T-POD detection and acoustic behaviour of bottlenose dolphins (*Tursiops truncatus)* in Cardigan Bay SAC: a comparison between T-POD recordings and visual observations.

By

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In association with Sea Watch Foundation

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Dedicated to my parents,

Juan Reyes & Mercedes Zamudio

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Abstract

T-PODs are acoustic data loggers that detect echolocation clicks from harbour porpoise (*Phocoena phocoena*) and bottlenose dolphin (*Tursiops truncatus*). In the past, T-POD research has focused mainly on harbour porpoises. This study aimed to investigate T-POD performance when studying bottlenose dolphins by: measuring the detection range and detection probability in the presence of dolphins, and investigating the possibility of identifying particular dolphin behaviours from T-POD data. Two T-PODs were deployed for a period of six weeks (27th June - 8th August, 2005), at two different locations (Mwnt and New Quay, Cardigan Bay Special Area for Conservation, West Wales). At each location visual observations were undertaken using theodolites to calculate the distance between T-POD and dolphins, and to observe their behaviour. Comparisons between data obtained with T-PODs and simultaneous visual observations showed that the maximum T-POD detection range of bottlenose dolphin clicks was 650m. When the dolphins were present within this range, the T-PODs only detected them 11 percent of the time, and there was a significant negative correlation between distance and the T-POD detection probability, with a sharp decline in detection rate beyond 300 m. In addition, the detection probability varied with dolphin behaviour so that dolphins that were feeding had a significantly higher probability of being detected by the T-POD than dolphins that were travelling. T-POD data showed that dolphins that were feeding emitted click trains with significantly higher numbers of clicks, and had significantly lower inter-click intervals than travelling dolphins, suggesting that click trains with high numbers of clicks (< 30) and low minimum inter-click intervals (< 350 µs) signify feeding behaviour in T-POD data. This could be a first step to use T-PODs to provide information on any spatio-temporal patterns of feeding.

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Contents

List of tables

List of figures

List of equations

List of appendices

Contents

1: Introduction

1. <u>Introduction</u>

Passive acoustic techniques provide useful, powerful and non-invasive methods for cetacean surveillance. The T-POD is a self contained, submersible, acoustic data-logger that enables one to collect data from harbour porpoise and bottlenose dolphin echolocation activity in an automated, continuous and objective manner, independent of daylight or weather conditions. It has been demonstrated that the outcomes of acoustic surveys were improved when combined with visual surveying (Evans and Chappell, 1994; Gordon *et al.*, 1999; Baines, 2000; Ingram *et al.*, 2004). This study focused on bottlenose dolphins, and combined T-POD data with visual observations in order to achieve a better understanding and validation of T-POD performance.

1.1 Study area: Cardigan Bay SAC

Cardigan Bay is the largest bay in the British Isles. It extends from the Lleyn Peninsula and Bardsey Island in the north, to within 100 km of St David's Head in the south, encompassing an area of approximately 5,500 km^2, (Fig **1.1**). Bottlenose dolphins are seen all year round in Cardigan Bay, more frequently during the summer months and into autumn, reaching a peak in August (Baine*s*, 2000). The number of individuals seen increases within 15 km of the southern coast, between Borth and Cardigan. Areas such as Cardigan Island, Mwnt, Aberporth, Ynys Lochtyn and New Quay are of particular importance to the bottlenose dolphin population (Evans, 1995). For this reason, efforts have been made to protect these animals by managing this region of the Bay. These efforts began in 1992 when the site was established as a voluntary Ceredigion Marine Heritage Coast. In early 1996, the southern part of Cardigan Bay was submitted as a candidate Special Area of Conservation (cSAC). Finally, in December 2004, it was formally designated as Special Area of Conservation (SAC) under the European Habitats Directive (Ceredigion County Council *et al.*, 2001)

The Cardigan Bay SAC covers an area of approximately 1,000 km^2 (Ceredigion County Council *et al*., 2001). The landmark boundary runs along the coast at the mean high water mark from Aberath (52º 15' 4" N, 4º13' 50" W), Ceredigion, to the South of the Teifi Estuary (52º 4' 5" N, 4º 46' 10" W), Pembrokeshire. The seaward boundary is situated approximately 23 km offshore between two defined locations (52º 25' 6" N, 4º 23' 48" W, and 52º 13' 7" N, 5º 0' 15" W).

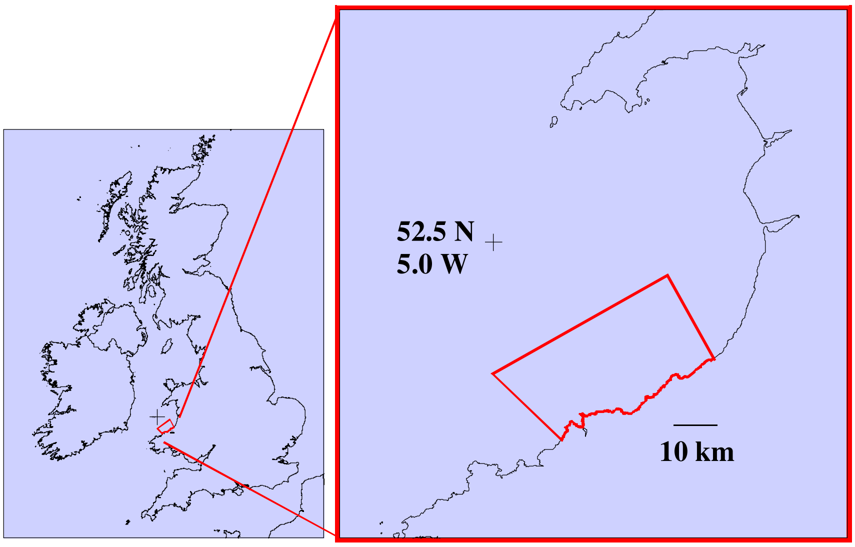


Figure 1.1. Diagram showing the study area: Cardigan Bay Special Area of Conservation, West Wales, UK.

1.2 T-POD

Delphinids are highly vocal animals having evolved a reliance on sound as their primary sense for communication, navigation, and foraging (e.g. Au *et al*, 1980; Au 1993; Au, 2003; Au and Herzing, 2002). For this reason, passive acoustic techniques, such as towed hydrophone arrays, statically moored hydrophones, sonobuoys, automated detection systems, Pop-Ups and T-PODs, all provide powerful, non invasive methods for recording the presence of dolphins. These techniques have the advantage over more traditionally visual surveys of being able to collect data continuously for extended periods of time, without relying on environmental parameters such as weather conditions and daylight. For example, the range of detection in visual dolphin surveys is affected by sea conditions (Baines *et al.*, 1999), and for abundance estimates usually ceases at Beaufort Sea States exceeding 3-4 (Hammond, 1990). There is a variety of equipment that can be used to collect acoustic data. The T-POD is a self contained, submersible, acoustic data-logger that detects clicks. The device was originally called a "POD" or Porpoise Detector (Baines *et al.*, 1999; Tregenza and Northridge, 1999), and it was developed partly to monitor the effectiveness of acoustic alarms for reducing porpoise by-catch by commercial fishing activities (Tregenza & Northridge 1999). A later version, the T-POD, (Tursiops and Porpoise Detector) was designed to detect bottlenose dolphins (*Turiops truncatus*) as well as porpoises (*Phocoena phocoena*). It has been reported that T-PODs also detect Risso's dolphins (*Grampus griseus*) (Pierpoint *et al.*, 2002), although the immunity of these detections from false triggers caused by other sources of noise was not tested.

T-PODs have been used in many coastal studies of harbour porpoises. These studies focused on feeding behaviour (Verfuss *et al*., 2002), habitat use (Kilian *et al*., 2003; Fisher and Tregenza, 2003), behavioural effects in relation to acoustic alarms (e.g. Cox *et al*., 2001; Bystedt *et al*., 2002), and proposed wind turbine developments (Teilmann *et al*., 2002; Henriksen *et al*., 2003; and Koschinski *et al*., 2002). Ingram *et al*. (2004) have used T-PODs for studying bottlenose dolphins in coastal waters off Ireland. They compared T-POD data with visual observations and theodolite data in order to test, validate and improve T-POD performance. A combination of visual surveying with acoustic data has been carried out by Evans and Chappell (1994), Gordon et al (1999) and Baines (2000). These surveys, demonstrated how acoustic monitoring improved the detection rate for odontocetes when combined with visual observations.

In Cardigan Bay SAC, passive acoustic monitoring of harbour porpoise using PODs was carried out from 1999 to 2001. Since 2002 T-PODs have been used to monitor bottlenose dolphin as well. Ten T-PODs are currently deployed along the coast (Fig **1.2**), in order to monitor presence and movements within the SAC for both species. The use of T-PODs in Cardigan Bay SAC has also been useful to investigate temporal-spatial habitat partitioning between harbour porpoises and bottlenose dolphins (Simon *et al.*, in prep.), which may provide clues to understanding the increase of porpoise deaths caused by bottlenose dolphins within this area.

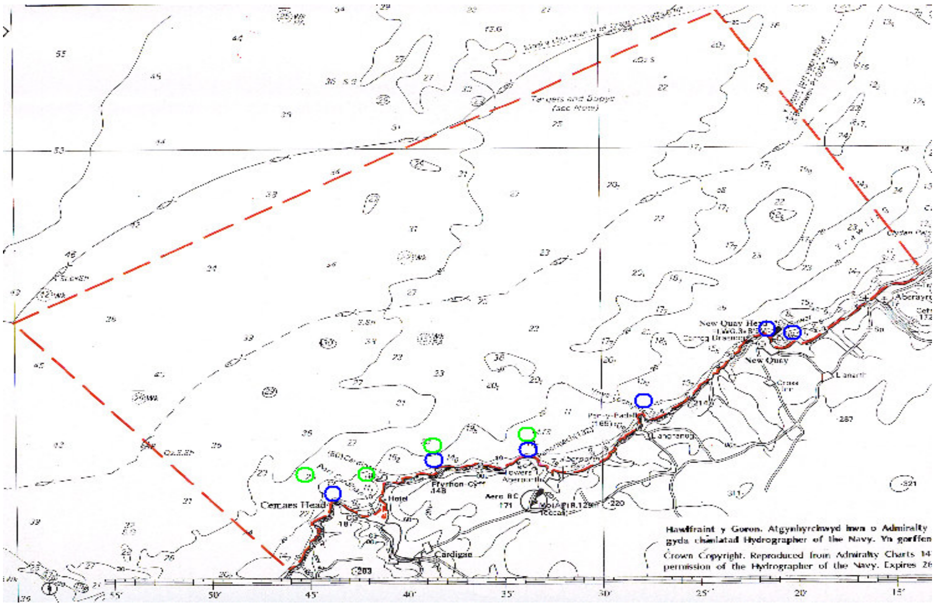


Figure 1.2. T-PODs location for the passive acoustic monitoring of harbour porpoises and bottlenose dolphins in Cardigan Bay SAC. T-PODs version 3 showed in green and version 4 in blue.

1.3 Visual observations with theodolite

Traditionally, the study of cetaceans has been dependent on visual observation methods of animals being sighted as they return to the surface to breathe. Visual observations allow for data collection on the animals' surface behaviour, abundance and distribution, and can be made from boat, plane or land. Boat-based studies mainly use photo-identification methods to study population structure, ranging patterns and social behaviour. Cardigan Bay has been the focus for shore-based studies on the coastal population of bottlenose dolphins for over 14 years (Bristow, 2004). Shore-based studies commonly involve a theodolite to track animal movement patterns. The use of theodolite is a completely non-invasive observation method, which does not alter the behaviour of the animals, thus being useful for collecting surface behavioural data of the dolphins. This method was first introduced by Payne (1972, cited in Wursig *et al.* 1991) for observing southern right whales, and the method was first described for dolphins by Wursig and Wursig (1979). A theodolite measures horizontal angles from an arbitrarily selected reference point ("zero"), and vertical angles relative to a gravity-referenced level vector (Davis *et al*, 1981; cited in Wursig *et al* 1991). The horizontal angles are used to calculate the distance (straight line) travelled by the dolphin between surfacings. The vertical angles are used to calculate the distance between the dolphins and the shore. Theodolite tracking of bottlenose dolphin has been used to study interactions between dolphins and boats (Acevedo, 1991), to describe movement patterns (Wursig & Wursig, 1979), and the effect of tide on spatio-temporal patterns (Mendes *et al.*, 2002). Theodolite tracking can also be used for purposes other than simply tracking movements. Denardo *et al.* (2001) used a theodolite to determine spatial relations between killer whales (*Orcinus* orca) in Norway. In the present study, theodolites were used to calculate the distances between bottlenose dolphins and a T-POD.

1.4 Bottlenose dolphin

The bottlenose dolphin is the archetypical dolphin, well known to the ancient Greeks and Romans because of its common nearshore presence throughout the Mediterranean Sea (Reeves *et al*, 2002). Nowadays it is probably the most characteristic of all delphinid species and the most common cetacean in captivity (Defran and Pryor, 1980). The bottlenose dolphin was first described by Montagu (1812), from a specimen caught in the River Dart in Devon, UK, which was later named *Tursiops* (Gervais, 1855). The current scientific name, *Tursiops truncatus*, derives from the Latin *Tursio* (dolphin), the Greek suffix -*ops* (appearance) and the Latin *trunco* (truncated).

The bottlenose dolphin has a wide head and body, a short stubby beak, a marked crease between the melon and the beak, long flippers, and a moderate tall, falcate dorsal fin. The colour pattern consists mostly of grey tones, sometimes brownish, with strong counter shading (dark dorsally and light, off white or pinkish, ventrally). There is considerable variability within the species. There are coastal (inshore) and pelagic (offshore) populations, which differ in gross morphology, haematology, cranial morphology, and parasite fauna (Hersh and Duffield, 1990; Van Waerbeek *et al*, 1990). The body length of the adults ranges between 2.2-4.1 metres, and the weight ranges between 150-650 kilograms (Reeves *et al*, 2002). The life span can be up to 50 years (Hohn *et al*, 1989), females reaching sexual maturity between nine and eleven years of age (Wells and Scott, 1999). Females produce a single offspring every 3-4 years, after a gestation that lasts about a year (Shroeder, 1990). Calves can be born at any season, but few are born in the colder winter months in temperate regions (Wells and Scott, 1999). They are not fully weaned until 18-20 months of age, and they may continue to associate with their mothers for several more years.

The bottlenose dolphin is a cosmopolitan species that occurs in oceans and peripheral seas at tropical and temperate latitudes (Shane, 1990). It occurs in a wide range of water temperatures; withstanding prolonged periods in hypo-saline (Caldwell and Caldwell, 1972), and hyper-saline (Smolker *et al*, 1992) habitats; and it also occurs in polluted waters such as Galveston Bay, Texas (Maze-Foley and Wursig, 2002). Around Britain and Ireland, three distinct resident populations have been described, one in the Moray Firth (Northeast Scotland), one in the Shannon estuary (western Ireland) and one in Cardigan Bay (West Wales), investigated in the present study (Lewis and Evans, 1993; Wilson, 1995; Ingram, 2000), although there are more transient populations elsewhere in Britain and Ireland. The population in Cardigan Bay was believed to be 'open' (Grellier *et al*, 1995; Evans *et al*, 2000), with resident dolphins throughout the year but also some transient individuals. Bottlenose dolphin movements are often related to depth (Wiley *et al*, 1994), tides (Irvine *et al*, 1981) and time of the day (Saayman *et al*, 1973), and those at New Quay were observed to move in correlation to tidal flow, when it was at its strongest (Gregory and Rowden, 2001). Weller and Wursig (2004) observed various degrees of movement patterns and site fidelity, leading to a mix of resident and transient animals.

Bottlenose dolphins form groups that vary greatly in size. Generally, inshore schools are smaller (2-15 individuals) than those offshore (tens or hundreds). The feeding and foraging behaviours can involve both individual and cooperative activities; Wursig and Wursig (1979) suggested that inshore searching for food involved mainly individuals, while deeper water prey searches relied on groups (greater than 15 individuals). However, it has been observed that inshore dolphins off the Bahamas coast forage individually on the seabed benthos (Rossbach and Herzing, 1997) as well as cooperatively through the water column (Rossbach, 1999). Bottlenose dolphins are known to use a wide range of feeding strategies (Leatherwood, 1975; Norris and Dohl, 1980; Wursig, 1986, cited in Rossbach, 1999; Bel'kovich *et al*. 1991), and they rely heavily on echolocation to locate and capture prey.

1.5 Bottlenose dolphin echolocation

Delphinid phonations have traditionally been classified into two structural types: narrow-band sounds referred to as whistles, and broadband clicks (burst-pulsed sounds and echolocation clicks). The whistles are long duration frequency modulated sounds used for interspecific communication, such as group cohesion (Smolker *et al.*, 1993; Janik and Slater, 1998). The clicks are short duration, broadband sounds used for echolocation (Au, 1993), and when produced with very short inter-click intervals, they are called burst-pulsed sounds. The function of burst-pulsed sounds is poorly known, but they are believed to have communicative value (Herzing, 2000).

The term echolocation was first applied by Griffin (1944, cited in Au, 1993) to describe animal navigation based on the transmission of ultrasonic pulses and the reception of echoes from objects. Nowadays, the terms sonar, echolocation and biosonar refer to the concept of object detection, localization, discrimination, recognition and orientation or navigation by animals emitting acoustic energy and receiving echoes.

Research on animal sonar began in the 1770s, when scientists observed the capability of blinded bats to avoid obstacles. The echolocation hypothesis was experimentally proven by Pierce and Griffin (1938, cited in Au, 1993). This discovery opened the door for the discovery of dolphin's sonar. Arthur (1947, cited in Au, 1993) was the first scientist to provide evidence that the Atlantic bottlenose dolphin may detect objects by using echolocation. Since early 1950s, several investigators began to give experimental evidence for this, although these experiments were not conclusive because their vision was not entirely eliminated. Norris *et al.* (1960, cited in Au, 1993) placed rubber suction cups over the eyes of a bottlenose dolphin, thus carrying out the first unequivocal demonstration of echolocation in dolphins. After this event, the echolocation characteristics of bottlenose dolphins have been widely investigated on captive individuals (Au, 1993).

Au (1993) observed that echolocation clicks from a stationary dolphin were emitted in a directional beam and signals measured off this major axis were distorted. Hence parameters such as distance and exact position of calling animals are usually unknown in the open ocean, and it is very difficult to obtain accurate measurements of free ranging, fast moving dolphins in the wild. The main difference when studying echolocation signals between captive and wild animals is that wild animals tend to produce clicks of higher amplitudes (Evans, 1973, cited in Au, 1993; Au *et al.* 1980; Au, 1993; Au, 2003).

Bottlenose dolphins are capable of producing a variety of tonal sounds and sonar pulses with peak frequencies between 30-135 kHz (Au, 1993). However, the mechanisms involved are not fully understood. The sonar signals are emitted in an adaptive way; with inter-click intervals, amplitude and waveform varying according to the environment and specific sonar tasks (Au, 1993). Echolocation pulses are very brief, normally around 50-200 µs in duration (Au, 2003), and usually comprise several clicks emitted in a train. The signals are emitted at intervals that are longer (20-40 microseconds) than the time required for a signal to reach the target and for the echo to come back. Peak frequencies have been reported on captive dolphins to vary from 115-121 kHz, and the bandwidths also have been observed to vary between 38 to 46 kHz. The amplitude of the signals is affected by target range and size, masking noise, and difficulty of the task. The source level of the signal can be relatively high (230 dB pp re 1 µPa at 1m) (Au, 1993).

