Can alerting sounds reduce bycatch of harbour porpoise?

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Preface

This master thesis addresses an alternative method to reduce incidental bycatch of harbour porpoise (*Phocoena phocoena*) in the commercial fishery, with particular focus on alerting sounds. The study has been carried out as a consequence of the implementation of the EU Council regulation No812/2004. According to the regulation all member states must implement acoustic deterring devices in areas and fisheries with known or foreseeable high levels of cetacean bycatch. "It is, however, feared that the implementation of such devices in large parts of the gillnet fishery can pose a threat to harbour porpoise populations through an exclusion of habitats, habituation and noise pollution. In order to minimize these possible threats, it has been investigated within the work of this thesis if another mitigation method, alerting sounds, can reduce the bycatch of harbour porpoise."

The EU Council regulation has been given a lot of international attention especially regarding the implementation of acoustic devises in the commercial fishery. During the work of this thesis the results have been presented as a working paper at the 59th International Whaling Commission meeting (Anchorage, Alaska , May 2007) and as a poster both at the 21st European Cetacean Society conference (San Sebastian, Spain, 2007) and at the 17th Biennial Conference on the biology of marine mammals (Cape Town, South Africa, 2007). Especially at the ECS-conference I received a lot of inspiring feedback and information about alerting sounds, which I have implemented into the thesis.

The thesis has been divided into four large sections. Part I "Introduction" gives an introduction to the biology of the harbour porpoise and further deals with EU regulation, bycatch and mitigation methods. Part II "Bycatch in the North Sea" describes the first experiment conducted in the North Sea where it was tested if an alerting sound pinger could work as a mitigation method to reduce bycatch of harbour porpoise. In order to clarify the results found in Part II it was decided to carry out two other experiments, Part III "Sonar activity in Jammerland Bay" and Part IV "Recordings of the PAS- and AQUAmark100 pinger in Øresund". Part III describes the experiments carried out in the Jammerland Bay, testing if alerting sounds can stimulate free living harbour porpoises to a higher click rate. Part IV describes the investigation of how pinger sounds propagate in water, relating to different heights and distances.

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Resumé

Nedgarnsfiskeriet er hvert år skyld i store utilsigtede fangster af marsvin (*Phocoena phocoena*) i de danske farvande. Akustiske alarmer (pingere) har vist sig at være effektive til at reducere denne bifangst. De har dog en række negative bivirkninger som f.eks. lyd forurening. Årsagen til at marsvin bifanges er ukendt, men en hypotese kan være at marsvin ikke er tilstrækkeligt opmærksomme på deres omgivelser. Hovedformålet med dette studie var derfor at fastlægge om opmærksomheds-pingere kan reducere bifangsten af marsvin. Idéen er at opmærksomhedslyden stimulerer marsvin til at ekkolokalisere mod pingeren og derved garnet. Marsvinet vil således få refleksioner tilbage fra garnet og derved opdage barrieren. Konceptet blev testet ved brug af kommercielt fremstillede pingere, kaldet PAS- pingere (Porpoise-Alerting-Sound pingere), i det danske kulmule fiskeri i juli og august måned 2006. PAS-pingerne udsendte kunstige marsvine-klik-tog (serier af klik, 110kHz, SL 125-138dB p-p re 1µPa @ 1 m, 50-2500 kliks pr. sek.), simulerende kliks marsvin ofte bruger. Der blev anvendt traditionelle garn, heraf havde 50% PAS-pingere og 50% placebo-pingere påmonteret for hver 130m. Observatører ombord indsamlede data omkring fiskeriindsats, fiskefangster og bifangst. Resultaterne viste ingen signifikant forskel i bifangstraterne mellem PAS-garnene og kontrol-garnene.

For at belyse årsagerne til resultatet blev der udført 2 nye eksperimenter. Det første undersøgte hvorvidt PAS-pingeren i virkeligheden stimulerede marsvin til at øge deres klikrate ved PAS-pingerens tilstedeværelse. To stationer blev opstillet i Jammerlandsbugten og fungerede skiftevis som alerting-station (Porpoise-Click-Logger (PCL) + PAS-pinger) eller kontrol-station (PCL). Signifikant forskel mellem alertingperioder og kontrolperioder blev kun fundet på den ene station.

Det andet forsøg skulle klarlægge PAS-pingerens lydudbredelse i vand. Forsøget blev udført i Øresund hvor pingeren blev optaget i forskellige dybder og på forskellige afstande. Optagelserne viste, at pingerens lydniveauer var svingende i styrke, dette kunne dog forklares ved pingerens teoretiske retningsbestemte lydudsendelse og fysiske love gældende for lydudbreddelse på lavere vanddybder. Med baggrund i alle tre forsøg kan det konkluderes, at PAS-pingeren ikke kunne reducere bifangsten af marsvin. Det er dog stadigt muligt at en alerting-pinger som virkeligt kan øge marsvins brug af sonar kan reducere bifangst.

Abstract

Coastal and high seas gillnet fisheries annually results in incidental take of large numbers of harbour porpoises (*Phocoena phocoena*) in the Danish Waters. Acoustic alarms (pingers) are effective in reducing this bycatch but they have adverse effects such as e.g. noise pollution. The reasons why porpoises are caught in gill nets are not well known, but one hypothesis is that porpoises are not paying sufficient attention to their surroundings. The aim of this study was therefore to test if pingers emitting alerting sounds could reduce bycatch, since these sounds cause far less noise pollution and have smaller energy needs. The theory was that alerting sounds could stimulate porpoises to echolocate at the pinger and hereby the net. This concept was tested by deploying custom made pingers, called PAS-pingers (Porpoise Alerting Sound pingers), in the Danish hake fishery during July and August 2006. Alerting sounds in this case are artificial porpoise click trains (110 kHz, SL = 125-138 dB p-p re 1µPa @ 1 m, 50-2500 clicks per sec) simulating the clicks porpoises often use investigating targets. Conventional nets were used, of which 50% had PAS pingers and 50% dummy pingers attached at intervals of 130m. On board observers collected data on fishing activity, fish catches and porpoise bycatch. Statistical analyses showed no difference in bycatch rates of harbour porpoise between the PAS pinger nets and the controls.

In order to expound the results two new experiments were conducted. The first tested if PAS-pingers in fact stimulated porpoises to a higher click rate. Two stations placed in Jammerlands Bay, DK, functioned in terms as control station (Porpoise-Click-Logger (PCL)) and alerting station (PCL + PAS-pinger). Significant difference between alerting and control was only found at one station. The second experiment tested how PAS-sounds propagated in water. The recordings were conducted in Øresund, DK where the pinger was recorded at different depths and from different distances. The results revealed that the pingers received source levels were highly variable.

With a background in the three experiments it can be concluded that the PAS-pinger can not reduce bycatch of harbour porpoise. It is however still possible that an alerting pinger which in fact stimulate porpoises to a higher click rate can reduce bycatch of harbour porpoise.

Glossary

CB: ChloroBiphenol

CIT: Clicks In Trains

CL: Click Length

CPUE: Catch Per Unit Effort

DDT: Dichloro-Diphenyl-Trichloroethane (pesticide)

D_I: Directivity Index

HPBF: High Band Pass Filter

ICL: Interval Inter Clicks

LBPF: Low Band Pass Filter

PAS- pinger: Porpoise Alerting Sound- pinger (110kHz)

PCB: PolyChlorinated Biphenyl

PCL: Porpoise Click Logger

P_N: Total Noise Power

R: Range

r: radius

RA: Relative Area

RL: Received Level

RMS: Rout-Mean –Square, the root of the mean of the pressure squared over a given window

SL: Source Level (dB re 1µPa @ 1m)

SN: Signal to Noise ratio

TL: Transmission Loss (dB re 1µPa)

T-POD: Timing POrpoise Detectors

Σ: Sum

1. Part I, Introduction

Incidental bycatch of harbour porpoises *(Phocoena phocoena)*, in various gillnet fisheries, has been documented in the last decades. There is focus on solving the problem which has led to many suggested solutions. To develop a mitigation method knowledge is needed on many aspects influencing the population both biological as well as anthropogenic. This introduction is therefore focused on the topics of relevance to develop such method.

1.1. Biology of harbour porpoise

Harbour porpoise is a small Odontocete, toothed whale. Most toothed whales have teeth, separating them from Mysticetes, baleen whales, and they have the ability to echolocate hereby detecting objects through sound. The harbour porpoise is widely distributed throughout the northern hemisphere (fig.1), and is the only cetacean known to breed in the Danish waters (Gaskin, 1984; Kinze, 1995). They are well adapted to the cold waters by having a robust body shape (normal length 110-130cm) and a thick blubber layer. Compared to other whales they have relatively little room to store food, and therefore cannot deposit energy well and need to be in close proximity of their prey (Read *et al.*, 1997). Thus, they can not afford to be too specialized and are in general believed to be opportunistic feeders. They prey on a variety of species Atlantic herring (*Clupea harengus*) has although been documented to be one of the dominating prey species for porpoises' bycaught or stranded in Scandinavian waters (Aarefjord & Bjørge, 1995; Börjesson *et al.*, 2003).

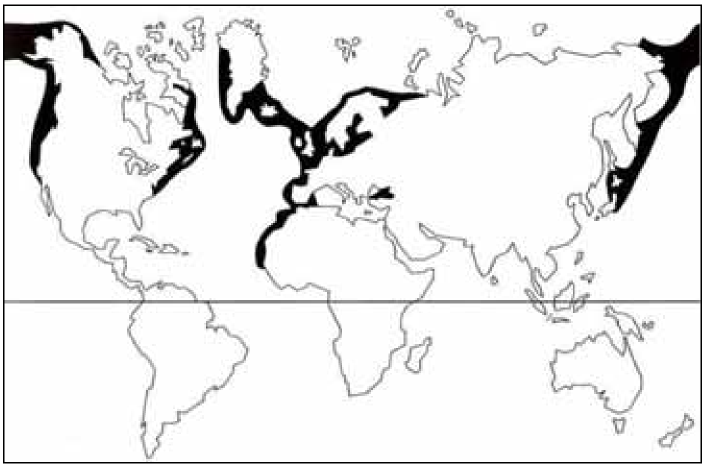

Figure 1: World distribution of harbour porpoise (*Phocoena phocoena*), (Read *et al.*, 1997).

1.1.1. Population structure and abundance

Knowledge of the population structure of harbour porpoises is essential for a proper evaluation of their distribution and abundance. Several populations and sub-populations are thought to exist in the North Atlantic and North Sea and Andersen (2003) suggested 13 distinct populations in the North Atlantic alone. In the Danish waters at least two populations have been recognised based on genetic studies; one in the inner Danish Waters including Kattegat and one in the North Sea including Skagerrak (Andersen, 2003). Until the 1960s a third rather large subpopulation existed in the Baltic Sea. This population has since radically declined and sightings of porpoises very seldom occur in the Baltic Sea (Berggren & Arrehenius, 1995; Kochinski, 2002; Bergren, 2004).

Accurate and precise population estimates of harbour porpoise is very difficult to conduct however, two large surveys have been conducted, SCANS I and II (Small Cetacean Abundance in the North Sea and adjacent waters). The surveys were conducted in July 1994 and July 2005 and carried out by observers onboard research ships and small aircrafts in the North Sea, Kattegat, Skagerrak, western Baltic, English Channel and Celtic Sea. The ships and aircrafts used line transect methods to collect distance sampling data to estimate the number of animals in the area. In SCANS I (1994) the population was estimated to approximately 341000 porpoises in the whole area (Hammond *et al.*, 1995) and in SCANS II (2005) the estimate was 340000 porpoises, when including only areas surveyed in both years (Hammond *pers. comm.*, 2007). This indicated no major change in the population from 1994–2005, there were although changes in the distribution. In 1994 high density areas were observed around Denmark, United Kingdom and Scotland, but had shifted further south in 2005. Higher densities were also observed in the Celtic Sea and high density areas around the north and west coast of Denmark occurred further offshore in 2005 (fig.2). The reasons for these changes are not known but changes in preferred prey abundance may lead to changes in predator distributions. This, however, is not necessarily the only explanation for the observed distributional shifts of harbour porpoises (Hammond *et al.*, 1995; Hammond *pers. comm.*, 2007).

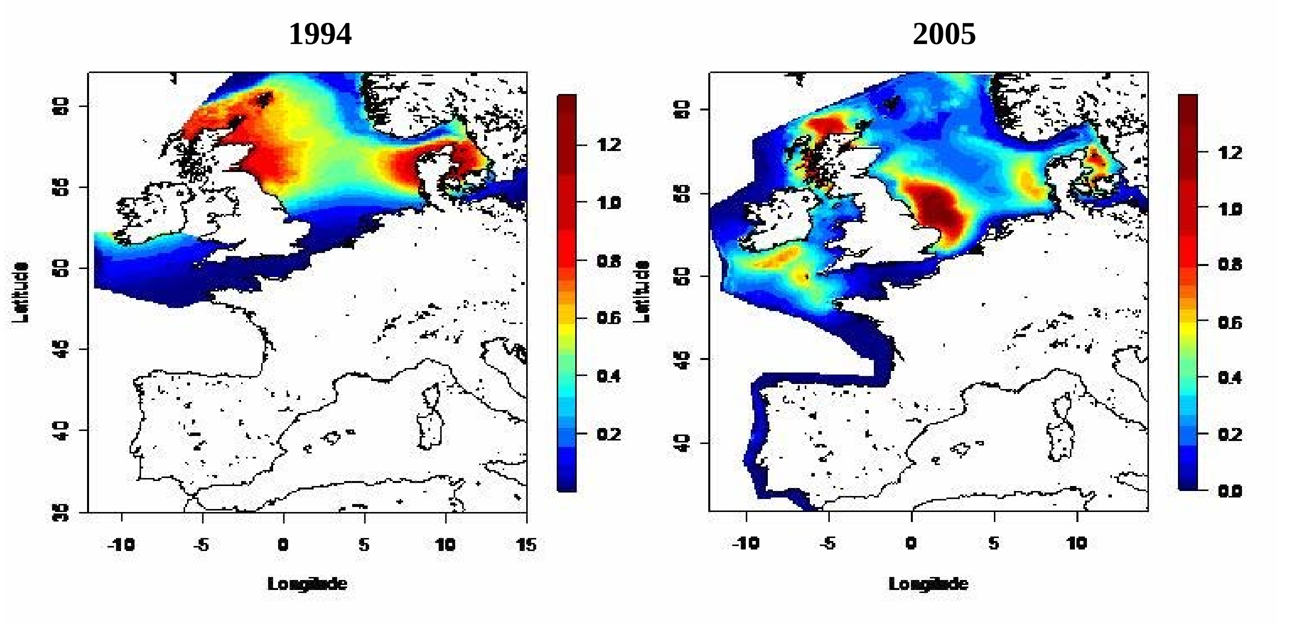

Figure 2: Estimated density surfaces for harbour porpoises (animals per km2) calculated from SCANS II 1994 and 2005 data (Hammond *et al.*, 1995; Hammond *pers. comm.*, 2007).

1.1.2. Sound emission

When a porpoise is echolocating it emits biosonar sounds and gets the returning echoes back from the object. The echoes are then used to determine the direction and distance to the object. Echolocating behaviour is used during feeding, orientation and social contact (Richardson *et al.*, 1995).

Two hypotheses exist on the sound production mechanism of odontocetes. One claims that the sound source is located near the larynx (Purves & Pilleri, 1983) and the other, which is the most favoured, places the sound source in the nasal plug area just below the blowhole (Amundin & Andersen, 1983). Evidence of the latter theory comes from measurements done with phonating dolphins by Amundin & Andersen (1983) and Cranford *et al.* (1996). However, Cranford *et al.*

(1997) provided the strongest evidence that the phonic lips, in the nasal plug area, were directly involved in the production of sound. The evidence was found on dolphins when he inserted an endoscope through the phonic lips, thereby preventing them from closing properly and disabling the dolphin to produce sound. Figure 3 views the position of the phonic lips. The sounds produced within the phonic lips will propagate forward through the melon into the water guided by the bony structures (Au, 2000).

The echolocation sounds consist of narrowband, series of clicks (Goodson *et al*., 1995; Au *et al*., 1999), commonly referred to as click trains, with a peak frequency centred on 130kHz (Møhl & Andersen, 1973; Au *et al.*, 1999; Teilmann *et al*., 2002). From porpoises in captivity, scientists have recorded a source level around 157-172dB re 1 µPa@1m (peak-peak) (Au *et al.*, 1999; Teilmann *et al.*, 2002). However, during a field recording study on wild harbour porpoises, Villadsgaard *et al.* (2007) found a peak frequency around 129-145 kHz but the source level to be 178-205 dB re 1 µPa@1m (peak-peak) which is much higher than the source level found in the studies from captivity.

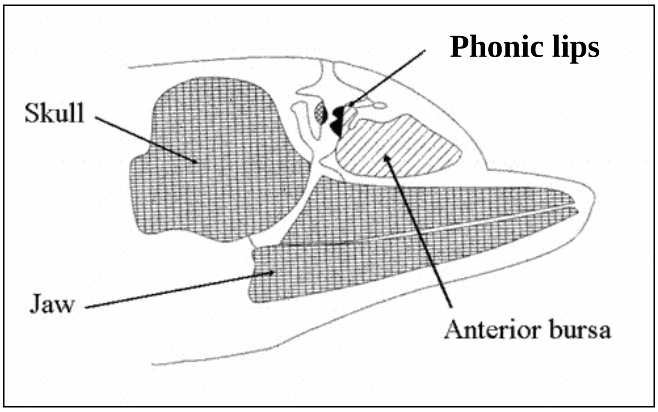

Figure 3: Placement of the phonic lips in the nasal plug area (Cranford *et al*., 1996).

1.1.3. Hearing and detection abilities

Harbour porpoises detect sound by three fundamental parts in the ear: (1) The outer ear (lower mandible) captures the sound, (2) the middle ear transfers the acoustical power into the inner ear, and (3) the inner ear performs a spectral analysis and transforms the middle ear's mechanical input into neural impulses (Ketten, 2000).

The porpoise's hearing depends on: (a) absolute threshold (the level of sound that is barely audible in the absence of significant ambient noise), (b) motivation (the ability to detect sound signals in the presence of background noise), (c) localization (the ability to discriminate sounds of different frequencies) and (d) levels (the ability to distinguish between sound signals and background noise) (Richardson *et al*., 1995). Kastelein *et al*. (2002) measured the underwater sensitivity of a 2 year old harbour porpoise in captivity. This study documented that porpoises' best hearing abilities lay between 16kHz and 140kHz and further maximum sensitivity ranges were found between 100-140kHz, which correlates with the earlier mentioned peak frequency of harbour porpoise (section1.1.2).

Most nets are made of nylon. Since nylon has low target strength (acoustic reflexivity) they are not easy to detect by echolocation. However, when back calculating from porpoise source levels, porpoises in captivity can detect an average size fish at 10m and a gillnet at 3-6m distance, whereas porpoises in the wild can detect fish (adult herring) and gillnets at 40m and 13-26m respectively (Kastelein *et al*., 1999; Kastelein *et al*., 2000; Villadsgaard *et al*., 2007).

1.2. Possible threats to harbour porpoises

The populations of harbour porpoises face several of potential risk, such as noise, ship activity, constructions at sea, pollution and incidental bycatch in gillnets. The following section deals with these possible risks and ends up in a larger section about incidental bycatch of harbour porpoise

1.2.1. Noise and acoustic disturbance

Noise can influence the detection range of any sonar system. It can be defined as any unwanted acoustic signal that will interfere with the effectiveness of a sonar system (Au, 1993) and there is an increasing concern about the effects of human-induced underwater sounds upon marine mammals (Richardson, 1995; NRC, 2000, 2003 & 2005). Sources of noise in the marine environment can be of natural origin, e.g. wave motions, currents, turbulence and rain, or they can be man-made, from e.g. ships, echo-sounders, offshore wind farms, airguns and a range of other activities. Because sound propagates relatively easy in water, sound effects are more pervasive in the marine environment than on land (Richardson, 1995). Noise may also cause masking of natural sounds, impair communication and affect prey detection negatively (Au, 1993). However harbour porpoises are often observed in areas with heavy ship and boat traffic, e.g. Sveegaard (2006) found the Great Belt in DK to be an area with high densities of harbour porpoises even though this area is a very busy shipping and boat traffic lane. Regarding constructions of offshore wind farms, the potential impacts of these constructions on harbour porpoise echolocation activity have been investigated. Assuming that echolocation activity is related to harbour porpoise density, a study showed that their habitat use changed considerably in a construction area, with the porpoises leaving the area. Therefore the aspect of noise during construction and operation must be considered (Carstensen *et al*., 2006).

1.2.2. Marine pollution

The uncontrolled use of persistent organochlorine chemicals like PCBs (polychlorinated biphenyl) in the 1960's and 1970's have been discussed as one of the reasons for the population declines seen in the Baltic Sea (Teilmann & Lowry, 1996). PCB and pesticides like DDT are relatively poorly metabolised and excreted by animals. As a consequence, species higher up in the food chain tend to accumulate these organic pollutants. PCBs have also been claimed to be responsible for immunological deficiencies or reproductive abnormalities (Bruhn *et al*., 1999) and organic pollutants like organochlorines have been recorded in considerable numbers in marine mammal tissue (Reijnders, 1992). Jepson *et al*. (2005) investigated a possible relationship between PCB exposure and infectious disease mortality in harbour porpoise from UK waters. They compared concentrations of chlorobiphenol (Σ25CB) from healthy porpoises, mainly bycaught, with Σ25CB values from porpoises that died of infectious diseases. The group which died from infectious diseases had significantly greater Σ25CB values than the bycatch group. This correlation occurred independently of other variables, such as age, sex, season, region, year found and indices of nutritional status. In porpoises with a total PCB level higher than 17 mg/kg lipid, the total PCB level was also significantly higher in the infectious disease group (Jepson *et al*., 2005).

Another study done by Berggren *et al*. (1999) showed that mature male harbour porpoises from the Baltic Sea had higher levels of PCBs than porpoises from Kattegat-Skagerrak and Norway. They also showed that levels of DDTs and PCBs were significantly higher in porpoises collected during 1978-1981 compared to porpoises collected in 1988-1990 indicating a temporal decline of these organo chlorines. However no evidence has been found of pollution effects on harbour porpoise survival, but it should still be regarded as a potential reducing factor of the population (Reijnders, 1992; Hammond *et al*., 1995; Breggren *et al*., 1999).

1.2.3. Incidental bycatch

Incidental bycatch of harbour porpoise are mainly documented by observer programs or voluntary reports from fishermen on national basis. An overall estimate, using the same methods, covering the European waters does not exist. Therefore the available recordings are listed on a national basis below.

