Can echolocation devices be used to define harbour use by Maui's dolphins?

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ABSTRACT

A pilot study was undertaken from 1 April to 30 June 2003 to investigate the distributional movement patterns of the Maui's dolphin (*Cephalorhynchus hectori maui*) within the Manukau Harbour region, New Zealand. Porpoise detection devices (PODs), which are self-contained submersible computers and hydrophone loggers that recognise and log echolocation ultrasound clicks of dolphins, were used. 'Acoustic fences' could be established across the width of the harbour entrance, using PODs to analyse time-specific data on direction of movement and time spent inside the harbour by Maui's dolphins. The pilot study was focused on calibrating the PODs and determining the feasibility of using them. Controlled POD tests were on recorded Hector's dolphin sounds over two days and again in different waterbodies within the Manukau Harbour. POD tests for dolphins actually sighted outside of the Manukau Harbour region were also done over a two-day period. Physical constraints important in planned moorings and placement of PODs across the harbour channel mouth were also reviewed. Actual and potential problems with the technique were discussed. Firm conclusions could not be drawn because of the lack of encounters with dolphins during the feasibility trials.

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Keywords: Maui's dolphins, *Cephalorhynchus hectori maui*, porpoise detection device calibration, acoustic fence, dolphin movements, dolphin vocalisations.

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1. Introduction

The Hectors dolphin (*Cephalorhynchus hectori*) is endemic to New Zealand and was historically found around the South Island and along the west coast of the North Island. The distribution range has decreased and become fragmented into four regional populations (Pichler 2002) comprising three populations of *C. h. hectori* and one of *C. h. maui* (Baker et al. 2002). A small population of Maui's dolphin remains along the west coast of the North Island (Martien et al. 1999) and is considered as 'critically endangered' by the IUCN (2000).

The reasons for the range restriction of Maui's dolphin are not well understood but it has been suggested that one of the main causes of the decrease in population size is fishing-induced mortality (Martien et al. 1999). Management should therefore focus on minimising fishing-induced mortality, which requires knowledge on where dolphin–fisheries interactions are likely to take place. Knowledge of the distribution of Maui's dolphins in harbours and along the west coast of the North Island is particularly limited (Ferreira & Roberts 2003) and it is likely that seasonal offshore movements for Hector's dolphins recorded by Dawson & Slooten (1988) could also characterise Maui's dolphins.