1.6 Aims of the Study

T-POD studies have focused mainly on porpoises, and little research has been carried out on bottlenose dolphins using T-PODs. Ingram *et al*. (2004) studied bottlenose dolphins comparing T-POD data with visual observations, a methodology very useful to achieve a better understanding of T-POD capabilities. This study also compared T-POD recordings and visual observations in order to achieve the following aims:

- **To obtain a T-POD detection distance range for bottlenose dolphin clicks**. Knowing how far the T-PODs can detect bottlenose dolphin clicks is crucial when planning the deployment location of T-PODs in future research.
- **To obtain a T-POD detection probability for bottlenose dolphin clicks**. A better understanding of T-POD performance and reliability, and the possible variables affecting click detection would provide not only useful information for future research, but also may open the doors for further applications of T-PODs that have not yet been considered.
- **To investigate the potential of identifying particular bottlenose dolphin behaviour from T-POD data.** This would be an important first step towards using T-PODs for studies of habitat use and spatio-temporal behavioural studies.

2: Materials and Methods

T. Collier

2. Materials and methods

2.1 Study sites

The observations and recordings for this study were conducted at two specific sites within Cardigan Bay Special Area of Conservation (SAC), West Wales, UK: Mwnt and New Quay (Fig 2.1). In Mwnt (N 52º 08.250, W 004º 38.605) the fieldwork was carried out for a period of six weeks (28th June to 9th August, 2005). In New Quay (N 54º 13.605, W 004º 21.764) the field was carried out during ten days (31st July to 9th August, 2005). Off these locations a T-POD was deployed and land-based observations were carried out.

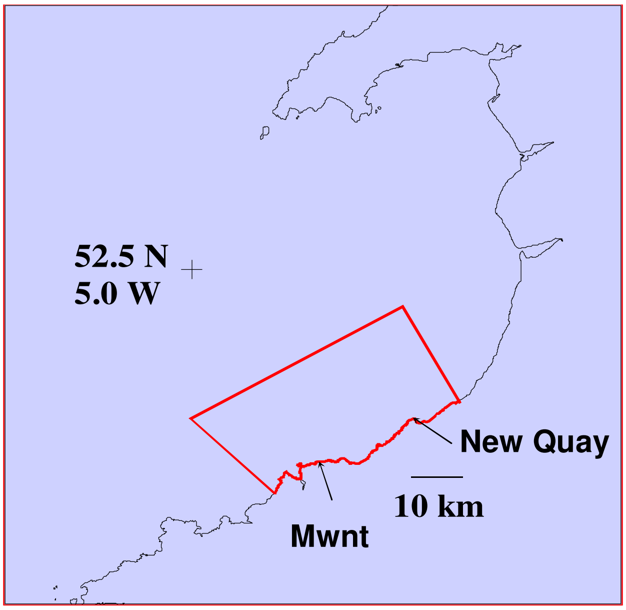


Figure 2.1. Field work locations, Mwnt and New Quay, within Cardigan Bay Special Area of Conservation (SAC) (illustrated by the red line), West Wales, UK.

2.2 T-POD recordings

2.2.1. T-POD's

A T-POD is a self-contained submersible electronic device that can be set to detect echolocation activity of harbour porpoises and bottlenose dolphins. The T-POD housing consists of a 50 to 70 cm PVC tube in which a ceramic transducer is embedded in the end of the cap (the hydrophone). An analogue click detector with digital timer and duration logger is also incorporated. One or two battery packs, each containing 6 alkaline D-cell batteries are used as source of power and the unit is sealed either with a bolt on or screw on lid (Fig **2.2**; Tregenza, 2001). This study used two T-POD units, one at each field site. The version 4, T-POD unit 421 was used at Mwnt (Figure **2.2**), and the version 3 T-POD unit 145 at New Quay.

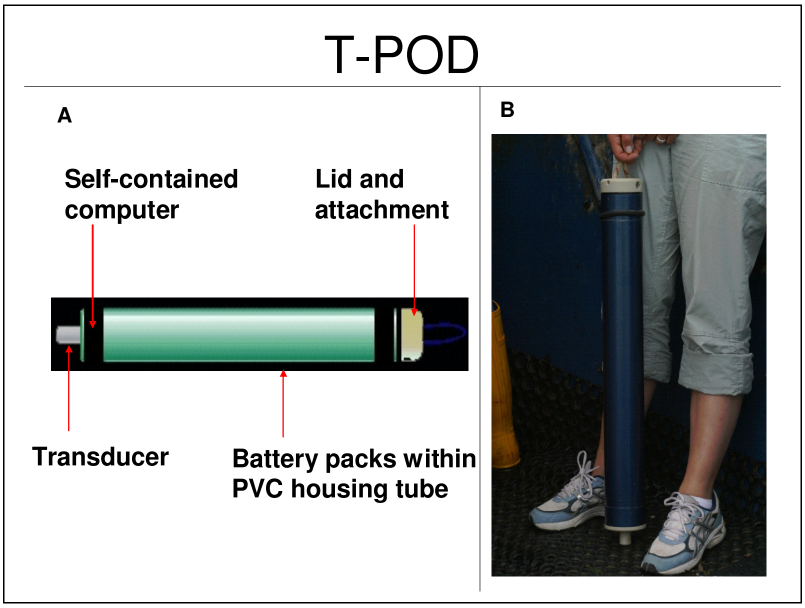


Figure 2.2. A. Diagram of a T-POD unit showing the position of the transducer, PVC housing tube for self-contained computer and battery packs, and lid with attachment. **B**. Picture of the version 4 T-POD unit 421 used at Mwnt in this study.

2.2.2. Calibration and settings

In order to compare data from different T-PODs it is important to know the relative sensitivity. A calibration in a controlled experimental setup reveals the absolute sensitivity of each T-POD's hydrophone, and it allows the user to set the sensitivity of each T-POD. The two T-PODs used in this survey were calibrated in a controlled experimental environment (Ursula Verfuß's Laboratory, German Oceanographic Museum, Stralsund, Germany) and in the field. The T-PODs were considered comparable when the sensitivities were within ± 2 dB re 1 μPa (Simon *et al.* in prep.; Appendix **1**). In addition, the omni-directionality of the T-POD hydrophones were measured to make sure the T-PODs had similar sensitivity from all angles around the hydrophones (Simon *et al.* in prep; Appendix **1**).

The T-POD does not record actual sounds, it detects clicks and the time and duration of any click detection is logged. Within the T-POD the sounds are received by an acoustic element and transmitted to an internal processor. The acoustic characteristics of echolocation clicks are identified by comparing two electronic filter outputs (filter A and B). These filters are set in pairs and each pair constitutes a channel. The T-POD scans through six such channels each minute, each scan lasting 9.2 seconds per channel, ending with a short pause before the next scan starts (Treqenza, 2001). The filters of each channel can be set for the spectral characteristics of the target sound. The T-PODs used in this survey were set so that channels 2, 4 and 6 would detect harbour porpoise clicks (filter A: 130 kHz; filter B: 92 kHz), and channels 1, 3 and 5 would detect bottlenose dolphin clicks (filter A: 50 kHz; filter B: 70 kHz) (Fig **2.3**).

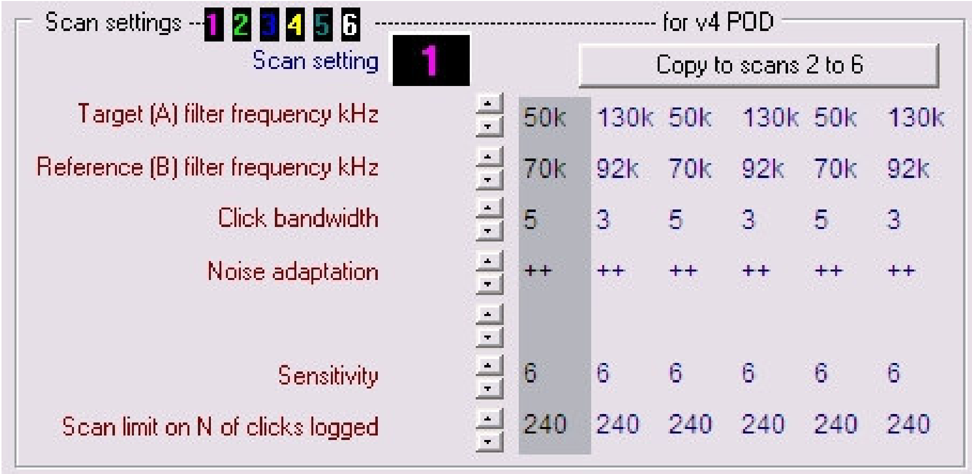
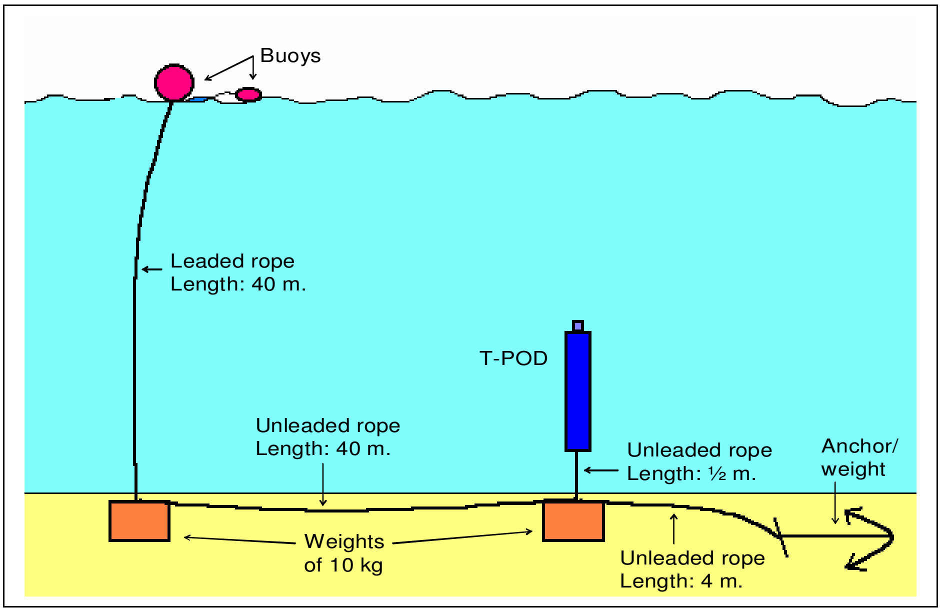


Figure 2.3. Example of a screen displaying T-POD settings. Each column of data shown in blue represents one of the six channels (e.g. channel 1 highlighted in darker grey). The target spectral characteristics set for each channel are defined on the first row (filter A) and second row (filter B). Channels 1, 3 and 5 were set for detecting bottlenose dolphin clicks. Channels 2, 4 and 6 were set to detect harbour porpoises.

2.2.3. <u>Deployment</u>

The T-PODs were deployed on moorings consisting of: an anchor or weight followed by 4 m. of unleaded rope (positively buoyant in order to have a loop to grasp with a hook if someone cut the surface buoy); then a weight to which the T-POD was attached by half a meter of unleaded rope; this weight was joined to a similar weight by 40 m. of unleaded rope; and finally the second weight held the buoys at surface by 40 m of leaded rope (negatively buoyant in order to keep it away from the surface, where it could be accidentally cut by passing propellers), (Fig **2.4a** and **2.5a**). The development of the mooring system was in cooperation with the fishermen; W. Evans and L. Walters.

The buoys were use as reference to locate the deployed T-PODs (Fig **2.4a**). The T-PODs were doubled secured to the mooring by a rope and a carabineer hook (Fig **2.5b**). The T-PODs were positively buoyant, so they remained relatively vertical in the water column, with the hydrophone positioned towards the surface, and approximately at 1 m. above the seabed.



a

b

Figure 2.4. a. T-POD mooring system, with labels showing the length and material of the ropes, and the weights. (Developed in cooperation with the fishermen; W. Evans and L. Walters). **b.** Mooring buoy as reference to locate the deployed T-POD.

a **b**

Figure 2.5. a. Picture of Mwnt T-POD mooring, note that a weight was used instead of an anchor. **b.** Picture showing the T-POD attachment to the mooring by a carabineer hook and an extra rope passing through T-POD lid. (Developed in cooperation with the fishermen; W. Evans and L. Walters)

The T-PODs were deployed from fishing boats (Fig **2.6**). In order to avoid entanglement, the deployment was conducted with the boat moving a little against the tide to keep the ropes straight. The moorings were carefully and slowly thrown at the rear of the boat, starting with the anchor and finishing with the buoy (Fig **2.7**). When retrieving the T-PODs, the rope attached to the buoy was caught with a hook sitting at the end of a pole. The mooring was then lifted with a winch (Fig **2.8**).

Figure 2.6. The fishing boat used to deploy the T-POD off New Quay.

a **b**

Figure 2.7. T-POD deployment from fishing boat. **a.** The anchor and preceding rope in the water and the T-POD and weight are ready to be deployed. **b.** T-POD on the way to the bottom.

a **b**

Figure 2.8. T-POD retrieving from fishing boat. **a.** Mooring ready to retrieved, rope caught with a hook. **b.** Mooring being pulled up with the winch and the T-POD is hanging on the side of the boat.

The T-PODs used in this survey were deployed near the shore (Fig. **2.9**). Off Mwnt the T-POD was deployed at approximately 350 m. from the land-based platform where visual observations were carried out from. The T-POD deployed off New Quay was approximately 450 m from the land-based point where the visual observations were carried out from.

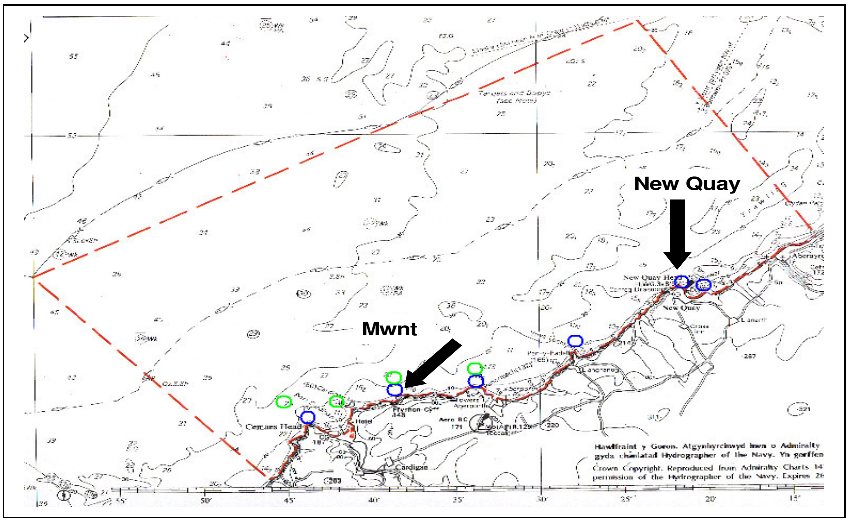


Figure 2.9. Locations for T-POD deployments off Mwnt and New Quay. T-POD units are represented with circles. Note that all T-POD units used in the passive acoustic monitoring of Cardigan Bay Special Area of Conservation, are shown; the units used in this study are indicated with arrows.

2.2.4. Data download and export

The data collected by the T-POD was downloaded using T-POD.exe (Appendix **A**). The T-PODs were connected to the computer by a printer communication cable. After the download, the T-POD software used a train detection algorithm to find click sequences with patterns characteristic for boat sonar and toothed whale echolocation. The software classifies the trains in relation to their likelihood of being of true cetacean echolocation, as Cet Hi (Cetacean High), Cet Lo (Cetacean Low), ? (doubtful) and ?? (very doubtful). Cet Hi and Cet Lo are normally considered to be truly cetacean origin; ? could be either from boat sonar or odontocete echolocation; ?? are often from boat sonar (Tregenza, 2001).

This study investigated T-POD performance for bottlenose dolphin click trains, from trains considered to be truly from dolphins, thus including only Cet Hi and Cet Lo trains in the analysis of T-POD detection range and probability.

This study included Cet Hi, Cet Lo and ? when investigating the possibility of identifying particular bottlenose dolphin behaviour from T-POD data. According to

Tregenza (2001), when researching behavioural responses where cetaceans are reasonably common and real trains will outnumber spurious ones, ? (doubtful) trains should be included. This would give both more valid data and would be better at including short, low pulse repetition frequency (PRF), trains from animals that are not feeding.

T-POD data was exported into Microsoft Excel. For the analysis on T-POD detection range and probability, the data was exported in the form of 'click times' in the export section A of T-POD software, (Appendix **B**). This format exported the time at which the trains were detected (in the format of minute of the year), the scan that detected them and duration of every train logged on the T-POD. The time of the trains was transformed into 24 hours time and date (day, month and year) using the following equation (Equation **2.1**; Tregenza, 2001):

$$\text{Time} = 38353 + (\text{minute of year})/1440$$

Equation 2.1. Transformation of T-POD time as minute in year, into day, hour and minutes.

For the analysis of the acoustic behaviour, the data was exported as 'train detail data' in the export section B of the T-POD software. This format export train details such as: scan, time, train class, train duration, number of clicks, maximum and minimum inter-click interval, maximum click duration and total duration of clicks (Appendix **C**).

2.3 Visual observations

2.3.1 Platforms

The visual observations were carried out from two land-based platforms, one at Mwnt (N 52º 08.250, W 004º 38.605), and one at New Quay (N 54º 13.605, W 004º 21.764). The platforms were located at relatively high cliffs with good visual range over the sea (Fig **2.10**). At low tide Mwnt platform had an altitude of approximately 40 m, and New Quay platform of approximately 60 m.

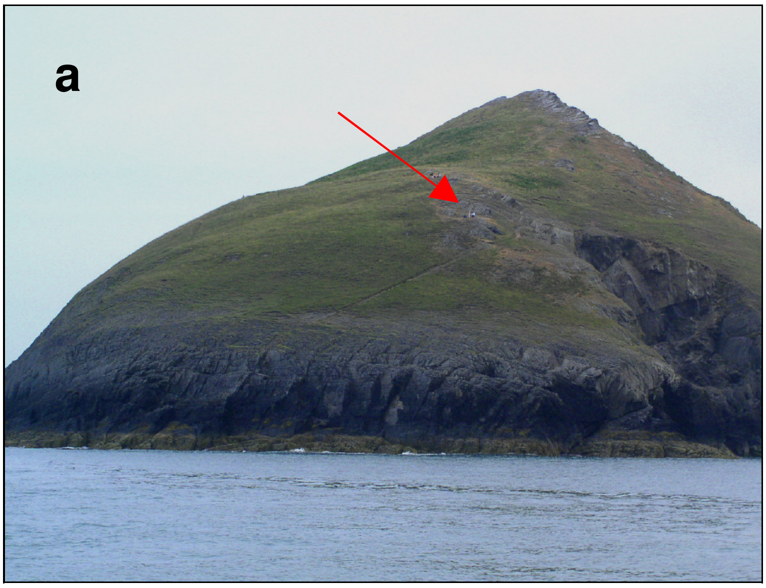


Figure 2.10. Visual survey platforms. **a.** Mwnt. **b**. New Quay

2.3.2. <u>Theodolite</u>

A theodolite has an incorporated telescope, which measures horizontal angles from an arbitrarily selected reference point ("zero"), and vertical angles relative to a gravity-referenced level vector of any target captured by the telescope. The theodolite used at Mwnt platform was a Leica TC(R) 110 Electronic Total Station (Fig **2.11**), with an angle accuracy of 10", a telescope of magnification 30x, and an aperture of 40mm. At the New Quay platform a Sokkisha DT5 theodolite, with an angle accuracy of 3', a telescope of magnification 30x, and an aperture of 45mm, was used.

