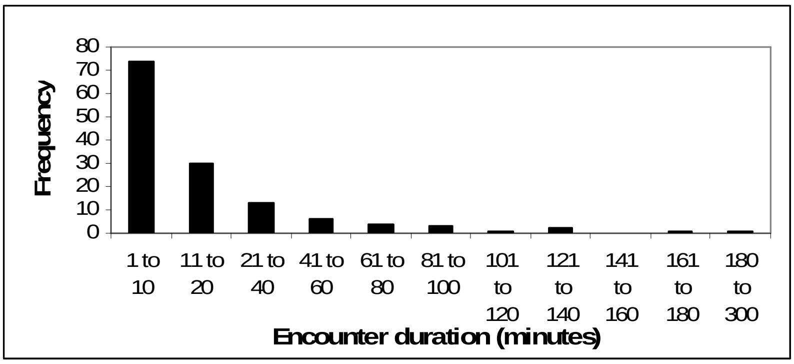


Figure 3.7 Frequency histogram showing the encounter duration of *D. delphis* during the 2004, 2005 and 2006 surveys

Figure 3.8 shows the signal strength of the vocalisations and the frequency at which each strength category was detected in sea states 0-2.5 and in sea states 3-4. Encounters detected during sea states 0 to 2.5 follow the same pattern as that in figure 3.6, with the greatest number of encounters detected when the signal strength was strong (n=41), followed closely by medium (n=38) then weak signals (n=35). Encounters detected during sea states 3 to 4 were less frequent in occurrence than those detected in sea state 0 to 2.5. The way the data is distributed also differs with the greatest number of encounters being detected at a medium signal strength (n=8), closely followed by strong (n=7) and weak (n=6) signals.

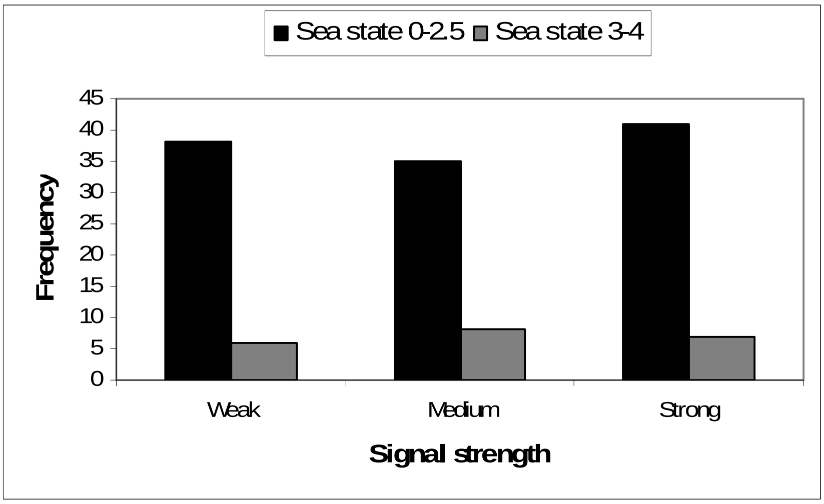


Figure 3.8 Frequency histogram showing the signal strength of *D. delphis* in varying sea states

The effect of sea state on encounter duration is shown in **figure 3.9**. For both sea state classes, encounter frequency decreased as encounter duration increased. With the exception of an encounter duration of 141 to 160 minutes, encounters in sea states 0 to 2.5 were detected at all duration ranges, the most frequent (n=65) lasting between 1 and 11 minutes, with the least number of encounters (n=1) lasting between 101 and 300 minutes. At sea states 3 to 4, with the exception of one encounter lasting between 121 and 140 minutes, the maximum time an encounter lasted was between 41 and 60 minutes (n=2).

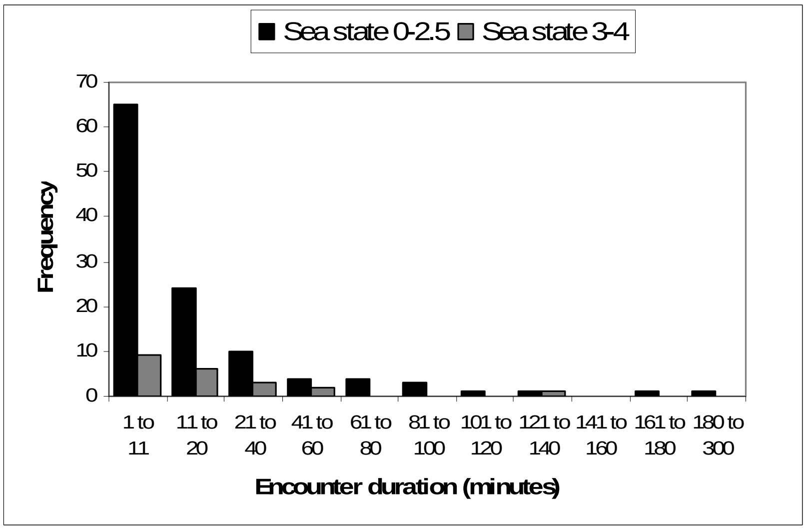


Figure 3.9 Frequency histogram showing the encounter duration of *D. delphis* in varying sea states

No significant differences were identified between signal strength (Mann-Whitney U test: W=7736.5; P=0.9230) or encounter duration (Mann-Whitney U test: W=7559.5; P=0.2390) in the two sea state classes. Testing the strength of relationships (**table 3.4**) between the three variables obtained from acoustic surveys identified no significant relationships between signal strength and increasing sea state or between encounter duration and increasing sea state. A significant relationship (Pearson correlation P=0.004) between signal strength and encounter duration was identified (**fig 3.10**), with encounter duration increasing as signal strength increased. The test statistic (R=0.249; -1 = perfect negative correlation; 0 = no correlation; 1 = perfect positive correlation) does however indicate that signal strength and encounter duration have a moderately weak correlation.

	Signal strength		**Encounter duration**	
	R	P	R	P
Sea state	-0.030	0.731	-0.013	0.879
Signal strength	-	-	0.249	0.004*

Table 3.4 Results of Pearson correlation tests (statistic and probability values) between sea state, signal strength and encounter duration (minutes). * very significant result (<0.01)

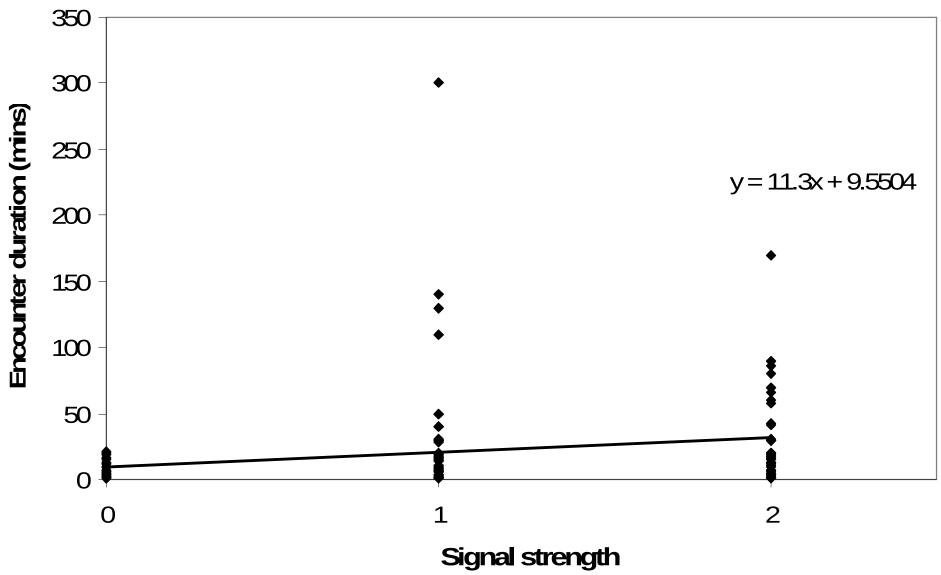
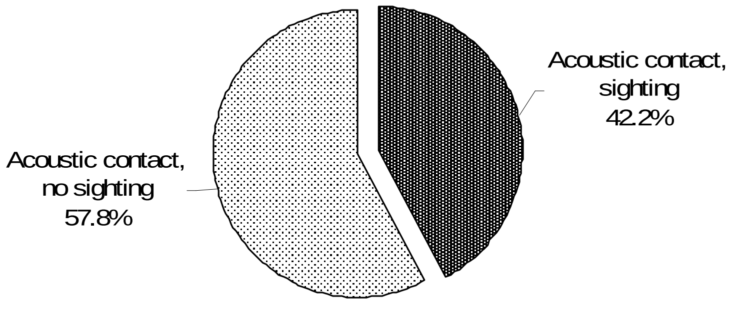


Figure 3.10 Scattergraph with trendline showing relationship between signal strength and encounter duration (minutes). 0-weak; 1-medium; 2-strong

3.3. Visual and Acoustic Encounters

Out of the 135 acoustic encounters, 57 (42.2%) encounters had acoustic contact and one or more visual sightings and 78 (57.8%) encounters had acoustic contact but no associated sighting (**fig. 3.11a**). Of the 57.8% where there was acoustic contact but no sighting, 28.9% of acoustic contact occurred within less than five minutes of a sighting, 34.2% of the signals recorded were weak in strength, 14.5% of the acoustic encounters were detected in sea states greater than two, 9.2% were weak signals and detected in sea states greater than two, and 13.2% due to other factors (**fig. 3.11b**) a)



b)

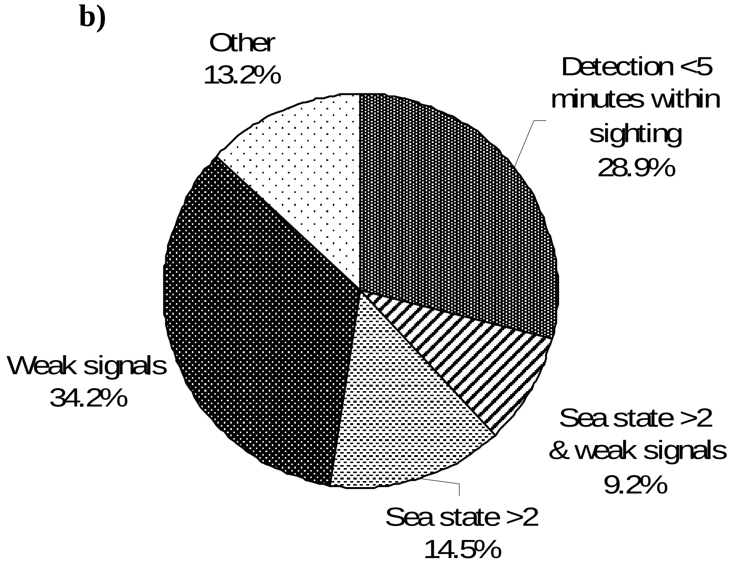


Figure 3.11 a) Acoustic encounters broken down into whether a sighting was detected or not at the time of the encounter, and **b)** factors contributing to why there may have been acoustic contact but no sighting

The stacked bar chart (**fig. 3.12**) shows as signal strength became stronger, the number of sightings detected increased. 13.6% (n=6) of sightings were detected when signals were weak whereas 62.5% (n=30) of sightings were detected when signals were strong. Sightings detected when the signal was considered to be a medium strength was slightly lower at 48.8% (n=21) than when there was no sighting (51.2%; n=22). Statistical analysis showed there to be a significant difference between the three signal strengths and whether or not a sighting was recorded (Kruskal-Wallis; H=16.37; DF=2; P =<0.001).