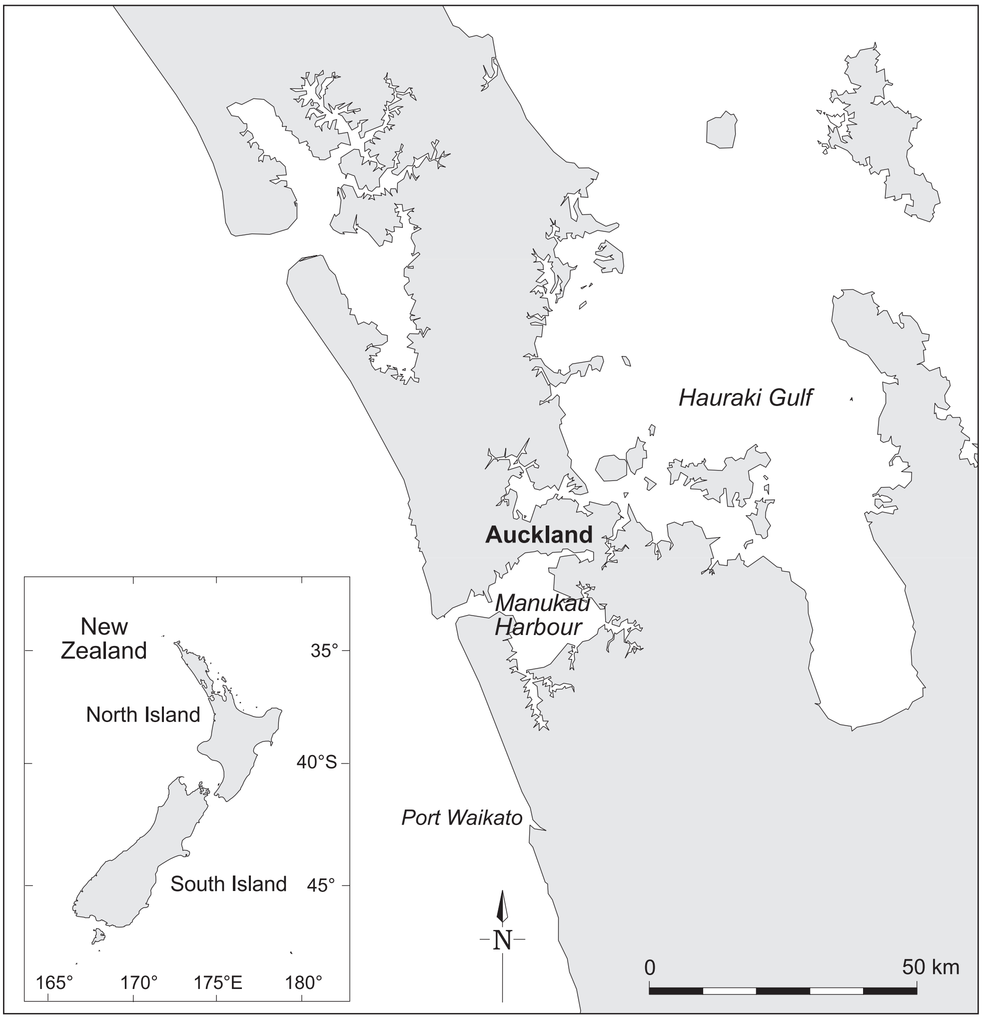


Figure 1. Map of locations in which porpoise detection devices (PODs) were tested for Maui's dolphins.

A number of techniques are available to define distribution and the extend of use of ranges: aerial surveys (Slooten et al. 2002; DuFresne et al. 2001; Ferreira & Roberts 2003); boat-based surveys (Clement et al. 2001; Dawson et al. 2000); and tracking devices (Defran et al. 1999; Dietz & Jørgensen 2002; Forney & Barlow 1998; Mate et al. 1998; Wells et al. 1999). More recently developed technology may assist in determining, in particular, inner harbour use including diurnal/nocturnal and seasonal variation. Porpoise detection devices (PODs) are self-contained submersible computers attached to hydrophone loggers that recognise and log echolocation ultrasound click trains from dolphins and porpoises (Tregenza 2003).

We designed trials to assess the feasibility of using PODs in a long-term study of the distribution and movements of Maui's dolphins in harbours along the west coast of the North Island, using Manukau Harbour (Fig. 1) as the main trial location. We developed a conceptual framework for using PODs to construct 'acoustic fences' across the harbour mouth to detect Maui's dolphin movements in and out of harbours. Our model identified technical, biological and physical constraints that could limit the use of PODs in an acoustic fence. Other POD studies combined with visual observations (Knowles 2002; Teilmann et al. 2002) have shown that dolphins are present within harbours and PODs could be a useful tool to answer questions about their distribution and movements.

2. Conceptual framework

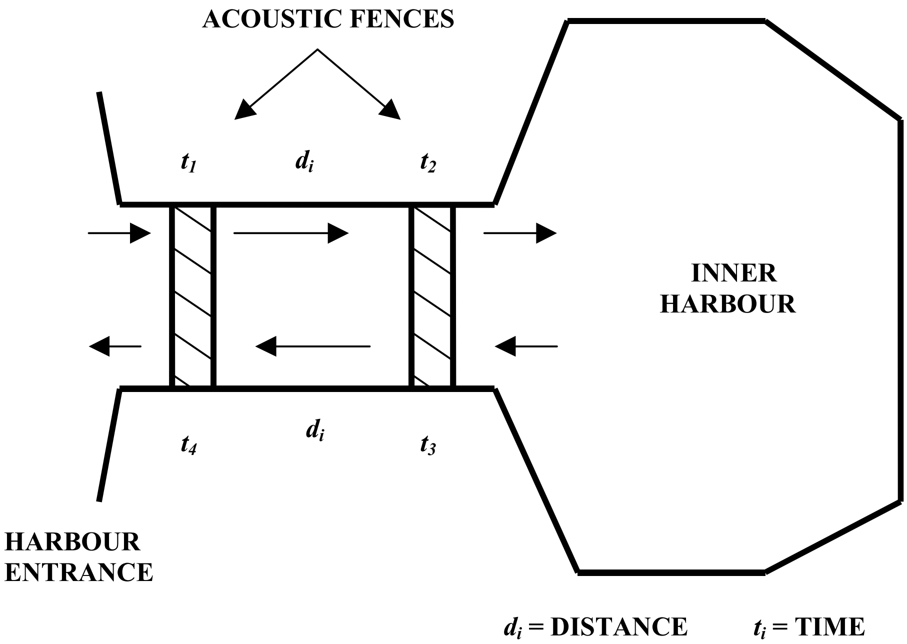
Analysis of time-specific data should allow the determination of direction of movement and time spent inside the harbour. Our model considered two key questions: Do Maui's dolphins use harbours? If they do, when and how long would they be present in harbours?

2.1 MODEL DESIGN

We envisaged that two acoustic fences using PODs could be moored across the width of the harbour entrance, the first inside the harbour mouth and the second a further distance (d_i) inside the harbour channel. PODs would be placed with slight overlap in putative detection ranges, in a zigzag linear formation across the width of the harbour entrance (Fig. 2).