Bycatch, Denmark

Bycatch of harbour porpoises in the Danish fisheries have been recorded since 1992 and high bycatches have been reported in the bottom-set gillnet fisheries for turbot (*Psetta maxima*), cod (*Gadus morhua*), hake (*Merluccius merluccius*) and plaice (*Pleuronectes platessa*) in the North Sea (Vinther, 1995; 1999). Vinther (1999) sampled bycatch of harbour porpoise in the commercial Danish gill-net fisheries by use of independent observers from 1992-1998. A total of 325 harbour porpoises were reported as bycatch from 5591km net. Extrapolation of the observed data from the North Sea gave an estimated total annual bycatch of 6785 porpoises in the period 1994-1998. Unfortunately, data was not sufficient to estimate the total bycatch for other areas. Vinther and Larsen (2004) estimated the bycatch from 1987-2001 in the North Sea, by using the 1992-1998 data from Vinther (1999) and additional bycatch data from the period 1998-2001. They used two methods for extrapolation: Landing-based (same as Vinther (1999)) and effort-based. When using landing-based, the mean estimated total annual bycatch was 5817 harbour porpoises, while the effort-based estimates had a total annual mean of 5591 harbour porpoises. Both methods estimated a significant reduction in bycatch in the recent years due to a reduction in fishing effort and landings (Vinther & Larsen, 2004). Bycatch from 2001-2008 have not been estimated in Danish waters.

Bycatch, Sweden

Berggren (1994) has used fishermen reports to estimate the minimum bycatch of harbour porpoise in the Swedish waters, Skagerrak, Kattegat and the Baltic Sea between 1973 and1993. The data showed a total of 169 bycaught porpoises in the period 1973-1988, 297 in 1988-1991, 6 in 1992 and 9 in 1993. During the period 1989-1991, 70% of the catches occurred in Kattegat followed by Skagerrak (22%) and the Baltic Sea (8%). The low numbers seen in 1992 and 1993 were due to the fact that data only was collected in the Baltic Sea. Regarding gear types gillnets fisheries were responsible for more than 80% of the bycatch in all three areas. In Skagerrak the highest bycatch rate was observed in gillnets set for spiny dogfish (*Squalus acanthias*) (water depths 40-80m) and in gillnets set for cod in Kattegat (water depths 20-60m). In the Baltic Sea the highest bycatch rates were found in driftnets for salmon (*Salmo salar*). No recent estimates of bycatch in the Swedish waters exist.

Bycatch, Germany

In Germany gillnets also have the highest bycatch rates of harbour porpoise (Benke, 1994; Kock & Benke, 1996; Rubsch & Kock, 2004). Kock and Benke (1996) conducted a study in the German North Sea and the Baltic Sea on data from schemes based on voluntary reports from fishermen. In the years 1987-1995, they registered 133 bycaught porpoises of which 95% were caught in gillnets. Since data was based on voluntary reports there was a possibility that the actual bycatch could be higher than reported and consequently the total level of bycatch could not be quantified. Rubsch and Kock (2004) assessed data on bycatch in the German part of the Baltic Sea from part-time fishermen by using questionnaires. A total of 42% fishermen responded, only 2% answered that they have had bycatch of harbour porpoise, even though the fishermen orally had reported a higher bycatch of porpoises. Still, Rubsch and Kock (2004) estimated that part-time fishermen were responsible for 27% of the total bycatch per year (82 harbour porpoises per year). Regarding harbour porpoise bycatch, the most important fishery in the German waters appears to be gillnets for cod around Schleswig-Holstein (Benke, 1994). This also correlates with the high records of bycatch in the Danish and Swedish cod gillnet fisheries.

Bycatch, United Kingdom
In 2005 and 2006 the Sea Mammal Research Unit (SMRU) collected data on cetacean bycatch by having observer's onboard fishing vessels larger than 15m. They monitored over 1350 days at sea, observed 2700 fishing operations, and recorded 20 bycaught harbour porpoises in static gear, 6 in tangle nets and 14 in gillnets. In conclusion they estimated a total bycatch for 2005 and 2006 between 222-704 and 364-1122 porpoises respectively in ICES sub-area VIIa, e, f, g, h and j. In ICES area IV and VI they could not predict bycatch rates due to over 400 observed operations without any cetacean bycatch (Northridge *et al.*, 2007). Another study, by Tregenza *et al.* (1997) estimated cetacean bycatch in set gillnet fisheries in the Celtic Sea. The data was collected from 1992-1994 by hauls of over 2500km net. Here a total bycatch of 43 harbour porpoises was observed. This resulted in a total bycatch estimation of 2200 porpoises per year. These numbers are much higher than the numbers estimated from Northridge *et al.* (2007) who estimated the bycatch in approximately the same area to be around 743 in gillnets and tangle nets. This indicates that bycatch can be highly variable depending on year, type of fishery and fishing methods.
The latest UK bycatch rates (Northridge *et al.*, 2007) do not pose a major conservation risk to harbour porpoises but if all bycatches from all European countries affect the same biological population, it could be a possible risk to the population. An overall bycatch assessment at a European level is therefore needed, to conclude if even small bycatches per country can contribute to a possible population threat.

1.3. Reasons for bycatch

The reason for incidental bycatch of harbour porpoises in gillnets is not known, although several hypotheses exist. To give an overview of the hypotheses they are in short described below together with the documented knowledge upon each hypothesis:

- Hypothesis: Porpoises can not detect nets at a sufficient distance to avoid entanglement. Knowledge: Experiments have shown that porpoises can detect gillnets at adequate distances to avoid them (Kastelein *et al.*, 2000; Mooney *et al.*, 2004; Villadsgaard *et al.*, 2007). In a true bycatch situation it might therefore be that the net echoes are masked in other echoes or background noise.
- Hypothesis: The porpoises can detect the nets but do not use their sonar all the time and therefore get entangled.
  Knowledge: Day variation in echolocation behaviour of wild porpoises most likely exist (Carlström, 2005) and evidence that porpoises do have silent periods are found (Akamatsu *et al.*, 2007). On the other hand, Verfuß *et al.* (2005) recorded a continuous use of sonar even in daylight with good visibility and in familiar surroundings by harbour porpoise. Whether porpoises do use their sonar continuously is therefore uncertain.
- Hypothesis: Porpoises have their sonar locked on another target than the net, such as prey, group members or obstacles in the water and do therefore not detect the nets.
  Knowledge: Entanglement of porpoises in a pool has been observed by Kastelein *et al.*, (1995). They documented that when introducing live fish or other porpoises, the test porpoise became distracted, which induced a higher entangle rate. Their observations therefore indicate a possibility of porpoises having their sonar locked on other targets.

- Hypothesis: Porpoises classify gillnets incorrectly. Maybe porpoises regard gillnets as material that they normally can swim through, like bottom vegetation.
  Knowledge: The above mentioned study by Kastelein *et al*. (1995) observed a learning process through a decline entanglement rate as an effect of time. Therefore the porpoises might not have classified gillnets as a barrier in the beginning of the study. This study might therefore indicate that gillnets are not classified as a barrier.
- Hypothesis: Porpoises use nets to herd fish.
  Knowledge: Porpoises are not known to prey on fish caught in nets, and since they swallow fish whole most net-caught fish will be too large for them to swallow (Recchia & Read, 1989). The available knowledge is therefore not very supportive of this theory.
- Hypothesis: Porpoises chase the same prey items as the target fish caught in gillnets.
  Knowledge: Stomach contents collected from porpoise stomachs and e.g. cod do have correlating prey species (Daan, 1973; Andreasen *pers*. *comm*., 2008). Correlations of stomach contents between porpoises and target fish from the same haul has however not been conducted.

1.4. Bycatch regulation

1.4.1. Council regulation 812/2004

In April 2004 the EU adopted council regulation No 812/2004, which lay down measures concerning incidental catches of cetaceans in fisheries. In short, the regulation promulgated (EU, 2004):

1. Member states should minimise the impact of fishing activities on marine ecosystems.
2. Member States should monitor incidental captures and killings of protected cetaceans and ensure that the captures do not have a significant impact on the species concerned.
3. Scientific information and techniques developed to reduce incidental captures of cetacean in fisheries justify additional measures being taken to further the conservation of small cetaceans in a consistent and cooperative manner at Community level.
4. Implementation of acoustic deterring devices in areas and fisheries with known or foreseeable high levels of cetacean bycatch and establishment of the technical specifications for the efficiency of such devises. Furthermore studies are needed to increase knowledge about the effect over time.
5. Member States are allowed to authorise the use of newly developed and effective types of acoustic deterring devices not in conformity with the technical specifications laid down in this regulation.
6. Independent observers are needed onboard to provide reliable estimates of the incidental catch of cetaceans. For fishing vessels less than 15m, which are unable to have an additional person onboard, data should be collected through scientific studies or pilot projects.
7. Member states should report annually on the use of pingers and on the implementation of on-board observers. Including the information on cetacean bycatch.
8. The use of driftnet in the Baltic Sea has a phasing-out period before a total ban by the January 1, 2008.

1.4.2. Council regulation 812/2004 in Denmark

In Denmark, the council regulation 812/2004 proclaims that acoustical devises (pingers) should be prescribed in ICES-area IV and section IIIa. The pingers are obligatory on all fishery with net chains ≤ 400m and fishery with mesh size ≥ 220mm for vessels larger than 12m. In ICES subsection 24 the regulation is valid on all set nets and drift nets until banned (EU, 2004).
The Danish Forest and Nature Agency and Ministry of Food, Agriculture and Fisheries have made a plan of action for protection of harbour porpoise in Danish waters. The objective is to reduce bycatch of harbour porpoise as much as possible and as a minimum to a level beneath 1.7% of the population per year as recommended by ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas) (ASCOBANS, 1997; 2000). Denmark should also contribute through research to identify areas with importance for porpoises, optimise the use of pingers, investigate pingers impact on porpoises, investigate population structure and migration, investigate porpoises use of sound in relation to bycatch, develop technologies to reduce bycatch, evaluate bycatch impact on the population and monitor the porpoise population, in the Danish waters, size and abundance (Jepsen, 2005).

1.5. Mitigation methods

1.5.1. Pingers

The only method to reduce bycatch of harbour porpoise which is included in the council regulation no 812/2004 is pingers. Pingers are acoustic devices which deter porpoises and they have shown to reduce bycatch of harbour porpoise (Kraus *et al.*, 1997; Larsen, 1999; Trippel *et al.*, 1999; Larsen, 2002; Larsen & Krog, 2006). Kraus *et al.* (1997) conducted an experiment in the Gulf of Maine herring sink gillnet fishery in cooperation with 15 commercial fishermen. It was designed as a blind, controlled experiment, testing if pingers could reduce bycatch of harbour porpoise. They used Dukane NetMark1000-pingers (source level 132dB re 1 µPa@1m, 10kHz), and dummi-pingers as controls. Dummi-pingers are identical to the test-pinger but with out emission of signals. The result showed a significant reduction (85%) in bycatch of harbour porpoise. Trippel *et al.* (1999) also showed a reduction of 77% in the gillnet fishery, when using Dukane Netmark 1000 in the Bay of Fundy. Other pinger types have also been shown to work. Gearin *et al.* (2000) tested a modified version of the Lien-pinger (source level 121.7-124.7dB re 1 µPa@1m, 3 and 20kHz) and recorded a significant reduction of harbour porpoise bycatch in the salmon gillnet fishery when the pinger was used. Larsen & Krog (2006) tested the AQUAmark100 (source level 136-145 dB re 1 µPa@1m, 20-160kHz) in the Danish hake fishery, and showed a significant reduction, also when spacing the pingers 455m and 585m which is a much larger spacing than recommended by the manufacturer.

The practical implications of deploying pingers in the fishery have been examined. Cosgove *et al.* (2005) assessed pingers in terms of their impact on fishing operations, durability and potential cost to the fishermen complying with the requirements of the regulation. They tested four types of pingers: Gill net pinger (Airmar Tecnology Corporation, Milford, NH USA), AQUAmark 100 (Aquatec Group Ltd, Hampshire, UK), FMDP-2000 (Fumunda Marine Products, Wathsonville, CA-USA) and Dolphin Saver- High Impact System (SaveWave, Delft, Netherlands). When attaching the pingers to the headrope all pingers proved a time consuming process. However, the Fumunda was the easiest to handle because of its small size. All pingers occasionally entangled the gear as they fell through the meshes when lying in the piles attached to nets. This caused problems, as the entangled pinger tended to block the flaking machine thereby tearing meshes when forced through. This occurred also with floats but presence of pingers increased the blocking frequency. Different solutions to this problem were tested, and it was found that placing the pingers and floats in a bag, could reduce the problem by 16%. The pingers functionality was tested after the trials. All 15 Airmars were still functional after the trials although a compression of the D-cell battery was observed in all of them. Just one (6%) Aquamark was non-functional, whereas three (20%) Fumundas were non-functional (due to internal damage to the spring) and 38 % of the Savewaves were non-functional at the end of the endurance trail. At the end a scoring system from 1 to 3 were applied the different categories, unit cost, size, weight, max depth, spacing, battery life, battery replacement, wet switch, not pinging %, damaged %, est. service cost and 5 year cost. Both the Airmar and FMDP-2000 collected the highest score, 29 where the AQUAmark100 and Savewave scored 23 and 16 respectively. Larsen (2006) and Seafish (2003; 2005) also conducted studies on handling of pingers. Their results more or less show the same picture of the problems as Cosgove *et al*. (2005). Therefore, even though pingers have shown fine results regarding bycatch reduction, they are not well accepted by fishermen due to their handling problems and high costs.

1.6. Alternatives to Pingers

Besides the handling problems and cost of pingers other concerns with the use of pingers have also been raised for example noise pollution, habituation and exclusion from habitats (Cox *et al*., 2001; Jepsen, 2005). Therefore, alternative mitigation methods to pingers are briefly described below.

1.6.1. Redistribution to other fishing methods - Longline

Longline fishery seems to be a potential alternative to gillnets with pingers. Longlines have been used with great success in other countries targeting cod and hake and therefore it might be possible to introduce a commercial longline fishery after cod and hake in the Danish waters. Longlining has shown to be cost-effective in various countries, here among Denmark. There have, however, been some problems with loss of bait, hook type, catch escapes and catch of unwanted species (Krog, 2003), but if these factors are improved upon, it can make longline fishery even more effective and profitable (Blæsbjerg, 2007).

1.6.2. Redistribution to other fishing methods - Pots

Pots have shown promising commercial possibilities, and could be an alternative to the use of gillnets. However, more experiments are needed if a trap fishery is to be implemented. In Danish and Norwegian experimental fisheries it has been shown that the traps used were too light and tended to break under strong currents. Therefore modifications of traps are needed if the trap fishery is to become commercially sustainable (Furevik & Skeide, 1994, 2002; Krog, 1998).

1.6.3. Time /area closing

Closing of certain areas for gillnets fishery have been used in other countries. The efficiency of area closing, regarding bycatch of porpoise, is although very hard to predict due to high yearly variation in bycatch (Murray *et al*., 2000). However, closures have big consequences for the commercial fishery. Therefore, if this method is to be used, high quality data about porpoise distribution and movement is needed (Dawson & Slooten, 1993) and for the time being, this kind of data is not available from the Danish waters.

1.6.4. Modifications of gillnet

To increase the acoustic reflectivity (target strength) different kinds of devices and materials have been attached to gillnet. However, until now these experiments have not given clear results and the effect of the devices is doubtful (Hembree & Harwood, 1987; Goodson *et al*., 1994; Koschinski & Culik, 1997). Use of chemically enhanced nets has been tested. The results are although unequivocal and further knowledge is needed to clarify the influence of breaking strength, acoustic reflectivity, weight and stiffness (Northridge *et al*., 2003; Trippel *et al*., 2003; Larsen *et al*., 2007). However, the latest documentation on this alternative indicates that even though chemically enhanced nets have higher target strength, compared to commercially used nets, the higher target strength might still not be enough for porpoises to detect the nets at sufficient distance to avoid entanglement (Mooney *et al*., 2007).

1.6.5. Alerting sounds

Alerting sounds are artificial porpoise-like sounds simulating the clicks porpoises often use detecting targets. These sounds have been used to stimulate porpoises to a higher click rate (Pleskunas &Trenenza, 2005; Amundin *pers. comm*., 2006; Desportes *et al*., 2006). In the earlier mentioned reasons for bycatch (section 1.3) a hypothesis was that porpoises do not use their sonar continuously and consequently they do not discover gillnets. It has therefore been discussed whether alerting sounds can make porpoises aware of gillnets and thereby avoid entanglement.

1.7. This master thesis

This master thesis was conducted as a small part of a larger collaborative project between the National Institute of Aquatic Resources and the Danish Fishermen's Association represented by Krog Consult. The purpose of the large project was to conduct a range of studies to develop and test alternative methods to reduce bycatch of harbour porpoise. The project was financed by the Directorate for Food, Fisheries and Agri Business and the Aage V. Jensen foundation.

As mentioned in the introduction (section 1.3), the hypotheses of why porpoises are caught in gillnets suggests that porpoises do not pay sufficient attention towards their surroundings, since they have their sonar locked on other targets or do not use their sonar continuously. A possible solution could therefore be to alert the porpoises in presence of gillnets.

Within this master thesis I have focused on alerting sounds as a tool to reduce bycatch. In cooperation with Aquatec Group Ltd, Hampshire, UK pingers emitting alerting sounds was produced, Alerting Sound pingers (PAS- pingers).

1.7.1. Part II, Bycatch in the North Sea

To test the effect of the PAS-pingers an agreement was negotiated with a fisherman from the Danish commercial hake fishery. He accepted to have an observer onboard recording all bycatches of harbour porpoises caught by his vessel.

The principle of the PAS-pinger is that alerting sounds would stimulate porpoises to echolocate at the pinger positioned on the net. The porpoise would get reflections back from the pinger and the net, thereby detecting the net barrier ahead.

If the PAS-pinger can reduce bycatch of harbour porpoise, it may become possible to produce a new type of pinger of smaller size, longer durability, because of its low energy needs, and a pinger with far less noise pollution compared to deterring sound pingers.

The purpose of this study was:

- To test if PAS-pingers could reduce bycatch of harbour porpoise

1.7.2. Part III, Sonar activity in Jammerland Bay

To shed light on the results and the principle of the pinger outlined in Part II, it was decided to carry out 2 further field experiments. Part III, Sonar activity, should determine whether the PAS-pinger in fact stimulated wild porpoises to echolocate at the net.

The purpose of this study was:

- To test if the PAS-pinger could stimulate harbour porpoise to a higher click rate

1.7.3. Part IV, Recordings of the PAS- and AQUAmark100 pinger

Another interesting question is how the PAS-signals propagated in sea water. E.g. does the position of the pinger in the water column have any effect on the received source levels which porpoises experience approaching nets? And has the dept and distance of which the porpoise approach any effect on the received source level the porpoise's experience?

These questions resulted in an experiment, testing how pinger sounds propagates in water. It was decided to test both the PAS-pinger and a deterring sound pinger (AQUAmark100) thereby being able to relate PAS-sounds to deterring-sounds since they differ both in source level and frequency.

The purpose of this study was:

- To test if there is a difference in received source level (RSL) between pingers position on the bottom or in the water column; and
- To test if there is difference in RSL according to different depths of the hydrophone and distances to the setup.

2. Part II, Bycatch in the North Sea

- *Testing if PAS-pingers can reduce bycatch of harbour porpoise*

2.1. Introduction

Costal and high seas gillnet fisheries results annually in the take of large numbers of harbour porpoises in the Danish waters (Vinther 1999; Vinther & Larsen, 2004). One of the main questions in relation to bycatch problems is why porpoises are caught in gill nets. There are different hypotheses relating to this question. One of them is that the porpoises are not always sufficiently attentive to their surroundings and therefore get caught. This has led to the idea of alerting the porpoises by transmitting sounds, which could stimulate porpoises to echolocate at their surroundings. Experiments with captive animals have shown that artificial porpoise click trains stimulate porpoises to explore the sound source (Amundin *pers. comm.*, 2006). Placed on a net, such sound sources should be able to reduce by-catch, by alerting the porpoise to the presence of the net. The aim of this study was therefore to determine if PAS-pingers could reduce bycatch of harbour porpoise.

2.2. Material and methods

2.2.1. Study area

The experiment took place in July-August 2006 in the North Sea, ICES square 41F7, 42F6 and 42F7 (appendix 8.1.1). The water depth was 27.8-34m and the bottom type was mainly stones and gravel. The area is primarily used for gill net fishery although trawling does occur.

2.2.2. Fishery and gear

The study was carried out in the Danish commercial hake fishery. The vessel was a commercial gillnet fishing vessel (23m long and 113.9BT) using around 400 gillnets with mesh size 130mm (full mesh size) and twine size 0.57mm. The net was 40.5 meshes high and 2000 knots long. The float line was 65m and the lead line 75m, giving a hanging ratio of 25%. The nets were tied together during setting to form fleets of nets ranging in size from 50 to 120 nets.

2.2.3. Pingers

The pingers were custom-made PAS-pingers and dummy-pingers manufactured by AQUATEC (Aquatec Group Ltd, Hampshire, UK). The PAS-pingers emitted artificial porpoise like click trains consisting of clicks with a pulse varying from 50-2500 clicks per sec. The source level (SL) was 126-138 dB p-p re 1 µPa @1m (110kHz) simulating the clicks porpoises often use observing or investigating targets. A spectrogram of PAS-signal is given in appendix 8.1.2. The two pinger types were superficially similar, size 164mm (length) x 58mm (diameter at widest point) and could only be distinguished from each other through the serial number and presence of a salt water switch on the PAS-pingers. The pingers were attached to the bridles between the nets with a float on both sides.

Before the pingers were attached the theoretical optimal pinger spacing was calculated to make sure of the pingers audibility to porpoises approaching the nets. This was done by calculating the Signal to Noise ratio (SN) through the sonar equation.

$$SN = SL - TL_{(\text{spreading + abs})} - (P_N - D_I)$$, (Urik, 1983)

Where, SL = Source Level
TL = Transmission Loss
P_N = Total Noise Power
D_I = Directivity Index

SL: The Source Level is the sound pressure level measured at one meters distance to the sound source (Urick, 1983).
TL: The transmission loss (spherical spreading) will follow 20log(R) where R is the distance (Urick, 1983). Absorption in sea water is around 0.5dB/km and therefore ignored in these calculations due to the short distances (Richardson *et al.*, 1995).
P_N: At 110kHz the noise level can be estimated to approximately 36dB (deep sea, sea state 4) (Richardson *et al.*, 1995). However, to this should be added the noise within this critical band width, which is calculated by 10 log(band width) (Richardson *et al.* 1995; Madsen *et al.*, 2006). The total noise power is therefore estimated to 47dB at 110kHz.
D_I: Harbour porpoises have directional hearing. Since the noise power mentioned above include noise from all directions, there has to be compensated for porpoise's directional hearing. This can be done by subtracting a receiving directivity index, estimated to 12dB (Kastelein *et al.*, 2005).