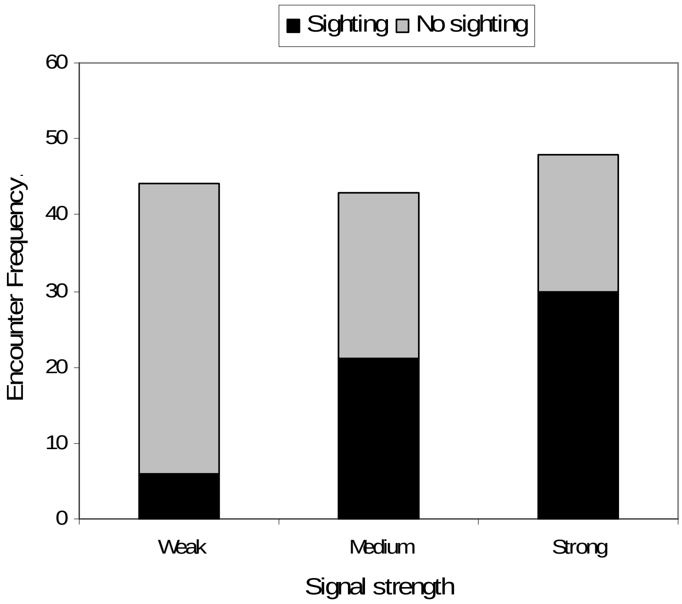


Figure 3.12 Signal strength versus whether or not a sighting was recorded

No significant relationship between distance to animal/signal strength; distance to animal/encounter duration and group size/signal strength was identified from the Pearson correlation (**table 3.5**). The test variable (R) did however identify a weak positive relationship (R=0.281) between signal strength and sighting distance to the animal. A significant positive relationship (Pearson correlation; R=0.529, P=0.004) was identified between group size and encounter duration, with acoustic encounters lasting longer in duration as group size increased (**fig. 3.13**). A significant positive correlation (Pearson correlation; R=0.488, P=0.001) was also identified between the number of visual sightings per acoustic encounter and encounter duration (**fig. 3.14**).

	Distance to animal		**Group size**		**No. sightings**	
	R	P	R	P	R	P
Signal strength	0.281	0.148	0.165	0.402	-0.081	0.312
Encounter duration	0.006	0.709	0.529	0.004*	0.488	<0.001*

Table 3.5 Results of Pearson correlation between acoustic and visual encounter variables. * very significant (<0.01)

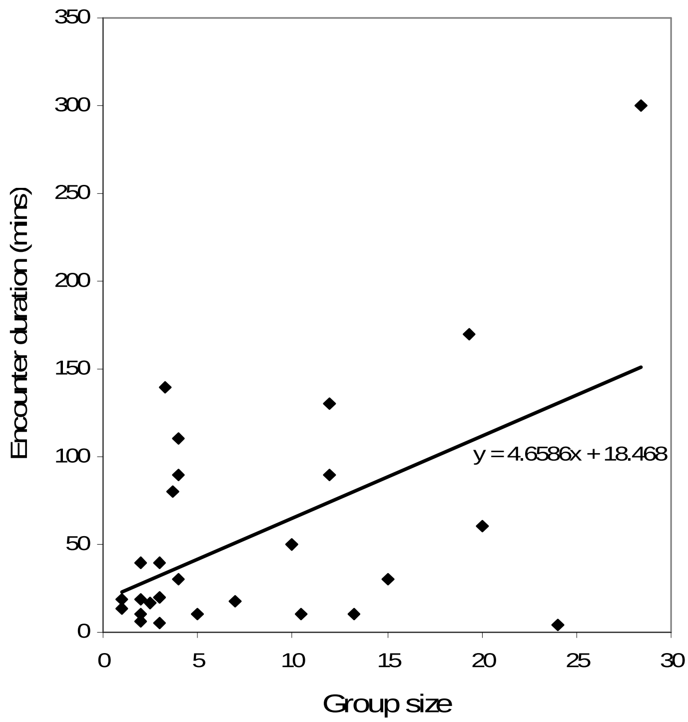


Figure 3.13 Scattergraph, with trendline, showing the relationship between group size and encounter duration (minutes)

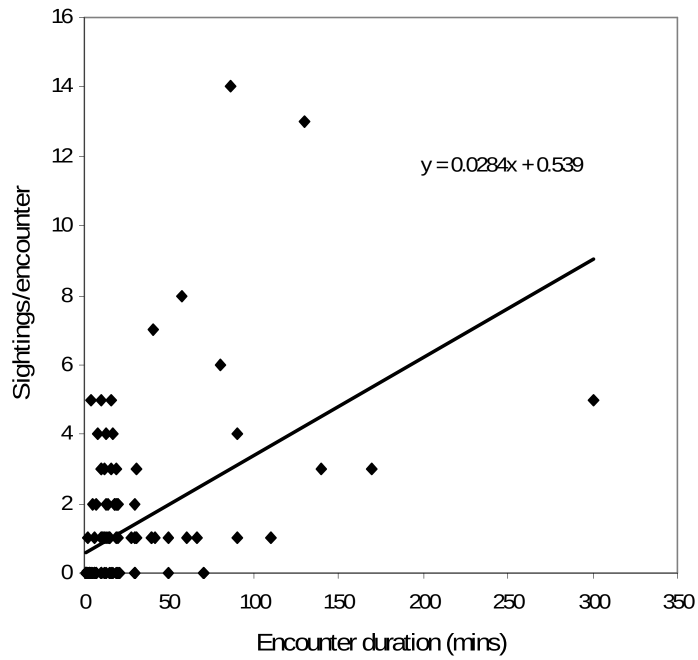


Figure 3.14 Scattergraph, with trendline, showing the relationship between the number of visual sightings per acoustic encounter and encounter duration

3.4 Environmental Variables and *D. delphis* Distribution

3.4.1 Depth

Acoustic and visual distribution of the short-beaked common dolphin in relation to depth is shown in **figure 3.15**. The figure shows that depth ranged from 0 to 126 metres with the dolphins distributed in all depth ranges above 5 metres.

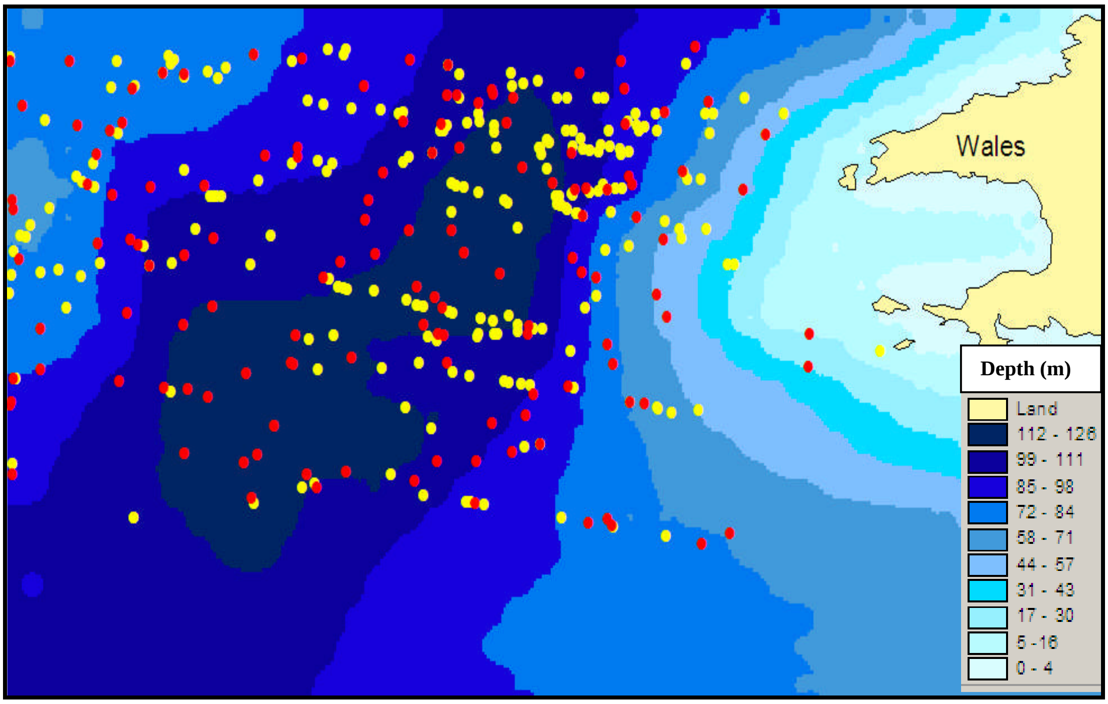


Figure 3.15 Distribution of the short-beaked common dolphin during 2004, 2005 and 2006 in relation to depth (metres) off the coast of south west Wales. ●-visual encounters ●-acoustic encounters.

3.4.2 Sea Surface Temperature

Figure 3.16 shows both temporal and spatial variability in SST over the three survey years. With the exception of 2004, the composites show that SST increased between June and August 2005 and June and July 2006. The survey conducted in July 2004 shows cooler temperatures than those present at the time of the June survey in the same year. The composites indicate that sea surface temperatures were generally warmer offshore than in coastal waters.

3.4.3 Chlorophyll-a

Composite images showing changing chlorophyll-a concentrations during the three survey years are shown in **figure 3.17**. The images show that higher levels of chlorophyll-a were concentrated around coastal waters, whilst lower levels were found in offshore waters. Although some composites are partially obscured by cloud, they do show a general decrease in levels of chlorophyll-a over time, with the greatest concentrations occurring in June of each year.

