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A comparison of visual and acoustic survey data collected from 2005 to 2008 in the Cardigan Bay SAC

for the

harbour porpoise and bottlenose dolphins

by

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sea watch FOUNDATION

DECLARATION & STATEMENTS

This work has not previously been accepted in substance for any degree and is not being concurrently submitted for any degree.

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

This dissertation is the result of my own independent work / investigation, except where otherwise stated.

Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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Abstract

Static acoustic monitors are widely used to monitor the presence of cetaceans and have advantages over visual survey methods that include being able to monitor in all weather and lighting conditions, and recently acoustic techniques have been used to derive density estimates using arrays of passive acoustic detectors. Few studies have compared trends in acoustic and visual data in monitoring of bottlenose dolphins and the harbour porpoise. This study compared visual data (within areas around T-PODs and absolute abundance estimates for Cardigan Bay SAC) to the acoustic data (median number of detection positive minutes) produced across 12 sites in the inshore Cardigan Bay SAC during 2005-08. When data was combined across years, high correlations were found between the visual and acoustic data for the harbour porpoise (r_s= 0.6000, d.f. = 12, P<0.05), and for the bottlenose dolphin (r_s= 0.6173, d.f. = 12, P<0.05), when grid cells around T-PODs were 1650m and 1300m respectively. Lower, but still significant correlations existed as the data was separated into years for both cetacean both species. Bottlenose dolphin behaviour affected correspondence between visual and acoustic data, where in comparison to the visual data a lower number of detection positive minutes was found. Additionally, for the harbour porpoise, a significant correlation was found between line transect survey absolute abundance estimate for the Cardigan Bay SAC and the and median detection positive minutes produced within the inshore Cardigan Bay SAC (r_s= 1.0, d.f.= 3, P<0.01). No correlation was found between the line transect or photo ID absolute abundance estimates and the median number of detective minutes for the bottlenose dolphin. A longer timescale of data collection be ideal to determine whether trends do exist between absolute abundance data and acoustic T-POD data in the inshore Cardigan Bay SAC. The close correspondence between the acoustic (median number of detection positive minutes) and visual data (total number of animals per km travelled) around T-PODs, suggests that the derivation of density estimates using acoustic data loggers has potential, although behaviour of the bottlenose dolphin needs further consideration.

Contents

Abbreviations

Throughout this thesis, these are the list of abbreviations used for the sites that T-PODs were deployed at in the inshore region of the Cardigan Bay SAC. The sites were:

CH_off: Cemaes Head offshore

CH_in: Cemaes Head inshore

CA_est: Cardigan Estuary

CA: Cardigan Island

MW_in: Mwnt inshore

MW_out: Mwnt offshore

AB_off: Aberporth offshore

AB_in: Aberporth inshore

YN: Ynys Lochtyn

NQ Fish: new Quay Fish

NQ Reef: New Quay Reef

GIL: Gilfachreda

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1. Introduction

Interest in acoustic methods using echolocation click detectors as a means of monitoring the presence of cetaceans has increased in recent years with the development of new technologies. Acoustic loggers have enabled cetacean species to be monitored in all weather and lighting conditions, and importantly whilst cetaceans are submerged beneath the water surface. For example, passive acoustic devices have recently been used to record the presence of harbour porpoise around oil rigs during the night time (Todd *et al.,* 2009), and have enabled easier investigation of the impacts of marine developments on cetaceans, including wind farm construction and gas pipeline installation (Tougaard *et al.,* 2005; Englund *et al.,* 2006, Tougaard *et al.,* 2006; Carstensen *et al.,* 2006; Gilles *et al.,* 2009; Philpott *et al.,* 2010). The production of large data sets has also enabled fine-scale spatial and temporal variation in the presence of bottlenose dolphins and harbour porpoise to be determined (Simon *et al.*, 2010), which visual observation would not have been able to achieve. Furthermore, using static acoustic arrays, estimates of density (total number of animals per unit area) for particular cetacean species have started to be derived and these have been shown to correspond well with visual density estimates (Lewis *et al.*, 2007; Marques *et al.*, 2009; Marques *et al.*, 2011; Kyhn *et al.*, 2012). In this study, the correspondence of visual and acoustic techniques will be investigated further for harbour porpoise and bottlenose dolphin in order to determine whether acoustic and visual survey methods provide similar trends in detections within the Cardigan Bay SAC, West Wales.

1.1: The study area: the Cardigan Bay SAC

Cardigan Bay in West Wales is the largest bay within the British Isles. It contains two Special Areas of Conservation where Britain's largest dolphin population receives protection. The Cardigan Bay SAC is located in the Southern part and encompasses an area of 956.65km^2, extending 12 miles offshore and bounded by the following coordinates 52.08°N, 4.76°W; 52.22°N, 5.00°W; 52.43°N, 4.40°W; 52.25°N, 4.23°W (CCW, 2009; Veneruso and Evans, 2012). The majority of the Cardigan Bay SAC is gently sloping and less than 30m deep, comprising a number of different habitat types including sandbanks, reefs and caves (CCW, 2009).

Under section IV of the 1992 EC Habitats and Species Directive, European member states are required to establish Special Areas of Conservation (SACs) for habitats listed under Annex I and species under Annex II. The harbour porpoise and bottlenose dolphin are both listed as Annex II species, and although currently no SACs have been listed in the UK for the harbour porpoise, the Cardigan Bay SAC represents one of three SACs in the UK for the bottlenose dolphin. These two SACs were identified as important inshore habitats for the reproduction and other key parts of the lifecycle of bottlenose dolphins within the UK. Bottlenose dolphin abundance increases during the summer months, and the shallow, sheltered coastal inshore waters provide suitable breeding and feeding habitat for the species (Pesante *et al.*, 2008; CCW, 2009; Veneruso and Evans, 2011).

1.2 The study species: Bottlenose dolphin and the harbour porpoise

The bottlenose dolphin is a cetacean species occurring worldwide in a wide range of habitats including both offshore and inshore waters, estuaries, harbours and even some freshwater areas. The bottlenose dolphin is typically 2-4m in length and is generally grey in colour with lighter flanks and a cream belly. Since the early 1990s, the genus *Tursiops* has been split into two species: the Indo-Pacific bottlenose dolphin *Tursiops aduncus*, and the common bottlenose dolphin *Tursiops truncatus* occurring worldwide in tropical to temperate waters (Möller and Beheregaray, 2002). Within the United Kingdom, a few semi-resident communities of the common bottlenose dolphin *Tursiops truncatus* can be found, located on the east coast of Scotland, Barra Sound (Outer Hebrides), North and West Wales and the Channel Islands. More mobile groups of bottlenose dolphins can also be found off SW England and in the Inner Hebrides (West Scotland) (Evans *et al.,* 2008).

Bottlenose dolphins have complex social structures, and form fission-fusion societies where groups of both sexes and varying ages form associations with smaller groups for periods of time, that may change on an hourly or daily basis (Connor *et al.*, 2000). These well developed social structures have resulted in cooperative feeding strategies being adopted, particularly in more offshore waters where shoals of pelagic prey are hunted (Jones and Sayigh, 2002). Within inshore environments, fission-fusion societies may still exist (Magileviciute *et al.*, 2007), but it is more beneficial for bottlenose dolphins to forage alone or in small groups due to the lower density of prey (Würsig, 1979; Barnes, 2011).

The harbour porpoise is much smaller (<2m in length) than the bottlenose dolphin and typically occupies continental seas of depths 20-100m (Evans *et al.,* 2008). Harbour porpoise are found across the Northern Hemisphere, and in the Atlantic are distributed along continental shelves from the Barents Sea down to coastal areas of Northern Africa that include Morocco and Senegal. In the United Kingdom the harbour porpoise is most abundant in Scotland, parts of Wales, and Southern and Western Ireland. Harbour porpoise are not as associated with group living as the bottlenose dolphins being typically solitary, although they may associate in small loose groups, and on occasions these can number in the tens or even low hundreds (Evans, 1987; Evans *et al.,* 2008).

The distribution of prey is one of the major influences that determines the distribution of bottlenose dolphin and harbour porpoise, with spatial, diurnal, tidal and seasonal variation in prey likely influencing the distribution of cetacean species (Nuuttila *et al.*, 2007; Pesante *et al.,* 2008). As the harbour porpoise has a high-energy requirement due to its high surface area to body ratio and the fact that female harbour porpoise spend the majority of their lives simultaneously pregnant and lactating, the species may be particularly distributed where there is high food availability. The distribution of bottlenose dolphins, which have been known to kill harbour porpoise, may also influence that of the distribution of the harbour porpoise (Simon *et al.*, 2010; Nuuttila *et al.*, 2007). Harbour porpoise feed on a wide variety of prey that includes small schooling fish such as whiting, sprat, sandeel and herring and cephalopods; other occasional food items include polychaete worms and crustaceans (Evans *et al.,* 2008; Evans and Hintner, 2010). Bottlenose dolphins also consume a wide range of different prey species including benthic, pelagic, solitary and schooling fish. In the United Kingdom, gadoids (e.g. whiting, cod, haddock), salmon, sprat, sandeel, flatfish, mullet and cephalopods form the diets of bottlenose dolphins (Wilson, 2008; Evans and Hintner, 2010).

Both the harbour porpoise and the bottlenose dolphin have an echolocation system which they use as a method for foraging for prey (Au *et al.*, 1993; Akamatsu *et al.,* 2007). It has been proposed that approximately 36-34 Ma the dispersal of coastal cetaceans into pelagic waters brought the animals into contact with nocturnally migrating prey species and resulted in the development of echolocation due to the advantage of being able to “see” at night (Lindberg and Pyenson, 2007). In addition to foraging, echolocation may also be used in communication and navigation by both species (Clausen *et al.*, 2011; Herzing, 2004).

1.3: Echolocation system of bottlenose dolphin and harbour porpoise

In recent years there has been much debate as to where and how echolocation occurs in the toothed cetaceans, odontocetes (Au *et al.*, 1993; Madsen *et al.,* 2010; Cranford *et al.,* 2011). However, one recent study that used high speed video endoscopy found that in bottlenose dolphin, two sets of phonic lips at the centre of the MLDB (monkey lips dorsal bursa) within the nasal passage are involved in sound production (Cranford *et al.*, 2011). It was found that clicks were produced as compressed air was forced through the MLDB, resulting in the vibration of the phonic lips and the associated MLDB complex. The production of one click was found to occur with a single cycle involving the opening and the closing of the phonic lips. The location of the phonic lips, beneath the blowhole in the harbour porpoise is shown in Figure 1. The vibration produced within the MLDB is then directed towards the melon, and where the sound waves are refracted and directed (as a result of changing composition of lipids within the melon) towards the target in the external environment (Litchfield *et al.*, 1973; Duggan *et al.*, 2009).

Bottlenose dolphins and harbour porpoises both produce echolocation clicks whose characteristics differ from one another in a number of respects. In a study carried out by Au *et al.* (1999) it was found that the harbour porpoise produces echolocation clicks with a mean source level of 157.2±6.9dB, a mean peak frequency of 127.5±7kHz and mean bandwidth of 16.4±4.3kHz. The source level refers to the energy of the sound waves produced as measured one metre on axis (directed towards the target). The beam width was found to be between 13.1° to 16° in the harbour porpoise (Au *et al.*, 1999; Koblitz *et al.*,

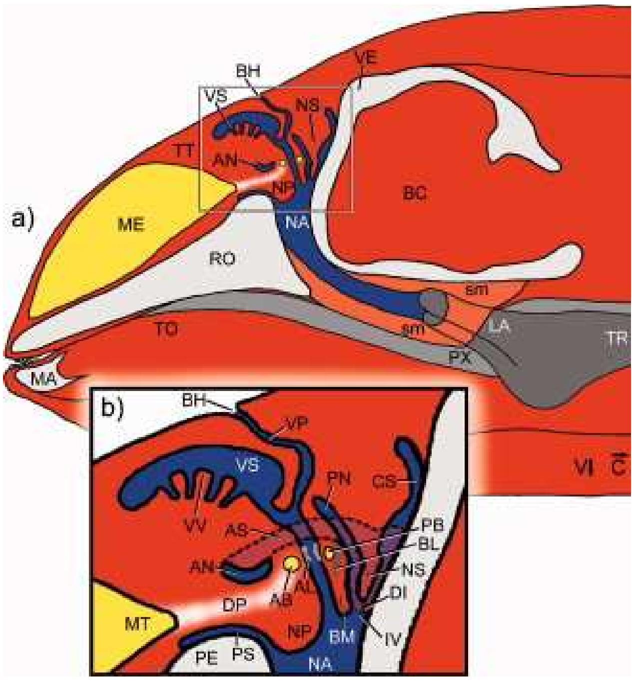


Figure 1 Schematic sagittal reconstruction of an adult harbor porpoise (*Phocoena phocoena*) head showing the nasal structures and the position of the larynx (LA). (a) overview. (b) detail of boxed area in (a). Blue, air spaces of the upper respiratory tract; gray, digestive system; light gray, cartilage, and bone of the skull; yellow, fat bodies. AB, rostral bursa cantantis; AL, rostral phonic lip; AN, anterior nasofrontal sac; AS, angle of nasofrontal sac; BC, brain cavity; BH, blowhole; BL, blowhole ligament; BM, blowhole ligament septum; C, caudal; CS, caudal sac; DI, diagonal membrane; DP, low density pathway; IV, inferior vestibulum; MA, mandible; ME, melon; MT, melon terminus; NA, nasal passage; NP, nasal plug; NS, nasofrontal septum; PB, caudal bursa cantantis; PE, premaxillary eminence; PN, posterior nasofrontal sac; PS, premaxillary sac; PX, pharynx; RO, rostrum; sm, sphincter muscle of larynx; TO, tongue; TR, trachea; TT, connective tissue theca; V, ventral; VE, vertex of skull; VP, vestibulum of nasal passage; VS, vestibular sac; VV, folded ventral wall of vestibular sac (Huggenberger *et al.*, 2009)

2012), and this is the angle either side of the horizontal and vertical axis where the sound energy has been reduced by 3dB. However, in the wild, harbour porpoise click mean source levels were found to be 30dB higher at 191dB re 1µPa pp (Villadsgaard *et al.*, 2007). As a result of the narrow bandwidth of clicks that harbour porpoise produce, both on axis and off axis clicks are similar, but weaker (Au *et al.*, 1999). The narrowband (16.4±4.3kHz) production of high frequency echolocation clicks by the harbour porpoise may be the result of the utilisation of only one set of symmetrical phonic lips (Starkhammer *et al.*, 2011). In contrast, bottlenose dolphins have the ability to produce more broadband echolocation clicks with a bandwidth that can exceed 85kHz (Houser *et al.*, 1999), and this may be a result of utilising both pairs of asymmetric phonic lips to produce echolocation clicks that usually incorporate lower frequency sounds, but which may also contain higher frequency elements (Starkhammer *et al.*, 2011). The broadband frequency range of clicks that bottlenose dolphins produce varies from 30kHz up to 130kHz (Au *et al.*, 1993). The average source level of the bottlenose dolphin was found to be 170dB re 1 µPa pp (Evans, 1973), but by increasing the frequency of the produced clicks bottlenose dolphins have the ability to increase the source level up to 228dB re 1µ Pa pp (Wahlberg *et al.*, 2011), a function that cannot be accomplished by the harbour porpoise. The beam width of bottlenose dolphins was found to be smaller and more directional than that of the harbour porpoise at 9-10° (Au *et al.*, 1993) and off-axis clicks are typically weaker and of lower frequencies.

1.4: Passive acoustic monitoring: The T-POD

Knowledge of the echolocation click characteristics of cetaceans helps to enable the successful recording of the species on passive acoustic monitoring devices according to the echolocation frequency (Philpott *et al.*, 2007; Simon *et al.*, 2010). T-PODs (The Timing Porpoise Detector; www.chelonia.co.uk) are static acoustic monitoring devices that are deployed in the water column to automatically monitor the presence of cetacean clicks. They were originally developed for recording the echolocation click trains produced by the harbour porpoise, but have since been redesigned to have the capability of detecting clicks from a larger number of echolocating odontocetes that now includes bottlenose dolphins.

Within a 50 to 70cm PVC tubing outer casing, the T-POD consists of a hydrophone, an analogue processor, a digital timer and a duration logger. The T-POD is set to record six scans of the external environment each minute, with each scan being of 9.3 second duration. Incoming sounds are amplified and then passed through two filters, a target filter set to the frequency of the clicks of the echolocating species and a reference filter that is set to a frequency with least energy within a click, with sounds being recorded if they meet these criteria. T-PODs are typically set up so that the target filter for the harbour porpoise is set to record peak frequencies of 130kHz, and the target filter for the bottlenose dolphin is set to record at lower frequencies e.g. 50kHz (Philpott *et al.*, 2007; Simon *et al.,* 2010) as bottlenose dolphins have omni-directional, high energy, low frequency, off axis clicks (Dos Santos and Almada, 2004).

The software (TPOD.exe) is used to find and determine the probability that click trains originated from a cetacean source in comparison to other sound sources that may be present in the external environment. Click trains are logged into categories by the software depending upon the likelihood that the train was of cetacean origin: *cet high* and *cet low* are recorded trains which have a high probability that they originated from a cetacean source whilst doubtful and very doubtful trains are those where the probability that the sound source originated from another source such as rain, propellers or boat sonar. Generally longer trains that originated in environments with low background noise are classified as being of a higher probability cetacean source.

1.5 Visual and acoustic comparisons

The examination of how sound travels in the water column is essential in determining how the echolocation clicks of harbour porpoise and bottlenose dolphins are affected as they travel towards T-PODs. As a cetacean echolocates, the sound is emitted in all directions (spreading), and as sound waves interact with the medium that they are travelling through, absorption also occurs as some of the sound energy is converted to heat energy. Absorption occurs more rapidly when sounds of a higher frequency are emitted as there is more interaction of the sound wave per unit time with the medium. Other factors including salinity, pressure and temperature also have the ability to affect the rate of absorption of sound by the medium (Schulkin and Marsh, 1962).

A source equation (Au, 1993) can be used to determine the energy transfers that occur during the transmission and the retrieval of a click that a cetacean produces. Under low ambient noise conditions, the source equation is as follows:

$$\mathbf{EE=SE-2TL+TS_E} \qquad \mathbf{(1)}$$

where EE is the return echo energy flux density that is measured one metre in front of the source (dB 1 $\mu Pa^2 s$), SE is the source energy flux density measured one metre in front of the cetacean source (dB 1 μPa^2s), TL is the transmission loss measured one metre from source and target (dB; this is multiplied by two as the equation takes into consideration the fact that sound waves travel from the target and back), and SE is the target strength ratio (dB; ratio between reflected energy one metre from the target compared to the initial energy received at the target).

The transmission loss, a result of spreading and absorption, is usually determined by the spherical spreading transmission loss model and has been found to accurately predict transmission loss in many locations (DeRuiter *et al.*, 2010), but was found to be less applicable where interactions with the seafloor occurred where cylindrical spreading models may be more applicable. Sometimes transmission loss may also be affected by sound channels in the water column that results in sound waves travelling further than the transmission loss model would predict (DeRuiter *et al.*, 2010). Transmission loss by spherical spreading can be calculated as follows:

$$\mathbf{TL=20log(R)+R\propto A} \tag{2}$$

where R is the distance one metre from the cetacean source (m) and $\propto$ is the frequency dependent absorption of sound wave energy and is 0.04dBm^{-1} at 135kHz (Fisher and Simmons, 1977).

Incorporation of the two equations above can be used to determine the distance that passive acoustic monitors, such as T-PODs, can detect echolocating marine mammals. This equation assumes that spherical spreading occurs, and also incorporates the angle at which the marine mammal is orientated (Urick, 1983):

$$\mathbf{DT=SL\text{-}TL=SL\text{-}20log(R)+0.04R\text{-}H\theta} \tag{3}$$

where DT is the detection minimum threshold of the acoustic monitors (123-132dB for T-PODs), SL is the source level (dB 1μPa pp; sound pressure measured one metre in front of the animal), and Hθ is the directivity of the sonar beam.

Using equation 3, the theoretical distance that a harbour porpoise in captivity could be detected by a T-POD with a mean source level of 165dB re 1μPa pp was found to be between 38-85m (Villadsgaard *et al.*, 2007). This low theoretical calculation for detection distance is a result of harbour porpoises producing high frequency clicks (Au *et al.*, 1999) which results in the transmission loss to surrounding molecules being high as there is more interaction with the medium per unit time. It was found that as a result of the higher source levels that wild harbour porpoises can potentially produce (mean source level 191 re 1µPa pp), that T-PODs can theoretically detect harbour porpoises in the wild between 260-400m away (Villadsgaard *et al.*, 2007). It was also found that off axis clicks would only be detected at distances of between 25-50m from a T-POD, as a result of the source levels of off axis clicks being 40dB lower (DeRuiter *et al.*, 2010). However, the presence of sound channels within the environment may enable on-axis harbour porpoise clicks to be detected at up to 1,200 metres away from a T-POD (DeRuiter *et al.*, 2010).