Direction of movement of dolphins from the harbour entrance into the inner harbour is indicated by the time recorded at different intervals (($t_2 - t_1$), ($t_4 - t_3$), etc.), speed of movement as $d_i/(t_2 - t_1)$ and/or $d_i/(t_4 - t_3)$, and time spent inside the harbour as $t_3 - t_2$. The number of constraints and/or assumptions that underpin this model and was the focus of our evaluation.

Figure 2. Schematic illustration of the conceptual 'acoustic fence' model.



2.2 CONSTRAINTS AND ASSUMPTIONS OF THE MODEL

2.2.1 Technical constraints

Acoustic energy propagates more efficiently in water than in almost any other medium so that the use of sonar and passive acoustic devices would seem to be an ideal way to probe for animals in an underwater environment (Au 1993). In water it consists of molecular vibrations that travel at the speed of sound along the direction of propagation. However, multi-path propagation variation in the physical characteristics of water affects the speed of sound waves through it (Tregenza 2003), and sound reception becomes more and more uneven, as the propagated waves reach more distant points by increasingly diverse paths, causing interference between waves arriving with different delays along different paths. This leads to signal degradation, which affects both frequency and phase characteristics.

Due to the uncertainties of propagation patterns and extremes of acoustic behaviour in Manukau harbour (Teilmann et al. 2002), reliably determining a 'maximum POD detection range' is problematic. An important criterion, however, for successful use of PODs within an 'acoustic fence' model would be to be able to determine the maximum detection range with certainty and reliability.

2.2.2 Biological constraints

Hector's dolphins echolocate and vocalise in one of the most silent parts of the marine sound spectrum at 115–135 kHz in pitch (Dawson & Thorpe 1990). They produce no whistles and very few audible sounds and it is hypothesised that dolphins may have the ability to gather information from the echoes of each other's sonar pulses (Dawson 1991). These listening dolphins possibly 'eavesdrop' on others rather than actively transmitting signals to each other, and this could be a major constraint in using PODs to record echolocation clicks. The sounds of Maui's dolphins are not known, but are likely to be similar to those of Hector's dolphins, and we assume that they produce distinctive high-pitched, narrow-band, pure tones of low power.

Frequency of vocalisation

Dolphins would most likely be purposely moving in a specific direction while passing through the harbour entrances into the inner harbour. Therefore, it is expected that dolphins should at least vocalise or echolocate once while passing through the fence, once a reliable detection range has been defined. We further assumed that frequency of vocalisation while moving could potentially be a significant constraint to the success of the acoustic fence model.

Directionality of vocalisation

Analysis of Hector's dolphin vocalisation showed that most sound emissions are simple, high-frequency, and narrow-band clicks (Thorpe & Dawson 1990). Their emission field appears to be sharp, so much of the variation in pulse structure reported in these studies could be explained by the dolphin's orientation towards the hydrophone (Dawson & Thorpe 1990). It has also been shown in a study on beluga whale vocalisations that only pulses emitted from at or near the axis of the sonar field are recorded with fidelity (Au et al. 1987). These directional signals will only be detectable within a narrow acoustic energy beam width from the POD position. Detection also depends on the animal looking in the direction of the POD, as reflected sonar will not be recognised (N.J.C. Tregenza pers. comm.). Directionality of vocalisation could also therefore prove to be a significant constraint while dolphins are moving through an 'acoustic fence' model.

2.2.3 Physical constraints

Width of harbour

The detection range of the POD is crucial in determining the number of PODs required to cover the width of the harbour. The Manukau Harbour channel is c. 2 km wide at its narrowest (Fig. 3).

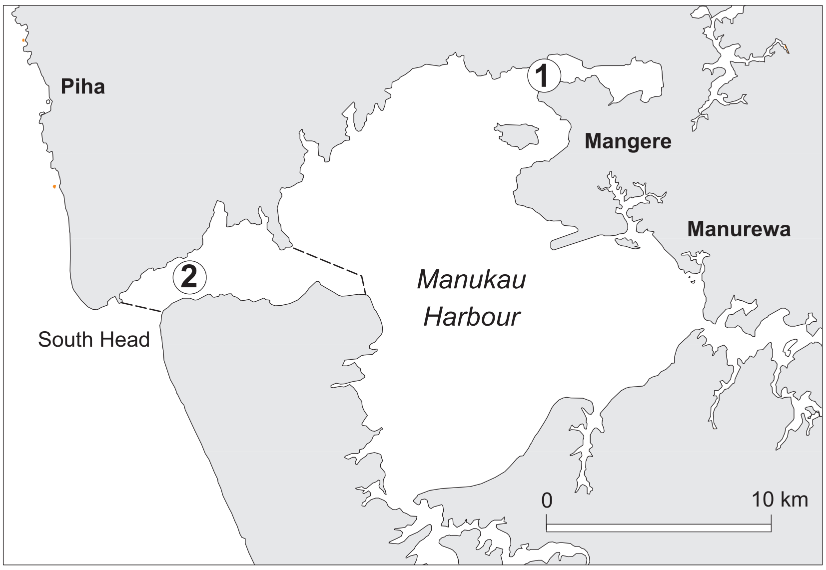


Figure 3. Sampling points used in Manukau Harbour to test calibration methodology for sound-induced POD range detection (1) outside and (2) within set-net ban enclosures.

