Final thesis

Evaluation of a new device for static acoustic monitoring of harbour porpoises in the wild

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CONTENTS

1. Abstract
The Porpoise Click Logger (PCL) is a new device for static acoustic monitoring of harbour porpoises. It was developed primarily for use in the Baltic Sea, where better knowledge of the distribution of porpoises is of high concern. The PCL is designed for usage by fishermen, and therefore requires different characteristics than existing monitoring devices. This study aimed at evaluating the PCL in respect to practical, technical and detection-functional aspects. This was done through calibrations, field studies in areas with high densities of porpoises and in a pilot project with professional fishermen. The maximum detection range of 155 m is of the same magnitude as other SAM devices. A detection proportion of 92 % was found. The detection range and proportion is necessary information for coming censuses using the PCLs. Overall, the PCL worked well and has shown to be robust and easy to handle. It is well suited for use in fishery. There were some problems, the most serious concerning the low and varying sensitivity of the hydrophones.

Keywords: Baltic Sea, *Phocoena phocoena*, Passive acoustic monitoring, PCL, Porpoise click logger, Sweden

2. Introduction
The harbour porpoise (*Phocoena phocoena,* L.) is one of the smallest cetaceans, with a weight of 46-65 kg and a length of 141-163 cm (Lockyer 2003). It appears mainly in relatively shallow waters, seldom deeper than 200 m. Benthic fish species is the primary food, but pelagic species and a small proportion of benthic invertebrates are also taken. The harbour porpoise is a social animal and is usually found in groups of 2-10 animals, although there are seasonal variations in the group composition (Klinowska 1991). The distribution is widespread in the temperate and shallow waters of the Northern hemisphere. It has always been the most common cetacean in European waters (Watson 1981). Abundance has however declined in many areas, due to extensive by-catch in fishing operations (Vinther 1999, Vinther & Larsen 2004). Depletion of prey populations, pollution and other anthropogenic disturbances are also believed to have contributed to the population declines (Reeves et al. 2003). There is a lack of information necessary for effective management of the species. However, the immediate conservation concern seems to be not for the species, but for some regional populations that have severely declined and remains threatened. One of those is the population in the Baltic Sea.

The harbour porpoise in the Baltic is classified as Vulnerable in the IUCN Red List, but may in fact be Endangered (Reeves et al. 2003). Historically, the range of the species extended into the easternmost and northernmost parts of the Baltic Sea. Since the late 1800s, the distribution range has narrowed and major declines in numbers have been reported (Koschinski 2002). For Swedish and Polish waters, the abundance today is very low compared to the early 20th century. The current eastern limit of regular occurrence seems to be around the Gdansk bay and the northern limit close to Öland or Gotland (Koschinski 2002). An aerial survey in 1995 and a following boat-based acoustic and visual survey in the summers of 2001 and 2002 confirmed the limited occurrence and very low relative abundance of harbour porpoises in the Baltic Sea (Gillespie et al 2005).

Although there are some uncertainties regarding the population structure, the existence of a distinct Baltic subpopulation appears to be a valid concept (Koschinski 2002) and should be treated as such for management (Palmé 2004). The level of by-catch appears to be the greatest threat to the Baltic population, and immediate management actions have been recommended to reduce the magnitude of by-catches (Berggren 1994, IWC 1996, Berggren et al. 2003, Koschinski 2002, Gillespie et al 2005). Several studies and reports have also stressed the need for more knowledge about the distribution and abundance of porpoises in the Baltic (Berggren 1994, Berggren et al. 2003, IWC 1996, Koschinski 2002). This is of high concern both for management objectives, and for being able to assess the long-term effectiveness of the mitigation measures that are employed.

One of the conventions mentioning the needs of further knowledge about harbour porpoises in the Baltic is the so called Jastarnia plan. It was established in 2002 by ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas), and the formal name is "Recovery Plan for the Baltic Harbour Porpoises". The goal of the Jastarnia plan is to restore the Baltic porpoise population to at least 80% of its carrying-capacity level. One of the objectives to reach this goal is to "improve knowledge in key subject areas as quickly as possible". Highest priority under this point is to develop and apply new techniques for assessing trends in abundance. "Given the apparently low-density occurrence of porpoises in the Baltic, standard distance sampling is unlikely to provide adequate statistical power to detect trends. Therefore, new approaches, such as acoustic monitoring, will be essential for assessing effectiveness of recovery efforts" (Anon. 2002).

Cetaceans generate ultrasonic pulses, called clicks (Akamatsu et al. 1994), and these makes so called acoustic monitoring possible. The porpoise clicks are used for communication (Amundin 1991) and echolocation during feeding (Akamatsu 1994, Goodson & Sturtivant 1996) and orientation (Verfuβ 2005). The distinct and easily distinguishable click trains from the harbour porpoise makes detection of the species possible, and submerged automatic logging systems are used for this purpose.

Based on the Jastarnia plan, earlier ASCOBANS-agreements, EU regulations, HELCOM recommendations and Swedish Environmental Quality Objectives, a Harbour Porpoise Action Programme for Sweden was established in 2003 (Lindahl et al. 2003). Two of the key questions to be answered according to the plan were the size of the porpoise populations in the Baltic Sea, Skagerrak and Kattegat, and the distribution of the populations within each area. Acoustic monitoring was said to be an interesting and potentially valuable and cost-effective supplement to visual censuses for this purpose (Lindahl et al. 2003).

In addition to national action plans, there is also a common regulation for the countries in the European Union. In 2004, the Council of the European Union established a regulation (812/2004), "laying down measures concerning incidental catches of cetaceans in fisheries". Here it is stated that cetaceans are given strict protection status and that "Member States are required to undertake surveillance of the conservation status of these species. Member States should also establish a system to monitor the incidental capture and killing of these species, to take further research and conservation measures as required to ensure that incidental capture or killing does not have a significant impact on the species concerned". It also requires the use of acoustic devices to deter cetaceans from fishing gear in areas and fisheries with known or foreseeable high levels of by-catch, taking into account the cost/efficiency of such requirement. One of the areas specified is the Swedish coast of the Baltic proper, between Utklippan and Falsterbo (Anon. 2004).

In response to the Council regulation, a new static acoustic monitoring (SAM) device has been developed and employed. This was done in a project funded by the European Union and run by the Swedish board of Fisheries, in cooperation with the Swedish Fishermen's Association, The new SAM device is called the Porpoise Click Logger (PCL; Aquatec Ltd, UK, Kolmårdens Djurpark, Sweden, and GDNatur, DK). The aim of this project is to investigate the distribution of harbour porpoises in the area affected by the council regulation. This is the first time SAM is employed in Swedish waters, but in other countries SAM has been conducted using a similar device, the Timing Porpoise Detector (T-POD, Chelonia Ltd., Long Rock, UK).

Most documented harbour porpoise studies using SAM have investigated relative differences in densities (Carstensen et al. 2006, Verfuβ et al. 2007). The potential of acoustic monitoring for estimations of group sizes has however been shown for Indo-Pacific humpbacked dolphins (*Sousa chinensis,* van Parijs 2002)*,* and suggested to be possible as well for finless porpoises (*Neophocoena phocaenoides*, Wang et al. 2005). Some unpublished studies have investigated the possibilities of using the T-POD for absolute abundance estimates of harbour porpoises (Tougaard et al. 2006), comparing SAM and mobile visual monitoring data (Rye 2006) and linking porpoise behaviour to issues of SAM (Leeney & Treganza 2006, Verfuβ et al. 2006). In 2002-2005 a SAM study using T-PODs confirmed a very low density of the species in the German part of the Baltic proper (Verfuβ et al. 2007).

Compared to the T-POD, the PCL is smaller, lighter, has shorter battery life, and most importantly, is much more easy-handled when it comes to charging of batteries and uploading of data[1]. This was a deliberate choice in the design since the deployment and handling was to be carried out by commercial fishermen and not by scientists or students, as in the case with the T-POD. The device should be small and robust enough to be deployed together with the net, and could be visited often enough in the normal course of the fisheries operations to allow for a shorter battery life.

As the PCL is a new product, calibration and test trials in the field are important for the validation of results from data collected by it. This thesis aims at assessing the function of the PCL as a device for detecting and monitoring harbour porpoises in the wild. The detection function will be tested through a validation study, and practicality through a pilot test in active fishery.

3. Materials and methods

3.1 The PCL

The PCL is an automated system for the passive detection of Phocoenid sonar. The trade name for the PCL (Figure 1) used in this study is *AQUAclick 100 Porpoise click recorder* (Ceurstemont 2006).

Figure 1. Porpoise Click Logger (PCL).

