University of Natural Resources
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Reduction of accidental bycatches in set-net fisheries by the use of acoustic signals

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Declaration in lieu of oath

I herewith declare in lieu of oath that this thesis has been composed by myself without any inadmissible help and without the use of sources other than those given due reference in the text and listed in the list of references. I further declare that all persons and institutions that have directly or indirectly helped me with the preparation of the thesis have been acknowledged and that this thesis has not been submitted, wholly or substantially, as an examination document at any other institution.

January 18, 2016

Date

Signature

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II. Abstract

Incidental bycatches of harbour porpoises and diving seabirds in set-net fisheries are one major threat throughout the northern Hemisphere. The reasons for bycatches of harbour porpoises are not fully understood but are thought to be related to insufficient attention to their surroundings. The aim of this study was to test the effectiveness of a new acoustic alarming device, the so called Porpoise Alarm (PAL), emitting life-like harbour porpoise warning signals. This narrow band signal with a centroid frequency at 133 kHz ± 8.5kHz has been proven to increase echolocation activity in previous studies instead of just deterring.

A long-term field experiment was conducted on board of two German set-net fishing vessels in the western part of the German Baltic Sea from August 2013 to October 2014. In the course of this thesis, the available data were further analysed.

The most affected species were common eiders (n=154), cormorants (n=31) and harbour porpoises (n=2). Although more common eiders (p=0.0038**) and cormorants (p=0.0284*) were bycaught in set-nets equipped with PALs, it is unlikely to be a result of the acoustic signal, since it is not in the hearing range of diving seabirds.

A decrease in harbour porpoise detections in the vicinity of set-nets equipped with PALs could be determined via static acoustic monitoring which either represents a deterring effect or a decrease in echolocation activity. No effect of the PAL on the catch rate of cod and flat fish species could be detected within this study.

The results of this study do not allow a conclusive evaluation of the effectiveness of the PAL due to a low number of harbour porpoise bycatches. In general, an effective prevention has to provide solutions for two different issues: On the one hand the reduction of the anthropogenic induced mortality, on the other hand the economic viability to maintain both, conservation and fisher's requirements. The last aspect can only be achieved by maintaining catch rates.

III. Zusammenfassung

Der ungewollte Beifang in der Stellnetzfischerei stellt für Schweinswale und tauchenden Seevögeln in der gesamten nördlichen Hemisphäre die größte Bedrohung dar. Es wird angenommen, dass Schweinswalbeifänge auftreten, weil Stellnetze zu spät erkannt werden.

In dieser Studie sollte die Wirksamkeit eines neuen akustischen Warngeräts, dem „Porpoise Alarm“ (PAL) getestet werden, welches artspezifische Warnsignale aussendet. Für das verwendete engbandige Warnsignal, das die größte Energie bei 133 kHz ±8,5kHz besitzt, konnte in einer vorherigen Studie bereits eine erhöhte Echoortungsaktivität ohne Vergrämungseffekt nachgewiesen werden.

In einem Langzeit Feldversuch im westlichen Teil der deutschen Ostsee wurden zwischen August 2013 und Oktober 2014 an Bord von zwei deutschen Fischereifahrzeugen Daten erhoben.

Die am stärksten betroffenen Arten waren Eiderenten (n=154), Kormorane (n=31) und Schweinswale (n=2). Obwohl mehr Eiderenten (p=0,0038**) und Kormorane (p=0,0284*) in Netzen mit PALs beigefangen wurden, ist es höchst unwahrscheinlich, dass dies durch das Warnsignal hervorgerufen wurde, da dieses nicht im Hörbereich von tauchenden Seevögeln liegt.

Durch ein statisch akustisches Monitoring konnten niedrigere Schweinswaldetektionen in der Nähe von Netzen mit PALs festgestellt werden, was entweder einen Vertreibungseffekt oder eine Verringerung der Echoortungsaktivität widerspiegeln könnte. Im Fangerfolg für Dorsch und Plattfische konnte kein Effekt des PAL gezeigt werden.

Die Ergebnisse dieser Studie lassen durch die geringe Anzahl von Schweinswal Beifängen keine abschließende Beurteilung der Effektivität des PAL zu.