Sea state and wave status

Creation of sound channels in the sea due to thermoclines, haloclines and pycnoclines will affect the propagation of sound through the water (Teilmann et al. 2002). The effects of these hydrographic features on the ability of PODs to detect dolphins, is unknown (Tregenza 2003). There is, moreover, no research published their effects on the echolocation sound emission of dolphins and how strongly they might show up on POD logging data (N.J.C. Tregenza pers. comm.). Manukau Harbour has a complicated bathymetry, large tidal variations, and strong tidal currents (Bell et al. 1998), with adjacent rough and hilly seafloor and these combine to produce considerable variation in sea state and wave status within the harbour entrance (Smith et al. 2002). Such variation could be a significant constraint on establishing an acoustic fence there.

Peak tidal flow rates

Measurements by Heath et al. (1977) and Bell et al. (1998) showed that peak tidal velocities ranging from 1.8 to 2 m/s occur in the entrance of Manukau Harbour. The most complex velocity patterns in the Manukau Harbour arise in the 9 km long channel and are strongly influenced by the bathymetry and complex shoreline geometry (Bell et al. 1998). The strong currents may force a moored POD out of the vertical plane and change the direction of sensitivity when logging and recording data (Tregenza 2003). In addition, strong tidal surges could potentially result in sand shifts that might affect POD efficiency and limitat secure mooring of PODs (N.J.C. Tregenza, pers. comm.).

Vessel activity

PODs should normally discriminate between marine mammal vocalisations and anthropogenic disturbances. However, cavitating propellers, especially from fast boats can mask data. Breaking waves entrain a lot of air into the water column, severely attenuating high-frequency echolocation signals. They can also generate significant wideband masking noise. Animals are less vocally active in such conditions and may seek out quieter foraging zones (A.D. Goodson, pers. comm.).

3. Methods

3.1 STUDY AREAS

We investigated some of the above constraints during May and June 2003. We first attempted to find Maui's dolphins and test detection range and vocalisation frequency in the area between Manukau Harbour and Port Waikato (Fig. 1). As Maui's dolphins were probably dispersed more widely during winter, which made locating them more difficult, we conducted range detection trials within the Hauraki Gulf, using common dolphins (*Delphinus delphis*), as part of marine mammal tourism outings conducted by Dolphin Explorer (Fig. 1).

In addition, sound-induced POD calibration trials using acoustic sounding equipment were run with NIWA at Greta Point, Wellington, under controlled conditions in a tank. Functional sound-induced trials to determine the POD range detection were then conducted within the Manukau Harbour region, both outside and within the proposed set-net ban areas (Fig. 3).

3.2 POD DETECTION RANGE

We considered two approaches to define detection range. Firstly, we envisaged recording dolphin vocalisations using PODs while simultaneously recording distances to visual sightings of dolphins. This method is only useful to define minimum detection ranges, since we could not be sure that the group of dolphins sighted was the group for which a vocalisation was recorded. In addition, the absence of vocalisation records could be a result of dolphins being out of range or not vocalising. We therefore decided to use induced sounds to overcome these constraints.

3.2.1 Dolphin sightings

A DOC boat equipped with depth-sounding equipment and a GPS (Garmin GPS 12 Personal Navigator) was used to locate Maui's dolphin groups (n = 2). A POD attached to a 12 mm nylon rope (50 m) and a waterlogged metal cylindrical weight (40 kg) were suspended 2 m above the seabed following dolphin group sightings along the west coast of the North Island. Depth sounding, position, type of behaviour and dolphin group size were recorded. A laser rangefinder (Buschnell Yardage Pro 1000, which features a Perma Focus monocular optical system for viewing a target at a maximum range of 1000 m) was used to target the dorsal fin of a dolphin to determine direction and distance from the boat at each surfacing of individuals within a group. The time at each surfacing was also recorded.

We repeated the approach in the Hauraki Gulf using the *Dolphin Explorer* as an observation platform to locate groups of common dolphins (n = 4). Groups comprised 100–200 individuals in various sub-groups.

3.2.2 Induced-sound trials under controlled conditions

Sounds were produced in water by driving a transducer with a signal generator, as described by Au (1993) and Mann et al. (1998). Sound waveform files recorded for Hector's dolphins at 353 kHz, with 16-bit resolution, were supplied by Steve Dawson, Otago University, in a Matlab format. The spectrum and waveform of a typical Hector's dolphin click was described by Dawson & Thorpe (1990).