Since bottlenose dolphins have the potential to produce echolocation clicks of lower frequency and at higher source levels than harbour porpoise, it could be expected that bottlenose dolphins can be detected by T-PODs at greater distances. In the Shannon Estuary, Ireland, good correspondence was found between detection of bottlenose dolphins on T-PODs, with 82% of all dolphins schools being detected within 500m of a T-POD, when schools were being visually monitored simultaneously (Philpott *et al.*, 2007). The furthest distance that bottlenose dolphins were detected from the T-POD was 1246m in this study. In a separate study carried out by Elliott *et al.* (2011) in Doubtful Sound, New Zealand, the maximum detection range of the T-POD was found to be similar at 1313m. However, it is likely that clicks at this range would have been on-axis with a high energy component (above the 123-132dB required to be detected on a T-POD), and that off axis clicks would not have been detected (Elliott *et al.*, 2011; Philpott *et al.*, 2007; Au *et al.*, 2012). Furthermore, in the Cardigan Bay SAC, the detection probability and the maximum detection distance from the T-POD was found to be lower at 650m (Reyes Zamudio, 2005).

Other factors that may affect acoustic to visual comparisons include the rate of vocalisation of cetaceans. By deploying D-TAGs on harbour porpoise in Danish waters it was found that the harbour porpoise echolocates almost continuously (Akamatsu *et al.*, 2007). In the study echolocation clicks were recorded on average every 12.3 seconds. In an experiment carried out in captivity, it was also found that harbour porpoises produced continuous echolocation clicks for navigational purposes despite having remained in the same enclosure for a period of one to three years (Verfuβ *et al.*, 2005). Harbour porpoise were also found to continuously echolocate during feeding related activities (Verfuβ *et al.*, 2009).

Bottlenose dolphins do not echolocate continuously and may remain silent for extended periods of time, thereby reducing the chance that such vocalisations are picked up by any surrounding passive acoustic devices. In the study carried out by Philpott *et al.* (2007), there were eleven visually sighted groups of bottlenose dolphins found around a T-POD with no corresponding acoustic detections, and even when a bottlenose dolphin was sighted 14m away from a T-POD, no detection was recorded. This may have been due to the fact that some of the clicks produced at close range were on-axis and so unlikely to be detected. The probability of detecting the presence of bottlenose dolphins was found to increase with the amount of time spent within the area surrounding the T-POD (Bailey *et al.,* 2009). In addition as outlined by Jones and Sayigh (2002), the frequency of echolocation behaviour in bottlenose dolphins may be modulated by factors that include group size and whether the animals are foraging or navigating.

1.6 Abundance estimation

Both acoustic and visual techniques are used in monitoring the presence of cetaceans. However, visual line-transect surveys and mark-recapture techniques are currently the main methods used in estimating population size. Line transect surveys estimate the average number of animals that occupy an area over the time period that sampling occurs. A feature of this method of abundance calculation is that a proportion of the objects that are found within the surveyed area are enabled to be missed (Buckland *et al.,* 2001). In line transect surveys randomly or systematically placed lines within the survey area are travelled by a suitable platform of observation which may be an airplane, a boat or a helicopter. All of the distances of all of the surveyed animals to the line are recorded, and the probability P_a of detecting the animal, given that it is in the area whilst the survey is being carried out, is calculated. The formula for the calculation of abundance for line transect surveys is as follows where n is the number of objects sampled during the survey, 2ωL is the area that is being sampled and P_a is the proportion of objects that are detected during the survey:

$$\widehat{D} = \frac{n}{2\omega L\widehat{P}_a} \tag{4}$$

An alternative to line transect methods in estimating the population size is the mark-recapture technique, photo ID. This form of abundance estimate establishes the total number of animals that inhabit an area during a period of time. To estimate abundance, mark recapture techniques use data on the number of animals that are initially marked, and this is then compared to the proportion of the animals that are subsequently re-sampled. Photo ID is applicable for assessing trends in populations of animals that have natural markings, such as bottlenose dolphins.

1.6 Objectives and hypotheses

This thesis focuses on how the echolocation activity of bottlenose dolphin and harbour porpoise recorded with T-PODs within the inshore region of the Cardigan Bay SAC can be related to visual sightings data derived from visual line transect and *ad libitum* surveys that were carried out during a four year time period through the months April to October 2005-08. The specific objectives were:

1. Determine a suitable area around a T-POD and examine the trends in the visual data to determine whether they are being reflected in the acoustic T-POD data for all years combined (2005 to 2008) for sites across inshore Cardigan Bay;
2. To consider whether there are trends between the visual and the acoustic data as these are further divided into each recording year for each site across inshore Cardigan Bay;
3. To make more direct temporal comparisons between the time of the visual sightings to determine whether the acoustic detections occurred within the hour of a sighting within a defined area surrounding a T-POD;
4. To consider whether there are any trends between the acoustic T-POD data in the inshore region of the Cardigan Bay SAC and the absolute abundance estimates for the entire Cardigan Bay SAC for both harbour porpoise and bottlenose dolphin.

The null hypotheses to be tested were:

1. There are no significant trends between the acoustic and the visual data by year and for all years combined for the harbour porpoise and bottlenose dolphins

2. There are no significant trends between the acoustic data within the inshore regions of the Cardigan Bay SAC and the absolute abundance estimates as derived from photo ID and line transect surveys for the entire Cardigan Bay SAC

2. Methods

2.1 T-POD deployment in the Cardigan Bay SAC

Ten T-PODs were deployed in the inshore region of the Cardigan Bay SAC between 2005 and 2010. The T-PODs were deployed across a total of 12 different sites as shown in Figure 2. In 2005 and 2006, seven T-PODs were placed at locations that were approximately 500m from the coastline at Camaes Head inshore, Cardigan Island, Mwnt inshore, Aberporth inshore, Ynys Lochtyn, New Quay Fish and New Quay Reef; and three T-PODs were placed at more 'offshore' sites 1.5km from the coastline, at Aberporth offshore, Cemaes Head offshore, and Mwnt offshore. In 2007 and 2008, T-PODs were introduced at two new localities: Gilfachreda and the Cardigan Estuary. During 2009, only one T-POD at Mwnt inshore was monitoring during months within the April to October time period. In 2010, no T-PODs were monitoring during April to October. Therefore, for this study only the acoustic data derived from the T-PODs that were monitoring at sites during April-October 2005-2008 were used.

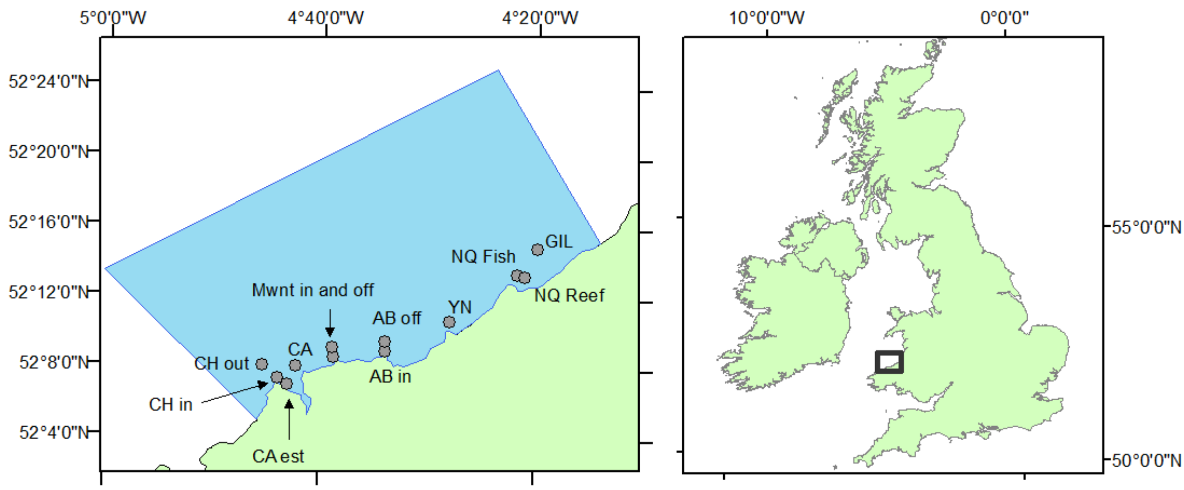


Figure 2: The location of the Cardigan Bay SAC. Circular symbols represent the location of T-PODs. Full names for the T-POD sites are given in the abbreviations section.

Four of the ten deployed T-PODs were version 3 (V3) T-PODs, and the remaining six T-PODs were version 4 (V4). The target filter for the harbour porpoise was set to 130kHz and the reference filter was set to 92kHz for version 4 T-PODs, or 90kHz for version 3 T-PODs. The target filter for bottlenose dolphins was set up to record off-axis bottlenose dolphin clicks that occurred at 50kHz, with the reference filter being set to 70kHz. All T-PODs were calibrated to minimise detection threshold variability, at the Oceanographic Museum in Stralsund, Germany. During the calibration test, harbour porpoise clicks were played at eight different positions around the horizontal plane of each T-POD. Each echolocation click was played at a decreasing energy level around each T-POD to determine its detection threshold. Detection thresholds for all T-PODs were set to 128dB re 1µPa pp (±2dB), with the exception of one V3 T-POD which could not be adjusted and which was set at 123dB re 1µPa pp and placed at the location Aberporth offshore in 2005 and 2006, and Cemaes Head offshore in 2007. The reference filter was also altered on the T-PODs to determine the bandwidth settings where bottlenose dolphin click frequencies were not being recognised or registered within the harbour porpoise settings.

To stabilise T-PODs within the water column, three weights were placed around each deployed T-POD. All T-PODs were suspended 1.5m from the seabed as shown in Figure 3. An echosounder was used prior to the deployment of each T-POD to ensure that there were no topographical barriers within 100m for incoming echolocation clicks.

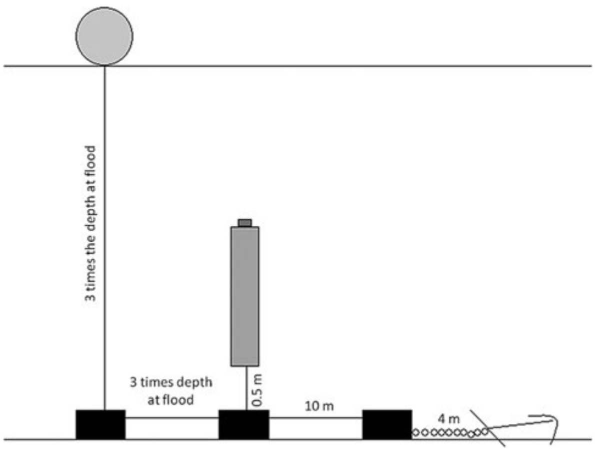
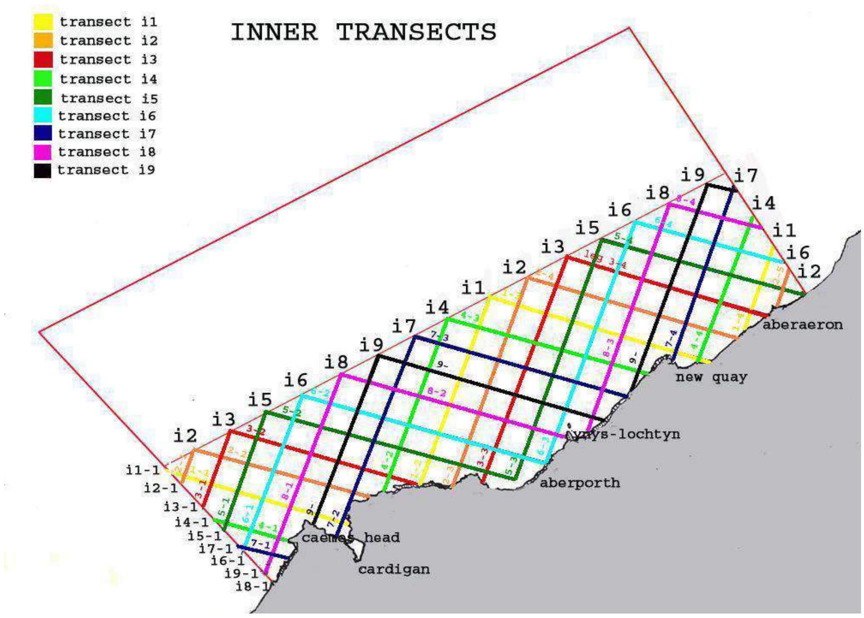


Figure 3: Schematic diagram showing how T-PODs were deployed in the water column across Cardigan Bay SAC. The upright T-POD is moored to a set of three weights and the first weight is anchored to a buoy to show the deployment location of the T-POD (Simon *et al.*, 2010)

2.2 Visual surveys in the Cardigan Bay SAC

During the time period 2005 to 2007, dedicated line transect surveys for harbour porpoise and bottlenose dolphins were carried out in the Cardigan Bay SAC by Sea Watch Foundation. For all line transect surveys, a 9.7m fibreglass boat (Dunbar Castle 2) with an observational platform height of 3.5m was used that travelled along the route at 8 knots. In 2005, a total of twenty five line transect trips were carried out, in 2006, twenty-seven line transect trips were conducted and in 2007 twenty-six line transect trips were carried out. Line transect survey effort was reduced in 2008 when due to lack of funding, only eight line transect survey trips took place.

Line transect survey routes were designed and placed systematically across the Cardigan Bay SAC. Both inner and outer transect routes were designed as shown in Figure 4, with each transect divided into different legs, and a start and end point attributed to each survey leg. On each day that a survey was carried out, a transect line was chosen at random (with the exception of the 2005 transects) from all inner and outer transects. The vessel then travelled along the designated route at a constant speed.



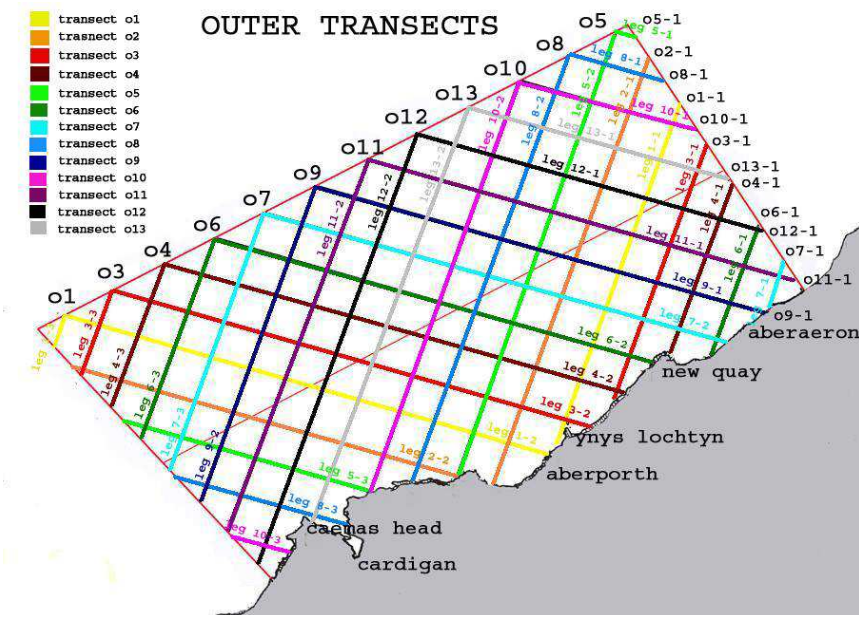


Figure 4: Line transect survey routes in the Cardigan Bay SAC with inner and outer transect numbers, points and legs (Veneruso and Evans, 2012)

For the most part each line transect survey that was carried out was a double platform survey. Two primary observers (POs) were positioned on the roof of the survey vessel and scanned 90° to their side and 10° to the other side, recording sightings as they occurred. Binoculars were only used by POs if a sighting of a bottlenose dolphin or harbour porpoise occurred. In addition to the two POs, two independent observers (IOs) were also positioned on the boat. Independent observers were positioned out of sight from the POs, and they independently recorded sightings. Effort data was also recorded every fifteen minutes or when there was a change of course or environmental conditions. Photo ID was carried out at the same time, when an encounter suitable for photography occurred. The vessel would leave the track line if bottlenose dolphins were sighted along the survey route and once all bottlenose dolphins in the group had been successfully photographed, the line transect survey would resume again at the point of departure, and would continue following the survey track line.

In addition to line transect surveys, *ad libitum* trips were also carried out along the inshore regions of the Cardigan Bay SAC during 2005 to 2008, utilising a local wildlife tour boat the Ermol VI. These trips did not precisely follow a pre-determined route and lasted either one to two hours. The method of surveying on *ad libitum* trips for cetaceans was similar to that carried out on line transect surveys, although surveys were not double platform and so there were only two observers located onboard recording cetacean sightings and effort data. Each of the observers scanned 180° from the bow to the stern with the aid of binoculars and filled in relevant sightings and effort forms.

The combination of *ad libitum* surveys that were carried out along inshore Cardigan Bay and line transect survey data provided the basis for sightings and effort data during this study around the T-POD sites.

2.3 Visual data processing

Visual survey data from the *ad libitum* and line transect surveys were imported into ArcGIS, and both effort points and sightings were plotted. The projected coordinate system WGS 1984 UTM zone 30N was used in ArcGIS to enable accurate distances to be measured. The sightings and effort data were broken down in ArcGIS to month each year. For every trip that occurred in the Cardigan Bay SAC from 2005 to 2008, the effort points were joined up using a point to polyline tool from ET Geowizards. A shapefile was created with a series of circles of different radii around every T-POD in the Cardigan Bay SAC. Circles with radii of

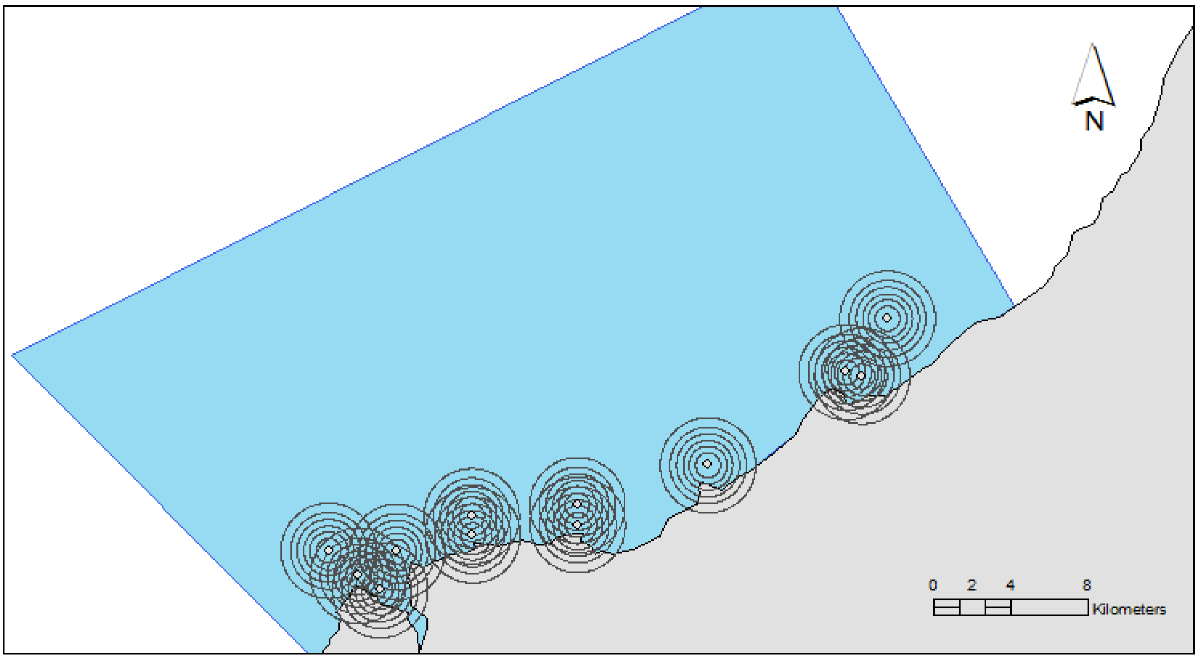


Figure 5: Circular grid cells that were applied around each T-POD within the inshore region of the Cardigan Bay SAC

650m, 1000m, 1300m, 1650m, 2000m and 2500m were used around each T-POD, as shown in Figure 5. Within each circle around each site, the effort lines were intersected and length of the lines calculated for each month (April to October) within each year (2005-08). Sightings data were spatially joined to the multiple circle shapefile to determine the number of sightings and the total number of each cetacean that occurred within each circle. The sightings data and the effort line length data were transferred and merged in Microsoft Excel, using the add-in program Ablebits. In addition, effort line length, the number of sightings and the total number of animals were also calculated for rectangular grid cells within the Cardigan Bay SAC, as shown in Figure 6. As T-PODs were often located between rectangular grid cells it was difficult to attribute a T-POD to one particular cell. T-POD allocations to each rectangular grid cell are also shown in Figure 6.

