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# *Using T-PODs to assess variations in the occurrence of coastal bottlenose dolphins and harbour porpoises*

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## ABSTRACT

1. Assessments of anthropogenic impacts on cetaceans are often constrained by limited data on the extent to which these species use particular areas.
2. Timing porpoise detectors (T-PODs) are autonomous data recorders for detecting cetacean echolocation clicks, potentially providing cost-effective opportunities for monitoring cetacean occurrence.
3. The performance of T-PODs was assessed in three areas off the Scottish east coast, where the relative occurrence of bottlenose dolphins and harbour porpoises was known to differ. Land-based observations in one area compared visual and acoustic detections of dolphins, while direct hydrophone recordings of dolphin echolocation clicks were compared with T-POD detections during boat surveys.
4. Land-based surveys recorded 89 groups of dolphins within 900 m of the T-POD. All groups spending $>30$ min in the area were detected on the T-POD, and the probability of detection declined in relation to distance from the recording site.
5. The number of dolphin clicks recorded on the independent hydrophone system was significantly related to the number detected by a T-POD. Between pairs of T-PODs, there was also significant correlation with the numbers of clicks recorded in each hour, both for channels set to detect bottlenose dolphins and for channels set to detect harbour porpoises.
6. Year-round deployments of paired T-PODs detected significant geographical variation in detections for both bottlenose dolphins and harbour porpoises. This pattern reflected published data from visual surveys, where dolphins occurred most regularly within the Moray Firth Special Area of Conservation, and porpoises were sighted more regularly in offshore waters.
7. T-PODs do not detect all cetaceans in the area, and care must be taken when interpreting data from mixed species communities. Nevertheless, these results confirm that T-PODs provide an effective method for monitoring the occurrence of bottlenose dolphins and harbour porpoises, and provide excellent potential for collecting baseline data from poorly studied areas and monitoring long-term temporal change in key areas of interest.


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KEY WORDS: cetaceans; passive acoustics; monitoring; echolocation; marine protected areas

## INTRODUCTION

Recent developments in survey techniques and analytical frameworks have greatly improved our understanding of broad-scale distribution and abundance of many coastal cetacean populations (Evans and Hammond, 2004; Redfern *et al.*, 2006). Nevertheless, efforts to assess the impact of specific coastal developments or to monitor the success of conservation action often remain constrained by a lack of finer-scale data on the occurrence of cetaceans in specific areas. Baseline data on temporal variation in the occurrence of cetaceans in affected areas is of particular importance for

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impact assessment and the identification of appropriate mitigation measures (Weilgart, 2007; Jefferson *et al.*, 2009). Typically, these assessments require data to be collected at scales of only a few to tens of square kilometres, over periods of at least one or two years. In contrast, cetacean survey techniques typically focus on providing larger-scale estimates of abundance (Hammond *et al.*, 2002), or modelling distribution (Weir *et al.*, 2001; Canadas *et al.*, 2005), across scales of hundreds to thousands of square kilometres. The effort required to survey such large areas consequently means that few of these studies are able to extrapolate beyond a single, short, time period.

Efforts to minimize the impact of coastal developments on these species therefore require the development and validation of cost-effective techniques that can be used to produce appropriate fine-scale data on cetacean occurrence. Furthermore, where data are required on temporal variability, these techniques cannot be dependent upon the good weather and daylight conditions required for large-scale visual surveys of cetaceans (Evans and Hammond, 2004). Because cetaceans use sound to communicate and navigate, passive acoustic surveys have the potential to improve detection probabilities in poor light or weather conditions (Di Sciara and Gordon, 1997). Such techniques are now commonly used independently and in combination with ship-based visual surveys (Norris *et al.*, 1999; Clark and Ellison, 2000; Wade *et al.*, 2006). Furthermore, acoustic recording devices that can collect data remotely over long periods provide additional opportunities for assessing temporal patterns of occurrence (Verfuss *et al.*, 2007).

T-PODs (timing-porpoise detectors) were developed to detect harbour porpoises (*Phocoena phocoena*), and have since underpinned a variety of studies on this species (Culik *et al.*, 2001; Carlström, 2005; Thomsen *et al.*, 2005; Carstensen *et al.*, 2006). These devices incorporate a hydrophone, analogue processor and digital timing system that automatically log the start and end of each echolocation click to 10 μs resolution. In every minute, the T-POD runs six successive scans within different user-defined frequencies, logging detections for periods of over five months depending upon battery configuration. An accompanying software program is used to post-process the recovered data, detect characteristic click trains, and remove noises from other sources such as boat sonar (see www.chelonia.co.uk for details). Resulting data on the number of click trains recorded in each minute can be used to determine the presence or absence of target species in different time periods, or to identify the timing and duration of encounters with target species. To detect the high frequency echolocation clicks of harbour porpoises, previous studies have used a target frequency of 130 kHz, resulting in estimated detection distances in the region of 200 m (Tougaard *et al.*, 2006). However, because cetaceans differ in the frequency range of their echolocation clicks, T-PODs have the potential to be used to detect other species. For example, using a target frequency of 50 kHz, Philpott *et al.* (2007) confirmed that T-PODs could successfully detect bottlenose dolphin (*Tursiops truncatus*) at distances of up to 1246 m, with over 80% of schools that were visually detected within 500 m of the T-POD also being detected acoustically.