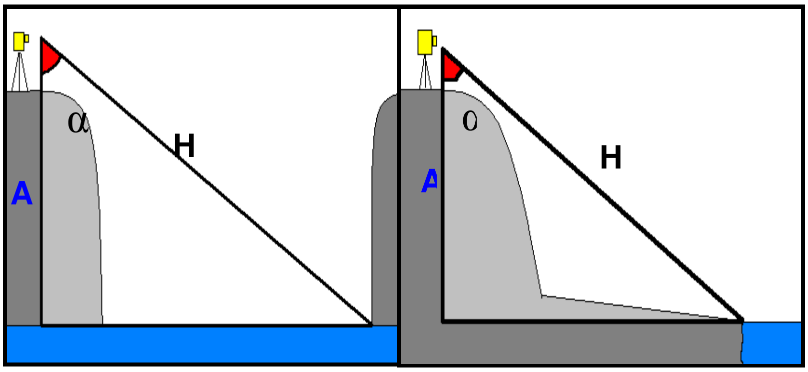
Figure 2.11. The theodolite used for visual observations at Mwnt.

The angles measured with the theodolites were used to calculate the distances between the T-PODs and the dolphins as shown in the section **2.3.4**, but in order to do so the height at which the angles were measured, thus the altitude at which the theodolites were, needed to be measured. The altitudes were measured by using the theodolite together with a laser rangefinder (Leupold RB 800 for Mwnt and the one incorporated in the theodolite Leica TC(R) 110 Electronic Total Station at New Quay).

The procedure involved creating a right angle triangle between the theodolite and the sea level, where the adjacent (A) side of the triangle was the required altitude, and the hypotenuse (H) was the distance between the theodolite and the sea level (Fig **2.12**). The theodolite telescope was projected towards the sea level line (the shoreline for New Quay and on a vertical cliff for Mwnt, Fig **2.13**), at this position the vertical angle (α) was measured; and the distance between the theodolite and sea level (H) was measured with the rangefinder. Then the altitude was calculated by using the cosine equation for right angle triangle (Equation **2.2;** Fig **2.12**):

$$A = \cos \alpha \, . \, H$$

Equation 2.2. Cosine equation used for calculating platform altitude, where **A** = Adjacent (platform altitude), **α** = angle (vertical angle measured with theodolite), and **H** = hypotenuse (distance between theodolite and dolphins or T-POD).



a **b**

Figure 2.12. Right angle triangle to measured platform altitude, where adjacent (**A**) = altitude; hypotenuse (**H**) = distance between theodolite and sea level; angle (α) = theodolite vertical angle. **a.** Mwnt: sea level measured on cliff. **b.** New Quay: sea level measured on shoreline.

a

b

Figure 2.13. Points selected for platform altitude measurement viewed from platform. Black arrows indicate sea level point selected for triangulation. White arrows indicate cliff point selected for measuring the tide height (Tide Reference Point, TRF). **a.** Mwnt **b.** New Quay.

At that at that specific time and tide, the platform altitude (from sea level to theodolite eyepiece) for Mwnt was 37.22 m, and for New Quay was 59.14 m.

To take into account that the altitude varies with tide; the tide height was measured at the exact moment as the altitude measurement was made. The tide height was measured on a vertical cliff that was in contact with the sea level at all tidal ranges. A specific point on the cliff was selected as reference point for tide height measurements (Tide Reference Point, TRP), through out the whole fieldwork. The tide height was measured by using a rope marked with electrical tape for every 1 m. and 25 cm, that was placed vertically from the top of the cliff (Fig **2.13** and **2.14**). This was carried out when the sea was calm (Beaufort scale 1 for Mwnt; and 0 for New Quay, and 0 m swell) to minimize error from waves and swell. At that specific tide height, the reference section on the cliff at Mwnt measured 16.32 m, and that at New Quay 6.5 m.

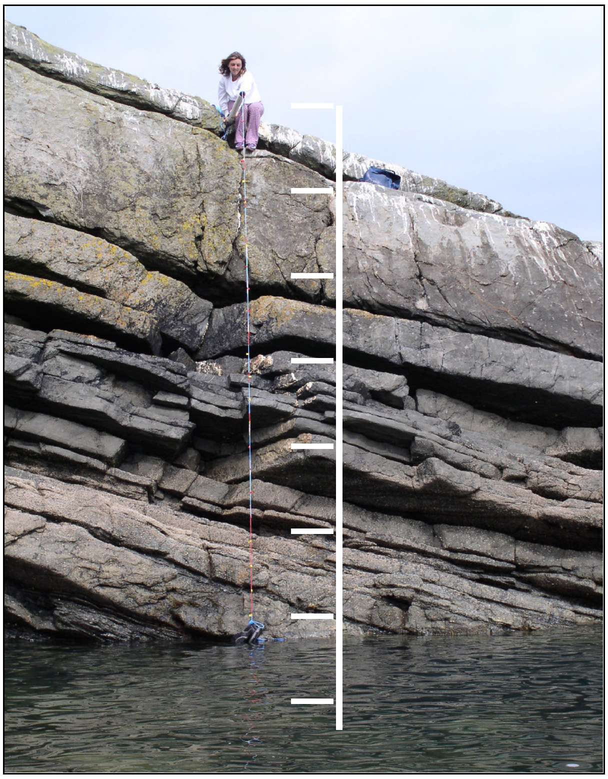


Figure 2.14. Measurement of tide height, with marked rope hanging from the TRF; and calibration of reticules (shown in white) from the reticulated binoculars, at New Quay.

After the calibration of the equipment, the tide height was measured with reticulated binoculars (Opticron Marina 2 7x50) through out all observations (at 15 min intervals), so that the platform altitude was known at all times. The reticules of the binoculars were calibrated into metres for the reference section of the cliff. This was done by using the meters marked on the ropes as reference (Fig **2.14**). The calibration showed that when observing from Mwnt platform, 1 reticule was 3.2 m. on the reference cliff; and observing from New Quay, 1 reticule was 2 m. of the reference cliff. The tide height (T) was calculated by multiplying the number of reticules (R) counted from the TRP down to the sea level, by the calibrated meters for 1 reticule (h) (Equation **2.3**). During the whole fieldwork, the binoculars were set up on a tripod and in the same position as the day of the calibration, to minimize error.

$$T = R \cdot h$$

Equation 2.3. Equation for calculating the tide height; where **T** is the tide height (m), **R** is the number of reticules, and **h** is distance that correspond to 1 reticule (3.2 m for Mwnt and 2 m for New Quay).

It was also taken into account that the height of the theodolite tripod could vary every time the theodolite was set up; therefore the height from the ground to the theodolite eyepiece was also measured everyday of the fieldwork by using a metric tape. On the day that the altitude was measured, the height for Mwnt theodolite eyepiece was 1.53 m; and for that of New Quay 1.55 m.

Excluding the theodolite eyepiece height (E) and the tide height (T) (from TRP to the sea level); the reference altitude (a) for Mwnt platform was 19.365 m; and for New Quay platform was 51.094 m. Therefore the total altitude (A) (from sea level to eyepiece) could be calculated at any time required by using the following equation (Equation **2.4**):

$$A = a + E + T$$

Equation 2.4. Equation for calculating the total platform altitude (m); where **A** is total altitude; **a** is the constant reference altitude (19.365 m for Mwnt; and 51.094 m for New Quay), **E** is the theodolite eyepiece height, and **T** is the tide height measured on reference section of cliff (from TRP to sea level; Equation **2.3**).

2.3.3. Data Collection

At the beginning of each observing day, the theodolite and the tripod were levelled by adjusting the air bubbles levellers incorporated in the equipment. Then the height of the theodolite eyepiece was measured as explained in section **2.3.2**. Finally, the horizontal angle was set as zero at fixed reference points (Zero Reference Point, ZRP), selected at each platform during the calibrations of the theodolites (an example is shown in Fig. **2.15**).

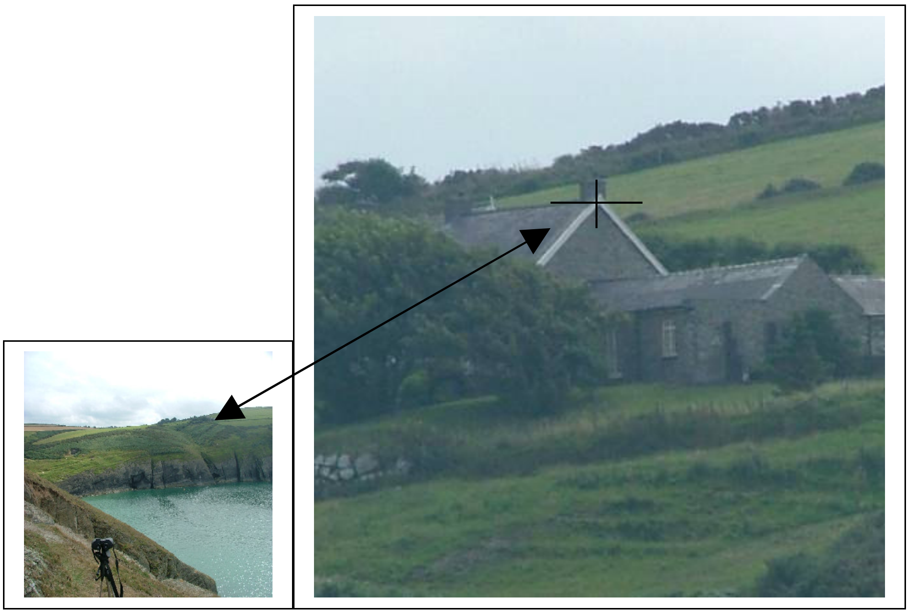


Figure 2.15. Mwnt reference point 'zero' for theodolite horizontal angle, (Zero Reference Point, ZRP).

Environmental data was collected at regular intervals of 15 min, involving the following parameters (example of an environmental form is shown in Appendix **2**):

- **Time (T)**: in hour and minutes. The watch used was synchronized with the T-POD clock.
- **Swell (S)**: the following 0-5 scale was applied:

  0 = none;
  1 = 0-0.25 m;
  2 = 0.25- 0.5 m;
  3 = 0.5-0.75 m;
  4 = 0.75-1 m;
  5 = +1 m; (in order to minimize error, no data was collected above 5).

- **Sea state (B)**: Beaufort scale applied (0-6). In order to minimize error no data was collected at Beaufort more than 3.
- **Tide height (H)**: as number of reticules (R) counted from the TRP down to sea level, as explained in section **2.3.2**.
- **Tide direction (D)**: as U (towards flood), H (high), D (towards ebb), and L (low).
- **T-POD position**: theodolite horizontal and vertical angles for the position of the T-POD were recorded.

Sea scanning for bottlenose dolphins was carried out over the surface area around the T-POD, with alternating direction of scanning at 8-10 min. intervals. (Fig **2.16**).

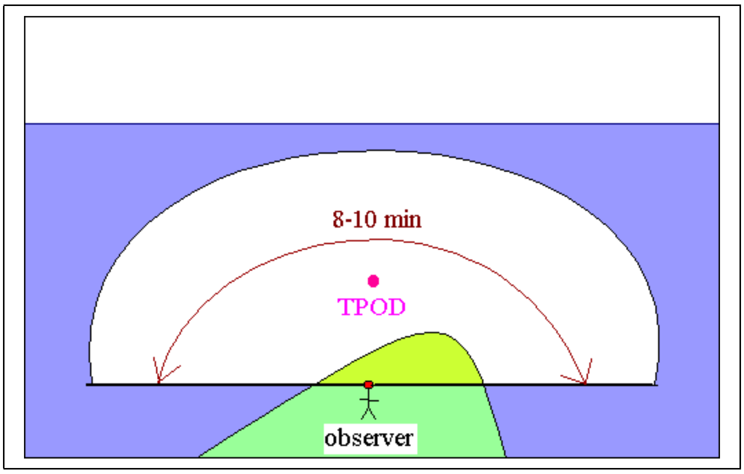


Figure 2.16. Sea scanning for bottlenose dolphins. The scanning direction was alternating left to right to left and was carried out at intervals of 8-10 min.

The following data was recorded for each bottlenose dolphin sighting (example of a sighting fieldwork form is shown in Appendix **3,** and all the data collected is presented in Appendix **D**):

- **Sighting number**: the total number of sightings of the whole fieldwork for each platform.
- **Group size**: total number of dolphins sighted.
- **Start and Stop time:** from the first moment that the dolphins were seen to the moment that the sighting ended. The sighting was considered over when: the dolphins were not seen for more than 20 min; or were difficult to spot with the theodolite or binoculars due to the distance.
- **Surfacing time:** in hours and minutes, at which the dolphin was spotted while surfacing and its position was recorded by theodolite angles.
- **Dolphin position:** theodolite horizontal and vertical angles were recorded for every surfacing of the dolphin. If more than one dolphin were present, effort focused on collecting data for the individual closest to the T-POD.
- **Behaviour**: feeding, travelling and other behaviours were recorded under the following definitions:
    - Travelling: Relatively regular surface intervals with relatively constant direction and speed.
    - Feeding: Repeated dives within the same area, deep dives (fluke seen when immersing), chasing fish on surface, fish seen out of the water and/or presence of active fish-feeding birds.
    - Other: undefined behaviour.

- **Direction**: if the dolphins were inshore, the local name of the shore/coast was recorded (e.g. Cardigan Island) followed by magnetic direction (e.g. North)

2.3.4. Distance calculations

The distance between the T-POD and dolphins were calculated by following two steps:

First, the distance between the theodolite and the T-POD or dolphin, was calculated by creating a right angle triangle with the vertical angle measured by the theodolite, when it was positioned towards the target. The hypotenuse of the triangle was the required distance, the adjacent was the platform altitude (calculated as explained in section **2.3.2**), (Fig **2.17**). The distance to the T-POD or dolphin was then calculated using the cosine equation for right angle triangle (Equation **2.2**).

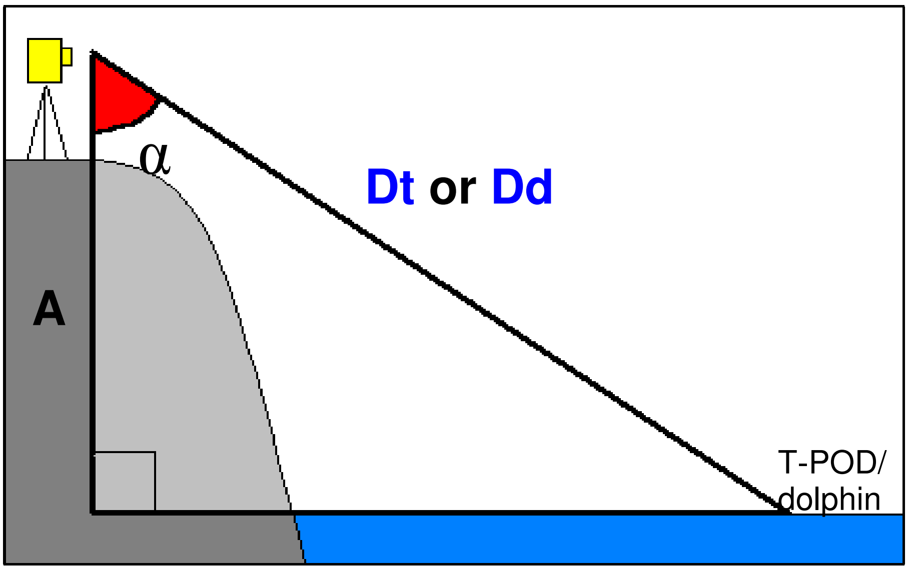


Figure 2.17. Right angle triangle to measure distance between the theodolite and: T-POD (Dt) or dolphin (Dd); by using the vertical angle measured by theodolite (**α**, illustrated in red) and the platform altitude (**A**).

Second, an irregular triangle was created by joining the theodolite, T-POD and dolphin positions; in order to calculate the distance between T-POD and the dolphins (Fig **2.18**).

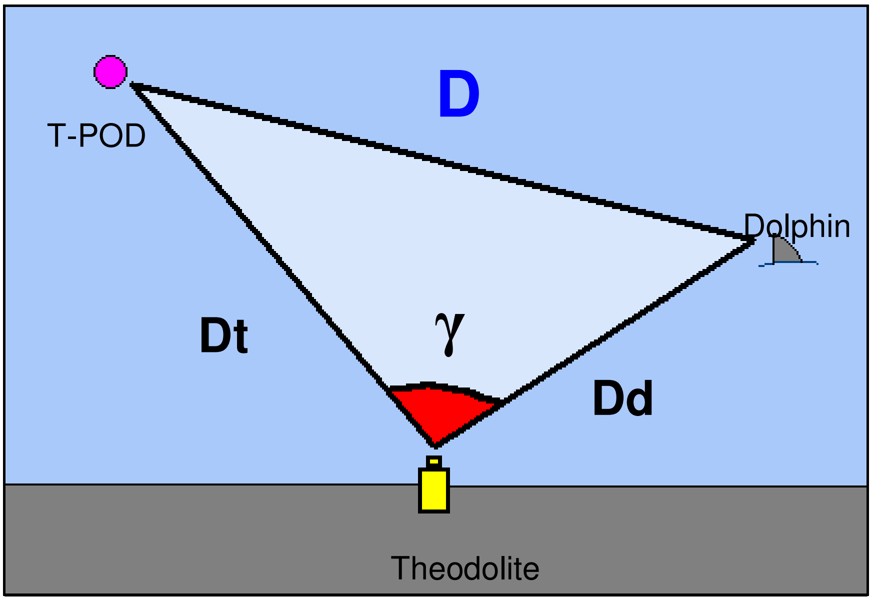


Figure 2.18. Irregular triangle to calculate distance (**D**) between the T-POD and the dolphins, where **Dt** is distance from theodolite to T-POD; **Dd** is the distance from the theodolite to the dolphin; and **γ** (illustrated in red) is the angle obtained from theodolite horizontal angles.

The angle (γ) created between the distance from the theodolite to the T-POD (Dt) and the theodolite to the dolphins (Dd) was calculated by subtracting the horizontal angles measured by the theodolite for each target position. The distance (D) between the T-POD and the dolphins was calculated by using the following cosine equation for irregular triangle (Equation **2.5**):

$$D = \sqrt{(Dd^2 + Dt^2 - 2 . Dt . Dd . \cos \gamma)}$$

Equation 2.5. Irregular triangle cosine equation to calculate distance (**D**) between the T-POD and the dolphins; where **Dt** is the distance from theodolite to the T-POD; **Dd** is the distance from theodolite to the dolphin; and **γ** is the angle obtained from theodolite horizontal angles.

2.3.5 Bias

Distances calculated from theodolite angles are always subjected to some degree of error due to: errors on the platform altitude when measuring it and from the swell height; and the earth curvature (Wursing *et al.*, 1991). The distances between the T-POD and the dolphins calculated in this study, took all these parameters into account.

Errors when measuring platform altitude could have arisen from:

- The ± 0.5 m. accuracy of the laser rangefinder (explained in section **2.3.2**) The platform altitude error derived from this source was ±0.065 m. for Mwnt, and ± 0.246 for New Quay.
- Visual error when measuring the tide height by counting the reticules within the reticulated binoculars (as explained in section **2.3.2**). A maximum error of 0.1 reticule was estimated, which leaded to a platform altitude error of ± 0.32 m for Mwnt and ± 0.2 m for New Quay.

In summary, the maximum possible error encountered when the platform altitude was measured was ± 0.385 m. for Mwnt and ± 0.446 for New Quay.

Errors on platform altitude derived from swell height, were defined by the swell scale used in this survey (section **2.3.3**); for example, if there was a swell of 1 (0-0.25 m), an error height of 0.25 m. was estimated

The bias of the distances between T-POD and dolphins calculated in this study is shown on table **2.1**, which was based on the calculations made by Wursing *et al.* (1991).

	Distance error (m) at: 500 m		1000 m	
Altitude error (m)	**Mwnt**	**New Quay**	**Mwnt**	**New Quay**
0 - 0.25	± 5.2	± 2.9	± 10.5	± 5.6
0.25 -0.5	± 8.5	± 5.7	± 17	± 11.4
0.5 - 0.75	± 11.7	± 8.6	± 23.5	± 17.2
0.75 - 1	± 15	± 11.5	± 30	± 23

Table 2.1. Bias for calculated distances (m) between T-POD and dolphins, accounting for platform altitude and curvature of earth, for targets at 500 and 1000 m from theodolite.