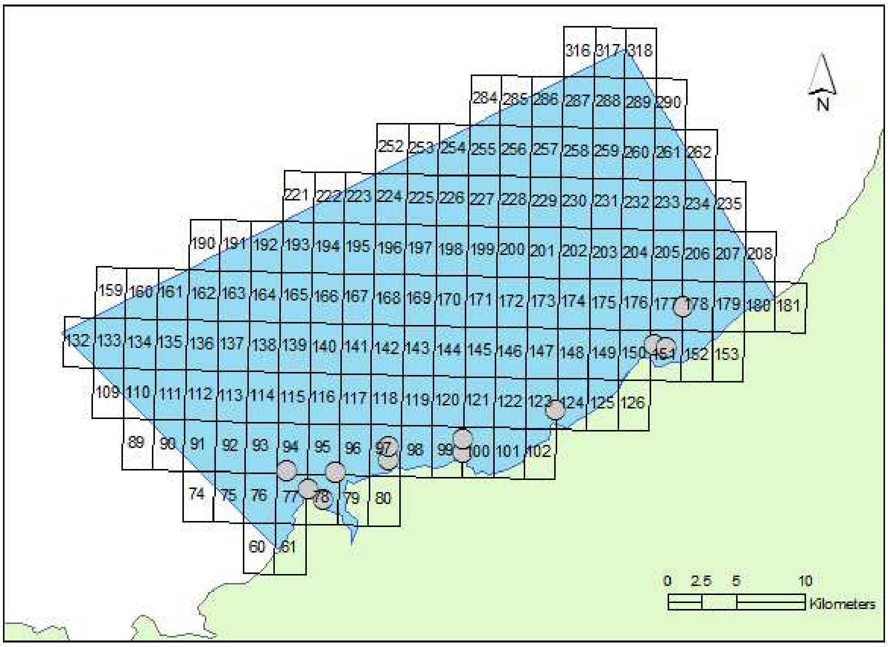
Within rectangular grid cells and the circular grid cells of different sizes, the encounter rate was calculated. The encounter rate per cell can be defined as:

$$\frac{n}{L} \tag{5}$$

where n is the total number of animals within the grid cell and L is the total length travelled in km within the grid cell (Evans and Hammond, 2004; Kiszka *et al.*, 2007; Pesante *et al.*, 2008). Although land was present within the radius of a number of the circular grid cells, correcting for effort to determine the proportion of animals that have inhabited the area should theoretically make the grid cells comparable both within and between sites.

Where azimuth, distance and angle data were available for sightings, hourly comparisons were carried out. Trigonometric vector addition was used to plot each sighting more accurately, so that the distance from the sighting to the T-POD could be measured. Using the distance between points tool provided by Hawths tools, all sightings within a 3000m radius of the T-POD were determined in ArcMAP. Little data were available within the effective detection radius of the T-POD (Kyhn *et al.*, 2012) for the harbour porpoise and so hourly comparisons weren’t carried out for this species. At some sites for the bottlenose dolphin, there were sufficient sightings within the determined maximum detection radius of

1.3km from the T-POD (Philpott *et al.*, 2007; Elliott *et al.*, 2011) and at 500m, close to the determined effective detection radius from the T-POD (Elliott *et al.*, 2011) for more detailed analysis to occur.



Site	Grid cell
CA_est	78
CH_in	77 and 78
CH_off	94 and 77
CA	95, 96, 78 and 79
Mwnt_off	97
Mwnt_in	97
AB_in	99 and 100
AB_off	99 and 100
YN	123 and 124
NQ_Fish	150 and 151
NQ_Reef	151
GIL	177 and 178

Figure 6: Map showing the locations of T-PODs and the rectangular grid cells used at each site to calculate the encounter rate within inshore Cardigan Bay

2.4 Acoustic data processing

Data that were included in the analysis were restricted to the acoustic trains that the software (TPOD.exe) had classified the probability for, arising from a cetacean source as being CET high or CET low; any doubtful and very doubtful trains were not included. The number of detection positive minutes (DPMs) per recording day was used in the majority of the analysis. Detection positive minutes show the number of minutes where click trains are recorded within either an hourly or a daily time period. Only entire days where the T-POD was recording for a full twenty-four hour period, were included in the analysis, and partial days where maintenance, data processing or removal of the T-POD from the site were excluded. To account for non-recording days, the average number of detection positive minutes was used instead of the total number of detection positive minutes. The number of detection positive hours (DPHs) was used to carry out more direct time comparisons with the visual data.

2.5 Statistical analysis

Acoustic data derived from T-PODs were not normally distributed and could not be transformed to a normal distribution. The Kruskal Wallis test and the extension of the Kruskal Wallis test, the Scheirer-Ray-Hare test, were used to determine the difference in detection positive minutes by year, by site and by month, and whether an interaction existed between month and year. Post hoc Mann-Whitney U tests were also used, where appropriate, to determine where there were significant differences.

Comparisons of acoustic data to absolute abundance estimates for the entire Cardigan Bay SAC were made using only the sites where T-PODs were recording every year. Acoustic data from 2008 were limited and comparisons with abundance estimates were therefore made excluding this year. The sites that were not recording in either 2005, 2006 or 2007 included Cardigan estuary, Gilfachreda, Aberporth inshore, Aberporth offshore and Mwnt offshore. Mwnt inshore was only recording in April and May of 2007, and so this site was also excluded from the analysis. A Spearman rank correlation was carried out between the abundance estimate and the median number of detection positive minutes each year across the six sites for the harbour porpoise, as the relationship was monotonic but not linear. Pearson's correlations were carried out between the abundance estimates, as determined by photo ID and line transect surveys for the bottlenose dolphin. The encounter rate (total number of animals per km travelled) across the sum of all ten T-PODs for both the harbour porpoise and the bottlenose dolphin was also calculated and correlated with the abundance estimates for the Cardigan Bay SAC: Spearman rank correlation for harbour porpoise and Pearson's correlation for the bottlenose dolphin. The median number of detection positive minutes and the encounter rate for harbour porpoise at six of the sites (sites used for the comparison with the abundance estimates) were correlated with the abundance estimates for the Cardigan Bay SAC. Spearman rank correlations were carried out for site comparisons with abundance estimates to account for the possibility that the relationship could be monotonic and not linear.

Correlation matrices were created for all years combined and for each year that T-PODs were recording (2005 to 2008). The correlation matrices compared the encounter rate (total number of animals per km travelled) across all twelve sites with varying radii, increasing from 650m (Reyes Zamudio, 2005) through to 2500m. Additionally, within the matrices, the visual data for each radius for all years combined and for each separate year, were correlated with the median and the mean acoustic number of detection minutes that occurred. Spearman rank correlation matrices were created as outliers were present within the data and some of the relationships were monotonic but not linear. All data across all 12 sites were used to create the correlation matrices. Corrections to the correlation matrices by year were attempted for the months within the year for which there was corresponding visual and acoustic data, but this was found to reduce the dataset too much. Ratios between the visual data at sites for all years combined were determined to see how those visual data changed as the radius increased to 2500m.

Regression analysis was also carried out to determine whether the number of sightings could also explain the acoustic data for each species of cetacean. Regression analysis was carried between the number of sightings per km travelled for all years combined at each site and the encounter rate (total number per km travelled). The number of sightings per km travelled was then correlated against the median number of detection positive minutes. Spearmans rank correlations were used as outliers were present within the dataset.

Visual sightings for the bottlenose dolphin (where distances from the T-POD were calculated within 3000m from T-PODs) were linked to the number of detection positive minutes that occurred within the same hour of the sighting. Additionally, detection positive minutes were considered either side of the hour that the sighting occurred, as the sighting could have occurred towards the end or beginning of the hour for which there was acoustic data. The number of detection positive minutes that occurred within the harbour porpoise detection criteria on the T-POD and which coincided within the hours that the bottlenose dolphin sighting occurred, were also considered. The behaviour of the cetacean at each sighting was determined from the visual transect and *ad libitum* survey data. At sites where there were sufficient sightings data, the percentage of sightings that occurred within a 500m and a 1300m radius and coincided with acoustic data, were calculated.

3. Results

3.1: Acoustic and visual comparisons for all years combined (2005- 08)

3.1.1. Correlation matrices comparing the visual data (total number of animals per km travelled) using different sized radii to the median number of detection positive minutes from T-PODs across the twelve sites

High correlations were found between areas of different sizes around T-PODs for the bottlenose dolphin visual data (total number of animals per km travelled) across the twelve sites between 2005-08. As the area around T-PODs increased, correlation coefficients between the visual data were found to decrease, as shown in Figure 7a. However, as the area around T-PODs increased, the decreasing correspondence with the visual data (total number per km travelled) did not affect the correlations that were found with the acoustic data. Similarly, high correlations between the acoustic and visual data were found at a 650m radius from T-PODs as were found at a 2500m radius from the T-PODs. A very high correlation was also found between the mean and the median number of detection positive minutes across the twelve sites for bottlenose dolphins, and both of these measures of acoustic central tendency also showed high correlations with the visual data when different areas around T-PODs were used.

High correlations were also found between areas of different sizes around T-PODs with the visual data for the harbour porpoise (total number of animals per km travelled) across the twelve sites 2005-08. However, when a 650m radius was used around T-PODs, much lower correlations were found with the visual data (total number per km travelled) in comparison to when larger areas were used around T-PODs. Excluding areas around sites with 650m radii, correlation coefficients for the visual data were higher (r_s >0.90) when comparing smaller areas around the T-POD e.g. areas with 1000 and 1300m radii, and when comparing areas with larger radii e.g. between 2000 and 2500m. Higher correlations >0.5 were found between the visual (total number of animals per km travelled) and acoustic median data when the smaller radiuses of 1000m, 1300m and 1650m were used. Lower correlations

(a)

	650m	1000m	1300m	1650m	2000m	2500m	Grid cells	Acoustic mean	Acoustic median
650m	1.0000	0.9228	0.8652	0.8441	0.7531	0.7391	0.6538	0.6095	0.6043
1000m		1.0000	0.9562	0.9492	0.8862	0.8722	0.7838	0.6935	0.6785
1300m			1.0000	0.9580	0.8951	0.8951	0.8561	0.6504	0.6173
1650m				1.0000	0.9231	0.9510	0.8667	0.6853	0.6667
2000m					1.0000	0.9301	0.8316	0.5804	0.5397
2500m						1.0000	0.9298	0.6923	0.6667
Grid cells							1.0000	0.7579	0.7080
Acoustic mean								1.0000	0.9912
Acoustic median									1.0000

(b)

	650m	1000m	1300m	1650m	2000m	2500m	Grid cells	Acoustic mean	Acoustic median
650m	1.0000	0.5141	0.5211	0.2958	0.2254	0.2113	0.2686	0.3169	0.4594
1000m		1.0000	0.9301	0.8182	0.8322	0.8392	0.8421	0.4545	0.5860
1300m			1.0000	0.8531	0.7972	0.7692	0.7439	0.4895	0.5860
1650m				1.0000	0.9161	0.9231	0.8421	0.5035	0.6000
2000m					1.0000	0.9510	0.9053	0.3217	0.4211
2500m						1.0000	0.9404	0.2867	0.4246
Grid cells							1.0000	0.1228	0.2764
Acoustic mean								1.0000	0.9684
Acoustic median									1.0000

Figure 7: Spearman rank correlation matrices comparing the correlation coefficients within grids of different sizes around T-PODs across sites when all years were combined (2005 to 2008) for the total number of (a) bottlenose dolphins (b) harbour porpoise per km travelled around T-PODs

Key:

	0.9-1
	0.8-0.9
	0.7-0.8
	0.6-0.7
	0.5-0.6
	0.4-0.5
	0.3-0.4
	0.2-0.3
	-0.1-0.2

were found between the visual and the acoustic data at 650m for the harbour porpoise, with similarly lower correlations when the radius around the T-POD was 2000m or greater.

3.1.2 Comparison of the number of sightings to the total number of animals within areas around T-PODs

Linear regression showed that for the harbour porpoise there was a significant relationship between the number of sightings and total number of animals (r^2=0.971, n=12, P<0.001) across the twelve sites for all years combined (2005-08) as shown in Figure 8 b, an unsurprising result given that most sightings are of lone individuals. An outlier at Cemaes Head inshore was found where the total number of harbour porpoise was higher than the number of sightings. Cubic regression also showed a high relationship between the number of sightings of bottlenose dolphins and the total number of bottlenose dolphins (r^2 = 0.974, n = 12, P<0.001), as shown in Figure 8a.

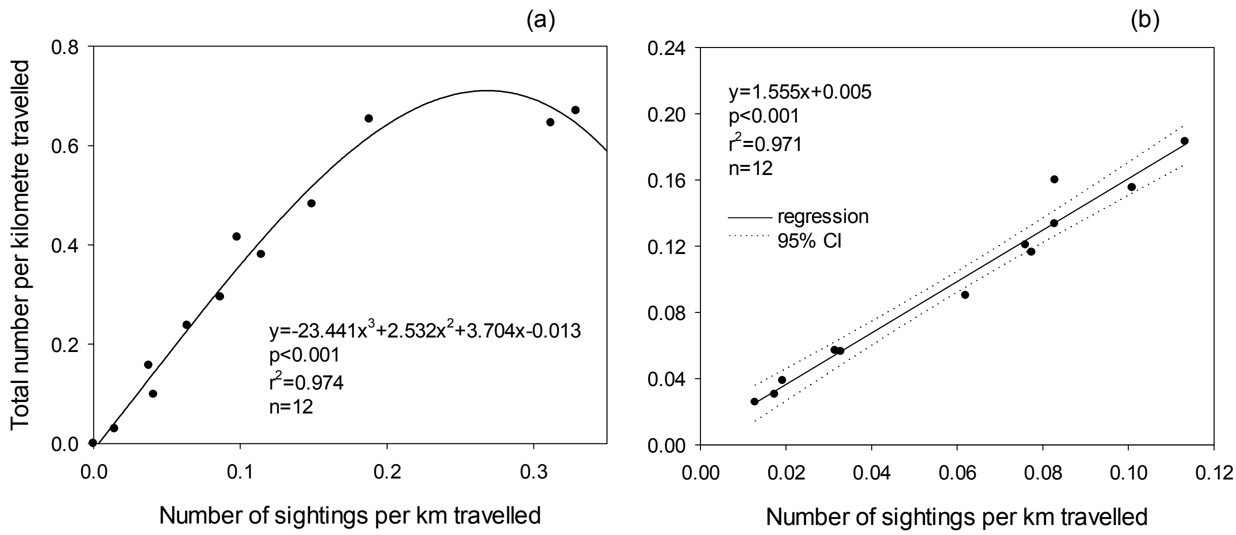


Figure 8: Comparison of the number of sightings per km travelled to the total number of animals per km travelled for (a) the bottlenose dolphin using a 1300m radius grid cell and (b) the harbour porpoise using a 1650m radius grid cell

3.1.3 Comparison of the number of sightings and the total number of harbour porpoise and bottlenose dolphins (per km travelled) to the median number of detection positive minutes

When the total number of sightings of harbour porpoise within a 1650m radius was compared to the acoustic data (median) across all 12 sites, a high correlation was found (r_s = 0.660, n = 12, P<0.05), and this was similar to the correlation found when the total number of animals per km travelled was compared around a 1650m radius (r_s= 0.600, n = 12, P<0.05). The number of sightings per km travelled was much higher than the total number of animals at sites, New Quay Fish and at New Quay Reef for the bottlenose dolphin, as shown in Figure 8a. When the number of sightings was compared to the acoustic median, overall slightly lower correlations were found when using different areas around the T-PODs, as shown in Table 1.

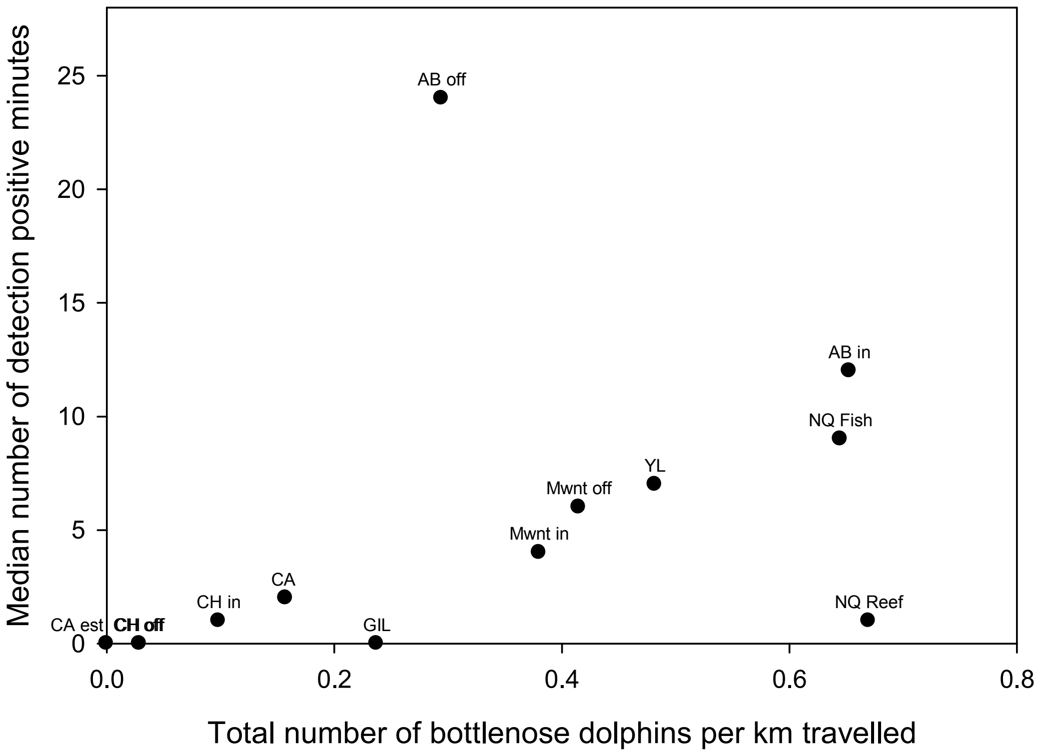
Table 1: Spearmans rank correlation coefficients for different size grid cells around T-PODs across all sites when all years were combined (2005 to 2008) for the comparison of the acoustic median with (a) total number and (b) number of sightings of bottlenose dolphins per km travelled around T-PODs

Area/distance from T-POD	(a) Total number	(b) Sightings number
650m	0.6043	0.5442
1000m	0.6785	0.6325
1300m	0.6173	0.5926
1650m	0.6667	0.6667
2000m	0.5397	0.4868
2500m	0.6667	0.6455
Grid cells	0.7080	0.4885

3.1.4: Correlations comparing the total number of animals found around T-PODs to the acoustic median data

A high correlation was found between the visual data within a 1300m radius grid cell (total number of bottlenose dolphins per km travelled) and the acoustic median data (r_s =0.6173, d.f. = 12, P<0.05) as shown in Figure 9. Low numbers of acoustic and visual detections occurred at the following sites: Cardigan Estuary, Cemaes Head inshore, Cemaes Head offshore, and Cardigan Island. Higher numbers of acoustic detections and visual sightings occurred further north in the inshore region of the SAC, at Mwnt, New Quay Fish, Ynys Lochtyn, and Aberporth. Outliers were depicted particularly well using a 1300m radius from

(a)



(b)

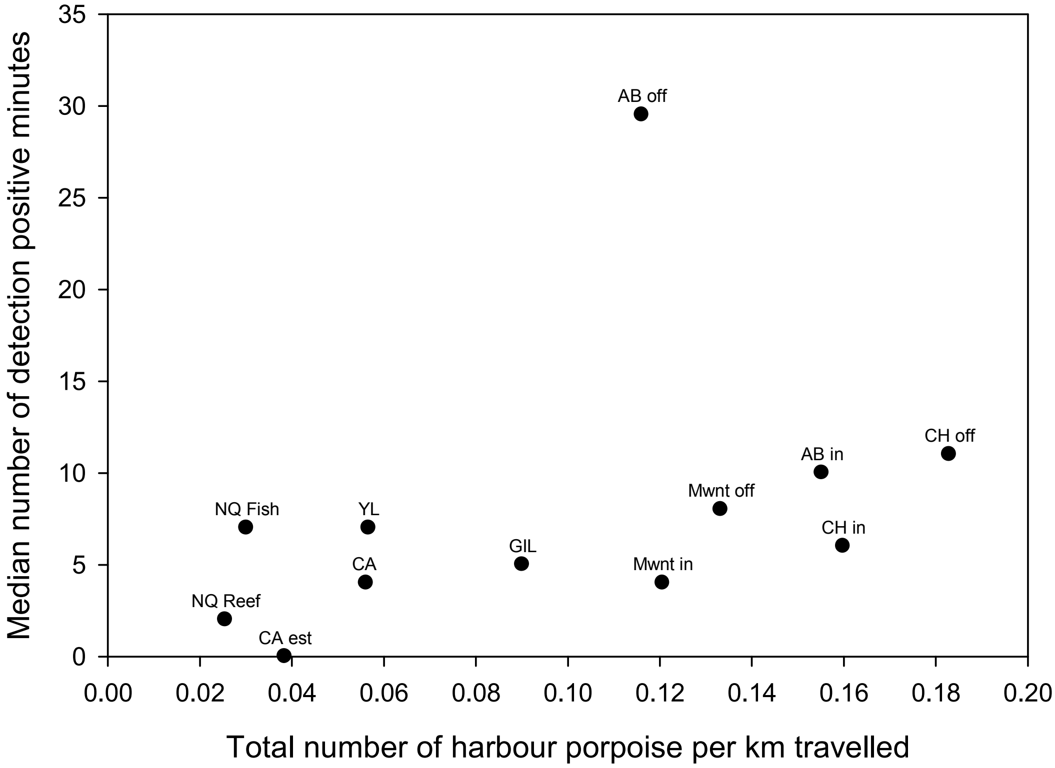


Figure 9: Median number of detection positives compared to the total number of animals per km travelled for (a) bottlenose dolphins within a 1300m radius grid cell and (b) harbour porpoise found within a 1650m radius grid cell, across the twelve sites when all years were combined (2005 to 2008)

the T-POD. Higher visual detections comparison to acoustic detections were found at sites New Quay Reef and at Gilfachreda, where the median number of daily detection positive minutes over the four year period was 1 and 0 respectively. Median number of detection positive minutes at the Aberporth sites, particularly at Aberporth offshore, was higher than the visual sightings over the four-year period.