2.2.4. Experimental design

First Setup

Two experimental set-ups were tried. During the first experimental trip 400 nets were used, 50% had PAS-pingers attached and 50% had dummy-pingers. Based on above mentioned calculations a pinger spacing of 3 nets or approximate 195m distance was used. The SN ratio calculated for this spacing was 15dB. Because of almost equal bycatches in active and controls fleets during the first trip, the first setup was adjusted to a second setup.

Second setup

On the following 5 trips a second setup was used. Due to almost equal bycatches in PAS and control fleets during the first trip the pingers spacing were reduced to every second net, or approximately 130m. The reduction was made to increase the audibility of the PAS-signals. The SN ratio calculated for this spacing was 19dB. Pounder arrangements onboard made it impossible to have pingers attached on all net fleets. Therefore, only the 180 nets, placed in the two front pounders, had pingers attached (still 50% PAS-pingers and 50% controls).

2.2.5. Data collections

Onboard

The fishing trials were fully covered by observers, whose main function on board was to record data on bycatch of harbour porpoises and carry out regular checks of the pingers. Data were collected on a station basis, where a station is a fleet of nets set at approximately the same time, either with PAS-pingers or dummy-pingers attached with the required spacing. Data collected for each station included time and position for setting and hauling of the nets, bottom type, average depth, number of nets set and number of pingers deployed. Data regarding fish catches and bycaught porpoises were also collected. The species length- and weight composition of random samples of fish was recorded. Porpoises were collected from both PAS- and dummy-pinger nets fleets and catch number, length, sex, position and distance to PAS-pingers were recorded. If possible, porpoises were landed for further dissection. In addition, information was collected on any handling problems experienced with pingers.

Harbour porpoise
On land the porpoises were separated into two groups, those which had drowned within 24 hours and those which drowned more than 24 hours before landing. Porpoises landed within 24 hours were brought directly to FTZ Forschungs- und Technologiezentrum Westküste, University of Kiel, Germany. Here their heads were scanned by computerized tomography (CT) and their ears were extracted (10% buffered formalin fixation) to check for brain damages and possible hearing impairment. All examinations were done by FTZ. All other landed animals were frozen for later dissections. The dissections were conducted to determine their physical conditions and collect stomach contents. For each animal, a dissection journal was completed (appendix 8.1.3). All examinations of harbour porpoise were done in co-operation with veterinarians and specialists from FTZ, Büsum, Germany.

Porpoise Click Loggers
To obtain knowledge on porpoise presence in the study area Aquaclick100 Porpoise Click Loggers (PCL, Aquatec group Ltd, UK) were deployed. The PCL-logger is a click recorder which monitors sonar activity from harbour porpoises or other Odontocetes. The logger records amplitude, time and duration (click length, CL) of the click. It has a low band pass filter (LBPF) at 60 kHz and a high band pass filter (HPBF) at 130kHz thereby making it possible to distinguish between broadband clicks, from e.g. dolphins and narrow band porpoise clicks. Both filters have sufficient bandwidth (30kHz) to allow porpoise sonar variations. To eliminate unwanted noise, hardware algorithms were set as followed by use of AQUAtalk for AQUAclick (vers. 1.10, Aquatec group Ltd, UK):

- For triggering the PCL to log a click the high threshold level was set to 0.039 volts (HBPF).
- Log only clicks when the received amplitude in the (HBPF) is higher than the amplitude in the (LBPF).
- Log only clicks where the interval between clicks (ICL) is 1ms-500ms.
- Log only clicks with an individual CL between 50µs-600µs

The PCL starts logging when it is deployed and the salt water switch is activated. It can be active for approximately 14 days depending on water temperature and logging activity.
In this experiment, four loggers were random attached at the end of nets with dummy pingers to collect data about porpoise presence in the area.

Hake stomachs
Hake stomachs were randomly collected when time was available on onboard. The hake's lengths were measured and their stomachs were removed and stored in 96% alcohol. In the lab the stomachs were examined undigested prey was if possible identified and length and weight recorded. No studies of digested prey items, such as otoliths, were conducted.

2.2.6. Data analysis

Bycatch
The sampling unit was a station and the bycatch was assumed to follow a negative binominal distribution. The number of bycaught porpoises per station was divided by the fishing effort (number of nets* fishing time), thereby calculating Catch Per Unit Effort (CPUE). A two sided analysis of variance (ANOVA, negative binominal distribution) within the R statistical package

(vers. 2.4.1., Technical University, Vienna, Austria) determined if there was an effect of the PAS-pingers.

Porpoise Click Logger
The recordings were analysed by use of AQUAclick View, vers.1.6b (Aquatec Group Ltd, Hampshire, UK). Within AQUAclick View the software filter settings were set as followed.

- Accept only clicks with a HGBPF/LBPF ration >3
- Accept only clicks with ICLs in the interval 1ms≤ ICL ≤ 300ms
- Accept only clicks with a CL between 50µs≤ CL ≤ 500µs

These software settings were almost identical to the hardware settings within the PCL, but the software filter settings were set to adjust the hardware filter settings of the PCL thereby minimizing false positives.

Only clicks in trains were used as identification of presence of porpoises. To identify the number of clicks in trains (CIT) additional filter settings were available in AQUAclick View. The applied detection settings are included in appendix 8.1.4. If all criteria’s were met the clicks were classified as porpoise CIT.

2.3. Results

2.3.1. Fishing effort

Six fishing trips were made with at total of 22 days of fishing and data were collected from 70 stations. Twelve of these were discarded due to PAS-pingers and control-pingers had been attached within the same net fleet. Of the remaining 58 stations, 25 had PAS-pingers attached and 33 had dummies.

2.3.2. Bycatch

A total of 32 harbour porpoises were caught during the experiment. The bycatch rate for stations with PAS-pingers was not significantly different from the bycatch rate for the control stations (P= 0.13; 1 d.f.) determining that the PAS-pinger did not reduce bycatch of harbour porpoise. The CPUE per trip are depicted in fig.4 below to give an overview of the collected data.

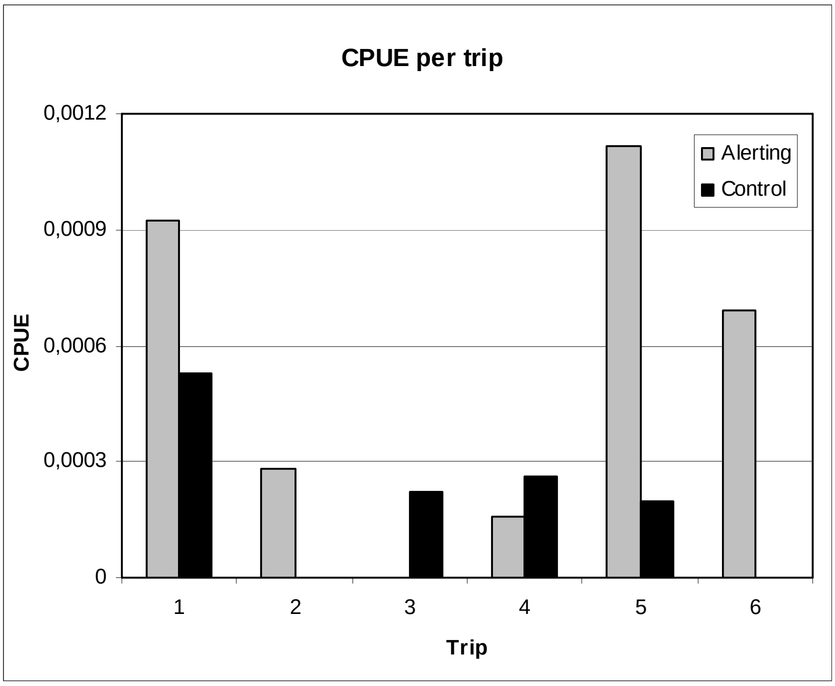

Figure 4: The CPUE (of harbour porpoise) per trip. The grey columns represent the CPUE on the stations with alerting pingers and the black columns represent the stations dummy-pingers.

2.3.3. Porpoise Click Logger data

Data recorded on presence of harbour porpoises were collected from 12 different positions. A total of 746.5hours were recorded on the PCL-loggers from control nets. Harbour porpoise click trains were recorded on 83% of the sound files with an average of 0.12 CIT/ hour* relative recording area (RA) of the PCL. The RA was calculated for each PCL, since the hydrophones differed in sensitivity. Calibrations of hydrophone sensitivity and calculations of the RA were conducted in Part III. Therefore further information and calculations are available within Part III.

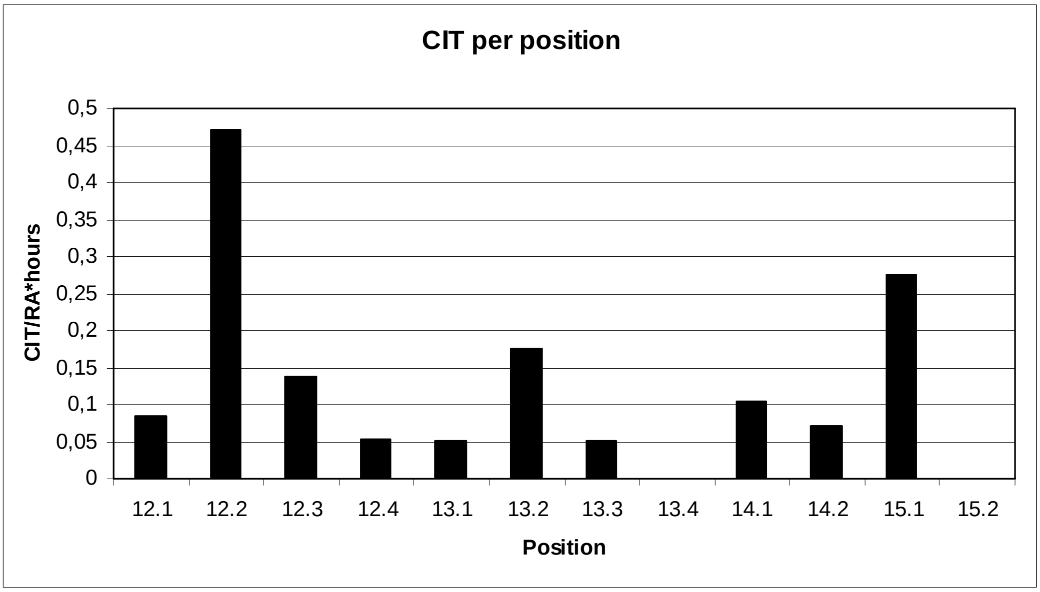

Figure 5: number of clicks in trains (CIT)/ relative area (RA)* hours recorded from 12 different positions in the study area.

2.3.4. Dissections

Eight of the 32 bycaught porpoises were brought ashore for further studies. The dissections showed that all animals had drowned. A summary of the dissection data (sex, weight, age, ear condition, cause of death & pathological findings) is included in appendix 8.1.5. Of the 8 porpoises 2 were females. They had a mean length and weight of 148.5cm and 45.7kg, respectively. Of the 6 male porpoises 2 were juveniles. The juveniles had a mean length and weight of 105.5cm and 19.9kg, while the adult males had a mean length and weight of 127.8cm and 35.2kg. All porpoises had from mild to severe parasite infestations in the ears.

Five of the porpoises had their ears extracted and brains scanned, which showed no signs of impaired hearing or other abnormalities (Prahl *pers. comm.,* 2007). Several other pathological conditions were found these were however, very common and in conclusion all animals were considered healthy.

Five of the 8 porpoises had their stomach content analysed. The results are shown in table 1 below.

Table 1: Prey items from porpoise stomach contents. (ID= Porpoise number, Common= common name, Number= number of the relevant species, Oto-number= number of otoliths, Tot fish= total number of fish found and Tot by oto= total number of fish found by the number of otoliths).

ID	Taxon	Species	Common	Number	Oto- number	Tot fish	Tot by oto
3465		STONE	-	7			
3465	Parasites	*Lernaeocera ssp.*	-	3			
3465		SAND	-				
3465	Ammodytidae	*Ammodytes ssp.*	Sandeel		14	7	14
3468	Parasites	Nematoda	-	X			
3468	Parasites	*Lernaeocera ssp.*	-	1			
3468		SAND	-				
3468	Ammodytidae	*Ammodytes marinus*	Sandeel		2	1	2
3468	Otolith	Unknown	-		2	1	2
3557	Parasites	Nematoda	-	1			
3557	Gadidae	*Merlangius merlangus*	Whiting		62	31	62
3558	Crustacea	*Diastylis ssp*	Crayfish	1			
3558	Parasites	Nematoda	-	15			
3558	Gobiidae	*Gobiidae ssp.*	Gobie		73	36,5	73
3558	Gadidae	*Merlangius merlangus*	Whiting		80	40	80
3558	Pleuronectidae	*Limanda limanda*	Dab		2	1	2
3558	Pleuronectidae	*Solea Solea*	Sole		7	3,5	7
3572	Parasites	Nematoda	-	X			
3572	Carangidae	*Trachurus trachurus*	Horse mackerel		99	49,5	99

2.3.5. Hake

All weight measurements of hake catches have been excluded because gutted and non-gutted hake catches not had been distinguished. A test comparing weight of hake landings from PAS-pinger nets with hake landings from controls-pinger nets will therefore become very inaccurate. It can therefore not be determined if the PAS-pingers had an effect on hake catches.

A total of 33 hake stomachs were collected. The maximum length and minimum length of the sampled hakes were 106 and 37cm respectively, with a mean of 73cm. The relative contents of prey species in the stomachs are, in percent, shown in table 2. Other species, such as Sprat (*Sprattus sprattus*) and Sea snail (*Buccinum undatum*) were also found within the stomachs but only in single individuals and are therefore not listed.

Table 2: The 3 main species found within the hake stomachs

Species	Common	%
Scomber scombrus	Mackerel	49
Merluccius merlussius	Hake	27
Clupea harengus	Herring	15

2.4. Discussion

2.4.1. PAS-pingers

The main purpose of the study was to test if PAS-pingers could reduce bycatch of harbour porpoises. The PAS-sound was expected to increase the porpoises' echolocation aimed at the pinger and net, thereby allowing the porpoises to detect the net. However, the results determined that the PAS-pingers used in this experiment could not reduce bycatch of harbour porpoises. The possible reasons for this include:

1. The porpoises could not hear the pingers; or
2. The sounds emitted by the PAS-pingers did not stimulate the porpoises to echolocate towards the pinger; or
3. The porpoises echolocated towards the PAS-pinger, but did not detect the net; or
4. The porpoises have their sonar locked on prey; or
5. The reason for porpoise bycatch is not lack of attention towards their surroundings.

The question of whether the porpoises could hear the pingers is complex and is therefore only discussed by use of theoretical calculations and assumptions below.

The pingers were spaced respectively 195m and 130m apart in the two set-ups and SN ratios were calculated for both spacings. The calculations indicated that the pinger signals were audible for porpoises in both setups. However, this type of calculation only gives the SN ratio when the porpoise is placed perpendicular (90°) to the sound source it is therefore uncertain whether the pingers are audible for porpoises approaching the net from other angles.

To shed light on this question a theoretical calculation of the PAS-pingers directivity was made. With a known frequency (110kHz) and a known transducer radius (18mm) the theoretical directivity index (directional factor θ) can be calculated for a circular transducer (Kinsler *et al.*, 1982). The results are depicted in appendix 8.1.6. Here it can be seen that the PAS-pingers are directive and this can affect the audibility. In fact, it is calculated that if the porpoises approach the PAS-pinger in an angle of 68° (when placing the pinger horizontal) the SL will drop more than 25dB. These drops in SL will lover the SN ratio remarkable thereby making it difficult for the porpoises to detect the pingers in angles with low SL.

Other studies measuring pingers in the same housing as the PAS-pinger have been carried out. They also found variation in SL when measuring the emitted signals at different angles to the pinger (Larsen *et al.*, 2006; Wahlberg, 2007). Their measures pinger-signals were however centred on lower frequencies (60kHz) and according to theory transducers will always be more directive at higher frequencies (Urik, 1983). Due to the differences in frequency a correlation between their conducted results from the AQUAmark100–pinger and the theoretical calculated from the PAS-pinger can not be preformed.

Even though it can be discussed whether the pingers were audible from all directions, observations of porpoises caught just 2m away from a pinger were made several times. This might indicate that the problem is not that the porpoises can not hear the PAS-pinger, but that their behavioural response to the alerting sounds is different than expected.

The head scans and ear investigations of the porpoises showed no signs of impaired hearing. The possibility that the animals caught in the PAS-pinger nets had impaired hearing is therefore very unlikely.

As for the second point, this study was based on the assumption that porpoise-like click trains, like those emitted by the PAS-pingers, would stimulate the porpoises to aim their sonar at the PAS-pingers. Previous studies have examined if alerting sounds could stimulate porpoises to increase their click rate. Amundin (*pers. comm.,* 2006) exposed two captive harbour porpoises to porpoise-like click trains (centred at 140 kHz) which resulted in higher click rates from the porpoises. Pleskunas and Tregenza (2005) also found an increased number of porpoise clicks when emitting a porpoise click train (130 kHz, repeated every 4 seconds). Both studies further suggested that alerting sounds could be employed to avoid bycatch. However, none of these studies presented results from a true bycatch situation. Petersen (2007) used alerting sounds (90kHz) to stimulate porpoises to trig an interactive pinger. He on the other hand found no differences in click rate when emitting the signals.
Stimulation of porpoises to a higher click rate is essential within the concept of the PAS-pinger. It would therefore be obvious to determine if the PAS-pinger in fact stimulated porpoises to a higher click rate.

Regarding the third point, it is possible that the porpoises were indeed stimulated to echolocate towards the PAS-pinger, but did not detect the net. Villadsgaard *et al*. (2007) reported that wild porpoises can echolocate with SL up to 200dB re 1µPa @ 1m, allowing them to detect gillnets at ranges of 13-26m, which is sufficient to avoid entanglement. This indicates that porpoises have the ability to detect the nets in time. How frequently they use such high SL is however unknown. It is also possible that the porpoises echolocated towards the PAS-pingers and thus the nets, but did not detect the nets because the net echoes were masked by the stronger echoes or sounds.

Another possibility is that porpoises prey on the same fish species as hake and therefore have their sonar locked prey instead of nets. The results from the porpoise stomach content showed that the porpoises had preyed on a variety of species. Findings of especially sandeels, whiting and gobies correlates with other stomach contents collected from the North Sea (Lockyer & Andreasen, 2001; Andreasen *pers. comm.,* 2007). The examinations of the hake stomach contents showed that their latest prey items had been mainly mackerel, hake and herring. According to the literature mackerel is an important prey item for hake (Du Buit, 1996). Hake and herring do occur but are not regarded as their main prey items (Guichet, 1995; Du Buit, 1996; Cabral & Murta, 2000). It should, however, be mentioned that the hake stomachs analysed within this literature are from other areas, which highly could influence the main prey items.
When comparing prey items of porpoises and hakes in this study, none of the same prey items were found within porpoises and hake. But according to the prey preferences listed in the literature there is an overlap in prey items, especially whiting could be a shared preference (Guichet, 1995; Du Buit, 1996; Cabral & Murta, 2000; Lockyer & Andreasen, 2001; Andreasen *pers. comm., 2007*).

Concerning point 5, it is possible that the reason for our results is that the basic concept is wrong, *i.e.* that porpoises are not bycaught because of insufficient attention to their surroundings. If this is the case alerting pingers will not be able to reduce bycatch. We therefore will have to look into one of the many other possible reasons of why porpoises are caught in gillnet to develop an alternative method to reduce bycatch of harbour porpoise.

Finally, it could be that PAS-pingers attracted the porpoises. The results showed no significant effect of the PAS-pingers in CPUE however, a higher trend in CPUE was calculated within the PAS-pinger nets. It is therefore possible that porpoises were attracted to the pingers and did not pay attention to nets, thereby causing the higher CPUE in the PAS-pinger nets. If the trend seen within the results is true a type 2 error has occurred. A type 2 error is when one mistakenly accept an incorrect H_0, where H_0 = no difference CPUE between PAS and control nets (Quin & Keough, 2002). This means the PAS-pingers can not reduce bycatch since the porpoises where attracted to the pingers. The P-value determining the effect of the pinger is although far from being significant indicating low chance of type 2 error. When developing an alerting sound pinger it is however, very important that the alerting sound only alert the porpoises and do not attracts them.

2.4.2. Sources of bias

No impression was gained by any observer that the fishing practice was being modified in any way to minimise bycatch. However, negative bias could arise from missed bycatches. It does happen that porpoises are shaken out of the nets or fall out spontaneously and especially at rough seas it can be very difficult for the observer to register these animals.

2.4.3. Echo-location activity

The main purpose of deploying PCL's on the nets was to identify, in case no porpoises were caught in gillnets, if there had been porpoises in the study area. The PCL results indicated that there had been porpoises in the study area during the whole experiment. Due to these positive results, a correlation between click rate and porpoise bycatch was expected, but it was not possible to find any relationships or trends within the data. Similar results have been found in other studies. Tregenza *et al*. (2001) tested if there was a significant relationship between click rate per day and porpoise catch on that day, using self-contained porpoise click loggers (T-PODs) on bottom set gillnets in the Celtic Sea, but found no relationships. Therefore, it may be that even though there is a high frequency of porpoises near gillnets, entanglement is a rare outcome for a porpoise encountering a net.

2.4.4. Dissections

Eight of the 32 porpoises were dissected. Since these porpoise were not randomly collected, the individuals are not a representative section of the total bycatch of porpoises. Examinations of larger samples of bycaught and stranded porpoises from the Danish waters indicate trends in larger proportions of males. The proportion rates are although not significant different (Lockyer *et al*., 2001; Lockyer & Kince, 2003). However, the proportion of males and females within the living population is not known and therefore one can not say if males have a higher tendency of entanglement because it could be a reflection of the population division.

Pathological findings of parasite infections in the ears have also been documented in several other studies (Lockyer & Kince, 2003; Prahl *et al*., 2006; Siebert *et al*., 2006a). The effect of the common findings of parasites infections within the ears on hearing is although still unknown (Prahl *et al*., 2006).