Four different types of click were extracted from these data (Macaulay unpubl. report 2003), two from the first half of the time interval and two from the second half. The data were transferred to the memory of an HP 33120A arbitrary function waveform generator. These signals were played back through an ITC 3003 120 kHz transducer, at a rate of 22.4 Hz (which corresponds to the click interval in the first part of the recorded data). A transducer was suspended in the deep tank at NIWA, Greta Point, approximately 1.5 m below the surface. A B&K 8104 hydrophone was placed at a distance of 0.6 m from the transducer face and normal to it. The hydrophone was connected to a Tektronix TDS 3034 digital oscilloscope (sampling at 10 MHz) to receive waveforms, which were recorded to a floppy disk. Once the correct sounds were produced by the transducer, a POD was placed between the transducer and hydrophone to test if the POD detects the sounds produced (G. Macaulay, pers. comm.).

3.2.3 Induced-sound POD calibration in the field

Sound-induced calibration tests were initiated at two sampling sites: the first functional test was outside the proposed set-net ban area during off-peak tidal surges; the second was within the proposed set-net ban area during the peak-tidal surge (Fig. 3).

Induced-sound acoustic equipment using a transducer and two-function waveform generators were used. One of these were programmed for four different types of click data tested in controlled conditions, the other being the programmable trigger mechanism to initiate the recorded click data. The transducer was mounted square onto a 6 m aluminium pole that plugged into the signal generators.

The voltage output of the function generator was set to 0.6 V to give an output close to the recorded dolphin loudness. A HP 33120A arbitrary function waveform generator with the programmed click data of Hector's dolphin sounds and an ITC 3003 120 kHz transducer was used. A Philips signal function generator acted as the trigger to induce sound at a rate of 22.4 Hz (which corresponds to the click interval in the first part of the recorded sounds of Hector's dolphin). A marine chart for the Manukau Harbour (scale 1:48 000) was used to determine test sites.

The functional test involved mooring a POD with a rope to a fixed buoy with a 40 kg cylindrical weight attached to the bottom at a depth of 5 m (POD and weight 2 m in length). A boat equipped with the induced-sound equipment was used to move away from the fixed POD position. At 50 m intervals the transducer-mounted pole was lowered over the side of the boat to a depth of 3 m (to be in horizontal line with the hydrophone positioned on top of the POD) keeping the transducer facing forward at right angles to the fixed POD position. The distance from the fixed POD position was calculated from the boat, using a rangefinder (Laser Ranging System, Buschnell Yardage Pro 1000) that had a maximum range of 1000 m.

3.3 FREQUENCY OF VOCALISATIONS

We attempted to record vocalisations of Maui's dolphins by using PODs while observing groups moving close (< 100 m) to the observation platform, and from this to calculate frequency of vocalisation. It was realised, however, that the frequency of vocalisation is constrained by its directionality, so a dolphin could be vocalising and not be detected.

3.4 PHYSICAL CONSTRAINTS

To determine the feasibility of mooring PODs within tidal surges, a POD was moored to the buoy at 5 m depth with a heavy weight attached. The POD data analysis software automatically records the angle of the POD due to a built-in tilt switch that measures the angle of the POD on all recordings. These results were analysed and compared with actual visual observations conducted while the POD was attached to the buoy.

4. Results

4.1 POD DETECTION RANGE

4.1.1 Dolphin sightings

No data on POD range detection from Maui's dolphin sightings were obtained, partly because there were only two sightings of dolphin groups. In the first instance (group comprising two individuals) the POD was not fully functional, whereas the second instance (one dolphin) recorded no vocalisations during 45 min of recording.

A similar POD technical malfunction resulted in two of the four observations of groups of common dolphins being unsuccessful. For the other two groups we recorded minimum detection ranges of PODs for common dolphin vocalisations up to 100 m away (Fig. 4).