A significant correlation between the acoustic and visual data (total number per km travelled) was found for the harbour porpoise (r_s= 0.6000, d.f. = 12, P<0.05), as shown in Figure 7 and Figure 9. Higher numbers of harbour porpoise were visually sighted at sites that included Mwnt offshore, Aberporth inshore, Cemaes Head inshore, and Cemaes Head offshore over the four-year time period (2005-08), as shown in Figure 9. Lower numbers of visual and acoustic detections were found at the sites New Quay Reef and Cardigan Estuary. Outliers existed at New Quay Fish, and Ynys Lochtyn and Aberporth offshore, where higher numbers of acoustic detections occurred at these sites by comparison to the visual sightings. Acoustic detections at the site Aberporth offshore were also considerably higher than the visual sightings.

3.1.5: Comparing how the total number of animals per unit effort changes with an increasing radius around a T-POD

Table 2: Comparison of the visual data (total number per km travelled) within a 1650m radius and a 2500m radius for the harbour porpoise (HP) and within a 1300m and 2500m radius for the bottlenose dolphin (BND)

Site	Ratio HP	Ratio minus 1 HP	Ratio BND	Ratio minus 1 BND
Aberporth (inshore)	1.44	0.44	1.79	0.79
Aberporth (offshore)	1.41	0.41	0.88	-0.12
Cardigan Estuary	0.48	-0.52	0.00	-1.00
Cardigan Island	0.79	-0.21	0.90	-0.10
Cemaes Head (inshore)	1.15	0.15	1.76	0.76
Cemaes Head (offshore)	1.24	0.24	0.43	-0.57
Gilfachreda	1.31	0.31	2.68	1.68
Mwnt (inshore)	1.13	0.13	1.15	0.15
Mwnt (offshore)	1.17	0.17	1.37	0.37
New Quay Fish Factory	1.07	0.07	1.73	0.73
New Quay Reef	0.90	-0.10	1.52	0.52
Ynys Lochtyn	0.84	-0.16	1.57	0.57

As shown in Table 2, the visual data (total number per km travelled) for the harbour porpoise was comparatively low at sites including Cardigan Estuary, Cardigan Island, Quay Reef and Ynys Lochtyn, as indicated by the lower ratio when a small radius was used. High ratios were found at Aberporth inshore and offshore, indicating that higher numbers of visual sightings (total number per km travelled) were made at these locations when using a smaller radius. For the bottlenose dolphin, lower visual data occurred (total number per km travelled) at Cardigan Estuary, Cardigan Island, and Cemaes Head offshore when using a smaller radius. Higher sightings (ratio >1.70) were found at sites Aberporth inshore, Cemaes Head inshore, Gilfachreda and New Quay Fish Factory when a smaller radius was used.

3.1.6: Comparing the median number of detection positive minutes across sites in the Cardigan Bay SAC

The acoustic data combined across four years (2005-08) showed that detection positive minutes differed significantly across the sites for both the bottlenose dolphin (Kruskal Wallis: $H = 1939.5$, d.f. = 11, $P<0.001$) and harbour porpoise (Kruskal Wallis: $H =1116.9$, d.f. = 11, $P<0.001$). The distribution of the acoustic data for both species was skewed towards the lower number of detection positive minutes as many zero detection positive days were found within the acoustic dataset, as shown in Figure 10. Low numbers of detection positive minutes were found for the bottlenose dolphin at sites Cemaes Head offshore, Cemaes Head inshore and Cardigan Estuary in the south of the inshore part of the Cardigan Bay SAC. In addition, lower numbers of detection positive minutes were found in the north of the inshore part of the SAC, at the sites New Quay Reef and Gilfachreda. The number of detection positive minutes increased for bottlenose dolphins towards the centre of this region, with the highest numbers of detection positive minutes being found at Aberporth offshore, closely followed by Aberporth inshore. Similarly, high numbers of detection positive minutes were found at Aberporth offshore and inshore for the harbour porpoise. Overall the number of detection positive minutes was more evenly spread across the SAC for the harbour porpoise when compared to bottlenose dolphin. Significantly higher numbers of detection positive minutes were found at sites Cemaes Head offshore, Cemaes

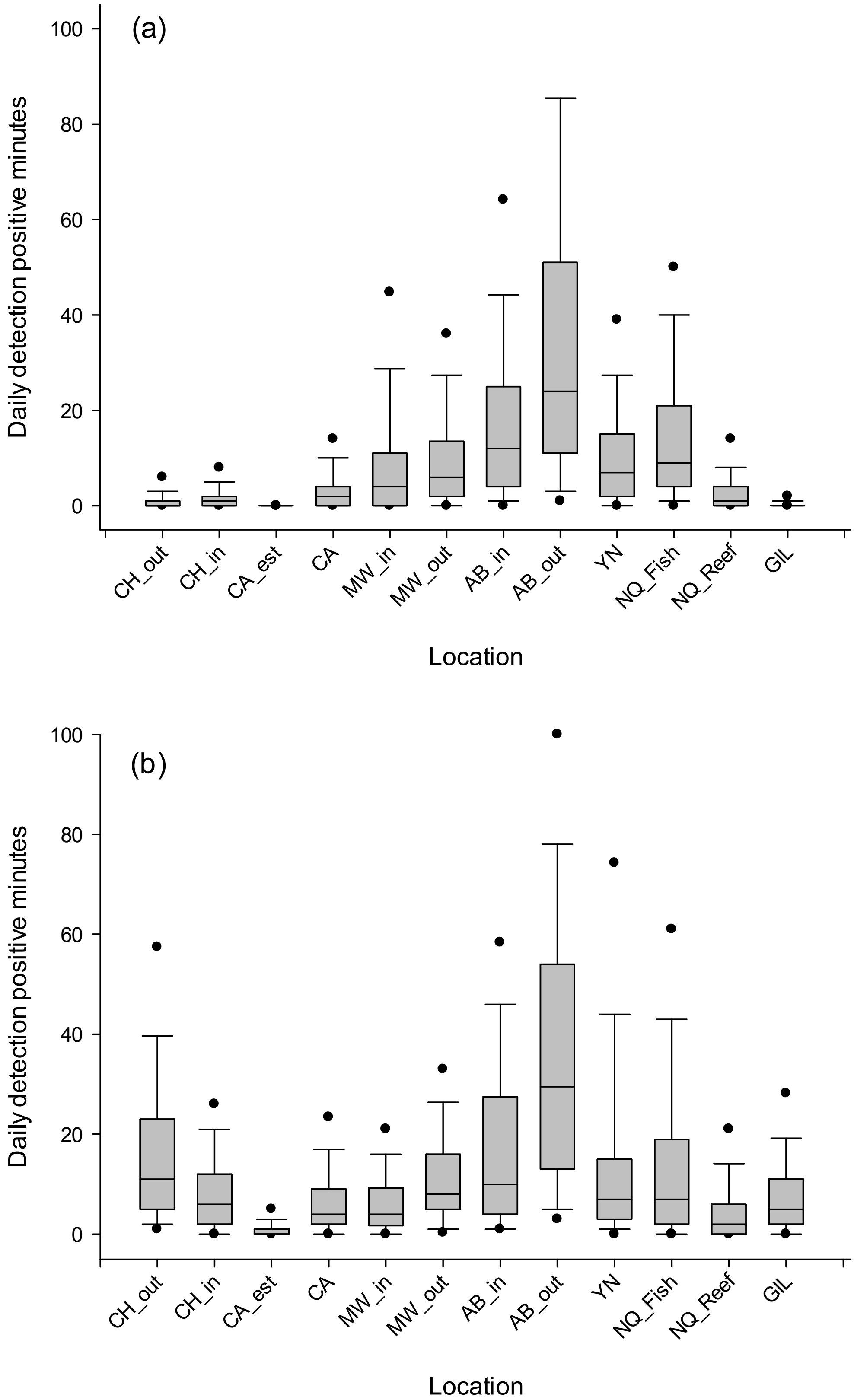


Figure 10: Box plots showing how the median number of detection positive minutes differed by site (1-12) for bottlenose dolphins (a) and the harbour porpoise (b) when all years were combined 2005-2008. Circular symbols represent the 5th and 95th percentiles.

Head inshore, Cardigan Estuary, Cardigan Island, New Quay Reef, and Gilfachreda for the harbour porpoise compared with the number of detection positive minutes for the bottlenose dolphin (Mann Whitney U: W = 3708827.0, Z =-19.9, P<0.001).

3.2: Acoustic and visual comparisons by year from 2005 to 2008

3.2.1. Correlation matrices comparing the visual data (total number of animals per km travelled) using different sized radii to the median number of detection positive minutes from T-PODs across the twelve sites

Very high correlations (r_s >0.85) were found between the visual data (the total number of bottlenose dolphins per km travelled) for the larger areas around T-PODs: 1650m, 2000m, 2500m and the grid cells, as shown in Figure 11. As the area used around T-PODs decreased across all sites, correlations between the visual data decreased. However, as the correspondence between visual data decreased when smaller areas around T-PODs were used, correlations of the visual data with the acoustic data increased. The highest visual-acoustic correlation that was found around T-PODs was when a 650m radius around T-PODs was used (r_s = 0.53, d.f. = 37, P<0.01). Very high correlations were found between the mean and median detection positive minutes, although higher correlations were found when comparing the median number of detection positive minutes to the visual sightings data (total number per km travelled).

A similar finding was obtained for the harbour porpoise. As the areas used around T-PODs became progressively smaller, correlations between the visual data (between larger and smaller areas) also decreased. In this case, however, no correlation between the acoustic data and the visual data was found when using a grid cell with a radius of 650m from the T-POD (r_s = 0.08, d.f. = 37, P = 0.65). The highest significant correlation between the visual and acoustic data was found when a radius of 1300m around T-PODs was used for the harbour porpoise (r_s = 0.34, d.f. = 37, P<0.05). Correlations of the visual data with the acoustic data decreased as increasingly large areas were used around T-PODs, but the grid cells showed better correspondence than when 2000m and 2500m radii from T-PODs were used. A high correlation was found between the mean and the median numbers of detection positive minutes, although the median number of detection positive minutes was found to correspond better with the visual data and higher correlations were found.

3.2.2: Correlations comparing the total number of animals found around T-PODs to the acoustic median data

An increasing correlation was found between the visual and acoustic data for the bottlenose dolphin, although several outliers were present, as shown in Figure 12a. The visual data (total number of animals per km travelled) were higher than the acoustic data at Mwnt inshore in 2008, Cemaes Head inshore 2006, New Quay Reef 2007-08, and Gilfachreda 2007. At the sites Aberporth offshore 2005-06, New Quay Fish 2007 and at Aberporth inshore 2005, the acoustic data (median number of detection positive minutes) were higher than the visual data (total number per km travelled).

An increasing trend between the visual and acoustic data was found for the harbour porpoise for all years combined, although there were outliers, as shown in Figure 12b. The median number of detection positive minutes were higher in comparison to the visual data (total number per km travelled) at Aberporth offshore during each year that a T-POD was placed at this site (2005-06) and at the sites Aberporth inshore and New Quay Fish in 2008. Visual sightings were higher than the median number of acoustic detections at Cemaes Head offshore in 2007.

(a)

	650m	1000m	1300m	1650m	2000m	2500m	Grid cells	Acoustic mean	Acoustic median
650m	1.0000	0.9325	0.8084	0.7665	0.7654	0.7416	0.7303	0.4317	0.5024
1000m		1.0000	0.9083	0.8613	0.8238	0.8149	0.8324	0.4586	0.5313
1300m			1.0000	0.8849	0.8366	0.7888	0.8174	0.3899	0.4802
1650m				1.0000	0.9778	0.9218	0.8802	0.3541	0.4282
2000m					1.0000	0.9288	0.8853	0.3307	0.3936
2500m						1.0000	0.8941	0.3834	0.4256
Grid cells							1.0000	0.3579	0.3999
Acoustic mean								1.0000	0.9590
Acoustic median									1.0000

(b)

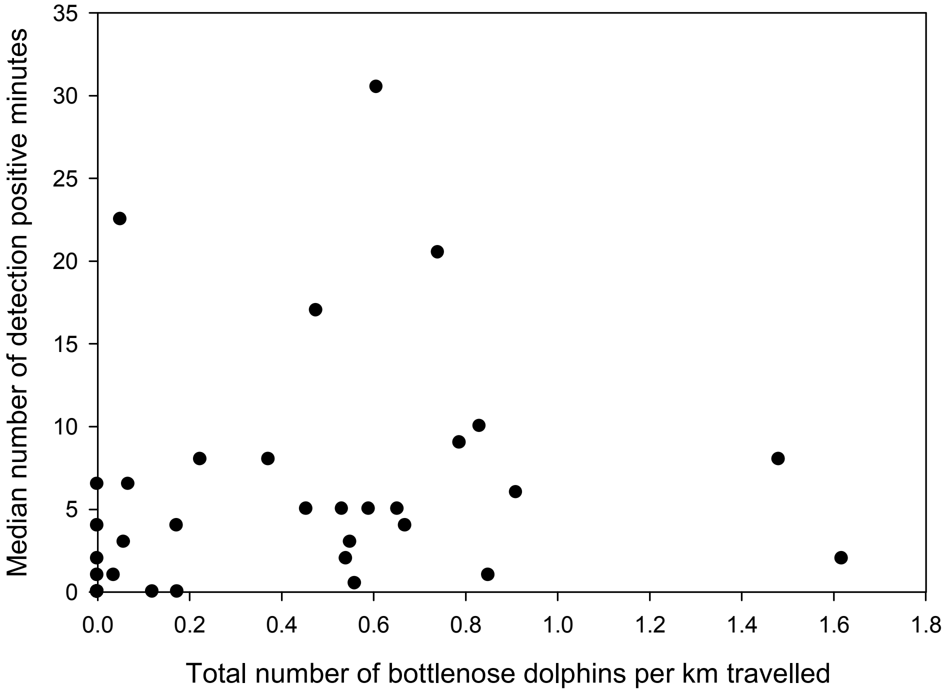
	650m	1000m	1300m	1650m	2000m	2500m	Grid cells	Acoustic mean	Acoustic median
650m	1.0000	0.5417	0.3962	0.3032	0.2621	0.1966	0.3127	0.0581	0.0775
1000m		1.0000	0.7591	0.7164	0.6877	0.5460	0.6434	0.2670	0.3388
1300m			1.0000	0.9351	0.8168	0.6689	0.8238	0.2605	0.3701
1650m				1.0000	0.8890	0.7434	0.8954	0.1908	0.3170
2000m					1.0000	0.8365	0.9106	0.0731	0.2221
2500m						1.0000	0.8171	-0.0156	0.1515
Grid cells							1.0000	0.0932	0.2663
Acoustic mean								1.0000	0.9482
Acoustic median									1.0000

Figure 11: Spearmans rank correlation matrices comparing the correlation coefficients within grids of different sizes around T-PODs across sites for each year where there was good acoustic-visual correspondence by month for the total number of (a) bottlenose dolphins (b) harbour porpoise per km travelled around T-PODs

Key:

Blue	0.9-1
Light blue	0.8-0.9
Green	0.7-0.8
Light green	0.6-0.7
Yellow	0.5-0.6
Orange	0.4-0.5
Grey	0.3-0.4
Light grey	0.2-0.3
White	-0.1-0.2

(a)



(b)

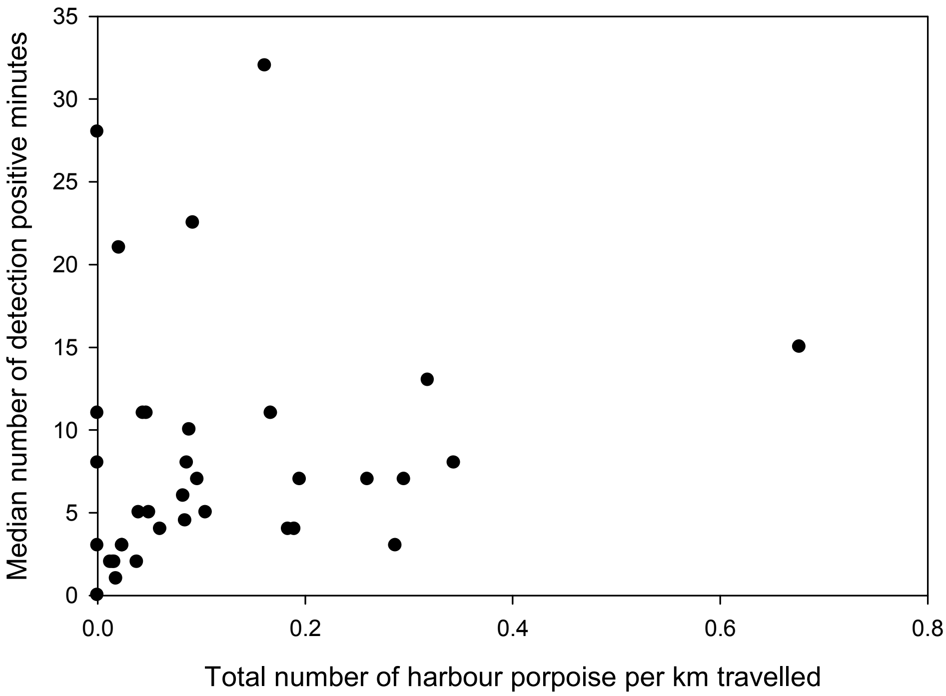


Figure 12: Median number of detection positive minutes compared to the total number per km travelled for of (a) bottlenose dolphins within a 1000m radius grid cell and (b) harbour porpoise found within a 1300m radius grid cell across the twelve sites each year 2005, 2006, 2007 and 2008

3.2.3: Comparison of the number of days per month that T-PODs were recording each year

Inspection of the acoustic dataset by year showed that at each site, the number of recording days differed. Higher numbers of recording days occurred in 2005 and 2006, compared with 2007 and 2008 (Table 3). Only five of the twelve sites had T-PODs that were recording for every year during the April to October period: Ynys Lochtyn, New Quay Reef, New Quay Fish, Mwnt inshore, and Cardigan Island. The number of recording days also varied by month at each site as shown in Appendix 1.