The T-PODs were not visible while deployed; instead they were spotted with the buoy attached to the mooring (see section **2.3.3**; Fig **2.4a**). Therefore, the distances between the T-POD and the dolphins calculated in this study, were in fact the distances between the buoy and the dolphins. The bias of this study took into account this type of distance error, and it also accounted for buoy movements with tides.

To calculate the distance between buoy and T-POD at low and at high tide, a right angle triangle was created for each tidal range, by joining the buoy with: the weight holding it; and its 'projection' on the seabed. The hypotenuse was the length of the rope (R) holding the buoy; the adjacent was the water depth (D_H at high tide; D_L at low tide); and the opposite was the shortest distance (D) between the buoy and the weight (Fig **2.19**).

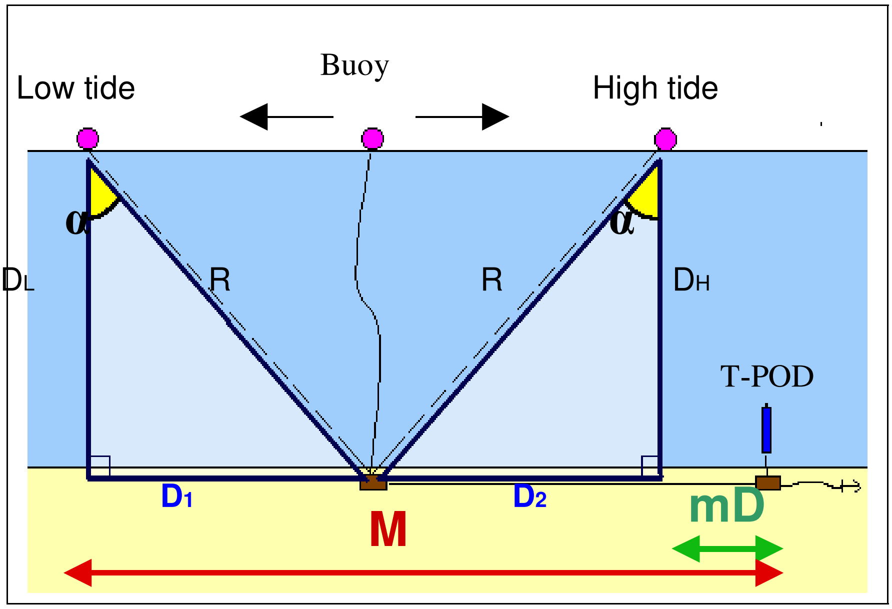


Figure 2.19. Minimum (**m**) and maximum (**M**) distance between the T-POD and the buoy at high and low tide. Right angle triangles involved in the calculation of **m** and **M**; where **D_H** is water depth at high tide and **D_L** at low tide (adjacent); **R** (hypotenuse) is the length of the rope holding the buoy, and **α** is the angle (illustrated in yellow) calculated for obtaining the shortest distance between the buoy and the weight at low (**D_1**) and high (**D_2**) tide.

The shortest distance between the buoy and the weight at high (D_1), and low tide (D_2) was calculated by: first, calculating α using R (hypotenuse, 40 m) and D_H or D_L (adjacent) in the cosine equation for right angle triangle (Equation **2.2**); second, using this angle (α) and R in the sine equation for right angle triangle (Equation **2.6**).

$$O = \sin \alpha \, . \, H$$

Equation 2.6. Sine equation for right angle triangle; where **O** = opposite (shortest distance between buoy and weight, D_1 or D_2); **H** = hypotenuse (rope length, R) and **α** is the angle calculated for the right angle triangle. (Fig **2.19**)

For these calculations, the water depth was measured using echo sounders from a fishing boat, this was done simultaneously with tide height measurements as shown in section **2.3.2**, so that as the tide varied, the water depth could be calibrated from tide height measurements. The T-PODs were deployed at flooding tide, with the fishing boat moving slowly in the opposite direction of the tide, so that the position of the T-POD with respect to the buoy was known.

The distance between T-POD and buoy, was calculated by subtracting D_2 (at high tide) or adding D_1 (at low tide) from the length of the rope (40 m) joining the weight holding the T-POD and the weight holding the buoy, (Fig **2.19)**.

In summary, the minimum distance between T-POD and buoy occurred at high tide and it was 2.5 m at Mwnt and 1.1 m at New Quay. The maximum distance between T-POD and buoy occurred at low tide and it was 78.3 m at Mwnt and 78.9 at New Quay.

The overall bias for distances between T-POD and bottlenose dolphins took into account errors from: theodolite calculations (platform height and earth curvature); and from distances between the T-POD reference buoy, and the T-POD itself.

2.4 Comparison between T-POD data and visual observations

2.4.1 T-POD detection range and probability

The time (date, hour and minute) at which bottlenose dolphin click trains (classified as Cet Hi and Cet Lo) were detected on the T-POD, was compared to the time at which visual observations were carried out. Acoustic and visual data that occurred simultaneously at the same time (± 1 min.) was considered as a 'match', thus considering that the click train matched was emitted by a dolphin observed at a specific distance from the T-POD and with a particular behaviour. (Appendix **F**)

2.4.1 Acoustic behaviour

The time (date, hour and minute) at which bottlenose dolphin click trains (classified as Cet Hi, Cet Lo and ?) were detected on the T-POD was compared to the time at which particular bottlenose dolphin behaviours were observed. Acoustic and visual data that occurred relatively at the same time (± 5 min.) was considered as a 'match', thus considering that the click train matched was emitted by a dolphin with the particular behaviour observed (Appendix **G**).

2.5 Statistical analysis

Various statistical tests were applied to relevant data to determine the presence of trends and significant differences. All the data was first test for normality (Anderson-Darling Normality test) and equal variance (F-test and Levene's test). Parametric data was tested for trends (General Linear Model) or for significant differences (Two sample t-test). Non parametric data was tested for significant differences (Mann-Whitney Test). (Appendix **4, 5**).

All statistical tests were conducted using the statistical software MiniTab 13.30.

3: Results

3 <u>Results</u>

3.1 Effort

3.1.1 <u>Mwnt</u>

During the six weeks of this study off Mwnt (42 days), visual observations were carried out on 21 days, with a total of 114 hours (6,840 min.) on effort. Forty-nine sightings of bottlenose dolphins were observed during 19 days for a total duration of 1,810 min, 26.5% of the total effort time. A total of 1,325 min of observations of animals surfacing, for which the distance to the T-POD was measured with the theodolite, was obtained; of these, the dolphins were within the T-POD detection range for 834 min. (Table **3.1;** Appendix **D, E**). The behaviour of the dolphins was identified during 91.8% of the visual observations (766 min), resulting in 538 min observations of feeding dolphins and 228 min observations of travelling dolphins. (Appendix **D**).

The T-POD was deployed for a total of 40 days, and during 19 days of these, simultaneous visual observations were carried out. The T-POD detected click trains were categorized as Cet Hi and Cet Lo (Cetacean High and Low) for a total of 675 detection positive minutes (DPM), of which simultaneous visual observations were carried out during 127 DPM. Successful matching between T-POD data and distances measured with the theodolite was achieved for 105 min. (Table **3.1**). (Appendix **F**).

A total of 28,027 click trains were categorised as Cet Hi, Cet Lo or ? (Doubtful), and 406 of these were matched with a visually identified behaviour (feeding, travelling or other). The number of click trains detected from feeding animals was 216, and from travelling animals 26 (Table **3.2**). (Appendix **G**).

Time (min.)			
Survey		Mwnt	New Quay
Visual	Effort Sightings Total distance records	6,840 1,810 1,325	3,720 552 361
T-POD	Total Total DPM	20,521 675	14,337 85
Visual & T-POD	**Distance records** **DPM** **Matched**	834 127 **105**	228 18 **15**

Table 3.1. **Visual survey**: effort time (minutes); sightings duration; total minutes of visual observations with distance measurements between dolphins and T-POD. **T-POD**: effort time (minutes); and total T-POD detection positive minutes (DPM). **Visual & T-POD**: Visual observations (within T-POD detection range) with distance measurements between dolphins and T-POD; T-POD DPM while visual observation occurred; and simultaneous minutes with distance records and DPM matched.

Click trains				
		Mwnt	New Quay	Total
Total detected	Cet Hi Cet Lo ?	9465 7106 3423	919 942 1424	
	Total	28027	3285	31312
Feeding	Cet Hi Cet Lo ?	36 62 92	6 12 16	
	Total	**190**	**34**	**224**
Travelling	Cet Hi Cet Lo ?	2 7 11	1 1 6	
	Total	**20**	**8**	**28**

Table 3.2. T-POD click train detection for Cetacean High, Cetacean Low and Doubtful click train classes by Mwnt and New Quay T-PODs during the whole survey; and simultaneous visually identified feeding and travelling behaviours.

3.1.2 New Quay

Visual observations at New Quay were carried out every day during a 10-day period of survey, with a total of 62 hours (3,720 min.) on effort. Dolphins were encountered on 6 days, with a total of 16 sightings and a total duration of 552 min, 14.8% of the total effort time. Observations with distance measured with the theodolite were made for 361 min, from which 228 min. the dolphins were observed within the T-POD detection range (Table **3.1;** Appendix **D, E**). During 99.6% (227 min) of the 228 min, the behaviour of the observed dolphins was identified, resulting in 122 min of feeding and 105 min of travelling, (Appendix **D**).

The acoustic survey was carried out for a 10-day period and acoustic monitoring was achieved for the whole period. Cet Hi and Cet Lo click trains were detected in a total of 85 DPM, from which 18 DPM were recorded while visual observation occurred. Matching between T-POD data and distances measured with the theodolite was achieved for 15 min (Table **3.1;** Appendix **F**).

The total number of Cet Hi, Cet Lo and ? click trains detected was 3,285, from which 42 click trains were matched with a visually identified dolphin behaviour. The number of click trains detected from feeding animals was 42, and from travelling animals 8 (Table **3.2;** Appendix **G**).

3.2 T-POD detection range

3.2.1 Mwnt

The dolphins were observed visually around the T-POD at distances that ranged from 5 to 4,250 m (Table **3.3,** Appendix **D**); however, the T-POD only detected click trains from individuals that were within a range of approximately 650 m. The maximum detection range of the T-POD to bottlenose dolphin clicks was measured as 638 m (± 53.6 m of maximum error; Table **3.3**).

3.2.2 New Quay

The distances at which the dolphins were observed around the T-POD ranged from 25 to 1500 m (Table **3.3,** Appendix **D**), but the T-POD only detected individuals that were within approximately 600 m from the T-POD. The maximum distance measured for T-POD detection of dolphin clicks was 590 (± 85.7) m. (Table **2.1**).

	Distance (m)			
	Mwnt		New Quay	
Detection	Min.	Max.	Min.	Max.
Visual	5.9 (± 92.6)	4247 (± 89.3)	29 (± 16.3)	1503 (± 47.7)
T-POD	10.8 (± 21.2)	**638** (± 53.6)	46 (± 41)	**590** (± 85.7)

Table 3.3. Minimum (min.) and maximum (max.) distance measured (± maximum standard error) between dolphins and Mwnt and New Quay T-PODs for: all visual observations; and visual observations occurring simultaneously with T-POD detection.

3.3 T-POD detection probability

3.3.1 Distance

3.3.1.1 Mwnt

The distance between: the dolphins that were within the T-POD detection range, and the T-POD; was measured for 834 min of visual encounters, of which 105 min were recorded as DPM on the T-POD. Therefore the T-POD detected dolphin clicks 12.5 % of the total number of minutes that the dolphins were visually observed around the T-POD.

T-POD detection of click trains varied with the distance from the dolphins to the T-POD location. Clicks emitted by dolphins that were within 100 m of the T-POD were detected as 40 DPM on the T-POD, and those emitted by dolphins between 100 and 200 m from the T-POD were detected as 46 DPM. However, at 200-300 m from the T-POD, only 12 DPM of dolphin clicks were recorded. Clicks from dolphins beyond 300 m from the T-POD were recorded for less than 5 DPM on the T-POD at each distance range of 100 m (1 DPM at 300-400, 4 DPM at 400-500, 1 DPM at 500-600 and 1 DPM at 600-700) (Fig **3.1**).

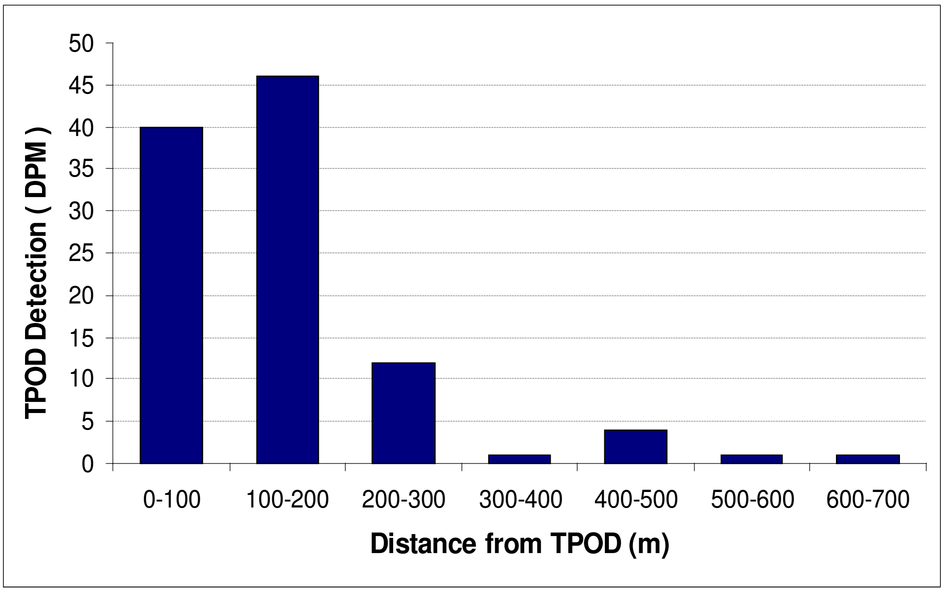


Figure 3.1. Mwnt T-POD detection (DPM) of bottlenose dolphin click trains for each distance category of 100 m.

There was a positive relationship between the amount of visual minutes recorded and T-POD DPM. Dolphins within 100 m from the T-POD were visually observed for 134 min; of these, 40 min were also recoded as DPM on the T-POD. The animals spent more time in the range of 100-200 m from the T-POD, where 344 min were recorded visually and 46 min were also recorded acoustically. The visual detection time was halved at the range of 200-300 m to 158 min, resulting in 12 min of DPM on the T-POD. Between 300 and 400 m from the T-POD, 63 min of visual detection were made, from which only 1min resulted in T-POD DPM. At distances of 400 m to 700 m, the dolphins were observed for less than 50 min at each range, with 4DPM at 400-500m, 1DPM at 500-600m and 1DPM at 600-700m. (Fig **3.2**)

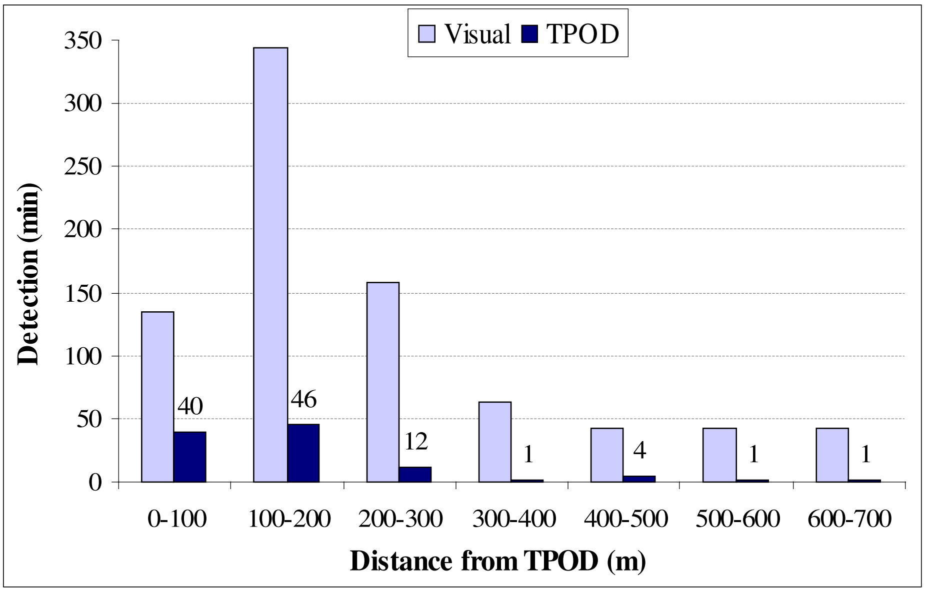


Figure 3.2. Visual and T-POD detection min. in 100 m range categories from Mwnt T-POD location. (Note that the values for T-POD detection min. (DPM) are also shown).

In order to obtain representative values for T-POD detection probability over distance, the percentages of T-POD DPM of the total number of minutes that the dolphins were visually observed at each distance category of 100 m, were calculated. A negative correlation between T-POD detection probability of dolphin click trains and distance was observed (linear regression, $F_{1,5}$= 9.38, p= 0.028; Fig **3.3;** Appendix **4**).

The highest percentage of T-POD DPM was found within the 0-100 m distance range, where click trains were detected 30% of the total time of visual observations within this range. Compared to the 0-100m range, the T-POD detection halved between 100-200m, where the animals were acoustically detected 13% of the time. Beyond 200m, the T-POD detection was always less than 10%: with 8% from 200-300 m; 2% from 300-400 m; 9% from 400-500 and 2% for each of the following two ranges of 500-600m and 600-700 m (Fig **3.3**).

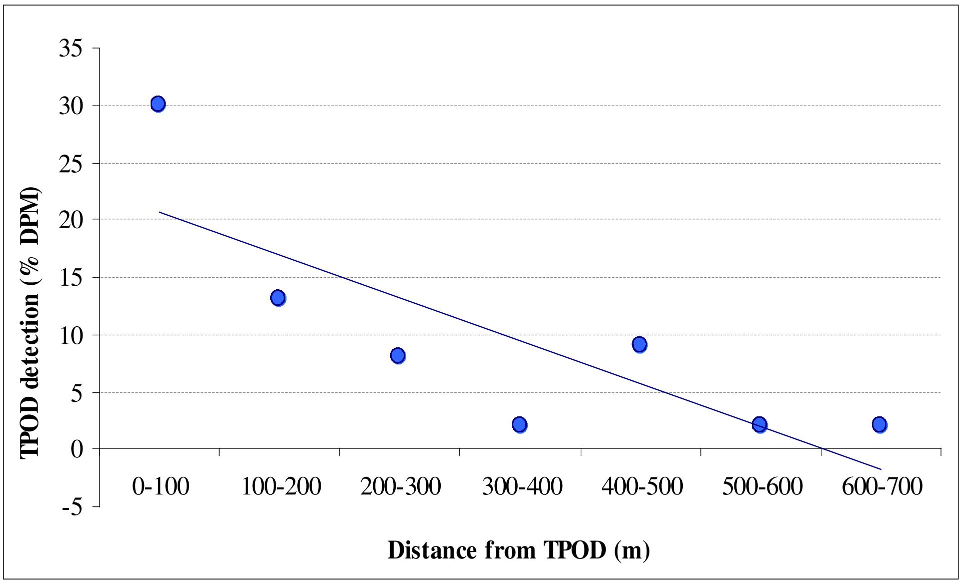


Figure 3.3. Mwnt T-POD detection probability as percentage of DPM of the total number of minutes that the dolphins were visually observed at each distance category of 100 m. T-POD detection line of best-fit.