3.1.1 Hardware

The PCL housing (made of delryn), contains a rechargeable battery pack (four C cell metal hydride

[1] pers. comm., Mats Amundin, Kolmårdens djurpark

batteries), the acoustic electronics (Figure 2) and an 8 Mb memory chip. The transducer is a rubber moulded, ceramic hydrophone (approximate nominate sensitivity -208 dB re 1V/µPa; producers specification) with a saltwater switch which activates the PCL when it is deployed into saltwater. The transducer is attached with a waterproof Subconn® via which uploading of data and charging of batteries can be done. The battery life is at least ten days. The weight of the PCL is 1.2 kg in air, about 0.3 kg in water, the length 240 mm and the diameter 83 mm.

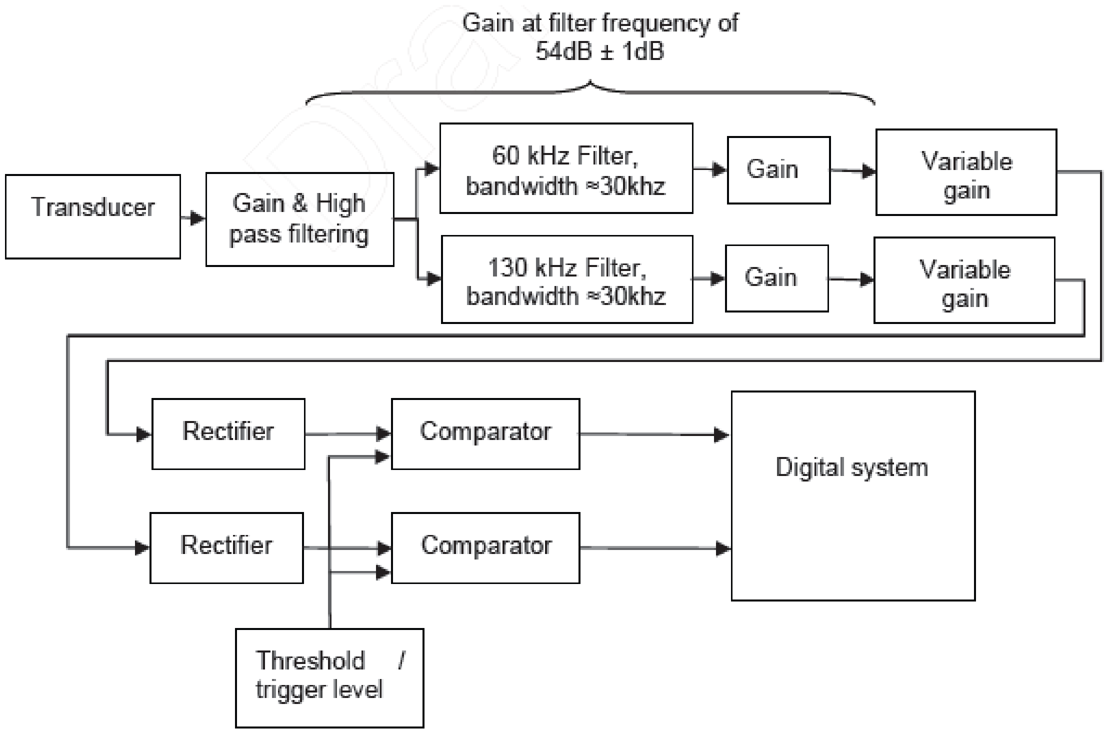


Figure 2. Outline of the acoustic electronics in the PCL (from Ceurstemont 2006).

3.1.2 Software

The PCL is configured and data is uploaded using the custom made software AQUAtalk for AQUAclick. The variable gain (0, 6, 12, 14, 18, 20, 24, 30 dB) and the threshold for the rectified click in the 130kHz filter channel to trigger the comparator (1-255; -37.76-10.37dBV) can be set, as well as the internal clock and the click detection parameters. Parameters for detection are click length (101-16000000 µs) and inter-click interval (hereafter ICI, 1-16000000 ms). There is also an option only to log clicks with an amplitude ratio >1 between the 130 kHz and 60 kHz filter channel output. The rational behind this is to eliminate noise and to be able to distinguish between broadband Delphinidae clicks and narrowband Phocoenidae clicks. The latter have most energy around 140 kHz

(Goodson & Sturtivant 1996, Villadsgaard et al. 2007), and will therefore have a high filter ratio. Delphinidae clicks have considerable energy below 100 kHz, and will have a filter ratio of one or below one (Au 1993). Noise usually have even lower fundamental frequencies and will also have a ratio below one. The harbour porpoise has been shown to prefer a mean Inter Click Interval (ICI) of around 60 ms, but ICIs varying from 6 to 200 ms have been seen in recordings in the wild (Villadsgaard et al. 2007). Source levels have been found between 134 dB_{RMS} re 1 μPa@1m (Goodson & Sturtivant 1996) and 205 dB_{p-p} re 1 μPa@1m (Villadsgaard et al. 2007) and duration of the clicks lies between 44 (Villadsgaard et al. 2007) and 200 μs (Kamminga 1987). The lag time, assumed necessary for processing the pulse-echo pair, has been measured to 14-36 ms (Verfuβ et al. 2005).

The logged click length is a variable value, depending on the click amplitude relative to the trig level settings. With weak clicks, only the highest amplitude part of the click might be over the trig level, and hence the click appears shorter than it actually is. The maximum duration, on the other hand, may be enhanced by reverberation. The ICI is defined as the time between clicks, measured from the end of one click to the start of the next, as defined in Figure 3.

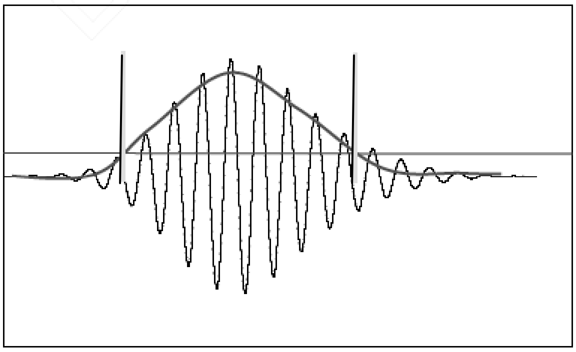


Figure 3. A porpoise click and how it is processed in the PCL. Curved line - Output from click detector rectifier. Horizontal line – Threshold for click detection. Vertical lines – Indicates the click length as recognised by the digital electronics (from Ceurstemont 2006).

The custom made software for viewing and processing the files is called Aquaclick View (Figure 4). In this software, a further sorting of the logged clicks can be done. It can be chosen to only display clicks that meet the detection settings, and the parameters determined in the logger can be sharpened. In the first software version these parameters were click length (1-2000 μs), interclick interval (1-1000 ms) and ratio between channel one and two (1-256). The software were further developed during the study, and in the final version, several more parameters could be set. In the first version of Aquaclick View, only individual clicks could be classified as originating from harbour porpoises or not. In the final version, also characteristics of porpoise clicks in trains can be distinguished. Further parameters that can be set in the click train-filter is minimum number of clicks (1-1000) within a certain time (1-10000 s) and the relative maximum (0-1000) and minimum (0-1000) ICI and amplitude change up or down between two consecutive clicks. Recommended settings are: Ratio: 3-255, Click length: 50-500 µs, ICI: 1-300 ms, Min number clicks; 4 in 1500 ms, ICI ratio for n<n-1: 0.3-1, and for n>n-1: 1-3; Amplitude ratio for n<n-1: 0-1, and for n>n-1: 1-10. The data from Aquaclick View can also be exported as a csv-file to be further processed in Excel. The data from Aquaclick View can also be exported as a csv-file to be further processed in Excel.