Eine effektive Methode zur Verringerung von Beifängen sollte generell verschiedene Aspekte des Naturschutzes und Bedürfnisse der Fischer berücksichtigen: Während einerseits die durch den Menschen induzierte Sterblichkeit gesenkt werden muss, sollte andererseits die Fischerei wirtschaftlich und dementsprechend Fangraten unbeeinflusst bleiben.

IV. Figures

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1. Introduction

Marine mammals and avifauna are confronted with human impacts on diverse levels. Marine wildlife shows flight reactions towards ship traffic (Bellebaum et al. 2006, Dyndo et al. 2015), suffers from noise pollution (Nowacek et al. 2007, Dähne et al. 2013) or is exposed to invisible barriers in form of fishing gear (Hammond et al. 2002, Žydelis et al. 2009, Sonntag et al. 2012, Bellebaum et al. 2013, Korpinen & Braeger 2013, Žydelis et al. 2013). The entanglement in fishing nets is one of the major threats for seabirds worldwide (Croxall et al. 2012, Žydelis et al. 2013) and harbour porpoises in the Baltic Sea (ASCOBANS 2002, Hammond et al. 2002, Culik & Würtz 2011).

The lack of systematic and continuous monitoring of bird and marine mammal bycatches in the Baltic Sea results in a highly fragmented knowledge of its impact on populations. Available information often arises from short-term studies or opportunistic observations (Hammond et al. 2002, Žydelis et al. 2009, Reeves et al. 2013, Žydelis et al. 2013) The recovery of the 'critically endangered' Baltic Sea Harbour porpoise subpopulation (Hammond et al. 2008) is a major concern of the International Union for Conservation of Nature (IUCN), the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) and the Helsinki Commission (HELCOM). Therefore, the ASCOBANS recovery plan (Jastarnia Plan) was appointed in 2002, aiming at a population of 80 % of its carrying-capacity level (ASCOBANS 2002). HELCOM's Baltic Sea Action Plan (BSAP) targets at viable populations of harbour porpoises, seals and seabirds with bycatch rates close to zero by 2015 (HELCOM 2007).

The biological impact of anthropogenic mortality on the population of harbour porpoises was evaluated by Hammond et al. (2002) for the Baltic region, defined as Skagerrak, Kattegat, Great and Little Belt Seas, Kiel and Mecklenburg Bights and Baltic Sea. They come to the conclusion that even minimum estimates of bycatches surpassed the calculated mortality limits and are not consistent with ASCOBANS's conservation plans. The evaluation of additive mortality on a population with minimum demographic information can be calculated as potential biological removal (PBR). The impact of seabird bycatches in the Baltic Sea was evaluated with this approach by Žydelis et al. (2009) who proposed that this additional mortality exceeds the level with regard to sustainable population sizes for at least two bird species. Along the German Baltic Coast stranding numbers of harbour porpoise carcasses increased from about 25 in 2000 to over 150 in 2007 (Herr et al. 2009, Koschinski & Pfander 2009, Wehrmeister et al. 2013) and decreased subsequently to around 70 in 2012. 47 % of all stranded harbour porpoises carcasses that were in a good or moderate state of conservation could be determined as suspected bycatches. Under the assumption that the status of stranded bycatches is independent from cause of death the result of 47 % of suspected bycatches could be transferred to all bycatches in 2007 which corresponds to 69 bycatches in 147 stranded animals. Applied to local abundances bycatch rates exceed the recommendation for a maximum sustainable bycatch level of 1 % provided by the Bergen Declaration and the International Whaling Committee (IWC 2000, ASCOBANS 2002, Herr et al. 2009).

Conflicts in the interaction between humans and wildlife can be encountered by three different approaches. The first is to change human behaviour by creating an atmosphere in which such changes are made voluntarily or to establish a compulsory regulation. The second approach targets at a change in the nature of the interaction by introducing or improving technology that would cause less negative effects to wildlife. The third option to oppose conflicts between humans and wildlife is the most challenging as it targets at a change in the behaviour of the animals themselves while the human behaviour is influenced marginally (Dawson et al. 2013).

