Passive acoustic detection and monitoring of dusky dolphins (*Lagenorhynchus obscurus*) in Admiralty Bay using the POD autonomous click detector – preliminary observations

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Summary

An automated dolphin sonar click train logger (POD) was deployed at four locations used by dusky dolphins (*Lagenorhynchus obscurus*) to evaluate the system with the aim of detecting and monitoring Delphinid species in areas with aquaculture developments.

The present system successfully detected dusky dolphins. Preliminary observations from click train data indicate that evidence can be obtained of click frequency prevalence, dolphin behavioural changes through click repetition rate changes, and diel patterns in click train detections are very clearly shown.

Clicks in trains were logged at frequencies in the range 50-150khz, with most click trains and ‘fast’ click repetition rates typically associated with feeding behaviour between 90 and 110 kHz, consistent with published literature. Further work is required to refine the detection settings for deployments in different habitats and depths to improve dolphin train detection rates.

Variance in click repetition rates and click counts at selected frequencies may be used to differentiate dolphin species that occur in the area but this would require much more work and at present the system provides a generic dolphin-dolphin identification.

Dusky dolphin click trains were detected throughout the day but were most prevalent around dawn and dusk, with 50% of detections during the hours of darkness. Nocturnal feeding in this species is generally associated with dolphins moving rapidly offshore to feed at depth on prey associated with the Deep Scattering Layer in the Kaikoura canyon. The regular occurrence of dolphins in the coastal waters at night could possibly be a response to diel changes in prey availability or catchability, or avoidance of boats (whilst resting).

Previous acoustic studies in Admiralty Bay were limited to a few days during daylight hours employing active sonar. Active sonar provides a powerful method of investigating predator prey relationships, in terms of dolphin abundance and group structure and the wider distribution of marine resources providing a greater understanding of ecosystem functioning. However, the potential effects of high-energy sonar on the behaviour of target (marine mammals) and non-target (fish) species are not fully understood.

Passive acoustic monitoring of dolphin echolocation sonar in combination with visual observations across a range of dolphin habitats is one method available to investigate the behaviour and occurrence of dolphins in coastal waters. PODs appear ideally suited to monitoring dolphins at various depths and spatial scales from aquaculture sites, which are often located in remote areas. The system provides continuous cost effective objective data, which can be readily used to determine temporal and spatial patterns and target study effort.

Recommendations for future research and monitoring at aquaculture sites are provided.

Introduction

This study was commissioned as part of a multi-species research programme to develop methods of monitoring the impact of aquaculture on marine mammals and seabird populations. One of the main requirements for such monitoring is the collection of objective baseline data, using a proven method, and which has the statistical power to detect a significant change in the habitat use, behaviour or abundance of the species of interest.

The main aim of the study is to assess whether acoustic detection of dolphin sonar clicks, using the POD (autonomous dolphin click detector) can be reliably employed to detect dusky dolphin (*Lagenorhynchus obscurus*) click trains and their presence (encounters) and to identify any logistical or operational issues that may be pertinent for related studies. Other related areas of interest, (i) the detection range of the POD and (ii) the identification of dusky dolphin click trains from other dolphin species found in the study area, Hector's (*Cephalorhynchus hectori*), common (*Delphinus delphinis*), bottlenose (*Tursiops truncatus*), killer whale (*Orcinus orca*) are discussed but not considered in detail in this report.

There has been a considerable amount of research undertaken on the dusky dolphin in New Zealand and Argentina. The species is considered on the edge of it's ecological range with geographically distinct populations exhibiting different feeding strategies, possibly as a consequence of differences in local ecological factors such as food availability, levels of predation and competition for resources from other higher marine predators. Kaikoura dusky dolphins remain in shallow coastal waters during the day and feed at night in large schools on prey associated with vertical migrating Deep Scattering Layer in the Kaikoura canyon (Cipriano, 1992). Dusky dolphin studies in Golfo San José, Argentina have shown the species to feed mainly in small groups, surface feeding in relatively shallow coastal waters, by herding southern anchovies (*Engraulis anchoita)* into tight balls, using the surface as a barrier to concentrate prey (Würsig and Würsig, 1980). Admiralty Bay is host to a population of over 200 dusky dolphins on any given week (based on photo-identification of 400+ animals), which exhibit range of feeding behaviours including co-ordinated surface feeding by groups of dolphins and feeding at depth (McFadden, 2003; Benoit-Bird & Würsig, 2004). A proportion of dusky dolphins migrate from Kiakoura to the Marlborough Sounds area, with most dolphins present during the winter months of June to August, with small numbers present year round. At least 55% of the dolphins captured by photo-identification return to Admiralty Bay each year. A large proportion of dusky dolphins in the bay are believed to be males (McFadden, 2003).

Previous studies of habitat use and feeding behaviour have undertaken boat transects to map the distribution of dolphins, focal studies of feeding by visual observations and active sonar. Dusky dolphins (and other cetacean species) are rarely seen within the perimeter of Admiralty Bay mussel farms, with few records of dolphins swimming between the lanes of partially harvested farms. The vertical lines of mussels present a 'barrier' but it is not clear whether dolphins avoid these areas (during daylight) because of the physical structures (and associated sonar image), the structures impede the dolphin's ability to locate and catch fish prey or because common fish prey are absent or dispersed around farms (Markowitz et al., 2002; in press). This 'exclusion' from mussel farms has led to concerns with large scale (2000-4000 ha) mussel farms proposed for some areas of New Zealand, including Admiralty Bay (Lloyd, 2003).

Toothed whales and dolphins (Odontocetes) are acoustically sensitive and rely on echolocation for navigation, feeding and communication. Studies of cetacean sonar have a wide array of applications in applied research and conservation management, providing a greater understanding of the marine environment. The frequency of dolphin click trains range from 10 to 200 kHz. A number of species, including Hector's dolphin and harbour porpoise (*Phocoena phocoena*) emit narrow band click trains centred around ~130 kHz. Larger dolphin species generally use a broadband of frequencies, mainly from 45 to 150 kHz, with some evidence to suggest that the frequency and intensity of the click train is a function of body size, signal produced (Au & Benoit-Bird, 2003). Recent work on Dusky and *Stenella* species also that a high proportion of their click trains are bi-modal, with frequencies centred over a broadband from ~50, 60, 75, 90, 110 to 130 kHz (Au and Herzig, 2003; Au and Würsig, manuscript).

Frequency modulation of the sonar click train may be employed by a number of cetacean species to maximise received sonar information. In general, increases in click repetition rates PRF are associated with feeding behaviour, representing the dolphin discriminating, and targeting prey (Kastelein *et a*l., 1999). Shifts in the pitch and repetition that clicks are emitted may also occur to avoid 'masking' from clicks produced by other marine animals, such as shrimps, and to avoid detection from prey or predators.

POD dolphin click detector

The POD is an autonomous dolphin click detector with a range of uses (see Bibliography). Recent research has included cetacean behavioural studies, habitat use, population distribution, surveillance and monitoring (impacts of fisheries bycatch, harbour and renewable energy developments). The POD receives click train signals via a hydrophone, which are processed via bandpass filters and software and stored on 32Mb or 128Mb flash memory for downloading and analysis later. See (www.chelonia.demon.co.uk) for a detailed description of the POD. Software efficient means of viewing data and preliminary analysis, further investigated by exporting data to Excel or Access. The scale of temporal and spatial analysis available is determined by the method of deployment and parameters set for 'logging' click trains. Large time scale (30 minute to weekly) displays can be used to look for diurnal, tidal or other time-based analysis. Fine scale (10 milli to micro) displays can used to view the structure of trains and clusters of clicks by their duration, interclick interval (ICI) and click repetition rates (also referred to PRF, pulse repetition frequency).

Sound wave propagation is affected by variations in the physical characteristics of water, especially clines in temperature and salinity, which can have major effects on sound conduction pathways. Signal degradation, as a result of wave propagation and interference affects both frequency and phase characteristics, which results in a single click being received as more than one click at the hydrophone. To avoid processing all these clicks as distinct single clicks, a tight cluster is selected as the sentinel click and the rest are suppressed, although they can still be viewed by selecting 'subsids' in the filters. The balance between specificity and sensitivity has to be assessed against the train detection function of the POD, so the aim is not to limit clicks to true positives, but to keep false positive clicks down to a level at which they are not so numerous as to significantly reduce the detestability of trains, or exceed the memory size. For dolphin detection the fraction of clicks logged that are classified as in trains is commonly below 5%. The highest classification rates are seen with porpoises in quiet environments and may reach 45% (Source: N Tregenza, TPOD Help).