Mwnt T-POD detection probability of bottlenose dolphin click trains over distance was expressed as the following straight-line function (Equation **3.1)**, where D = T-POD detection probability (% DPM); and d = distance (m). (Constant and distance coefficient values obtained from linear regression analysis, Appendix **4**). (Fig **3.3**):

$$D = (-0.0375)\, d + 22.554$$

Equation 3.1. Mwnt T-POD detection probability of bottlenose dolphin click trains over distance; where D = T-POD detection probability (% DPM); and d = distance (m).

3.3.1.2 New Quay

Bottlenose dolphins that were within the T-POD detection range were visually observed for a total of 221 min, from which 15 min were also recorded as DPM on the T-POD. Therefore, the T-POD detected the dolphins 6.8% of the total time that they were visually observed around the T-POD.

New Quay T-POD detection of dolphin clicks differed with the distance from the dolphins to the T-POD location. The lowest number of dolphin clicks detected as DPM on the T-POD actually occurred within 100 m from the T-POD, with only 1 DPM. Dolphins between 100 and 200 m from the T-POD were detected as 4 DPM on the T-POD, and those at 200-300 m from the T-POD, as 3 DPM. Clicks from dolphins beyond 300 m from the T-POD, were recorded as 2 DPM at 300-400 m, 3 DPM at 400-500 m and 2 DPM at 500-600 m. (Fig **3.4**).

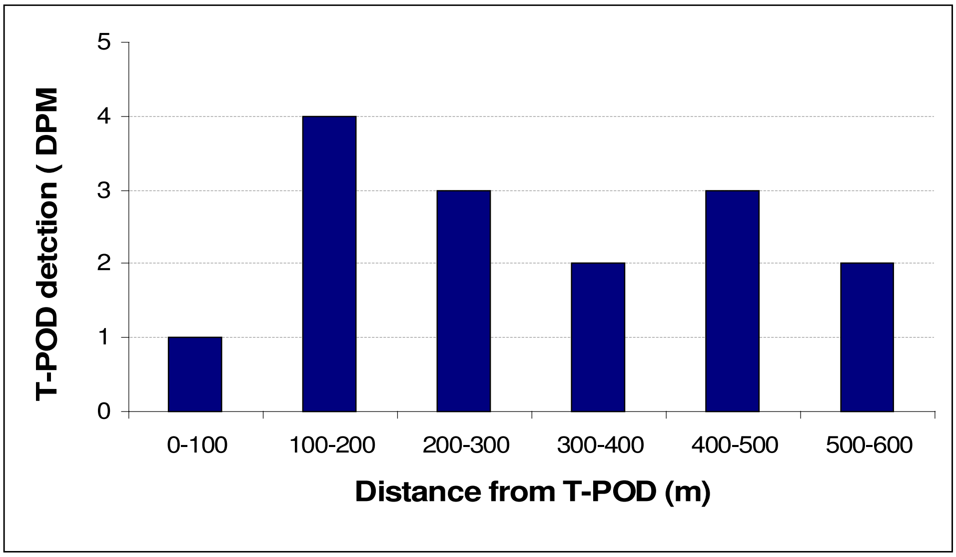


Figure 3.4. New Quay T-POD detection (DPM) of bottlenose dolphin click trains for each distance range of 100 m from the T-POD.

The dolphins were observed to spend the least amount of time (22 min) within the distance range of 0-100 m, where only 1 min resulted as DPM on the T-POD. They spent more time at the distance ranges of 100-200m (46 min) and 300-400m (43 min) from the T-POD, where 4 and 2 min respectively were detected as DPM on the T-POD. The range at which dolphins were visually observed for the next greatest amount of time was 200-300m with 35 min of visual detection and 3 DPM of acoustic detection. The visual detection time decreased slightly for the ranges of 400-500 m (32 min) and 500-600 (23 min), where 3 and 2 min were also detected as DPM on the T-POD (Fig **3.5**).

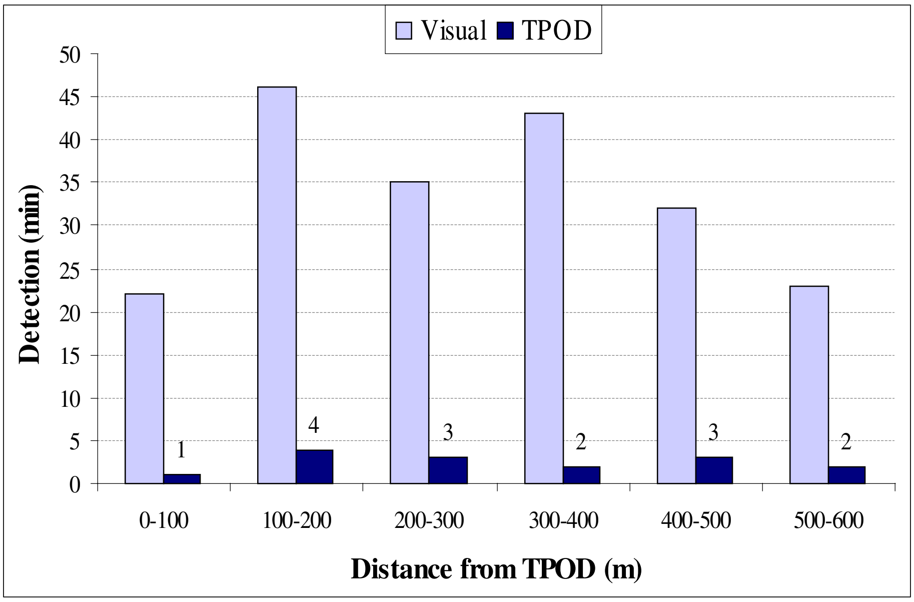


Figure 3.5. Visual and T-POD detection min. in 100 m range categories from New Quay T-POD location. (Note that the values for T-POD detection min. (DPM) are also shown).

New Quay T-POD detection probability over distance was represented as percentages of T-POD DPM of the total number of minutes that the dolphins were visually observed at each distance category of 100 m. T-POD detection probability tended to remain relatively constant over distance (linear regression, $F_{1,4}$= 0.83, p= 0.414, Appendix **4**). The lowest detection probability values were obtained at the ranges of 0-100 m, and 300-400 m, where the animals were detected 5% of the total time that they were observed at each distance category. The detection probability values obtained for dolphins that were at each of the remaining distance categories were 9% for each range (Fig **3.6**).

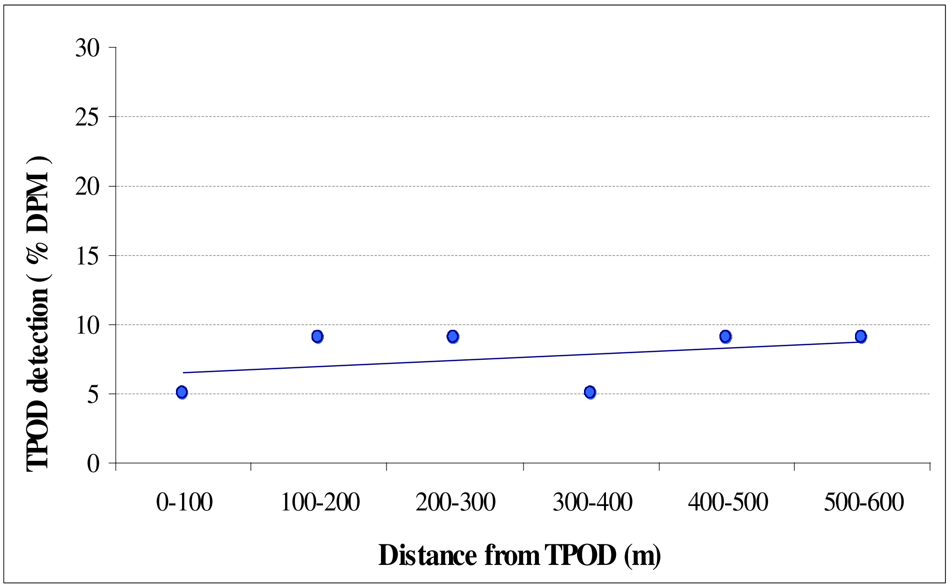


Figure 3.6. New Quay T-POD detection probability as percentage of DPM of the total number of minutes that the dolphins were visually observed at each distance category of 100 m. T-POD detection best fit straight line.

New Quay T-POD detection probability over distance was expressed as the following straight-line function (Equation **3.2**), where D= T-POD detection (% DPM); and d= distance (m). (Constant and distance coefficient values obtained from linear regression analysis, appendix **6;** Fig **3.8**):

$$D = (0.004571)\ d + 6.295$$

Equation 3.2. New Quay T-POD detection probability of bottlenose dolphin click trains over distance; where D= T-POD detection (% DPM); and d= distance (m).

3.3.1.3 Comparison between Mwnt and New Quay

The T-POD detection probability of bottlenose click trains varied between Mwnt and New Quay T-PODs. Mwnt T-POD detection decreased with increasing distance, while that of New Quay T-POD remained relatively constant. The statistical analysis, when comparing T-POD detection probability between Mwnt and New Quay, revealed no significant difference between the T-PODs (T_7= 0.71, p= 0.499; Appendix **4**).

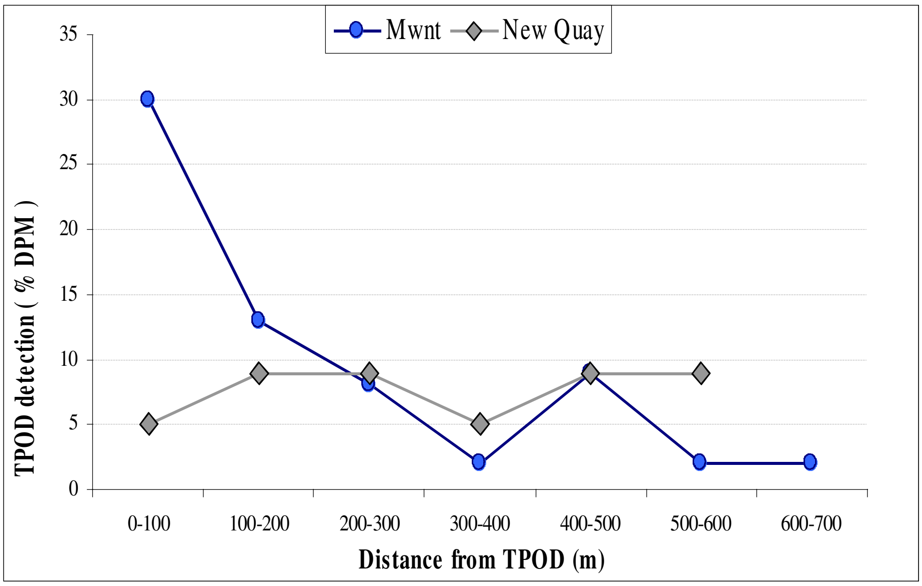


Figure 3.7. Mwnt and New Quay T-POD detection as percentage of DPM of the total number of minutes that the dolphins were observed at each distance category.

The data obtained from both T-PODs were analysed as a single data set. It was observed that the dolphins were detected 11.4 % of the total time that they were visually observed around the T-PODs. The values obtained for T-POD detection probability over distance for both T-PODs, revealed a negative correlation between T-POD detection probability of dolphin click trains and distance (linear regression, $F_{1,5}$= 8.15, p= 0.036; Fig **3.8**).

The highest value of T-POD detection was observed within 100 m of the T-POD, where the dolphins were detected 26% of the total time that they were visually observed within this range. Compared to the 0-100m range, the T-POD detection rates halved between 100-200m, where the animals were acoustically detected 12% of the time. Beyond 200m, the T-POD detection was less than 10%: with 5.6 % from 200-300 m; 2.7% from 300-400 m; 9% from 400-500, 4.4% from 500-600 and 1.6% from 600-700 m (Fig **3.8**).

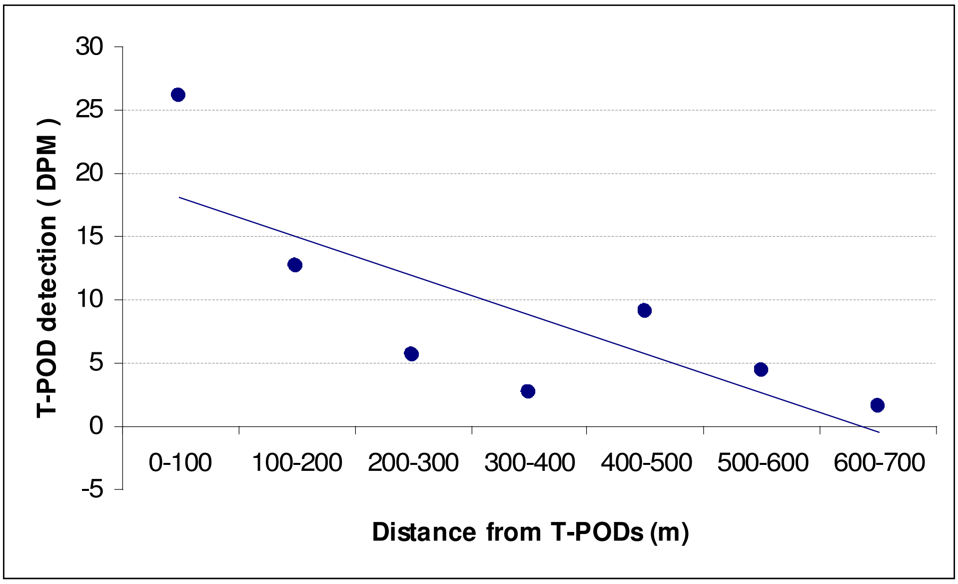


Figure 3.8 T-POD detection probability as percentage of DPM of the total time that the dolphins were observed at each distance range, for Mwnt and New Quay T-PODs combined. T-POD detection best fit straight line.

T-POD detection probability of bottlenose dolphin click trains over distance was expressed as the following straight-line function (Equation **3.3**), where D = T-POD detection probability (% DPM); and d = distance (m). (Constant and distance coefficient values obtained from linear regression analysis; Fig**. 3.3**; Appendix **4**):

$$D = (-0.03096)\, d + 19.709$$

Equation 3.3. Mwnt and New Quay T-POD detection probability of bottlenose dolphin click trains over distance; where D = T-POD detection probability (% DPM); and d = distance (m).

3.3.2 Behaviour

3.3.2.1 Mwnt

Bottlenose dolphin behaviour was visually identified as feeding or travelling 91.8% and unidentified 8.2% of the total time that they were observed within the T-POD distance detection range. The dolphins were observed to spend more time feeding (538 min) than travelling (228 min) (Fig **3.9**). Those within 300 m of the T-POD showed a significantly higher T-POD detection rate than those between 300 and 650 m distance ($W_{12,14} = 204.5$, $p = 0.0308$, Appendix **5**). Feeding animals within 300 m of the T-POD were detected acoustically for 85 min, and those travelling were detected for 4 min. Feeding animals between 300 and 650 m of the T-POD were detected acoustically for 3 min, and those travelling were detected for 4 min. (Fig **3.10;** Appendix **4**).

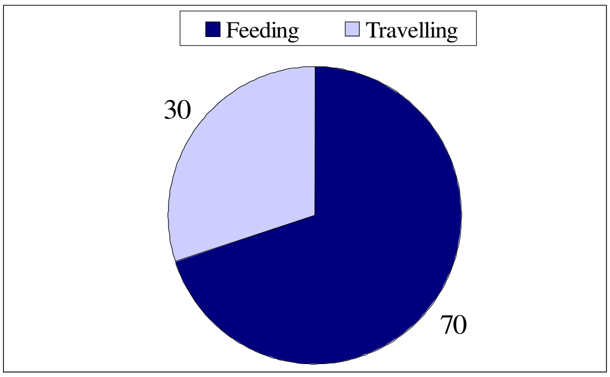


Figure 3.9. Visual observation time (min) of feeding and travelling dolphins within Mwnt T-POD distance detection range.

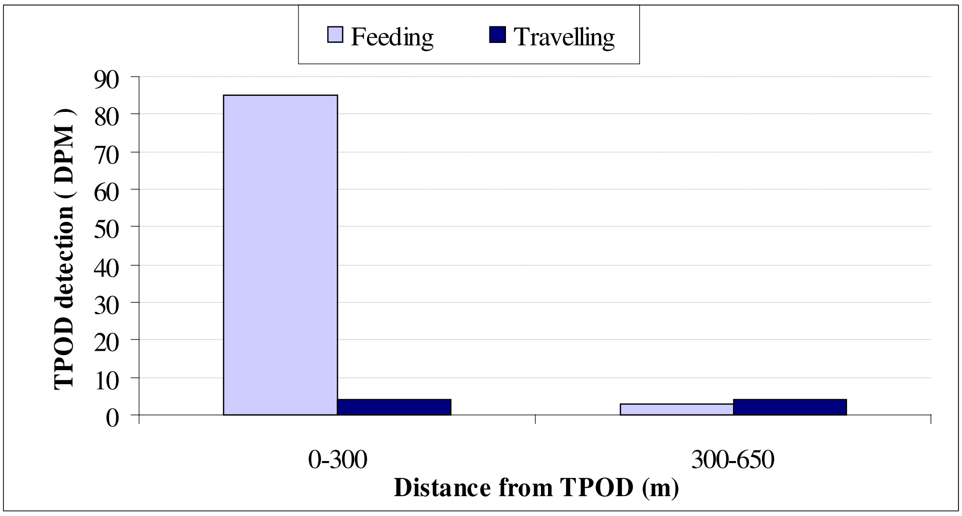


Figure 3.10. Mwnt T-POD detection time (DPM) of feeding and travelling animals at 0-300 m and 300-650 m from the T-POD.

T-POD detection probability was represented as the percentage of DPM of the total number of minutes that the animals were observed to be feeding or travelling at each 50 m range interval. Dolphins that were feeding within 300 m of the T-POD showed a significantly higher T-POD detection than those travelling (T_6= 3.86, p= 0.008, Appendix **4**).

Dolphins that were feeding within 50 m of the T-POD showed a 25 % higher T-POD detection than those travelling. At 50-100 m from the T-POD, the difference increased slightly to 27%. At 100-150 m, no travelling dolphins were detected acoustically. At 150-200 m, T-POD detection of feeding dolphins was 12 % higher than those travelling. At 200-250 m, the difference decreased slightly to 10 %. At 250-300 m, only feeding animals were acoustically detected (Fig **3.11**). Beyond 300 m, there was no significant difference between feeding and travelling animals ($W_{7,7}$ = 43.5, p = 0.2774, Appendix **4**). Click trains for both behaviours were detected less than 15% of the total time that the dolphins were visually observed. At 300-350, 400-450 and 500-550 m from the T-POD, no feeding animals were detected by the T-POD. There was no T-POD DPM for any of the behaviours when the dolphins were within

350-400 and 550-600 m. At 450-500 m, travelling animals showed a 2% higher T-POD detection (11%) than feeding animals (9%). At 600-650 m, no click train from travelling dolphins was detected, (Fig **3.12**; Appendix **4**).

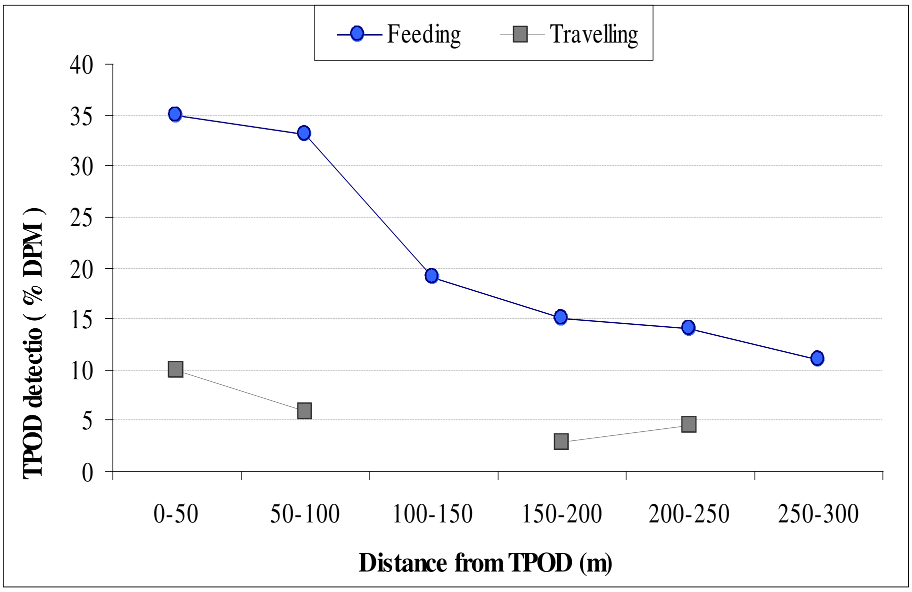


Figure 3.11. Mwnt T-POD detection for feeding and travelling dolphins as % of DPM of the total number of minutes that the dolphins were visually observed at each 50 m range interval within 300 m of the T-POD.