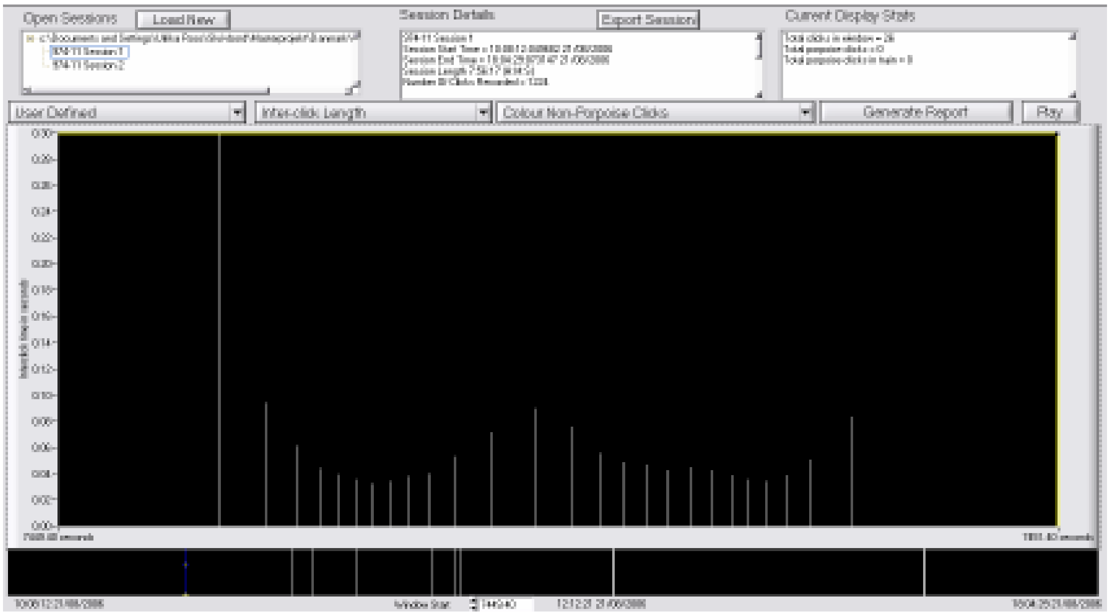
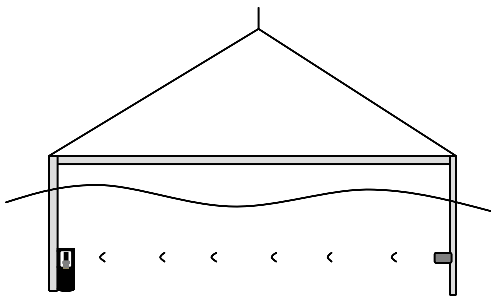


Figure 4. Inter Click Intervals of a harbour porpoise click, viewed in AquaclickView.

3.2 Calibration

Before the PCLs were put into operation, they were calibrated. This was done in open water from a floating jetty, using a custom-built sound generator (hereafter "clicker") mimicking the sonar signals from the harbour porpoise. The clicker in turn was calibrated using a Reson TC4013 hydrophone. The clicker source level (SL) varied between 149 and 171 dB_{p-p} re 1µPa@1m, and a mean value of 165 dB was used for the calculations. The PCL and the clicker were fixed 1 m apart from each other (Figure 5), the clicker pointing towards the transducer of the PCL. They were kept around 1 m below the water surface for about a minute.



Figur 5 Outline of the calibration setup

The amplitude of the clicks logged in the PCL was read in Aquaclick View, and an average was calculated. The hydrophone sensitivity (HS) was calculated by subtracting the variable gain (VG), fixed internal gain (IG), and the clicker SL from the signal read in the PCL (S_{PCL}), expressed in dB (Equation 1, the incoming signal in the was converted from volts to decibels (dB=20logV/1)).

$$HS = S_{PCL} - SL - VG - IG \qquad (1)$$

When the sensitivity of the individual PCL hydrophones was known, the internal gain was adjusted aiming at a system sensitivity of -158 dB. This could not always be obtained, since the gain could only be adjusted in irregular steps of 2-6 dB.

3.3 Validation study

The aim of the validation study was to test the PCLs in waters with high densities of harbour porpoises, in order to obtain e.g. maximum detection distances and detection probabilities. The trials were conducted between the 14th and 24th of August 2006. Trial hours varied between 10 am and 7 pm depending on weather conditions. The PCLs were deployed every morning with a boat. They were suspended about two meters above the sea floor and marked by buoys (Figure 6). The deployment positions were at around 40 m distance from the shore where the water depth was around 4 m. On the 17th and the 18th, five PCLs were deployed on three different positions, in two pairs and one single. The rest of the time they were deployed in a cluster beneath the middle buoy. The PCLs were tied together with cable ties, with the hydrophones facing each other. On the 24th, 15 extra PCLs were deployed in two clusters of 7 and 8 units beneath the two other buoys. One single PCL was deployed overnight between the 19th and 24th.

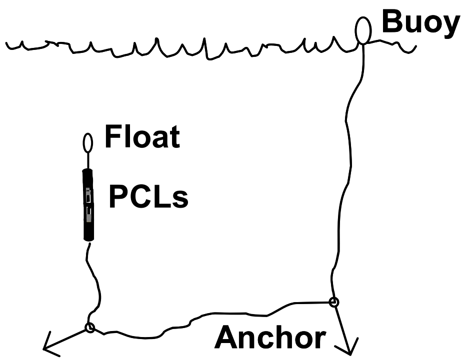


Figure 6. Deployment setup of the PCLs in Denmark.

Visual observations were made from a vantage point on the shore, about 20 m above sea level. At least one person, but often two or three, was watching continuously for surfacing porpoises. When an animal was sighted, its surfacing was traced using a digital theodolite (Geodimeter 468). Hereafter, such a surfacing position will be called a track point and a series of track points from the same animal/animals for a track. A traced animal/group of animals is hereafter called a pod. The theodolite was connected to a laptop running Cyclopes 2004 (The University of Newcastle, Callaghan, NSW 2308, Australia), logging the time and the horizontal and vertical angles of the position. This made the calculation of the distance from the PCLs to the track points possible through triangulation. The number of individuals and calves in the pod was noted, together with the apparent behaviour of the animals. In an adult/calf group the adult was followed. When more than one adult was spotted together, the animal closest to the PCLs was followed. Motorboats and vessels in the vicinity of the PCLs were also traced, with at least two positions indicating its route. The buoy/PCL positions were logged with the theodolite several times each day. Every full hour the height of the tide on a pole placed off the shore for this purpose was also logged. The clocks in the theodolite, laptop and the PCLs were synchronized every day. After finishing the observations, the PCLs were collected, data was uploaded and analysed, and necessary changes in the settings were made for next day's trials. The PCLs were deployed, i.e. made ready for recording at the base lab, but the actual recordings were not started until the unit came into the water. Settings used for trials were to trig from the 130 kHz filter and only log clicks with an amplitude ratio greater than one, a click length between 50 and 500 μs and an inter-click length between 1 and 3000 ms. The variable gain and trig level settings varied between the units and can be found in the results.

In Table 1, effort and characteristics of the observations for the trials in Denmark is presented. 18 pods were tracked, with a total of 37 animals sighted during the time for the trials. Average pod size was 2.4 for pods used in analyses.

Table 1. Effort and characteristics of observations in Denmark.

	Total	Used in analyses
Observation time	31:43:00	
Number of tracks	18	15
Number of sightings	509	485
Sighted animals	37	
Total track time (h.m.s)	4.44.27	3.48.04
Single animal	2	2
Adult + Calf	11	8
Three animals	1	1
Four animals	3	3

3.3.1 Study area

The study area is located in Denmark at the northern entrance of the Great belt. On the north-eastern tip of the island of Funen, there is a nature reserve called Fyns hoved (Figure 7 & 8). It has up to 20m high steep hills along the western shore, offering very good observation conditions of the waters below. The area is exposed to frequent traffic by leisure boats, fishing-boats, and there is a main cargo-ship route going through the Great belt. The area is also popular for angling from the shore.

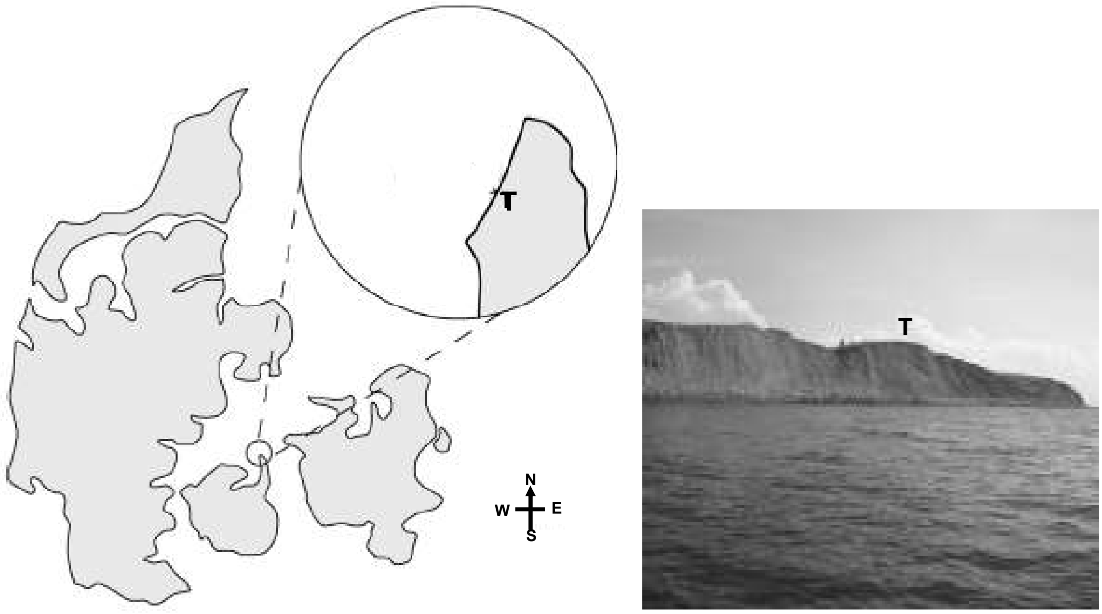


Figure 7a & b Study area in Denmark. T indicates the theodolite station and observation point (Figure 7a modified after Poulsen 2004).