Study area

Four PODs were anchored off Clayface Point on separate moorings approximately 200m apart in ~ 40 m of water. The PODs were secured to the mooring rope 10 to 12 m below the surface (MHWS 4m). In July PODs 256, 255, 254 and 253 were moored in a line from W to East. Studies of feeding behaviour by Markowitz *et al*., were mainly undertaken in Inner Admiralty Bay south of Clayface Point. A POD was also deployed for several days in Penguin Bay and south of Stewart Island, both areas known to have regular occurrences of dolphins. This report deals only with observations at Clayface Point.

(Map of study area)

Methods

POD settings and deployment

The six POD channels were set to 'Normal sensitivity Dolphin sweep' (50, 70, 90, 110, 130, 150 kHz) for deployments in June. POD 253 and 254 were initially deployed to the south of Stewart Island and centre of Penguin Bay, from 10th to 16th June respectively. PODs 255 and 256 were deployed off Clayface Point, to the north and south (Inner Admiralty Bay) from 10th to 16th and all PODs were deployed off Clayface Point from 17th to 19th June (locations to be confirmed by Brian/Simon). The Eastings and Northings for POD moorings and deployment dates are listed in the Appendix.

The PODs were re-deployed off Clayface Point (similar location to June 17th deployment) from 12th to 16th and 17th to 19th July with the same target frequencies but modified reference frequencies for each scan. 40-50 kHz is a modal peak frequency for uni- and bimodal clicks for dusky dolphin and probably a number of other Delphinid species. Clicks at a target frequency of 50kHz will tend to block the detection of clicks using the 50kHz as a reference frequency. To avoid this occurring the reference frequency for all scans was lowered below the 50 kHz peak to 30kHz. The range of target frequencies was not changed to allow comparison with the June click data.

Clusters of clicks identified by a train detection algorithm were classified as the following train classes: Cet Hi, Cet Lo, ..?.. (Doubtful), ..??.. (Very Doubtful) and Boat sonar. Click data was processed using the version 1 and development version 2 train detection algorithm to assess the frequency of CetAll, Doubtful trains and Boat sonar for further analysis.

Sequences of dolphin encounters were copied to new train files, batch processed and exported to Excel to remove 'unwanted noise', and assess the integrity of the data and possible effects of 'noise' and random clicks on classified click trains.

Ratios of click counts from click data were compared by deployments and pooled by month to identify any differences in click rates between train classes and significant differences in sensitivity of PODs.

The Train Export B process was used to obtain click train details for analysis in Excel. The Train Export A process with the hourly count and 10 minute silent period selected was used to export encounter durations to Excel.

The sum of click trains per hour was used to derive the %Total Positive Hours (TPH) for 'daylight' and 'darkness' periods to investigate diel patterns. The number of clicks per hour were exported from the PDT train data files to Excel and sorted by hour of day. Only hourly counts above 10 clicks were considered, to reduce the likelihood of including counts with few click trains from random clicks. All TPH counts from 7PM to 6AM were classified as occurring during the hours of 'darkness'.

Results

Dusky dolphin observations vs dolphin click detections

Four PODs were observed for a total of 18 hours 30 minutes from Clayface Point, comprising 7 hours 35 minutes in June and 10 hours 55 minutes in July. One POD watch of 2 hours 32 minutes was undertaken from Penguin Bay beach.

There were four occasions when dolphins were seen transiting within 500 m of a POD; discrete clusters of clicks were logged but not classified as a cetacean click trains on three occasions. Dolphin trains were detected prior to the dolphins being observed at 08:40 hours on 17 June (Table 2.1).

Dolphin trains were detected on PODs 254 and 255 during feeding bouts observed within 500 m of a POD at 11:25, 11:44 and 11:56 hours, 11 June (Table 2.2). The corresponding train detections were from 11:55 to 12:28 hours. The orientation of the dolphins with respect to the PODs was not noted. POD253 stopped logging prior to the feeding bout, the reason for this is unknown.

No CetAll train detections were logged during the periods when dolphins were not observed. Three 'Very Doubtful' trains were classified during the watch from 09:00 to 13:25 hours, 17 July when no dolphins were seen. Sighting conditions were good during this watch with a variable wind, force1-2, sea state = 1 (slight), swell < 1 m (low), and occasional fine precipitation.

Table 2.1 Observations of dusky dolphins transiting through the POD study area, Clayface Point

Date & POD observation		No of dolphins, time and distance	Transiting	POD detection, start and finish
Clayface Point				
11-Jun-05 255	10:18 to 11:39 11:19	c.20 dolphins pass W around point (no distance given)	Transiting to center of outer Bay	11:16 to 11:26, fixed PRF boat sonar from mussel harvester No dolphin trains detected
255 & 256	11:29	c.20 dolphins, >1 km from coast		(Outside of POD detection range)
255 & 256	11:39	c.20 dolphins, >1.5 km	Slowly moving to center of bay	
17-Jun-05 255	08:40 to 13:00 08:40	3 dolphins (no distance given)	Transit, north edge of Clayface Pt	Train detection from 08:29 to 09:53
18-Jun-05 253 & 255	13:42 to 14:42 14:06	1 dolphin?	Transiting within 10 m off coast (PMcG)	Cluster of clicks 14:05 PRF<20/s, no trains
13-July-05 255	09:15 to 15:15 12:09	4+ dolphins, 100 m	Transiting between line PODs & coast	Clusters of clicks 12:09on all scans, no trains

Table 2.2 Observations of dusky dolphins feeding around PODs, Clayface Point

Date & POD observation	No of dolphins, time and distance	Feeding	POD detection, start and finish
Clayface Point 11-Jun-05 10:18 to 11:39 255 & 256 11:25	c.20 dolphins, c.400 from both PODs	Feeding, fish ball mid way between POD255 and 256	No dolphin trains detected
253 11:44 11:56	20 dolphins 1 dolphin	50 m from POD 10 m from POD	POD 253 stopped logging at 10:22
254 11:56	Group dolphins around POD	Feeding	Trains 11:55, 11:58
255 & 256 11:56	No dolphins seen	(Feeding)	255, trains from 11:57 to 12:28 256, no trains detected

Table 2.3 Observations at PODs when no dusky dolphins were visually detected

Date & POD observation	No of dolphins, time and distance	No dolphins present	POD detection, start and finish
Penguin Bay 11-Jun-05 13:52 to 16:24	No dolphins seen	MV Manaia at POD 14:03	Clusters of clicks 70, 90 & 110 at 14:03, not classified as trains (sonar scan?)
Clayface Point 16-Jun-05 16:13 to 17:07 255 & 256	No dolphins seen		No train detections
13-July-05 09:15 to 15:15	No dolphins seen after 12:09		No trains recorded at other times
14-July-05 10:10 to 12:00	No dolphins seen		No trains detected
15-July-05 09:00 to 13:25	No dolphins seen		3 ?? very doubtful trains detected

Detection of dolphin click trains

The click data from four PODs deployed off Clayface Point totalled 1304 hours; the number of hours was split equally between the months of June and July. The current version and version 2 (v1 + boat sonar adaption) train detection software in TPOD was used to summarise and view the characteristics of click trains. The version 2 algorithm increased the proportion of CetAll clicks and improved the cluster of cetacean trains detected, with fewer instances of Doubtful trains occurring without CetAll trains (Figure 1). Clicks correctly classified as Boat sonar with the v1 algorithm were misclassified as CetHi and CetLo trains using the v2 algorithm. Boat sonar were relatively scarce, numbering less than 10% of the click trains classified as CetAll clicks.

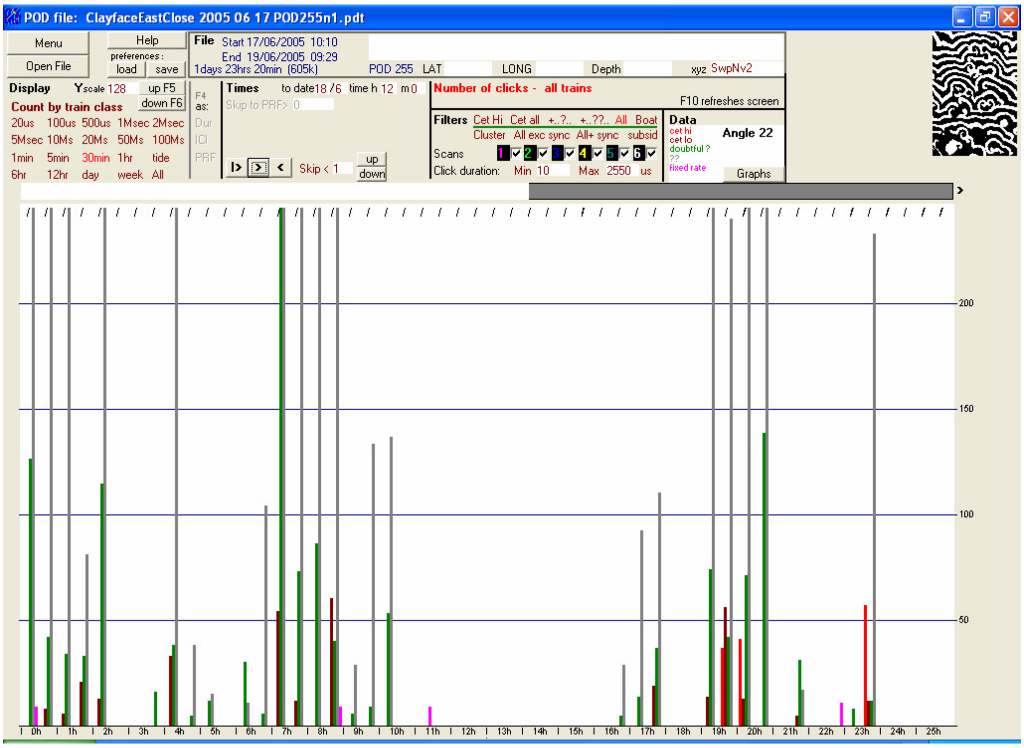
6.2 million clicks were registered with 95,410 clicks classified as click trains, 47,240 of these trains were classified as CetAll trains. The percentage of clicks classified in Cetacean and Very Doubtful trains was 3.8 and 0.7% for June and July deployments. The total clicks per hour increased from 3575 for June to 5638 for July deployments (Table 1).