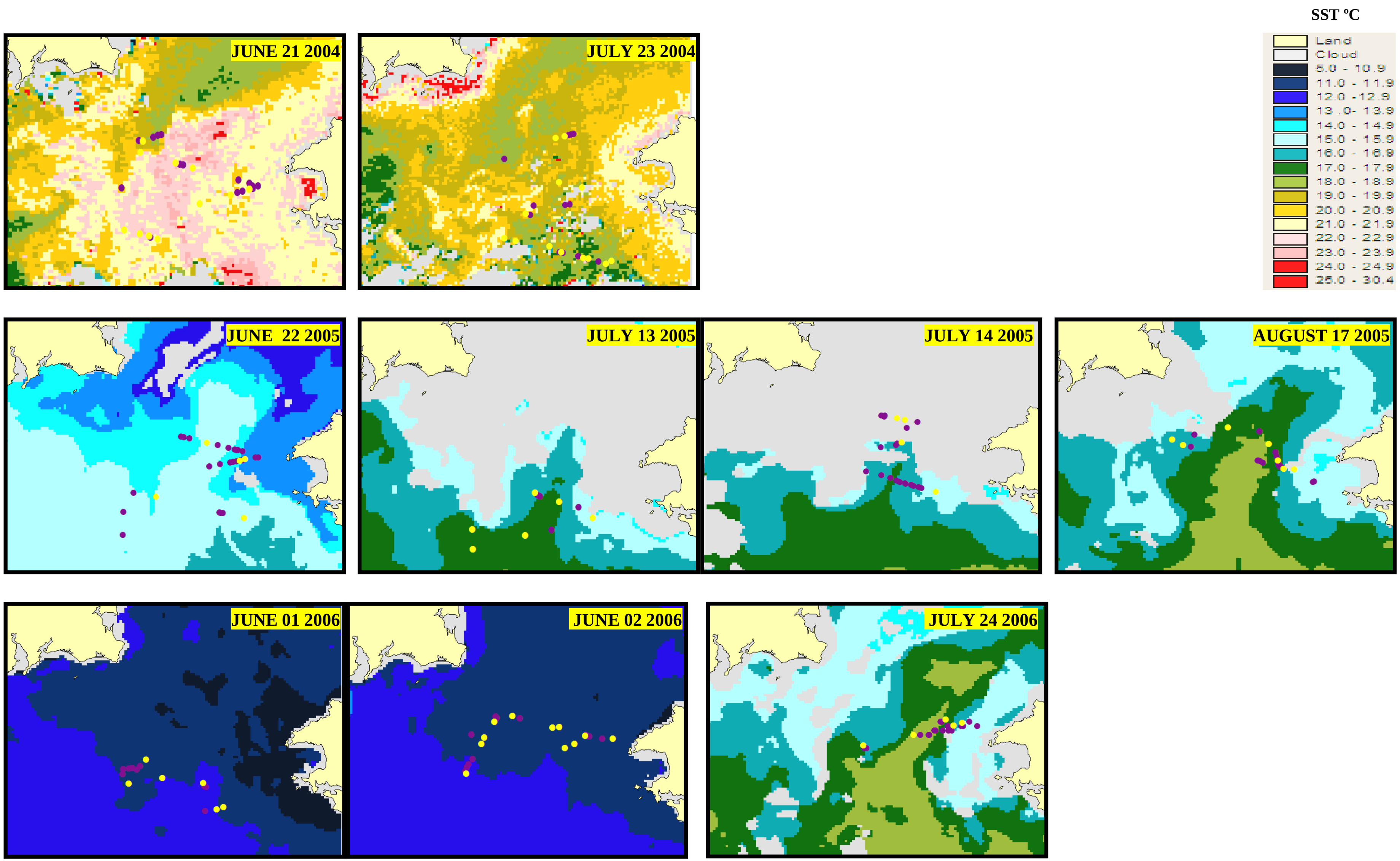


Figure 3.16. AVHRR daily composite images showing the sea surface temperatures (SST ºC) for St.George's channel for **2004** June 21; July 23; and **2005** June 22; July 13; July 14; August 17 and for **2006** June 01; June 02 July 24. *D. delphis* distribution ●- visual encounters ●- acoustic encounters

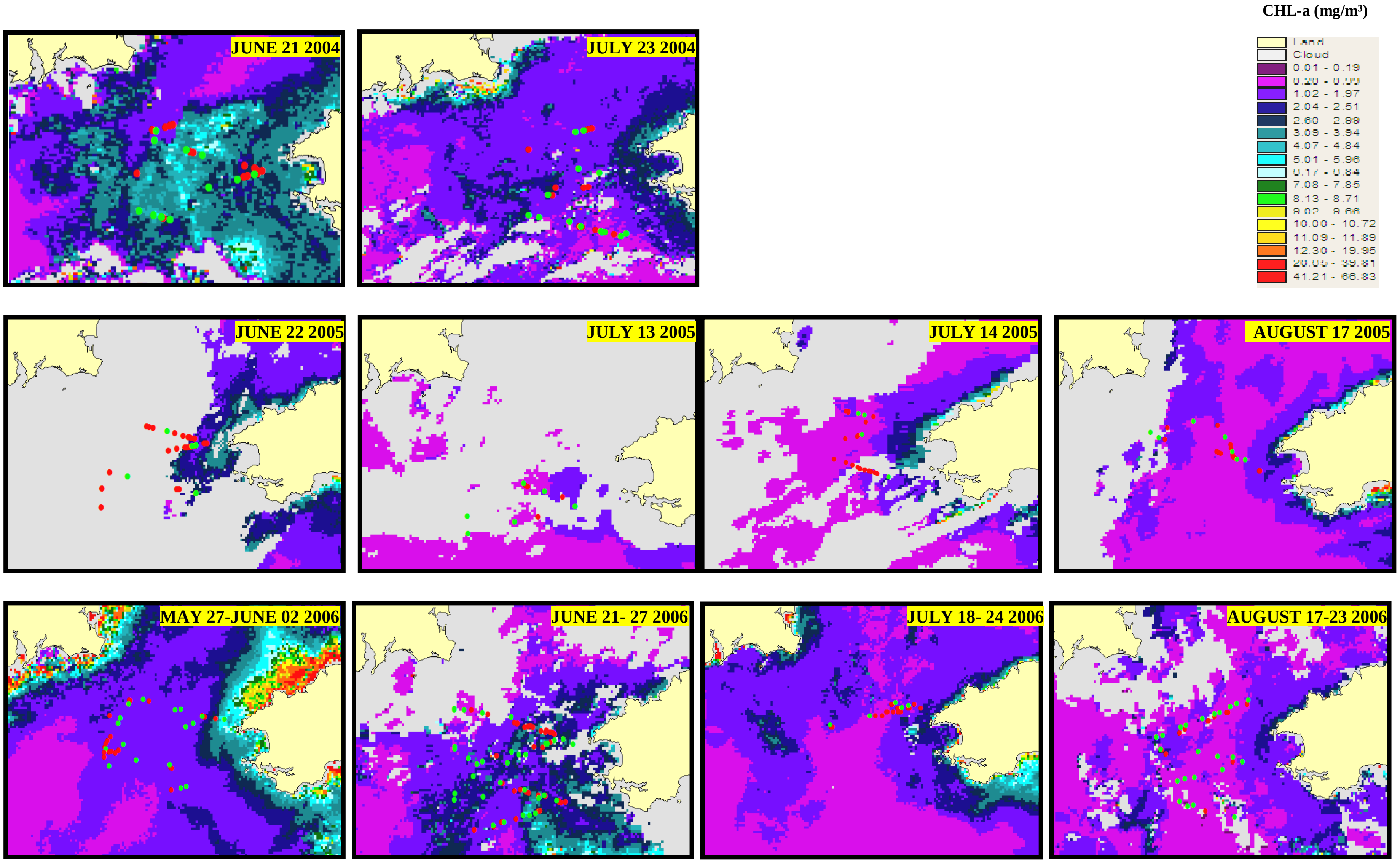


Figure 3.17 SeaWiFS daily composite images showing chlorophyll a concentration (CHL-a mg/m³) for St. George's channel for **2004** June 21; July 23. MODIS daily composite images for **2005** June 22; July 13; July 14; August 17 and MODIS 7 day composite images for **2006** May 27-June 02; June 21-27; July 18-24; August 17-23. *D. delphis* distribution ●- visual encounters ●- acoustic encounters.

3.4.4 Front Maps

The three-day composite images in **figure 3.18** show the Celtic Sea front at the time of the 2006 surveys, as well as the distribution of the short-beaked common dolphin, derived from visual and acoustic surveys, in relation to front. The composites show the formation of the front over the survey months. The front appears to be less established at the time of survey one, however, at the time of survey three the front seems to be well established. The distribution of *D. delphis* appears to be closely related to the formation of the front, with distribution in greater proximity to the front the more established it became.

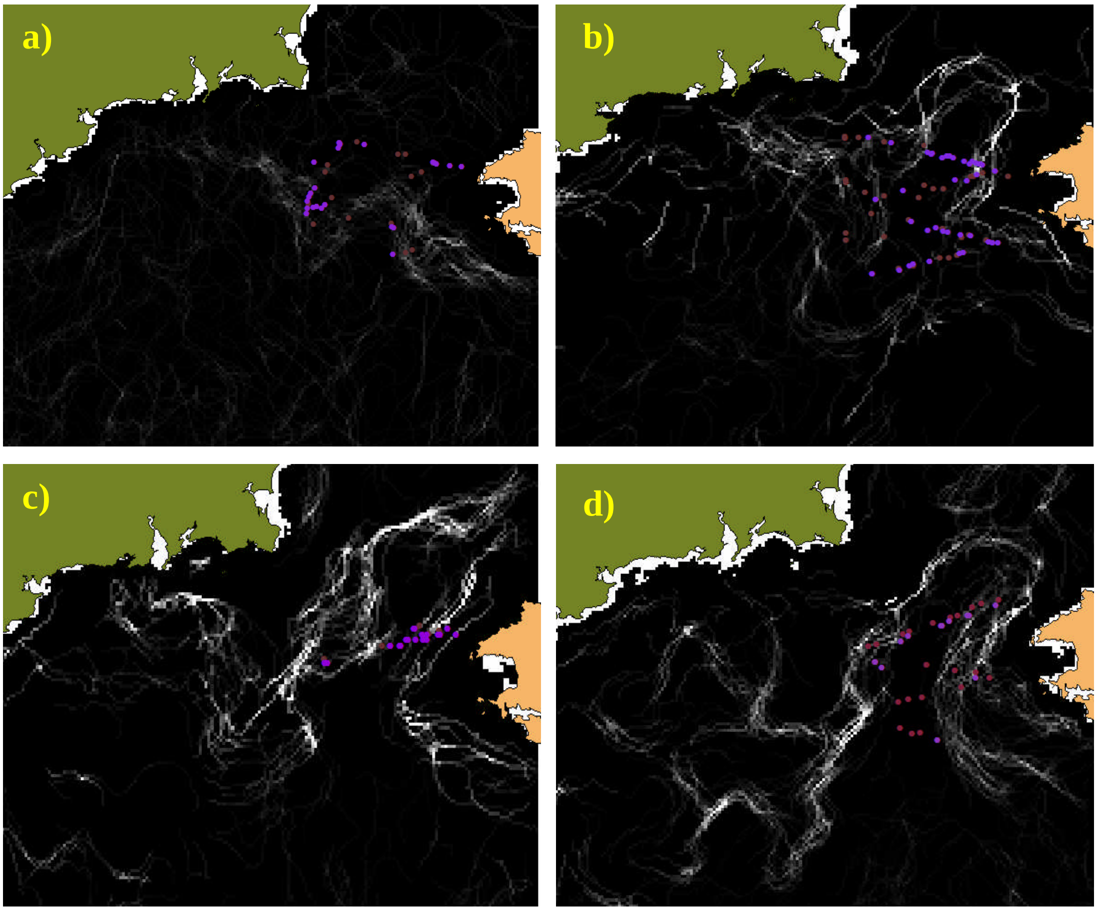


Figure 3.18 3-day composites, derived from AVHRR SST, indicating position of Celtic Sea front in 2006 with visual and acoustic encounters (● visual; ● acoustic) Image a) Survey 1 (May 31 – June 02*) ; b) Survey 2 (June 25-27*); c) Survey 3 (July 22-24*) and d) Survey 4 (August 21-23*). Green represents Ireland, Pink represents Wales. *date of composite