3.3.2 Analyses

PCL-data from 21-24/8 was used in analyses. During the other days the deployment and settings in the PCLs varied, making it difficult to compare data between units. Only data from four of the five PCLs was analysed, because of inconsistent data from the last one. Data from the 16 additional PCLs deployed on the 24/8 has been partly included in the analyses. Their variable gain was set according to the original calibration, but there was no time to adjust gain further as had been done with the PCLs used earlier. Therefore, the data is not directly comparable.

To evaluate the function of the PCLs, the distance from the units to the phonating porpoise had to be calculated. The varying altitude over sea level for the station, because of changes in the tide, had to be accounted for. A function for the tidal changes each day was derived from the measurements on the tide pole. From the time of each track, a new instrument altitude was calculated using this function. From the height and the vertical angle, the distance from the station to the track could be calculated (Figure 8). This distance and the horizontal angle could then be used to calculate the distance from the buoy to the track. The data from the PCLs was searched through for click trains during the periods where animals were tracked with the theodolite. This was done manually, using no filters. To be accepted, a train should consist of at least four clicks within about 1 s, and look "porpoise-like". A train was dedicated to the track point closest in time.

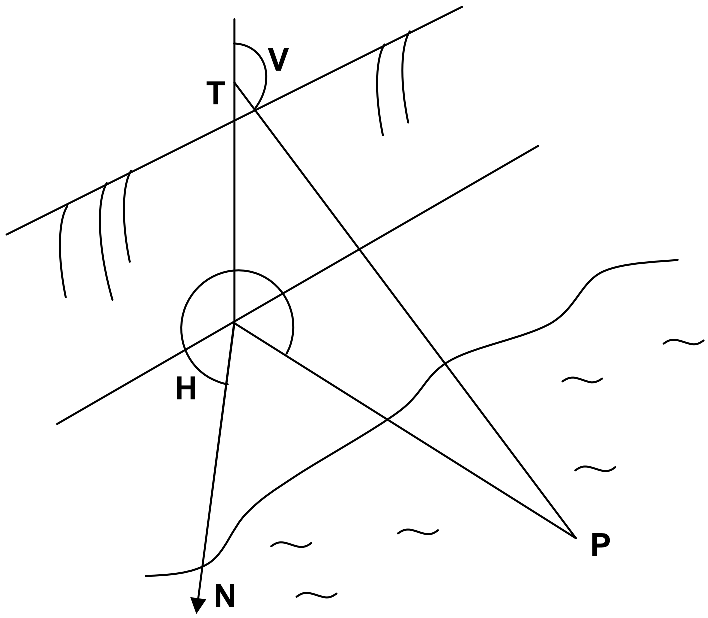


Figure 8. Outline showing the angles measured by the theodolite. T=theodolit, P=porpoise, N=north, V=vertical angle, H=Horizontal angle.

Data can be exported from Aquaclick View to an Excel-sheet, including all the parameters of clicks such as click length, ICI and amplitude in both filter channels. The time stamp on each click is presented in seconds since the start of the session. Therefore, to be able to compare individual clicks from different PCL units, the times had to be synchronized. The units start logging when they are deployed in saltwater, but the start might differ with a few seconds for different units. The internal time stamp is however given with an accuracy of 10 µs.

The theoretical detection distance for the PCLs can be calculated from the minimum required received level for trigging, the transmission loss and the harbour porpoise sonar source level (SL). As mentioned earlier this can vary, but an SL of 180 dB re 1 µPa @1m was used here. The minimum required received level (RL) is derived from the trig level (DT) and the system sensitivity (SS) (Equation 2).

$$RL = DT - SS \qquad (2)$$

From the minimum required received level and the source level (SL), the maximum allowed transmission loss can be calculated (Equation 3-6). Transmission loss (TL) is derived from spreading (S) and absorption (α). Here we used spherical spreading. Then, the corresponding distance (R) resulting in this transmission loss can be found.

$$S = 20 \log (x) \qquad (3)$$
$$\alpha = 0.04\ x \qquad (4)$$

$$TL = SL - RL \qquad (5)$$
$$TL = \alpha R + S R \qquad (6)$$

3.4 Pilot test

Professional fishermen were engaged for deploying PCLs off the south and southeast coast of Sweden, from Utklippan to Falsterbo. This is the area covered by the EU pinger regulation (812/2004). The fishermen were visited and instructed on how to handle the PCL. They were provided with 1-3 PCL units, a specially designed user manual, alcohol for washing the saltwater switches on the transducer, a cable for uploading of data and charging of batteries, a battery charger and a CD-ROM with the program needed for uploading of data. The fishermen brought the PCL ashore every 10-14 day for charging of batteries and, in most cases, also for uploading of data. The uploaded data was sent to a SBF database via e-mail. If there were no possibilities for the fishermen to handle this by themselves, they were visited for uploading of the data. The fishermen received a monthly symbolical sum of money for their help.

The PCLs were distributed to the fishermen from late June to November 2006. Both eel fishers using traps and cod fishers using fixed gill nets participated in the study. Eel fishers attached the PCL either to the eel trap setup, or placed it by its own in the vicinity of the trap anchor. Some cod fishermen attached the PCLs to the net or the anchor in the end of a net fleet; others deployed them separately in a potential fishing area.

4. Results

4.1 Hydrophone sensitivity

The calibrations of the hydrophones revealed a peak to peak sensitivity varying between -225 to -253 dB re 1V per µPa. The mean for all units was -232 dB, with a standard deviation of 4.6. Calibration values for all hydrophones can be found in the appendix.

4.2 Range and detection proportion

The maximum detection distance was 155 meters, logged on PCL 2. The detection at 155 m occurred at 12.05.44. This was 25 seconds after nearest track point before at 153 m distance, and nine seconds before next track point at 155 m (Table 2). The calculated theoretical maximum detection distance is 157 m, for a PCL system sensitivity of -158 dB re 1 µPa, a porpoise SL of 180 dB re 1 µPa@1m, an absorption factor of 0.04 and spherical spreading. This gives a coverage area of approximately 0.077 km^2 for the PCLs.

Table 2. Example of times and distances from PCL of visual track points and time for acoustic detection in PCL.

Time	Distance (m)	PCL Detection
12:04:48	213	
12:05:01	213	
12:05:09	203	
12:05:14	204	
12:05:19	153	12.05.44
12:05:53	155	
12:05:59	153	
12:06:09	150	
12:06:25	145	
12:06:32	134	

Of the 13 pods passing within 157 m of the PCLs, one pod was not detected by any of the PCLs. This gives a detection proportion of 92 %. The minimum distance from the not detected pod to the PCLs was 104 m according to the visual observations.

4.2.1 Differences between units

Variable gain for the PCLs was adjusted during the first days of trials to get files as comparable as possible. This resulted in different final system sensitivities for the different units. Different system sensitivity also results in different theoretical maximum detection distances and area coverage. PCL#2 had the highest system sensitivity resulting in a theoretical area coverage of 0.038 km^2, in contrast to PCL#1 with an area coverage of 0.019 km^2 (Table 3).

Table 3. Settings, fixed gain and hydrophone sensitivity for the PCLs (dB re 1 µPa) and its implications.

	PCL 1	PCL 2	PCL 3	PCL 4
Variable gain	14	24(trig 4)	18	14
Fixed gain	54	54	54	54
Hydrophone sensitivity	-229	-227	-229	-227
Final system sensitivity	-161	-152	-157	-159
Trig level (dBV)	-28	-26	-28	-28
Min incoming signal SPL	133	126	129	131
Theoretical max distance (m, SL 180)	137	196	168	147
Theoretical area coverage (km^2)	0.019	0.038	0.028	0.022

The mean first detection distance for all PCLs was 64 m with a standard deviation of 41 m. Detection distances for the different PCLs varied quite remarkably (Figure 9). Comparing the detection distances for PCL #1 and #2, for example, shows that #2 had the majority of furthest detections between 100-150 m, while #1 had the majority between 0-50 m (Figure 10). PCL #3 also had the majority of furthest detections between 0-50 m, whereas #4 lies in the 50-100 m span.