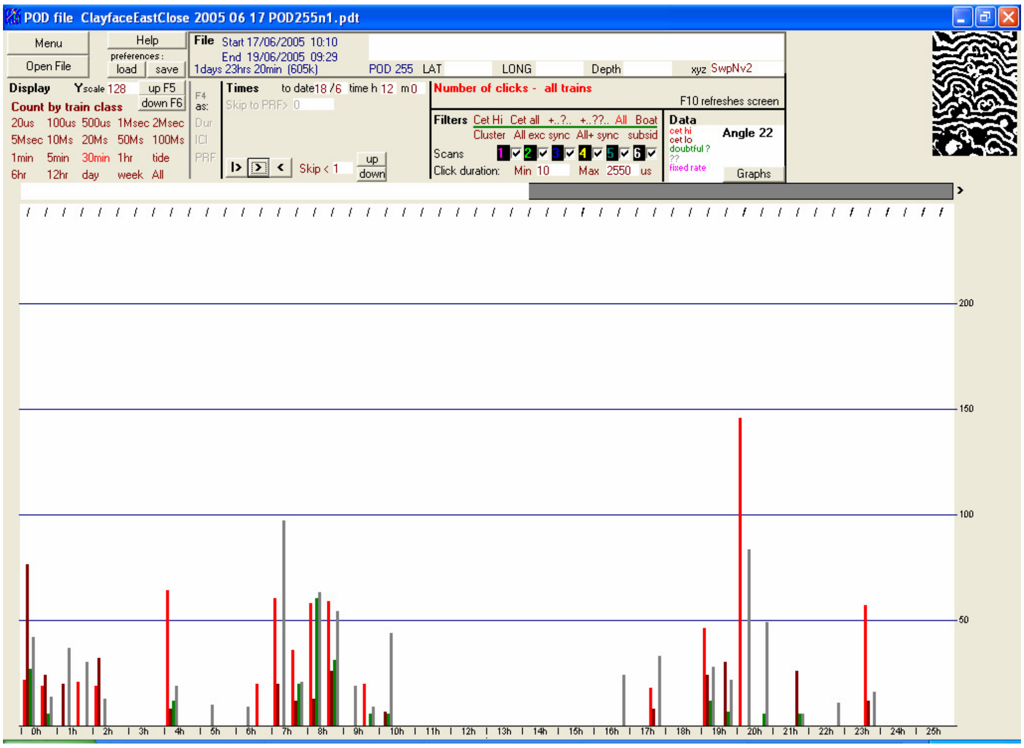
Table 1. Number of clicks classified in trains for Clayface Point POD deployments

	CetAll	+??	All	Clicks/Hr
June	36596	70054	1986869	3575
July	10644	25357	4202810	5638
Total clicks	**47420**	**95411**	**6189769**	

POD settings:
June 50v30*4 70v30*4 90v50*4 110v50*4 130v70*4 150v90*4 Scan limit 160 clicks
July 50v30*4 70v30*4 90v30*4 110v30*4 130v30*4 150v30*4 Scan limit 240 clicks

POD253 was retrieved with 40% more clicks than other PODs deployed for the same duration so excluded from the above comparison. The additional clicks were not classified as trains; 55% of the clicks were in scan 1 (50 kHz). The high click count here is most likely explained by the POD deployed too close to the surface and exposed to ambient wave noise.





Figures 1 and 2. Version 1 train detection (top) and Version 2 train detection (above) showing more CetHi trains and fewer doubtful trains. Boat sonars are shown as pink bars, only classified and shown in the v1 train detection here.

Train classification

Trains of clicks can arise by chance from non-cetacean sources and are produced by boat sonars. The TPOD software classifies trains according to its assessment of their likelihood of being dolphin trains.

Using the current version of this the data, Figure 1 shows that even the most doubtful categories identified by the software are strongly associated temporally with the most reliable. This is good evidence that the classification is highly conservative and rarely identifies chance trains as dolphin trains.

Figure 2 shows the same data classified by a development version of the software. This is intended to achieve the same accuracy with less misclassification of dolphin trains as ‘Very doubtful’.

Three checks were made to confirm the validity of the dolphin train classification. The occurrence of CetAll clicks and +?? Trains were examined at the 30-minute display and All train filter setting. Click trains were centred on CetAll (yellow and red bars) trains and there was no continuous distribution of click trains or sequences of clicks with no CetHi trains from breaking waves or other marine sounds occurring. Click repetition frequencies for CetAll and ??+ trains were examined at the 100 millisecond display to look for ‘rate ramps’ and boat sonars, which were evident (Figure 3). The Cluster filter was selected to show the ‘sentinel clicks’ and surrounding clicks not classified as trains to assess the level of clicks detected and dolphin encounters. The four POD files were also viewed simultaneously to compare the occurrence and consistency of train detections between files.

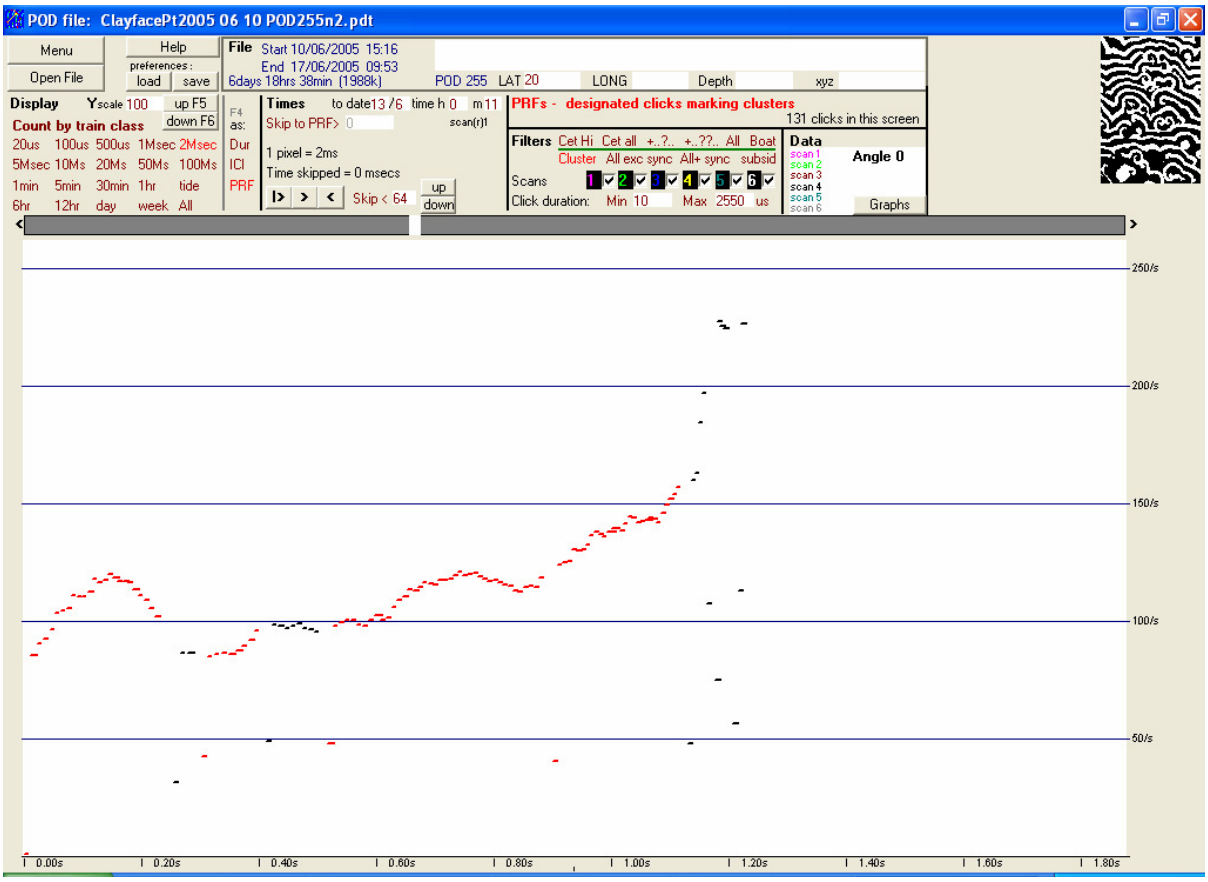


Figure 3. Typical click train with 131 clicks represented on the screen. The duration of the click train is 1.2 seconds with a click repetition frequency of up to 150 clicks/s. Clicks classified as CetHi (red) and CetLo (brown) are shown from Clayface Point 13/6/05 00:11 AM.