Table 3: The number of recording days each year (2005 to 2008: April to October) by site

Site	2005	2006	2007	2008
CA	171	75	155	190
CH_in	113	155	88	*
CH_out	47	105	140	*
CA_est	*	*	99	84
GIL	*	*	92	66
AB_in	161	185	*	51
AB_out	142	190	*	*
MW_in	142	136	73	111
MW_out	166	179	*	*
NQ_fish	95	197	184	63
NQ_reef	119	170	202	197
YN	145	160	187	145
Total	***1301***	***1552***	***1220***	***907***

*Zero recording days during the year at site

3.2.4: Changes in detection positive minutes by month that could affect yearly comparisons

A significant difference in the number of detection positive minutes was found across months for all years (2005 to 2008) for the bottlenose dolphin (Scheirer-Ray-Hare test, df=6, SS=567312064, H=274.504, p<0.0001) and for the harbour porpoise (Scheirer-Ray-Hare test, df=6, SS=57806.998, H=128.1704001, p<0.0001). For bottlenose dolphins, the median number of detection positive minutes and range increased from a minimum in April up to a maximum in July before decreasing again towards October across all sites, as shown in Table 4. However, the visual data showed that the total number of animals per km travelled was higher in August, September and October across all sites for all years combined. No correlation was found between the acoustic and visual data per month for the bottlenose dolphin (r=0.399, d.f.=7, P=0.375). By comparison, the median number of detection positive minutes for the harbour porpoise was highest in April and then decreased in May and June before increasing in July and then remaining relatively stable through to October, as shown in Table 4. The visual data also showed that a higher number (approximately double compared to any other month) of harbour porpoise per km travelled occurred in April when all years were combined across all sites, as shown Table 4. A positive though non-significant correlation was found between the overall visual and acoustic data by month for the harbour porpoise (r=0.722, d.f.=7, P=0.067). However, inter-annual variability by month was also found in the acoustic detection positive minutes for the bottlenose dolphin (Scheirer-Ray-Hare test, df=18, SS=508773587, H=246.179, p<0.0001) and for the harbour porpoise (Scheirer-Ray-Hare test, df=18, SS=83719.759, H=185.6244983, p<0.0001).

Table 4: The median and upper and lower quartiles for the daily number of detection positive minutes for the bottlenose dolphin and harbour porpoise when all years were combined 2005-2008. The visual data is also shown for both species.

Month	Acoustic Median	Acoustic Lower quartile	Acoustic Upper quartile	Visual (total no. of animals per km travelled)
Bottlenose dolphins				*1300m radius*
April	0	0	3	0.171213
May	1	0	6	0.380784
June	4	1	14	0.459547
July	6	1	19	0.3384
August	4	1	13	0.787237
September	4	0	12	0.666279
October	3	0	13	0.76636
Harbour porpoise				*1650m radius*
April	12	5	30	0.14655
May	4	1	10	0.07081
June	4	1	10	0.052235
July	7	3	15	0.058941
August	6	2	16	0.03195
September	5	1	15	0.07216
October	6	2	16	0.03849

However, attempting to correct the correlation matrices in Figure 11 for only the months for which there were corresponding visual and acoustic data, resulted in lower correlations, possibly due to low sample sizes

3.3: Hourly Visual-Acoustic comparisons for bottlenose dolphin

3.3.1: Hourly comparisons at New Quay Fish

A total of 106 sightings for bottlenose dolphin occurred within a 1300m radius of the T-POD from 2006 to 2008, and 84 of those were within independent hourly time slots. At 1300m, the % of sightings (31 sightings) that coincided with acoustic detections within the hourly time period was found to be 44%, and when harbour porpoise click settings on the T-POD were included in the analysis, this figure rose to 48%. When taking into consideration clicks that occurred either side of the hourly time period, the percentage of sightings coinciding with acoustic detections was found to be 77%, and when harbour porpoise clicks were also considered this rose to 86%. The number of sightings found within 1300m from the T-POD together with acoustic data is shown in Figure 13.

When a 500m radius was used from the T-POD at New Quay Fish, 31 sightings were found to occur within the same hour of the acoustic detections. 32% of these sightings corresponded with acoustic detections within the same hour, and if harbour porpoise settings were included on the T-POD, this figure rose to 35%. When considering sightings of bottlenose dolphin at New Quay Fish, 74% of these were associated with either an acoustic detection on either side of the hourly time period, or if harbour porpoise settings on the T-POD were included, this figure rose to 83%.

3.3.2: Hourly comparisons at New Quay Reef

The total number of sightings that were within a 1300m radius of a T-POD at New Quay Reef was 101, with 88 sightings occurring in independent hourly time slots, as shown in Figure 14. Twenty percent of these sightings corresponded with acoustic detections within the same hour as the sighting. This percentage increased to 24% if detections that included settings for the harbour porpoise were included. If hours either side of the visual sightings were considered, correspondence with the acoustic detection increased to 48%, whilst if harbour porpoise settings were used, this figure increased further to 52%.

However, when considering a lower 500m radius from the T-POD at New Quay Reef, correspondence between the visual and acoustic data was slightly higher. A total of 22 sightings occurred within a 500m radius of the T-POD. Twenty three percent of these sightings co-occurred with an acoustic detection on the T-POD within the same hour (27% if harbour porpoise settings are included), and 64% if hours either side of the visual detection of bottlenose dolphins were included (68% if harbour porpoise settings on the T-POD were included).

3.3.3: Feeding behaviour of bottlenose dolphin at New Quay Fish and New Quay Reef

At New Quay Fish there were 13 feeding behaviours observed and 12 non feeding behaviours observed within 500m of the T-POD. Six behaviours were unknown or not recorded. Excluding the behaviours that weren't recorded 48% of the behaviour observed was feeding and 52% was non-feeding. At New Quay Reef 7 feeding behaviours were recorded within 500m of the T-POD and 13 non-feeding behaviours were recorded. Two behaviours were unknown or not recorded. Excluding the behaviours that weren't recorded 35% of the behaviours were feeding and 65% were non-feeding.

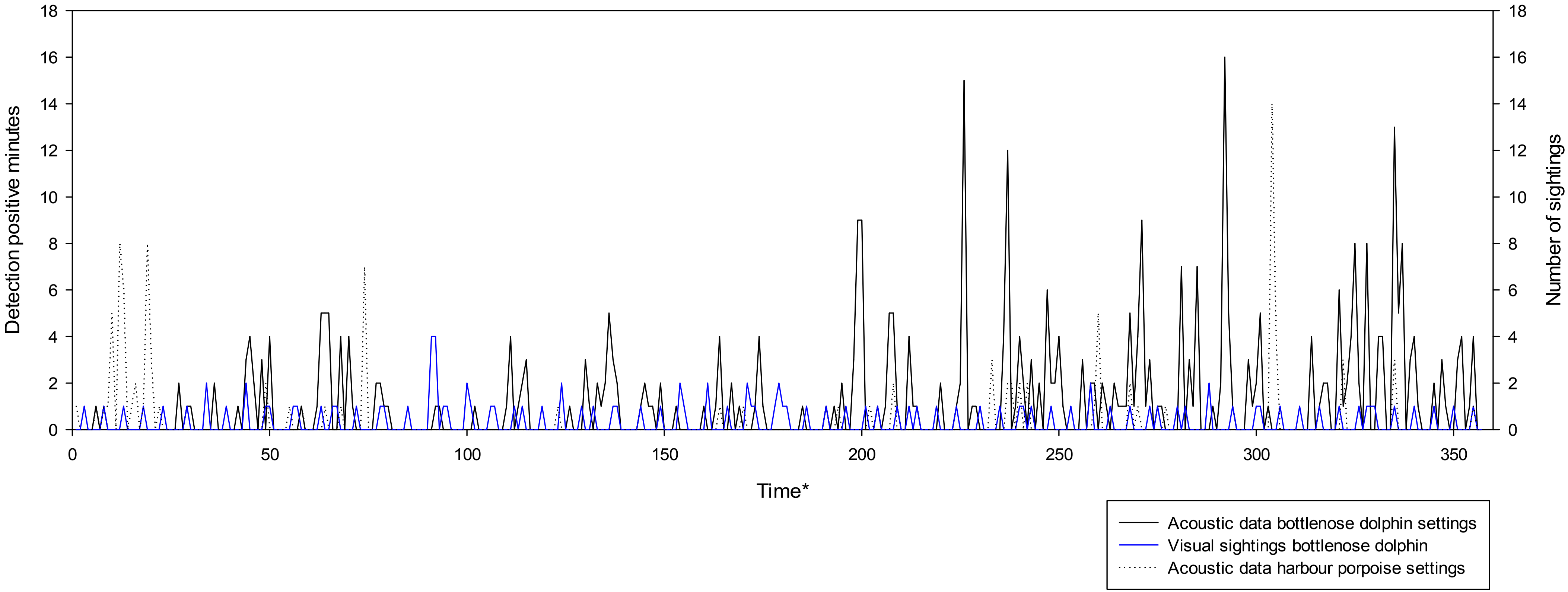


Figure 13: Direct comparison of sightings of bottlenose dolphins within a 1300m radius of the T-POD at New Quay Fish with acoustic T-POD data. Both settings of the T-POD of the acoustic data (harbour porpoise and bottlenose dolphin settings) are displayed. *Time period details (1-198: year 2006, 199-337: year 2007, 338-357: 2008).

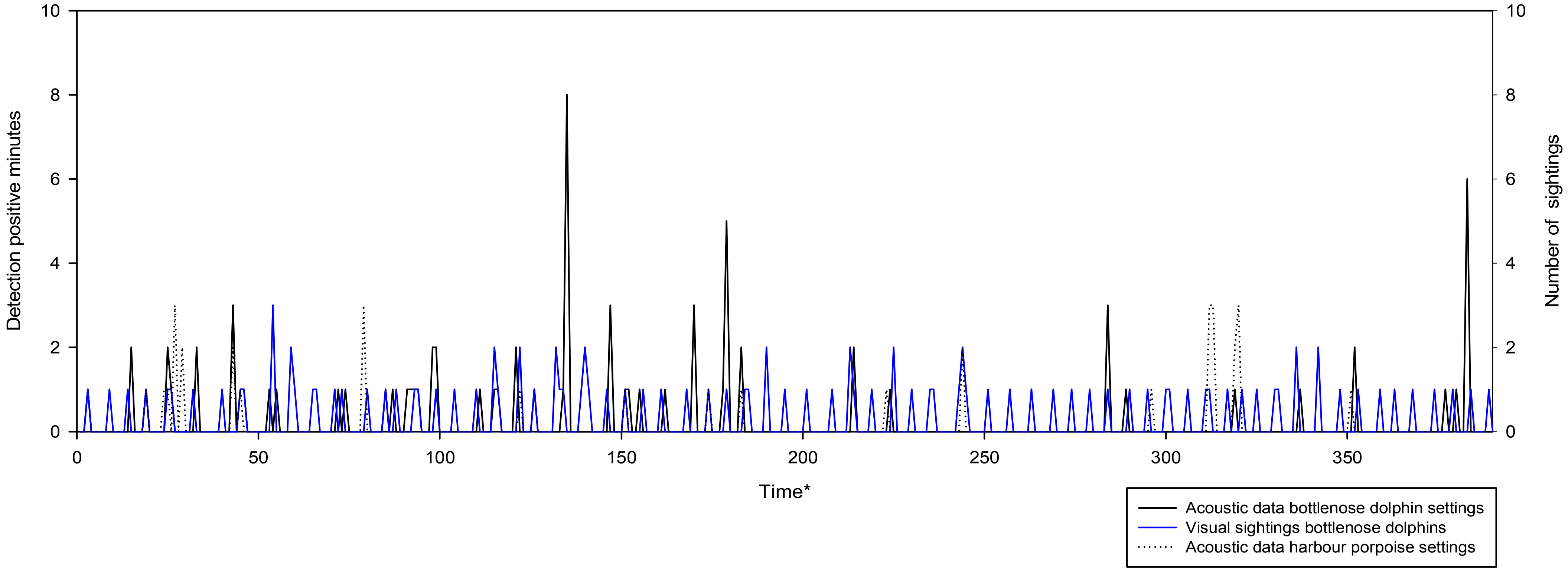


Figure 14: Direct comparison of sightings of bottlenose dolphins within a 1300m radius of the T-POD at New Quay Reef with acoustic T-POD data. Both settings of the T-POD of the acoustic data (harbour porpoise and bottlenose dolphin settings) are displayed. *Time period details (year 2006: 1-154, year 2007: 155-272, year 2008: 273-390).

3.3.4: Hourly comparison at Ynys Lochtyn

Fifteen sightings of bottlenose dolphins occurred within a 500m radius of the T-POD at Ynys Lochtyn. Only 13% of these sightings were found to have a corresponding acoustic detection within the same hourly period, but this increased to 47% when considering acoustic detections on either side of the hour that the visual sighting was made. If the radius around the T-POD was further increased to 1300m, a total of 28 sightings occurred over the years within this range. Twenty eight percent of these sightings were associated with corresponding acoustic detections within the same hour, and if hours either side were considered, then this value rose to 55%. Figure 15 shows the visual and associated acoustic detections at Ynys Lochtyn when a 1300m radius was used.

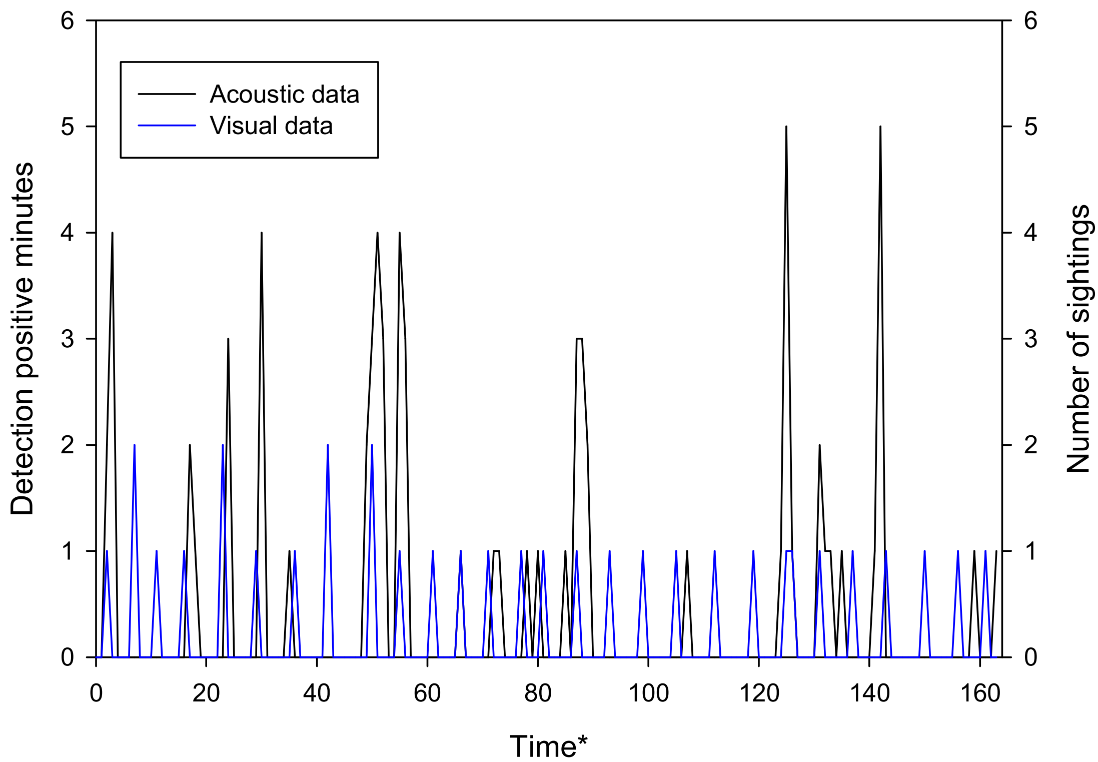


Figure 15: The sightings and corresponding acoustic detections over the three year period (2006-2008) when a T-POD was monitoring the site Ynys Lochtyn within a 1300m radius. Time period details (1-121: year 2006, 122-144: year 2007, 144-163: 2008).

3.3.5: All other sites

Data available for the other sites were more limited, and there were only a few sightings where acoustic-visual time comparisons could be made, as shown in Table 5. The majority of the sightings of bottlenose dolphins across the remaining sites exceeded a 1300m range from the T-POD. At sites Cardigan Estuary, Aberporth offshore and Cemaes Head offshore, no visual-acoustic sightings were found within 1300m of the T-POD. At Cardigan Island and Cemaes Head inshore, most sightings exceeded 1300m, and of the sightings that occurred within 1300m of the T-POD at each of the two sites, no corresponding acoustic detections were recorded. At Gilfachreda, two sightings occurred within 600m from the T-POD, but neither of these recordings was detected on the T-POD.

In 2006 at Mwnt inshore, one sighting of bottlenose dolphin within 1300m radius corresponded to an acoustic detection on the T-POD within the same hour, whilst for a separate sighting, acoustic detections were recorded outside the hour time period (within one hour either side of the hour). In 2008 at Mwnt inshore, no corresponding visual and acoustic detections were recorded even though bottlenose dolphins were seen less than 200m from the T-POD.

At the site Mwnt offshore, all visual sightings of animals within a 1300m radius of the T-POD had corresponding acoustic detections within the same hour. At Aberporth inshore, one sighting occurred within the same hour as detections were recorded on the T-POD, and all other visual sightings that occurred were associated with detections on the T-POD either side of the hour time period.

Table 5: Acoustic visual comparisons by hour for the bottlenose dolphin sites where there were few sightings over the years within 3000m of the T-POD. Years used in the comparison were 2006-2008 data from line transect and ad libitum surveys. Acoustic recordings are those recorded on the T-POD for dolphin settings only. Distances highlighted in red are distances within 1300m found to be the maximum distance bottlenose dolphins could be detected (Philpott *et al.*, 2007; Elliott *et al.*, 2011) with corresponding detections also highlighted in red. Behaviour SS=slow swim, NS=normal swim, FS=fast swim, SF=suspected feeding, FF=feeding (fish seen), L=leaping, B=bowriding, R=resting/milling, S=socializing, O=other, U=unknown, N=not recorded.

Date	Time	Distance from T-POD (metres)	Number of acoustic recordings in same hour	Number of acoustic recordings in surrounding hours	Behaviour
Cardigan Island					
15.09.06	12:23	2548	0	1	NS
19.04.07	14:23	1735	0	0	NS
01.08.07	13:03; 13:15; 13:44	531 1969 1581	0	0	NR FS FS
30.05.08	10:49	2691	0	0	NS
09.06.08	15:18 15:20 15:28	2780 1874 1770	0	0	SS SS SS
Cardigan Estuary					
01.08.07	13:03	2579	0	0	NR
09.06.08	15:18 15:20 15:28	1740 1757 1110	0	0	SS SS SS
Cemaes Head Inshore					
27.07.06	12:53	2558	0	0	L
26.09.06	14:20 14:42 14:49	2704 454 2317	0	0	NS NS FS
Cemaes Head Offshore					
26.09.06	14:20 14:42	2840 1634	0	0	NS NS
01.08.07	13:44	2880	0	0	FS
09.08.07	12:05	2602	0	0	NS
Gilfachreda					
07.09.07	08:41 08:55	598 1748	0	0	SF NR
06.10.07	07:23	565	0	0	NR
Mwnt inshore					
05.07.06	12:39	205	3	1	NR
27.07.06	11:45 11:56	1361 690	0	3	NS NS
27.07.06	15:11	1741	0	1	NS
11.05.08	13:09 13:19 13:22	576 186 214	0	0	NR
30.05.08	10:31 10:49	974 1409	0	0	NR

Date	Time	Distance from T-POD (metres)	Number of acoustic recordings in same hour	Number of acoustic recordings in surrounding hours	Behaviour
Mwnt offshore					
05.07.06	12:39	919	6	7	NR
27.07.06	11:45 11:56	584 310	4	16	NS NS
27.07.06	15:11	801	2	1	NS
10.09.06	14:03 14:13	1117 1470	1	0	NS SS
15.09.06	12:23	2058	0	1	NS
16.09.06	11:51	2681	0	1	NR
16.09.06	12:06	1281	1	3	NS
26.09.06	15:29	2615	1	0	NR
Aberporth inshore					
08.06.06	15:44	567	0	4	NR
26.09.06	11:47	2828	1	0	NS
05.05.07	11:41	1260	0	0	NS
05.05.07	12:13 12:23	792 978	0	3	NS FS
05.07.07	10:23	2640	1	6	NS,B
19.07.07	14:52	905	0	2	SS
19.07.07	15:02 15:14 15:58	615 371 1101	2	17	SF
31.07.07	12:40	2780	0	1	SF
29.09.07	14:44	939	0	1	NS
Aberporth offshore					
08.06.06	15:44	1569	0	2	NR
16.09.06	11:51	2905	1	5	NR
26.09.06	11:47	2272	9	5	NS

3.4: Comparison of acoustic data at T-POD sites to overall abundance estimates for the Cardigan Bay SAC

3.4.1: Trends in acoustic detections across years

Bottlenose dolphin

The number of detection positive minutes differed significantly across the years 2005 to 2007 for the bottlenose dolphin (Kruskal Wallis: $H=41.747$, d.f.=2, $P<0.001$) as shown in Figure 16. Pairwise tests, revealed that all years except 2006 and 2007 were significantly different from each other (2005 and 2006: W=612397.0, Z=-6.545, P<0.001; 2005 and 2007: W=743662.5, Z=-4.629, P<0.001; 2006 and 2007: W=770136.0, Z=-1.261, P=0.207; 2007 and 2008: W=410534.5, Z=-5.198, P<0.001). Detection positive minutes were significantly lower in 2006 and 2007 compared to 2005, and were significantly lower in 2008 compared to 2007.