In this master thesis an example of the third approach is analysed: the attempt to change harbour porpoise behaviour close to gillnets with the aim to decrease lethal entanglements.

1.1. Network of Natura 2000 - Management of protected species

Harbour porpoises are affected negatively by numerous anthropogenic activities, like prey depletion by reason of fisheries (DeMaster et al. 2001), toxins (Huber et al. 2012, Mahfouz et al. 2014), noise pollution (Nowacek et al. 2007, Dähne et al. 2013, Hermannsen et al. 2014) and mainly by incidental bycatches in the fisheries (Rubsch & Kock 2004, Herr et al. 2009, Koschinski & Pfander 2009, Culik & Würtz 2011, Korpinen & Braeger 2013, Reeves et al. 2013, Wehrmeister et al. 2013). Anthropogenic disturbances could induce alterations in natural patterns of animal behaviour and physiology.

In addition this could influence the conservation status of a population if the individual is affected on a level of growth, survival and breeding (King et al. 2015). Harbour porpoises are listed in Annex II of EU Habitats Directive list which means that important areas must be protected according to its ecological requirements. Additionally, as listed also in Annex IV a strict protection management must be applied within and outside of Natura 2000 sites (Commission of the European Communities 1992).

The Natura 2000 Network was established for the protection of endangered species and habitat types. The member states of the EU were obligated to establish a coherent network of protected areas with the adoption of the Habitats Directive (Habitats Directive 1992). The network of Natura 2000 consists of sites of Community Importance (SCI) under the Habitats Directive and Special Protection Areas (SPA) under the Birds Directive (EU 2009). Maintaining and restoring biodiversity on land and on sea is the major aim of this network. The declaration of marine Natura 2000 sites depends on the presence and distribution of specific species of marine mammals, sea birds and fish, and the occurrence of precious habitat types of international importance. These are habitats with high conservation values like sandbanks and reefs. The aim of designating the sites is to protect these special, threatened habitats and species. In 2004 Germany proposed six Natura 2000 sites in the German exclusive economic zone (EEZ) in the Baltic Sea to the European Commission (Federal Ministry for the Environment Nature Conservation Building and Nuclear Safety 2004). These comprised five pSCI and one SPA. These proposed areas represent about 25 % of the whole Baltic Sea area of Germany (Federal Agency for Nature Conservation (BfN) 2015) (assessed 30th of September 2015, https://www.bfn.de/0314_daten-meeresflaeche.html).

The Pomeranian Bay was designated in 2005 as a German nature conservation area and European SPA under the EU Birds Directive and serves as a protected area for birds. The five other sites (Fehmarn Belt, Kadet Trench, Adler Ground, Western Rønne Bank and Odra Bank) proposed as Habitats Directive sites were confirmed in 2007 by the EU as SCIs (EU 2009, Federal Agency for Nature Conservation (BfN) 2015). Within six years the EU member states are obliged to set the proposed sites under protection as Special Areas of Conservation (SAC) and present management plans. Although 271 habitats-directive sites were reported for Schleswig-Holstein in 2010, management plans for 11 sites were finished and 15 are under preparation only (assessed 30th of September, https://www.bfn.de/0316_stand-umsetzung-deutschland.html). Management plans are currently delayed and the status of the SCIs has not changed yet since 2007.

In the Palearctic, the Baltic Sea is the most important wintering area for migrating diving waterbird species (Skov 2011). Its clustered occurrence leads to high density areas which overlap widely with coastal fisheries even within protected areas (Pedersen et al. 2008).

One SPA, the Eckernförder Bight, with a size of 12,064 ha is located in the study area. This area serves as an important resting ground for seaducks (*Merginae*) (Ministry of Energy Transition Agriculture the Environment Rural Areas Schleswig-Holstein 2014). Additionally, harbour porpoise abundance is likely to be highest in the western part of the German Baltic Sea (Benke et al. 2014) with a relative high amount of mother and calf sightings (Viquerat et al. 2014). Concluding this could legitimate a declaration as a SAC with concrete management plans.