Number of clicks in cetacean trains at scan frequencies 50 to 150 kHz

Click trains were detected at all frequencies scans from 50 to 150kHz. The peak number of clicks in trains was recorded at 90 kHz for June deployments, and 90 and 130 kHz for July deployments (Figure 4).

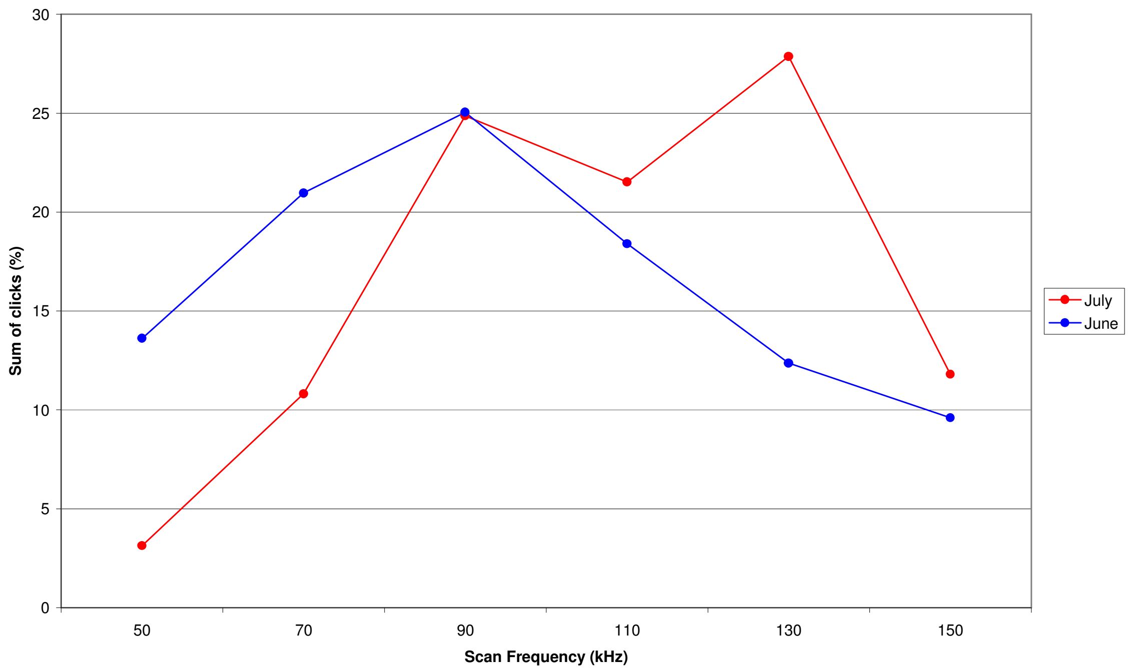


Figure 4. Number of clicks in trains logged at frequencies in the range 50 to 150 kHz

The frequency distribution of PRFs for clicks in trains was examined using the TPOD graphs option. In general trains with PRFs >10/s and 20/s were the most common for all frequency scans (50 to 150 kHz). However, 'fast' PRFs >100 and >200 clicks/s were also noted at all scan frequencies but not in all deployments, which may indicate a particular dolphin behaviour (resting) or mode of echolocation (e.g. feeding or social 'buzzes') during the period sampled (Figure 5.).

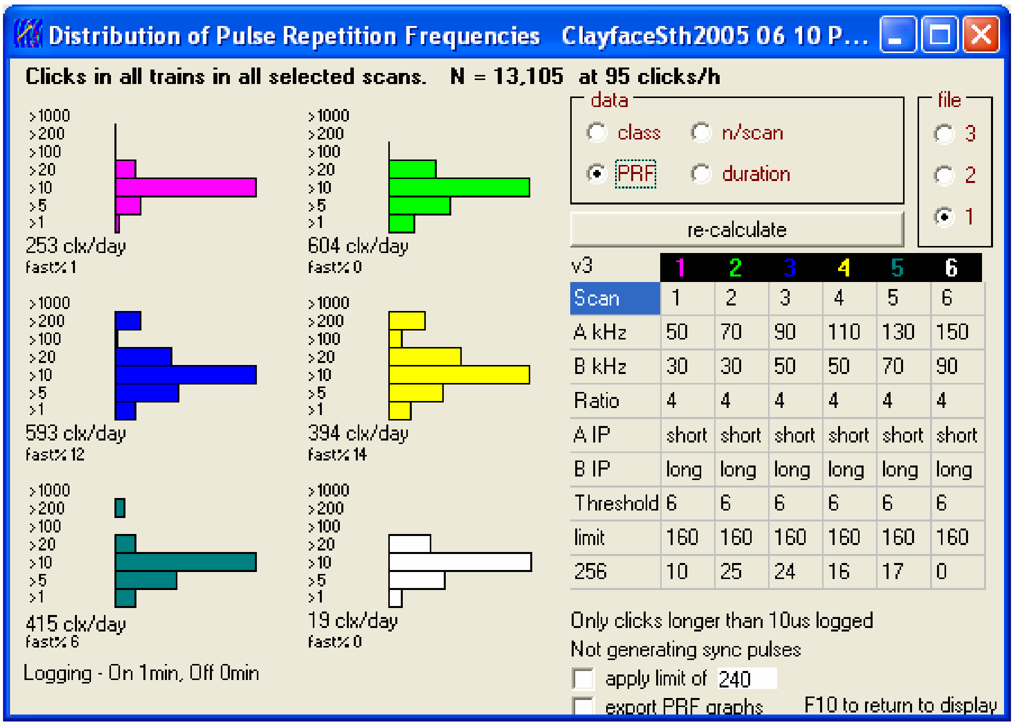


Figure 5. Frequency distribution of click repetition rates (PRFs) for the range of scan frequencies from 50 to 150 kHz. Peaks in the distribution are present at >10 clicks/s and >200 clicks/s for the deployment Clayface South 10 June 2005 illustrated above. The 'fast%' value shown for each scan is the number of interclick intervals at PRFs above 200/s as a % of those above 10/s. The greatest proportion of fast clicks logged here were at 90 kHz (12%) and 110 kHz (14%) in scans 3 and 4.

The PRFs for all classified dolphin trains (CetAll and Doubtful) were exported from the click data file using the Export B process and pooled for each month in Excel. The distribution of PRFs at each scan frequency was similar to the distribution displayed for individual deployments (Figure 5), with most PRFs below 20 clicks/s, the maximum bin was >200 clicks/s.

The mean click repetition rate (PRF) of trains for each scan frequency was calculated for June and July data. Overall there was a rise in average click repetition rate with frequency from 50 to 90 kHz, with the highest Mean PRFs at 90, 110 and 150 kHz for June and 90, 110 and 130 kHz for July deployments. The Mean PRF was consistently higher in June than July for the frequencies in the range 50 to 150 kHz, save 130 kHz (Figure 6). 'Fast' PRFs, defined as the percent of click trains with click repetition rates greater than 100/second were also most prevalent at the frequencies of 90 to 130 kHz (Figure 7). The divergence in the mean and %PRF values at 150 kHz in both Figures may be a function of sample size, with the least number of click trains logged at this frequency.