Parasite infections in other organs are very often seen (Siebert *et al*., 2001; Lockyer & Kince, 2003; Siebert *et al*., 2006a). The infestation rate increases with age and it is possible that large parasite infections may develop into fatal condition if the function of the organs are reduced (Lockyer & Kince, 2003). The results found in this study documented that the porpoises had parasite infections within many organs. The infestation rate had although not influenced the function of the organs and the porpoises were determined to be in healthy conditions.

2.4.5. PAS–sounds and hake

Unfortunately it was not possible to determine if there were differences in fish catches between PAS-pinger nets and control nets since gutted and non-gutted hakes not had been distinguished. However, it has been documented that fish are able to detect and respond to a wide range of sounds.

Fish use sounds in numerous behaviours including aggression, protection of territory, defence and reproduction (Zelick *et al*., 1999). It is therefore important to know if PAS-pingers will affect the fish catch rates.

Appendix 8.1.7 views the hearing thresholds for a variety of fish species, and it suggest that none of the mentioned species (Atlantic salmon (*Salmo salar*), plaice (*Pleuronectes platessa*), Atlantic cod (*Gadus morhua*), scaled sardine (*Harengula jaguana*), goby (*Gobius niger*) and bull shark (*Carcharhinus leucus*)) can detect sounds above 1100Hz (Fay, 1988; Hastings & Popper, 2005) which is below the frequencies used by the PAS-pinger (110kHz).

Studies on fish reactions to pingers have been conducted. Peddemors *et al*. (1999) recorded area use around inactive and active (Dukane NetMark^{TM} and Loughborough PICE 97074, 20-160kHz) pingers on 17 species of fish, representing 13 families. They found no significant response to the Dukane pinger, while the clupeid redeye roundherring (*Etrumeus whiteheadi*) and chub mackerel (*Scomber japonicus*) were significantly attracted to the PICE pinger. Hughes *et al*. (1999) and Culik *et al*., 2001 tested Pacific herrings (*Clupea pallasi*) response to pingers and found no significant effect of pinger in catch rates or in herring distribution. Experiments in the commercial fishery found no differences in catch rates from pinger and non pinger nets (Kraus *et al.*, 1997). Unfortunately none of the above mentioned studies include hake. However, since the PAS-pingers have a higher frequency than the above mentioned pingers it is very unlikely that hakes can hear the PAS-pingers making the chances of behavioural responses even smaller and less catch rates even smaller.

2.4.6. Habituation

Habituation is one of the main concerns when using the traditional pingers (Gearin *et al.*, 2000; Cox *et al*., 2001). Habituation is defined as the relative permanent waning of a response as a result of repeated stimulation which is not followed by any kind of reinforcement (Thorpe, 1996). In relation to bycatch, pingers represent a case of repeated presentations of a stimulus where no reinforcement is imposed on the porpoises to avoid entanglement. One can say they are rewarded for swimming away from the device by a reduction in received sound pressure level of the pinger sounds. A failure response is, however, not connected with a learning experience since porpoises most likely will be entangled and drown. Porpoises that have been repeatedly exposed to the same pinger sounds would therefore be expected to show a decrease in avoidance response. However, habituation will in this case only be a problem if the distance between porpoise and net becomes too small to avoid entanglement.

Cox *et al*. (2001) did a field experiment testing if porpoises will habituate to pingers. Their results indicated that porpoises habituated to the Dukane Netmark^{TM} pinger and others have seen trends towards habituation in studies of free-ranging and captive porpoises (Jørgensen, 2006; Teilmann *et al*., 2006). However, until now pinger studies from the commercial fishery have not demonstrated habituation to a level where the pingers have no effect on bycatch.

In order to slow down the habituation effect, some companies have introduced different kinds of semi-randomized signal intervals and frequency characteristics of the deterring sound (e.g. AQUAmark100, Aquatec Ltd, Hampshire, UK). The semi-randomized signal intervals were also implemented within the PAS pinger. The PAS-pinger also had one additional advantage. Since the PAS-sounds do not deter the porpoises away from the nets, the porpoises will have a chance of learning that the PAS-sound is correlated with a barrier in the area. Due to the continuous sound emission habituation can however, constitute a risk subsequently leading to a reduced effect of the pinger.

2.4.7. Further research

The results within in Part I determined that the PAS-pinger could not reduce by-catch of harbour porpoise. However why the pinger had no effect is not known. It was therefore decided, as mentioned in section1.7 to carry out two new experiments, Part III and Part IV, to shed lights on why the PAS-pingers did not work as expected.

3. Part III, Sonar activity in Jammerland Bay

- *Testing if the PAS-pinger can stimulate harbour porpoise to a higher click rate*

3.1. Introduction

The idea behind an alerting pinger is to make the harbour porpoise aware of the net and thereby avoid entanglement. However, the results collected within Part II documented that PAS-pingers could not reduce bycatch of harbour porpoise. The reason for the insignificant results was although not found but a possible hypothesis was that the sounds emitted by the PAS-pingers did not stimulate the porpoises to a higher click rate. It was therefore determined to carry out a field experiment testing if PAS-pingers could stimulate free living porpoises to a higher click rate.

3.2. Material and methods

3.2.1. Study area

The experiment was conducted from March to June 2007 in Jammerland Bay, in the Great Belt, Denmark. Two positions were selected station South (55° 38'548 N - 11°01'378 E, water depth 7m) and station North (55°38'555 N -11°01'177 E, water depth 10m) (appendix 8.2.1). The area was chosen due to its high densities of harbour porpoise (Teilmann, 2003; Jørgensen, 2006), limited fishing activity and low water depths.

3.2.2. Acoustic equipment, PAS-pinger, PCL and T-PODs

The PAS-pinger and the PCLs were the same as used in Part I. The PCL's were all calibrated before use to determine their sensitivity. The calibrations were carried out in cooperation with University of Lund, department for Electrical Measurements, Sweden. The PCL hydrophones were mounted vertically on a pole in an 80L aquarium at the same depth as the transmitting transducer. The distance between the two transducers was measured to 100μs, equal to approximately 15cm. The walls of the aquarium were sound dampened by custom made rubber sheets to reduce reverberations (fig.6a). The transmitting transducer was a ½"HS/150 (Sonar Research and Development Ltd, Yorkshire, UK) for frequencies >100 kHz and a 1"HS/70 for frequencies <100 kHz. A HP3314A tone generator (Hewlett- Packard Ltd., Ontario, Canada) was used to feed 1-10 cycles of a sinus waveform, gated with a square window, to the transducer. Both transducers were shielded with Styrofoam plastic to reduce reverberations. The transducer output was measured using a Reson TC4013 (Reson A/S, Slangerup, Denmark) calibrated hydrophone, connected via an EtecA1001 preamplifier (etec, Frederiksværk, Deanmark) to a Textronix TDS 360 Digital Real-Time Oscilloscope (Tektronix Inc., Oregon, United States). The PCL hydrophones were also connected via the EtecA1001 preamplifier to the Textronix TDS 360 Digital Real-Time Oscilloscope (fig.6b). The angels (0°, 90°, 180°, 270°) for the directionality measurements were referenced to the Subconn®pins (plug connecting the hydrophone to the PCL, appendix 8.2.2).

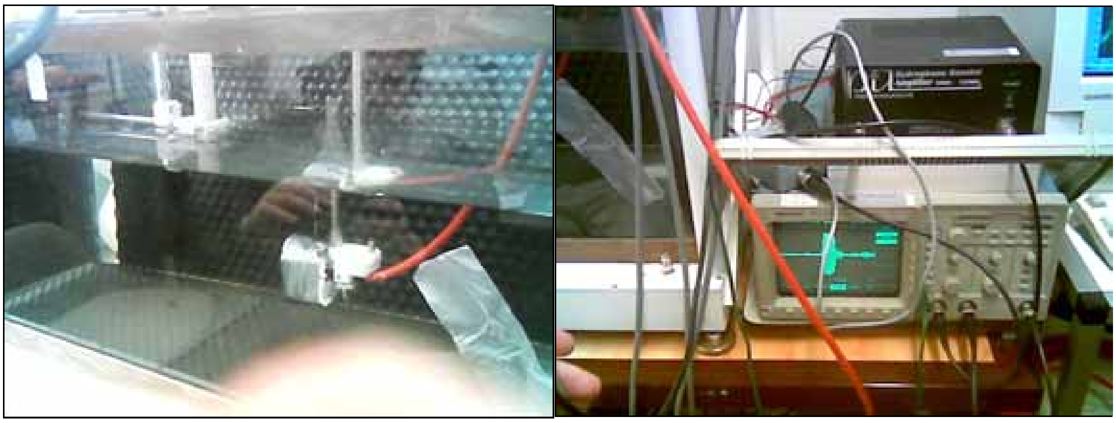

Figure 6: Calibrations setup of the PCL-hydrophones. Left side (a): aquarium containing hydrophone and transmission transducer and the right side (b): equipment used.

T-POD’s, Timing POrpoise Detectors (Chelonia Ltd., Long Rock, United Kingdom) are self-contained data loggers for cetacean echolocation clicks. The T-POD’s consists of a hydrophone, filter and a digital memory. They register the presence and the length of high frequency click sounds matching a harbour porpoise and can stay at sea for long periods due to their great battery capacity. The T-POD software comprises a train detection algorithm that detects and then classifies trains of registered clicks according to how likely they are to be a cetacean train (Treganza, 2007). Both T-PODs were calibrated before use by the Department of Arctic Environment, National Environmental Research Institute, DK. T-PODS were used to make a collation between PCL and T-POD data possible.

3.2.3. Setup

The stations were placed in the southern and northern part of Jammerland Bay to avoid acoustic influence on each other. They functioned in weekly turns as control and alerting station according to a time schedule (appendix 8.2.3). On each station a unit containing two anchors, two buoys and 3 cables was placed. One cable was stretch between the anchors and the others were connected the buoys to the anchors. The alerting station contained a PAS-pinger (1,5m from the bottom) and above a PCL and a T-POD (2m from the bottom) (fig.7a). The recorders were separated from the pinger by a disc, lined with closed neoprene, to avoid recordings of the PAS pinger on the sound files (fig.7b). The control station contained a PCL and T-POD (2m from the bottom). The PCLs were changed every week due to their short battery life, while the T-PODs stayed on the same position during the whole experiment. All PCL- hardware algorithm settings were the same as used within Part II.

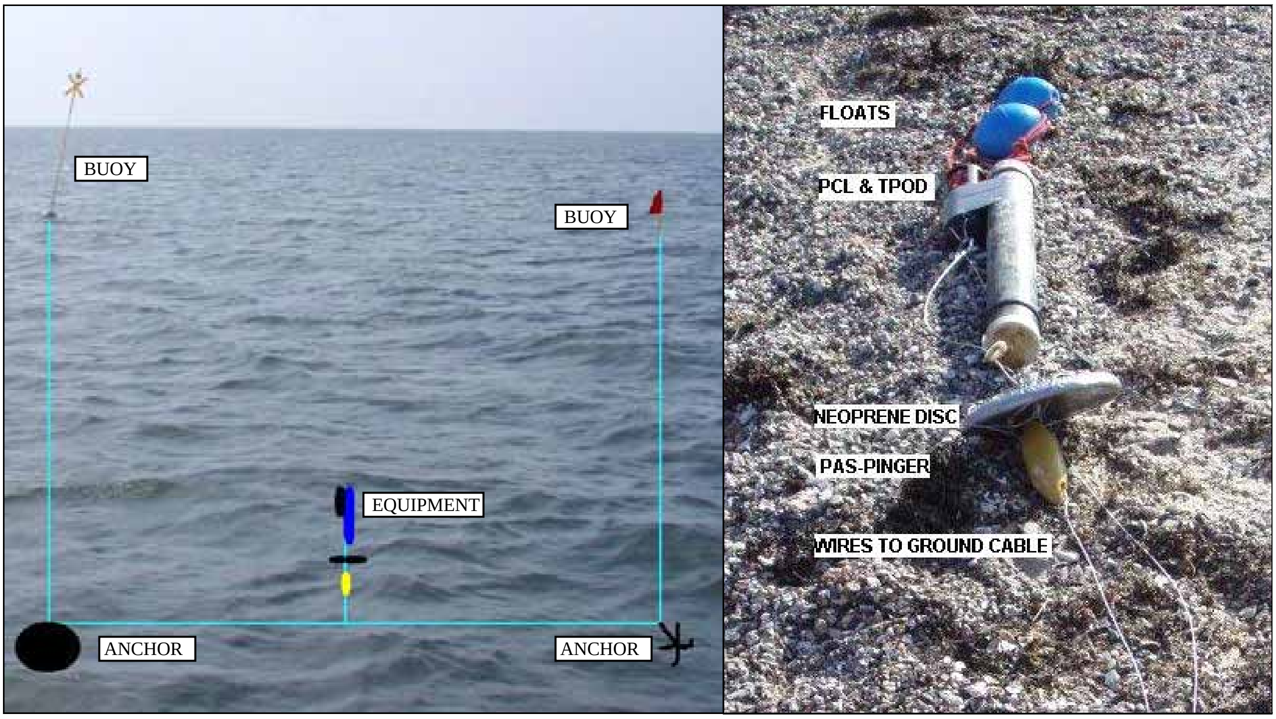

Figure 7: Setup used in Jammerlands Bay. The left side (a): Placing of equipment on the alerting station. Right side (b): equipment setup on the alerting station. On the control station the gear was placed the exact same way however with out the PAS- pinger and neoprene disc

3.2.4. Data analysis

In order to correlate recordings from station North and South, two assumptions were made:

- Densities of harbour porpoise were equal on both stations
- Porpoises have equal click rates on both stations

If these two assumptions are correct the data collected on the two stations can be correlated.

The PCL files were analysed in AQUAclick View, vers.1.6b. The data were sorted by day, and the number of CIT was determined by use of the same detections settings as used in Part II (section 2.2.6).

To test if there was an effect of the PAS-pinger the control periods were tested against the alerting periods by linear regression. To meet the demands for linear regression the data was log transformed to approximate a normal distribution. The statistical test was done by use of ANOVA within the R statistical package (vers. 2.4.1., Technical University, Vienna, Austria).

3.3. Results

3.3.1. PCL-calibrations

The calibrations of the PCLs determined that the 4 hydrophones differed a lot in sensitivity. The results are given in appendix 8.2.4 & 8.2.5. When hydrophones differ in sensitivity their recordings can not be compared directly since they will record data from a differently sized area. Their relative recording areas were therefore determined and applied as a correction factor in the obtained PCL results. Calculations of relative recording areas are given in appendix 8.2.6.

3.3.2. Data collections

Seventy-nine days of data were collected in the Jammerland Bay, although only 63 days of recordings were used from the PCL's due to errors on the remaining sounds files. All T-POD data was excluded because of downloading problems. The timestamp on the T-POD file was not recorded, thereby making a correlation between PCL and T-POD data impossible within the time span of this project.

3.3.3. Control data

The PCL results from control periods from station South and North are plotted in fig.8 below. Each dot represents the number of CIT/RA on station South and station North.

Station South (fig.8)
The control data from station South are represented in period 3, 6, 8 and 9. During period 3 and 6 the number of CIT increases and then decreases. The mean number of CIT/RA within these 2 periods was 3.7 CIT/RA per day. At the end of period 6 the number of CIT/RA decreases and stabilises at a level around 0.6 CIT/RA per day throughout period 8 and 9. The total mean of the four control periods was 2.5 CIT/RA per day.

Station North (fig.8)
Period 4, 5 and 7 represents the data on station North. The number of CIT/RA increased through the periods 4, 5 and 7. In period 4 and 5 the mean was 5.4CIT/RA per day. During period 7 the mean increased to 13.8 CIT/RA per day. The mean for all three periods were 8.2 CIT/RA per day.

When comparing the number of CIT/RA recorded on station South and North a significant difference was found ($P<0.001$). This result indicates that the assumption of equal densities of porpoises on both stations; or that porpoise's use the same click rate on both stations are not correct. Therefore a comparison between station North and station South which was intended is not possible and the results from each station are thus handled separately below.

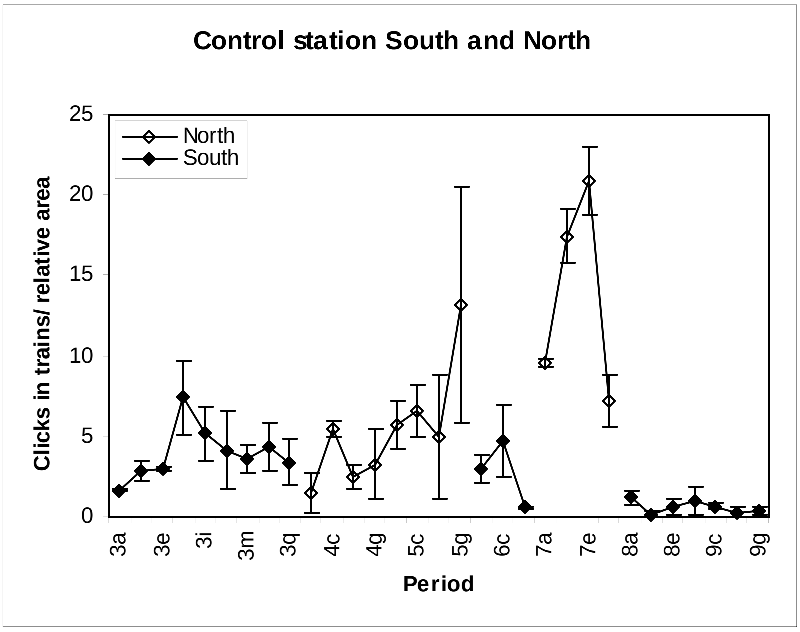

Figure 8: The number of CIT/ RA recorded in the control period on station North and station South. Each square represent the mean of two days recording, where the bars indicate the standard error.

3.3.4. Effect of alerting

Station South

Figure 9 below depicts the results from station South. Each dot represents the mean number of CIT/RA per day per period. The control periods (3, 6, 8 and 9) was ≤ 4 CIT/RA per day (mean = 2.5 CIT/RA per day), while alerting periods (2, 5 and 7) was ≥6 CIT per day except period 4 (3.2 CIT/RA per day). During the experiment the number of CIT/ RA per day recorded in alerting periods increased where the number of CIT/ RA per day recorded in the control periods decreased. When testing the number of CIT/ RA per day in control periods with the number of CIT/ RA per day in alerting periods a significant effect of the alerting was found (P<0.001).

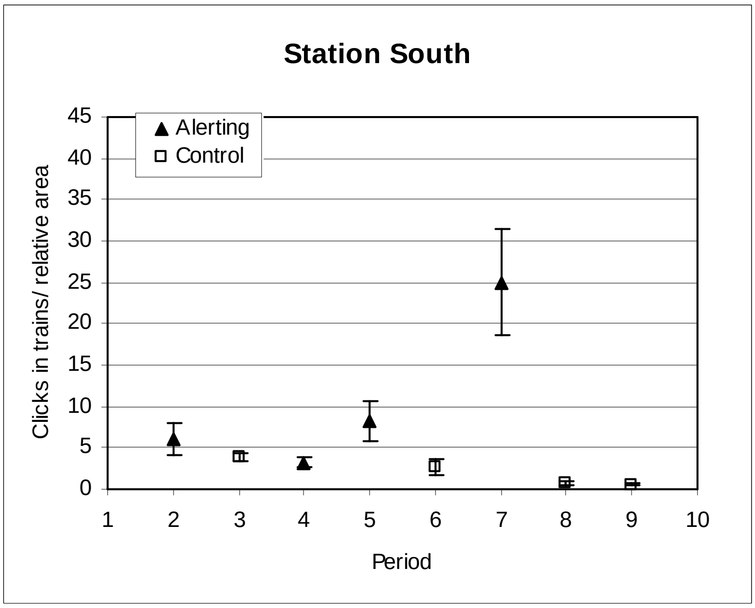

Figure 9: The number of clicks in trains recorded in the control and alerting period for station South. Each dot represents the mean of each period where the standard error is indicated by error bars.

Station North

Figure 10 below illustrates the results from station North. In the control periods the mean number of CIT/RA was 8.2 per day where the mean number of CIT/RA was 14.3 per day in the alerting periods. During the experiment the number of CIT/ RA per day increased both alerting and control periods. When testing the number of CIT/ RA per day in control periods with the number of CIT/ RA per day in alerting period no significant effect of the alerting was found(P=0.180).

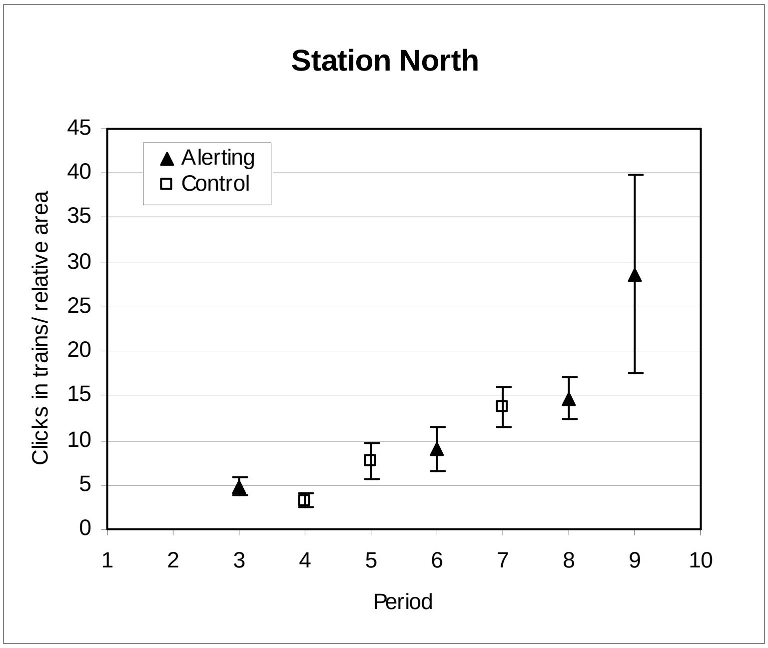

Figure 10: The number of clicks in trains recorded per day from station South (left) and station North (right). The black dots represent the alerting periods and blue dots stand for the control periods.

3.4. Discussion

3.4.1. Sonar activity

Control periods

Within the control periods the number of CIT/RA increased on station North and decreased on station South. The reasons for these changes are not known but a possible reason is that the presence of porpoises, in the PCL recoding area, has changed during the experiment. Jørgensen (2006) recorded harbour porpoise clicks on the same positions from April-August 2005 by use of T-PODs. He however, did not find any changes in the number of clicks when comparing the two positions. But seasonal differences in days with positive detection of harbour porpoise in the German Baltic Sea and the inner Danish waters have been documented (Svegaard, 2006; Verfuß *et al*., 2007). The changes in sonar activity were although found when monitoring clicks or satellite tracks over much longer periods compared to this study.