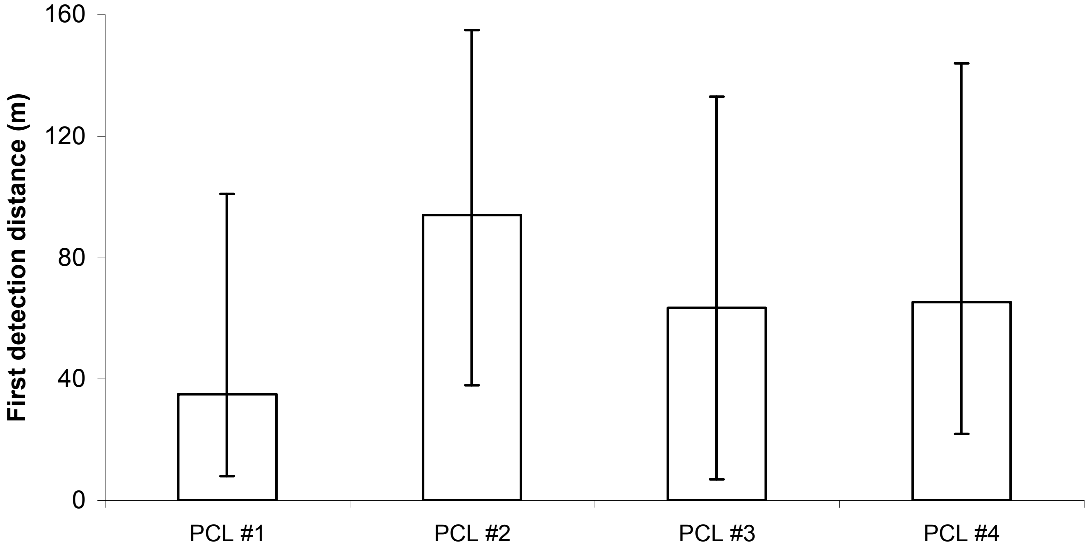


Figure 9. Mean first porpoise detection distances for the PCLs and the maximum and minimum values for each unit (n=12).

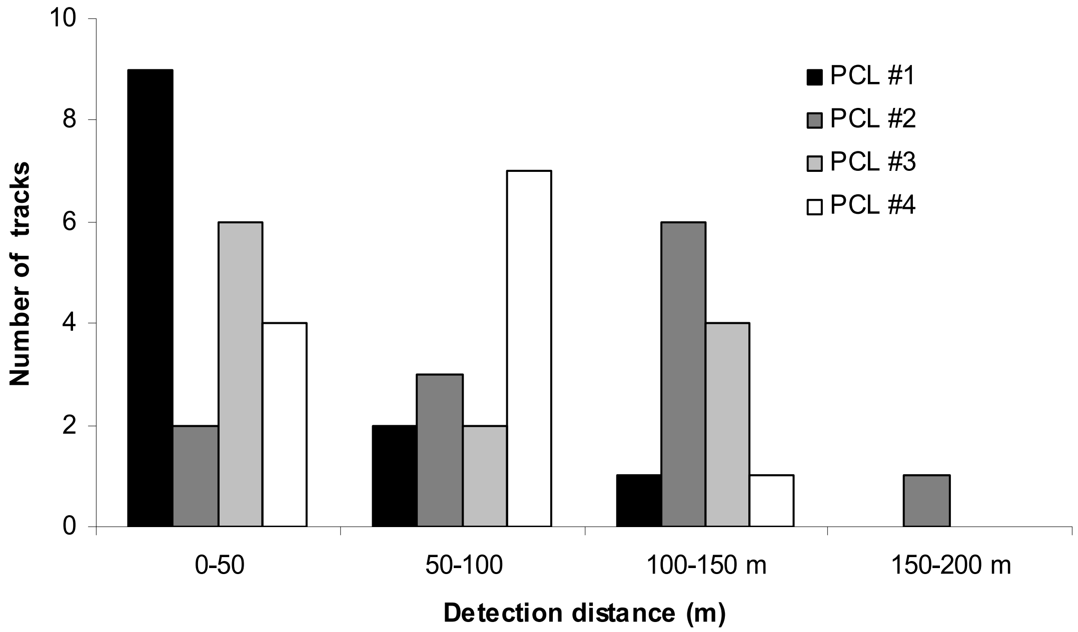


Figure 10. Number of first detections for different PCLs in distance categories.

While looking at furthest detections in cumulative distance categories, the number of detected pods decreases with increasing distance from the PCL clusters. I.e., between 0-50 m all tracked pods within 50 m of the cluster were detected, while between 150-200 m only one of the tracked pods was detected. The majority of the visual detections were in contrast in the 50-100 m category (Figure 11).

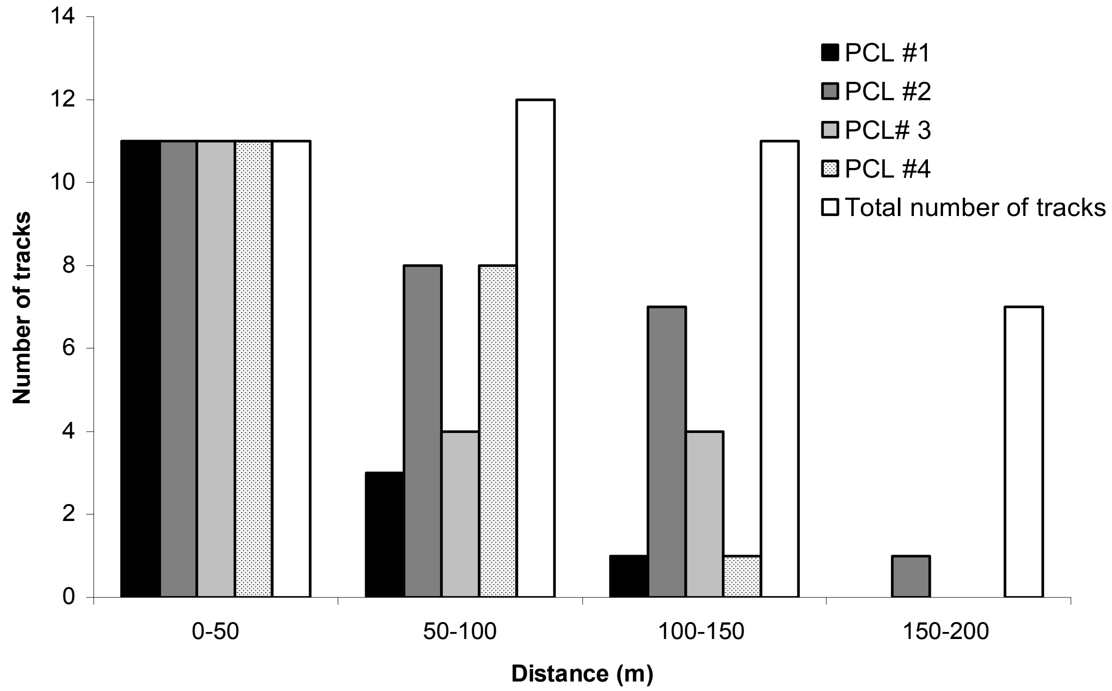


Figure 11. Detections in cumulative distance categories. I.e., when a train is already detected in a further distance category, it is present in all the nearer categories too that the porpoise visited.

4.3 Reliability

In Figure 12, an example of a visualised track is shown. When looking at the tracks, it is common with click trains that have not been detected on all PCLs. Most of the time, a train was only detected by all units if the animal was close. But there are exceptions, where logging has occurred on all units despite a large distance to the animal. Also, the direction of the tracks is interesting to look at. Quite often an animal was not detected, although apparently travelling right towards the units.

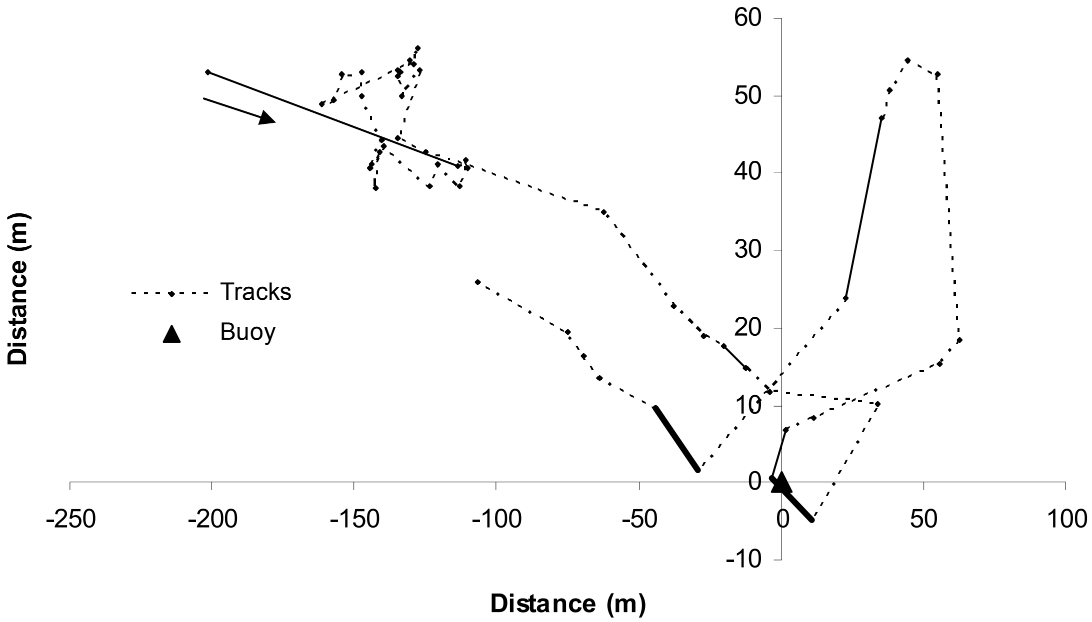


Figure 12. Visualised track (24/8 L) from a travelling porpoise. Thin line indicates that detection has occurred on some of the PCLs, and thick line detection on all PCLs.