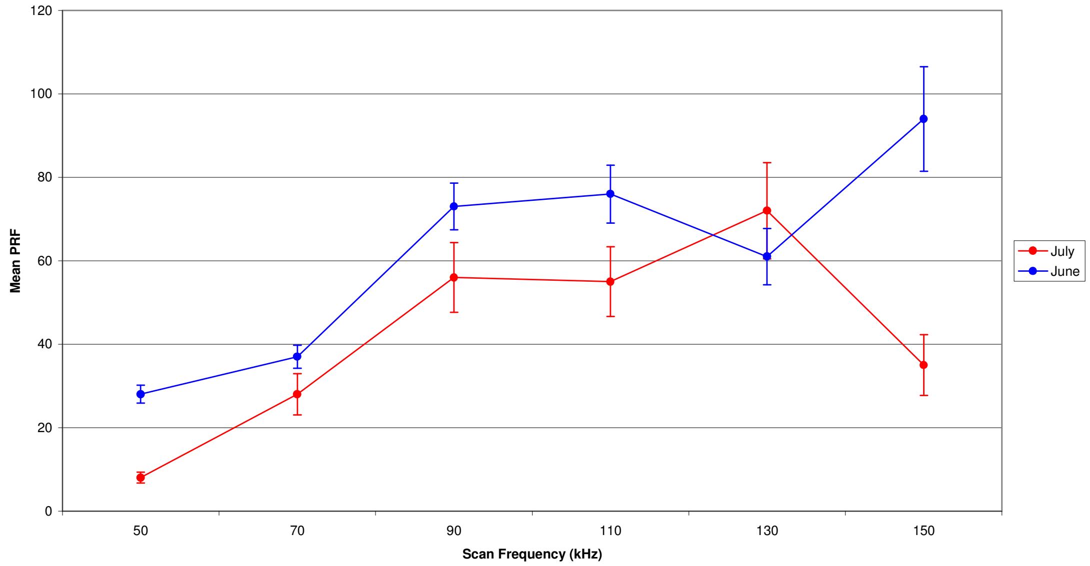


Figure 6. Variation in Mean PRFs logged at frequencies in the range 50 to 150 kHz

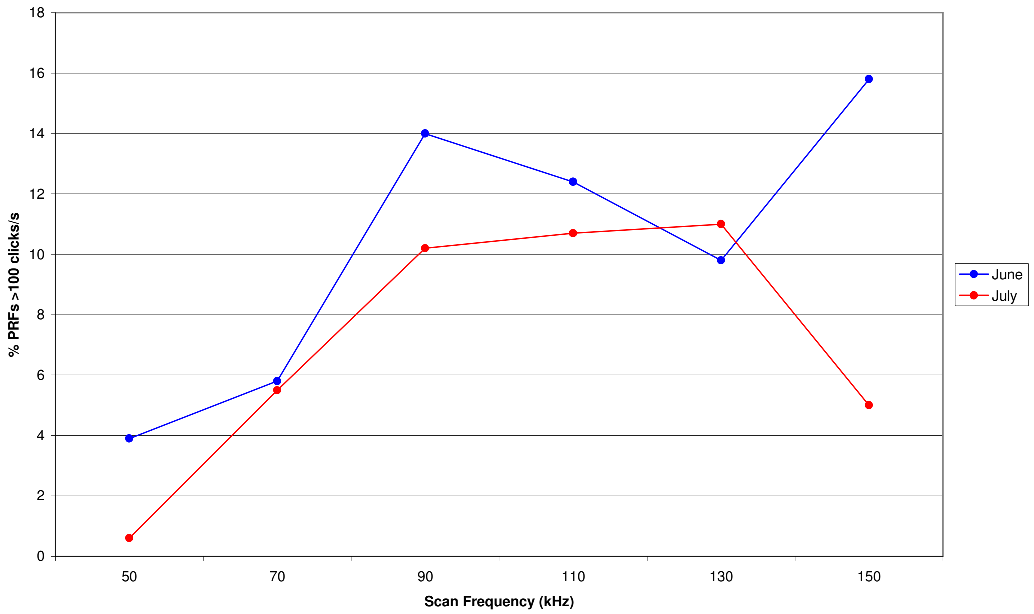


Figure 7. Prevalence of 'Fast' PRFs logged at frequencies in the range 50 to 150 kHz

Encounters durations from train detections

Encounter durations were calculated for all POD deployments at Clayface Point using a 10-minute silent period to delineate encounters. An encounter here means the time one or more cetaceans remain within the detection range of the POD. In June, the duration of encounters ranged from 1 minute to 168 minutes (15:55 to 18:43 hours 17 June), with an average encounter of 16 minutes (n=395). The number of clicks for encounters in June ranged from 5 to 4643 clicks (max count: 05:10 hours 20 June), with an average of 217 clicks. The duration of encounters in July were significantly shorter (ANOVA, df=898, F=108.2, P<0.001) with an average encounter of 5 minutes (n=504), ranging from 1 to 1 hour 44 minutes (18:48 to 20:32 hours 12 July). The number of clicks in encounters for July were significantly less than in June, with an average 50 clicks (ANOVA, df=898, F=53.9, P<0.001) ranging from 6 to 2089 clicks (max count: 18:48 hours 12 July).

The frequency distribution for dolphin encounters (in minutes) was similar between months with the modal peak at the bin range of 20 minutes. For June deployments, 50% of encounters lasted less than 30 minutes, compared to less than 20 minutes in July (Figure 7). The lowest bin category of 1 to 4 minute encounters was excluded from this Figure to reduce the likelihood of incorporating random clicks classified as doubtful trains.

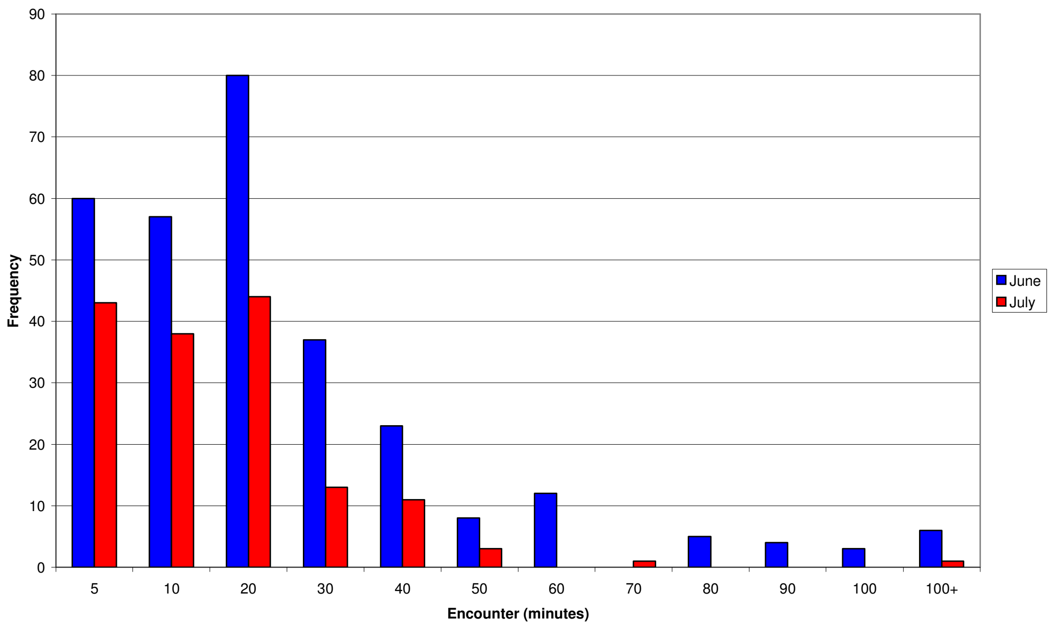


Figure 7. Duration of dolphin encounters (minutes) for June and July using a 10-minute ‘quiet period’ to delineate between encounters. The frequency distribution is for encounters of 5 minutes or more.

There was a general trend for the number of clicks to increase with respect to the duration of encounters as shown in Figures 8 and 9 for June and July deployments. The linear Spearman Rank correlation R^2 was calculated at 0.61 and 0.68 for June and July data, respectively.