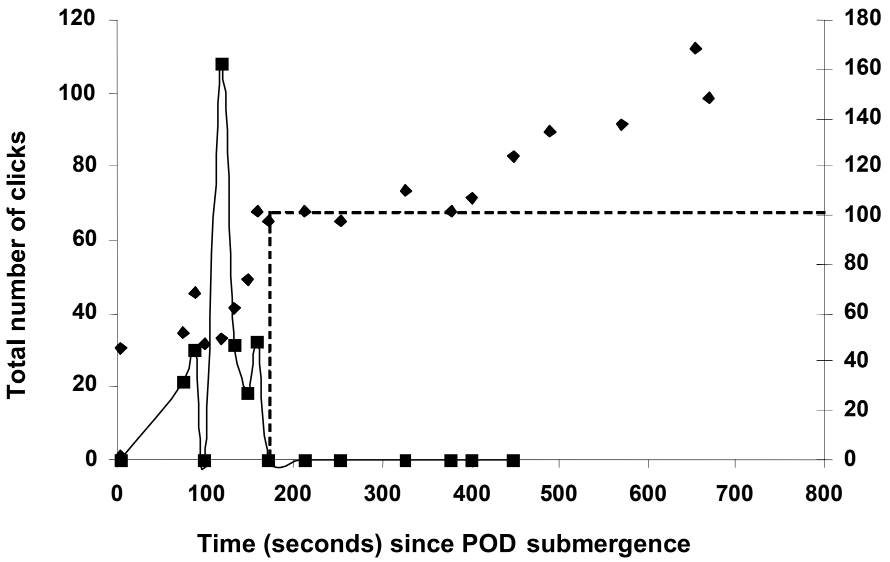
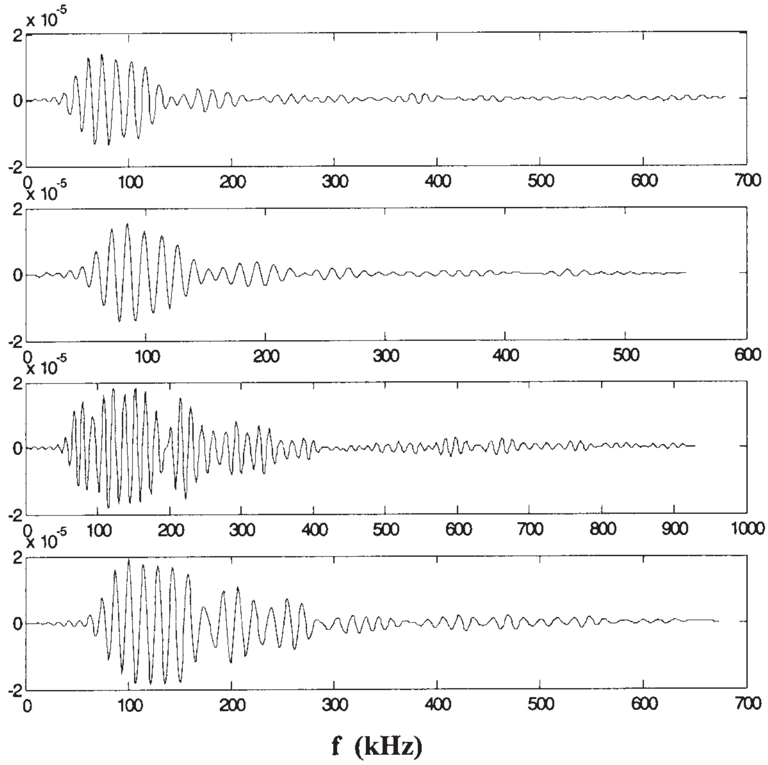


Figure 4. Common dolphin clicks recorded by a POD (squares) in relation to distance measured from the POD (diamonds) using a range finder. The broken line indicates the range at which detection stopped.

4.1.2 Induced controlled sounds

The voltage of the four clicks for Hector's dolphin at the oscilloscope via the hydrophone was 6 mVpp (Fig. 5). Most of the energy in the received signal was

Figure 5. Schematic illustration of the sound spectra (amplitude V) of four different types of click extracted from recorded Hector's dolphin sounds and programmed into a signal generator (S.M. Dawson, Otago University).



at frequencies between 110 and 140 kHz. The hydrophone has a calibrated receiving voltage response of –115.1 dB re 1 V per μbar at 120 kHz, which is equivalent to a sensitivity of 1.758×10^{-11} V/μPa. Hence the peak acoustic pressure at the hydrophone is given by $6 \times 10^{-3}/1.758 \times 10^{-11}$, which is 341 Pa.

The hydrophone was 0.6 m from the transducer, and to express the sound pressure level (SPL) in standard form (dB), the equivalent sound at 1 m from the hydrophone is required. This is obtained from the sonar equation:

$$\mathrm{SPL} = 20\log_{10}(P_0/P_r) - 20\log_{10}(R/R_0),$$

where the reference values R_0 = 1 m, P_r = 1μPa. R is 0.6 m and P_0 = 341 Pa. Hence SPL is 175 dB re 1 μPa at 1 m. To achieve an SPL of approximately 150 dB the pressure at the hydrophone will need to be approximately 19 Pa, hence the signal fed into the transducer will need to be less by a factor of 19/341, which is about 0.06. The signal generator voltage output was about 9.5 V, hence a value of approximately 0.6 Vpp should give an SPL of 150 dB re 1μPa at 1 m.