A train was detected by only one of the PCLs in the cluster at 20 occasions. It was detected by two PCLs at 11 occasions, and by three at eight occasions. A train was detected by all four PCLs at 21 occasions. Hence, detection has occurred on only one PCL in almost as many cases as on all units.

In figure 13, the amplitudes in a click train from four of the PCLs can be compared. It can be seen that amplitudes between units is varying within the click train. For example, for the first click PCL #4 has the lowest amplitude, while on the last click in the train it has the highest amplitude.

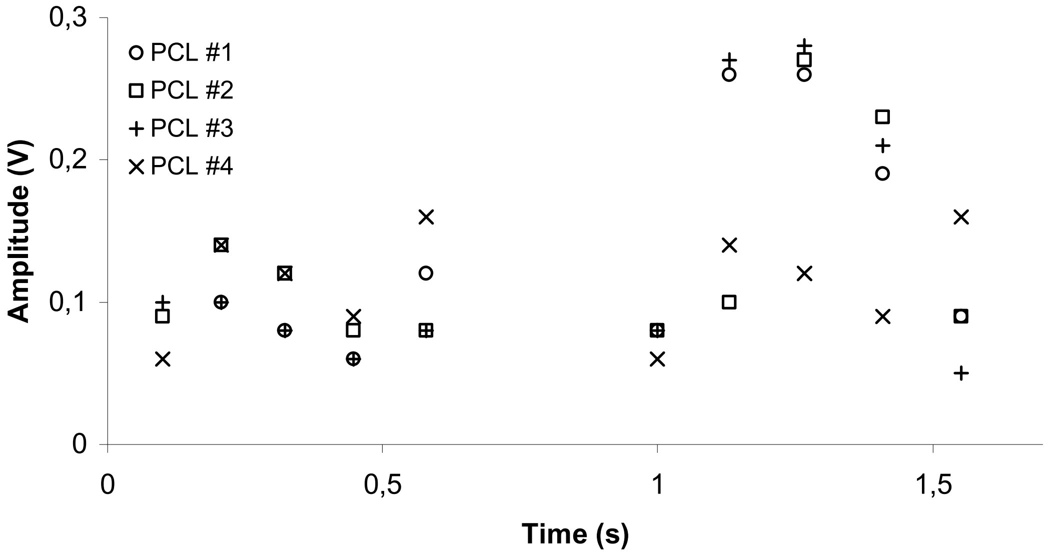


Figure 13. Amplitudes of a click train as logged by four PCLs in a cluster.

4.4 Practicality

The fishermen gave the PCL a grade of 4.4 (1-5 scale, n=7) regarding practicality and easiness to handle. Thirty-seven PCLs were tested in professional fishery with help from 21 fishermen. Six of them were eel trap fishers, three were fishing with eel traps but also engaged in cod gill net fishery, and 12 were cod gill net fishers. All but three fishermen have been able to handle the uploading of data themselves and all have been charging the batteries without problems. Many PCLs have been in use for several months with fishermen. The strain that the units have to suffer during this handling can surely often be rough, but all but one units have shown no signs of suffering from this.

A notion about the handling of the PCL should be made regarding the transducers. According to the manufacturer, these should be handled with extreme care. In spite of this and the fact that the hydrophones had to be removed each time data was uploaded and batteries charged, no problems occurred with the hydrophones.

4.5 Technical problems

There have been some technical problems with the PCLs reported by the fishermen. Most of the time, these problems have been due to a full memory. This have resulted in problems with uploading the files and could also lead to a PC system crash. Sometimes the overloaded memory was caused by the variable gain being set too high, resulting in noise being recorded. It has also been due to an error with the saltwater switch, resulting in the unit turning on and off uncontrolled, thereby creating lots of very small sessions. Six of 37 PCLs have shown this error. There have also been problems with the internal clock of the PCL, resulting in wrong time- or date-stamps on the sessions. Twelve PCLs have had this problem (courtesy Malin Berglind).

5. Discussion

The results show that the PCL is well suited for usage in professional fishery. A detection range of 155 m and a detection proportion of 92 % was found. This is very valuable information for coming inventories using the PCL. Results do however vary between units. Some improvements are necessary concerning the electronics of the units, software and varying hydrophone sensitivities.

5.1 Hydrophone quality and calibration

The hydrophone sensitivities, revealed from the calibration, were between -225 and -253 dB_{p-p} re 1V /µPa (Appendix). This is much lower than the manufacturer's specification (-208 dB re 1V /µPa; Aquatec Group, UK) and also more varying than would have been preferred. The variation either shows a very varying quality of the hydrophones, or that the calibration was badly performed. It should be taken into consideration that the source level of the porpoise-like clicker signal, when measured with a hydrophone connected to an oscilloscope, varied between 149 and 171 dB_{p-p} re 1uPa@1m. These varying values are not unlikely since the clicker was a directional sound source that might have led to a varying incoming signal. We also have concerns about the quality of the moulding of the hydrophones. If the moulding is not homogenous or contains air bubbles, this could result in different outcomes depending on which side the signal hits the hydrophone. This would make calibration difficult and maybe misleading. If the quality of the hydrophones is in fact this varying, it raises some concerns. Since the maximum variable gain is not recommended by the manufacturer, it is impossible to compensate for the low sensitivities of the worst ones. Even if trying to compensate for the varying sensitivities by setting the variable gain, this can never truly mean that they reach the same quality. This is because raising the gain will also raise the internal noise level.

5.2 Filters

The new filter characteristics developed during the study can use some explanations. We added a condition concerning minimum number of clicks within a set time in order to eliminate noise, and have also required a maximum ditto. Isolated clicks may originate from a harbour porpoise, but this can not be said for sure, and therefore we wanted to be able to sort them out. To restrict the maximum number of clicks in a set time is a way to eliminate noise from e.g. vessel engines and propellers. These often consists of lots of clicks during an extended period of time, in contrast to the porpoise click trains which most often are rather shorter. There is a risk using this type of filter, that "bursts" from the porpoise will be eliminated, since they consist of many clicks with a very short ICI. These are thought to be used both during hunting and for social purposes (Amundin 1991). However, the chance of detecting such bursts is considered very small, so they will at best only be a very small fraction of the recordings. Hopefully, in those cases, the porpoise will be detected from other click trains. We also added two filters regarding the relative change of amplitude and ICI between two consecutive clicks. Harbour porpoise clicks almost always change amplitude and ICI smoothly, as can be seen in Figure 4. The typical noise from boats is very irregular in both amplitude and ICI.

5.3 Reliability

Our data show quite varying performances for the different PCLs (Figure 9 & 10). This will have important implications when it comes to the maximum detection distance and the area covered by a unit, and hence needs further investigation. Comparing the final system sensitivities (Table 3) with detection distances (Figure 10), PCL#2 had by far the farthest detections and also had the highest system sensitivity. PCL#1 with the lowest system sensitivity was also the unit with the lowest share of far detections. When looking further at a specific track, it can be seen that the detection distances for the different PCLs in track 21/8 C (Figure 12) are about 150 m for PCL#2, 130 m for PCL#3, 80 m for PCL#4 and 10 m for PCL#1. As can be seen in Table 3, these values are in conjunction with the system sensitivity of the different units. But it is not always this simple. In some cases, only units with low system sensitivities have logged clicks. Since it is more common that a train is not logged on all units when the animal was far away, this is probably related to the sound intensity. It is possible that the incoming signal might vary between units because of shading effects. The upper part of the PCLs should be sound transparent, with exception for the hydrophone. But at low intensities, it is possible that even the shading from the upper housing of the PCL would be enough to decrease the sound intensity to levels below the trig. Another explanation can also be heterogeneities in the moulding of the hydrophone, resulting in variations in the omni-directionality of the hydrophone. This hypothesis is also supported by Figure 13. Here it can be seen that it is not consistently one PCL that always show the highest amplitudes. Instead the relative amplitude is varying between the units. An explanation to this can also be the characteristics of the harbour porpoise sound beam. The amplitude is highest in the middle of the beam, and a click train detected in the edge of the beam might give varying results for different units.