Effect of alerting

The purpose of the this study was to test if alerting sounds generated by a PAS-pinger could stimulate free living harbour porpoises to a higher click rate. On station South a significant increase in CIT/RA was found within absence of the PAS-pinger. This correlated with the expectation that PAS-pingers stimulated porpoises to a higher click rate. However, on Station North no significant effect of the PAS-pinger was found. Possible reasons for the insignificant results found on station North could be due to the following reasons:

- Something in the area of station North stimulated a natural high click rate; or
- A high level of ambient noise on station North; or
- The PAS-pinger had no effect on the porpoises click rate and the results merely reflects an increase in presence of porpoise within the PAS-pingers recording area

According to the first point, it is possible that porpoises have a natural high click rate within the PCL detection area of station North. Natural high click rates can be caused by high prey densities, objects on the seafloor or social behaviour (Richardson *et al*., 1995). This means that if the porpoise have a natural high click rate, within the PCL's detection area, it is possible that the natural high click rate shaded the effect of alerting. Consequently it is not possible to document an effect of the PAS-pinger when comparing alerting periods with controls. However, as mentioned above Jørgensen (2006) did not find any differences in the number of clicks when comparing the two same positions, indicating no natural high click rate on station North.

Concerning the second point, detection of a signal is limited by high levels of ambient noise. This means that the PAS-signals can be masked if ambient noise within the same frequency bands is high. The ambient noise levels on the two stations were not recorded, but according to literature the ambient noise level at 110kHz is below the hearing threshold of porpoises (Richardson *et al*., 1995). But if a high ambient noise level, at the frequency band of 110 kHz, was to be found on station North this could be the reason for the non-significant results obtain on station North.

Regarding point 3 it might be that the PAS-pinger had no effect on sonar activity. This does however not correspond with the significant effect of alerting found on station South. The results found on station North although indicate that the PAS-pinger do not work within all conditions, which is not desirable. Therefore even though significant results are found on station South the effect of alerting is very limited because of the insignificant results found on station North. Consequently one can not be sure that the alerting sounds used within this PAS-pinger can stimulate a higher click rate.

There are other factors which can affect the number of CIT/RA. Since it is not possible to distinguish between individuals on the sound files (Amundin *pers. comm.*, 2007) group size will affect the number of vocalisations and thus interpretations of e.g. number of clicks in trains. Therefore it is central to know how the group size of harbour porpoises varies. From 1982 to 2002 incidental sightings of group size was collected in the Baltic and the North Sea. In the Baltic 85% of the sightings were noted from May-September, while 53% were noted during the same months in the North Sea. In the North Sea 78.9% of the sightings had a group size <2 individuals, while 66.3% of the sightings had a group size <2 individuals in the Baltic (Siebert *et al*., 2006b). A way to be more secure of group size influence on experiments like the one conducted in Jammerland Bay is by visually observing the recording area.

3.4.2. Other experiments

Other experiments with alerting sounds have been carried out. Petersen (2007) tested if alerting sounds could stimulate porpoises to trig an interactive deterring sound pinger (90kHz). He did within 22 days of alerting and 31 days of control not find any differences in the use of sonar activity, suggesting no effect of the alerting sound. Pleskunas and Tregenza (2005) tested if click trains (4-click train, 130 kHz, lasting 0.4 sec, produced every 4 sec, 130 dB re 1 µPa) could increase the number of clicks detected. They found that the number of porpoise detections next to the device increased from 2.5 times to 18 times in several different locations. Due to these results they suggest that alerting alone might be enough to reduce bycatch, but trials are needed in the fishery.

3.4.3. Sources of bias

The calibrations of the PCL hydrophones showed high difference in sensitivity. Since the PCLs recording area is correlated with its hydrophone sensitivity, calculations of the PCLs relative recording area were completed thereby making it possible to compare the PCL-recordings. The relative recording areas were calculated corresponding to the hydrophone sensitivity at 130kHz, since porpoise clicks mainly is centred around this frequency. However the calibrations (appendix 8.2.5) depicted that the hydrophones differed in sensitivity according to the other measured frequencies (110, 120, 140kHz). Therefore the relative recording areas will be different in size according to porpoise signals at other frequencies and this will bias the RA.

The experiment investigated the potential stimulation of harbour porpoise click rates with PAS-pingers, by testing a control station against an alerting station. But due to significantly different recordings of CIT/RA within the control periods on the two stations, a comparison between the two stations was not conducted. Not being able to compare control recordings and alerting recordings from the same time span can bias the results. Since presence of harbour porpoises in the recording area might fluctuate. A setup correlating recordings from the same time period, as designed, would therefore have been preferred. Another type of setup making it possible to compare alerting periods with control periods from the same position and within the same time span will be suggested in future design below.

Any object introduced into the path of porpoises could alter their behaviour, such as approach distance and interest. But since the equipment was almost the same in alerting and control periods it was presumed that the reactions to the equipment were the same. Poulsen, (2004) tested the effect of an acoustic platform in the natural environment of porpoises and found no effect in the distribution of porpoises. It is, however, seen that porpoises can investigate PCLs carefully by echolocating towards the PCL at short distances (Amundin *pers. comm.*, 2007) and this can bias the results.

T-PODs have long durability and therefore the same hydrophone could stay on the same station for the whole period thereby avoiding bias in the recordings due to sensitivity differences. The time stamp was however destroyed when downloading the files, thereby making it difficult to determine the periods of alerting and control which is essential when analysing for effect of alerting sounds.

3.4.4. Future design

The results found within this study did only determine an effect of the PAS-pinger at one station. But if the study is to be repeated another method to conduct this type of data is recommended to avoid bias.

In future design it would be favourable to have:

- Recordings obtained with the same hydrophone during the experiment. This will eliminate the bias from differences in hydrophone sensitivity.
- Shorter intervals between alerting and control periods. This will reduce the effect of porpoise density differences. Since the density effect is related to time.
- More than two recordings stations. This will eliminate differences in CIT due to unknown area specifications.

A pinger repeatedly playing alerting sounds for a short period with alternate equal period silent as control assembled with a PCL with long durability could serve as unit for this type of setup. It is although very important to have an exact time recorder within the PCL to be able to distinguish alerting periods from control periods.

3.4.5. Part III in relation to Part II

Part III was conducted in order to assist the interpretation of the results collected within Part II, Bycatch in the North Sea. The results from the North Sea showed no significant effect of the PAS-pinger. The possible reasons for the insignificant result in Part II have been discussed within section 2.4.1 but whether the PAS-pinger in fact stimulated the porpoises to a higher click rate needed to be investigated to interpret the results correctly. The results collected in Part III unfortunately depicted an equivocal effect of the PAS-pinger since the PAS-pinger only stimulated the porpoises to a significant higher click rate on station South. One can therefore not determine if the PAS-pingers had stimulated porpoises to a higher click rate within Part II. But what can results collected in Part III then contribute to?

- Fist of all the results from Part III documented that the effect of the PAS-pinger was very uncertain. In relation to Part II it is therefore very optimistic to expect that the PAS-pinger could reduce bycatch. The insignificant results collected within Part II can therefore be a consequence of the unclear effect of the PAS-pinger.
- Second, further knowledge is obtained on signal types which not can be used as an alerting sound. The experiment has pointed out how essential the signal is and the importance of testing the alerting sounds in the porpoise's natural environment, both to make sure that the porpoises is stimulated to a higher click rate and to make sure that the porpoises are not attracted towards the net.

4. Part IV, Recordings of the PAS- and AQUAmark100 pinger in Øresund

- Testing differences in received source levels according to different depths of the hydrophone and distances to the setup; and
- Testing if there is difference in received source level between positioning pingers on the bottom or in the water column.

4.1. Introduction

Pingers are becoming widely used to reduce incidental bycatch of harbour porpoise since they have been documented to reduce bycatch significantly (Kraus *et al*., 1997; Larsen, 1999; Trippel *et al*., 1999; Larsen, 2002; Larsen & Krog, 2006). The optimal pinger spacing do although depend on several different factors, e.g. source level of the pinger, frequency, background noise, propagation losses, directivity of the pinger and the directional hearing harbour porpoise. Pinger sounds propagation loss in water can be theoretically calculated (Urik, 1983) however, little experimental data exit.
The results from Part II documented an insignificant effect of the PAS-pinger. A possible reason for this could be due to the PAS-pingers audibility. The aim of this study was therefore to determine the RSL, from both a PAS-pinger and a deterring sound pinger both, according to different depths of the hydrophone and distances to the pingers; and determine if there is a difference in RSL when placing the pinger on the bottom compared to placing it in the water column.

4.2. Material and methods

4.2.1. Study area

The experiment was carried out in Øresund north of Copenhagen (55° 49'6 N - 12° 37'8 E) onboard the research vessel Havkatten (6.1BT) on May 31st and October 10th 2007. The bottom type was soft sand and no pycnocline was recorded.

4.2.2. Pingers

The PAS-pinger was the same as described in Part II. The deterring sound pinger was a AQUAmark100 pinger manufactured by AQUATEC (Aquatec, 2007). It emitted 8 different signals in random order; two with constant frequency and six with frequency sweep signals. The signals varied both in source level and frequency (20kHz to 160kHz) but were centred around 60kHz and 145dB re 1µPa @ 1m (RMS). Duration of the signals was 200-300ms. Two types of AQUAmark100 signals are depicted with appendix 8.3.1.

4.2.3. Setup

The recordings of the PAS-pinger and AQUAmark100 were made by using a Reson TC 4032 hydrophone (Reson A/S, Slangerup, Denmark) with a sensitivity of -170dB re 1V/1µPa (at 250Hz) in a frequency range from 5Hz to 120kHz. A pistonphone(4223) calibration of the hydrophone was performed before recording. The hydrophone was connected to an etec A1101 amplifier (etec, Frederiksværk, Denmark) and a PC (laptop) containing a sound card (NI PCMCIA DAQ Card-AI-16E-4, National Instruments, Hørsholm, Denmark) installed with BatSound Pro recording software (ver. 3.31, Pettersson Elektronik AB, Uppsala, Sweden). The sampling frequency for the channel was 454ksample/sec and the amplifier settings were 40 dB gain and 1kHz highpass.

Figure 11 depicts the experimental setup. The two pingers were deployed horizontal on a line with 4 floats (A). The position of line A in the water column was recorded by a diving watch placed between the 2 pingers. The pinger line (A) was attached to two vertical ropes (B_1, B_2). Both vertical ropes (B_1, B_2) had an anchor and a buoy attached to each end. To tighten the setup and making it possible to place it perpendicular to the current one extra line with buoy (C) was attached the anchor of line B_1. The pinger lines (A) were placed, one at the time, in two different positions during the recordings: At the bottom (A_2) and 3m above (A_1). For each position of line A the ship was placed at different distances (5, 15, 50 and 100m) on a square angle to the setup. The recordings were conducted from the front side of the ship and at each distance the pingers were recorded from 3 different hydrophone depths (bottom, mid water, and 1m from surface). Three recordings (30 sec) were made on each position of the hydrophone. During each recording the engine and all ship electronic devices were switched off, and the distance to the array were continuously measured with a laser range finder (Yardage Pro^{TM} 500, Bushnell, Kansas, USA).

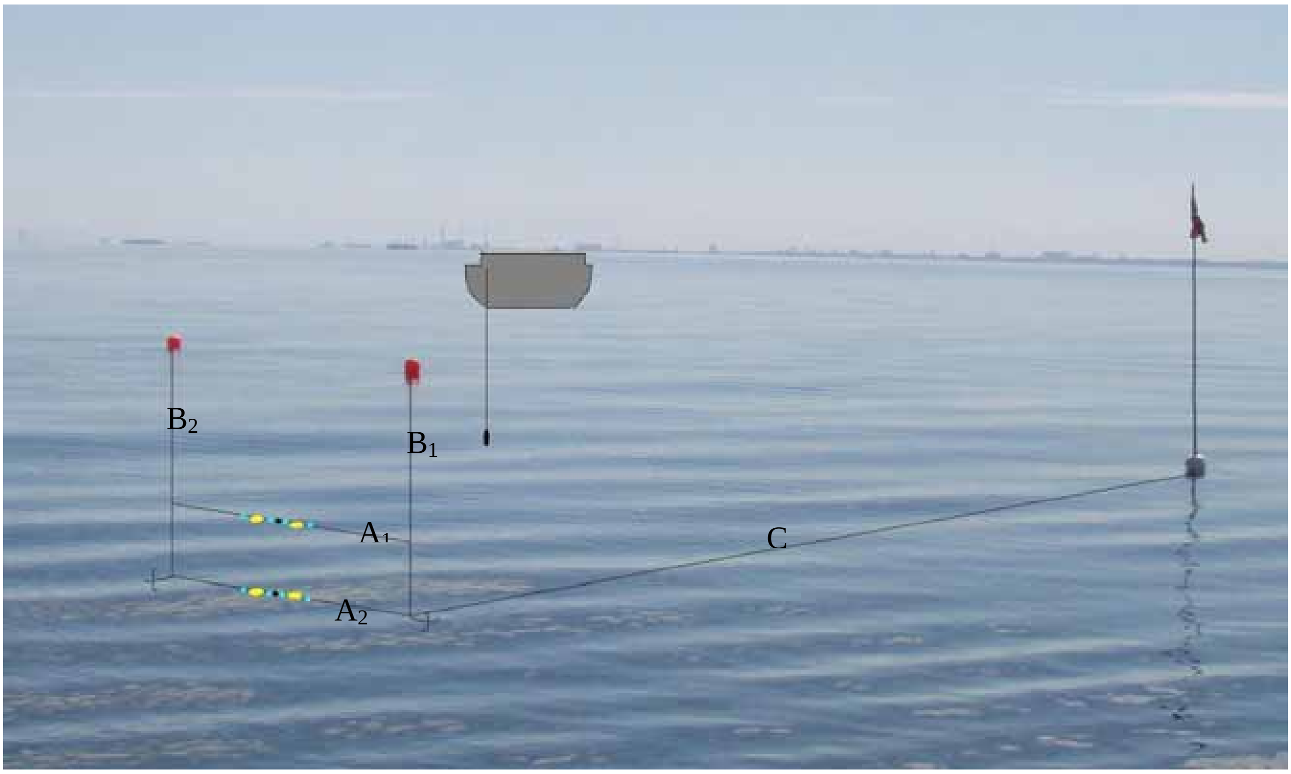

Figure 11: Field setup of pinger recordings in Øresund. In the figure both occurring heights of pinger line (A) is indicated, however only one height was recorded at a time.

4.2.4. Calculations of received source level

To calculate the RSL from the pingers, a calibration signal from the piston calibration of the hydrophone was used as reference value and RSL was calculated as;

$$\text{RSL} = \text{Piston SL} + 20 \log_{10} (P/P_0),$$ (Richardson *et al.*, 1995)

Where SL is the Source Level measured at 1m distance to the sound source, P is the RMS (Root-Mean-Square) value of the pinger signal and P_0 is the calibrated RMS value. The values were found by use of SigPro (ver.3.21, 3-04). All signals from the AQUAmark pinger were filtered from 10kHz

to 200kHz and all signals from the PAS-pinger were filtered from 30kHz to 200kHz. P and P_0 are given in RMS for all signals.
The receiving sensitivity of the TC4032 hydrophone drops around 70kHz (fig. 12). This can be roughly corrected by adding 6dB to the PAS-pingers final RSL calculations since most energi of this unit is centred on 110kHz.

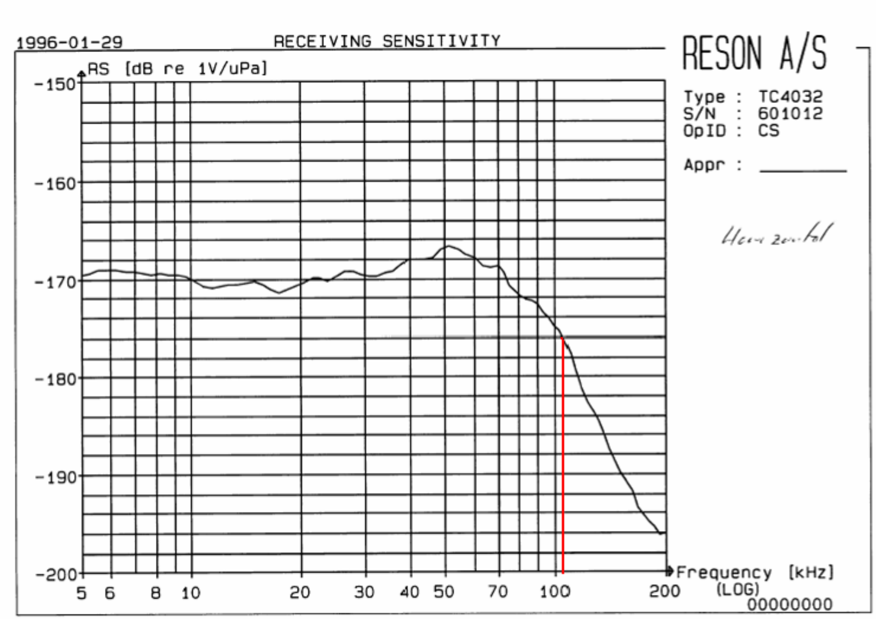

Figure 12: Receiving sensitivity of a TC4032 hydrophone in the 5-200 kHz frequency band (Reson, 2007).

4.2.5. Transmission loss in theory

When a sounds source, e.g. a pinger, is positioned in the Sea, the Sea and boundaries (surface and bottom) form a complex medium for the propagation of sound and the transmission loss can be considered as the sum of all los due to spreading and attenuation. Spreading loss represents the weakening of a signal as it spreads outward from the source and attenuation represents the effects of absorption, scattering and leakage out of sound channels (Urik, 1983).

Spherical spreading
In theory, transmission loss can be explained by the spherical law of spreading. When placing a sound source in a medium with homogenous sound velocity and no reflecting boundaries, the signal is radiated equally in all directions. This means that the intensity of the sound is weakened over an ever increasing spherical surface area of a radius equal to the range to the sound source which corresponds to a decrease of 20 log r. With spherical spreading the sound level diminish by 6dB when doubling the distance to the sound source (Urik, 1983; Richardson *et al*. 1995; Wahlberg, 2007).

Transmission loss in shallow waters
However, when a sound is transmitted through shallow water the medium is no longer homogeneous since reflections from surface and bottom will interfere with the direct path. This type of transmission loss can be explained by cylindrical spreading. The sound intensity will decrease over an area determined by an ever expanding cylinder of radius r, which corresponds to a decrease of 10 log r. With cylindrical spreading the sound levels diminish by 3dB loss per doubling distance (Urick, 1983; Richardson *et al*. 1995; Wahlberg, 2007).

Because of this these theories a 10log and a 20log line was overlaid all result figures to give an indication if the pingers' sound spreading follows a spherical homogenous spreading or a cylindrical spreading in the study area.

4.3. Results

4.3.1. Field recordings

The 31st of May, 18m water depth

All recordings from 31st of May have been excluded. Due to strong current it was not possible to control the positions of the pingers, ship and hydrophone in relation to each other. Therefore none of the recordings on 18m water depth have been used to determine the RSL.

The 10th October, 7m water depth

The recordings were conducted at 7m water depth and more control of the positioning of the equipment was obtained. However new problems occurred. It was not possible to position the hydrophone at the designed distances due to current (correct measured distances are shown in table 3) and the laptop could not always record without external power. Since external power produces intense background noise, hereby masking the signals, recordings obtained with external power can not be used for calculations. The recordings obtained are listed in table 3 below and the ones made with external power are marked by (x) and can not be used in calculations.

Table 3: Recordings made in Øresund, October 10th (H= hydrophone).

Station	Pinger position	Distance to pinger	Gain (dB)	H-bottom	H-middle	H-surface	PAS audible by click detector	AQUA audible by click detector	Comments
0	1m	1m	20&40			X	X	X	
1	Bottom	24m	50	X	X	(x)	X	X	
2	Bottom	15m	50	X	X	(x)	X	X	only AQUA recorded middle
3	Bottom	49m	50	(x)	(x)	(x)	X	X	
4	Bottom	100m	40&50	(x)	X	X		X	
5	Bottom	30m	50				X	X	
6	3 meter	45m	40&50	X	X	X	X	X	
7	3 meter		40		X				Position fail
8	3 meter	19m	40&50	X	X	X	X	X	

4.3.2. Recordings of the PAS-pinger

Pinger placed on the bottom

The recordings of RSL, when the PAS-pinger was placed on the bottom, are illustrated in fig.13. Usable recordings were obtained at 15, 24, 30, 49 and 100m distance and the signals were identified at 15 and 24m.

- At 15m distance the average RSL was 121 dB when placing the hydrophone on the bottom. No other recordings at 15m distance (hydrophone middle, surface) were usable due to power interference.
- At 24m the average RSL was 112dB (hydrophone bottom) and 106dB (hydrophone middle). No useful results were obtained when placing the hydrophone near the surface due to power interference.
- At 30 and 49m the signals were audible through the click detector, but not detectable on the sound files due to power interference.
- At 100m distance no signals were audible or detectable on sound files.

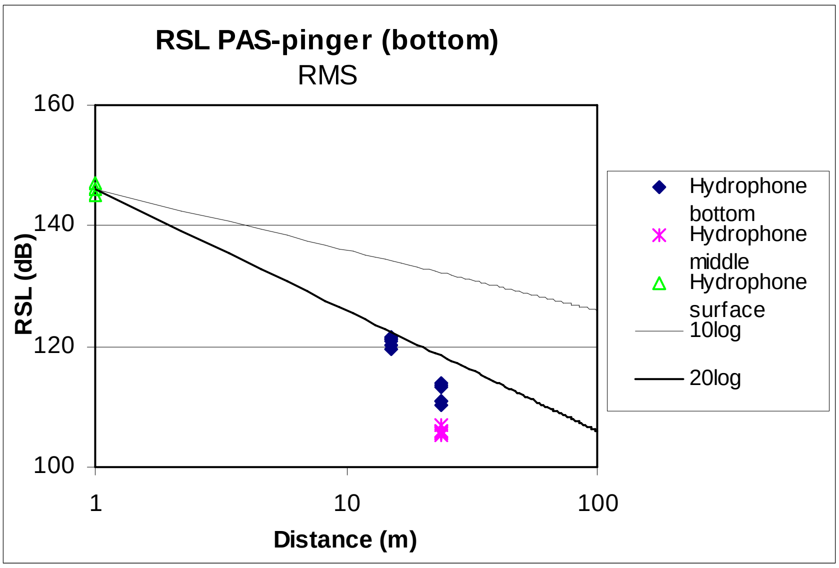

Figure 13: RSL recordings of the PAS-pinger placed at the bottom. It was possible to detect the pinger at 15 and 24m distance to the setup.