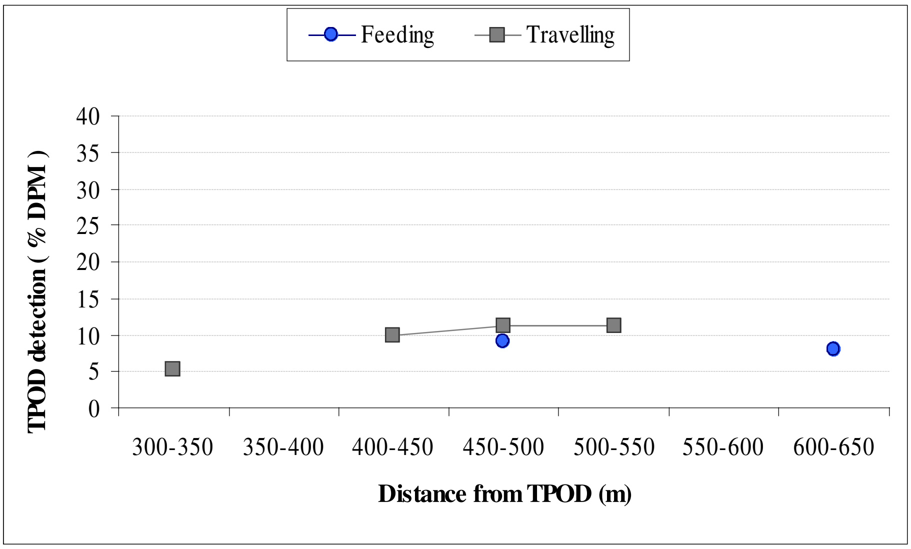


Figure 3.12. Mwnt T-POD detection as % of DPM of the total number of minutes that the dolphins were visually observed to be feeding or travelling at each 50 m range interval within 300-650 m of the T-POD.

3.3.2.2 New Quay

Bottlenose dolphins behaviour was visually identified 99.5% of the total time that they were observed within the T-POD detection range. They spent more time feeding (122 min) than travelling (105 min) (Fig **3.13**). T-POD detection of clicks from dolphins within 300 m of the T-POD was not significantly different to those at 300-600 m ($W_{12,12}$ = 163.5, p= 0.4529, Appendix **5**). Dolphins that were feeding within 300 m of the T-POD were detected as 6 DPM on the T-POD, and those that were travelling as 2 DPM. Dolphins that were feeding between 300 and 650 m from the T-POD were acoustically detected as 6 DPM, and those that were travelling were detected as 1 DPM (Fig **3.14**).

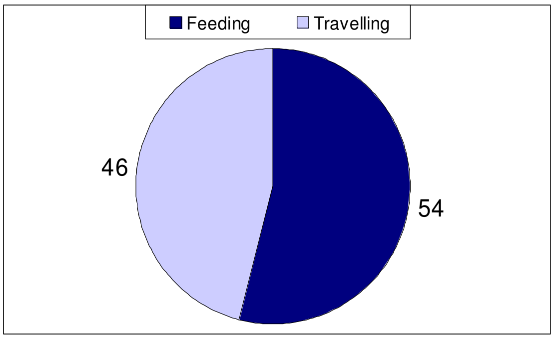


Figure 3.13. Visual observation time (min) of feeding and travelling dolphins within New Quay T-POD distance detection range

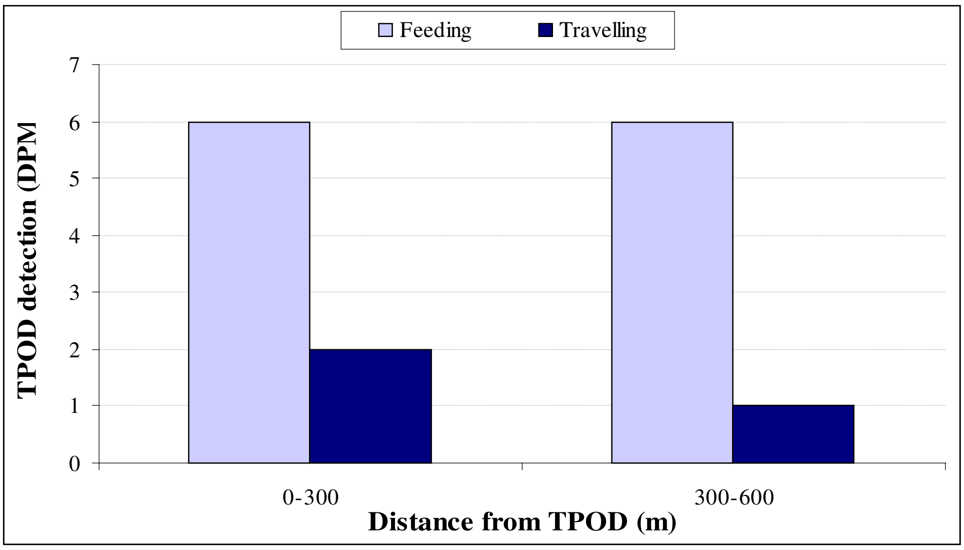


Figure 3.14. New Quay T-POD detection time (DPM) of feeding and travelling animals at distance ranges of 0-300 and 300-650 m from the T-POD.

T-POD detection probability was represented as the percentage of DPM of the total number of minutes that the animals were visually observed to be feeding or travelling at each 50 m range interval. The T-POD detection rate for feeding dolphins was significantly higher than for those travelling ($W_{11,12} = 167.5$, $p = 0.0312$; Appendix **4**).

The highest T-POD detection was observed for dolphins that were feeding within 50 m of the T-POD, where they were detected 50% of the time. Although dolphins were observed travelling within this range, they were not detected acoustically. At 100-150 m, T-POD detection of clicks from dolphins that were feeding was higher (by 4%) than for those travelling. Between 250 and 350 m from the T-POD, travelling dolphins showed a higher T-POD detection (by 4%) than that of feeding animals. At ranges of 150-200, 400-500 and 550-600 m, only feeding animals were detected acoustically. There was no acoustic data for both behaviours at 50-100, 200-250, 350-400 and 500-550 m, (Fig **3.15**).

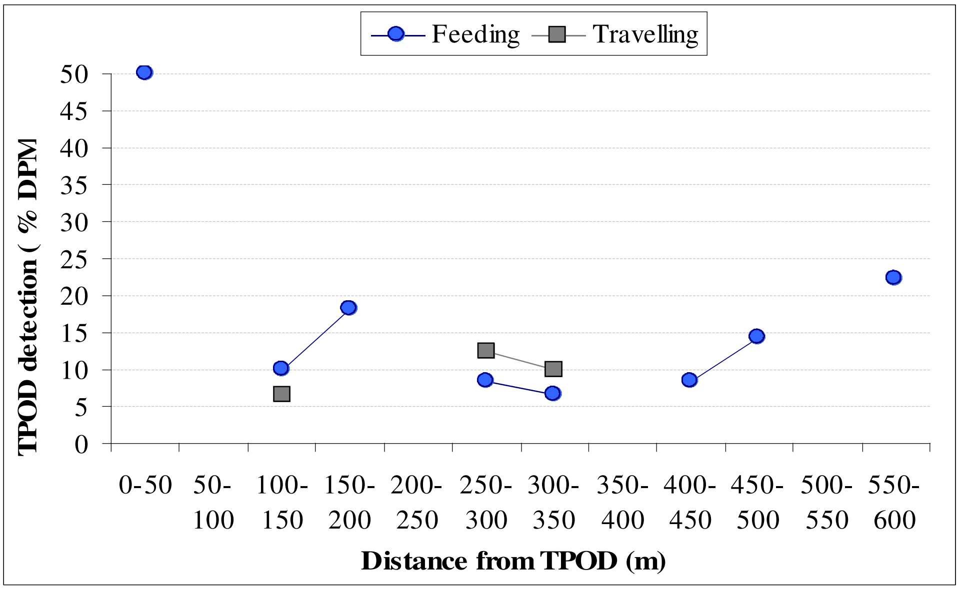


Figure 3.15. New Quay T-POD detection as % of DPM of the total number of minutes that the dolphins were visually observed to be feeding or travelling at each 50 m range.

3.4 Acoustic behaviour

Bottlenose dolphin click trains detected by the T-POD showed a relatively wide range of duration, number of clicks and inter-click intervals (ICI). The longest and shortest click trains were recorded when the animals were feeding, with a maximum duration of 485.5 ms, and a minimum of 3.7 ms. Click trains produced by travelling animals had a maximum duration of 232 ms, and a minimum of 11 ms. The minimum number of clicks in the trains was 4 for both behaviours. The maximum number of clicks was 68 for feeding, and 25 for travelling. Inter-click intervals (ICI) in trains produced by dolphins that were feeding, ranged from 239 to 286 μs, and those travelling ranged from 666 to 1839 μs, (Table **3.4**; Appendix **G**).

	Feeding		Travelling	
	Max	**Min**	**Max**	**Min**
Train Durat. (ms)	485,5	3,7	232	11
No of Clicks	68	4	25	4
ICI (μs)	286	239	1839	666

Table 3.4. Click train maximum and minimum values for: Train duration (ms), Inter-click interval (ICI) (μs) and Number of clicks; for feeding and travelling behaviours.

Train duration of click trains emitted by dolphins that were feeding showed no significant difference with train duration of travelling animals ($W_{211,26}$ = 24828.0, p= 0.3951; Appendix **5**). However, click trains from feeding dolphins showed a significantly higher number of clicks ($W_{211,26}$ = 25785.0, p= 0.0406; Appendix **5**) than click trains from dolphins that were travelling. Travelling dolphins produced click trains that ranged from 4 to approximately 30 clicks, whereas feeding click trains ranged from 4 to approximately 70 clicks. A positive relationship was observed between mean click train duration and number of clicks, except for: travelling click trains of 10-20 clicks which had a mean duration time slightly lower than that of trains with 4-10 clicks; and feeding click trains of 60-70 clicks which had a mean duration time lower than that of trains with 20-60 clicks, (Fig **3.16**).

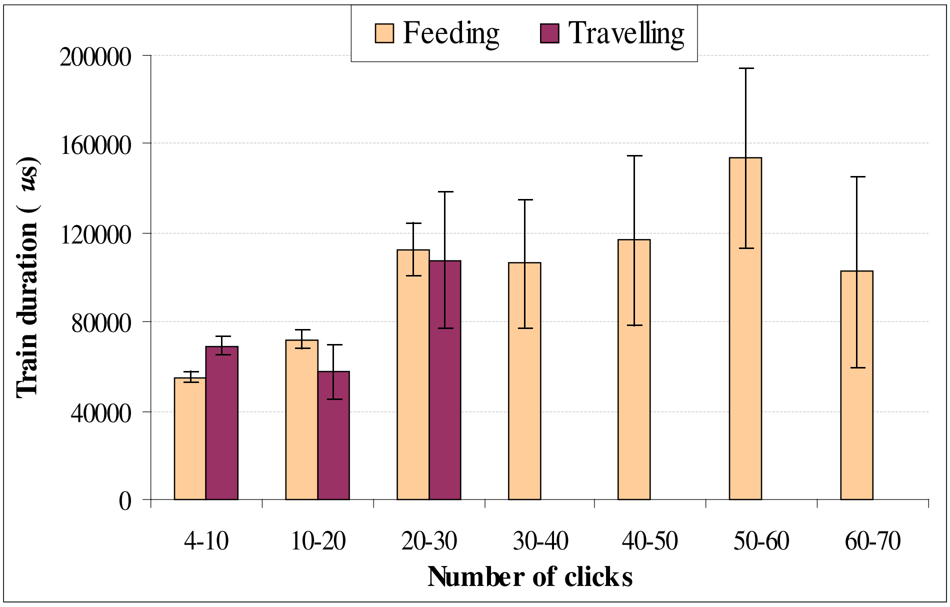


Figure 3.16. Mean (SE mean) train duration time (µs) of feeding and travelling click trains with increasing number of clicks (10 clicks intervals).

Maximum ICI for click trains from feeding dolphins were significantly lower than those of click trains from travelling dolphins ($W_{176,20}$= 16817.9, p= 0.0310, Appendix **5**). This difference involved click trains with max ICI that differed by more than 1000 µs between feeding and travelling animals. Minimum ICI were also significantly lower for click trains emitted by feeding dolphins than those by travelling animals ($W_{177,20}$ = 17011.0, p= 0.0343, Appendix **5**), with values that differed by slightly less than 50 µs, (Fig **3.17**).

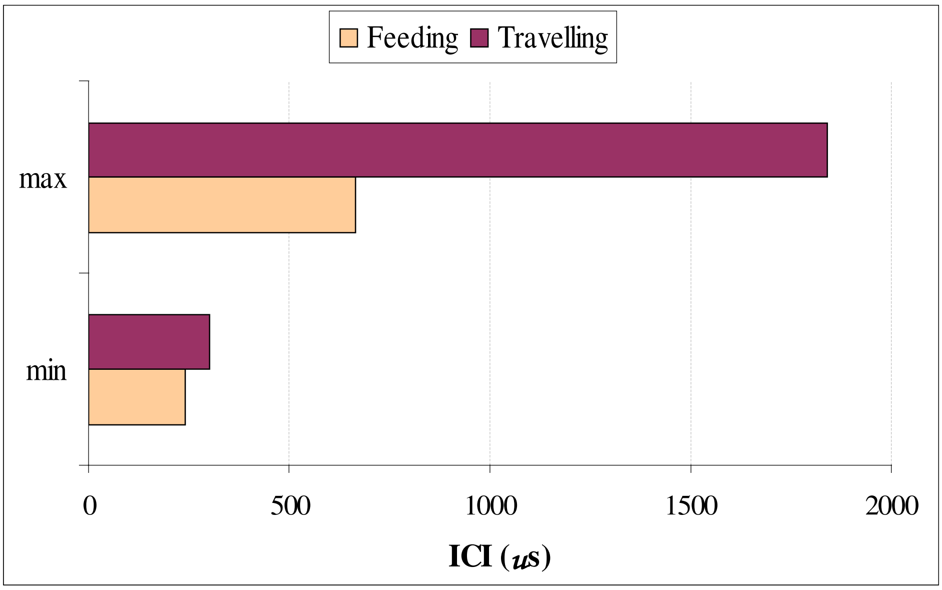


Figure 3.17. Maximum (max) and minimum (min) ICI of click trains emitted by travelling and feeding dolphins.

4: Discussion

4 Discussion

4.1 Success

The objectives of the visual observations were to record distances between bottlenose dolphins and the T-PODs; and to determine whether one could acoustically identify feeding and travelling behaviour of the observed dolphins. Distances between dolphin and T-POD were achieved for a high proportion of the total observations (71.3% for both locations; 73.2% for Mwnt and 65.3% for New Quay). Distance records for every minute of the sightings were not achievable, due to the fact that the dolphins surfaced at irregular time intervals that ranged from a few seconds to several minutes. The distances obtained ranged from a few metres to four kilometres between the dolphins and the T-PODs, thus providing a wide range for analysing T-POD detection range and probability. Identification of feeding and travelling behaviour was successfully achieved for a large proportion of data (93.5%), which provided good data sets for comparing T-POD detection probability for feeding and travelling animals.

The T-POD survey had the objective of detecting click trains from bottlenose dolphins. The mooring system performed excellently, and the T-POD remained at the exact deployment location throughout the study period. The T-PODs successfully recorded click trains except for one deployment off Mwnt T-POD (unit 421), which did not record any data from the 13th to the 31st of July.

Comparison between both surveys aimed to obtain T-POD detection range and probability, and to investigate the possibility of identifying particular dolphin behaviours from T-POD data. For the analysis of T-POD detection range and probability, a total of 127 DPM were recorded on the Mwnt T-POD during which visual observations were carried out. Of these, 105 DPM were matched with visual data, and at New Quay a total of 18 DPM were recorded, resulting in 15 DPM matched with visual data. Therefore the proportion of 'minute units matched' from the total 'minute units shared' between surveys was 82.7% (82.7% for Mwnt and 83% for New Quay). This proportion was relatively high bearing in mind that bottlenose dolphins can hold their breath for up to 8 minutes (Skrovan *et al*. 1999; Reynolds *et al*. 2000). Thus the diving duration could be several minutes long, leading to relatively big gaps in time between the acoustic and visual detection. This study only matched data with a maximum of (±) one minute gap in order to minimize distance errors. The proportion of T-POD DPM matched with visual data when analysing acoustic behaviour was 1:1. In this case, only visual identification of behaviour was required, so that matching with time gaps of up to five minutes was viable.

4.2 T-POD detection range

The T-POD detection ranges obtained for Mwnt and New Quay T-PODs were relatively similar with maximum distances of 638 m (± 53.6) and 590 m (± 85.7), respectively. Bearing in mind possible errors from theodolite tracking, T-POD detection range for Mwnt T-POD was considered to be up to 650 m, and for New Quay T-POD up to 600 m. It should be mentioned that this study had a shorter survey period and smaller sample size for New Quay than for Mwnt. In addition, at Mwnt, the dolphins were mainly close to the T-POD whereas at New Quay, they were less closely associated with the site. The total simultaneous acoustic and visual data matched for New Quay was only 15 'minute' units, suggesting the possibility that the 'top' T-POD detection distance range was not obtained at this site.

The relatively small difference in detection range could be related to the different absolute sensitivity of the T-PODs. Previous simultaneous deployments of T-

PODs have shown that different T-POD versions and units had different sensitivities (Ingram *et al.,* 2004, Simon *et al.* in prep.). Therefore one might expect to find some degree of detection range difference for every T-POD. Nevertheless, Mwnt and New Quay T-PODs were calibrated to provide comparable sensitivities (Simon *et al*. 2005): Mwnt T-POD (421 version 4) had an absolute sensitivity of 129 dB re. 1 µPa, and New Quay T-POD (145 version 3) had an absolute sensitivity of 126 dB re. 1 µPa, (both with a bias of ± 2 dB re 1 µPa).

Taking into account distance errors, it should be considered that the detection range for both T-PODs is approximately 650m. T-POD detection range depends not only on the sensitivity of the T-PODs but also on the abilities of the dolphin sonar. Ivanov (2004) studied the abilities of bottlenose dolphin sonar under laboratory conditions, and he found that the dolphins were able to detect objects at distances exceeding 650 m.

Ingram *et al.* (2004) investigated T-POD performance off the west coast of Ireland and obtained a detection range of approximately 1,500 m, with a maximum distance of 1,631 m. This range was considerably larger than the 638 m obtained in this survey, suggesting that maybe the bottlenose dolphins in Ireland were making louder clicks or using more click trains than those in Cardigan Bay.

Ingram *et al.* (2004) calculated the distances between bottlenose dolphins and T-PODs by using theodolite data for animals around a total of nine T-PODs, and for a total period of nine months. Similarly to this study, they deployed the T-PODs 1 m above the sea bed, at approximately 10 m depth. The methodology was similar to the one used in this study, but they had greater survey effort, which gave them a greater probability of encounters with acoustic detection. However, they obtained fewer comparable visual and acoustic data (14 days) than this survey (25 days).