3.5 Environmental Analysis

The visual and acoustic distribution of the short-beaked common dolphin in relation to depth, sea surface temperature and chlorophyll-a concentration can be seen in **figure 3.19**. Results for depth show that the dolphins were encountered at all depth ranges between 0 and 126 metres, although they were more frequently encountered, both acoustically and visually, as depth increased. *D. delphis* were encountered in sea surface temperatures ranging from 10 to 24ºC. Acoustic and visual encounters both show the greatest number of encounters occurred in temperatures between 16 and 18ºC, with the fewest number of encounters occurring in temperatures ranging between 22 and 24ºC. The range of chlorophyll-a concentrations of 1 to 1.9 mg/m^3 was the concentration range in which *D. delphis* was frequently, visually and acoustically, encountered. Although *D. delphis* was encountered at concentrations ranging from 0 to 5.9 mg/m^3, they were less frequently encountered in concentrations ranging from 5 to 5.9 mg/m^3.

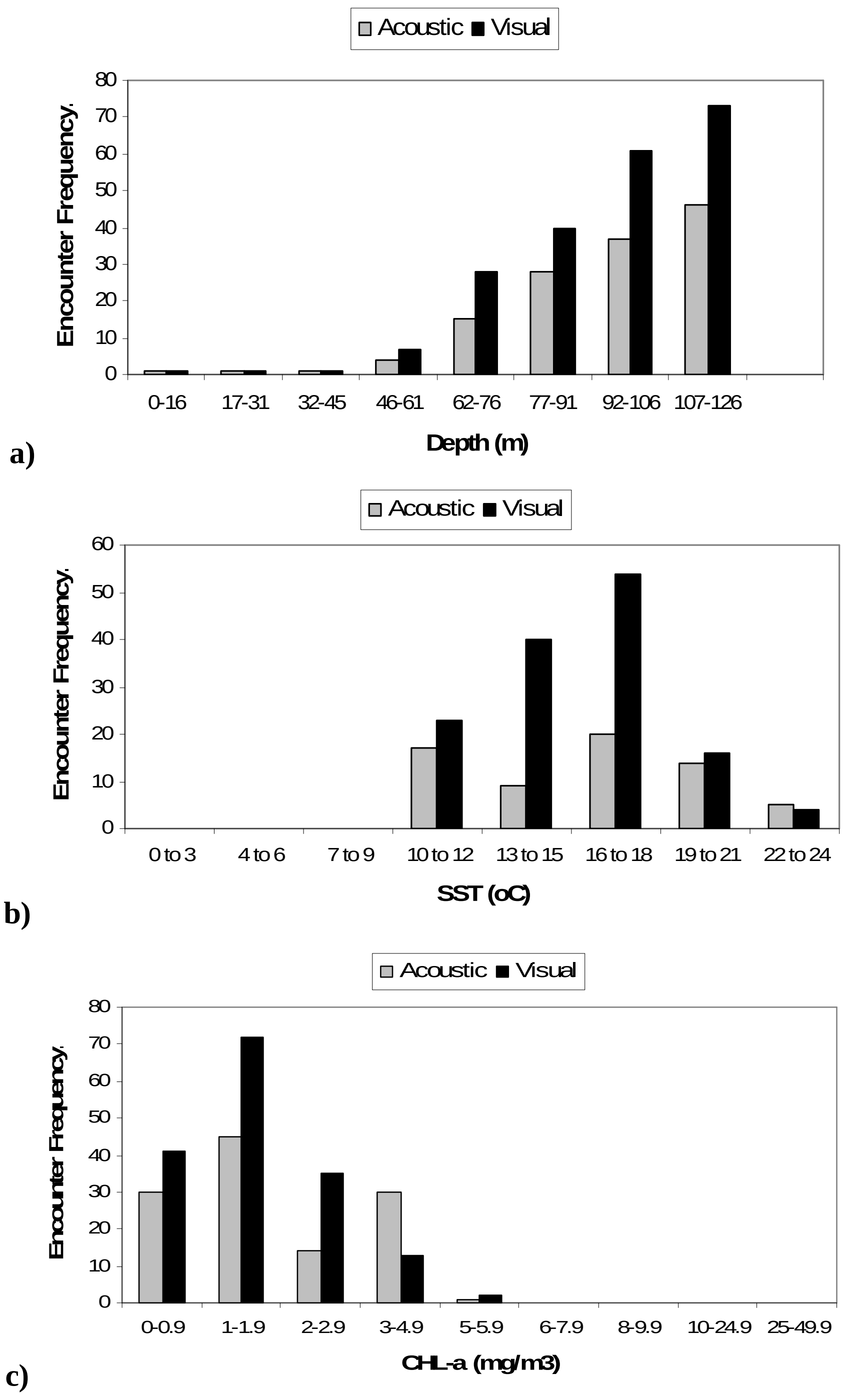


Figure 3.19 Histograms showing acoustic and visual distribution of the short-beaked common dolphin in relation to **a)** depth (metres); **b)** sea surface temperature (ºC) and **c)** chlorophyll-a concentration (mg/m³)

The mean, minimum and maximum values for the three environmental variables were calculated for both visual and acoustic encounters (**table 3.6**). With the exception of depth, the minimum and maximum values for SST and CHL-a were identical for both acoustic and visual encounters. Visual encounters gave the greatest depth range. The means for CHL-a and SST were highest with acoustic encounters, whilst the mean depth was greatest with visual encounters.

		Mean	**St. Dev.**	**Min**	**Max**
Depth	Acoustic	94.5	19.4	16.5	122.5
	Visual	95.3	19.1	8.9	121.8
SST	Acoustic	16.6	3.7	11.3	22.9
	Visual	16.1	3.0	11.3	22.9
CHL-a	Acoustic	1.8	1.1	0.2	5.8
	Visual	1.7	1.0	0.2	5.8

Table 3.6 Mean, minimum and maximum depth (metres), sea surface temperature (ºC), and chlorophyll-a concentration (mg/m^3) for acoustic and visual encounters

The results of the Anderson-Darling normality test (appendix G) showed that depth, SST and CHL-a data were not normally distributed, therefore the non-parametric Mann-Whitney U test was used to determine any significant differences (**table 3.7**). No significant differences were observed between acoustic and visual distribution of the short-beaked common dolphins in relation to the environmental variables.

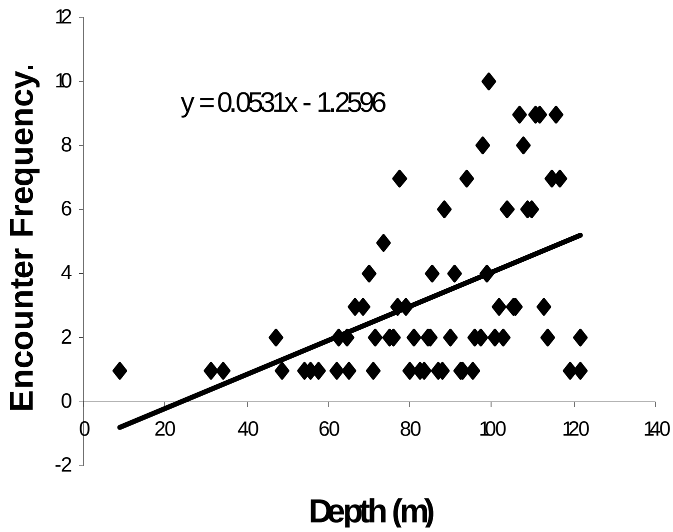
Variable	**W**	**P**
Depth	23300.0	0.8352
SST	7023.5	0.2729
Chlorophyll-a	15183.0	0.9287

Table 3.7 Results of Mann-Whitney U tests (W=test statistic value, P=probability value) used to determine differences between *D. delphis* distribution from acoustic and visual surveys in relation to depth (metres), sea surface temperature (ºC) and chlorophyll-a concentration (mg/m^3).

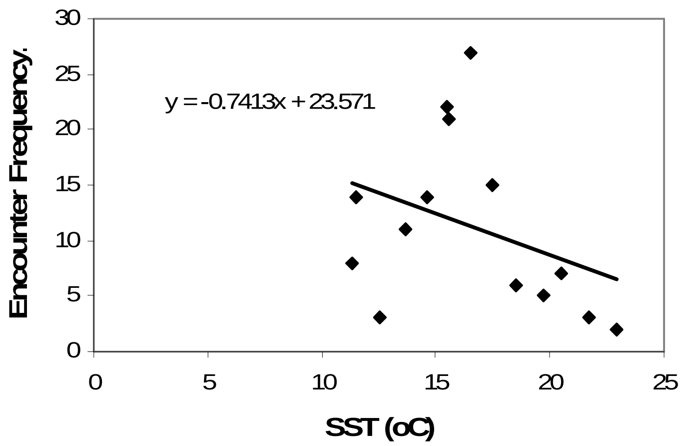
Pearson correlations were used to determine if there were any significant relationships between the visual distribution of short-beaked common dolphins and the three environmental variables, depth, SST and CHL-a concentration. **Table 3.8** shows the results of these tests. The tests showed that the short-beaked common dolphins were significantly correlated with depth and chlorophyll-a concentration, but not with sea surface temperature. Although not significant (P=0.253), a weak negative correlation was identified (R=-3.28) between *D. delphis* distribution and sea surface temperature. Scattergraphs showing the relationships between the environmental variables and visual distribution are shown in **figure 3.20**.