T-PODs therefore have the potential to provide a finer-scale technique for assessing long-term variability in the occurrence of certain cetacean species in specific sites. Previous assessments of the performance of T-PODs have focused on studies of harbour porpoises (Thomsen *et al.*, 2005; Tougaard *et al.*, 2006). This study builds upon Philpott *et al.*'s (2007) work by assessing the potential for using T-PODs to examine local geographic variation in the occurrence of bottlenose dolphins. In particular, it was desired to compare the performance of replicate T-PODs moored at sites that were known to differ in the relative probability of sighting harbour porpoises and bottlenose dolphins. Philpott *et al.*'s (2007) recommendation for assessing T-POD detection rates by using independent visual and acoustic methods to validate automatic detections of dolphins was followed. Finally, the resulting data on geographic variation in the occurrence of these two species are discussed, in relation to those derived from independent sources, to assess the potential for using T-PODs to support management and monitoring programmes for coastal cetaceans.

## METHODS

### Study area

The study was carried out in the Moray Firth, NE Scotland, part of which has been designated as a Special Area of Conservation (SAC) to protect bottlenose dolphins under the EU Habitats Directive (Figure 1). Previous studies indicate that there is a summer peak in the abundance of bottlenose dolphins in the inner Moray Firth (Wilson *et al.*, 1997; Hastie *et al.*, 2004). The primary study site was in the mouth of the Cromarty Firth, where shore-based visual observations could be made from a headland overlooking this area (Hastie *et al.*, 2003a). The second site was also within the SAC, but at the eastern boundary near Lossiemouth, where dolphins were sighted less frequently. Finally, a third site was located in the central part of the Moray Firth, outside the SAC, where bottlenose dolphins are rarely recorded (Hastie *et al.*, 2003b). In contrast, previous studies indicate that the probability of sighting harbour porpoises is lower in the inner Moray Firth but increases in more offshore areas (Hastie *et al.*, 2003b; Bailey and Thompson, 2009). We therefore predict that these three sites should provide a gradient of decreasing occurrence of bottlenose dolphins and increasing occurrence of harbour porpoises.

### Acoustic data collection

Version 4 T-PODs were used to detect echolocation click trains, and all data were processed using version 8.17 of the manufacturer's software (v.4 train filter). Following the manufacturer's guidelines for use in areas where both harbour porpoises and bottlenose dolphins might be detected, T-PODs were configured to detect clicks from dolphins and porpoises on alternate channels. For dolphins, a target frequency of 50 kHz and reference frequency of 70 kHz (bandwidth = 5 and sensitivity = 6) were set. For porpoises, a target frequency of 130 kHz and reference frequency of 92 kHz (bandwidth = 4 and sensitivity = 6) were set.

T-PODs were moored in pairs with concrete blocks and a surface float for easy recovery (Figure 2). In the Cromarty Firth and at Lossiemouth, the T-PODs were 20 m apart, about 2 m above the seabed in 10 m water depth (Figure 2(a)). In the



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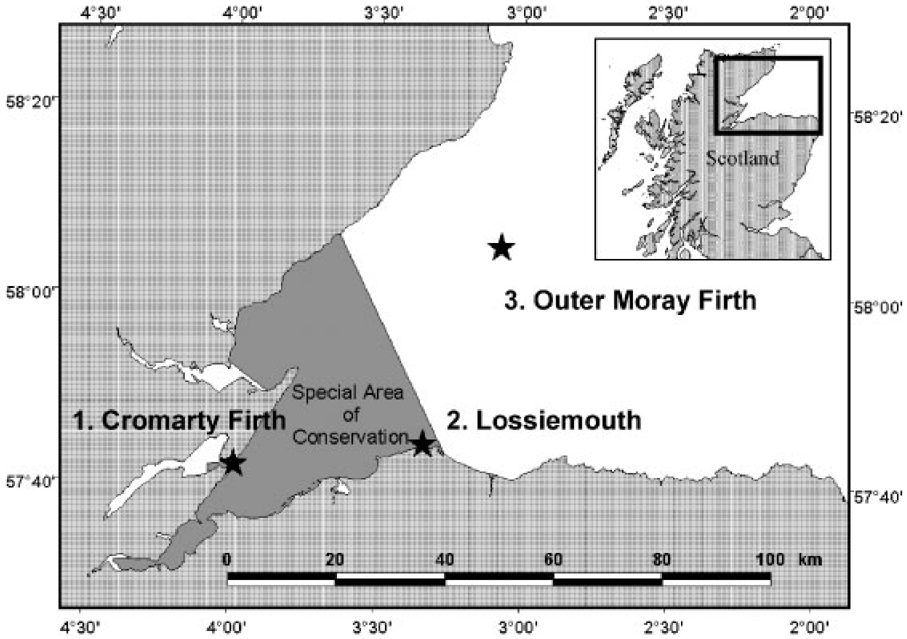



Figure 1. Map of the study area showing the location of the Moray Firth Special Area of Conservation, and the location of the three T-POD monitoring sites (black stars).

outer Moray Firth, the water depth was approximately 45 m. Here, T-PODs were moored at approximately 15 m and 40 m depth (Figure 2(b)). T-PODs were powered with 12 alkaline 1.5 V D-cells or 12 lithium 3.6 V D-cell batteries, and retrieved every 10 or 20 weeks, respectively. A total of 10 different version 4 T-POD units were used, rotating individual units between pairings and locations during the study.