The very varying detection distances, presented in Figure 9, are also a result of the few hits on the PCLs. If there was a hit on two of the PCLs on 150 m distance for instance, the next hit on any of the PCLs might not be until the animal is 50 m away. This results in very different detection distances and might give a picture of a highly varying sensitivity on the units, which is not really correct. This can also partly explain that one porpoise passed undetected by all the PCLs. If the animal is travelling at a quite steady, straight route, even though it is close to the units, it might pass by undetected. The probability for detection is discussed further in paragraph 5.6.

The classification of clicks is an issue that needs some discussion. All data from Fyns hoved was analysed manually. We have been quite restrictive when it comes to accepting a train as originating from a porpoise. This might mean that some trains are probably left out, but this was considered better than taking the risk of accepting false trains. To be accepted, a train should consist of at least four porpoise-like clicks within about 1 s.

5.4 Range and detection proportion

One of the most important aspects in evaluating the function of the PCL is to find the maximum detection distance of a porpoise. The theoretically determined detection distance was calculated assuming spherical spreading and a SL of 180 dB re 1µPa@1m. Spherical spreading is most often used when calculating SL for odontocetes (Au 1993). The quite shallow water at the study area could, however, mean that some of the spreading at the longer distances was cylindrical instead of spherical. With only cylindrical spreading (10log(x)), the theoretical maximum detection distance would instead be 600 m. Thus, at some cylindrical spreading the actual theoretical range might be larger than we determined. There are also other factors to consider, such as stirred-up bottom sediments and air bubbles in the water which may attenuate waves at 130 kHz very effectively. This is hard to compensate for, but will narrow the detection range.

The theoretically determined range of 157 m (at the aimed system sensitivity of -158 dB and SL of 180 dB) corresponds well with our maximum tracked detection distance of 155 m. This is comparable to detection distances for visual surveys. Detection probability has been shown to decline steadily with distance for shipboard surveys, and to be flat out to about 200 m and then declined sharply for aerial surveys (Hammond et al. 2002). The uncertainty that comes with the method used makes a further investigation of our maximum detection distance necessary. The next furthest detections were 144 and 124 m (Figure 12). The detection at 155 m occurred at 12.05.44, 25 seconds after nearest track point before at 153 m distance, and nine seconds before next track point at 155 m (Table 2). Although a porpoise can probably move a considerable distance in nine seconds when travelling fast, when looking at the times and distances for the tracks before and after the detection, it seems highly unlikely that that this porpoise would have done so. The ICI for this detection was 44.5 ms, corresponding to a range locked distance of 19 m from the PCL, and a non-range-locked distance of 34 m. This shows that either this porpoise was range locked on something much closer than the PCL, or it was not range locked at all, or the detected animal was not the tracked one. Being range locked on something as close as 19 m would make sense since the porpoise was moving forward very slowly at the detection (just a few meters in half a minute), which might indicate engagement in foraging behaviour. However, 44 ms is not an unusual ICI for just checking ahead without being locked on any target (Petersen, 2007).

The single pod not detected by the PCLs also prompts some further investigation. As can be seen from the track, the pod was several times travelling straight towards the units, but still was not detected. On the other hand, when looking at other tracks, even pods travelling towards the units at a very short distance (ca 10 m, Figure 12) have not been detected either. But this is once again most likely due to the directionality of the beam, so maybe it should not be found so strange. Indeed, it might be considered quite remarkable that all but one pod have been acoustically detected. Still, a striking feature when looking at the visualized tracks is that the porpoise is so seldom detected by the PCLs, even though they are swimming right towards them.

The aim when setting the variable gain for the PCLs was a total system sensitivity of -158 dB. However, since this was the first time these units were used in open water, we initially tried a wide range of settings, to get an indication of the effect of noise. Guided by the resulting log files, we ended with the settings shown in Table 3. With these, and assuming a porpoise click source level of 180 dB re 1 μPa@1m, the theoretical detection distance would be 137, 196, 168 and 147 m for PCL #1, #2, #3 and #4 respectively. The long distances should be looked upon with scepticism, since when increasing the variable gain, the system noise level is also raised. But the short distances are to be taken seriously, and for

PCL#1, we had no detections on a further distance than 101 m. This changes the area covered by the PCLs, an important factor in SAM. When calculating the area of detection for the three PCLs with lower detection distances, they were 0.019, 0.022 and 0.025 km^2. However, when looking at Figure 10, showing that PCL#2 has the majority of furthest detections between 100-150 meters, while #1 have the majority between 0-50 meters, this implies that the differences may in fact be much larger. The covered area for 50 m range is only 0.0025 km^2.

To calculate the theoretical maximum detection distance, we have used a porpoise click source level (SL) of 180 dB re 1uPa@1m. Of course the SL of the phonating porpoise also has implications for the detection distance and area coverage. SLs have been measured from 134 dB_{RMS} re 1uPa@1m (in captivity, Goodson & Sturtivant 1996) to 205 dB re 1uPa@1m (in the wild, Villadsgaard et al. 2007). This corresponds to a detection distance difference of 450 m. However, Villadsgaard et al. (2007) recorded SLs of 178 $dB_{p\text{-}p}$ re 1uPa@1m at the lowest for harbour porpoises in the wild. This shows that we have been as restrictive as necessary when using an SL of 180 dB re 1uPa@1m in our calculations.

5.5 Precautions of the validation study

The low precision of the distance estimation from the units to the animals is a problem that needs to be addressed. The exact distance will only be known if the animal is detected acoustically and visually at the same time. But even then, the assumption is made that the phonating animal is the one observed visually, which may not always be the case. This is a problem especially for estimations of maximum detection distances, since it can sometimes be difficult to exclude that another animal was closer than the one being tracked. Also, it cannot be said where an animal goes between two surfacings. With a very restricted approach, the animal might be said to be almost anywhere. One way to try to get an estimation of the position as precise as possible is to assume that the animal is travelling in a straight line between the track points and relate the time of the logged click train to this distance. However, in this study, we have dedicated the click train to the track point closest in time. Another way to approach this problem could be to use the ICI of the logged click trains. If range locked on a target, the distance to the ensonified object can be derived from the ICI. Therefore there is a possibility to use the ICI for a more precise estimation of the distance from the animal to the unit. The problem with this approach is that it assumes a range locking on the PCL, which is not likely at maximum detection ranges. This could probably also be linked to SL, since it has been shown for dolphins that SL is coupled to target range (Au & Beonit-Bird 2003).

There are also some further precautions concerning this study that need to be considered. The distance from the shore to the deployed PCLs is one. It seemed like the porpoises off Fyns hoved often followed the shore, possibly searching for food (Stenback 2006). This meant that the PCLs often were in their route, possibly leading to an overestimation of the proportion of detections. On the other hand, they were often engaged in "bottom grubbing" (Anon. 1997) with their sonar beam directed towards the bottom, which may have lowered the numbers of PCL detections. Because of these reasons, it is possible that our results are not really applicable to a situation where the PCL is deployed in open water. The same applies to the fact that in 13 of 15 pods at least one of the animals was a calf, and the calves often showed interest and stayed near the units for some time, possibly examining it acoustically. Our average pod size of 2.36 can be compared to 1.4 (n=13) in a visual survey performed in Little Belt in the summer of 2002 (Gillespie et al. 2005). As Fyn Hoved is a shallow costal area, the type of habitat where harbour porpoises are thought to give birth, it is likely that pods with calves are overrepresented compared to other areas. In the SCANS (Hammond et al. 1995), indications that calves were more common closer to the coast were seen. Some precaution should also be made regarding the software used to analyse the tracks. Sometimes, it seemed as if the crf.-file and the exported xls.-file did not really fit together. This might have led to some inaccuracy in the analyses of the tracks. Regarding the detection proportion of 92 %, the sample size of 13 pods is a bit small.

5.6 Probability for detection

The probability for detection of a porpoise by the PCLs is dependent on many factors and hard to estimate (see Tougaard et al. 2006). The directionality of the sound beam, the behaviour of the animals and the ambient noise level are some of those factors. For an animal pointing at the PCL with its sonar, the probability for detection should fall with distance. But the expected proportion of detections should in contrary initially rise with increasing distance. This is because an increasing distance also means a larger sea area covered by the PCLs. In Figure 11, it can be seen that the majority of the visual tracks are found in the 50-100 m distance category. With a larger sample size, this would probably have been the case also for the acoustic detections. That an animal is close does, however, not mean that it has to be detected. The beam is about 16°, and though the focusing is not sharp (Au et al. 2006), there is no detectable energy outside it

(Goodson & Sturtivant 1996). The directionality of the beam becomes more important at smaller distances as shown in Figure 14. At close distance, the sonar only covers a very small arc. As discussed in Goodson and Sturtivant (1996), “the directional nature and lack of detectable energy outside the narrow sonar beam make these animals extremely hard to track underwater. It seems likely that, even at very close range, they will remain difficult to detect unless pointing directly at the receiving hydrophone.” (Goodson and Sturtivant 1996).