Figure 8. Number of clicks logged for each encounter in June

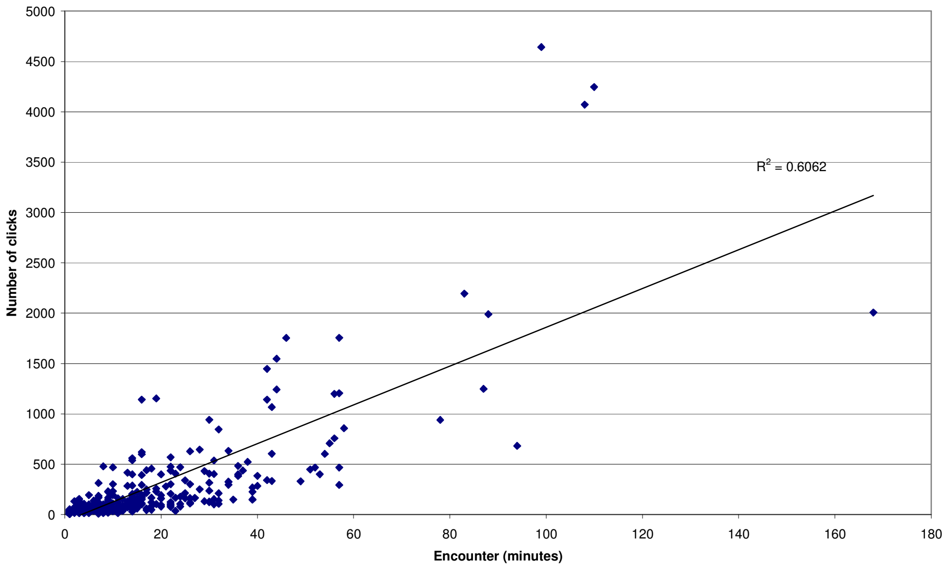
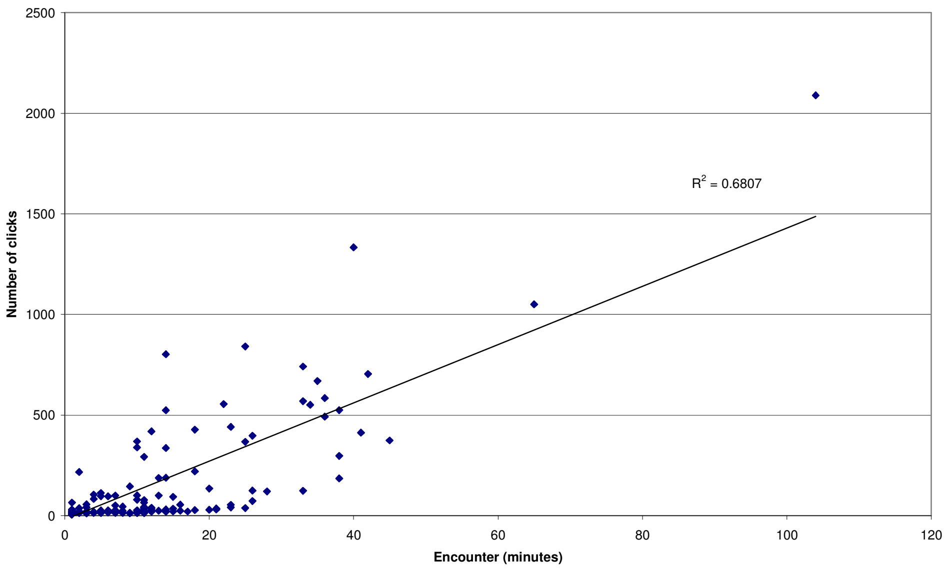


Figure 9. Number of clicks logged for each encounter in July



Dolphin encounters were detected throughout the day (Figures 10 and 11). However, the longest encounters were generally logged around 7AM (dawn) and 7PM (dusk) for June and July (Figures 10 and 11). 50% of dolphin encounters (%Total Positive Hours) occurred during the hours of darkness (7PM to 6AM) in June, compared to 59% of encounters in July.

Figure 10. Plot of encounter durations against hour of day, June POD deployments

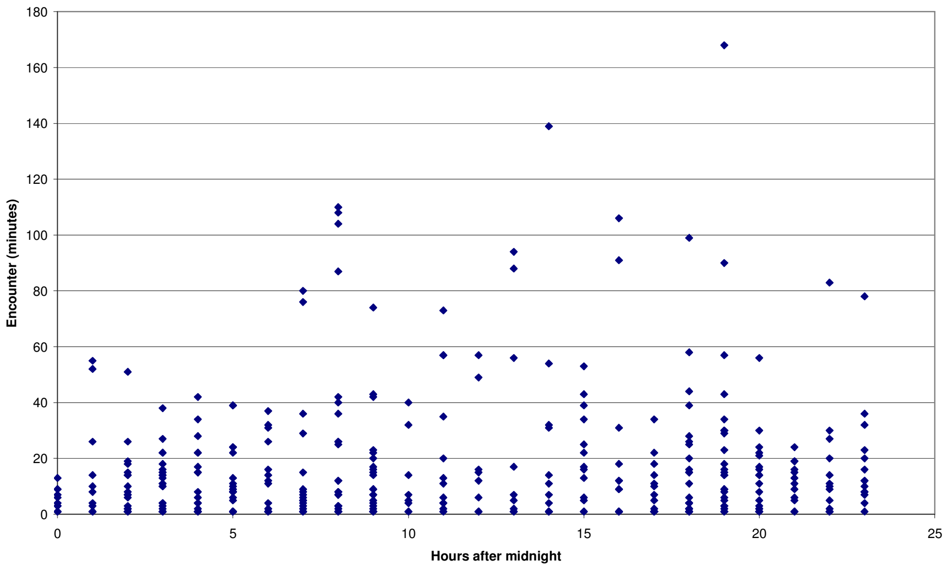
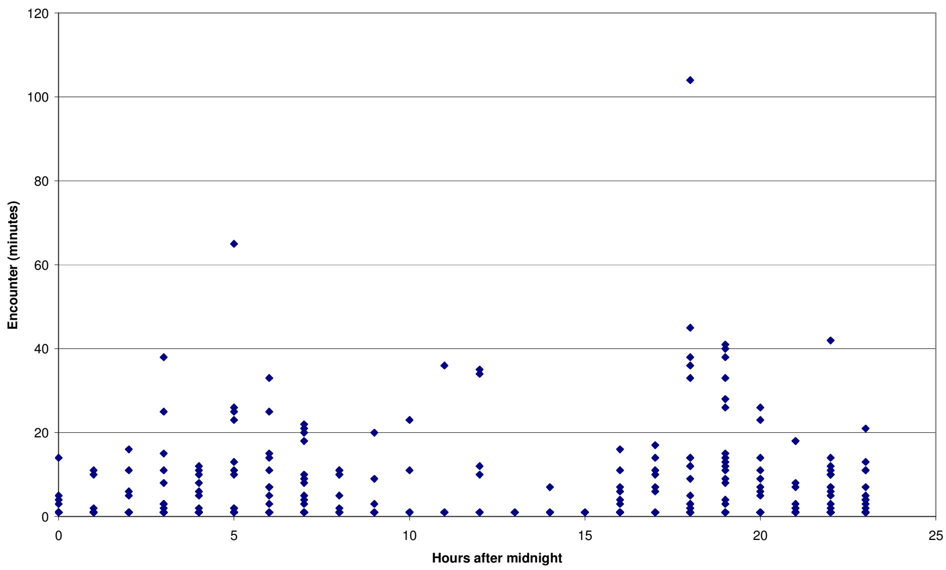


Figure 11. Plot of encounter durations against hour of day, July POD deployments



The diurnal occurrence of dolphin click detections is further illustrated by the plot of the 2 hour click counts against hour of the day (Figure 12). The peak in click detections occurs around dawn and dusk for June and July.

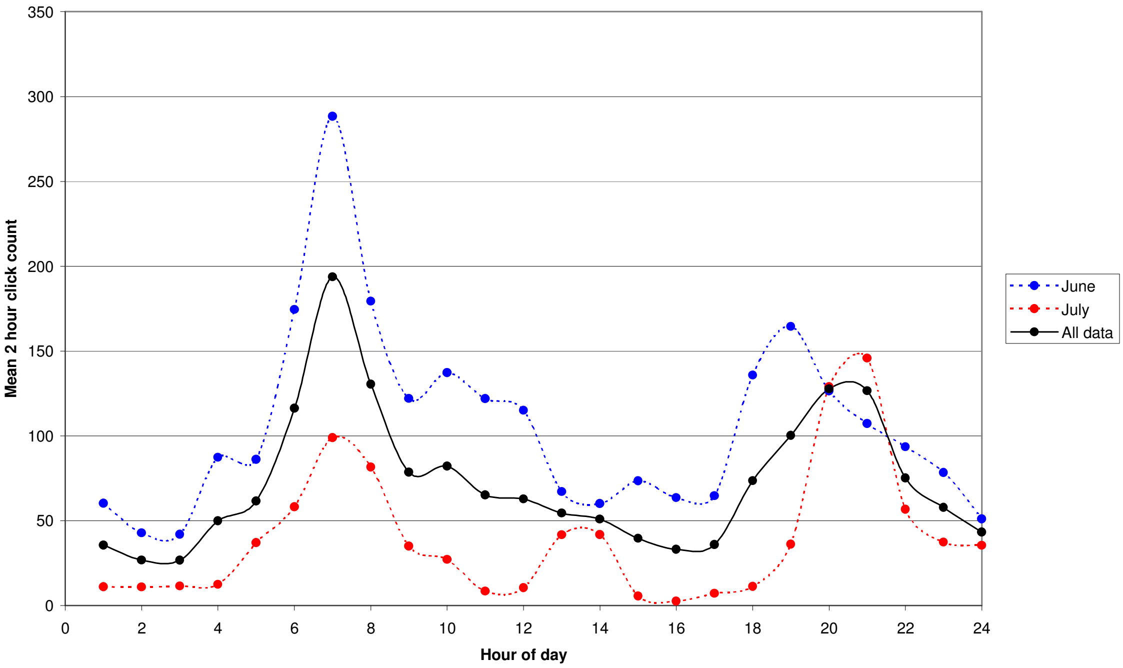


Figure 12. Diurnal occurrence of dolphin click train detections. The mean 2 hour click counts are shown.