1.2. Study species

1.2.1. Seabirds

The German part of the Baltic Sea serves as an important wintering area for 773,000 sea ducks, 10,250 grebes, 5,600 divers and 5,800 auks a year (Bellebaum 2011).

Generally vision is the primary sense in birds (Martin 2012). It is assumed that Anseriformes (e.g. ducks), Gaviiformes (e.g. loons), Podicipediformes (e.g. grebes), Charadriiformes (e.g. gulls), Pelecaniformes (e.g. cormorants) which are foraging in the water column or close to the bottom use vision to detect and pursue prey (Martin & Crawford 2015). Accordingly, due to low visual ranges especially in turbid waters, detection ranges are comparably low. Cormorants have low detection ranges of less than1 m and therefore try to force hidden prey to perform flight reactions resulting in a better detection (White et al. 2007, White et al. 2008). Although foraging rhythms of visual predators are strongly influenced by light levels (White et al. 2007, Zimmer et al. 2008, Elliott & Gaston 2015) common murres (*Uria aalge*) perform frequently dives at night. This behaviour is assumed to rely on close-range visual perception or a non-visual perception to acquire randomly encountered prey (Regular et al. 2011).

Although little is known about underwater hearing in diving birds, adaptions of the outer and middle ear are supposed to protect the tympanum and middle ear from large changes in the pressure during a dive. In particular, feathers which are attached to muscles likewise muscles and blood vessels surrounding the external ear canal may function as a waterproof seal to prevent possible injuries while diving (reviewed in Dooling & Therrien 2012).

The visual perception of birds is of high importance in terrestrial and aquatic surroundings. Due to the fact that dives occurred also at night and diving depth with a maximum of 500 m could be ascertained for the emperor penguin (*Aptenodytes forsteri*) (Kooyman & Kooyman 1995) this behaviour likely depends on a different sense than vison because there is little light available at this depth and night. By reason that marine mammals and fish use sound for navigation, foraging and communication hearing is also suspected to be important for diving birds. Especially since individually distinctive vocalizations enable both emperor and king penguins to identify their partners within a noisy and dense packed colony of several thousand individuals (Jouventin 1982, Aubin et al. 2000). Highest acoustical in-air sensitivity could be assessed at 1000 – 3000 Hz across ten species of diving birds (Crowell et al. 2015).

Although in-air hearing ability of birds has been studied, knowledge about hearing of diving birds is lacking due to remote and inaccessible habitats (Crowell et al. 2015). Therrien (2014) measured underwater auditory thresholds for the first time in any diving bird species for longtailed ducks (*Clangula hyemalis*). In this experiment the longtailed-duck as a representative for the *Anatidea* responded to sound stimuli greater than 117 dB re 1 µPa between 0.5 and 2.86 kHz with the highest sensitivity at 2 kHz.

1.2.2. Seals

There are three seal species generally occurring in the Baltic Sea. These are the grey seal (*Halichoerus grypus*) which is the most abundant and largest, the ringed seal (*Phoca hispida*) and the harbour seal (*Phoca vitulina*). Grey seals occur over the whole Baltic Sea but densities are highest north of latitude 58° (Harding & Härkönen 1999). Extensive hunting and environmental toxins, primarily DDT (Dichlorodiphenyltrichloroethane) and PBC (Polychlorinated biphenyl), threatened seal populations substantially. Excessive hunting led to decreased population sizes but the low number of individuals in the early 2000s were due to lowered fertility rates caused by environmental toxins after 1965 (Bergman 1999, Harding & Härkönen 1999). Nevertheless their health status has slowly improved (Bergman 1999). Since the population is still increasing (Herrmann 2013) enormous conflicts as reported for Swedish coastal fisheries could become a problem in future (Königson 2011). It is assumed that the impact of accidental bycatches of seals on population demography and size is larger than reported but information is few (Korpinen & Braeger 2013). Highest acoustical in-air sensitivity could be determined at 1 – 20 kHz for grey seals (Ruser et al. 2014). However, more important for orientation during foraging behaviour of true seals (Phocidae) is the use of their vibrissae for hydrodynamic perception (reviewed in Hanke et al. 2013. This sense is comparable to the hydrodynamic perception with the lateral line system in fish and enables Phocidae to detect local water movements and follow hydrodynamic trails which could have been produced by passing prey items(Hanke et al. 2013).