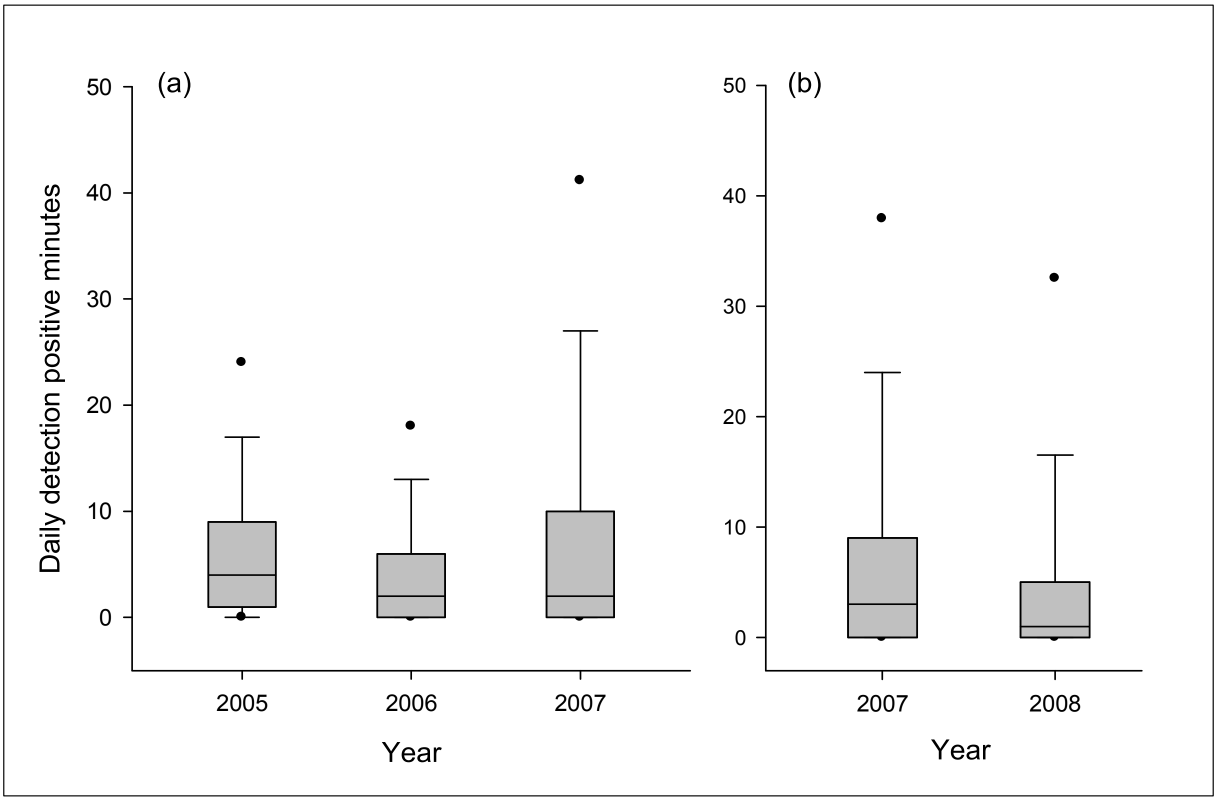


Figure 16: Box plots comparing changes in the number of detection positive minutes by year for bottlenose dolphins when using only sites where there were similar number of monthly recording days between years (a) 2005-2007 (b) 2007-2008. Circular symbols represent the 5th and 95th percentiles. Sites used for 2005-07 recordings included CA, CH_in, CH_out, NQ_Fish, NQ_Reef and YN. Sites used for 2007-08 included CA, MW_in (April-June), NQ Fish (April-June), NQ Reef and YN.

Harbour porpoise

Detection positive minutes were found to be significantly different for the harbour porpoise (Kruskal Wallis: H =41.741, d.f.=2, P<0.001) over the years, as shown in Figure 17. Detection positive minutes were significantly different across all years (2005 and 2006: W=503031, Z= -3.749, P<0.001; 2005 and 2007: W=506933.0, Z=-6.460, P<0.001); 2006 and 2007: W= 752873.5, Z=-2.792, P<0.001). Detection positive minutes in 2008 were significantly higher than in 2007 (W=435883.0, Z =-3.159, P<0.01).

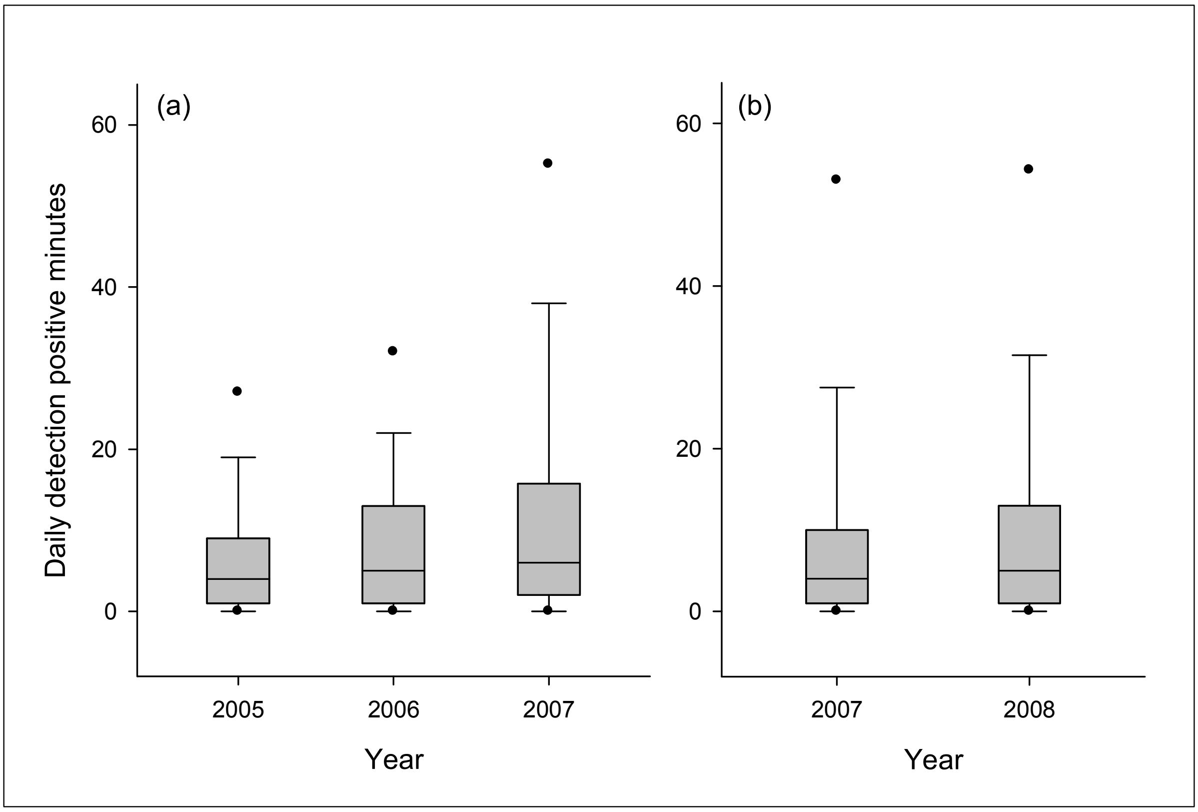


Figure 17: Box plots comparing changes in the number of detection positive minutes by year for harbour porpoise when using only sites where there were similar number of monthly recording days between years (a) 2005-2007 (b) 2007-2008. Circular symbols represent the 5th and 95th percentiles. Sites used for 2005-2007 recordings included CA, CH_in, CH_out, NQ_Fish, NQ_Reef and YN. Sites used for 2007-2008 included CA, MW_in (April-June), NQ Fish (April-June), NQ Reef and YN.

3.4.2: Comparison of trends in sightings around T-PODs and the Cardigan Bay SAC abundance estimates across years

Bottlenose dolphins

For the bottlenose dolphin, no statistically significant relationships were found between the visual sightings around T-PODs (total number within 1300m radius grid cells) and the overall abundance estimates for the Cardigan Bay SAC using the line transect survey abundance estimate (r=-0.573, d.f.=3, P=0.611), the "open model" mark-recapture population estimate (r=-0.499, d.f =4, P=0.501), and the "closed model" mark-recapture population estimate (r=0.440, d.f.= 4, P=0.560).

Harbour porpoise

For the harbour porpoise, no statistically significant correlation was found between the line transect survey absolute abundance estimate and the visual sightings around T-PODs (total number within a 1650m grid cell) (r_s =0.5, d.f.=3, P=0.667), although an increase in visual sightings around T-PODs in 2007 corresponded well with the increase in absolute abundance, as derived from line transect surveys (Figure 18). The sites that contributed primarily to the increase in visual sightings around all T-PODs in 2007 included Aberporth offshore, Cemaes Head inshore, Cemaes Head offshore, New Quay Reef, and Gilfachreda.

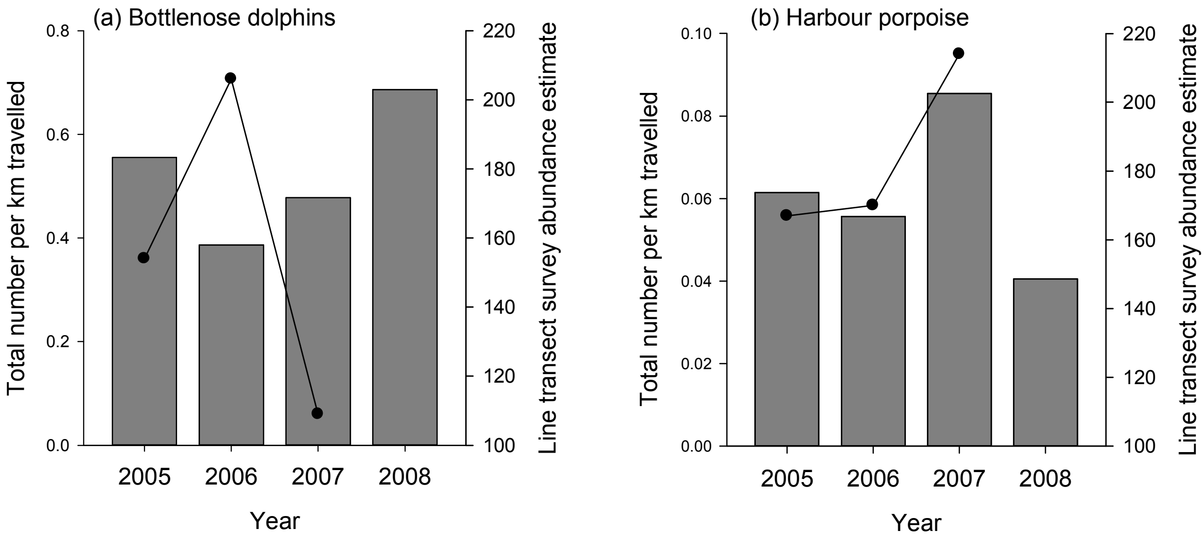


Figure 18: Comparison of the visual data (total number per km travelled) for the harbour porpoise within a 1650m radius grid cell and for the bottlenose dolphin within a 1300m radius grid cell. Line transect survey absolute abundance estimates are also shown with a line overlay

3.4.3: Comparisons of acoustic data with abundance estimates

Harbour porpoise

When the median number of detection positive minutes for the years 2005-07 was compared to the abundance estimate for the entire Cardigan Bay SAC for the harbour porpoise, a significant correlation was found with the three data points used (r_s =1.0, d.f.=3, P<0.01), as shown in Figure 19. The higher detection positive minutes in 2007 were found to correspond well with the higher abundance estimate in that year. The majority of the sites

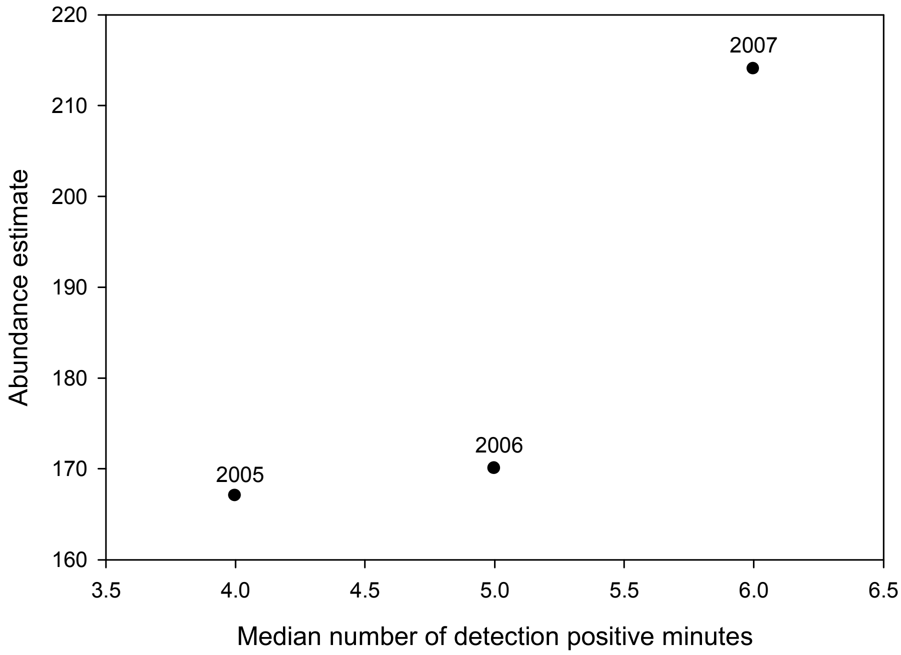


Figure 19: Median number of acoustic detection positive minutes all sites combined, compared to the absolute abundance estimate as determined by line transect survey in the Cardigan Bay SAC for the harbour porpoise

followed an increasing trend, with Ynys Lochtyn and New Quay Fish significantly following the abundance estimates as shown in Table 6. Correlations by site for visual data were also calculated, and although no significant correlations were found with abundance estimates for the Cardigan Bay SAC (Table 6), sites Cemaes Head inshore, New Quay Fish and New Quay Reef all showed similar increases as the acoustic data.

Table 6: Spearman rank correlations comparing the median number of acoustic detections and visual sightings around the T-POD by site to the absolute abundance estimates for the Cardigan Bay SAC as determined by line transect survey for the harbour porpoise between 2005 to 2007.

Site	Acoustic		Visual	
	r_s	p	r_s	p
Cemaes Head offshore	0.866	0.333	0.500	0.667
Cardigan Island	0.500	0.667	-1.000	0.667
Cemaes Head inshore	-1.000	<0.05	0.500	0.667
New Quay Fish	1.000	<0.05	0.500	0.667
New Quay Reef	0.866	0.333	0.500	0.667
Ynys Lochtyn	1.000	<0.05	-1.000	<0.05

Bottlenose dolphins

No significant correlation was found when comparing the line transect survey absolute abundance estimate to the median number of acoustic detections for the bottlenose dolphin between 2005 to 2007 (r=-0.42, d.f.=3, P=0.973 as shown in figure 20. Lower detection minutes in 2007 did coincide with the low line transect survey absolute abundance estimate in 2007 for the bottlenose dolphin. However the increase in the absolute abundance estimate in 2006 was not reflected in the acoustic T-POD data.

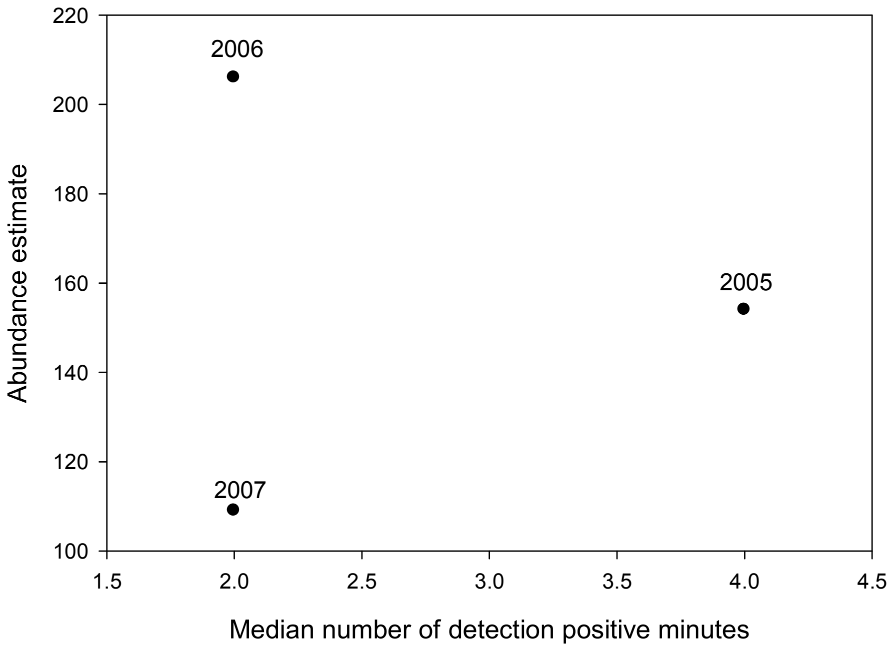


Figure 20: Median number of acoustic detection positive minutes compared to the absolute abundance estimate as determined by line transect survey in the Cardigan Bay SAC for the bottlenose dolphin

No significant positive correlations were found for the bottlenose dolphin when comparisons were made with the population estimates as derived from photo ID for the Cardigan Bay SAC for either the closed population model (r=-0.920, d.f. = 3, P=0.256) or the open population model (r =-0.993, d.f.=3, P=0.076), as shown in Figure 21.

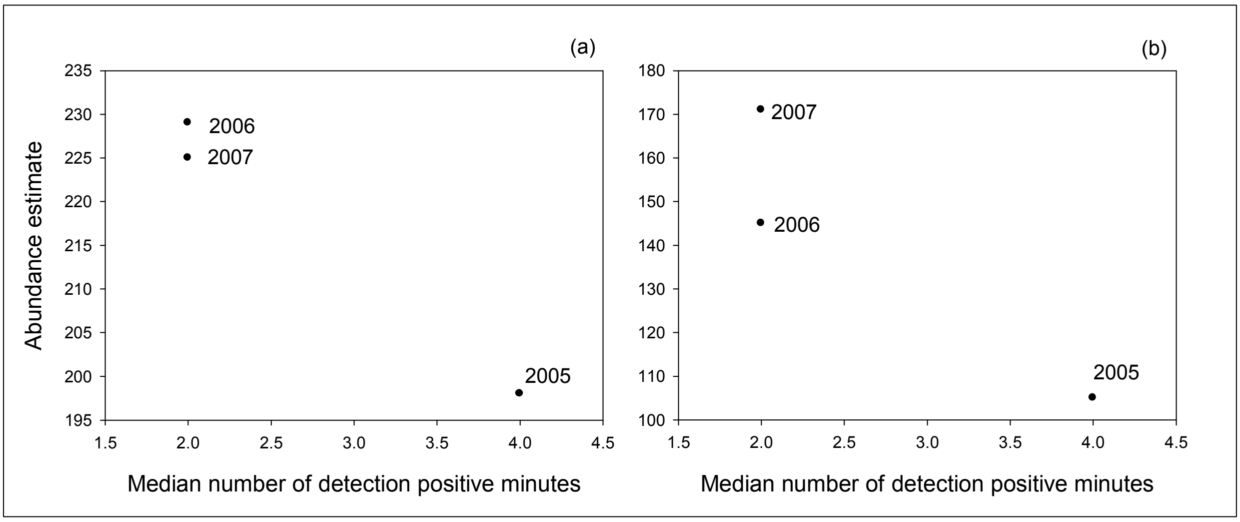


Figure 21: The median number of detection positive compared to absolute abundance estimates for the bottlenose dolphin 2005 to 2008 (a) "closed" population model (b) "open" population mode.

4. Discussion

4.1 Comparisons of visual acoustic data across sites

T-PODs were found to have the capabilities to detect the trends that occurred with the visual sightings data in the area immediately surrounding T-PODs by year and when all years (2005 through to 2008) were combined, for both species of cetacean that occur regularly within the Cardigan Bay SAC: the harbour porpoise and the bottlenose dolphin. This suggests that T-PODs have for the most part the capability to track trends in relative abundance (numbers of animal per unit effort) over time. This is advantageous as visual surveys are both time intensive and expensive; in some years visual line transect surveys have not been carried out within the Cardigan Bay SAC as a result of a lack of funding (Pesante *et al.*, 2008). In addition, the poor weather conditions in 2007 reduced the number of visual surveys that could be carried out within the Cardigan Bay SAC. The deployment of T-PODs at localities could therefore have the potential at least to determine relative increasing or decreasing trends of echolocating cetacean species in the area immediately around a T-POD (Bailey *et al.*, 2010).