Discussion

Observations vs PODs

Dusky dolphin click trains were detected by the POD at six frequencies selected in the range of 50 to 150 kHz and train times were found to correspond with sightings of dolphins around PODs. Also click trains were not detected during periods when PODs were under observation and dolphins were not sighted. Sightings of dusky dolphins on the north coast of Clayface Point were of animals travelling in or out of Inner Admiralty Bay, generally within 100 m of the coast.

Dusky dolphins regularly occupy Admiralty Bay during June to August. However, other species, comprising bottlenose dolphin, killer whale and common dolphin are also recorded annually passing through French Pass and around D'Urville Island. The array of PODs at Clayface Point could have logged any one of these species at other times in the day or night. However, there were no reports of other cetacean species off Clayface Point during this POD fieldwork from the local wildlife tour operator and Texas A&M researchers.

Clusters of dolphin clicks were logged (n=3 encounters) when dolphins were seen travelling on the surface close to the array of PODs buoys but clicks were only classified as trains on one occasion. The lack of train detections here may be because the dolphin echolocation is infrequent when travelling close the surface (compared to foraging near the surface or at depth), and because clicks may be directed ahead of the dolphins rather than toward the seabed and PODs. The POD train classification is designed to be 'conservative', to reduce the probability of false positive detections in very noisy marine environments (e.g. high velocity tidal races) but has been shown to work for a number of species (Bibliography), and improvements will make the system more sensitive.

More detailed observations are required using a video-theodolite to compare click detections with dolphin encounters, taking account of behaviour, distance and orientation of dolphins to PODs under various environmental conditions (see below).

The deployment and running times of each POD was satisfactory, operating in a variety of sea state conditions ranging from calm to choppy seas (25+ knot winds). POD253 stopped logging on two occasions prior to retrieval, which may be related to a software or laptop communication issue that requires further investigation.

The POD is a very simple spectral analyser but gives large volumes of accurate data on train structure, so it is most suited to studying the train structure and not the frequency spectrum of the clicks.

Click repetition rates

PRF frequency distribution plots for each deployment showed peaks in PRF counts at >20 clicks/s at all frequencies from 50 to 150 kHz, but with varying levels and >200 clicks/s and '%FastPRFs' (PRFs >100/s). PRF data by month showed a prevalence of clicks at 90 and 130 kHz, with PRF with click repetition rates greater than 100/second also most prevalent at the frequencies of 90 to 130 kHz. The divergence in the mean and %PRF values shown in both Figures may be a function of sample size, with the least number of click trains logged at 150 kHz. These observations indicate possible changes in behaviour because click repetition rates (PRFs) are known to vary with behaviour – high rates are used in feeding and by some species in social buzzes, low rates during travelling. The relative levels of PRFs > 100 clicks/s for a range of frequencies may be one method to discriminate dolphin species (discussed later).

Encounter durations

The number of clicks and duration of encounters were generally higher in June compared to July and may reflect a greater abundance of dolphins and feeding activity in June. The higher click rate in June is also shown by consistently higher click counts for the range of frequencies scanned. Around 50% of the encounters logged lasted up to 20 minutes, using the 10 minute 'silent period'. The frequency distribution of encounter durations was similar for click data by month and may reflect a predator-prey relationship; the presence of dolphins in the same area for a while may make their prey harder to catch (also see diel activity below). Further investigation using a range of 'silent period' values and time series analysis (autocorrelation function) is required to evaluate this time characteristic.

A lower reference frequency of 30 kHz was used in July deployments, which has the effect of reducing the specificity of PODs and therefore ought to increase the click detection rate. The difference in sensitivity of PODs and levels of ambient marine noise will have some effect on train detection and ultimately encounter duration, which should be considered in future trials. Encounter rates are likely to be less representative in areas or seasons with potentially low click rates or where animals spend little time, i.e. small numbers of dolphins or areas primarily used for travelling. There is a possibility of using the encounter duration as an index of sensitivity. This is because a passing animal is detectable for longer by a more sensitive POD (Tregenza et al. 2005).

There are a number of methods available for monitoring the habitat use of dolphins, determined largely by the resources available and power of analysis required to detect a change. Focal visual studies are generally limited to daylight hours, subject to prevailing weather and sea conditions and require a considerable investment in terms of human and boating time. Boats may also have impact on dolphin behaviour (or their prey) and bias or invalidate some observations.

Acoustic studies of click trains are reliant on the animal's echolocation being detected in the 'noisy' marine environment. Whilst dolphins may be 'silent' for periods of their daily lives, areas characterised by animals being present but silent have not been reported yet. Other studies have shown that the number of echolocation clicks increase considerably during 'feeding bouts'. Differences in click rates between encounters may therefore infer changes in behaviour, group size or reflect environmental and sampling differences (i.e. orientation and distance of dolphin from POD). Individuals within groups of dolphins probably share information (from click trains) and therefore click rates for known durations are unlikely to give a reliable estimate of group size.

Diel patterns in click train detections

The number of clicks in trains per hour (2 hour mean) was plotted against the hour of day; this index of dolphin click activity was used to combine aspects of behaviour with a measure of presence. A diel pattern in the number of click trains detected per hour was evident and consistent for June and July, with peaks in click counts around dawn and dusk.

Groups of dolphins within Admiralty Bay appear to utilise a range of behaviours to catch prey (McFadden, 2003). The high occurrence of dusky dolphin in the Bay around dawn, dusk and during night is presumed to be associated with feeding, supported by the prevalence of ‘fast’ click repetitions in trains. Dusky dolphins may also use the near-shore areas to avoid predation from killer whales and sharks at night (Cipriano, 1992; Constantine, 1998).

Studies of diel variation in the catchability (by trawl) of marine fish have shown that species exhibiting diel vertical migrations, such as sandlance (*Ammodytes sp*) and haddock (*Melanogrammus aeglefinus*), were caught in higher proportions during the day, whereas non-migrating species, such as flatfish, which rely on visibility as a means of escapement, were caught in higher proportions during the night. Analysis of the effect of depth indicated that catchability during the day, relative to the night, increased significantly with depth for some species (Casey and Myers, 1988). Depths in the inner Admiralty Bay are uniformly shallow around c.45 m. Flatfish, flounder would be expected on the predominantly mud substrate. Other common fish species associated with coastal habitats and with man-made structures such as mussel farms include; leatherjacket (*Parika scaber*) and spotty wrasse (*Notolabrus celidotus*), as well as red cod (*Pseudophycis bachus*), blue cod (*Parapercis colias*), parore (*Girella tricuspidata*) spotted dogfish, stargazer (*Crapatalus novaezelandiae*), opalfish *Hemerocoetes monopterygius*, juvenile flatfish, and red gunnard (*Chelidonichthys kumu*). Snapper, kingfish (*Seriola lalandi*), and leatherjacket may be attracted to farms during seeding out and harvesting (Inglis and Gust 2003).

An alternative explanation for the diel click train patterns could be that dusky dolphins are taking small shoaling fish (e.g. New Zealand pilchard *Sardinops sagax*, sprats *Sprattus antipodum and* anchovy *Engraulis australis*) and juvenile fish that migrate in to open water forming shoals around first light (anti-predator response), and disperse to shelter over reefs or other refuges at night. Here it is assumed that the catchability of the shoaling fish will decrease as the shoal disperses, to a level that is too costly in time or energy for the dolphin. Similar diel patterns have been found with harbour porpoise but require an assessment of local fish (e.g. saithe *Pollachus virens*) abundance and distribution at various times of the day and tidal state to confirm this (Fisher & Tregenza, unpublished data).

<u>Future research and recommendations</u>

Previous work by the Würsig research group has provided an invaluable insight into the ecology, feeding behaviour, group structure and movements of dusky dolphins in New Zealand waters. However, there has not been any concerted attempt to measure the presence and habitat use of dusky dolphins (or other Delphinid species) at mussel farm sites using passive acoustic monitoring, which is required to make a comprehensive assessment of whether dolphins are present at any given time, particularly when dolphins may be undetected from visual observations (ie periods of choppy seas, darkness and when foraging underwater and surfacing further a field in open water). Around 50% of dolphin click trains reported in this study were detected during the hours of darkness!