Variable	**R**	**P**
Depth	0.479	<0.001*
SST	-0.328	0.253
Chlorophyll-a	-0.536	0.002*

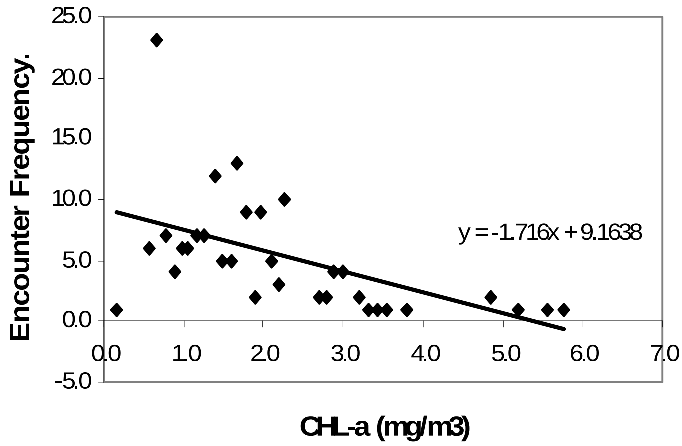
Table 3.8 Results of Pearson's correlation tests (R=test statistic value, P=probability value) used to determine relationships between *D. delphis* distribution and depth (metres), sea surface temperature (°C) and chlorophyll-a concentration (mg/m³)
* very significant results (<0.01)



a)



b)



c)

Figure 3.20 Scattergraphs, with added trendlines, showing the relationships between *D. delphis* 'visual' distribution and a) depth; b) sea surface temperature and c) chlorophyll-a concentration.

The mean SST and CHL-a concentrations were calculated per survey month (**figure 3.21**). The mean SST was at its warmest during July (acoustic 18.1ºC, Standard Deviation (sd)=1.755; visual 17.2ºC, sd=1.32) and at its coldest during June (acoustic 15.4ºC, sd=4.585; visual 15ºC, sd=3.622), with August exhibiting acoustic and visual temperatures of 16.7ºC (sd=0.84) and 17ºC (sd=0.842) respectively. Mean chlorophyll-a concentrations showed a decrease in concentration from June (acoustic 2.1 mg/m^3, sd=1.066; visual 2.3 mg/m^3, sd=0.97) through August (acoustic 0.8 mg/m^3, sd=0.322; visual 0.9 mg/m^3, sd=0.353). The mean acoustic and visual values for the month of July were 1.4 mg/m^3 (sd=0.863) and 1.1 mg/m^3 (sd=0.425) respectively.

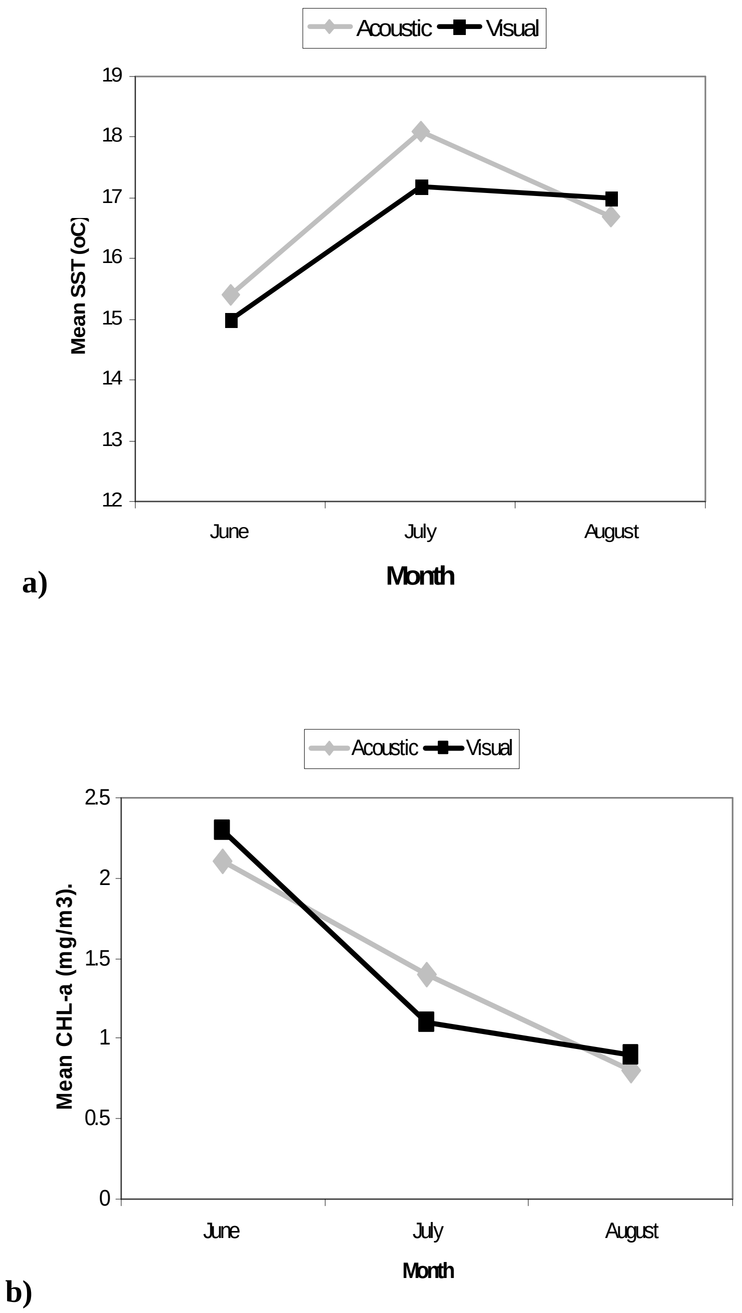


Figure 3.21 Mean **a)** sea surface temperature and **b)** chlorophyll-a for survey months during the three survey years (2004, 2005, 2006)

3.6 Summary of Results

- 142 and 220 *D. delphis* encounters were detected via acoustic and visual survey techniques, respectively, during 2004-2006.

- Group size ranged from 1 to 56 individuals, with encounter frequency decreasing as group size increased.

- Sighting distance ranged from 4 to 3000 metres, with encounter frequency decreasing as sighting distance increased.

- No significant difference was observed between group size and the two sea state classes.

- A significant difference was observed between sighting distance and the two sea state classes (Mann-Whitney U test, $W = 20724$; $P = 0.0018$).

- No significant correlations were observed between sea state and group size, or, sea state and sighting distance.

- A significant positive correlation was observed between group size and sighting distance (Spearman rank correlation, $R = 0.301$; $P = <0.001$).

- No significant difference was observed between weak, medium and strong signals associated with *D. delphis* encountered via acoustic survey techniques.

- Acoustic encounters lasted between 1 and 300 minutes, with encounter frequency decreasing as encounter duration increased.

- No significant correlations were observed between sea state and signal strength, or, sea state and encounter duration.

- A significant positive correlation was observed between encounter duration and signal strength (Pearson correlation, $R = 0.249$; $P = 0.004$).

- 57.8% of *D. delphis* acoustically detected were not visually detected within the same timeframe, yet, 28.9% of these were acoustically detected within < 5 minutes of a sighting.

- A significance difference was observed between signal strength and whether or not a visual sighting was recorded (Kruskal-Wallis test, $H = 16.37$; $DF = 2$; $P = <0.001$).

- A significant positive correlation was observed between encounter duration and group size (Pearson correlation, $R = 0.529$; $P = 0.004$).

- A significant positive correlation was observed between encounter duration and the number of visual encounters per acoustic encounter (Pearson correlation, $R = 0.488$; $P = <0.001$).

- No significant correlations were observed between group size and signal strength, sighting distance and signal strength, sighting distance and encounter duration, or, signal strength and No. of sightings per acoustic encounter.

- *D. delphis* were encountered at depths between 8.9 and 122.5 metres, in SST of 11.3 to 22.9 ºC and in CHL-a concentrations between 0.2 and 5.8 mg/m^3.

- No significant differences were observed between *D. delphis* encounters recorded by visual and acoustic survey techniques, in relation to depth, SST or CHL-a concentration.

- A significant positive correlation was observed for *D. delphis* distribution, derived from visual survey techniques, in respect to depth (Pearson correlation, R = 0.479; P = <0.001).

- *D. delphis* distribution did not significantly correlate with SST.

- A significant negative correlation was observed for *D. delphis* distribution, derived from visual survey techniques, in respect to chlorophyll-a concentration (Pearson correlation, R = -0.536; P = 0.002).

- *D. delphis* were distributed in the vicinity of the Celtic Sea front.

5.0 Discussion

4.0 Discussion

4.1 Visual Encounters

The data obtained in this study showed that as group size increased, the frequency of *D. delphis* encounters decreased. The mean group size in the study region consisted of 8 individuals. During the SCANS survey conducted in 1994, Hammond *et al.,* (2002) observed a mean group size of 10.8 (CV 0.25). The line-transect surveys conducted during the SCANS survey, however, encompassed the whole of the Celtic Sea, providing a greater study area for which data could be collected. As with group size, the frequency at which *D. delphis* were encountered was affected by the distance at which they were located from the vessel. The greater the distance, the harder it was to detect them. Although line-transect surveys are methods used to help estimate abundance of a species at a particular time, in a particular area, a more accurate estimate can only be achieved if data is collected correctly. One weakness of visual surveys that can affect animal detectability is the ability of the observer to make a correct identification and record data accurately. This is a skill however that be improved with practice. Sea state is a major variable that can affect detectability, with the probability of detecting an animal decreasing as sea state increases. This is particularly relevant with sea states three and above (Evans & Hammond, 2004) when white caps start to appear on the surface. Sea state in this study did not significantly affect group size or sighting distance, nor were there any significant correlations between these variables. The results did illustrate differences in the frequency of encounters at differing sea states, particularly with sighting distance; however 77 % of the surveys were conducted in sea states below three, which could account for the observed differences. A significant positive correlation was identified between sighting distance and group size, and was shown to follow the general hypothesis that a smaller group size is less likely to be detected at a greater distance than a larger group (Forcada & Hammond, 1998). Whilst surveying the short-beaked common dolphin off the coast of South Africa, Cockcroft and Peddemores (1990) found evidence that smaller groups occurred less frequently at greater distances. Though the group size and sighting distances were generally greater than those in the present study, a relationship between the two variables was established.