Trends in the distribution of bottlenose dolphins across the Bay were consistent with previous studies carried out in the Cardigan Bay SAC. A lower presence of bottlenose dolphins was found in the south of the Cardigan Bay SAC, as determined by both acoustic and visual data at the sites Cardigan Estuary, Cemaes Head offshore, Cemaes Head inshore and Cardigan Island, whilst an increasingly higher presence was found towards in the northern sector, from Mwnt inshore, Mwnt offshore, Ynys Lochtyn and New Quay Fish (Pesante *et al.*, 2008; Pierpoint *et al.*, 2009; Simon *et al.*, 2010; Vereruso and Evans., 2012). However, across the four years at New Quay Reef and Gilfachreda the visual sightings rates were found to be much higher compared to the acoustic detections, whereas acoustic detections at Aberporth offshore were much higher than the visual sightings. Thus the use of acoustic detections as a relative index of abundance may not be applicable at some locations for the bottlenose dolphin.

Unfortunately carrying out hourly more direct comparisons didn't always lead to comparisons between a sighting and recording that was detected on a T-POD. At most sites sightings exceeded the detection capabilities of a T-POD (Reyes Zamudio *et al.,* 2005; Philpott *et al.,* 2007; Elliott *et al.,* 2011), and so it is unclear whether the bottlenose dolphin would have moved closer to within the detection range. However at the sites New Quay Reef and New Quay Fish the number of sightings was high and the data was found to be more useful in determining the rate of cetacean detection on T-PODs.

The high visual but low acoustic detections found at New Quay Reef and Gilfachreda suggest that the bottlenose dolphin may not be echolocating frequently in these locations as suggested by both hourly comparisons and by year and all years combined. Direct comparisons showed that at Gilfachreda there were two occasions within the dataset where bottlenose dolphins were recorded within 500m of the T-POD, but no coinciding acoustic detections occurred within the same hour as the sighting. At New Quay Reef, a lower proportion of the sightings occurring within a 500m radius were detected on the T-POD within the same hour by comparison to the T-POD at New Quay Fish. In a previous study by Philpott *et al.* (2007), it was found the majority of dolphins that were not detected within 500m of the T-POD were carrying out travel behaviour. Milling and travel type behaviours were also found to result in fewer detections in a study carried out by Jones and Sayigh (2002), and it was suggested that bottlenose dolphins may echolocate less whilst navigating at sites where there was greater familiarity with the landscape. On the other hand, in this study, at Gilfachreda and New Quay Reef, bottlenose dolphins were carrying out suspected feeding type behaviours within 500m and were not being detected on the T-POD, and the T-PODs were chosen across the Cardigan Bay SAC as they were potential feeding sites (headlands with strong currents). Therefore it could be that bottlenose dolphins are not producing echolocation clicks whilst foraging for prey in these areas. Low dolphin echolocation rates were found in the Sado estuary, Portugal, when travel-feeding behaviours were carried out suggested that the species was utilising passive listening of the movement of prey in the water whilst foraging (Dos Santos and Almada, 2004). Alternatively the production of clicks may be lower due to a low production of clicks as a result of different foraging methods. At other sites, including New Quay Fish, bottlenose dolphins may be foraging along the seabed for prey (Shane, 1990; Pierpoint *et al.,* 2009), and this may be result a high production of echolocation clicks as dolphins are in close range to their target prey (Johnson *et al.,* 2008). The presence of boats within the area may also result in disrupting the echolocation abilities of the bottlenose dolphin. Bottlenose dolphins have been found to change heading and increase their speed in response to boats in Sarasota Bay, Florida (Norwacek et al., 2001). The presence of boats has been found to decrease foraging behaviour and increase travelling behaviours (Christiansen et al., 2010), which would impact on echolocation rates. This could explain why a slightly lower % foraging activity occurred at New Quay Reef. Alternatively another study found that power boat presence affected surface behaviour but didn't impact on echolocation rates (Lemon *et al.,* 2006).

At New Quay Fish which is only 870m from the Reef T-POD, a much higher proportion of bottlenose dolphins that were sighted within 500m of the T-POD, were also acoustically detected around the time of the sighting. Although comparisons of a visual sighting to the acoustic data within an hourly time period cannot determine whether it was the dolphin that was sighted creating the detection on the T-POD, it does indicate that at the site the presence of bottlenose dolphins was being recorded and that acoustic visual correspondence is better at this site. In a study carried out by Bailey *et al.* (2010) it was found that all groups that spent >30 minutes within the locality were detected on the T-PODs. As the T-POD at New Quay Fish is located closer to a factory that legally discharges shells from the common whelk *Buccinum undatum* into the near shore waters it may be that this area is a better foraging ground and that bottlenose dolphins are tending to remain at the site for longer periods of time whilst carrying out foraging activities (Pierpoint *et al.*, 2009; Denton *et al.*, 2012), resulting in a higher number detections being recorded on T-PODs (Bailey *et al.*, 2010; Reyes-Zamudio, 2005).

Much higher detections of bottlenose dolphins were recorded on the T-POD at Aberporth offshore than indicated from the relative abundance (numbers of animal per unit effort) by comparison to other sites for those years that the T-POD was recording at the site (2005-06). The detection threshold of the T-POD deployed at Aberporth offshore was lower than for other T-PODs and this could have contributed a higher number of detection positive minutes being recorded on the T-POD as the source levels of echolocation clicks would not need to be as high for a detection to be recorded. Furthermore, examination of the click trains found that a higher level of foraging activity occurred at this site during the summer months, and compared with all other sites (except Cardigan Island), and that detections mainly occurred during the night time (Alford, 2006).

In contrast, for the harbour porpoise, there were not times where high relative abundance (numbers of animal per unit effort) were coupled with low acoustic detections. As the harbour porpoise echolocates continuously (Akamatsu *et al.*, 2007), it is likely that its presence at a site is going to be reflected more accurately than for the bottlenose dolphin where behaviour could strongly influence echolocation rates. As was the case for the bottlenose dolphin, lower overall visual sightings (numbers of animal per unit effort) of the harbour porpoise occurred over the years at Aberporth offshore, which is thought to be a result of night time foraging behaviour (Alford, 2006).

A higher overall number of acoustic detections compared with relative abundance (numbers of animal per unit effort) were recorded for the harbour porpoise around the sites Yyns Loctyn and New Quay Fish over the years. The times of day that visual surveys occurred may not have corresponded well with harbour porpoise presence, and this could have led to a low number of visual observations. In Monterey Bay, California, during 1984-85, harbour porpoises were found to occur between 07:00 to 10:00h, and it is possible that the presence of harbour porpoise occurred at times when surveys were not being carried out (Sekiguchi, 1995). Although harbour porpoise are more active Cardigan Bay SAC at night time (Pesante *et al.,* 2008), nocturnal acoustic detections weren't found to be higher in a study carried out by Alford (2006), where acoustic detections were analysed for one of the years (2005). However, perhaps a more likely explanation is that bottlenose dolphins are being recorded instead on T-PODs within the settings for the harbour porpoise. Although T-PODs are set up to record low frequency off axis clicks within the bottlenose dolphin channel on the T-POD, bottlenose dolphins also produce on-axis clicks with a high frequency component of 100kHz or higher. On the other hand, a previous study found that only 0.6-0.8% of detections of harbour porpoise and bottlenose dolphin occurred at these sites within the same minute (Simon *et al.*, 2010). Nevertheless, some of the bottlenose dolphin sightings around T-PODs occurred in the absence of acoustic detections on the dolphin settings of the T-POD, but did occur within the same hour on the porpoise settings. Further research should be undertaken to determine whether it is the acoustic or the visual data that is more representative of harbour porpoise presence relative to other sites.

4.2 Visual acoustic comparison across sites with increased search areas used around T-PODs

When data across all years (2005 to 2008) was used, for the bottlenose dolphin, high correspondence with the acoustic data was found at even 2500m range from the T-POD when acoustic-visual comparisons were compared across sites. This is well beyond the detection capabilities of a T-POD for bottlenose dolphins (under normal conditions without sound channels) (Reyes Zamudio, 2005; Philpott *et al.*, 2007; Elliott *et al.*, 2011). High correspondence at areas that exceeded the detection capability of T-PODs for the harbour porpoise was also found (Villadsgaard *et al.*, 2007; Kyhn *et al.*, 2012; De Ruiter *et al.*, 2010). This suggests that trends in occurrence of the two species from acoustic-visual data across sites can be determined using areas that are larger than the detection capabilities of a T-POD. However, variable changes in the encounter rate (numbers of animals corrected by effort within a defined area) at sites were found to occur as the area around T-PODs was increased. For example, at Cardigan estuary, a site characterised by low acoustic detections, an increase in area around the site resulted in an increase in the visual sightings (total numbers per km travelled) that would have been out of the detection range of the T-POD. Thus, using larger areas to derive the visual data may result in a reduction in accuracy when comparisons are made with the acoustic data across sites, since the visual data collected becomes progressively less representative of the visual data within the detection radius of the T-POD. The changes in the visual data as the area around the T-PODs increased was sufficient enough to alter and reduce correlations with the acoustic data for the harbour porpoise when all years were combined, and for both species of cetaceans when correlations were carried out across sites or by year (2005 to 2008).

The limitations of the dataset were revealed when acoustic visual comparisons were made for the harbour porpoise using smaller areas around the T-POD, resulting in low correlations with visual data for larger areas, and with the acoustic data. This was particularly apparent when grid cells with a 650m radius were around sites. Since the harbour porpoise is distributed more evenly around the inshore Cardigan Bay SAC compared with the bottlenose dolphin (Pesante *et al.*, 2008), fewer visual sightings data were available, and so in order to make visual-acoustic comparisons, areas that were larger than the detection radius of the T-POD were used. As the effective T-POD detection radius for the harbour porpoise may only be between 22 and 104m (Kyhn *et al.*, 2012), the acoustic-visual comparisons that were made up to 1650m away, would not have been directly comparable with the T-POD data.

4.3 Best explanation for acoustic data: The number of sightings or the total number of animals surrounding the areas of T-PODs

In this study, the comparison of the total number of bottlenose dolphins inhabiting a defined area around T-PODs was found to best describe the number of acoustic detections that were recorded within the area, than the number of sightings. At the majority of the sites, the number of sightings and total number of animals increased linearly. This seems to show that at the majority of sites, group size should not be effecting the comparisons that are being made. The exceptions were two sites: New Quay Fish and New Quay Reef. At these sites, the number of bottlenose dolphin sightings was higher than the total number of bottlenose dolphins in comparison to the other sites, suggesting that group size in the area was lower. This appears to be consistent with a previous study that found the number of sightings in New Quay Harbour to be high but the group size to be relatively low compared with other localities such as Mwnt, Ynys Lochtyn and Aberporth (Pierpoint *et al*., 2009).

As T-PODs do not have the ability to determine the number of animals that contribute to recordings on a T-POD, it is important to consider how group size may be affecting the number of detections over the years, when compared to other sites. Group size has been shown to affect the rate of the production of echolocation within a locality. In the study by Jones and Sayigh (2002), echolocation production increased at the majority of sites as group size increased from 1-2 animals, to 3-5, 6-10, 11-20 and >20 animals. On the other hand, in a study carried out by Nowacek (2005), lone foraging bottlenose dolphins were found to produce significantly higher rates of echolocation compared with foraging groups of bottlenose dolphins. Since bottlenose dolphins in inshore Cardigan Bay SAC are generally small, with a mean group size varying between 1.7 and 2.7 animals across all sites, with 44% of sightings consisting of single animals between 2004 and 2007 (Pierpoint *et al*., 2009), the effect of group size on echolocation rate is probably less pronounced than in areas where cooperative foraging occurs. Therefore, the total number of animals within the area appears to best describe the relationship with acoustic detections as it disregards the effect of group size, which could not explain the relationship any better across the Cardigan Bay SAC, on the number of detection positive minutes that were recorded at particular sites.

A close linear relationship was found between the number of porpoise sightings and the total number of porpoise individuals across sites within the Cardigan Bay SAC. This demonstrates that either the number of sightings or the total number of individuals can be used to explain the porpoise acoustic data across sites. This is because harbour porpoise are generally found in much smaller groups than bottlenose dolphins, occurring mainly singly or in small groups (Evans, 1987).

4.4 Comparison of T-POD acoustic detections with abundance estimates for the entire Cardigan Bay SAC

The absolute abundance of the harbour porpoise within the Cardigan Bay SAC appeared to follow a similar trend to the visual data (as determined across inshore Cardigan Bay as with the total number of animals in areas surrounding T-PODs), and the acoustic T-POD data across sites. All three sources of data corresponded well and recorded that the harbour porpoise increased in the year 2007. However as only three years of data was available for comparison, the amount of data is too low to infer whether T-PODs are really mirroring the changes in the absolute abundance of the harbour porpoise for the entire Cardigan Bay SAC. A greater data set over time is required to determine whether this is the case.

Since the harbour porpoise is more evenly distributed across the Cardigan Bay SAC (Pesante *et al.*, 2008), it may be that this species is a more appropriate species for comparisons to be made with absolute abundance estimates for the entire Cardigan Bay SAC. The yearly increase or decrease in numbers of harbour porpoise within the inshore region of the SAC, seem to be occurring throughout or in some areas of the Cardigan Bay SAC, resulting in the correspondence of the encounter rate and acoustic data from the inshore region of the SAC with the absolute abundance estimate. In addition, absolute abundance estimates derived from line transect survey methods may be relatively accurate estimate of abundance for the harbour porpoise within the Cardigan Bay SAC for comparisons to be made to. This is because the harbour porpoise is present across the SAC in large numbers which improves the estimation of the detection probability, and the fact that harbour porpoise detection is not usually affected by its behaviour (*Pesante et al.,* 2008).

The absolute abundance estimate for bottlenose dolphins did not correspond well with either the visual data (total numbers of animals per km travelled in areas with 1300m radii around T-PODs) or the annual acoustic data derived across T-PODs. The absolute abundance estimate in 2006 was much higher than the total number of animals found around T-PODs, and for the acoustic T-POD data for that year. However, the bottlenose dolphin has a clumped distribution within the inshore waters of the Cardigan Bay SAC and so absolute line transect abundance estimates, may result in an underestimation of abundance due to the methodology used. Furthermore, the line transect survey absolute abundance estimate for the bottlenose dolphin in 2007 was not believed to be an accurate measure of abundance as a result of the bad weather experienced during the year which resulted in a lower number of sightings (*Pesante et al.,* 2008). However, the acoustic T-POD data and visual encounter rate that were derived around T-PODs did correspond better and both showed a decrease from higher estimates in 2005 within the inshore Cardigan Bay SAC. This shows that the numbers of bottlenose dolphin within the inshore Cardigan Bay SAC, where correlations were found to occur across sites, don't seem to be reflected in the absolute abundance estimates as determined by the line transect survey methods.

The absolute abundance estimate as derived from photo ID for the bottlenose dolphin potentially provides a better estimate of abundance for the bottlenose dolphin within the Cardigan Bay SAC (*Pesante et al.,* 2008). However no positive correlation was found between the acoustic data and the photo ID absolute abundance estimates for the bottlenose dolphin within the inshore Cardigan Bay SAC. Ideally more data from both line transect surveys and photo ID studies should be carried out and compared with data derived across T-PODs, because using three estimates is probably not enough to elucidate a trend, particularly with variability due to the low sightings of bottlenose dolphins in some years.

Given that recording was not consistent at all sites throughout the time period 2005-10 only T-PODs that were recording across all three years 2005-07 were included in the comparisons, and this inevitably reduced the size of the dataset. It would have introduced bias to include the T-POD at Aberporth offshore in yearly comparisons, as the T-POD was recording high numbers of detection positive minutes for the two years that it was recording, which could have had a large influence on the trend in detection positive minutes. Therefore, only a small portion of the area within the Cardigan Bay SAC was being monitored by the T-PODs over the longer term, and caution should be applied when extrapolating this to the entire Cardigan Bay SAC. Kyhn *et al.* (2012) suggested that extrapolation to areas outside of the range of the T-POD should not be made, and that robust survey design utilising systematically placed T-PODs should be carried out, which could then be compared with absolute abundance estimates.

4.5 Conclusion

Overall T-PODs that were placed within inshore Cardigan Bay followed the visual data collected around T-PODs (in terms of total numbers of animals per km travelled) for both species: the bottlenose dolphin and the harbour porpoise. Furthermore, the relationship between the visual data (total number per km travelled) and the acoustic T-POD data were generally found to correspond better if smaller areas around T-PODs were used, which fits well with the current knowledge on the limited detection range of T-PODs (Philpott *et al.,* 2007; Elliott *et al.,* 2011, Kyhn *et al.,* 2012) and that the encounter rate changes as the area increases radially around T-PODs. This is useful as it shows that the T-PODs are working well and that determining density estimates for both species by acoustic means is a possibility, as has already been shown for the harbour porpoise (Kyhn *et al.,* 2012). Furthermore, the acoustic detections on T-PODs in inshore Cardigan Bay SAC may be able to reflect what is going on in the whole Cardigan Bay SAC, as shown for the harbour porpoise, although this is very difficult to determine over a short three year timescale and inaccuracies may have been present in the absolute abundance estimates and/or the acoustic data that was available.

More effort in terms of the time spent monitoring a site with passive acoustic monitors and by visual survey methods within a year would be beneficial, as the relative occurrence of both the harbour porpoise and bottlenose dolphin were found to vary by month. This will hopefully be made easier in future studies with the introduction of C-PODs, the newer version of the T-POD, which are able to monitor for longer periods of time (chelonia.co.uk), and will help reduce gaps in datasets. Additionally more visual survey effort, particularly to the south of the Cardigan Bay SAC would have improved the accuracy of both the encounter rates and absolute abundance estimates for the SAC, although this would have required a lot more financial input to achieve. Consideration was given to correcting the data by month within each year, but this would have reduced the datasets too much, and may not have been entirely effective as species occurrence by month appears to vary differently between years. More extensive time series data over the years would have also been beneficial for acoustic and visual comparisons, particularly for comparisons with the absolute abundance estimates. However, due to the costs involved with visual surveys this was not possible, and absolute abundance estimates were limited to the years 2005-07 (Pesante *et al.,* 2008).

The visual survey data could have benefitted from being plotted more accurately for encounter rate calculations, but as required data was limited in 2005 this wasn't possible and so boat coordinates were used. However, for all hourly comparisons that were carried out, the location of the cetacean from the boat was calculated. Even if all sightings data could have been used plotted at distances and angles from the boat, there may still have been inaccuracies due to problems associated with measuring distance to cetaceans at sea (Baird and Burkhart, 2000; Williams et al., 2007; Thomas *et al.,* 2010). However, the training received at Sea Watch foundation would have helped to reduce any bias in distance estimation (Baird and Burkhart, 2000; Thomas *et al.,* 2010) and perhaps using laser range finders in future efforts would further reduce this problem (Baird and Burkhart, 2000). Nevertheless, although biases may have been more prevalent when smaller circles around T-PODs were used to calculate encounter rates, progressively decreasing acoustic-visual correlations were found across sites as the area increased radially from the T-POD, which seems to suggest a decrease in correspondence between the visual and acoustic data with distance from the T-POD.

As the number of sightings for the harbour porpoise was relatively low within the inshore region of the Cardigan Bay SAC, it was encouraging to see how well the acoustic and visual data corresponded for this species. As harbour porpoise and bottlenose dolphins may both alter their behaviour in response to boats (Polachectk and Thorpe, 1990; Norwacek *et al.,* 2001), and they both spend a significant amount of time underwater, it could be expected that these factors may have affected the relationships between the visual survey and acoustic data. Additionally, sightings rates may have been affected by factors including the sea state, where the number of sightings of harbour porpoise was found to halve with an increase in sea state to sea state 2 (Baines and Evans, 2012). If these factors did affect the visual data, there is no way of knowing to what extent, although boat traffic may have reduced echolocation rates of bottlenose dolphin in New Quay Reef.

It would be beneficial to carry out further research on the reasons for finding lower acoustic detections in comparison to the visual sightings data at these Gilfachreda and New Quay Reef. As little information is known about the distribution of fish species within the Cardigan Bay SAC (Peasante *et al.,* 2008), it would be useful to determine what fish species occur in the areas of Gilfachreda, New Quay Reef and New Quay Fish, and whether this could influence foraging strategy at these sites. Further examination of the differences in boat occurrence between the three sites would also be beneficial, as this may also have contributed to the low number of detection positive minutes that were being recorded at Gilfachreda and New Quay Reef.