Information on the grey- and harbour seals within the study area is rare due to the small population size.

1.2.3. Harbour porpoises

The harbour porpoise (*Phocoena phocoena*) is the only regularly occurring and reproducing cetacean species in the Baltic Sea (Siebert et al. 2006). Due to their small body size of 1.50-1.65 m (Bjorge & Tolley 2009) and high thermoregulatory costs caused by the frigid waters they inhabit, harbour porpoises have high energy demands (Koopman 1998). Their small size does not allow the storage of energy reserves thus leading to a high dependence on the perennial availability of food resources (Santos et al. 2004). Therefore, seasonal shifts in porpoise distribution (Verfuss et al. 2007, Benke et al. 2014) may be explained best by changes in prey densities (Sveegaard et al. 2012). Diet regularly consists of the most abundant prey items (Christensen & Richardson 2008), which is typical for a generalist and opportunistic feeder. In the adjacent Danish waters the most abundant fish species in the harbour porpoise diet are herring (*Clupea harengus*), cod (*Gadus morhua*) and gobies (*Gobiidae*) (Borjesson et al. 2003, Sveegaard et al. 2012). These species vary in size, caloric content, life cycle, depth preference and migratory potential. Therefore, the availability of preferred fish species varies throughout the year (Sveegaard et al. 2012). A daily consumption of 3.5-5.5 kg has been reported for porpoises in human care (Lockyer et al. 2003). Furthermore, there appear to be differences in the diet composition between harbour porpoises of different ages. For instance, gobies and shrimps are more commonly preyed upon by subadults (Lick 1991, Santos et al. 2004).

Due to morphologic and genetic differences two subpopulations of Harbour porpoises can be distinguished in German waters (Tiedemann et al. 1996, Huggenberger et al. 2002, Wiemann et al. 2010, Galatius et al. 2012). These are the more abundant Belt Sea subpopulation and the ‘critically endangered’ Baltic Proper subpopulation (Hammond et al. 2008). This subpopulation has been estimated recently to 447 individuals with a

95 % confidence interval ranging from 90 to 997 animals (SAMBAH 2014) whereas the Belt Sea subpopulation was estimated at 27,767 (CV=0.45, 95 % CI=11,946-64,549) in 1994, apparently decreased to 10,865 (CV=0.32, 95% CI=5,840-20,214) individuals in 2005 and increased to 18,495 in 2012 (CV=0.27, 95% CI=10,892-31,406) (Sveegaard et al. 2013). The Baltic proper subpopulation is restricted to the area of Arkona Sea and waters off the eastern Swedish coast, whereas the Belt Sea subpopulation occurs in the Skagerrak, Kattegat, Belt Seas, Oresund, Kiel Bight, Lubeck Bight and Fehmarn Belt Sea (Huggenberger et al. 2002).

1.2.3.1. Echolocation of Odontocetes

Marine mammals can be disturbed or affected in their natural behaviour by noise.

Harbour porpoises rely critically on echolocation for navigation, foraging and communication (Verfuss et al. 2005, Verfuss et al. 2009) and are therefore potentially affected by anthropogenic introduced noise (Dyndo et al. 2015). Negative effects of noise exposure on marine organisms can be acute (on a short time scale) or chronic (on a long time scale) (Tasker et al. 2010). Additionally, an alteration in hearing abilities can be the result of a loud sound exposure. These alterations can be temporary (temporary threshold shift = TTS) (Nachtigall et al. 2003, Nachtigall et al. 2004) or permanent (permanent threshold shift = PTS). In addition, lethal effects are also possible.

Signals of low frequencies can travel larger distances in comparison to signals of high frequencies. Wider ranges are affected by sounds of low frequencies but the concrete effects on any organism depends on species specific hearing abilities. Adverse effects of sounds outside their detection range are less presumably (Tasker et al. 2010).