## Comparison of visual and acoustic detections of bottlenose dolphins

Land-based visual observations were made during April–June 2005 and 2006 from a vantage point (57° 40.7′ N, 4° 00.7′ W) overlooking the Cromarty Firth, 133 m above sea level. Observation periods lasted between 1 and 5 h, and were abandoned if weather conditions deteriorated to either poor visibility or sea state $\geqslant 3$. Throughout each observation period, an area of approximately 1–3 km around the T-POD surface buoy was scanned by eye and with binoculars (Opticron $7 \times 50$) to determine when dolphins were present in the study area. Positions of surfacing groups were also determined as frequently as possible using a surveyor's theodolite (Hastie *et al*., 2003a). Previous studies at this site indicate that these positions were accurate to within 2.8 m (Hastie *et al*., 2003a). However, some sectors around the T-POD site had a more restricted view, and it was not possible to be sure that dolphins were absent from the zone 1–3 km west and south of the T-POD buoy.

Following recovery of the acoustic data, it was first determined whether or not dolphins were detected in each minute through the deployment. The train detection algorithm in the T-POD software assigns trains into several different categories. The category CET ALL, which combined both the high probability click trains (CET HI) and less distinctive trains (CET LO) was used, following the recommendation of the manufacturer (www.chelonia.co.uk) and previous assessments of performance for detecting harbour porpoises (Thomsen *et al*., 2005).

Those T-POD recordings that coincided with periods in which the presence of dolphins had been confirmed by visual observations were selected. These data were first used to estimate the probability that the T-POD detected the presence of each group in relation to the amount of time that the group remained in the area. Second, for each group, theodolite positions of surfacing events were used to estimate the closest distance that the group approached the T-POD location during that encounter. These data were then used to determine how the probability of detection varied in relation to how close each group approached the T-POD.

## Comparison of T-POD detections and direct recordings of dolphin echolocation clicks

Boat-based studies were carried out on three days in June 2006 to obtain simultaneous acoustic recordings using both a T-POD and an independent hydrophone and hard disc recorder (Brüel and Kjaer model 8103 hydrophone) with a NEXUS$^{TM}$ conditioning amplifier (frequency response 0.1 Hz–180 kHz, sensitivity $-211$ dB re 1 V$\mu$Pa$^{-1}$) and Sound Devices 722 HDD recorder (sampling at 192 kHz and 24 bit depth, giving an effective frequency range up to 96 kHz). Recordings using both the hydrophone and an independent T-POD were made at 5 m depth from a moored 8.5 m vessel at the entrance to the Cromarty Firth (57° 41.4′°N, 3° 58.8′ W), both in the presence and absence of visual sightings of dolphins. Dolphin group size, distance from the boat and behaviour were also noted. No porpoises were observed during any of these sampling periods, and parallel studies between 2004 and 2008 also indicated extremely low occurrence of porpoises in this area (only one sighting during 236 boat-based photo-ID surveys conducted through this area between 2004 and 2008). Recordings were made in the presence and absence of dolphins for 10-min sample periods. The pulse train analysis function in Avisoft SASLab Pro