4.2 Acoustic Encounters

Whilst the mean signal strength of the vocalisations acoustically detected was 1, a medium strength, statistical tests showed there to be no significant difference between the three strength categories. Acoustic signals and their detection can be affected by a number of factors including the ambient noise, the source level of the vocalisation (Richardson *et al.*, 1995) and the distance of the dolphin from the hydrophone. Goold (1996) estimated that *D. delphis* vocalisations were distinguishable approximately 500 metres from the hydrophone, well within the 200 to 1000 metre range identified by Fish & Turl (1976). Scullion (2004) suggested *D. delphis* in the St. George's Channel could be detected at a distance of 3000 metres, however Ansmann (2005), in her study, excluded any sighting occurring at a distance greater than 2000 metres as, at this distance, she thought it would be unlikely that *D. delphis* vocalisations would be detected by the hydrophone. Although the encounter frequency for the differing signal strengths was greater in sea states less than three, no significant difference was identified between them. As the surveys were conducted simultaneously with the visual surveys, the difference in frequency between sea state classes may also be attributed to the 77% of the surveys that were conducted in sea states below three.

Acoustic encounters lasted a mean time of 21.19 minutes. Though no mean was calculated by Goold (1996), acoustic contacts during his study lasted from several minutes to several hours, as did the acoustic contacts in this study. There was no significant difference or significant correlation between sea state and acoustic contact although a significant positive, but weak, correlation was observed between signal strength and encounter duration. It was found that the stronger the strength of the vocalisation, the longer the encounter duration. The variables which can affect the detectability of a signal have been touched upon; however, additional variables such as the behavioural state of the dolphin at the time of the encounter may have affected the number of acoustic encounters, and to a certain extent signal strength. If the dolphins were feeding then, through the use of echolocation, vocalisation rate may have increased in frequency so increasing the ability to detect the signal. A dolphin exhibiting feeding behaviour is more likely to remain in the vicinity for a longer period of time than a travelling dolphin, whose signal may last only a few seconds, decreasing the chance of detection. Neither whistle density nor behaviour was investigated during the present study, so it was not possible to test this hypothesis.

4.3 Visual and Acoustic Encounters

Of the short-beaked common dolphins acoustically encountered, 57.8% were not visually detected during the same time period. 28.9% of encounters within this percentage were acoustically detected within less than five minutes of a sighting. Acoustically, detection ranges are generally greater than when trying to locate an animal visually (Goold, 1996, Evans & Hammond, 2004), so the 'delay' between acoustic contact and visual sighting could be attributed to this factor. If a submerged dolphin were to surface behind the boat and then travel in the same direction as the boat, the probability of visual detection before acoustic detection would be low. Behavioural data was not utilised during this study so this could not be investigated. For acoustic surveys to work efficiently they rely upon the animal vocalising. Some whales, such as the large baleen whales in the eastern north Atlantic, have been acoustically detected during calving and mating seasons, however visual observations have shown these whales to be present in the area outside this season, only their presence was never detected acoustically (Evans & Hammond, 2004). This is less problematic with dolphins such as *D. delphis* who are generally very vocal (Goold, 1996).

Sea state and acoustic signal strength may have been contributing factors as to why there were no visual sightings even though there was acoustic contact. Sea state and general weather conditions have less of an affect on acoustic detection ranges than visual techniques. In higher sea states, when visual detection rates are reduced, acoustic surveys can provide more homogeneous data, with the data being less vulnerable to the variability in the observers' experience to spot an animal (Evans & Hammond, 2004). The chance of missing a sighting was significantly affected by the signal strength, with the number of short-beaked common dolphins sighted increasing as the signal strength became stronger.

One weakness of acoustic surveys is calculating animal numbers. Estimating group size solely by acoustic means is very difficult (Goold 1996). Several attempts to do so have been made. A 'significant, moderately strong regression between whistle density and group size' of *D. delphis* was found by Ansmann (2005), with Wakefield (2001) also identifying a positive linear relationship between group size and vocalisation rate of *D. delphis*. The short-beaked common dolphin is not the only dolphin species in which relationships between group size and vocalisations have been identified. Whilst studying the inshore Pacific humpback dolphin, *Sousa chinensis*, Van Parijs *et al.*, (2002) determined that it was possible, using a mathematical model, to estimate both group size and occurrence within an area by vocalisations alone. Although whistle density was not measured during this study, a very weak, though not significant, correlation was identified between group size and signal strength, with a stronger signal increasing the number of dolphins detected. Encounter duration was found to be positively correlated with group size. As expected, the larger the group size, the greater the length of time of the acoustic contact.

The overall number of visual encounters was higher than the total number of encounters acoustically detected. Although the total number of acoustic encounters was less than that of visual surveys, a significant positive correlation was observed between the number of sightings per acoustic encounter and the duration of a single acoustic encounter. The relationship showed that the longer the acoustic contact, the greater the number of sightings occurring per encounter.

4.4 Environmental Variables and *D. delphis* Distribution

4.4.1 Fixed Variables

Depth was the only fixed parameter investigated throughout this study. The depth within the survey area ranged from 0 to 126 metres, with the deepest waters found in more offshore waters. Short-beaked common dolphins were encountered in all depth ranges, with the frequency at which they were encountered showing a significant correlation with depth. As depth increased the number of encounters increased. This pattern was observed for encounters resulting from both acoustic and line-transect surveys, although no significant difference in the survey types was found. The observed difference in encounter frequency between the two different survey types is not surprising considering the overall number of encounters was visually greater. Although encounter frequency increased with depth, this does not provide sufficient evidence of the depth preference of *D. delphis*. It may be that the area covered during the surveys did not show much variation between depth ranges. In fact, when the depth of the survey area itself was calculated by percentage, the number of *D. delphis* encountered at a particular depth was shown to follow a general relationship with the depth of the region, with encounter frequency increasing as percentage increased. One exception to this was the depth ranging between 107 and 125 metres. Encounters were greatest at this depth range yet this depth range only constituted 7.5 % of the survey area, compared with the depth range between 92 and 106 metres which made up 23.2 % of the survey area, and had the second highest number of encounters. One possible explanation could be due to prey distribution. Although mackerel (*Scomber scomrus*), sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) consumed by *D. delphis* around the coast of the United Kingdom inhabit various depths, they all inhabit the depth ranges identified during the present study. Herring in particular spend the majority of the day in deeper waters, surfacing at night to feed (www.fishbase.org). The author's personal observations witnessed a general lack of visual and acoustic encounters during the hours of 12.00 and 15.00. Though Goold (2000) suggested a diel pattern of feeding, feeding may have occurred during the day, away from the boat at depth where the herring gathered.

D. delphis prey is abundant in the region during the spring and summer, when the majority of spawning takes place (www.fishbase.org). Sightings of the short-beaked common dolphin off the coast of Britain fluctuates in both number and distribution, yet is correlated with prey distribution (Pascoe, 1986). Although their study could not confirm correlation with prey distribution, Gowens and Whitehead (1995) did identify a positive correlation regarding abundance and depth with *D. delphis* in the Gully, a submarine canyon on the Scotian Shelf. As depth increased, the number of dolphins encountered increased.

4.4.2 Non-Fixed Variables

Remote sensing can involve recording and analysing electromagnetic radiation that has been reflected, emitted or backscattered from the earths’ surface (Greegor, Jr, 1986; Roughgarden *et al.*, 1991). Remote sensing is a powerful tool which and has been used in past marine studies to investigate relationships between marine mammals and distribution of environmental variables, such as sea surface temperature and chlorophyll-a, (Brown & Winn, 1989; Burtenshaw *et al.*, 2004), and is widely used to monitor the worlds’ oceans. Many features of the ocean such as phytoplankton blooms, ice coverage, slicks and fronts can be identified from imagery derived from remotely-sensed data. In contrast to using boats for data collection in a specific region, which may take several weeks, complete coverage of the earth is available in a single day and one satellite image can show the conditions in an entire region at a single point in time (Buechner *et al.*, 1971; Richardson, 1996). Although satellite data can be less accurate at a single sampling point than data collected from boats, in-situ data, it does mean that it is possible to observe and monitor real-time changes over a specific period of time (Smith *et al.*, 1986).

Calculating the sea surface temperature for the survey region at the time of the surveys revealed that sea surface temperature ranged from 10ºC to 24ºC. This may provide an explanation as to why no short-beaked common dolphins were distributed in temperatures above or below this range. Though the results obtained from the visual and acoustic surveys showed different distribution patterns, no significant difference was identified between them. The results from both survey methods showed that *D. delphis* had a preference for the same temperature range (16 to 18ºC). The use of the different survey methods also indicated that *D. delphis* were encountered less within the same temperature range (22 to 24ºC). The ranges identified could be attributed to the overall SST within the study area. The greatest percentage, 41.9%, of the survey area, showed a temperature of between 16 to 18ºC, with the lowest percentage, 2.7%, identified as 22 to 24ºC. This increases the probability of an encounter falling within 16 to 18ºC and decreases the probability of an encounter falling within the 22 to 24ºC range.

A number of studies looking at SST and distribution of *D. delphis* have revealed that they inhabit a range of SST worldwide (Neumann, 2001). Seizer & Payne (1988) observed *D. delphis* on the continental shelf of the north eastern United States in temperatures ranging from 5 to 22.5ºC while Gaskin (1968) suggested *D. delphis* around New Zealand do not associate with temperatures below 14 ºC. Mean SST obtained by Wakefield (2001) and Seizer & Payne (1988) identified *D. delphis* acoustic associations with temperatures of 14.5 ºC and 11 ± 3.67 ºC respectively. Though exhibiting a lower mean SST than that of the present study, the SST will vary according to the time of year and the area in which the study is undertaken. Wakefield's study was conducted in the vicinity of the present study; however, the survey area was spatially larger so providing more opportunity for variation in SST. In addition, his SST was derived from hull temperature, making it very difficult to compare with the data obtained from remotely-sensed images.

The present study showed no significant correlation between encounters and sea surface temperature, yet a similar distribution pattern, with a similar mean temperature of 16.9ºC, was observed by Gowans and Whitehead (1995) during their observations of the short-beaked common dolphin. Goold (1998) and Neumann (2001) observed that short-beaked common dolphins migrate offshore during autumn/winter as the inshore temperature becomes colder, indicating a seasonal offshore change in their distribution, in association with SST. Though the present study did not look between seasons, colder mean temperatures were identified during the early months, with inshore waters generally cooler than offshore waters.

Interesting observations were made with regard to distribution of the short-beaked common dolphin and chlorophyll-a concentration within the survey area. Chlorophyll-a, itself an indicator of biological activity, showed a significant negative correlation with regard to distribution, with the number of encounters decreasing as chlorophyll-a increased. Overall, *D. delphis* were distributed in areas of relatively low productivity which, as the composite images show, were located in offshore waters which were, generally deeper and warmer than inshore waters. A similar finding was observed by Solanki *et al.,* (2001) who, through the use of satellite imagery investigated relationships between chlorophyll concentration and sea surface temperature. They observed an inverse relationship between chlorophyll and SST, with higher levels chlorophyll found in the cooler water, the enhanced primary productivity as a result of an increased quantity of nutrients in the euphotic zone.