Pinger placed in the water column

Figure 14 illustrates the results when placing the PAS-pinger in the water column, 3m from the bottom. The pinger was recorded at 19 and 45m distance.

- At 19m the average RSL was 115dB (hydrophone bottom), 112dB (hydrophone middle) and 118dB (hydrophone surface).
- At 45m distance the signals were not detectable in the sound files, but were audible through the click detector placing the hydrophone in all depths.

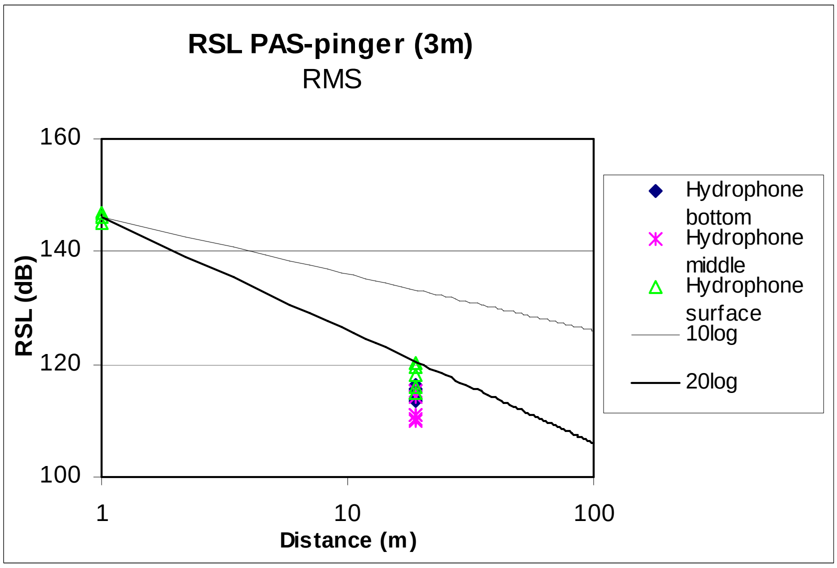

Figure 14: RSL recordings of the PAS-pinger placed 3m from the bottom. It was possible to detect the pinger when the hydrophone was placed at the bottom at 19m from the setup.

4.3.3. AQUAmark100-pinger

Pinger placed on the bottom

Figure 15 depicts the RSL results when the AQUAmark100 pinger was placed on the bottom. The pinger was recorded at 15, 24, 30, 49 and 100m distance.

- At 15 and 24m the average RSL recorded was 125.5 dB and 113.3dB (hydrophone bottom) and 129 dB and 122dB (hydrophone middle), respectively.
- At 30 and 49m the signals were audible through the click detector, but not detectable on the sound files due to power interference.
- At 100m the average RSL dropped to 112.5 (hydrophone middle) and 113.5dB (hydrophone surface).

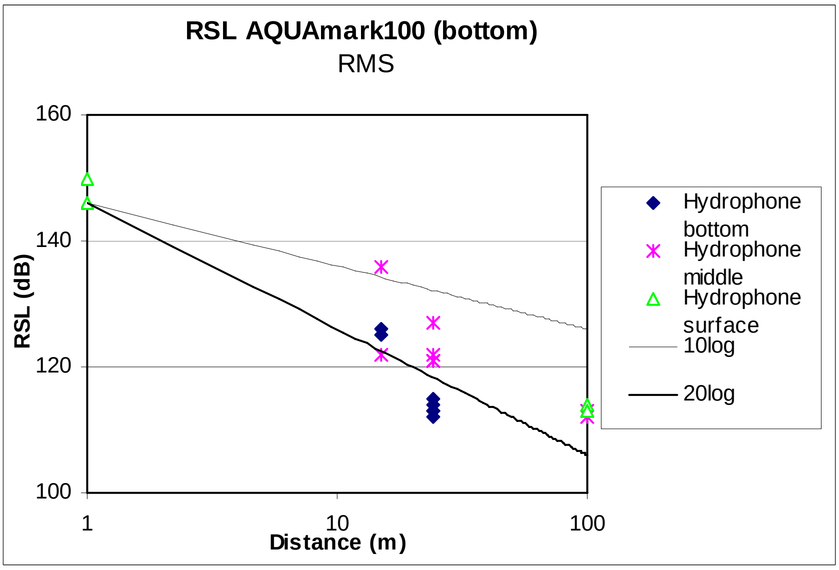

Figure 15: RSL recordings of the AQUAmark100-pinger at 15, 24 and 100m distance when the pinger was placed on the bottom.

Pinger placed in the water column

Figure 16 depicts the results when placing the AQUAmark100 pinger in the water column, 3m from the bottom. The pinger was recorded at 19 and 45m distance.

- At 19m distance the average RSL was 129.6, 117.6 and 114.3dB respective to the hydrophone positions at bottom, middle and surface.
- At 45m distance the average RSL was 107.6, 106.75 and 113.4dB respective to the hydrophone positions at bottom, middle and surface.

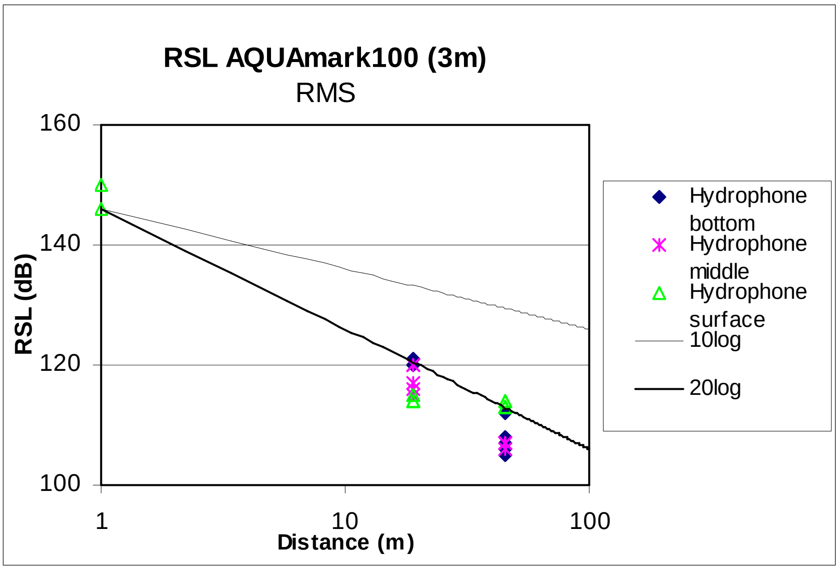

Figure 16: Shows the RSL recordings of the AQUAmark100-pinger placed at the bottom, when the hydrophone was placed 19 and 45m from the pinger.

All figures illustrates that the points more or less follow the 20log r line, which corresponds to spherical spreading, indicating no major reflections from the bottom or surface. However, there is a great RSL variability from the same recordings which will be further commented in the discussion.

4.4. Discussion

4.4.1. Received source level recordings

The purpose of this study was to investigate how RSL differs when recording a PAS-pinger and an AQUAmark100-pinger placing the hydrophone is placed at different depths and distances to the pingers; and further test if there is an effect of the pingers position in the water column. To document this purpose the recording results however, indicate the need for a repetition of the experiment since many recordings are missing due to the use of external power. The obtained results although indicate trends which are discussed below.

4.4.2. PAS-pinger

Effect of hydrophone position

The results from the PAS-pinger recordings showed variability in RSL when placing the hydrophone at different depths. The lowest RSLs were recorded when placing the hydrophone in the middle of the water column. When placing the hydrophone on the bottom, the RSL was respectively 6dB (pinger on bottom) and 3dB (pinger in the water column) higher compared to when the hydrophone was in the middle.

Recordings, with the hydrophone placed near the surface, suitable for RSL calculations were only obtained once for the PAS-pinger. The recording showed a 6dB higher RSL when comparing to the hydrophone placed in the middle of the water column. It is however, difficult to make any certain statements based on these results, due to the many missing recordings.

The variation seen within the calculated RSL of the PAS-pinger correlates with the theory of transmission loss in shallow waters (Urick, 1983). This suggests that the lowest RSL should be found when placing the hydrophone in the middle of the water column due to effects of spherical spreading; the highest RSL should be found near the bottom or the surface due to effects of cylindrical spreading. The results do, however, not follow a precise 10log or 20log transmission loss although a tendency is seen.

Effect of pinger position

When comparing the PAS-pingers’ RSL as an effect of pinger position in the water column, the RSL recordings are less variable when the pinger is placed in the water column. This statement is again very uncertain because of the few comparable recordings. The observed differences could however, indicate that when placing the pinger in the water column it has a more homogeneous transmission loss thereby inducing more uniform RLS compared to placing the pinger on the bottom.

4.4.3. AQUAmark100

Effect of hydrophone position

The results from the AQUAmark100 showed a more equivocal picture of the effect of the hydrophone position compared to the PAS-pinger. Here it was not possible to detect general tendencies in RSL as an effect of hydrophone position. But it can be seen that at 100m from the setup there is no difference in RSL relative to hydrophone depth. This corresponds with the theory; that less variation is seen on longer distances (Urick, 1983).

Effect of pinger position

When comparing the AQUAmark100 RSL between the two pinger positions, the RSL-points are less variable when the pinger is placed in the water column compared to placing it on the bottom.

This is the same pattern as seen for the PAS-pinger and can be explained by a more homogeneous spreading loss if the pinger is placed in the water column.

Some of the variability recorded in RSL from the AQUAmark100 is, however, due to the signals specifications. The AQUAmark100 emits 8 different signals in random order, which vary considerably both in SL and frequency distribution. This could explain some of the variability seen for this pinger.

4.4.4. Multipath propagation and directivity

The variability in the RSL measured from both AQUAmark100 and PAS could be caused by a combined effect of multipath interference, source level in signals and source directionality. Multipath propagation occurs whenever there is more than one propagation path between source and receiver. Multipaths commonly occur in absence of a duct such as when multiple bottom reflections take place; in shallow water and in the surface duct (Urick, 1983). Multipath propagation is, however, reduced or eliminated by transducer directivity. The PAS-pinger has the most directive transmitting due to its higher frequency. The effect of multipart propagation will therefore be less for the PAS-pinger compared to the AQUAmark100. A way to reduce multipath propagation is to make the transducer more directional. This, however, is not a beneficial solution regarding pingers since it will make the pinger more audible in some directions than others.

Variation in RSL can also be induced by directivity of the sound source. Since the PAS-pingers theoretical have shown to be directional (appendix 8.1.6) the positions of the hydrophone have to be in the exact same angle to the pinger during each recording to get the same RSL. Therefore small movements of the pinger can cause the variation in RSL. It is however not known how much RSL variability there is due to directionality, multipath variation or difference in signals.

4.4.5. Pycnocline

No pycnocline was observed by the echo sounder during the recordings. During other seasons and at other water depths pycnoclines occur which may cause sound propagation to differ from the straight path approximation and the transmission loss to look different (Kinsler *et al.*, 1982; Urick, 1983). But due to the weather conditions prior to the experiment, the low water depth and no detection of density variation on the echo sounder, a pycnocline was not believed to exist.

4.4.6. Bottom type

A soft bottom is known not to be a good reflector (Urick, 1983), and therefore only very little reflections from the bottom in the study area were expected. However, the soft bottom may have reflected sound better than expected, making the differences in acoustic propagation between this bottom type and a reflective bottom small. The reflectivity from the bottom may therefore have confounded effects on bottom properties on multi path propagation.

4.4.7. Additional studies

Additional recordings of the AQUAmark100 have recently been made by Larsen *et al.* (2006) and Wahlberg (2007). Both found variability when measuring the SL in 6 directions of the pinger, thereby determining directional sound propagation of the pinger. This indicates that the RSL measured within these recordings are highly affected by SL of the signals. Wahlberg (2007) also measured the received level (RL) as a function of range for the AQUAmark100 pinger. He found the RL to be approximately 85dB re 1 $\mu Pa^2 s$ at 100m. This can however not be direct correlated with the RSL found in Øresund since the measuring units are unequal.

In relation to a bycatch situation the results by Wahlberg (2007), Larsen *et al.* (2006) and the presented recordings indicate that porpoises can analyse were complex sound fields. Because porpoises approaching a pinger sound field (e.g. gillnets with attached pingers) will, according to these recordings, meet a very complex sound field since they will be exposed to great RSL variations over very short distances. If the porpoise determines the direction of the sound source due to variation in RSL this could give them very unreliable information to determine the sound source direction and location. It has however been documented that the AQUAmark100 pinger can reduce bycatch by 100% when spacing the pinger by 455m (Larsen & Krog, 2006). This indicates that porpoises are able to analyse complex sounds fields since they can avoid entanglement.

To minimize the interference seen within these measurements it is possible that a reduction in the duration of the signal could improve porpoise's ability to analyse a sound field. However Kastelein *et al*. (2007) tested a captive harbour poise ability to locate a sounds source. They documented that the porpoise' ability to locate a sound source increased when the duration of the signal was increased from 600 to 1000ms. This indicates that porpoise ability to locate a sound source is increased by a longer signal. Detection of a signal does however depend many factors e.g. signal properties, hearing abilities of the animal and background noise. The AQUAmark100 signals are between 200-300ms suggesting that porpoises can locate the sound source, due to the avoidance of gillnets, even though they have short duration. If shortening a signal it is however important that the signal is long enough for the porpoise's to registrar.

4.4.8. Improvements of the setup

The recordings conduced within this study highly indicate the need for a repetition of the experiment since many recordings are missing due to the use of external power. But before carrying out a new experiment some simple changes can improve the setup.

- Carry out the experiment in areas with less shipping noise. This will reduce the background noise recorded on the sound files which can interfere with the results.
- A connection of the hydrophone cable to a steady weight on the bottom would help stabilising both cable and hydrophone during recording and minimise vibration due to water movements.
- Recordings of water characteristics such as salinity, temperature, pressure, depth and density with a more precise recorder, e.g. a CTD-recorder (Conductivity-Temperature-Depth), would more exactly state the absence of a pycnocline. This would eliminate the question if the variation in RSL is due to density divisions of the water column.
- Carry out the experiment in an area with more clam waters. This will enable recordings on higher water depths which will reduce the effect of multipath.
- When analysing the data, a division of the signal types from the AQUAmark100 would eliminate the variation caused by different signals. However, this requires a considerable amount of data material.

4.4.9. The results in relation to Part II

Part VI was conducted to determine how the PAS-pinger and the AQUAmark100-pinger propagated in water in order to assist the interpretation of the results collected within Part II, Bycatch in the North Sea. The results collected within Part IV were although very sparse but trends indicated that:

- There are differences in RSL when placing the pinger on the bottom or in the water column; and
- There are differences in RSL when placing the hydrophone in different depths; and
- The obtained transmission loss followed approximately 20log

Porpoise's detection abilities of pingers are influenced by all these measured parameters and this will affect the entanglement rate in a bycatch situation like Part II. When developing a pinger it is therefore important that the pinger can be heard from all directions and positions of porpoises to avoid bycatch. However, even though these recordings indicate a very confusing sound field the AQUAmark100-pinger has shown significant results in reducing bycatch of harbour porpoise (Larsen & Krog, 2006). So although we would think that a sound field in close range of a pinger would be a very confusing place to be the porpoise's ability to analyse sound signals is so much better than ours that they can determine the direction towards the sound source. The PAS-pinger is however more directive than the AQUAmark100, due to its lower frequency and same transducer since, and if the PAS-sounds did stimulate a higher click rate within Part II, the distances at which porpoises detects the PAS-pingers are very different and this could effect the bycatch rate.

5. Conclusion and perspectives

The results collected within Part II, Bycatch in the North Sea documented that the PAS-pingers could not reduce bycatch of harbour porpoises in the Danish hake gillnet fishery. Why the PAS-pinger had no effect on bycatch of harbour porpoise was however, not determined but in order shed light on this question 2 other field experiments were conducted Part III, Sonar activity in Jammerland Bay and Part IV, Recordings of the PAS- and AQUAmark100-pinger in Øresund. The results from Part III depicted that whether PAS-pingers in fact stimulated porpoises to a higher click rate, was equivocal. One can therefore not be sure that the PAS-pingers stimulated a higher click rate therefore the PAS- signals might be the reason for the insignificant results obtained within Part II. Part IV indicated that the RSL of PAS- signals differed according to both pinger- and hydrophone position. A part of this difference can be explained by physical laws of sound propagation in water. However theoretical calculations of the PAS-pingers sound propagation indicated that the PAS pinger was very directional which also will affect the RSL. Based on all three experiments the main conclusion is that the PAS-pinger can not reduce bycatch of harbour porpoise. The reason for the insignificant result could however be due to the PAS-pinger signal regarding both composition and signal propagation.

Since the exact reason for incidental bycatch of harbour porpoises is unknown it is still possible that alerting sounds can reduce bycatch of harbour porpoises. Only by testing an alerting sound which significantly stimulates porpoises to a higher click rate it can be determined if alerting sounds pingers can reduce bycatch of harbour porpoises. It is although very important that the alerting sounds do not attract the porpoise but only stimulates them to at higher click rate. However if an alerting-pingers can reduce bycatch of harbour porpoise, it may become possible to produce a new pinger with far less requirements than commonly used pinger thus enabling smaller size, longer durability, less concern about habituation and a pinger with far less noise pollution compared to normally deterring sound pingers. Therefore further research are needed on alerting sounds and their influence on harbour porpoise's behavioural respond to determine if alerting sounds can function as mitigation method to reduce bycatch of harbour porpoise.

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7.1. Personal comments

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8. Appendix

8.1. Appendix, Part II, Bycatch in the North Sea

8.1.1. Study area in the North Sea

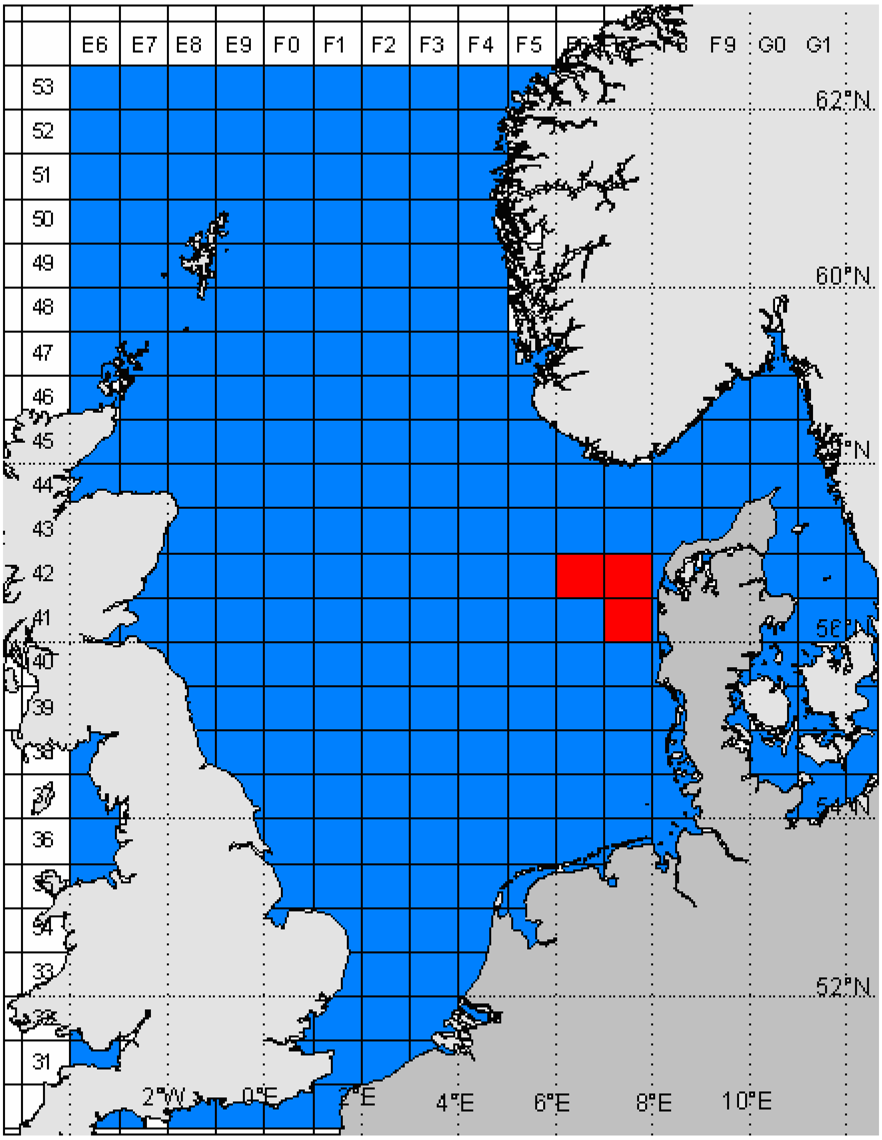


Figure 17: Study area used when testing the PAS-pinger, given in ICES-squares.