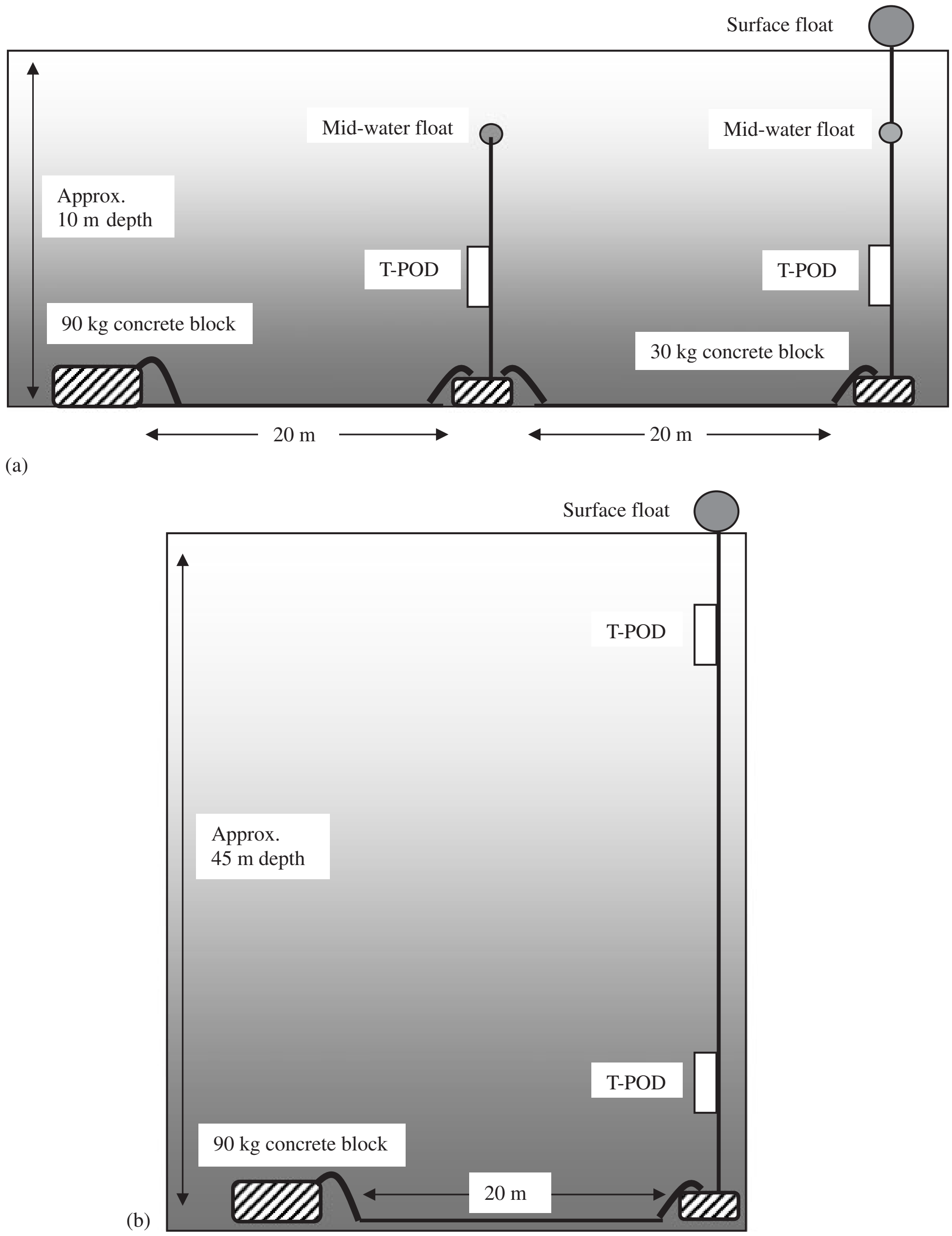



Figure 2. Schematic of (a) the T-POD shallow water moorings in the Cromarty Firth and Lossiemouth sites and (b) at the deeper water site in the outer Moray Firth.

version 4.39 was then used to count the number of echolocation clicks in those sections in which dolphins were present. Settings for the Avisoft pulse train analysis were determined by listening to a short sample of the recordings and adjusting the settings to match the number of clicks that were audible. These data were then compared with the number of clicks detected on the T-POD during the same time period.

## Comparability between T-PODs

Detections between pairs of T-PODs deployed at the same site were first compared by calculating the mean similarity between T-POD pairs. This was calculated from the number of hours in which both T-PODs gave the same response (detection present or absent) divided by the total number of hours during the deployment. The percentage of detections contributed by each T-POD was then calculated by taking the number of detections on each single T-POD and dividing this by the total number of detections from the two T-PODs combined. The number of echolocation click trains detected in each hour by each of the paired T-PODs were compared using a Pearson correlation. Each of these comparisons was repeated both for dolphin detections and porpoise detections.

## Determining relative habitat use using T-PODs

Data from the T-PODs were then used to assess whether there were differences in the frequency of detections of dolphins and porpoises at the three study locations. Detections were analysed for the period May 2005 to June 2006 in the Cromarty Firth and Lossiemouth, and August 2005 to June 2006 for the site in the outer Moray Firth. Comparisons were based on the proportion of hours in each month that dolphins or porpoises were detected at each location.

## RESULTS

Paired T-PODs were successfully deployed at all three sites for periods of approximately 12 months, although there were some short gaps within the record caused by battery failure before recovery (Table 1). Units powered by alkaline batteries were typically still recording when recovered after 8 to 10 weeks. Units powered by lithium batteries recorded for periods of up to 28 weeks.

### Ability of T-PODs to detect bottlenose dolphins

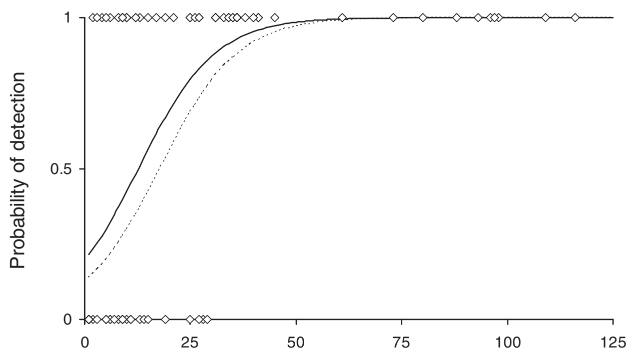
Land-based observations were made overlooking the T-POD in the Cromarty Firth on 20 days in 2005 and 22 days in 2006. Dolphins were observed within 2.5 km of the T-POD locations on 12 and 17 of these days respectively, on 89 occasions (mean = 30.6 min; range = 1–155 min). All groups were recorded within 900 m of the T-POD location at some point during each of these 89 encounters. Analyses of the T-POD records from each of these periods confirmed that the probability of detecting the group at some point during the encounter increased with the amount of time that the group spent in the area, and that all groups remaining in the area around the T-POD for over 30 min were detected at least once (Figure 3(a)). As expected, the probability of detecting groups also varied in relation to how close they approached the T-POD (Figure 3(b)), but some of the groups of dolphins were detected at a range of at least 800 m. For both duration and detection, there was a slight increase in detection probability when using data from a pair of T-PODs rather than a single T-POD (Figure 3).

### Accuracy of T-POD detections of dolphin clicks

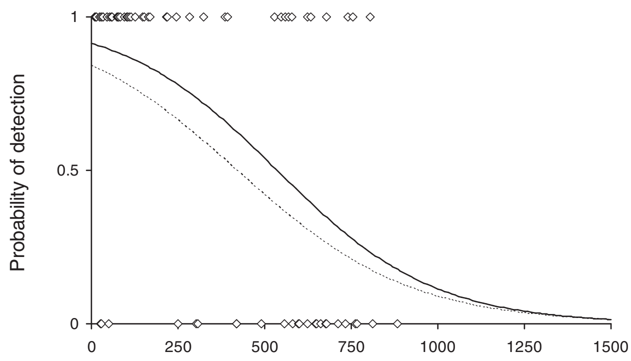
Boat-based surveys resulted in five encounters with dolphins over three days, with estimated group sizes of between two and seven individuals. During these encounters, 27 different 10 min samples were recorded using both the hydrophone system and the T-POD. Dolphins were visually observed during 25 of these samples. Echolocation clicks were detected on the hydrophone system in all 25 of these 10 min samples, and a significant positive relationship was found between the number of clicks recorded on the hydrophone system and the T-POD (Figure 4). This relationship remained significant even when the higher value outliers were removed, although the variation