Similar to Ingram *et al.* (2004), the visual observations in this study recorded dolphins at relatively long distances, ranging from a few metres to four kilometres. Approximately a third of these data involved distances greater than the 650 m of T-POD detection range. This reflected the fact that although dolphins were present at relatively large distances, no acoustic detection occurred. It should be mentioned that calculating distances from theodolite data could itself be an important source of error. This survey counteracted for errors that derived from swell, tide height, platform altitude and target distance. Ingram *et al.* (2004) collected data on days of good conditions, in order to minimise swell error; but they did not account for any of the other parameters. The consequences of ignoring these factors could lead to very great distance errors. For example, one metre error in platform height could lead to distance errors of up to approximately 400 m (Pryor and Norris, 1998).

The matching analysis between acoustic and visual data differed between both surveys. Ingram *et al.* (2004) matched T-POD data with the closest approach of distance record, which involved time gaps of up to 5 minutes. One example of such a gap was their maximum distance obtained of 1,631 m: one dolphin was visually recorded at this distance (13:07 hours), five minutes before it was acoustically detected (13:12 hours), and two minutes later (13:14 hours) it was visually recorded at 914 m. The animal had come closer to the T-POD, suggesting that the T-POD may have detected the dolphin when it was at 914 m from the T-POD instead of 1,631 m, thus showing that these time delays could lead to great distance errors. Nevertheless, Ingram *et al.* (2004) obtained synchronous matching within a 1,500 m range. The present study tried to minimize this type of distance error: first, by synchronizing accurately the T-POD clock and the clock used in visual observation; and second, by matching visual and T-POD data with only a (±) one minute gap. Another source of error when matching visual and acoustic data is the presence of two or more animals that are not close together. This could lead to mistakes when matching acoustic data with animals that are at a greater distance. In order to counteract these errors, Ingram *et al* (2004) as well as in this study, ensured that the visual observations focused on the individual(s) closest to the T-POD.

It is important to choose the T-POD mooring location carefully, investigating the topography in the area, because the propagation of dolphin echolocation clicks is easily scattered and reflected by underwater sea mounts, etc. (Urick, 1983; Au, 1993; Richardson, 1995). The hydrophone of the T-PODs deployed in this study was located at approximately one and a half metre above the sea bed. Bathymetric maps of the study area (Simon *et al*. in prep**.**) showed it to be relatively flat with no significant elevations or slopes. In addition, the deployment sites were investigated using echo sounders to ensure that there were no obstacles near the Mwnt and New Quay T-PODs.

T-POD detection range could be determined by several parameters of a physical and biological nature, such as: underwater acoustics; source level and propagation of dolphin clicks; and acoustic behaviour of the animal. Since these factors could not be controlled by the study, they were considered to affect T-POD detection probability, and are thus discussed further in section **4.3**

4.3 T-POD detection probability

The T-POD detection probability of bottlenose dolphins varied between Mwnt and New Quay T-PODs. The detection probability was expressed as percentage of T-POD detection positive minutes (DPM) out of the total time (in 'minute' units) that the dolphins were visually observed within the T-POD detection range. Dolphins observed around Mwnt T-POD were acoustically detected 13 percent of the time, whereas those around New Quay T-POD were acoustically detected only 7 percent of the time. It is important to mention that there was a big difference in sample size. Mwnt visual and acoustic data were matched for 105 minutes, and New Quay data were matched for only 15 minutes. Therefore, New Quay T-POD data were considered less representative than those from Mwnt.

Overall, the T-POD detection probability value obtained for both T-PODs was 11 percent, reflecting that the T-PODs detected the dolphins for only a small proportion of time. This study was the first one investigating T-POD detection probability of bottlenose dolphin clicks, thus there are no data in the literature for comparison. Although, Ingram *et al.* (2004) did not account for detection probability, they noticed that dolphins approaching the T-PODs were not always detected acoustically.

Passive acoustic techniques rely on animals being vocal, so that T-POD detection is limited by the possibility of the dolphins being silent or using frequencies outside the T-POD detection range. Studies on captive bottlenose dolphin have shown that echolocation signals may vary between individuals and within the same individual, with peak frequencies ranging between 100-300 kHz (Au, 1993; Au & Herzing, 2002; Au, 2003; Ivanov, 2004). Studies on wild spotted dolphin (*Stenella frontalis*; Au & Herzing, 2002), beluga (*Delphinapterus leucas*; Au *et al.* 1987) and false killer whale (*Pseudorce* crassidens; Au *et al.* 1995) reported that the central frequency of echolocation signals tends to vary with the intensity of the emitted click. They observed that higher intensity clicks contained higher frequencies than lower intensity clicks. However, even with all these possible variations of frequencies within echolocation clicks, most of such signals normally comprise frequencies within the frequency range set on the T-POD channels to detect bottlenose dolphins, and should therefore be recorded.

The results showed that the distance between the dolphins and the T-POD affected T-POD detection probability. T-POD detection probability was calculated for range categories of 100 m. It was observed that the probability of detecting dolphin clicks decreased as the dolphins were further away from the T-POD, with a sharp decline in detection rate beyond 300 m. Knowles (2002) produced a feasibility report on T-PODs at Durlston Marine Research area, and similar to this study, she found a minimum T-POD detection range of bottlenose dolphin clicks of 300 m.

The reception of sonar activity on the T-PODs depended on the received level (RL) of the clicks. Echolocation signals are subjected to factors such as variation of source levels (SL), transmission loss, masking effects and directionality, which could all have influenced the received level at the T-POD, and could therefore play an important role in T-POD detection probability.

Au (1993) studied captive bottlenose dolphins and showed that the source level fluctuated among and within individuals. He observed a source level maximum variation of 20 dB re 1 μPa, and that it occurred under the influence of variations in target size and range, difficulty of discrimination task, background noise, and whether the sound was masked by noise of reverberation, with the source level of their echolocation signals increasing as target range increased, target size decreased, and the difficulty of the discrimination task increased (Au, 1980; Au, 1993; Au & Herzing, 2002). Au (1993) observed that the dolphins also increased their source levels as the masking noise increased, except for dolphins that were already producing relatively high intensity signals and could not increase the power of their signals any further; no dolphin increased the amplitude of the signal when the masking noise was above 12 dB re 1 μPa.

The propagation of sonar signals are always subjected to transmission loss over distance, where the higher the source level, the higher the distance that the signal can travel (Au, 1993). Thus, as the dolphins were further away from the T-POD, the source level of the echolocation signals needed to be higher in order for the received level of the clicks to be detected by the T-POD hydrophone. In addition, transmission loss is affected by water depth and substrate, becoming greater in shallow waters, where there is much loss of sound by reflection off the seabed (Au, 1993). It was suggested that as the distance between dolphins and the T-POD increases, and as the dolphins emit sonar signals with relatively low source levels (e.g. when scanning big, easy to discriminate, nearby targets, and without any masking noise), the received level of the clicks tend to decrease, having a negative effect on T-POD detection probability.

The echolocation signals of many delphinids have been shown in the literature to be directional. Evidence of this phenomenon for bottlenose dolphins has been given by Norris *et al*. (1961), Evans *et al.* (1964), Evans (1973), Au *et al*. (1978), Au (1980), Au *et al.* (1986) and Au (1993). Au (1993) found that the click projection had a 3 dB re 1 μPa beam width of approximately 10º in both the vertical and horizontal planes. In the horizontal plane, the beam was pointed ahead of the dolphin and parallel to the longitudinal axis of the animal. In the vertical plane, the beam was directed between 5º and 10º above the longitudinal axis of the animal. This narrow propagation of sonar pulses could diminish significantly the received level of clicks reaching the T-POD.

Therefore, it is suggested that directionality plays an important role in T-POD detection probability, and that many of the echolocation clicks that reached the T-POD came from signals emitted by dolphins with the head pointed towards the T-POD.

The results showed that T-POD detection was affected by bottlenose dolphin behaviour: when the dolphins were feeding, the T-POD detection probability was significantly higher than when they were travelling. The first factor to consider is the amount of sonar activity in each behaviour. Dolphins locate prey by using their sonar (Au, 1993), and therefore it is suggested that they emit more echolocation clicks when they are feeding and foraging than when they are travelling. Dos Santos *et al.* (1990) studied bottlenose dolphins in the wild and reported that the dolphins produced the highest amount of click trains when they were feeding or scanning. Acevedo-Gutierrez and Stienessen (2004) recoded feeding and non feeding groups of wild bottlenose dolphins, and observed that more whistles than burst pulse sounds and click trains were produced when the dolphins were feeding. They also observed no difference in the proportion of each sound type produced when the dolphins were not feeding. To my knowledge, there is no reference on the literature to the amount of click trains produced when the dolphins are travelling. The T-PODs detected travelling dolphins, which reflects that they were indeed emitting click trains, probably performing some degree of scanning or simply using echolocation while travelling. Nevertheless, the difference in T-POD detection observed in this study suggested that the dolphins were producing more sonar pulses when they were feeding (this has also been reported for other odontocetes e.g. killer whales; Ford, 1989). Furthermore, in many cases, travelling dolphins that were visually recorded within 50 m from the T-POD, were not acoustically detected. Therefore, even if travelling dolphins were showing relatively high sonar activity, some other factor must be affecting T-POD detection.

Echolocation signals are highly directional, and head orientation controls the direction of the propagation of the pulses (Norris *et al.,* 1961; Evans *et al.*, 1964; Evans, 1973; Au *et al.*, 1978; Au *et al.,* 1986 and Au, 1993). It is suggested that feeding and foraging dolphins would tend to move around more, for example when chasing a school of fish from different positions. This would lead to the head position varying within the horizontal and vertical planes, increasing the probability of emitting signals in the same direction as the T-POD location, and therefore favouring T-POD detection probability. In addition, it has been reported that the dolphins also move their head while they are scanning (Au, 1993), and it may be possible that dolphins scan while travelling, but that they might not move around as much as when they are feeding because they travel in a straight line. Therefore, it is suggested that direction of travel may be an important factor affecting T-POD detection probability of travelling dolphins.

4.4 Acoustic behaviour

The amount of click trains detected as DPM on Mwnt and New Quay T-PODs, and matched with visual identified behaviour, differed between behaviours. A much larger sample size for click trains from feeding dolphins (224 min.) was obtained than for those from travelling animals (28 min.). This difference in sample size forced one to use non-parametric statistics, and thus no powerful analysis could be carried out. Nevertheless, the statistical analysis revealed that there was no significant difference in train duration, but there was a significant difference in the number of clicks and inter-click intervals (ICI).

There was a positive relationship between train duration and number of clicks, except for click trains with more than 60 clicks. This relationship agreed with Au (1993) who studied captive bottlenose dolphins and found that the amount of time that the dolphins spent performing a sonar signal was directly proportional to the number of clicks emitted. This study showed that dolphins that were travelling emitted click trains with less than 25 clicks, whereas click trains from feeding dolphins produced up to 68 clicks. There is a tendency for dolphins to emit more clicks as a sonar task becomes progressively more difficult (Au, 1993; Herzing, 2000; Au, 2003). Feeding dolphins need to locate specific targets, i.e. relatively small prey, and therefore it is expected that they emit click trains with more clicks than travelling dolphins, which generally are not scanning specific targets, or targets with such degree of difficulty. Au (1993) observed that the number of clicks emitted when scanning specific targets ranged from 33 to 199. The maximum number of clicks in a train found by Au (1993) when studying captive dolphins was therefore generally higher than for this study.

Click trains from dolphins that were feeding also showed a significantly lower maximum and minimum ICI than trains emitted by dolphins that were travelling. Echolocation click trains have been classified into two or three general types:

'orientation clicks' with relatively long ICI that are used to scan the environment (Richardson *et al.*, 1995); 'discrimination clicks', often at briefer intervals that are used to obtained detailed information about a target (Popper, 1980; Au, 1993) and some click trains that may represent 'non-functional collateral acoustic behaviour', or part of the pulse production process (Au *et al.*, 1987). Therefore, travelling dolphins may have been emitting 'orientation clicks' with long ICI; hence they are not locating any specific target, but searching the general environment. On the other hand, feeding dolphins may have been locating specific prey by using 'discrimination clicks' with shorter ICI.

This study has found that bottlenose dolphin echolocation activity varied between travelling and feeding dolphins. This difference in acoustic behaviour could be identified from the click trains logged on the T-PODs by looking at the number of clicks and ICI. Feeding behaviour could be reflected by click trains comprising 4 to 70 clicks, and with ICI shorter than 350 µs. Travelling behaviour could be identified from click trains with 25 or less clicks, and with ICI longer than 600 µs.

4.5 Limitations of the survey and future research

One of the main problems of this study has been the sample size, which was significantly reduced due to the failure of one T-POD during part of the fieldwork. A longer study period would have provided a greater quantity and therefore more reliable data. The land-based visual observations carried out in this study had the advantages of: providing accurate distances between the dolphins and the T-POD; and being non invasive, thus not altering the behaviour of the dolphins. T-PODs are a powerful tool for monitoring both bottlenose dolphins and harbour porpoises over long periods of time, and through all weathers, and are useful in the study of habitat use by the two species (Verfuss *et al*., in prep. and Simon *et al,* in prep). Weather and light conditions limit traditional types of visual survey used to estimate animal abundance. T-PODs are potentially a useful tool for estimating dolphin abundance, but many variables, including: group size, distance between the animals and the T-POD, background noise, and click rates during different behaviours; affecting click detection rates, all have to be clarified first. This study was a first attempt to clarify some of these variables, showing a clear dependence of the T-POD detection probability on the distance of the dolphins from the equipment, and the type of dolphin behaviour. This is the first study to suggest that T-PODs might be a useful tool to identify particular bottlenose dolphin behaviours. Further research is needed in this field, and a next step could be to deploy the T-PODs near a bottom moored hydrophone in order to obtain better information on those clicks, and other bottlenose dolphin phonations, not recorded by the T-POD.

5: Conclusions

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5 Conclusions

This study aimed to investigate T-POD performance when studying bottlenose dolphins by: measuring the detection range and probability in the presence of dolphins and investigating the possibility of identifying particular dolphin behaviours from T-POD data.

The T-POD detection range showed that the T-PODs detected bottlenose dolphin echolocation activity within a distance range of 650 m. This survey showed that when bottlenose dolphins were present within this range, the T-PODs detected them 11.4% of the time.

T-POD detection probability was negatively affected by distance. As dolphins moved further away from the T-POD, the detection rate decreased, with a sharp decline in detection rate beyond 300 m. In addition, the detection probability varied with dolphin behaviour so that dolphins that were feeding had a significantly higher probability of being detected by the T-POD than dolphins that were travelling.

Finally, this survey showed that particular bottlenose dolphin behaviour could be identified from T-POD data. T-POD data showed that dolphins that were feeding emitted click trains with significantly higher numbers of clicks, and had significantly lower inter click intervals than travelling dolphins, suggesting that click trains with high numbers of clicks (< 30) and low minimum inter click intervals (< 350 μs) identify feeding behaviour in T-POD data.

This study was a first attempt to clarify some of the variables affecting T-POD detection of bottlenose dolphin clicks, which could be an important first step towards the use of T-PODs for studies on abundance estimation, habitat use and spatio-temporal behavioural patterns.

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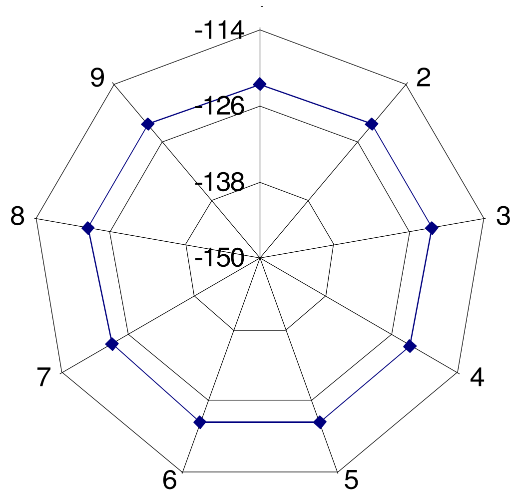
Appendix: 1 - 5

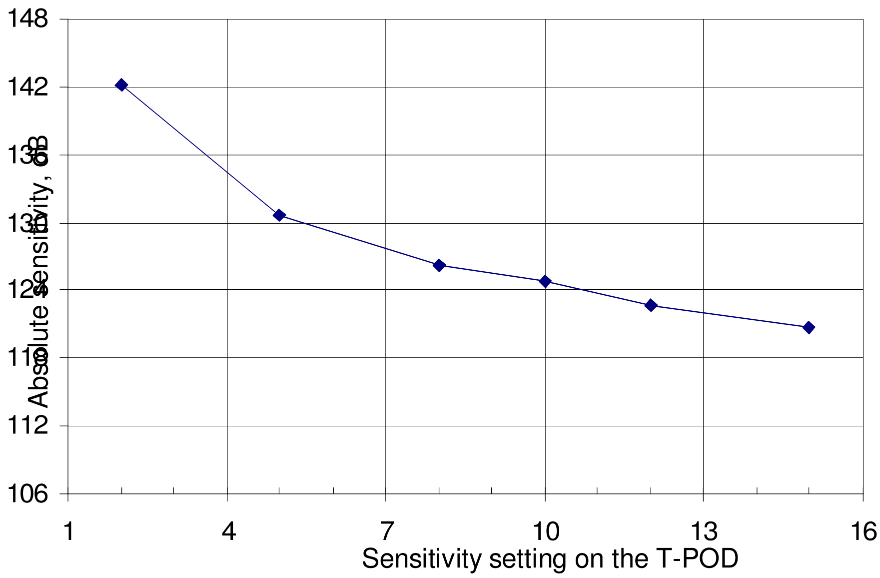
Appendix 1

T-PODs calibration

Mwnt T-POD: Pool calibration of T-POD 421 (Version 4)



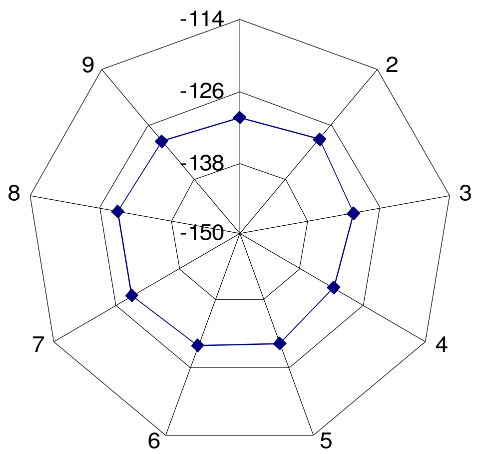
The hydrophone of T-POD 421 has an omni directionality of ±0.7dB.



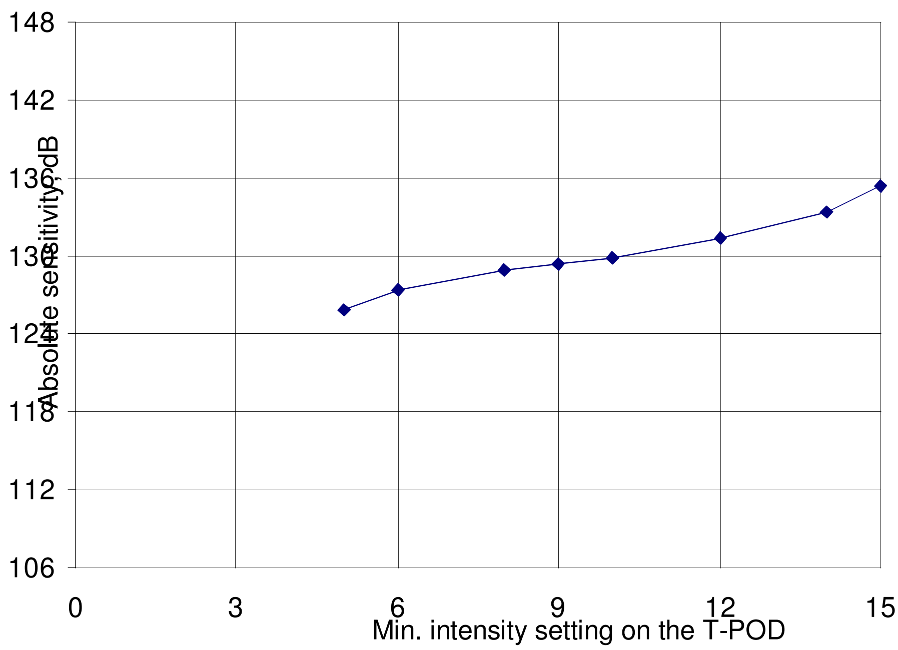
Absolute sensitivity of T-POD 421 at the different sensitivity settings.