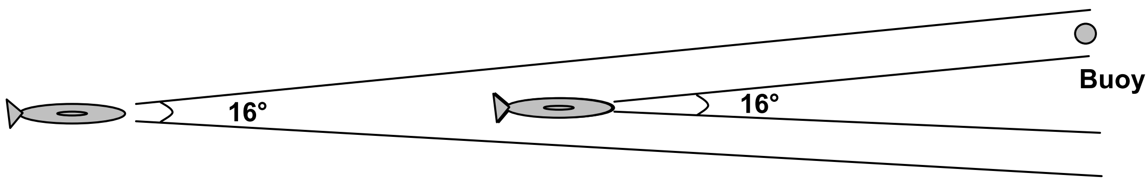


Figure 14. Showing the directionality of the sound beam and its implications at close and distant range.

The sonar behaviour of the animals is something that is hard to evaluate, and there are few studies covering this subject. Goodson and Sturtivant (1996), however, found evidence of many short click bursts, strongly suggesting that the porpoise was scanning a small sector ahead with its sonar. Behaviour can also embrace both vocalisation rates and source level (Akamatsu et al. 2001). An approaching porpoise might not emit any clicks, or be investigating the bottom with the sonar, an often observed behaviour probably connected to search for prey (Anon. 1997). Further controlled studies are needed in this area. However, preliminary data from harbour porpoises in captivity indicates that even in familiar enclosures, the animals use their sonar almost uninterruptedly. These data also show clear circadian rhythms in the use of sonar[2]. A 4 h acoustic tag recording of a wild porpoise showed that this porpoise were phonating almost continuously, being silent in only very short periods of time (Akamatsu et al. 2007).

5.7 PCL vs T-POD

The T-POD has been the only commercially available product for SAM until now. The PCL, in contrast to the T-POD, was developed primarily to be hardy and easy to handle and thereby make the deployment in connection with commercial fishing operations possible. The PCL can quickly and easily be connected to the cable for uploading of data and

[2] pers. comm.., Mats Amundin, Kolmårdens Djurpark

charging of batteries. The T-POD on the other hand, needs to be opened with tools to be able to upload data and charge batteries. Otherwise, the largest difference is the size. The T-POD weighs 4.4 kg and has a length of 860 mm, compared to the PCL with 1.2 kg and 240 mm respectively. The T-POD has a larger battery pack and a minimum battery life of 90 days, compared to 14 days for the PCL. The longer deployment time aimed at with the T-POD also reflects in the memory size, 128 Mb, compared to 8 Mb for the PCL. The absolute sensitivity of the T-PODS hydrophones is not given. Instead, they are standardized using simulated porpoise clicks of 1 Pa p-p sound pressure level. The standard is detection of 50% of the clicks when the T-POD is rotated at 30 rpm to account for radial variabilities. Only transducers having a radial variation of <±2 dB relative to the mean sensitivity are used (Chelonia 2007). Similar trials should be done with the PCLs aswell. In an unpublished study, Tougaard et al. (2006) present results of a porpoise detected at over 300 m distance from the T-POD. On the other hand, Koschinski et al. (2003) found that no clicks were received from porpoises more distant than 170 m from the T-POD. 98 % of all their sightings corresponded to a click detection within 150 m (Koschinski et al. 2003). We have had no detections of animals further away than 157 m. The four PCLs used in this study required a minimum incoming signal SPL of 126 to 133 dB re 1 μPa (Table 3). This compares well to the T-PODs used in Verfuβ et al. (2007) study, which were set to a standard detection threshold of 127 dB re 1μPa.

5.8 Suggested improvements of the PCL

The PCL software has been further developed during the course of this study, but there are still improvements to be made both concerning hardware and software. As discussed earlier, a thorough quality assessment of the transducers is necessary, including a radial calibration. Hydrophones with low sensitivity and/or with errors in their omni-directionality should be exchanged. The internal clock for the PCLs has been shown to drift, and this needs to be improved. It would be good to have the choice of two battery packs, one for a longer deployment time than the present. Also, in the top of the PCL, there is a need for a device to facilitate the attachment to a float during deployment. The saltwater switch has also been the cause of much trouble, and this needs to be improved. The steps of the variable gain should also be made smaller, or at least regular. The internal clock has an excellent accuracy of 10 μs, but the units can not be synchronized to better accuracy that 1 s, because of the low accuracy of the PC clock. It would be nice to be able to account for the time difference afterwards, for example to determine the start time of the viewing window. A way to synchronize the units would be to use an acoustic synch pulse. This is easy to accomplish at experimental deployment.

It should also be considered if it would be better to show the time stamps in real time, instead of seconds from the start of the window. The time stamp for the individual clicks is also something that needs some reflection. At present, the time of the click is given as the start time. However, this might vary with the settings, as shown in Figure 3. A higher trig level will result in a shorter click and a later start time. It should be considered if the time stamp for the click should instead be set at the highest amplitude point, thus in the middle of the click. This would result in the same time stamp irrespective of the settings.

5.9 Further studies

Further studies are needed for a fully comprehensive assessment of the PCLs. A radial calibration as described for the T-PODS would be appropriate. Otherwise, a less directional sound source could be preferred which probably would give more accurate results compared to the directional source used in this study. This would also give possibilities to do a “distance-calibration”, where the source could be kept at distances of for example 50, 100 and 150 m. This would be a more precise way to find out e.g. maximum detection distances compared to visual tracking. For studies where the aim is to assess porpoise densities, the maximum detection distance is a key issue that must be known for sure. It is also of high importance that sensitivities and area coverage of different PCLs are comparable. For such studies it should however be considered if the coverage of a PCL should actually be given as an area. In open water it should maybe be given as the covered volume instead. Further studies are needed to assess this issue and possibly estimate an appropriate function for volume coverage of the PCL. It seems reasonable to expect that the coverage will not be as large vertically as horizontally. This could also be related to known habitat use and spatial occurrence of porpoises. Studies in this area are also needed to find out the optimal deployment depth for the PCL. In earlier studies with T-PODS, the units have been deployed at a certain distance from the surface (Verfuβ et al. 2007), instead of from the bottom as in this study. Further studies would also be useful around the sonar scanning behaviour of harbour porpoises, since this is tightly linked to the detection probability in SAM.

A possible way to improve the covered area of a PCL would be to set it in the end of a lead net. This would be most appropriate near the coast, where it may be difficult to know on what distance porpoises would travel along the coast. In open water, where the swimming directions of the animals are less predictable, an L-shaped lead net would cover all directions. Of course the net would need to go from the sea floor to the surface, and have a "safe" mesh, not in any way risking entanglement. The disturbance of such nets on the movements of porpoises also needs to be assessed before such a method can be fully adopted.

5.10 Conclusions

The PCL has proven to be hardy and easy to handle, and is well suited for use in fishery. The handling of data has worked well, and the size of memory and battery pack is sufficient. The detection range could have been better, but is of the same magnitude as other SAM devices. The quite low and varying hydrophone sensitivities are a problem. Therefore, necessary improvements concern primarily the transducer and the saltwater switch. The trials in Denmark also imply a varying sensitivity of the hydrophones, resulting in different maximum detection distances and area coverage. This is not acceptable. There are also improvements to be made regarding the software. The study has shown in what random manner harbour porpoises were detected by the PCL units, which is important knowledge when assessing data collected by SAM devices.

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Appendix

Appendix 1. Hydrophone sensitivities and unit nr of all PCLs, and the alias used for the PCLs in the study.

Alias used in study	Unit nr	Hydrophone sensitivity @130 kHz
1	**2**	-229
2	**3**	-227
	4	-239
	5	-227
	6	-230
	7	-230
	8	-225
	9	-227
	10	-230
3	**11**	-229
	16	-231
	17	-235
	18	-232
	19	-229
	21	-233
	22	-236
	23	
	24	-231
	25	-228
	26	-236
	27	-238
	28	-236
	30	-232
	31	-230
	32	-231
	34	-230
	35	-230
	36	-226
	38	-234
	39	-233
	40	
	41	-234
	42	-253
	43	-233
	44	-237
	45	-227
	46	-231
	47	-233
	48	-229
	49	-231

Alias used in study	**Unit nr**	Hydrophone sensitivity @130 kHz
	50	-235
	51	-233
	52	-230
	53	-233
	54	-231
	55	-231
	56	-231
4	**57**	-227
	59	-232