Table 1. Deployment details for the paired T-PODs used at the three study sites. See Figure 1 for site locations

| ID | Location | POD A | POD B | Start date | End date |
|---|---|---|---|---|---|
| 1 | Cromarty Firth | 427 | 429 | 12/05/2005 | 16/06/2005 |
| 2 | Cromarty Firth | 425 | 428 | 16/06/2005 | 05/08/2005 |
| 3 | Cromarty Firth | 426 | 432 | 02/09/2005 | 13/10/2005 |
| 4 | Cromarty Firth | 520 | 527 | 03/11/2005 | 21/11/2005 |
| 5 | Cromarty Firth | 426 | 427 | 21/11/2005 | 10/02/2006 |
| 6 | Cromarty Firth | 527 | 520 | 10/02/2006 | 11/04/2006 |
| 7 | Cromarty Firth | 426 | 428 | 11/04/2006 | 15/06/2006 |
| 8 | Lossiemouth | 426 | 432 | 12/05/2005 | 02/08/2005 |
| 9 | Lossiemouth | 430 | 431 | 02/08/2005 | 09/09/2005 |
| 10 | Lossiemouth | 425 | 428 | 20/10/2005 | 01/01/2006 |
| 11 | Lossiemouth | 429 | 432 | 31/01/2006 | 02/06/2006 |
| 12 | Outer Moray Firth | 427 | 429 | 11/08/2005 | 30/10/2005 |
| 13 | Outer Moray Firth | 431 | 430 | 03/11/2005 | 22/03/2006 |
| 14 | Outer Moray Firth | 427 | 520 | 18/04/2006 | 06/06/2006 |




(a)




(b)

Figure 3. Changes in the probability of detection by a pair of T-PODs (solid line) and a single T-POD (dashed line) in relation to (a) the amount of time that the dolphin group spent in the area around the T-POD and (b) the group's minimum approach distance to the T-POD. Lines are fitted by logistic regression, all significant at $P < 0.001$. Raw data plotted as open diamonds.

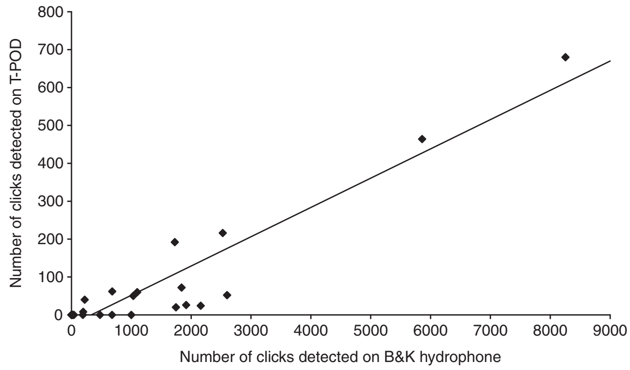



Figure 4. Relationship between the numbers of clicks recorded from the hydrophone and the numbers of clicks detected by the T-POD. Data are from 10-min sample recordings taken during boat surveys when dolphins were within 200 m of the survey vessel. Fitted line based on linear regression ($F_{1,25} = 184.1$, $P < 0.001$, $r^2 = 0.88$) .



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explained was lower (linear regression: $F_{1,23} = 16.52$, $P < 0.001$, $r^2 = 0.4$). Overall, the T-POD detected dolphins in 11 (44%) 10-min samples during which dolphins were visually sighted around the boat and echolocation clicks were recorded on the hydrophone. The number of clicks recorded by the hydrophone in those samples in which T-POD detections were made was significantly higher than in those samples in which the T-POD failed to detect dolphins (detection: median = 1793, n = 14. No detection: median = 26, n = 11; Mann–Whitney U = 7.00, $P < 0.001$). There was no significant relationship between the number of clicks recorded and group size over the small range of group sizes observed during this work (linear regression: $F_{1,3} = 1.23$, $P = 0.348$). There was also no significant relationship between the number of clicks detected on the T-PODs and group size when using the larger data set from all of the visual surveys ($F_{1,38} = 0.46$, $P = 0.504$).

## False positives

During the boat surveys, there were only two 10 min recording periods in which dolphins were not observed visually and where no dolphin clicks were recorded on the hydrophone. No dolphin detections were recorded on the T-POD during either of these 10 min samples. During visual observation periods in which there were no positive sightings of dolphins, the T-POD detected dolphin clicks in 238 (5.8%) of 4100 1-min samples. However, 80% of these detections were within 15 min of a positive visual sighting, and all were within 80 min of dolphins being recorded in the area.

Throughout the whole study, only one porpoise was observed during the land-based observations, and this was only for a few minutes on a single day in 2005. No detections were recorded on the T-POD's porpoise channel during that sighting. However, detections on the porpoise channel occurred frequently during periods in which dolphins were also detected on the T-POD. For example, in 33 (44%) of 75 h in which dolphins were both visually sighted and detected on the T-POD, there were also detections on the porpoise channels. Overall, 87% of the porpoise detections recorded on the T-POD at this site occurred during hours in which dolphins were also detected. Given the very low frequency of visual sightings of porpoises at this study site, and known aggressive conflicts between bottlenose dolphins and porpoises in this area (Ross and Wilson, 1996; Thompson *et al.*, 2004), it is assumed that detections on the porpoise channel that occur at the same time as dolphin detections are false positives resulting from misclassification of dolphin clicks.