Additionally further study on the higher detection rates of the harbour porpoise on T-PODs at New Quay Fish and Ynys Lochtyn would also be beneficial. It may be that detection positive minutes are higher due to an increased night time presence at the locations (Pesante *et al.,* 2008), although a study carried out by Alford (2006) didn't find this to be the case for acoustic data that was analysed in 2005.

In this study detection positive minutes were compared to the total number of animals corrected for effort found within areas around T-PODs. However a limitation of acoustic technology is that the T-PODs aren't able to distinguish between whether a single vocal cetacean or whether a group of vocalising cetaceans contributed to a recording on a T-POD. Overall the detections that are recorded on a T-POD are more likely to be representative of the numbers of the harbour porpoise due to its low group size (Evans *et al.,* 2008) and relatively high and constant echolocation rate (Akamatsu *et al.,* 2007; Verfuβ *et al.,* 2005; Verfuβ *et al.,* 2009). This is why the density of the harbour porpoise has been determined by acoustic means, and hasn't been yet for the bottlenose dolphin (Kyhn *et al.,* 2012).

The continued use of both acoustic techniques and visual survey methods is therefore beneficial for monitoring cetaceans, as both methods clearly have advantages and disadvantages. Acoustic monitoring alone won't reveal trends in population birth rates, survival rates and social structure, yet visual methods won't be able to easily reveal fine scale temporal variations in the relative occurrence of a species. It is therefore ideal to continue to research and develop both acoustic technology and visual survey methodology as a means of monitoring cetacean populations, so as to maintain habitats that are important for their lifecycle, such as in the Cardigan Bay SAC in Wales.

Appendix

Site	2005								2006						
	4	5	6	7	8	9	10		4	5	6	7	8	9	10
CA	4	31	24	30	29	25	28		18			16	29	12	
CH_in			2	32	26	25	28		19	22	30	25	29	26	4
CH_out				16		6	25		18	6	30	13		26	12
CA_est															
GIL															
AB_in		30	26	30	22	28	25		25	28	22	28	31	23	28
AB_out		30	7	23	29	28	25		25	28	22	28	31	28	28
MW_in	4	31	17	11	26	25	28		20	22	30	25	29		10
MW_out	4	31	24	28	26	25	28		20	22	30	25	29	26	27
NQ_fish				23	18	27	27		28	30	23	28	31	28	29
NQ_reef			7	30	28	27	27		28	2	23	28	31	29	29
YN	3	31	7	20	29	28	27			24	22	28	31	27	28

Site	2007								2008						
	4	5	6	7	8	9	10		4	5	6	7	8	9	10
CA	17	30	30	13	31	30	4		8	31	30	29	31	30	31
CH_in	15	31	30	12											
CH_out	17	31	16	31	31	14									
CA_est				9	31	30	29		8	31	20			25	
GIL				1	31	30	30		30	31	5				
AB_in									30	9		10	2		
AB_out															
MW_in	16	31	26						8	31	30	26	10	1	5
MW_out															
NQ_fish	25	28	11	31	31	27	31		30	28	5				
NQ_reef	25	31	26	31	31	27	31		30	31	28	30	31	26	21
YN	25	31	26	31	25	18	31		23	31	30	29	19		13

Appendix: The number of recording days per month for each T-POD at sites from 2005 to 2008. Months are labelled from 4 (April) to 10 (October).

References

Alford, L. (2006). *Bottlenose dolphin and harbour porpoise presence and foraging patterns in relation to tidal cycle, height of tide, lunar activity and strength of current*. MSc Thesis, University of Wales Bangor. 76pp.

Akamatsu, T., Teilmann, J., Miller, L.A., Tougaard, J., Dietz, R., and Wang, D. (2007). Comparison of echolocation behaviour between coastal and riverine porpoises. *Deep Sea Research Part II: Topical studies in Oceanography*, 54, 290-297.

Arcangeli, A.A., and Crosti, R. (2009). The short-term impact of dolphin-watching on the behavior of bottlenose dolphins (Tursiops truncates) in western Australia. *Journal of Marine Animals and their Ecology,* 2, 3-9.

Au, W.W.L. (1993). *The sonar of dolphins*. 1st edition. Springer-Verlag, Berlin, Heidelberg, and New York.

Au, W.W.L., Kastelein, R.A., Rippe, T., and Schooneman, N.M. (1999). Transmission beam pattern and echolocation signals of a harbour porpoise (*Phocoena phocoena*). *Journal of the Acoustical Society of America*, 106, 3699-3705.

Au, W.W.L., Branstetter, B., Moore, P.W., and Finneran, J.J. (2012). The biosonar field around an Atlantic bottlenose dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America*, 131, 569-576.

Bailey, H., Clay, G., Coates, E.A., Lusseau, D., Senior, B., and Thompson, P.M. (2009). Using T-PODs to assess variations in the occurrence of coastal bottlenose dolphins and harbour porpoises. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 20, 150-158.

Baird, R.W., and Burkhart, S.M. (2000). *Bias and variability in distance estimation on the water: implications for the management of whale watching.* IWC Meeting document

SC/52/WW1 presented to IWC Scientific Committee in Adelaide, Australia. Available from www.iwcoffice.org

Barnes, C. (2011). *Social structure of Bottlenose dolphin (Tursiops truncates) in Cardigan Bay, Wales.* BSc Thesis, University of Wales, Bangor. 46pp

Buckland, S.T., Anderson, D.R., Burnham, K., Laake, J., Borchers, D., and Thomas, L. (2001). *Introduction to distance sampling: Estimating abundance of biological populations.* Academic Press, London.

Carstensen, J., Henriksen, O. D., and Teilmann, J. (2006). Impacts on harbour porpoises from offshore wind farm construction: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs) *Mar. Ecol. Prog. Ser.,* 321, 295–308.

Christiansen, F., Lusseau, D., Syensland., E. and Berggren, P. (2010). Effects of tourist boats on the behavior of Indo-Pacific bottlenose dolphins off the south coast of Zanzibar. *Endangered Species Research*, 11 (1): 91-99.

CCW (2009). Cardigan Bay European Marine Site: Advice provided by the Countryside Council for Wales in fulfillment of regulation 33 of the conservation (natural habitats) regulations 1994.

Clausen, K.T., Wahlberg, M., Beedholm, K., Deruiter, S., and Madsen, P.T. (2011). Click communication in harbour porpoises *Phocoena phocoena*. *Bioacoustics*, 20, 1-28.

Connor, R.C., Wells, R.S., Mann, J. & Read, A.J. (2000). The bottlenose dolphin: Social Relationship in a Fission-Fusion Society. Pp. 91-126. In: *Cetacean Societies: Field studies of dolphins and whales* (Editors J. Mann, R.C. Connor, P.L. Tyack and H. Whitehead). The University of Chicago Press, Chicago and London.

Cranford, T.W., Elsberry, W.R., Van Bonn, W.G., Jeffress, J.A., Chaplin, M.S., and Blackwood, D.J. (2011). Observation and analysis of sonar signal generation in the bottlenose dolphin (*Tursiops truncatus*): Evidence for two sonar sources. *Journal of Experimental Marine Biology and Ecology*, 407, 81-96.

Denton, J. (2012). *Bottlenose dolphin (Tursiops truncates) abundance in Cardigan Bay, Wales, in relation to shellfish factory discards.* BSc thesis, University of Swansea. 45pp.

DeRuiter, S.L., Hansen, M., Koopman, H.N., Westgate, A.J., Tyack, P.L. and Madsen, P.T. (2010). Propagation of narrow-band-high-frequency clicks: Measured and modeled transmission loss of porpoise-like clicks in porpoise habitats. The Journal of the Acoustical Society of America, 127, 560.

Dos Santos, M.E. and Almada, V.C. (2004). A case for passive sonar: Analysis of click train production patterns by bottlenose dolphins in a turbid estuary. Echolocation in Bats and Dolphins. The University of Chicago Press, Chicago, , 400-403.

Duggan, Z.P., Koopman, H.N. and Budge, S.M. (2009). Distribution and development of the highly specialized lipids in the sound reception systems of dolphins. Journal of Comparative Physiology B: Biochemical, Systemic, and E

Elliott, R.G., Dawson, S.M. and Rayment, W.J. (2011). Optimizing T-pod settings and testing range of detection for bottlenose dolphins in Doubtful Sound, New Zealand. *Journal of the Marine Biological Association of the United Kingdom*, 1, 1-7.

Englund, A., Coleman, M. & Collins, C. (2006). *Marine mammal monitoring in Broadhaven Bay: June–September 2005. Project report to RSKENSR Group Plc. Coastal and Marine Resources Centre, University College Cork, Cork 40pp*

Evans, W. (1973). Echolocation by marine delphinids and one species of fresh□water dolphin. *Journal of the Acoustical Society of America*, 54, 191-199.

Evans, P. G. H. *(*1987*).* The natural history of whale and dolphins*.* Christopher Helm, London.

Evans, P.G.H., Lockyer, C.H., Smeenk, C., Addink, M., and Read, A.J. (2008) Harbour Porpoise *Phocoena phocoena*. Pp.704-709. In: *Mammals of the British Isles*. (Eds. S. Harris and D.W. Yalden). Handbook. 4th Edition. The Mammal Society, Southampton. 800pp.

Evans, P.G.H. and Hammond, P.S. (2004) Monitoring Cetaceans in European Waters
Mammal Review, 34, 131-156.

Evans, P.G.H. and Hintner, K. (2010) *A Review of the Direct and Indirect Impacts of Fishing Activities on Marine Mammals in Welsh Waters*. CCW Policy Research Report No. 104. 160pp.

Fisher, F., and Simmons, V. (1977). Sound absorption in sea water. *Journal of the Acoustical Society of America*, 62, 558.

Gilles, A., Scheidat, M. & Siebert, U. (2009). *Seasonal distribution of harbour porpoises and possible interference of offshore wind farms in the German North Sea.* Marine Ecology Progress Series, 383, 295-307.

Herzing, D.L. (2004). Social and Non-Social uses of Echolocation in Free-Ranging *Stenella frontalis* and *Tursiops truncatus*. Pp. 404-409. In: *Advances in the Study of Echolocation in Bats and Dolphins*. *Springer-Verlag Press.*

Houser, D., Helweg, D., and Moore, P. (1999). Classification of dolphin echolocation clicks by energy and frequency distributions. *Journal of the Acoustical Society of America*, 106, 1579-1585.

Huggenberger, S., Rauschmann, M. A., Vogl, T. J., and Oelschläger, H. H.A. (2009). Functional morphology of the nasal complex in the harbour porpoise (*Phocoena phocoena* L.). *Anatomical Record*, 292, 902–920.

Jones, G.J., and Sayigh, L.S. (2002). Geographic variation in rates of vocal production of free ranging bottlenose dolphins. *Marine Mammal Science*, 18, 374-393.

Johnson, M., Hickmott, L.S., Aguilar Soto, N., and Madsen, P.T. (2008). Echolocation behavior adapted to prey in foraging Blainville's beaked whale (*Mesoplodon densirostris*). *Proc. R. Soc. B,* 275, 133-139.

Kiszka, J., Macleod, K., Van Canneyt, O., Walker, D., and Ridoux, V. (2007). Distribution, encounter rates, and habitat characteristics of toothed cetaceans in the Bay of Biscay and adjacent waters from platform-of-opportunity data. *ICES Journal of Marine Science*, 64, 1033-1043.

Koblitz, J.C., Wahlberg, M., Stilz, P., Madsen, P.T., Beedholm, K., and Schnitzler, H.U. (2012). Asymmetry and dynamics of a narrow sonar beam in an echolocating harbour porpoise. *Journal of the Acoustical Society of America*, 131, 2315-2324.

Kyhn, L.A., Tougaard, J., Thomas, L., Duve, L.R., Stenback, J., and Amundin, M. (2012). From echolocation clicks to animal density: Acoustic sampling of harbour porpoises with static dataloggers. *Journal of the Acoustical Society of America*, 131, 550-560.

Lemon, M., Lynch, T.P., Cato, D.H., and Harcourt, R.G. (2006). Response of travelling bottlenose dolphins (*Tursiops aduncus*) to experimental approaches by a powerboat in Jervis Bay, New South Wales, Australia. *Biological Conservation*, 127 (4), 363-372.

Lewis, T., Gillespie, D., Lacey, C., Matthews, J., Danbolt, M., and Leaper, R. (2007). Sperm whale abundance estimates from acoustic surveys of the Ionian Sea and Straits of Sicily in 2003. *Journal of the Marine Biological Association of the United Kingdom*, 87, 353-357.

Lindberg, D.R. and Pyenson, N.D. (2007). Things that go bump in the night: Evolutionary interactions between cephalopods and cetaceans in the Tertiary. *Lethaia*, 40, 335-343.

Litchfield, C., Karol, R., and Greenberg, A. (1973). Compositional topography of melon lipids in the Atlantic bottlenose dolphin *Tursiops truncatus*: Implications for echolocation. *Marine Biology*, 23, 165-169.

Madsen, P.T., Wisniewska, D., and Beedholm, K. (2010) Single source sound production and dynamic beam formation in echolocating harbour porpoises (*Phocoena phocoena*). *Journal of Experimental Biology* 213:. 3105-3110.

Magileviciute, E., Pesante, G. and Evans, P.G.H. (2007). *Social networks of bottlenose dolphins in Cardigan Bay, Wales*. Poster at the 21st Annual Conference of the European Cetacean Society, San Sebastian, Spain, 22-25 April 2007.

Marques, T.A., Thomas, L., Ward, J., DiMarzio, N., and Tyack, P.L. (2009). Estimating cetacean population density using fixed passive acoustic sensors: An example with Blainville's beaked whales. *Journal of the Acoustical Society of America*, 125, 1982-1994.

Marques, T.A., Munger, L., Thomas, L., Wiggins, S., and Hildebrand, J.A. (2011). Estimating North Pacific Right Whale *Eubalaena japonica* density using passive acoustic cue counting. *Endangered Species Research*, 13, 163-172.

Möller, L.M., and Beheregaray, L.B. (2001). Coastal bottlenose dolphins from Southeastern Australia are *Tursiops aduncus* according to sequences of the mitochondrial DNA control region. Marine Mammal Science, 17, 249-263.

Nowacek, S.M., Wells, R.S., and Solow, A.R. (2001). Short term effects of boat traffic on bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Marine Mammal Science,* 17 (4): 673-688

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

Nuuttila, H., Simon, M., Alford, L., and Evans, P.G.H. (2007). Seasonal variations in bottlenose dolphin and harbour porpoise habitat use within Cardigan Bay SAC in relation to time of day and tidal cycle from T-POD recordings. In: Abstracts, 21st Annual Conference of the European Cetacean Society, San Sebastian, Spain, 22-25 April, 2007.

Nuuttila, H., Meier, R. Cunningham, E, Turner, J and Hiddink, L. (2012). Investigating factors affecting C-POD detection probability of bottlenose dolphin. In: Abstracts, 26th Annual Conference of the European Cetacean Society, Galway, Ireland, March 2012

Pesante, G., Evans, P.G.H., Baines, M.E., and McMath, M. (2008). *Abundance and Life History Parameters of Bottlenose Dolphin in Cardigan Bay: Monitoring 2005-2007*. CCW Marine Monitoring Report No: 61, 1-75.

Philpott, E., Englund, A., Ingram, S., and Rogan, E. (2007). Using T-PODs to investigate the echolocation of coastal bottlenose dolphins. *Journal of the Marine Biological Association of the United Kingdom*, 87, 11-17.

Pierpoint, C., Allan, L., Arnold, H., Evans, P., Perry, S., and Wilberforce, L. (2009). Monitoring important coastal sites for bottlenose dolphin in Cardigan Bay, UK. *Journal of the Marine Biological Association of the United Kingdom*, 89, 1033-1043.

Polachectk, L. and Thorpe (1990). The swimming direction of harbor porpoise in relationship to a survey vessel. Report of the International Whaling Commission 40:463-470.

Reyes-Zamudio, M. (2005). *Acoustic behaviour of bottlenose dolphins (Tursiops truncatus): a comparison between T-POD and visual surveys*. MSc Thesis, University of Wales, Bangor. 117pp

Schulkin, M., and Marsh, H. (1962). Sound absorption in sea water. *Journal of the Acoustical Society of America*, 34, 864-865.

Sekiguchi, K. (1995). Occurrence, behaviour and feeding habits of harbour porpoises (*Phocoena phocoena*) at Pajaro Dunes, Monterey Bay, California. *Aquatic Mammals*, 21, 91-103.

Shane S. (1990) Comparison of bottlenose dolphin behaviour in Texas and Florida, with a critique of methods for studying dolphin behaviour. In Leatherwood S. and Reeves R. (eds) The bottlenose dolphin. San Diego, CA: Academic Press, pp. 541–558.

Simard, P., Hibbard, A.L., McCallister, K.A., Frankel, A.S., Zeddies, D.G., Sisson, G.M. (2010). Depth dependent variation of the echolocation pulse rate of bottlenose dolphins (*Tursiops truncatus*). *Journal of the Acoustical Society of America*, 127, 568-578.

Simon, M., Nuuttila, H., Reyes-Zamudio, M.M., Ugarte, F., Verfuß, U. and Evans, P.G.H. (2010). Passive acoustic monitoring of bottlenose dolphin and harbour porpoise, in Cardigan Bay, Wales, with implications for habitat use and partitioning. *Journal of the Marine Biological Association of the United Kingdom*, 90, 1539-1545.

Starkhammar, J., Moore, P.W., Talmadge, L., and Houser, D.S. (2011). Frequency-dependent variation in the two-dimensional beam pattern of an echolocating dolphin. *Biology Letters*, 7, 836-839.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R.B., Marques, T.A. and Burnham, K.P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. *The Journal of Applied Ecology*, 47 (1): 5-14.

Todd, V.L.G., Pearse, W.D., Tregenza, N.C., Lepper, P.A., and Todd, I.B. (2009). Diel echolocation activity of harbour porpoises (*Phocoena phocoena*) around North Sea offshore gas installations. *ICES Journal of Marine Science*, 66, 734-745.

Tougaard, J., Carstensen, J., Teilmann, J., Bech, N.I., Skov, H. & Henriksen, O. (2005). *Effects of the Nysted Offshore wind farm on harbour porpoises.* Annual Status Report for the T-POD Monitoring Program.

Tougaard J., Carstensen, J., Wisz M.S., Teilmann, J., Bech, N.I., Skov, H. (2006). *Harbour porpoises on Horns Reef — effects of the Horns Reef wind farm.* Tech rep to Elsam Engineering A/S, National Environmental Research Institute, Roskilde

Urick, R.J. (1983). *Principles of Underwater Sound*. McGraw-Hill, New York. 423 pp.

Veneruso G. and Evans P.G.H. (2012) *Bottlenose dolphin and harbour porpoise monitoring in Cardigan Bay and Pen Llŷn a'r Sarnau Special Areas of Conservation.* CCW Monitoring Report No. 95. 65pp.

Verfuß, U.K., Miller, L.A. and Schnitzler, H.U. (2005). Spatial orientation in echolocating harbour porpoises (*Phocoena phocoena*). *Journal of Experimental Biology*, 208, 3385-3394.

Verfuß, U.K., Miller, L.A., Pilz, P.K.D. and Schnitzler, H.U. (2009). Echolocation by two foraging harbour porpoises (*Phocoena phocoena*). *Journal of Experimental Biology*, 212, 823-834.

Villadsgaard, A., Wahlberg, M., and Tougaard, J. (2007). Echolocation signals of wild harbour porpoises, *Phocoena phocoena*. *Journal of Experimental Biology*, 210, 56-64.

Wahlberg, M., Jensen, F.H., Aguilar Soto, N., Beedholm, K., Bejder, L., Oliveira, C., Rasmussen, M., Simon, M., Villadsgaard, A., and Madsen, P.T. (2011) Source parameters of echolocation clicks from wild bottlenose dolphins (*Tursiops aduncus* and *T. truncatus*). *Journal of the Acoustical Society of America*, 130(4): 2263-2274.

Wilson, B. (2008) Bottlenose dolphin *Tursiops truncates*. Pp. 709-715. In: *Mammals of the British Isles*. (Eds. S. Harris and D.W. Yalden). Handbook. 4th Edition. The Mammal Society, Southampton. 800pp.

Williams, R., Leaper, R., Zerbini., A.N., and Hammond, P.S. (2007). Methods for investigating measurement error in cetacean line-transect surveys. *Journal of the Marine Biological Association*, 87, 313-320.

Wursig, B., and Wursig, M. (1979). Behaviour and ecology of the bottlenose dolphin, *Tursiops truncatus*, in the South Atlantic. Fishery Bulletin, U.S. *Fisheries Bulletin*, 77(2), 399–412.