8.1.2. PAS-pinger click train

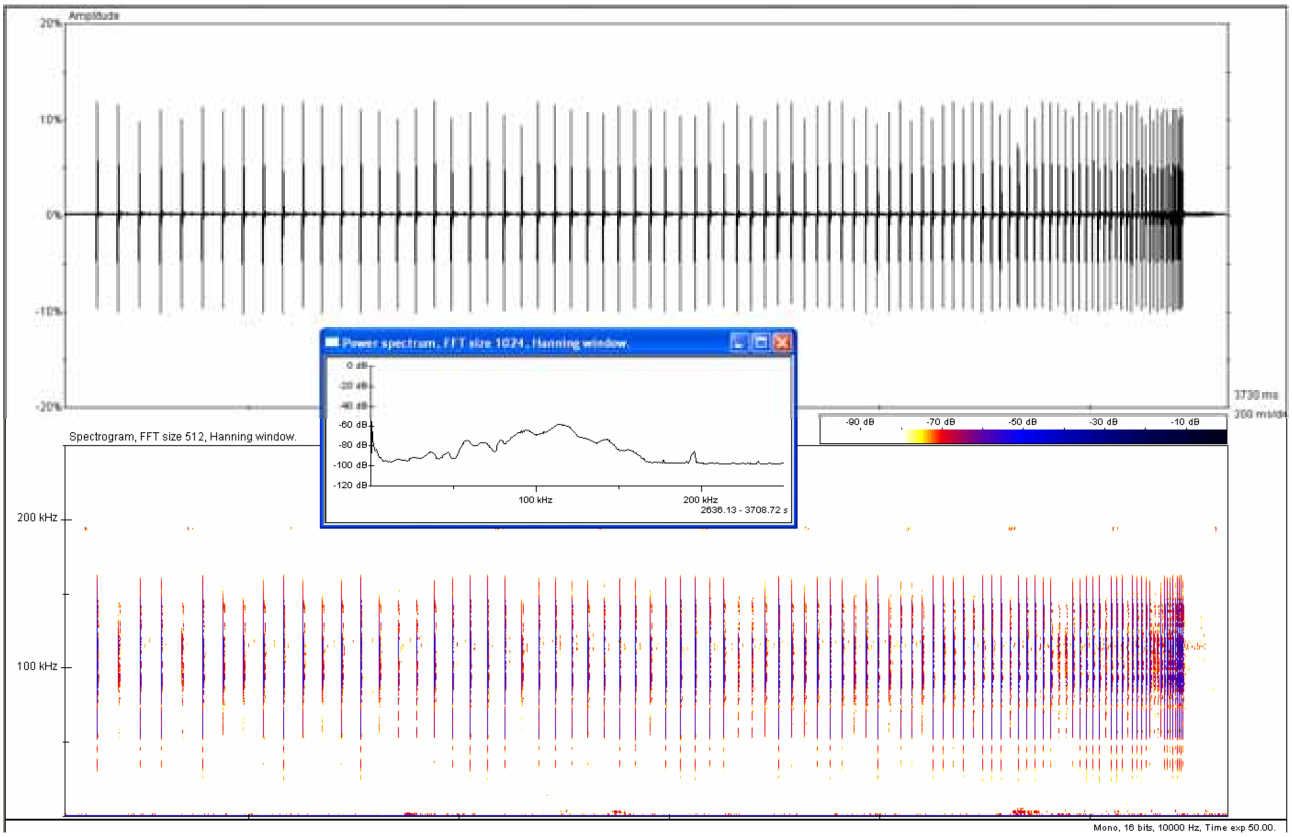


Figure 18: PAS- pinger click train centred on 110kHz. Viewed in BatSound Pro 3.31.

8.1.3. Dissection scheme

CETACEA – PROTOKOLLBLATT *Sektionsteam:*

Bearb.Nr. .... **Art** .... Gesamtlänge...
.... cm

Funddatum .... Präp.Dat. .... Gewicht...
.... kg

Fundort .... Geschlecht m
w

Finder .... NS ☐ OS ☐ Alter geschätzt: ☐
neonat

Präparation: frisch tiefgekühlt Beifang: ☐ ja ☐ nein ☐
juvenil

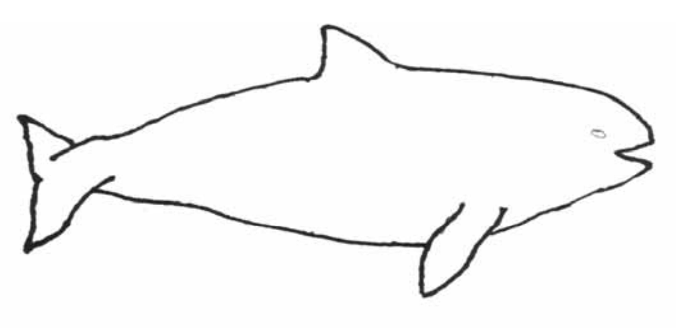
Verwesungsgrad ☐ (1-5) **☐ONNE** **☐enetik** ☐
adult

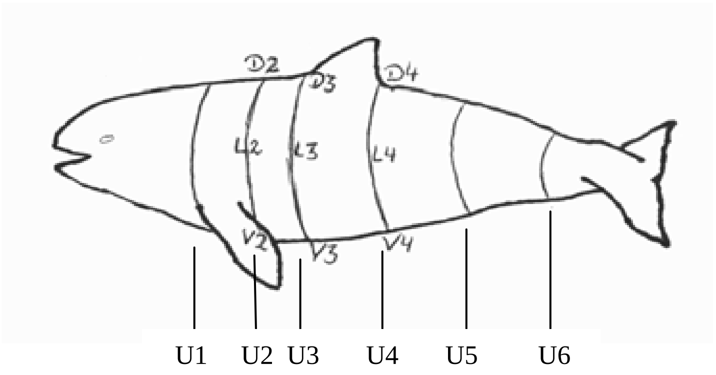
☐

Magen, Musk., Fett

Speckdicken: D2-D4; L2-L4; V2-V4
Umfänge: U1-U6

Läsionen, Netzmarken oder
Besonderheiten in die Skizze eintragen





Vorbericht: ☐ **Fotos:** ja ☐ nein ☐

Messstrecken: (1) .... SchnSpitze - Einkerbung Fluke (= Gesamtlänge)
(cm) (2) .... SchnSpitze - hintere Kante d. Finne
(3) .... SchnSpitze - vordere Kante d. Blasloches
(4) .... SchnSpitze - vorderer Ansatzpunkt d. Flippers
(5) .... Breite der Fluke
(6) .... vorderer Ansatzpunkt d. Flippers - Spitze d. Flippers
(7) ………………SchnSpitze - Mundwinkel
(8) ……………… SchnSpitze - Nabel
(9) ……………… SchnSpitze - Mitte Genitalöffnung/Anus

Nur bei dänischen Tieren!

Umfänge U1 .... U4 .... **Speckdicken** D2 ………..... D3 ……….. D4………..
(cm) U2 .... U5 .... (mm) L2 ………..... L3 ……….. L4………..
U3 .... U6 .... (ohne Haut) V2 ………... V3 ……….. V4 ………..

Hartteile Skelett ☐ Teilskelett ☐ Zahn ☐ (Anzahl)

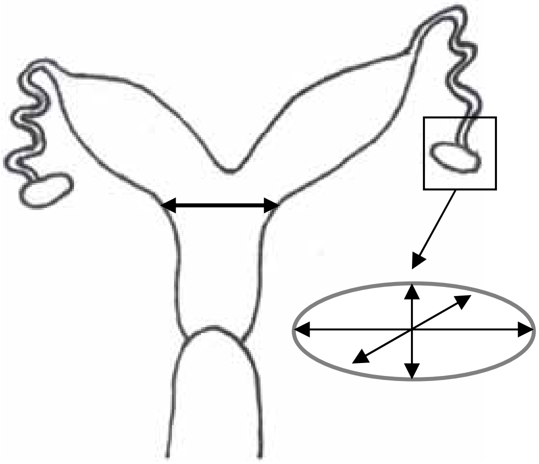
Verbleib des Skeletts ....

Organgewichte: Fett .... Herz (erst spülen!).......................
Milz.............................. (g)
Muskulatur........................... Leber................................. Thymus
....
Nieren li .... re.....................
Gehirn………………...
Nebenniere li................... re ....
Hoden mit NH li ………….. re ....
Hoden ohne NH li .... re ....…
Ovarien li .... re …................

Vermessung Uterus/Ovarien//Hoden:

Ovar (re): L………….. B .... H .... [cm]
Appendix:++/ 3
Ovar (li): L…………... B ……………. H ………… [cm]

Uterus: .... [cm] (Durchmesser; Übergang zur Teilung)



Ovar

Hoden + NH (re): L.................. B..................... H .... [cm]
Hoden + NH (li): L .... B …........…. H ……......… [cm]
Hoden (re): L .... B .... H .... [cm]
Hoden (li): L .... B .... H .... [cm]

Ernährungszustand gut ☐ mäßig ☐ schlecht ☐

Parasiten

Lunge keine ☐
Lokalisation: Bronchien ggr. ☐ mgr. ☐ hgr. ☐
Gefäße ggr. ☐ mgr. ☐ hgr. ☐

Herz keine ☐
Lokalisation: re Vorhof ggr. ☐ mgr. ☐ hgr. ☐
re Kammer ggr. ☐ mgr. ☐ hgr. ☐
li Vorhof ggr. ☐ mgr. ☐ hgr. ☐
li Kammer ggr. ☐ mgr. ☐ hgr. ☐

Magen keine ☐
Lokalisation: 1. Komp. ggr. ☐ mgr. ☐ hgr. ☐
2. Komp. ggr. ☐ mgr. ☐ hgr. ☐
4. Komp. ggr. ☐ mgr. ☐ hgr. ☐

Darm keine ☐
Lokalisation: Amp duo ggr. ☐ mgr. ☐ hgr. ☐
Darm ggr. ☐ mgr. ☐ hgr. ☐

Leber keine ☐ ggr. ☐ mgr. ☐ hgr. ☐

Ohren **li** keine ☐ ggr. ☐ mgr. ☐ hgr. ☐
re keine ☐ ggr. ☐ mgr. ☐ hgr. ☐

Notizen

8.1.4. Detection settings

Detection settings used in AQUAclickVIEW. Clicks are classified as clicks in trains if the following criteria are met.

- MIN_PORPOISE_RATIO = 3
- MAX_PORPOISE_RATIO = 255

- MIN_CLICK_LENGTH = 50
- MAX_CLICK_LENGTH = 500

- MIN_INTERCLICK_LENGTH = 1
- MAX_INTERCLICK_LENGTH = 300

- NUM_CLICKS_IN_TRAIN = 4
- DURATION_CLICKS_IN_TRAIN = 1500

- MIN_ICI_CHANGE = 0.33
- MAX_ICI_CHANGE = 1

- MIN_ICI_CHANGE2 = 1
- MAX_ICI_CHANGE2 = 3

- MIN_AMPLITUDE_CHANGE = 0
- MAX_AMPLITUDE_CHANGE = 1

- MIN_AMPLITUDE_CHANGE2 = 1
- MAX_AMPLITUDE_CHANGE2 = 10

8.1.5. Dissection summery

Table 4: Dissection summery of 8 bycaught harbour porpoises

number	sex	length [cm]	weight [kg]	age	ear condition	most likely cause of death	other important pathological findings
3465	m	122	29,8	adult	right and left moderate parasite infestation	by-caught (cuts by nets found)	severe bronchopneumonia;
3466	m	123	33	adult	right severe, left moderate parasite infestation	by-caught (cuts by nets found)	moderate to severe granulomatous inflammation in lung, lymphnode and stomach
3467	m	132	36,3	adult	right and left severe parasite infestation	by-caught	mild to moderate pneumonia and moderate pulmonary endoparasitosis; pericholangitis;
3468	m	134	41,6	adult	right and left mild parasite infestation	by-caught or blunt trauma (subcutan hemorrhages)	pericholangitis; moderate pneumonia; moderate gastritis
3469	f	148	43,8	adult	right mild, left no parasite infestation; mild concentration of *Staphylococcus epidermidis* and *Alcaligenes sp.* in the right middel ear	by-caught (cuts by nets found)	mild pneumonia;
3557	m	106	19,4	juvenile	not examined	by-caught (cuts by nets found)	mild parasitic infestation in bronchial tree and pulmonary blood vessels, mild bronchopneumonia
3558	m	105	20,4	juvenile	right and left severe parasite infestation	by-caught (cuts by nets found)	mild parasitic infestation in bronchial tree and pulmonary blood vessels, mild bronchopneumonia
3572	f	149	47,6	adult	not examined	by-caught (fin, flipper, fluke partly cut of)	moderate parasitic infestation in bronchial tree and pulmonary blood vessels, moderate bronchopneumonia

8.1.6. Radiation diagram of the PAS-pinger

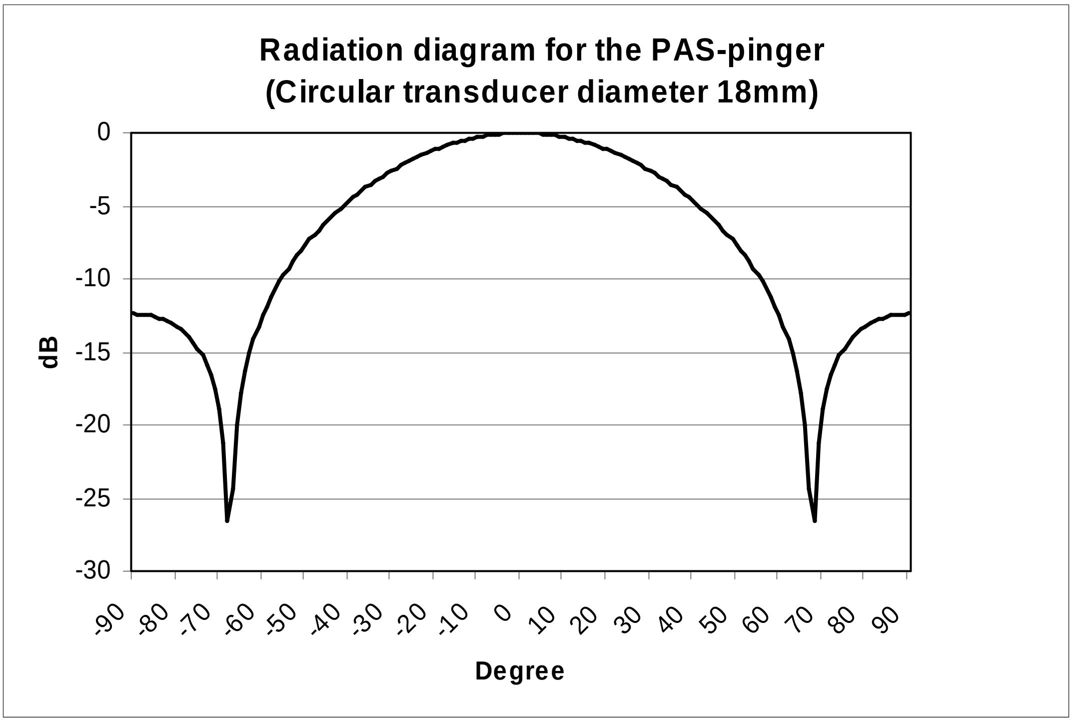


Figure 19: Radiation diagram of the PAS-pinger.

8.1.7. Hearing thresholds for 6 species of fish

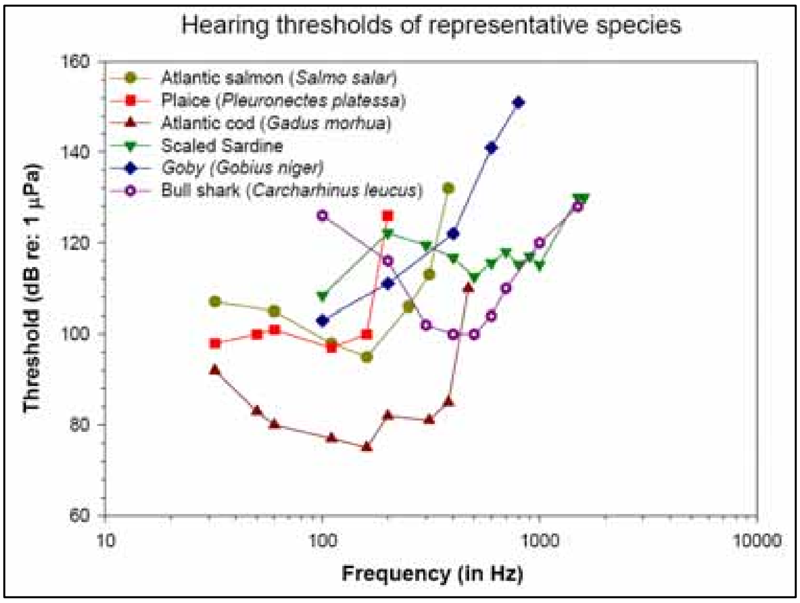


Figure 20: Hearing thresholds for 6 species of fish. These data suggest that none of the species detects sounds much higher than 1100Hz. Data were compiled from Fay (1988).

8.2. Appendix, Part III, Sonar activity in Jammerland Bay

8.2.1. Study area in Jammerland Bay

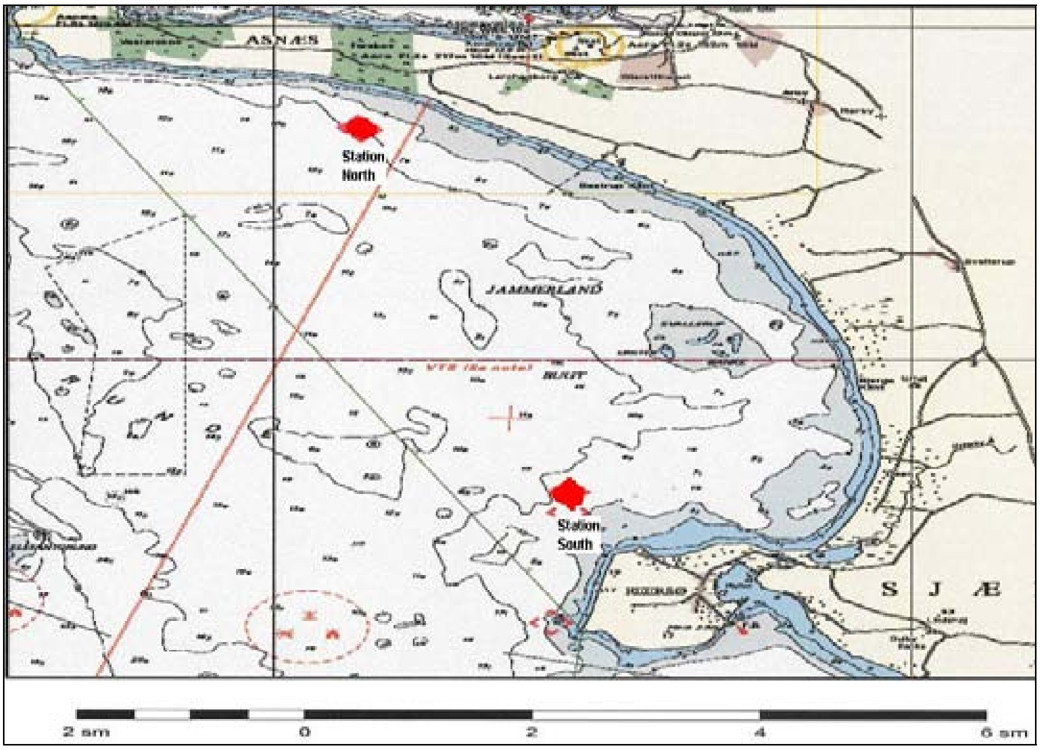


Figure 21: Study area in Jammerland Bay, pointing out station North and South.

8.2.2. Measured angles of the PCL-hydrophone

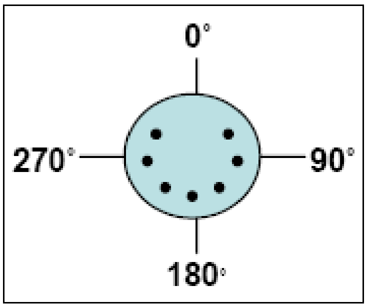


Figure 22: Hydrophone as seen from above; hydrophone pointing downwards.

The angles for the directionality measurements were referenced to the Subconn®pins.

8.2.3. Time schedule

Table 5: Weekly time schedule for station N and S regarding T-POD, PCL and alerting.

Station N												
Week	1	2	3	4	5	6	7	8	9	10	11	12
T-POD number	374	374	374	374	374	374	374	374	374	374	374	374
PCL number	12	14	15	13	12	14	15	13	12	14	15	13
PAS station	X		X			X		X	X		X	
Station S												
Week	1	2	3	4	5	6	7	8	9	10	11	12
T-POD number	335	335	335	335	335	335	335	335	335	335	335	335
PCL number	15	13	12	14	15	13	12	14	15	13	12	14
PAS station		X		X	X		X			X		X