## Comparability between T-PODs

There was a significant correlation between the number of clicks recorded on each of the paired T-PODs for both dolphin channels (Figure 5(a): Pearson correlation $r = 0.81$, $P < 0.001$) and porpoise channels (Figure 5(b): Pearson correlation $r = 0.67$, $P < 0.001$). These correlations were significant for all individual deployments, with the exception of deployment 14, which detected dolphins in only three different hours (Tables 2 and 3). Overall, the similarity between each T-POD's ability to detect dolphins or porpoises in any hour was high (Tables 2 and 3), and the relative contribution to detections from any single T-POD suggests that there were no

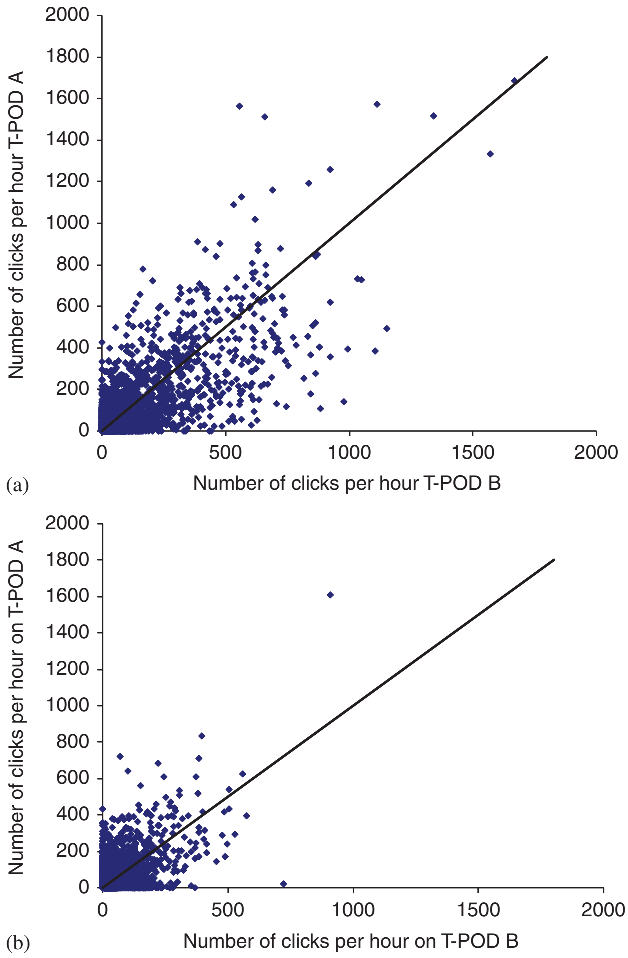


Figure 5. Comparison of the number of clicks detected in each hour on the individual T-PODs that were moored as pairs. Data are pooled for all deployments through the study and are presented (a) for dolphin clicks and (b) for porpoise clicks. The line of equality is also presented on each figure.

systematic differences in detection ability between positions on the mooring at the sites in the Cromarty Firth and at Lossiemouth. However, there were consistently more dolphin detections on the T-POD nearer the seabed (POD A) than that nearer the surface (POD B) at the Outer Moray Firth site, although this was not the case for porpoise detections during those same deployments (Tables 2 and 3).

## Determining relative area-use using T-PODs

There was a significant difference in the frequency with which dolphins and porpoises were detected at the three sites. Dolphins were detected regularly at the site in the Cromarty Firth, only rarely in the outer Moray Firth, and at an intermediate level at Lossiemouth on the south coast. The opposite pattern was seen for porpoises, which occurred regularly in the outer Moray Firth but only rarely in the inner Moray Firth. This pattern remained similar when using all detections on the porpoise channel, or when using only the porpoise detections obtained during hours in which dolphins were not detected (Figure 6). Given the likelihood that the presence of dolphins resulted in false detections on the



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Table 2. Comparison of the detection of dolphin clicks on each of the paired T-PODs deployed through the study. n is the number of 1-h samples in each deployment, and the similarity is expressed as the percentage of those samples that returned the same result (i.e. presence or absence during the hour)

| ID | n | Similarity | %POD A | %POD B | r | *P* |
|---|---|---|---|---|---|---|
| 1 | 840 | 87.38 | 95.70 | 79.00 | 0.74 | <0.001 |
| 2 | 1202 | 83.44 | 91.32 | 74.13 | 0.74 | <0.001 |
| 3 | 992 | 91.33 | 79.22 | 83.55 | 0.80 | <0.001 |
| 4 | 433 | 90.99 | 75.00 | 80.68 | 0.68 | <0.001 |
| 5 | 1938 | 97.01 | 77.78 | 92.93 | 0.72 | <0.001 |
| 6 | 1439 | 96.39 | 81.72 | 62.37 | 0.69 | <0.001 |
| 7 | 1560 | 91.22 | 89.61 | 86.27 | 0.87 | <0.001 |
| 8 | 1970 | 97.66 | 61.43 | 72.86 | 0.53 | <0.001 |
| 9 | 920 | 96.41 | 67.57 | 87.84 | 0.84 | <0.001 |
| 10 | 1758 | 97.50 | 89.39 | 43.94 | 0.52 | <0.001 |
| 11 | 2934 | 99.18 | 38.71 | 83.87 | 0.12 | <0.001 |
| 12 | 1923 | 99.79 | 80.00 | 40.00 | 0.23 | <0.001 |
| 13 | 3340 | 99.73 | 80.00 | 30.00 | 0.21 | <0.001 |
| 14 | 1175 | 99.66 | 75.00 | 25.00 | −0.01 | 0.96 |

The relative contribution of each of the pods in the pair to the positive detections is presented as %POD A and %POD B. The significance of a Pearson correlation between the number of clicks recorded in each sample is also presented.