As with SST, CHL-a concentration at the time of the encounters closely followed that of the overall CHL-a concentration in the area. One main difference between the available and observed chlorophyll-a concentrations was the maximum concentration. Though the maximum concentration in the study area over the survey days was 49.9 mg/m^3, values ranging from 6 to 49.9 mg/m^3 only made up a total of 2.1% of the area. As previously discussed, the highest CHL-a concentrations were located around inshore waters where *D. delphis* were less frequently distributed. No significant difference was observed between the encounters in relation to CHL-a concentration, resulting from the acoustic and visual survey techniques. With the exception of a peak concentration at 3 to 4.0 mg/m^3 from results obtained from the acoustic survey, the results of both surveys followed the same distribution pattern. No specific reason can be attributed to the occurrence of this peak, it could, however, be speculated that *D. delphis* were feeding at the time of the acoustic encounter in a region abundant in prey. Oceanographic features including chlorophyll concentration are thought to be major factors in the distribution of prey, which can itself affect cetacean distribution (Smith *et al.*, 1986; Seizer & Payne, 1988; Neumann, 2001). As well as consuming alternative prey, mackerel and herring often feed on zooplankton (www.fishbase.org). The zooplankton rely on the presence of phytoplankton in order to feed and sustain themselves.

4.5 Fronts

The composite images show a clear formation of a frontal system during the 2006 surveys, which closely follows that previously described by Pemberton *et al.*, (2004). Whilst in the Pemberton *et al*. study the development of the 'U' shaped contours of sea surface temperature, typically observed within the Celtic Sea front, was evident at the start of May, it was not evident in the present study until the end of June. The Celtic Sea front develops during the spring and summer each year and is a region of high productivity (Goold, 1998). The development of phytoplankton is controlled by the formation of the seasonal thermocline (Fasham *et al.*, 1983), which is affected by a number of variables. Differences in the water column structure can influence both the onset and duration of phytoplankton production. Phytoplankton requires nutrients, carbon dioxide and light for growth. In deep water there is insufficient light to act on the nutrients and carbon which are locked in the sediment. On the buoyant surface layer where there is sufficient light for phytoplankton growth there are insufficient quantities of nutrients. When mixing of stratified water, due to tides and atmospheric forces, allows the nutrients locked in the sediments to be released, areas of high primary production are created, e.g. during the onset of autumn when the stronger winds overturn the thermocline triggering the autumn bloom (Pingree *et al*., 1976).

Marine mammals have been shown to be associated with productive thermal fronts. Weir & O'Brien (2000) observed the highest density of harbour porpoise in the vicinity of the Irish Sea front. They associated fronts with harbour porpoise distribution, and found enhanced primary production at the interface of the fronts, resulting in an increased number of zooplankton and fish. The Irish Sea frontal region was found to be an energetically efficient place for the porpoises to forage. In the present study, *D. delphis* appeared to be distributed south of the front. Though difficult to determine the exact temperature contrast in SST during 2006 due to lack of cloud free images, a contrast in surface waters either side of the front was identified. Surface waters in the stratified Celtic Sea to the south were approximately 1 to 2ºC warmer during the first survey than the waters of the tidally mixed Irish Sea to the north. The contrast in SST increased to an approximate 3ºC difference during July, the time of the third survey. A surface temperature gradient is typical with seasonal fronts (Savidge & Foster, 1978) with a similar temperature contrast to the present study being recorded during the time of the Celtic Sea front by James (1977).

The present study also observed a contrast in surface CHL-a concentration north and south of the front, with levels generally greater in the northern mixed waters. During survey two, conducted 01-02 June 2006, CHL-a concentrations were approximately 1.02 to 1.97 mg/m^3 in northern waters and 0.20 to 0.99 mg/m^3 in southern waters. Although Pemberton *et al.,* (2004) used in-situ data to determine CHL-a concentration, they too found that levels were greater north of the front than to the south. They also noted that surface concentrations were lower in waters exhibiting strong stratification, where waters were not well mixed. If the waters were not well mixed at the time of the present study then the thermocline, the interface between mixed and stratified water, would be situated deeper in the water column. The position of the thermocline in the water column can be affected by certain variables, including strength of tidal mixing and increased winds, which can drive the top wind mixed layer deeper and deeper into the water column (Pingree *et al.*, 1976). The nutrient exchange between the wind mixed top layer and the tidally mixed bottom layer, in waters that are not well mixed, is limited, with both Pingree *et al*. (1976) and Pemberton *et al*. (2004) detecting a greater concentration of nutrients below the thermocline in these waters. As the satellites sensors only detect CHL-a levels in the surface layers, where nutrient concentration is low, the CHL-a concentrations detected would appear low in value.

The food web supported by the Celtic Sea front is important to top predators such as the short-beaked common dolphin. Through the use of acoustic survey data and satellite SST images, Goold (1998) showed distribution was greatest in the vicinity of the front. He concluded that, although *D. delphis* may have simply preferred the warmer waters south of the front, their distribution around the front was most likely due to the distribution of their prey. The breakdown of the front saw a shift in the distribution of *D. delphis*. If distribution was indeed linked to prey dispersal then this would be expected as prey would no longer be in abundance due to the lack of available nutrients required to sustain their prey.

Although, in the present study, short-beaked common dolphins appeared to be spatially distributed in waters south of the front, there may be related bias. Unfortunately, the selected way points were limited to waters mainly south of the front.

4.6 Limitations

It is recognised that the methodology of the present study had a number of limitations which may have introduced error and therefore complicated the interpretation of results. One such limitation was consistency of data collection over the three survey years. Equipment malfunctions lead firstly to a number of different hydrophones with differing cable lengths being used. This could have affected the detection range and subsequent signal strength of any vocalisation. Secondly equipment malfunctions meant recordings were not necessarily continuous, perhaps leading to vocalisation events being missed. Although sightings when the hydrophone was inoperable were excluded from the data set, the sample size would have been greater if these results could have been included.

Another limitation was in determining the strength of the acoustic signal. The method used to categorise the signal strengths were very subjective and inaccuracies could have been made, especially between surveys when the recordings were listened to almost one month apart. This was particularly relevant when obtaining acoustic data from 2005 as, unlike with 2004 and 2006, the author did not have access to survey recordings, so had to rely on the judgement of the 2005 author, whose subjective opinion may have differed from the author's own opinion.

The satellite images used to determine both sea surface temperature and chlorophyll-a concentration were greatly affected by cloud cover in the region at the time of the survey, therefore many values could not be generated and were excluded from analysis. When selecting the satellite imagery, monthly and two-weekly composites should have been selected. Although a greater temporal resolution than daily composites, they would have been affected, to lesser degree, by cloud cover and would have generated a greater number sample size leading to a more realistic representation of SST and CHL-a.

5.0 Conclusion

5.0 Conclusion

Depth and chlorophyll-a concentration significantly affected the distribution of the short-beaked common dolphin. A number of studies have concluded that environmental features such as depth and chlorophyll-a concentration, and indeed sea surface temperature, have no major direct effect on the spatial distribution of cetaceans. As a result of these studies, the general consensus is that a combination of fixed and non-fixed variables affect the distribution of their prey. Therefore, spatial and temporal distribution of the short-beaked common dolphin is most probably related to prey movement, with the dolphins following the migrating prey. The use of remotely-sensed data enables continuous monitoring and tracking of the ocean variables. Knowledge of the behaviour and biology of the short-beaked common dolphin, or target species, will allow satellite imagery to be used as a tool to help predict their distribution, especially if their relationship with oceanographic features such as the Celtic Sea front is known. By identifying patterns and features that allow us to predict distribution, further investigations into the short-beaked common dolphin can be made.

Though the results of the present study show there to be no significant differences in detection rates between visual and acoustic survey techniques, acoustic methods cannot completely replace the traditional visual surveying methods. For acoustic survey techniques to be useful, they rely upon the animal vocalising, yet, it may be advantageous to use this method over visual techniques when animals are known to be distributed over a large area and visibility is problematic. In contrast, even though acoustics can be used to identify certain cetacean species and predict group size, visual techniques, at present, are more accurate at estimating these variables. Preferably, a combination of acoustic and visual techniques should be used, each technique bringing its own strengths and weaknesses which can work in conjunction with each other to provide a more accurate representation of the status of the species.

Future studies and methodology should concentrate on improving the usefulness of acoustic survey techniques, in particular, in assessing the degree of relationships between those data obtained from acoustic and visual surveys. The use of programmes, such as ArcGIS, and remote sensing should continue to be used in order to investigate correlations between environmental features and spatial and temporal distributions. With regard to future studies on the short-beaked common dolphins in the region of St. George's Channel, coverage should be extended to include regions north of the front, with studies conducted not only during spring and summer, when the front is present, but at all times of the year, allowing a more in depth investigation into the spatial and temporal distribution of the short-beaked common dolphin to be made.

6.0 Acknowledgements

6. 0 Acknowledgements

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7.0 References

7.0 References

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8.0 Appendices

Appendix A. Waypoints for 2006 surveys

May 2006 - 51 32 N, 06 20 W to 51 395 N, 05 30 W to 51 47 N, 06 20 W to 51 545 N, 05 30 W to 52 00 N, 06 075 W

June 2006 - 51 30 N, 06 20 W to 51 375 N, 05 30 W to 51 45 N, 06 20 W to 51 525 N, 05 30 W to 52 00 N, 06 20 W

July 2006 - 51 34 N, 06 20 W to 51 415 N, 05 30 W to 51 49 N, 06 20 W to 51 565 N, 05 30 W to 52 00 N, 06 00 W

August 2006 - 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

Appendix B. Example of, a) Simple sighting form, b) Independent observer form used by the Sea Watch Foundation to record sighting data

a)

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The Cetacean Monitoring Unit

SEA WATCH
· f o u n d a t i o n ·

SIMPLE SIGHTINGS RECORDING FORM

RECORD AS MUCH INFORMATION AS POSSIBLE, BUT REMEMBER THAT EVEN PARTIAL DATA MAY BE HELPFUL!