Hearing in the water differs from terrestrial hearing systems because of the physical properties of air and water (Au & Hastings 2008). In terrestrial hearing sound is collected by the outer ear and transported to the ear drum through the ear canal. Alterations in the sound pressure set the ear drum into vibration which is transferred to the three middle ear bones (stirrup, hammer, anvil). Movements of the ear drum are converted into motion in the fluid of the inner ear by the stirrup. The auditory sensory cells are located in the inner ear and translate the motion of the fluid to electric nerve impulses which transmit information about the sound to the brain.

In contrast, aquatic hearing differs from terrestrial because biological tissue consists to a large degree of water which enables sound to transfer with very low loss from the environment into the body. Sound can enter the inner ear via the soft tissue and bones of the skull and lower jaw resulting in an alteration of the stimulation of the ear drum. For that reason the functionality of the air-adapted ear in the water is restricted. As a result the sensitivity of hearing is decreased and it is also impossible to determine the direction of the sound source which is assumed to be the case for diving birds.

On the contrary, toothed whales (odontocetes) have a completely blocked and non-functional ear canal. However, the lower jaw is filled with a special type of fat with adjusted conduction properties to transmit the sound into the middle ear, which is encapsulated in the acoustic bulla. Due to the high density of the bulla, the sound in the fat channel can be translated into movement of the middle ear ossicles. The fat channel is the only pathway transferring sound to the middle ear in odontocetes because the bulla is not connected to the skull and is only attached by ligaments.

In water, sound is transmitted much faster in comparison to the transmission in air. The sound velocity in air accounts about 343 m/s at 20°C while the speed in seawater reaches about 1500 m/s. The visibility in the ocean is very poor which makes sound a much better long distance communication channel. As a result many marine mammals developed distinct hearing abilities and complex sound communication. Signals of lower frequency can travel larger distances in comparison to signals of high frequencies. The acoustic energy of a sound is represented by the sound pressure. The sound pressure level corresponds to a mean of the effective pressure for a defined period in time in reference to a standard pressure. In detail acoustic pressure is indicated in decibel (dB) which is the root mean square of acoustic pressure. Due to the logarithmic scale an alteration in the SPL of ±6dB results in a doubling of the sound pressure. In underwater acoustics the reference pressure is defined as 1 µPa. Due to different reference pressures and the differences in impedance in air and water SPL values in water cannot be directly compared to those in air.

For a comparison of sound of different durations the sound exposure level (SEL) could be used. The correction for the time period is enabled by a measure of the accumulated energy over a defined period of time. The SEL is determined as a level in decibels over a precise period, defined as the integral of the squared acoustic pressure with respect to time. Standard psycho-acoustic techniques were used to assess the hearing threshold for a stranded male harbour porpoise (Kastelein et al. 2002). Narrow-band sinusoidal frequency modulated signals were preferred over pure tones to reduce propagation effects like multipath interferences in the signals reaching the tested animal. Values for hearing threshold could be slightly lower by virtue of fact that narrow-band frequency modulated signals have a slightly higher arousal effect than pure tones. However, the relative stable SPL of the signals received by the animal compensates this known error but prevents a comparison with other studies. The hearing sensitivity of one harbour porpoises was tested for 18 center frequencies between 25 and 18000 Hz. Maximum sensitivity was reported for frequencies between 100 and 140 kHz with values from 32 to 36 dB (re 1 µPa) (Fig. 1).