Table 3. Comparison of the detection of porpoise clicks on each of the paired T-PODs deployed through the study. n is the number of 1-h samples in each deployment, and the similarity is expressed as the percentage of those samples that returned the same result (i.e. presence or absence during the hour)

| ID | n | Similarity | %POD A | %POD B | r | *P* |
|---|---|---|---|---|---|---|
| 1 | 840 | 83.81 | 90.05 | 42.29 | 0.39 | <0.001 |
| 2 | 1202 | 90.26 | 58.50 | 61.90 | 0.39 | <0.001 |
| 3 | 992 | 94.86 | 70.42 | 57.75 | 0.46 | <0.001 |
| 4 | 433 | 94.69 | 56.76 | 81.08 | 0.51 | <0.001 |
| 5 | 1938 | 96.13 | 58.93 | 74.11 | 0.30 | <0.001 |
| 6 | 1439 | 95.56 | 73.17 | 74.80 | 0.69 | <0.001 |
| 7 | 1560 | 88.85 | 70.32 | 68.20 | 0.60 | <0.001 |
| 8 | 1970 | 97.97 | 64.15 | 60.38 | 0.46 | <0.001 |
| 9 | 920 | 96.74 | 70.00 | 55.00 | 0.31 | <0.001 |
| 10 | 1758 | 98.01 | 62.96 | 72.22 | 0.57 | <0.001 |
| 11 | 2934 | 97.41 | 41.76 | 74.73 | 0.41 | <0.001 |
| 12 | 1923 | 92.46 | 75.11 | 62.66 | 0.49 | <0.001 |
| 13 | 3340 | 87.04 | 85.13 | 74.37 | 0.73 | <0.001 |
| 14 | 1175 | 93.36 | 75.94 | 82.35 | 0.63 | <0.001 |

The relative contribution of each of the pods in the pair to the positive detections is presented as %POD A and %POD B. The significance of a Pearson correlation between the number of clicks recorded in each sample is also presented.

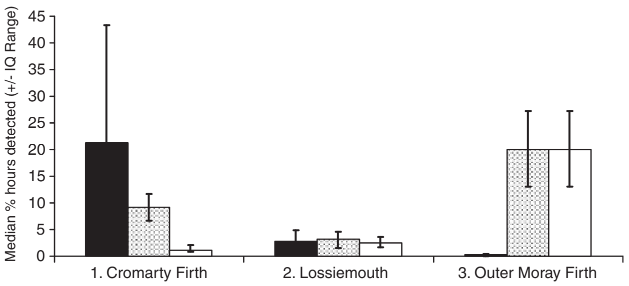


Figure 6. Median (+/− IQ range) of the percentage of hours in each month in which there were detections at the three T-POD sites within the Moray Firth (see Figure 1). Data are presented for detections (a) on dolphin channels (solid bars), (b) on porpoise channels (shaded bars), and (c) on porpoise channels excluding all detections when dolphins were detected in the same hour (open bars).

porpoise channel when using the selected frequency and bandwidth settings (see previous section), it is suggested that the most robust measure of porpoise occurrence is obtained by using only those porpoise detections from hours in which dolphins were absent. Using this data set, site differences in the monthly percentage of hourly samples that recorded positive detections were significant both for dolphins (Kruskal–Wallis one-way ANOVA. K-W test statistic −24.9, $P<0.001$) and porpoises (Kruskal–Wallis one-way ANOVA. K-W test statistic −22.67, $P<0.001$).

## DISCUSSION

Cetaceans spend only a small fraction of their time at the surface, and variations in both sea state and light conditions can often lead to low and variable detection probabilities when carrying out visual surveys at sea. Acoustic survey methods offer the potential to help overcome this problem, and have been employed both from ship-based platforms to provide wide-scale spatial data (Barlow and Taylor, 2005), and from fixed sites to provide information on temporal patterns of cetacean occurrence within local areas (Wade *et al.*, 2006). However, more wide-scale use of these techniques has often been limited by the high expense of acoustic equipment and the technical expertise required to collect and analyse these data. T-PODs were designed to provide a low-cost and user-friendly technique for monitoring the occurrence of harbour porpoises, and they have since been applied widely to studies of this species (Carlström, 2005; Verfuss *et al.*, 2007). Philpott *et al.* (2007), have also demonstrated that T-PODs can be used reliably to detect bottlenose dolphins. Nevertheless, one key constraint of early versions of the T-POD (i.e. v.1, v.2 and v.3) was that there could be marked variability in the detection rates of individual units. Consequently, considerable effort had to be put into cross-validating all the units to be used in a study before they could be deployed at different sites. Subsequent hardware changes have meant that the manufacturers are now confident that individual v.4 T-POD units will provide more consistent detections, but field tests to confirm this have not previously been reported.