POD recording trials (n = 10) of induced dolphin recorded sounds varying from 15 min to 30 min were initiated. All tests were successful in digitally recording the time logged for each trial but no analogue data were recorded by the POD to view the induced recorded sounds. There was a possible fault with the analogue computer board in the POD (N.J.C. Tregenza, pers. comm.), and no POD data for the induced-sound trial tests with NIWA could be shown. Nonetheless, our results illustrate that we could reproduce selected sounds of Hector's dolphins which could be used in the field.

4.1.3 Induced-sound range detection in the field

Results of the initial functional induced-sound test, completed outside the proposed set-net ban area in calm off-peak tidal conditions, showed that on the first 50 m position for inducing sounds, most (80%) was not recorded. We varied the angle relative to the POD and believe that the low recordings were possibly due to directional signals being emitted from the boat. When aimed at the POD hydrophone, much of the detection range was lost due to boat or hand movements, resulting in sonar pulse emissions transmitting off-axis, and being detectable only within a very narrow acoustic energy beam width from the POD position.

The second position was tested within the proposed set-net ban area during peak tidal surge, but strong tidal currents prevented any recording.

4.2 FREQUENCY OF VOCALISATION

No data on the frequency of vocalisations of Maui's dolphins were recorded using PODs, due to the infrequent sightings of dolphin groups, dolphins not vocalising within a recorded period, and the limited number of field trips conducted for this pilot study within a short time-frame.

4.3 PHYSICAL CONSTRAINTS

Difficulties were experienced in collecting and recording the physical attributes constraining acoustic recording across the width of Manukau Harbour. For instance, the mooring within the proposed set-net ban area during peak tidal surge (c. 5 knots) resulted in the POD and the weight system being lifted horizontally from the buoy to 60 ± 5.0° (n = 2) from the normal vertical recording position. Our observations of POD orientation while drifting in the Hauraki Gulf recorded PODs at approximately 20 ± 5.0° (n = 10) in a current of c. 2 knots. We did not attempt to evaluate other constraints.

5. Discussion

Encounters with either Maui's dolphins or common dolphins were too few to allow reasonable conclusions to be drawn. Nevertheless, in view of the difficulties experienced in these trials, we consider it useful to discuss actual and potential constraints that need to be taken into account in doing this sort of work if valid recommendations are to be made.

5.1 TECHNICAL CONSTRAINTS

Our results suggest that POD detection range could not be estimated reliably. We recorded a minimum range of 100 m from our sightings method, but with some uncertainty about whether the dolphins at observed distances were the ones actually vocalising. In addition, POD detection may be constrained by the directionality of dolphin vocalisations. At Fynes Hoved, Denmark, it was reported that porpoises moved close to the shore and relatively few were detected by a POD only 100 m or so outside their main movement corridor (Teilmann et al. 2002). The contribution of silent porpoises to this result is unknown. Because of the uncertainties of propagation patterns and extremes of acoustic behaviour, it does not seem that any figure for 'maximum range' will be reliable or useful. Teilmann et al. (2002) suggested that logging 'median range to dolphins' would have some potential use, but only in situations in which dolphins were approximately evenly distributed around the POD. The effect of different behaviours, especially feeding and travelling, may be sufficiently important to need qualification, but the identification of such behaviours from click rates recorded by PODs is unknown and has not been investigated (Teilmann et al. 2002).

Other studies using visual v. acoustic observation have been presented at a POD workshop at the National Environmental Research Institute, Roskilde, Denmark, in October 2001. A study on porpoises deployed two PODs 16 times over a four-month period, during which 277 hours of POD data and 31 hours of visual surface observations were collected (Teilmann et al. 2002). Comparing POD data with surface observations revealed that, on the channels set to detect narrow-banded sounds, whenever a porpoise was within 250 m of the POD there was activity centred around 130 kHz with durations of less than 500µs. If no porpoises were in sight there were never events with high activity on the POD. The program could not distinguish between passage of one or two porpoises, making it impossible to estimate the number of porpoises (Teilmann et al. 2002).

Our own results on common dolphins gave no acoustic POD data for visual observations > 100 m. However, we could not distinguish between visual records associated with dolphin vocalisations that were not detected and visual events when dolphins did not vocalise. We conclude that it will be unlikely to show maximum detection range of PODs from dolphin sightings.

Our attempts to determine POD detection range through induced sounds were constrained by the directionality of acoustic events in seawater. We detected induced-sound events at 50 m, but even at this distance a slight deviance in direction resulted in significant loss of recordings. We conclude that PODs can at best record Maui's dolphins at a range < 100 m and possibly only if a dolphin faces the POD when vocalising.