8.2.4. Calibrations of Porpoise Clicks Loggers

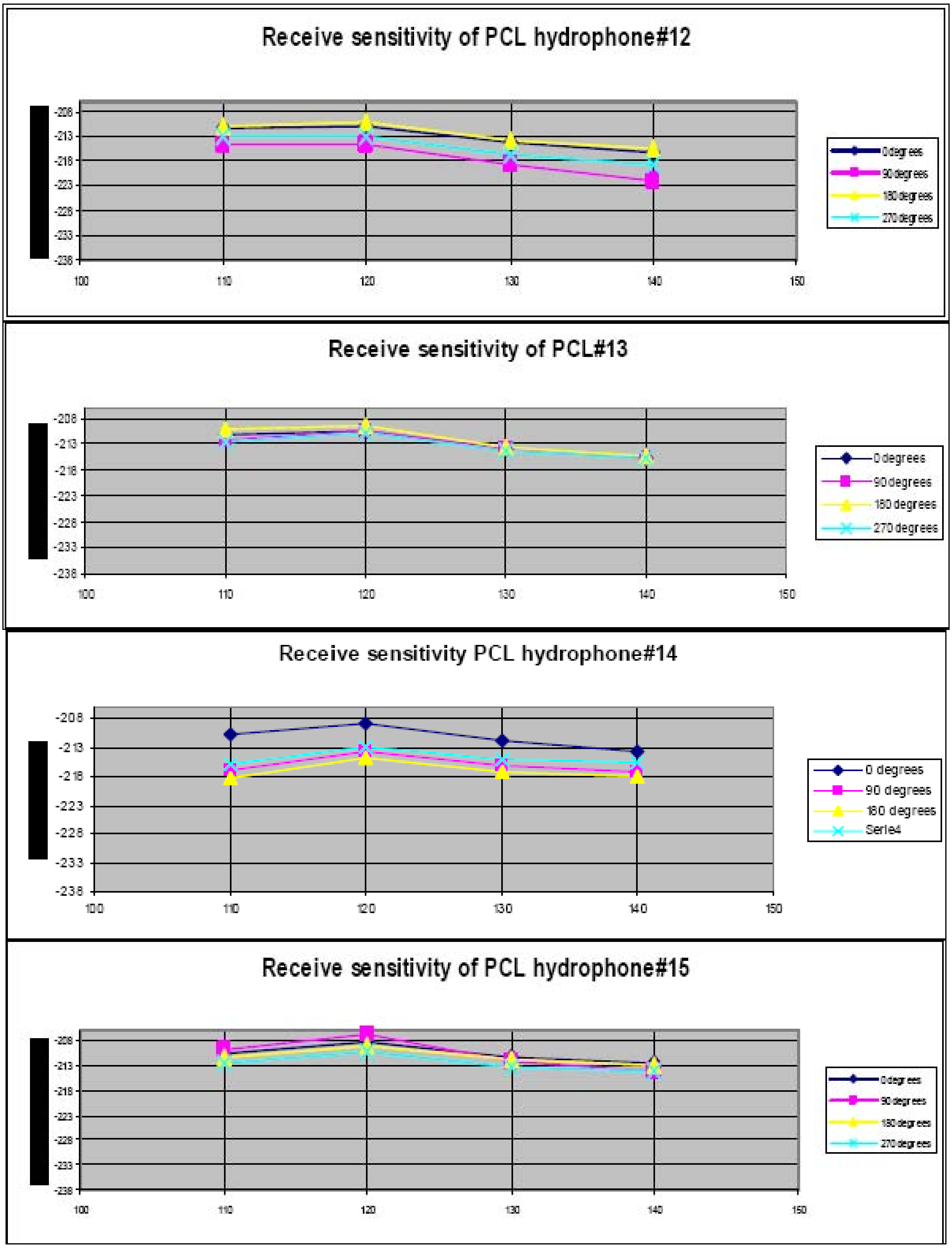


Figure 23: Receiving sensitivity in the PCL hydrophones

8.2.5. Directionality of PCL-hydrophones

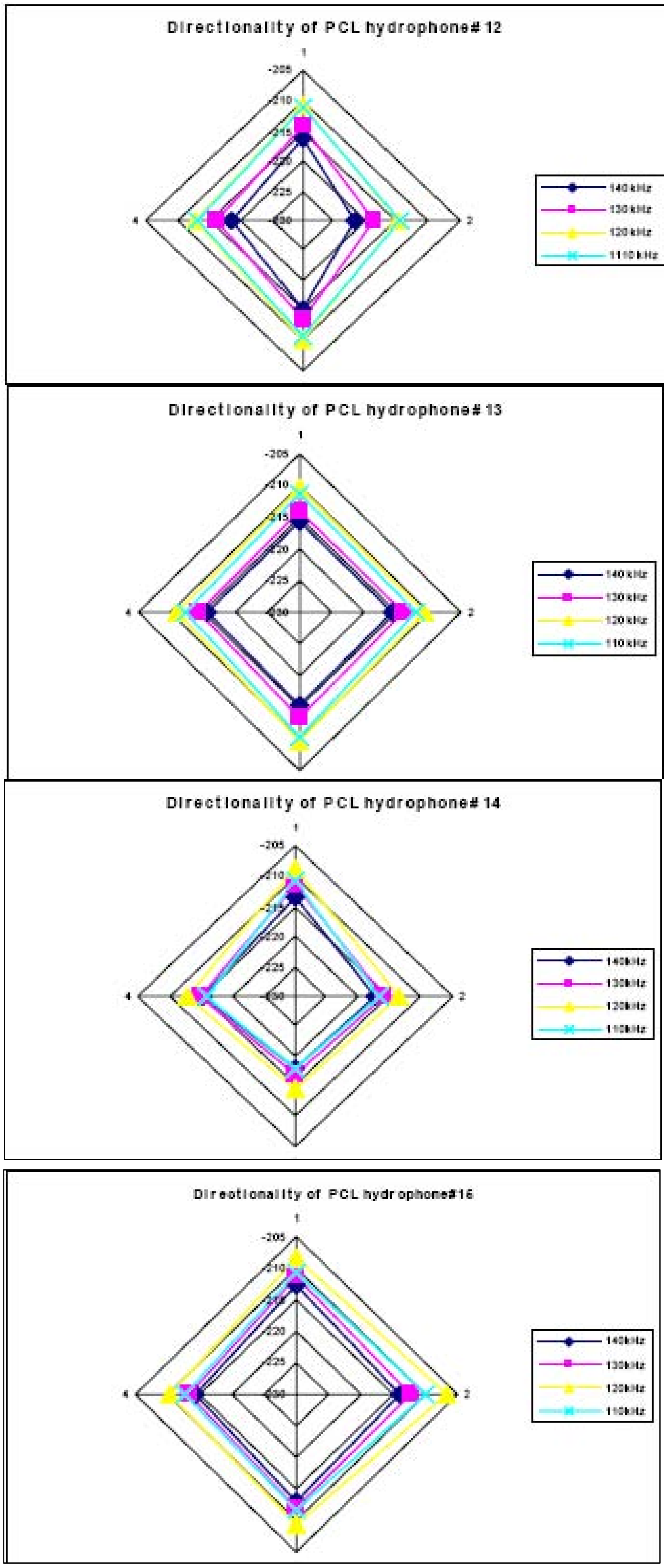


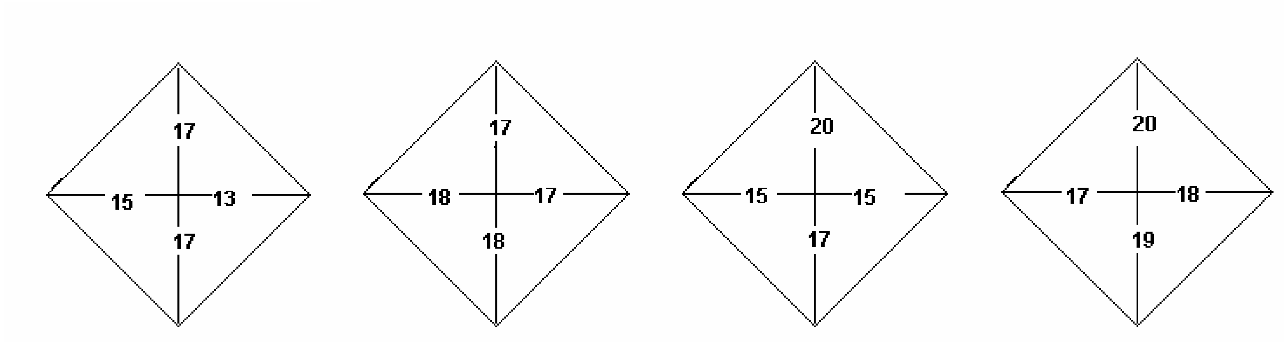
Figure 24: Directionality of the PCL's

8.2.6. Calculations of relative recording area

Calculations of relative recording areas at 130kHz. The relative area was calculated from the directional sensitivity recordings appendix 8.2.5. Since the hydrophone only was measured in 4 angles the relative recording area was calculated as a square even though the true recording areas of the hydrophones are circular.

Distances in dB:

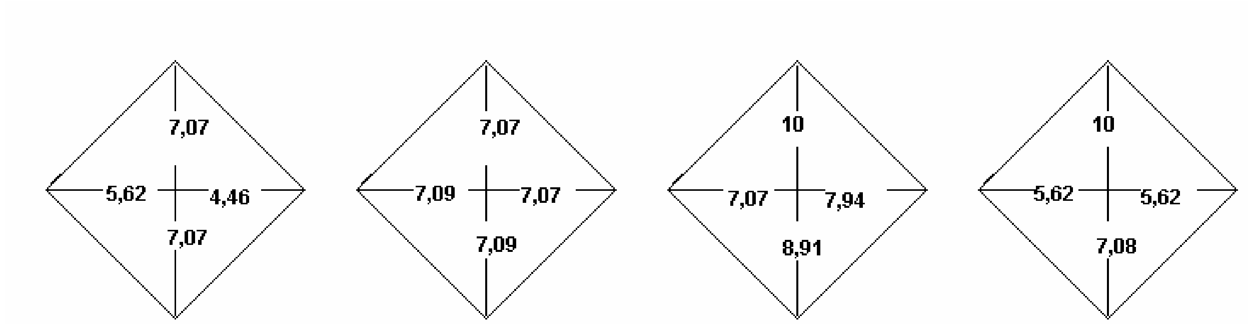
Hydrophone: 12 Hydrophone: 13 Hydrophone: 14 Hydrophone: 15



Calculation of distances:

(Conversion from dB to relative distance), Distance= 10^ (distance in dB/20)

Hydrophone: 12 Hydrophone: 13 Hydrophone: 14 Hydrophone: 15



The relative recording area is therefore (area of triangle= 0.5* height* ground line):

Hydrophone: 12 Hydrophone: 13 Hydrophone: 14 Hydrophone: 15

8.3. Appendix Part IV, Recordings of PAS- & AQUAmark100 pinger in Øresund

8.3.1. AQUAmark100-pinger signals

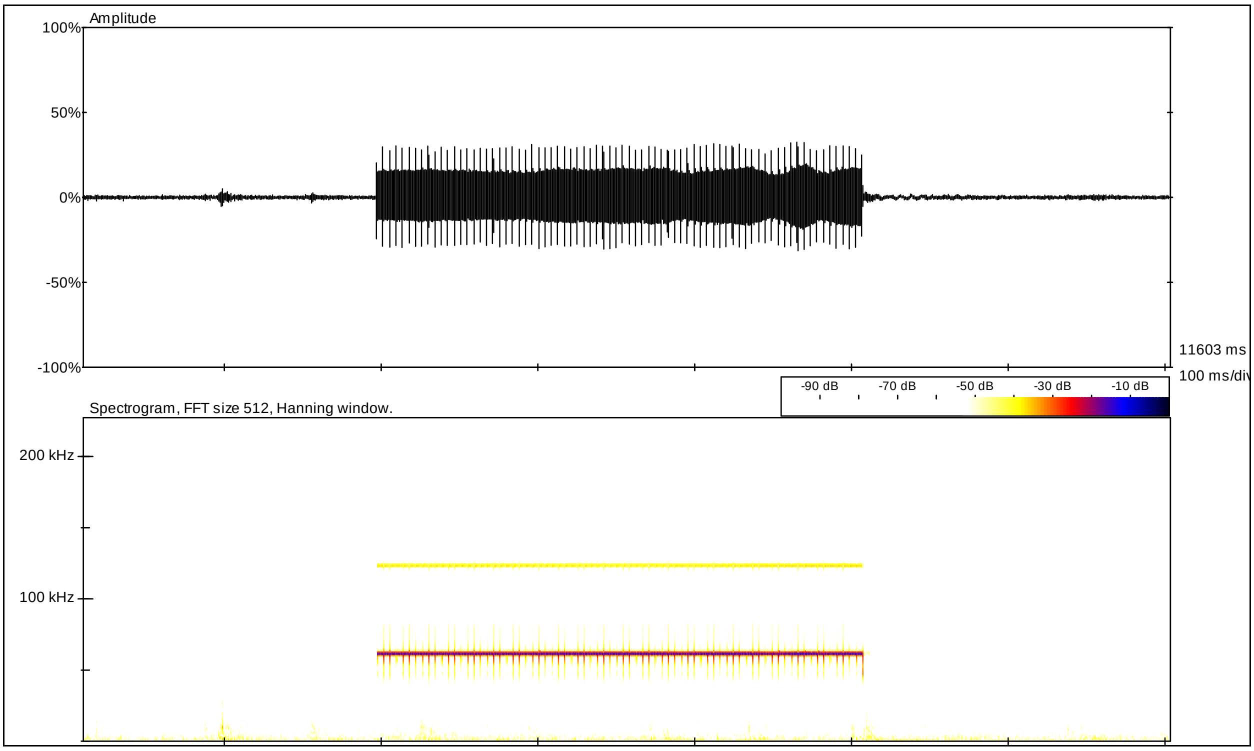


Figure 25: AQUAmark100 pinger signal. Viewed in BatSound Pro 3.31.

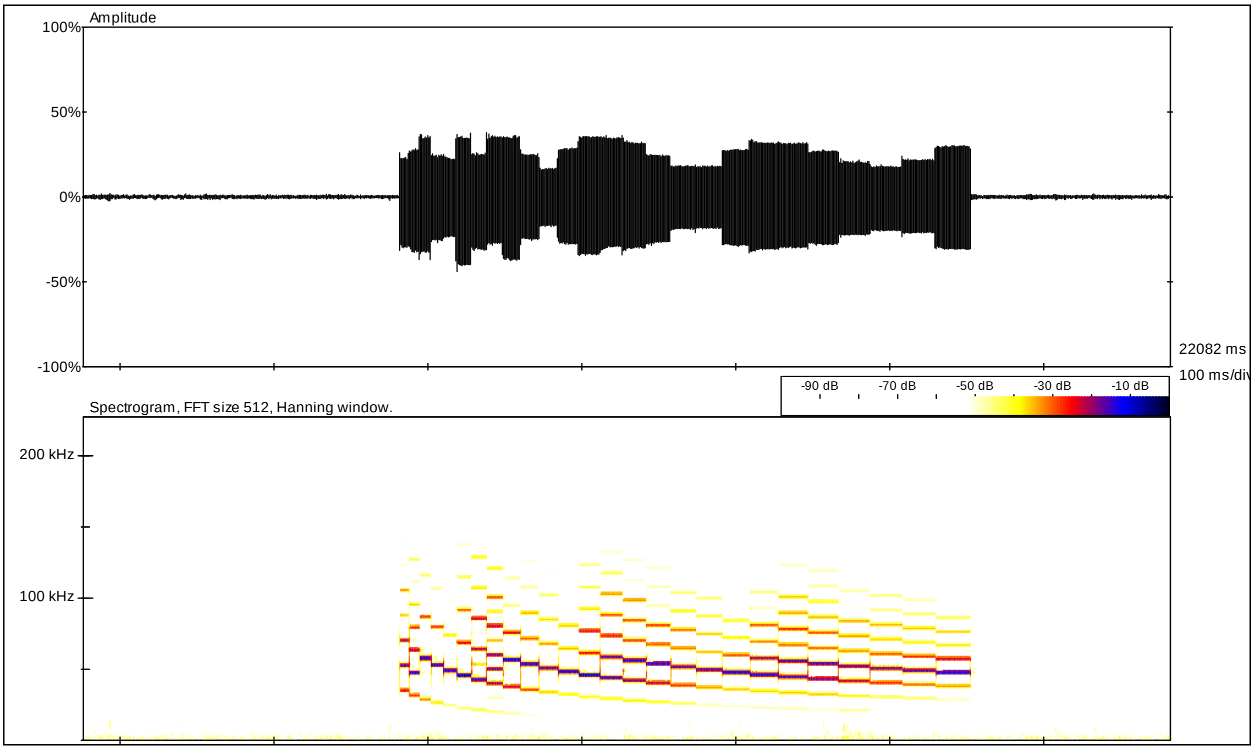


Figure 26: AQUAmark100 pinger signal. Viewed in Batsound Pro 3.31.

DTU Aqua-rapportindex

Denne liste dækker rapporter udgivet i indeværende år samt de foregående to kalenderår. Hele listen kan ses på DTU Aquas hjemmeside www.aqua.dtu.dk, hvor de fleste nyere rapporter også findes som PDF-filer.

Nr. 158-06	Østers (*Ostrea edulis*) i Limfjorden. Per Sand Kristensen og Erik Hoffmann
Nr. 159-06	Optimering af fangstværdien for jomfruhummere (*Nephrops norvegicus*) – forsøg med fangst og opbevaring af levende jomfruhummere. Lars-Flemming Pedersen
Nr. 160-06	Undersøgelse af smoltudtrækket fra Skjern Å samt smoltdødelighed ved passage af Ringkøbing Fjord 2005. Anders Koed
Nr. 161-06	Udsætning af geddeyngel i danske søer: Effektvurdering og perspektivering. Christian Skov, Lene Jacobsen, Søren Berg, Jimmi Olsen og Dorte Bekkevold
Nr. 162-06	Avlsprogram for regnbueørred i Danmark. Alfred Jokumsen, Ivar Lund, Mark Henryon, Peer Berg, Torben Nielsen, Simon B. Madsen, Torben Filt Jensen og Peter Faber
Nr. 162a-06	Avlsprogram for regnbueørred i Danmark. Bilagsrapport. Alfred Jokumsen, Ivar Lund, Mark Henryon, Peer Berg, Torben Nielsen, Simon B. Madsen, Torben Filt Jensen og Peter Faber
Nr. 163-06	Skarven (*Phalacrocorax carbo sinensis* L.) og den spættede sæls (*Phoca vitulina* L.) indvirkning på fiskebestanden i Limfjorden: Ecopath modellering som redskab i økosystem beskrivelse. Rasmus Skoven
Nr. 164-06	Kongeåens Dambrug – et modeldambrug under forsøgsordningen. Statusrapport for første måleår af moniteringsprojektet. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.
Nr. 165-06	A pilot-study: Evaluating the possibility that Atlantic Herring (*Clupea harengus* L.) exerts a negative effect on lesser sandeel (*Ammodytes marinus*) in the North Sea, using IBTS-and TBM-data. Mikael van Deurs
Nr. 166-06	Ejstrupholm Dambrug – et modeldambrug under forsøgsordningen. Statusrapport for første måleår af moniteringsprojektet. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.
Nr. 167-06	Blåmuslinge- og Stillehavsøstersbestanden i det danske Vadehav efteråret 2006. Per Sand Kristensen og Niels Jørgen Pihl
Nr. 168-06	Tvilho Dambrug – et modeldambrug under forsøgsordningen. Statusrapport for første måleår af moniteringsprojektet. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.

Nr. 169-07	Produktion af blødskallede strandkrabber i Danmark - en ny marin akvakulturproduktion. Knud Fischer, Ulrik Cold, Kevin Jørgensen, Erling P. Larsen, Ole Saugmann Rasmussen og Jens J. Sloth.
Nr. 170-07	Den invasive stillehavsøsters, Crassostrea gigas, i Limfjorden - inddragelse af borgere og interessenter i forslag til en forvaltningsplan. Helle Torp Christensen og Ingrid Elmedal.
Nr. 171-07	Kystfodring og kystøkologi - Evaluering af revlefodring ud for Fjaltring. Josianne Støttrup, Per Dolmer, Maria Røjbek, Else Nielsen, Signe Ingvardsen, Per Sørensen og Sune Riis Sørensen.
Nr. 172-07	Løjstrup Dambrug (øst) - et modeldambrug under forsøgsordningen. Statusrapport for 1. måleår af moniteringsprojektet. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.
Nr. 173-07	Tingkærvad Dambrug - et modeldambrug under forsøgsordningen. Statusrapport for 1. måleår af moniteringsprojektet. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.
Nr. 174-07	Abildtrup Dambrug – et modeldambrug under forsøgsordningen. Statusrapport for 1. måleår af monitoreringsprojektet. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen, Anne Johanne Tang Dalsgaard.
Nr. 175-07	Nørå Dambrug – et modeldambrug under forsøgsordningen. Statusrapport for 1. måleår af moniteringsprojektet. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen, Anne Johanne Tang Dalsgaard.
Nr. 176-07	Rens Dambrug – et modeldambrug under forsøgsordningen. Statusrapport for 1. måleår af moniteringsprojektet. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.
Nr. 177-08	Implementering af mere selektive og skånsomme fiskerier – konklusioner, anbefalinger og perspektivering. J. Rasmus Nielsen, Svend Erik Andersen, Søren Eliasen, Hans Frost, Ole Jørgensen, Carsten Krog, Lone Grønbæk Kronbak, Christoph Mathiesen, Sten Munch-Petersen, Sten Sverdrup-Jensen og Niels Vestergaard.
Nr. 178-08	Økosystemmodel for Ringkøbing Fjord - skarvbestandens påvirkning af fiskebestandene. Anne Johanne Dalsgaard, Villy Christensen, Hanne Nicolajsen, Anders Koed, Josianne Støttrup, Jane Grooss, Thomas Bregnballe, Henrik Løkke Sørensen, Jens Tang Christensen og Rasmus Nielsen.
Nr. 179-08	Undersøgelse af sammenhængen mellem udviklingen af skarvkolonien ved Toftesø og forekomsten af fladfiskeyngel i Ålborg Bugt. Else Nielsen, Josianne Støttrup, Hanne Nicolajsen og Thomas Bregnballe.
Nr. 180-08	Kunstig reproduktion af ål: ROE II og IIB. Jonna Tomkiewicz og Henrik Jarlbæk

Nr. 181-08	Blåmuslinge- og stillehavsøstersbestandene i det danske Vadehav 2007. Per Sand Kristensen og Niels Jørgen Pihl
Nr. 182-08	Kongeåens Dambrug – et modeldambrug under forsøgsordningen. Statusrapport for 2. måleår af moniteringsprojektet med væsentlige resultater fra 1. måleår. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.
Nr. 183-08	Taskekrabben – Biologi, fiskeri, afsætning og forvaltningsplan. Claus Stenberg, Per Dolmer, Carsten Krog, Siz Madsen, Lars Nannerup, Maja Wall og Kerstin Geitner.
Nr. 184-08	Tvilho Dambrug – et modeldambrug under forsøgsordningen. Statusrapport for 2. måleår af moniteringsprojektet med væsentlige resultater fra 1. måleår. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.
Nr. 185-08	Erfaringsopsamling for muslingeopdræt i Danmark. Helle Torp Christensen, Per Dolmer, Hamish Stewart, Jan Bangsholt, Thomas Olesen og Sisse Redeker.
Nr. 186-08	Smoltudvandring fra Storå 2007 samt smoltdødelighed under udvandringen gennem Felsted Kog og Nissum Fjord. Henrik Baktoft og Anders Koed.
Nr. 187-08	Tingkærvad Dambrug - et modeldambrug under forsøgsordningen. Statusrapport for 2. måleår af moniteringsprojektet med væsentlige resultater fra første måleår. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.
Nr. 188-08	Ejstrupholm Dambrug - et modeldambrug under forsøgsordningen. Statusrapport for 2. måleår af moniteringsprojektet med væsentlige resultater fra første måleår. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen, Jens Skriver, Søren Erik Larsen, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen og Anne Johanne Tang Dalsgaard.
Nr. 189-08	The production of Baltic cod larvae for restocking in the eastern Baltic. RESTOCK I. 2005-2007. Josianne G. Støttrup, Julia L. Overton, Sune R. Sørensen (eds.)
Nr. 190-08	USER’S MANUAL FOR THE EXCEL APPLICATION “TEMAS” or “Evaluation Frame”. Per J. Sparre.
Nr. 191-08	Evaluation Frame for Comparison of Alternative Management Regimes using MPA and Closed Seasons applied to Baltic Cod. Per J. Sparre.
Nr. 192-08	Assessment of Ecosystem Goods and Services provided by the Coastal Zone System Limfjord. Anita Wiethücther.
Nr. 193-08	Modeldambrug under forsøgsordningen. Faglig slutrapport for ”Måle- og dokumentationsprojekt for modeldambrug”. Lars M. Svendsen, Ole Sortkjær, Niels Bering Ovesen,Jens Skriver, Søren Erik Larsen, Susanne Bouttrup, Per Bovbjerg Pedersen, Richard Skøtt Rasmussen, Anne Johanne Tang Dalsgaard og Karin Suhr.
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Nr. 196-08 Udsætning af geddeyngel som bestandsophjælpning i danske brakvandsområder – effektvurdering og perspektivering. Lene Jacobsen, Christian Skov, Søren Berg, Anders Koed og Peter Foged Larsen.

Nr. 197-08 Manual to determine gonadal maturity of herring (*Clupea harengus L*)
Rikke Hagstrøm Bucholtz, Jonna Tomkiewicz og Jørgen Dalskov

Nr. 198-08 Can alerting sounds reduce bycatch of harbour porpoise? Lotte Kindt-Larsen