CONTACT NAME ______________________ **ADDRESS** ______________________

E-mail: ______________________ **PHONE** ______________________ **BOAT NAME** ______________________

Ref. No.	SPECIES	CONF.	TOTAL NO.	NO. ADULTS	NO. CALVES	LOCATION	TIME BST/GMT	DATE dd/mm/yy	DIR. TO ANIMAL	P(ort) / ST(arboard)	DIST. TO ANIMAL	BEHAVIOUR (incl. dir. of travel)	ASSOC. SEABIRDS	OBSERV. NAME

DATA DEFINITIONS: *use categories provided where possible;* *Continue on separate sheet if necessary*

Reference No.: number each sighting sequentially to allow for cross-reference **Time:** 24-hour clock; circle BST or GMT

Location: record latitude and longitude (deg., min., sec. or as decimal degrees), if lat/long unavailable, note location in relation to local landmarks

Species: give the best judgement of species ID; use general categories if unsure (e.g. dolphin species); **Confidence:** Definite; Probable; Possible **Total No.:** give range if unsure of exact number

Adults/Juveniles: estimate counts of different–sized animals in 2 size classes relative to percent adult body size

Sea State: enter number: 0 = mirror calm; 1 = slight ripples, no foam crests; 2 = small wavelets, glassy crests, but no whitecaps; 3 = large wavelets, crests begin to break, few whitecaps; 4 = longer waves, many whitecaps; 5 = moderate waves of longer form, some spray; 6 = large waves, whitecaps everywhere, frequent spray; 7 = sea heaps up, white foam blows in streaks

Behaviour: Slow/Normal Swim; Fast Swim; Feeding; Leap/Splashing; Bow-ride; Rest/Milling; Sexual **Direction of Travel:** note general direction of movement, or whether direction is variable

Birds: note seabird association with the animals; record species of bird, if known

Please return to Sea Watch Foundation, 11 Jersey Road, Oxford, OX4 4RT or your Regional Group Co-ordinator b)

SWF/RF 2b Oct 2005 Page .... of ....

The Cetacean Monitoring Unit

SEA WATCH ·foundation·

INDEPENDENT OBSERVER RECORDING FORM

RECORD AS MUCH INFORMATION AS POSSIBLE, BUT REMEMBER THAT EVEN PARTIAL DATA MAY BE HELPFUL!

CONTACT NAME .... **ADDRESS** ....

E-mail: .... **PHONE** .... **BOAT NAME** .... **DATE**............

I.O. No.	SPECIES	CONF.	TOTAL NO.	NO. ADULTS	NO. CALVES	LOCATION	TIME BST/GMT	SEEN by 1°	PRIMARY REF. NO.	DIR. TO ANIMAL	BOAT COURSE	DIST. TO ANIMAL	BEHAVIOUR (dir. of travel)	MOVE BEFORE DETECTION	OBSERV. NAME

DATA DEFINITIONS: *use categories provided where possible;* *Continue on separate sheet if necessary*

Reference No.: number each sighting sequentially to allow for cross-reference **Time**: 24-hour clock; circle BST or GMT

Location: record latitude and longitude (deg., min., sec. or as decimal degrees), if lat/long unavailable, note location in relation to local landmarks

Species: give the best judgement of species ID; use general categories if unsure (e.g. dolphin species); **Confidence:** Definite; Probable; Possible **Total No.:** give range if unsure of exact number

Adults/Juveniles: estimate counts of different–sized animals in 2 size classes relative to percent adult body size

Sea State: enter number: 0 = mirror calm; 1 = slight ripples, no foam crests; 2 = small wavelets, glassy crests, but no whitecaps; 3 = large wavelets, crests begin to break, few whitecaps; 4 = longer waves, many whitecaps; 5 = moderate waves of longer form, some spray; 6 = large waves, whitecaps everywhere, frequent spray; 7 = sea heaps up, white foam blows in streaks

Behaviour: Slow/Normal Swim; Fast Swim; Feeding; Leap/Splashing; Bow-ride; Rest/Milling; Sexual **Direction of Travel:** note general direction of movement, or whether direction is variable

Movement before Detection: C = closer to track; F = further from track; N = neither

Please return to Sea Watch Foundation, 11 Jersey Road, Oxford, OX4 4RT or your Regional Group Co-ordinator

Appendix C. Example of Effort form used by the Sea Watch Foundation

SWF/RF 5a Oct 2005 Page .... of ....

The Cetacean Monitoring Unit

SEA WATCH ·foundation·

VESSEL-BASED EFFORT RECORDING FORM

RECORD AS MUCH INFORMATION AS POSSIBLE, BUT REMEMBER THAT EVEN PARTIAL DATA MAY BE HELPFUL!

Day/Month/Year .... **Vessel:** .... **Route From:** .... **To:** ....

No. of Obs. in Dedicated Search .... **Contact Name/Add:** .... **Tel/E-mail:** ....

Start Time .... ☐ **GMT** ☐ **BST** **End Time** .... **Total Time** .... **Obs. Ht Above Sea Level (m)** .... **Field of View:** 180° fwd; 90° L; 90° R; 360° (tick)

	Location: record every 15 minutes;		Vessel Details;			Environmental Conditions;					
TIME GMT/BST	LATITUDE (deg, min, sec)	LONGITUDE (deg, min, sec)	BOAT COURSE	SPEED knots	EFFORT TYPE	WATER DEPTH	SEA STATE	SWELL HEIGHT	VISIB.	SIGHT. REF.	BOAT ACTIVITY

DATA DEFINITIONS: *use categories provided where possible* *Continue on separate sheet if necessary*

Time: 24-hour clock; specify GMT or BST **Location:** record position (as deg., min., sec. or as decimal degrees, if necessary) every 15 minutes or when course changes

Vessel Details: record bearing (as deg. magnetic), speed (in knots, if available) and whether primarily under motor or sail during the 15 minute period

Sea State: 0 = mirror calm; 1 = slight ripples, no foam crests; 2 = small wavelets, glassy crests, but no whitecaps; 3 = large wavelets, crests begin to break, few whitecaps; 4 = longer waves, many whitecaps; 5 = moderate waves of longer form, some spray; 6 = large waves, whitecaps everywhere, frequent spray; 7 = sea heaps up, white foam blows in streaks; 8 = long, high waves edges breaking, foam blows in streaks; 9 = high waves, sea begins to roll, dense foam streaks

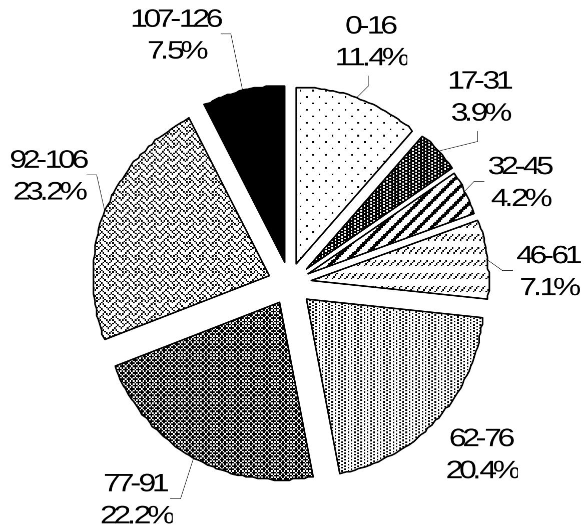
Swell Height: Light = 0-1 m; Moderate = 1-2 m; Heavy = >2 m **Visibility:** <1 km; 1-5 km; 6-10 km; >10 km

Sighting Reference: refer to No. on Sighting Record Form **Effort Type:** NOTW = not watching; CASW = casual watching; DEDS = dedicated search; LINE = line transect method

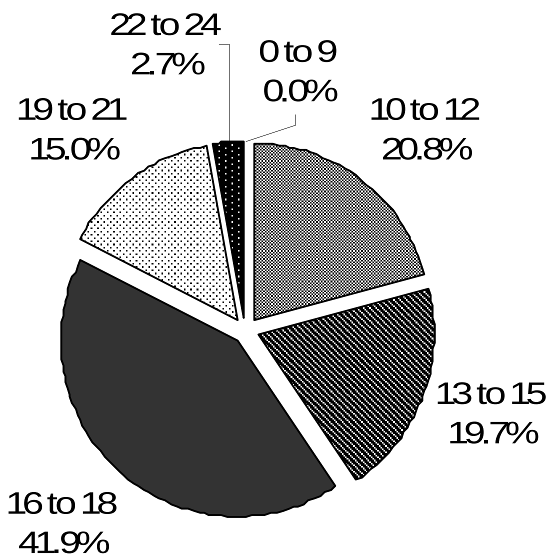
Boat Activity: Record No of each and type: NB = No boats, VE = unspecified vessel, YA = yacht, RB = row boat or kayak, JS = jet ski, SB = speed boat, MB = motor boar, FI = fishing boat, FE = ferry, LS = large ship , SV = seismic vessel, WA = warship

Please return to Sea Watch Foundation, 11 Jersey Road, Oxford, OX4 4RT or to your Regional Group Co-ordinator

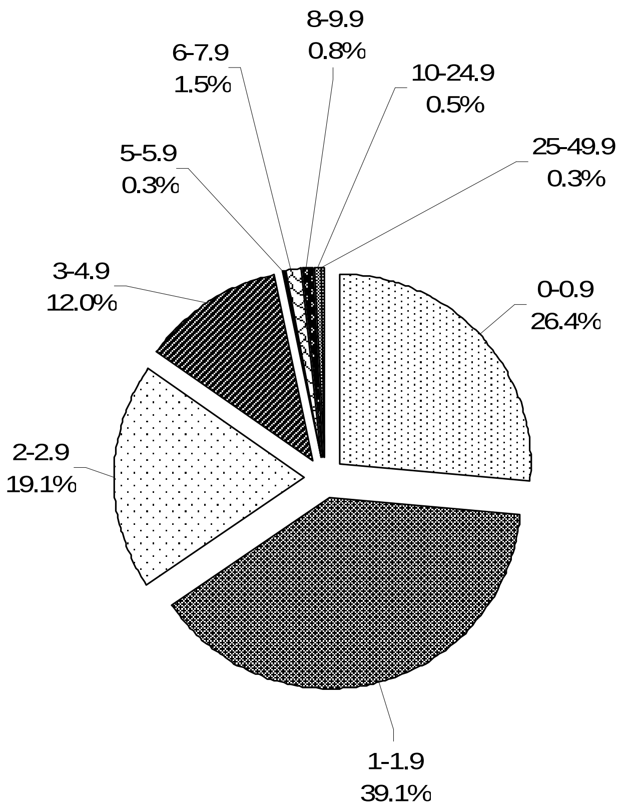
Appendix D. Pie chart representing the total depth (metres) of the survey area



Appendix E. Pie chart representing the sea surface temperature ranges (°C) of the survey area



Appendix F. **Pie chart representing the chlorophyll-a concentration ranges (mg/m^3) of the survey area**



Appendix G. Results of Anderson-Darling test for normality on environmental variables, depth (metres), sea surface temperature (°C) and chlorophyll-a concentration (mg/m^3)

		A-Squared	P-Value
Depth	Acoustic	2.257	<0.001
	Visual	5.020	<0.001
SST	Acoustic	1.368	0.001
	Visual	1.096	0.007
CHL-a	Acoustic	3.313	<0.001
	Visual	4.607	<0.001

CD ROM: Raw data