These calibrations were made in Ursula Verfuß's laboratory.

New Quay T-POD: Pool calibration of T-POD 145 (Version 3)



The hydrophone of T-POD 145 has an omni directionality of ±2.6dB.



Absolute sensitivity of T-POD 145 at the different minimum intensity settings.

These calibrations were made in Ursula Verfuß's laboratory

Appendix 2

Environmental Form

Date: ______________ Observer: ________________

Station: ________________

Eyepiece height: __________ cm

T	S	B	H	D	Theod. Angles	C	Sighting #
					V		
					H		
					V		
					H		
					V		
					H		
					V		
					H		
					V		
					H		
					V		
					H		
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					V		
					H		
					V		
					H		
					V		
					H		
					V		
					H		

Appendix 3

Sighting form

Station: ____________________ Date ____________________

Sighting #: ____________ Observer ____________________

Specie: ____________________ Group size: ____________________

Start time: ____________________ Stop time: ____________________

Time	Vertical angle	Horizontal angle	Behaviour	Direction

Appendix 4

Statistical analysis for T-POD detection

T-POD detection probability over **distance**

Normal Prob Plot: RESI2

```
Anderson-Darling Normality Test
A-Squared: 0.285
P-Value:   0.573
```

Test for Equal Variances

```
Response    time
Factors     site
ConfLvl     95.0000

Bonferroni confidence intervals for standard deviations

  Lower      Sigma     Upper      N  Factor Levels

 6.09624   10.0309   25.2328    7  MW
 2.10111    3.4572    8.6967    7  NQ

F-Test (normal distribution)

Test Statistic: 8.418
P-Value       : 0.020

Levene's Test (any continuous distribution)

Test Statistic: 1.861
P-Value       : 0.198
```

Test for Equal Variances: time vs site

MWNT

General Linear Model: % TPOD Detection (min) versus

```
Factor     Type Levels Values

Analysis of Variance for % TPOD D, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Distance    1     393.75     393.75     393.75    9.38  0.028
Error       5     209.96     209.96      41.99
Total       6     603.71

Term          Coef   SE Coef        T      P
Constant    22.554     4.937     4.57  0.006
Distance  -0.03750   0.01225    -3.06  0.028
```

% detection = -0.0375distance + 22.554

NEW QUAY

General Linear Model: % TPOD Detection (min) versus

```
Factor      Type Levels Values

Analysis of Variance for % TPOD D, using Adjusted SS for Tests

Source      DF      Seq SS      Adj SS      Adj MS       F       P
Distance     1       3.657       3.657       3.657    0.83   0.414
Error        4      17.676      17.676       4.419
Total        5      21.333

Term           Coef    SE Coef         T       P
Constant      6.295      1.735      3.63   0.022
Distance   0.004571   0.005025      0.91   0.414
```

% detection = 0.004571 + 6.295

MWNT AND NEW QUAY

Two-Sample T-Test and CI: Mwnt, NQ

```
Two-sample T for Mwnt vs NQ

      N       Mean      StDev   SE Mean
Mwnt  7        9.4       10.0       3.8
NQ    7       6.57       3.46       1.3

Difference = mu Mwnt - mu NQ
Estimate for difference:  2.86
95% CI for difference: (-6.63, 12.35)
T-Test of difference = 0 (vs not =): T-Value = 0.71  P-Value =
0.499  DF = 7
```

General Linear Model: T-POD prob versus

```
Factor      Type Levels Values

Analysis of Variance for T-POD pr, using Adjusted SS for Tests

Source      DF      Seq SS      Adj SS      Adj MS       F       P
distance     1      268.46      268.46      268.46    8.15   0.036
Error        5      164.69      164.69       32.94
Total        6      433.15

Term           Coef    SE Coef         T       P
Constant     19.709      4.372      4.51   0.006
distance   -0.03096    0.01085     -2.85   0.036
```

T-POD detection probability for **feeding and travelling**

MWNT

Comparing feeding and travelling at 300 m

NORMALITY

Normal Prob Plot: C2

p=0.144 NORMAL

VARIANCE

```
 p=0.049 NOT EQUALLY DISTRIBUTED
```

Test for Equal Variances

```
Response    C2
Factors     Subscripts
ConfLvl     95.0000

Bonferroni confidence intervals for standard deviations

  Lower     Sigma     Upper     N  Factor Levels

 6.03003   10.2843   29.4228    6  Mw F 300
 2.24133    3.8226   10.9363    6  Mw T 300


F-Test (normal distribution)


Test Statistic: 7.238
P-Value       : 0.049


Levene's Test (any continuous distribution)


Test Statistic: 2.518
P-Value       : 0.144
```

Test for Equal Variances: C2 vs Subscripts

COMPARISON

Two-Sample T-Test and CI: C2, Subscripts

```
Two-sample T for C2

Subscrip    N      Mean     StDev   SE Mean
Mw F 300    6      21.2      10.3       4.2
Mw T 300    6      3.88      3.82       1.6

Difference = mu (Mw F 300) - mu (Mw T 300)
Estimate for difference:  17.29
95% CI for difference: (6.32, 28.25)
T-Test of difference = 0 (vs not =): T-Value = 3.86  P-Value =
0.008  DF = 6
```

FEEDING AND TRAVELLING +300M

NORMALITY

Normal Prob Plot: C2

p=0.000 NOT NORMAL

Variance

p= 0.239 EQUAL VARIANCE

```
Macro is running ... please wait
```

Test for Equal Variances

```
Response    C2
Factors     Subscripts
ConfLvl     95.0000

Bonferroni confidence intervals for standard deviations

  Lower      Sigma      Upper      N  Factor Levels

 2.52677   4.15761   10.4585    7  Mw F 650
 3.27167   5.38328   13.5417    7  Mw T 650


F-Test (normal distribution)


Test Statistic: 0.596
P-Value       : 0.546


Levene's Test (any continuous distribution)


Test Statistic: 1.536
P-Value       : 0.239
```

Test for Equal Variances: C2 vs Subscripts

Comparison

Not significant difference

Mann-Whitney Test and CI: Mw F 650, Mw T 650

```
Mw F 650   N =   7     Median =       0.000
Mw T 650   N =   7     Median =       5.263
Point estimate for ETA1-ETA2 is      -2.000
95.9 Percent CI for ETA1-ETA2 is (-11.109,-0.000)
W = 43.5
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.2774
The test is significant at 0.2284 (adjusted for ties)

Cannot reject at alpha = 0.05
```

NEW QUAY

FEEDING AND TRAVELLING 300M

NORMALITY

Normal Prob Plot: C2

p= 0.001 NOT NORMAL

Variance

p=0.329 EQUAL VARIANCE

Test for Equal Variances

```
Response    C2
Factors     Subscripts
ConfLvl     95.0000

Bonferroni confidence intervals for standard deviations

  Lower      Sigma      Upper      N  Factor Levels

 10.3151   17.5926   50.3314     6  NQ F 300
  3.0967    5.2814   15.1099     6  NQ T 300


F-Test (normal distribution)


Test Statistic: 11.096
P-Value       :  0.019

Levene's Test (any continuous distribution)


Test Statistic: 1.051
P-Value       : 0.329
```

Test for Equal Variances: C2 vs Subscripts

COMPARISON

SIGIFICANT DIFFERENCE

Results for: Worksheet 1

Mann-Whitney Test and CI: NQ F 300, NQ T 300

```
NQ F 300   N =   6     Median =       10.00
NQ T 300   N =   6     Median =        0.00
Point estimate for ETA1-ETA2 is       10.00
95.5 Percent CI for ETA1-ETA2 is (-0.01,37.51)
W = 50.0
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.0927
The test is significant at 0.0807 (adjusted for ties)

Cannot reject at alpha = 0.05
```

FEEDING AND TRAVELLING +300M

Normal Prob Plot: C2

0.001 NOT NORMAL

VAriance

```
Macro is running ... please wait
```

Test for Equal Variances

0.111 EQUAL VARIANCE

```
Response    C2
Factors     Subscripts
ConfLvl     95.0000

Bonferroni confidence intervals for standard deviations

  Lower     Sigma     Upper     N  Factor Levels

 5.04125   8.59790   24.5981    6  NQ F 600
 2.39370   4.08248   11.6798    6  NQ T 600


F-Test (normal distribution)

Test Statistic: 4.435
P-Value       : 0.128


Levene's Test (any continuous distribution)


Test Statistic: 3.047
P-Value       : 0.111
```

Test for Equal Variances: C2 vs Subscripts

Comparison

NO SIGNIFICANT DIFFERENCE

Mann-Whitney Test and CI: NQ F 600, NQ T 600

```
NQ F 600   N =   6     Median =        7.50
NQ T 600   N =   6     Median =        0.00
Point estimate for ETA1-ETA2 is        6.67
95.5 Percent CI for ETA1-ETA2 is (0.00,14.28)
W = 48.0
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.1735
The test is significant at 0.1291 (adjusted for ties)

Cannot reject at alpha = 0.05
```

MWNT

comparing 300 m to 600 feeding and travelling toguether

Mann-Whitney Test and CI: C15, C16

```
C15        N =  12     Median =       10.50
```

```
C16         N =  14     Median =        0.00
Point estimate for ETA1-ETA2 is        5.88
95.2 Percent CI for ETA1-ETA2 is (0.00,14.00)
W = 204.5
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.0308
The test is significant at 0.0261 (adjusted for ties)
```

nq

Mann-Whitney Test and CI: NQ 300, NQ 600

```
NQ 300     N =  12     Median =        7.50
NQ 600     N =  12     Median =        0.00
Point estimate for ETA1-ETA2 is        0.00
95.4 Percent CI for ETA1-ETA2 is (-1.66,10.00)
W = 163.5
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.4529
The test is significant at 0.4218 (adjusted for ties)

Cannot reject at alpha = 0.05

Saving file as: C:\My Documents\thesis\data comparison\Tpod detc
BEHAVIOUR 50 m at 300 and 650.MPJ
* NOTE  * Existing file replaced.
```

NEW QUAY F and T NO DISTANCE DISTINCTION

Two-Sample T-Test and CI: NQ F, C22

```
Two-sample T for NQ F vs C22

       N      Mean     StDev   SE Mean
NQ F  12      12.3      13.8       4.0
C22   12      2.43      4.57       1.3

Difference = mu NQ F - mu C22
Estimate for difference:  9.90
95% CI for difference: (0.86, 18.95)
T-Test of difference = 0 (vs not =): T-Value = 2.36  P-Value =
0.034  DF = 13
```

Mann-Whitney Test and CI: NQ F, C22

```
NQ F        N =  12     Median =        9.17
C22         N =  12     Median =        0.00
Point estimate for ETA1-ETA2 is        8.33
95.4 Percent CI for ETA1-ETA2 is (0.00,14.28)
W = 190.0
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.0226
The test is significant at 0.0147 (adjusted for ties)
```

NEW QUAY F and T NO DISTANCE DISTINCTION

Two-Sample T-Test and CI: NQ F, C22

```
Two-sample T for NQ F vs C22

       N      Mean     StDev   SE Mean
NQ F  12      12.3      13.8       4.0
C22   12      2.43      4.57       1.3

Difference = mu NQ F - mu C22
Estimate for difference:  9.90
95% CI for difference: (0.86, 18.95)
T-Test of difference = 0 (vs not =): T-Value = 2.36  P-Value =
0.034  DF = 13
```

Mann-Whitney Test and CI: NQ F, C22

```
NQ F       N =  12     Median =        9.17
C22        N =  12     Median =        0.00
Point estimate for ETA1-ETA2 is        8.33
95.4 Percent CI for ETA1-ETA2 is (0.00,14.28)
W = 190.0
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.0226
The test is significant at 0.0147 (adjusted for ties)
```

Appendix 5

TRAIN DURATION

NORMALITY

all toguether

NOT NORMAL p=0.000

Feeding NOT normal p=0.000
Travelling NOT normal p=0.002

Normal Prob Plot: C2

Normal Prob Plot: F tr duratio

Normal Prob Plot: T tr duratio

VARIANCE

```
 EQUAL VARIANCES  p= 0.398
```

Test for Equal Variances

```
Response    C2
Factors     Subscripts
ConfLvl     95.0000

Bonferroni confidence intervals for standard deviations

  Lower      Sigma      Upper      N  Factor Levels

 70525.0   79000.0   89688.9    176  F tr duration
 42155.6   57540.1   89146.7     20  T tr duration


F-Test (normal distribution)


Test Statistic: 1.885
P-Value       : 0.108


Levene's Test (any continuous distribution)


Test Statistic: 0.717
P-Value       : 0.398
```

Test for Equal Variances: C2 vs Subscripts

COMPARISON

NOT significant difference p= 0.7035

Mann-Whitney Test and CI: F tr duration, T tr duration

```
F tr dur   N = 176     Median =       48506
T tr dur   N =  20     Median =       58181
Point estimate for ETA1-ETA2 is       -4282
95.0 Percent CI for ETA1-ETA2 is (-22605,16655)
W = 17244.0
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.7035

Cannot reject at alpha = 0.05
```

BASIC STATS

Descriptive Statistics: F tr duration, T tr duration

```
Variable             N       Mean     Median     TrMean      StDev
SE Mean
F tr dur           176      76115      48506      66076      79000
5955
T tr dur            20      71098      58181      65499      57540
12866

Variable       Minimum    Maximum         Q1         Q3
F tr dur          3679     485491      23064      96020
T tr dur         10879     232102      32149      92789
```

NUMBER OF CLICKS

Normality

all toguether NOT normal p=0.000

Feeding NOT normal p=0.000
Travelling NOT normal p= 0.001

```
Welcome to Minitab, press F1 for help.
Macro is running ... please wait
```

Results for: Worksheet 2

Normal Prob Plot: C2

```
Macro is running ... please wait
```

Results for: Worksheet 1

Normal Prob Plot: F num cl

```
Macro is running ... please wait
```

Normal Prob Plot: T num cl

VARIANCE

equal variance p=0.222

```
Macro is running ... please wait
```

Results for: Worksheet 2

Test for Equal Variances

```
Response    C2
Factors     Subscripts
ConfLvl     95.0000

Bonferroni confidence intervals for standard deviations

  Lower      Sigma     Upper      N  Factor Levels

 10.5551   11.8235   13.4233    176  F num cl
  4.4966    6.1377    9.5091     20  T num cl

F-Test (normal distribution)

Test Statistic: 3.711
P-Value       : 0.002

Levene's Test (any continuous distribution)

Test Statistic: 1.502
P-Value       : 0.222
```

Test for Equal Variances: C2 vs Subscripts

COMPARISON

SIGNIFICANT DIFFERENCE p= 0.0109

Mann-Whitney Test and CI: F num cl, T num cl

```
F num cl   N = 176     Median =      10.000
T num cl   N =  20     Median =       6.500
Point estimate for ETA1-ETA2 is       3.000
95.0 Percent CI for ETA1-ETA2 is (0.998,5.001)
W = 17948.5
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.0109
The test is significant at 0.0107 (adjusted for ties)
```

BASIC STATS

Descriptive Statistics: F num cl, T num cl

```
Variable            N       Mean     Median     TrMean      StDev
SE Mean
F num cl          176     14.165     10.000     12.519     11.824
0.891
T num cl           20       9.25       6.50       8.67       6.14
1.37

Variable      Minimum    Maximum         Q1         Q3
F num cl        4.000     68.000      7.000     16.000
T num cl         4.00      25.00       5.00       11.0
```

MAX ICI

NORMALITY

all toguether
Not normal p=0.000

Feeding NOT normal p=0.000
Travelling Normal p=0.342

```
Welcome to Minitab, press F1 for help.
Macro is running ... please wait
```

Normal Prob Plot: C2

Normal Prob Plot: F max ICI

Normal Prob Plot: T max ICI

VARIANCE

```
 EQUAL VARIANCE p=0.586
```

Test for Equal Variances

```
Response    C2
Factors     Subscripts
ConfLvl     95.0000

Bonferroni confidence intervals for standard deviations

  Lower      Sigma      Upper      N  Factor Levels

 7953.30   8909.05   10114.5    176   F max ICI
 6634.51   9055.75   14030.0     20   T max ICI


F-Test (normal distribution)


Test Statistic: 0.968
P-Value       : 0.851


Levene's Test (any continuous distribution)


Test Statistic: 0.298
P-Value       : 0.586
```

Test for Equal Variances: C2 vs Subscripts

COMPARISON

SIGNIFICANT DIFFERENCE p=0.310

Results for: Worksheet 1

Mann-Whitney Test and CI: F max ICI, T max ICI

```
F max IC   N = 176     Median =        5434
T max IC   N =  20     Median =       12023
Point estimate for ETA1-ETA2 is       -3807
95.0 Percent CI for ETA1-ETA2 is (-8517,-378)
W = 16817.0
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.0310
The test is significant at 0.0310 (adjusted for ties)
```

BASIC STATS

Descriptive Statistics: F max ICI, T max ICI

```
Variable             N        Mean      Median      TrMean       StDev
SE Mean
F max IC           176        9261        5434        8427        8909
672
T max IC            20       13277       12023       12948        9056
2025

Variable       Minimum     Maximum          Q1          Q3
F max IC           302       44524        2814       14057
T max IC          1839       30641        4594       19829
```

MIN ICI

NORMALITY

ALL TOGUETHER
not normal p=0.000

Feeding NOT normal p=0.000
Travelling normal p=0.458

VARIANCE

Equal Variance p=0.682

Normal Prob Plot: C2

Normal Prob Plot: F min ICI

Normal Prob Plot: T min ICI

VARIANCE

Test for Equal Variances

```
Response    C2
Factors     Subscripts
ConfLvl     95.0000

Bonferroni confidence intervals for standard deviations

  Lower      Sigma      Upper      N  Factor Levels

 5190.83   5812.84   6596.81    177  F min ICI
 4493.53   6133.43   9502.50     20  T min ICI


F-Test (normal distribution)


Test Statistic: 0.898
P-Value       : 0.682


Levene's Test (any continuous distribution)


Test Statistic: 0.583
P-Value       : 0.446
```

Test for Equal Variances: C2 vs Subscripts

COMPARISON

SIGNIFICANCE DIFFERENCE p=0.043

Mann-Whitney Test and CI: F min ICI, T min ICI

```
F min IC   N = 177     Median =      4449.0
T min IC   N =  20     Median =      8441.5
Point estimate for ETA1-ETA2 is     -2882.5
95.0 Percent CI for ETA1-ETA2 is (-5999.9,-226.9)
W = 17011.0
Test of ETA1 = ETA2  vs  ETA1 not = ETA2 is significant at 0.0343
```

BASIC STATS

Descriptive Statistics: F min ICI, T min ICI

```
Variable             N        Mean      Median      TrMean       StDev
SE Mean
F min IC           177        6322        4449        5828        5813
437
T min IC            20        9123        8442        8895        6133
1371

Variable       Minimum     Maximum          Q1          Q3
F min IC           239       25171        1850        8119
T min IC           666       21691        3386       14981
```

Appendix: A - G

This box should contain a Data CD Rom

Contact: zamerce@yahoo.es