Monitoring a site prior to the installation of mussel farm to detect any change before, during and after (using BACI experimental design) will probably provide the most meaningful results but unlikely to be a plausible option because AMAs are largely designated where aquaculture currently exists and such studies require considerable time (several years) to complete. The Department of Conservation is currently undertaking a 3 year research programme to develop monitoring methods suitable for investigating the effects of mussel farms on marine mammals and seabirds.

Ecological information is required for a number of ongoing resource consent applications, where aquaculture sites are proposed in areas with significant marine mammals (and seabird) populations, e.g. Marlborough Sounds. Two key questions should be addressed in the EMP as part of the FRIA for proposed aquaculture sites (new or extensions) where *important*[1] populations of dolphins and their prey are considered to occur. Each site should be taken on a case-by-case basis. The suggested survey methods are currently available:

1. Will the aquaculture farm exclude marine mammals (within 500m radius)?

Passive acoustic detection of dolphins at mussel farm sites
Six POD monitoring stations strategically located within 500 m of the *proposed* farm (anchor lines) perimeter: two positioned between the inner mussel lines and one POD at the north, south, east and west approach to the farm. PODs may be set at greater distances moving away from the farm in one direction where farms are sited in a narrow channel or semi-enclosed bay. The depth of the POD deployment will alternate every two weeks between surface and seabed at each station to investigate detection rates and habitat use with depth. Further POD monitoring stations may be required at large open water mussel sites. The distribution and abundance of dolphins around the mussel farm and maritime approaches should be recorded in concert with the acoustic monitoring. The POD click train detection range is up to 500m.

2. Will the aquaculture farm have any effect on the distribution and abundance of locally important prey (for marine mammals and other key wildlife species)?

Acoustic surveys of local fish prey
Active sonar may be employed from boat transects to sample the concentration of shoaling fish prey at various spatial and temporal scales accounting for tidal effects and seasonality of spawning and migrating fish prey. This method is not suitable for all fish prey species, particularly species that may be sensitive to the boat sonar. Other important prey such as benthic living fish and molluscs may form an important component of the prey, which may be surveyed by SCUBA transects.

POD acoustic surveys and behavioural studies – technical issues

Detecting broadband frequency dolphin click trains
Use the 'Normal Sensitivity Dolphin Sweep' with a reference frequency of 30 kHz. The lower range of frequencies (<70 kHz) will log most of the clicks associated with breaking waves and other sources of marine noise. The ratio of target / reference (=specificity) and the gain value (=threshold) may require a higher setting if the frequency of clicks >320 per scan. Dolphin clicks are relatively loud compared to other marine sounds, so increasing the gain in increments of 1 from 6 up to 10 is favoured over increases in the specificity.

[1] Species or habitat of conservation importance at local or national level

Species identification

The present system is usable for monitoring but discrimination between the most common species, bottlenose, common and killer whale is difficult. A POD was deployed from the MV Manaia ahead of travelling bottlenose dolphins on two occasions in April. Dolphin trains were logged on these occasions, which detected clicks on all frequencies in the range from 50 to 150 kHz. The encounter was too short to reliably compare bottlenose click or PRF rates with the dusky dolphin data. The sensitivity of the POD transducer, which requires a soak time of at least three hours to reach full sensitivity, should be considered when comparing click trains from different deployments.

Variance in PRFs and click counts at selected frequencies may be used to differentiate dolphin species that occur in the area but this would require much more work and at present the system provides a generic dolphin-dolphin identification.

Click bandwith distribution may be used to differentiate species, requiring encounter analysis. Au and Wursig (in press) reported clicks at 90 and 110 kHz as dominant frequencies for dusky dolphin (as well as 40-60 kHz). These relatively high frequencies are used by other dolphin species but probably to a lesser degree.

One approach to identify dusky dolphins from common and bottlenose would be to set the target frequency of scans at 90 and 110 kHz and the reference frequencies either side, ie. 90/30 and 110/150, selecting a high gain value. The analysis would then compare the ratio of clicks at 90 and 110 kHz scans. The reference of 30 kHz can be used on a separate scan to assess the relative click intensity at the lower frequency. 130kHz clicks only over periods of minutes or hours will be from Hector's or Maui's dolphin. Some account will be needed to standardise the volume of data (i.e. click totals or encounters).

Set POD scan settings (A/B) to 90/30, 90/150 and 110/150, 110/30
Set (A/B) ratio to 4
Set threshold to 6, increase in 1+ increments to 9 over several deployments.
Set no limit on the number of clicks.
Other scans may be set to 50/30 and 70/30

Behavioural studies

Study click train structure for various behaviours and describe good sequences of click trains for comparative studies between modes of behaviour and species. Method for characterising click trains for various behaviours using Normal dolphin sweep, reference (B) @ 30 kHz, ratio A/B from 4 to 6, threshold 6 to 10:

Travelling behaviour: deploy two PODs on the same mooring, one close (~3 m) from the surface pointing to the seabed and a second POD mid water or just above the seabed pointing to the surface. Compare PRFs and detection / classification rates at the various depths.

Feeding behaviour: as above, deployed in the Inner Bay at sites that can be observed from land with video-theodolite.

Mussel farm behaviour: deploy two PODs (as above) between two farms in the Inner Bay and ~ 600 m away (outside detection range of mussel farm POD). Take a series of observations with video-theodolite at various times of day and tide.

Changes in click rates and PRFs in response to navigational hazards (e.g. shallow water habitats, aquaculture structures) and conditions of poor visibility during darkness or in turbid water have yet to be investigated.

Characterisation of Non-Cetacean click trains

Clicks from fish and crustaceans may present substantial background noise that can inhibit cetacean train detection and or cause dolphins to switch to other frequencies (). Broadband audio recordings in conjunction with POD data could be used to investigate marine noise at from various sources in Admiralty Bay.

Characterise the click train structure of marine noise at dusky dolphin study sites.

e.g. clicks from fish and crustaceans, breaking waves at various deployment depths and POD settings.

Boat sonars from various types of craft (mussel harvesters, fishing boats). Most Boat sonar can be readily identified using the default train detection algorithm and excluded from analysis.

These studies will help to develop an understanding of marine noise in various habitats and it's effect on click train detection rates.

Habitat use / Population demography

Some work is required to match visual density data with acoustic statistics. A descriptive analysis of the geographical and temporal scale of coherence would be valuable as an indicator of POD numbers/spacing required in a range of habitats to give useful statistics.

POD statistics for cetacean monitoring and behavioural studies

(Notes from Tregenza 2005)

Significance of PRF / ICI (inter-click interval) values. POD data often show 'travel clouds' where a steadily downward trend in ICI is seen over a minute or more. Periods of stable ICI in which the actual value of ICI appears to be closely related to water depth. Feeding /investigation buzzes have been studied in detail and are seen in POD data, although almost invariably only fragments of the actual long sequence produced by the animal are captured on the POD.

Detection positive minutes per hour/day is a mainly measure *level of habitat use* defined as time spent in the habitat. Time corresponds directly to density while the value of DPM/day is low. As it rises towards 1440 it is bound to underestimate density.

Detection positive days per week/month is in use as a measure of *regularity of habitat use* for very low density areas. This measure has the same property of minimising differences between higher densities, but starts to do that at a lower level.

The advantages and disadvantages of these two measures differ. Both reflect the chance of the POD capturing a train which will to some extent be affected by whether animals are echolocating, how loud this is, and how much they sweep their sonar beam around by changing their orientation. Also low PRFs will be more susceptible to being obscured if there is a prevailing high rate of false clicks. These factors correspond to the issues in distance line transect surveys of behavioural factors that may vary g(0) (the chance of detecting animals on the trackline).

Detection positive minutes per day may reflect density but this depends on the animals being free to move in and out of detection range as they forage or travel. In effect the POD is sampling an area defined both by the detection range of the POD and by the movement patterns of the animals.

Mean PRF in detection positive minutes provides a statistic that has little or no density element but does reflect behaviour in a way that is not yet clearly defined, and will be complex.

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APPENDIX

POD	Location	Date PutOut	WayPt	Eastings	Northing
253	Sth of Stewart Is	10-Jun-05	253	2585272	6035115
254	Penguin Bay	10-Jun-05	254	2587137	6039160
255	E of Clayface pt	10-Jun-05	255	2582353	6030219
256	Sth of Clayface pt	10-Jun-05	256	2581993	6029709
253	N of Clayface point	17-Jun-05	257	2581922	6020890
254	E of Clayface pt - distant	17-Jun-05	259	2582559	6029887
255	E of Clayface pt	17-Jun-05	255	2582353	6030219
256	NE of Clayface Pt	17-Jun-05	260	2582491	6030856
		Line of PODs ~NE orientation			
256	N of Clayface point	12/07/2005	6	2581930	6030736
255	N of Clayface point	12/07/2005	7	2582143	6030655
254	N of Clayface point	12/07/2005	8	2582350	6030599
253	N of Clayface point	12/07/2005	9	2582536	6030526