Pairs of v.4 T-PODs were deployed in three areas with differing densities of bottlenose dolphin and harbour porpoise, and confirmed that there was within-pair consistency in the detection rates of both species (Figure 5; Tables 2 and 3). Nevertheless, there was considerable residual variability in this relationship (Figure 5). Pairs of T-PODs were moored approximately 20 m apart. Thus, differences in the number of detections recorded on each unit within the pair are also likely to have resulted from differences in the number of clicks heard by each unit, particularly given the directional nature and narrow beam of bottlenose dolphin and harbour porpoise echolocation calls. In future it would be possible to apportion these different sources of variation by deploying pairs of T-PODs attached directly to each other. However, the design of mooring used in this study (Figure 2) means that the precise position of individual T-PODs may vary by ~20 m between subsequent deployments. Thus, it is the combined variability resulting from any differences in T-POD sensitivity and slightly different locations that needs to be considered when using these devices to monitor changes in occurrence at particular sites. Comparison with direct hydrophone



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recordings at the same position also demonstrated that T-PODs did not detect all echolocation clicks (Figure 4). These data, together with the comparison of visual sighting and T-POD detections suggest that T-PODs did not necessarily detect dolphins every time they were observed in the survey area. Nevertheless, while acoustic methods clearly cannot detect the presence of dolphins every time they enter an area, these studies do indicate that the technique offers good opportunities for providing robust relative measures of occurrence in specific local areas.

Further research exploring the factors that influence detection probability would now be useful, particularly in relation to the influence of water depth and the position of the T-POD in the water column. In the meantime, as long as studies are carried out at appropriate scales, existing data now offer sufficient evidence that T-PODs provide a robust method for monitoring spatial and temporal variations in the occurrence of bottlenose dolphins and harbour porpoises. Observations demonstrated that T-PODs detected the presence of bottlenose dolphins on every occasion that dolphins were observed in the area for $>30$ min (Figure 3(a)), and that their detection probability was $>0.5$ for all groups of dolphins that were observed within 500 m of the T-POD (Figure 3(b)). Thus, in shallow coastal waters such as those in the Moray Firth, T-PODs provide a practical method for assessing variations in the occurrence of bottlenose dolphins within 800–1250 m around the sampling site (this study; Philpott *et al*., 2007). Nevertheless, when interpreting T-POD data from other sites, factors such as water depth, mooring depth, levels of background noise and variations in the echolocation behaviour of animals using that site may all influence detection probability.

In this study, differences in the relative number of T-POD detections from bottlenose dolphins and harbour porpoises at the three sampling sites (Figure 6) reflected existing data from land- and boat-based visual surveys. As predicted, bottlenose dolphins were recorded most frequently in the inner Moray Firth, at a site that is recognized as a key foraging area for this population (Wilson *et al*., 1997; Hastie *et al*., 2004). In contrast, harbour porpoises were detected regularly in the outer Moray Firth, but dolphin detections were rare (Hastie *et al*., 2003b; Bailey and Thompson, 2009). Detection rates for the two species were similar, but at a low level, on the southern coast of the Moray Firth at Lossiemouth; an area in which visual sightings of both species are recorded at a similar frequency (Thompson *et al*., 2004). These differences were clearly apparent from the T-POD data (Figure 6), despite inevitable (and often unquantifiable) differences in the other factors that potentially affect detection rates. As such, these data provide further support for using these techniques to collect data on local geographical variation in the occurrence of these species, and to explore temporal patterns of occurrence in these areas. At the same time, these data also highlight how uncertainty over species identification can constrain the interpretation of data from T-PODs. In the sampling protocol, three of the six channels on the T-POD were used to detect dolphins (target frequency 50 kHz, reference frequency 70 kHz) and the others to detect harbour porpoises (target frequency 130 kHz, reference frequency 92 kHz). This was based on bottlenose dolphins having broadband echolocation clicks that still contain high energy at the lower frequency of 50 kHz (Au *et al*., 1974), whereas the narrowband harbour porpoise clicks do not (Au *et al*., 1999). However, at the Cromarty Firth observation site, it was found that the T-POD regularly detected clicks on the porpoise channel, despite porpoises being rarely sighted in this area. Further investigation revealed that these detections occurred almost entirely during hours in which dolphins were also detected. Given that bottlenose dolphins are capable of higher peak frequencies, for example when producing echolocation clicks at higher source levels (Au, 1993), it was assumed that porpoise detections occurring in hours in which bottlenose dolphins are also detected were highly likely to be false detections. This assumption is also supported by known aggressive behaviour between bottlenose dolphins and porpoises (Ross and Wilson, 1996) and fine-scale segregation of these two species where their ranges do overlap (Thompson *et al*., 2004). In future, better discrimination between dolphins and porpoises should be possible by restricting the bandwidth in the porpoise channel to exclude wider bandwidth clicks from dolphins. However, there will still be limitations on the interpretation of T-POD data where several dolphin species co-occur because it is not currently possible to discriminate between these different dolphin species based on their echolocation click characteristics (Soldevilla *et al*., 2008). In this study, this was most likely to be an issue in the outer Moray Firth, where dolphin sightings are rare, but typically involve common dolphins (Delphinus delphis) rather than bottlenose dolphins. Thus, the T-POD data collected in this study cannot be used to confirm the presence of bottlenose dolphins in the Outer Moray Firth, but they do indicate that, if they do occur in the area, it is only very rarely (Figure 6).

In conclusion, this study has shown that acoustic monitoring using T-PODs can provide an effective method for monitoring the occurrence of bottlenose dolphins and harbour porpoises in coastal waters. Like visual surveys, these acoustic methods cannot provide 100% detection probabilities, and particular care must be taken over the interpretation of data where mixed species communities occur. Nevertheless, where studies are made at appropriate temporal and spatial scales, these techniques offer the potential to collect data over periods of many months, in areas that may be impossible to access regularly using other means. In particular, where T-POD data can be supplemented with data from visual surveys, these techniques provide valuable opportunities for collecting the data required to support the conservation and management of these populations.

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