5.2 BIOLOGICAL CONSTRAINTS

Frequency of vocalisation while moving was not assessed for Maui's dolphin, as we recorded no vocalisations during 45 min of continued recording. For Hector's dolphins, which produce no whistles and very few audible sounds, it has been suggested that echolocation is not the sole function of clicks, and that echolocation and communication are likely to be closely linked (Dawson 1991). It is hypothesised that dolphins may have the ability to gather information from the echoes of each other's sonar pulses. The constant use of echoes generated by other dolphins, conspecifics or not, suggests that avoidance of sound may be related to their choice to of where to locate themselves relative to that echo

(Stone et al. 2000) rather than whether to echolocate or not, or to increase or decrease the echolocation rate. This may reduce the need for a large number of vocal signals, and may explain the apparent simplicity of the acoustic repertoires of some odontocetes (Dawson 1991). This so-called 'eavesdropping' hypothesis for dolphin communication, with dolphins 'eavesdropping' on others rather than actively transmitting signals to each other (Caldwell & Caldwell 1977; Wood & Evans 1980), could be a major constraint in determining the frequency of vocalisations of Maui's dolphins.

An additional difficulty could be distinguishing between Maui's dolphin echolocation and clicks made by other dolphin species. Overlap can occur in the frequency ranges of echolocation used by different species. The method currently used to distinguish between species is based on analysis of the bandwidth of the clicks. However, most Hector's dolphin vocalisations are simple, high-frequency, narrow-band clicks (Thorpe & Dawson 1990) and are low-level signals compared to other cetaceans (Dawson & Thorpe 1990); there are few different types of high-frequency clicks, and audible 'squeals' caused by fast repetition rates of high-frequency clicks. In comparison to many other delphinids, which have a rich repertoire of audible signals in addition to their high-frequency clicks, the repertoire of Hector's dolphins appears simple (Dawson & Thorpe 1990). Assuming that Maui's dolphins have similar echolocation characteristics, we can conclude that overlap with other species is not likely to be a constraint.

Like long-tailed bats (Parsons et al. 1997) and a teleost fish species (Mann et al. 1998), which are true echolocators, not simply ultrasonic receptors, i.e. they 'image' their environment by analysing echoes from a self-generated ultrasonic signal (Kellogg 1959; Norris et al. 1961; Pilleri 1983; Popper 1980; Watkins & Wartzok 1985; Wood & Evans 1980), all modern odontocetes are assumed to be able to detect and emit high-intensity pulse ultrasound clicks. Echolocation has been found to be a two-way function, i.e. to be an effective echolocator, an animal must have a coordinated means of generating a highly directional signal and receiving its echo (Ketten 1998). For instance, most aerial-feeding insectivorous bats use echolocation to detect, locate and classify prey (Schnitzler & Kalko 1998). This is a 'typical' design of echolocation signals used by open-space foragers during the search phase (Kingston et al. 2003), and could also be used by dolphins in detecting, locating and classifying prey species within an open ocean environment. As it swims into an area, a dolphin might produce clicks intermittently in narrow beams that sweep around only insofar as the animal changes its direction or attitude.

From our induced-sound trials, it was concluded that sounds were directional and most were missed by the POD. Although the sounds produced were slightly softer than those expected from real dolphin sounds (N.J.C. Tregenza pers. comm.), the directionality problem would remain. Much of the detection range was lost due to boat or hand movements, and sonar pulse emissions were only detectable within a very narrow acoustic energy beam width from the POD position. Our results probably reflect real dolphin sounds since Hector's dolphins have sharp emission fields, so that when an animal turns slightly away from the hydrophone the signal/noise ratio drops markedly (Dawson & Thorpe 1990).

In other studies it has been shown that single sonar pulses from beluga whales (Au & Turl 1987) and other odontocetes (Au & Hann 1978; Au & Pawlowski 1986; Au & Turl 1987; Pilleri et al. 1983) vary considerably, with only those pulses at or near the axis of the sonar field being recorded with fidelity. Sonar pulses are not emitted equally from all parts of a dolphin's head, but are generally projected in a beam, which, in Hector's dolphins, consists of simple, high-frequency, narrow-band 'clicks'. These results show that directionality of sonar pulses serves as a significant constraint to our conceptual model.

5.3 PHYSICAL CONSTRAINTS

Our minimum detection range suggests that at least 10 PODs would need to be placed within one acoustic fence to accommodate POD range restrictions. The feasibility of mooring these and maintaining their station within a harbour mouth where water depth varies between 6 and 40 m and tidal surges top 5 knots is low. In addition, we observed that, in a tidal surge of 5 knots, for most of the time the POD was not in a position to record any vocalisation events.

Underwater sound is dominated by thermal noise—pressure waves generated by the random jostling of water molecules (Tregenza 2003). At lower frequencies, breaking waves, rain, moving sediments, and biological noises predominate, with ships and other man-made noises being major sources of ambient noise in many places. However, putting the scanning frequency of the POD to known sensitivity settings for Maui's dolphin frequencies, assumed to be similar to Hector's dolphins (S.M. Dawson pers. comm.), will probably overcome this particular problem.

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