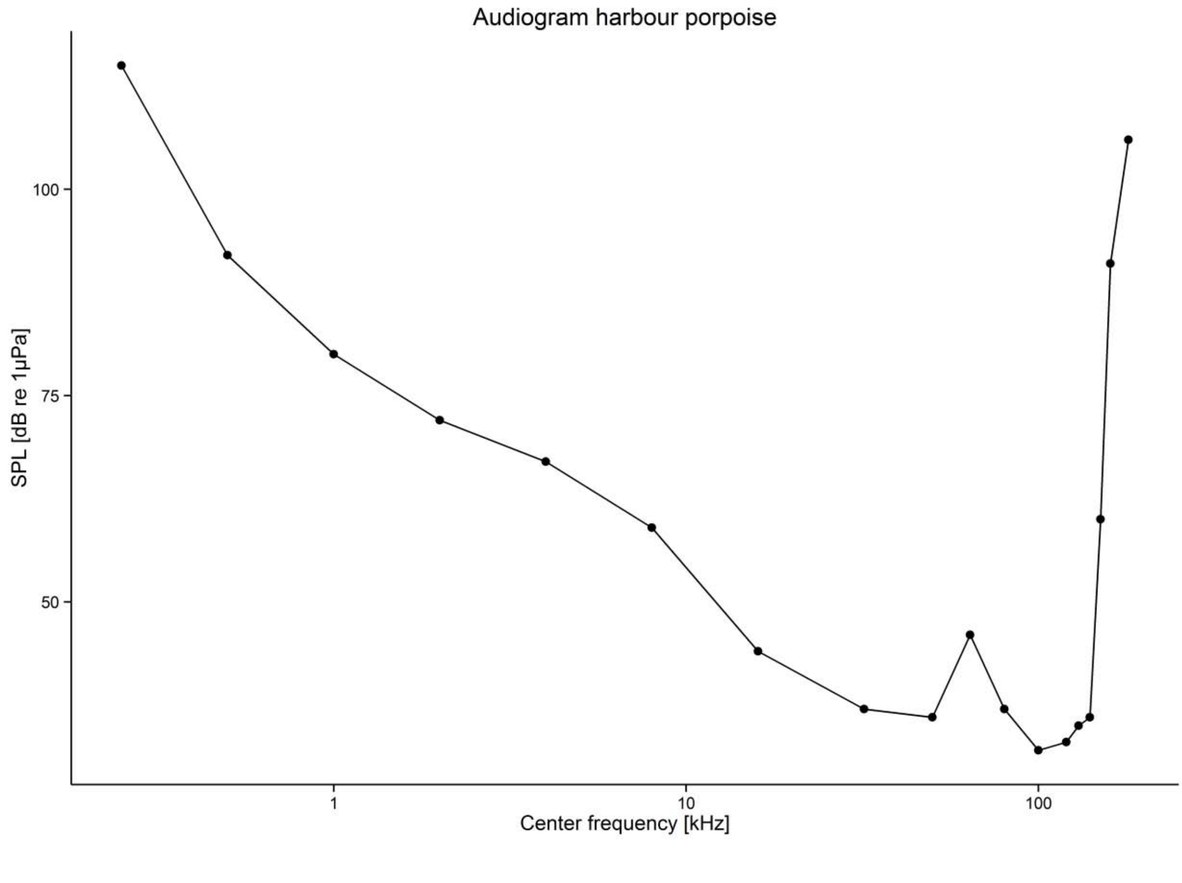

Figure 1: Audiogram of a male harbour porpoise tested in Hardewijk dolphinarium. Mean 50 % detection thresholds in dB (*re* 1 µPa) for the tested narrow-band frequency modulated. The figure was created according to the results in Kastelein et al. (2002) table 1.

Toothed whales (Odontoceti), to whom the harbour porpoise belongs, developed an active sense, echolocation, to acquire information about their environment. This active sense has evolved independently in mammals multiple times and (Kellogg et al. 1953, Griffin 1958, Griffin & Thompson 1982) and birds (Konishi & Knudsen 1979, Brinkløv et al. 2013). Nonetheless, echolocation with the aim to search, find and hunt prey is only used by laryngeally echolocating bats and toothed whales. They emit series of high frequency clicks to receive information on their surrounding as well as on possible prey items through the returning echo (Au, W. W. L. 1993). In the case of harbour porpoises the high frequency signals have their highest energy content at around 130 kHz (Au, W. W. L. 1993; Au, W. W. L. and Hastings 2008a; Au et al. 1999).

Odontocetes evolved phonic lips which are located high in the blowhole and function as specialized sound producing structures (Fig. 2). The pneumatic actuation of the phonic lips while air is forced past them enables odontocetes to produce click signals (Cranford et al. 1996). The produced click propagates into the adjacent fatty melon which is capable of the animals' characteristic round-headed look and enters the water as a directional beam (Au, W. W. L. et al. 1986). The beam is asymmetric with a slightly dorso-ventral compression and has a horizontal range of 13° and a vertical range of 11° (Koblitz et al. 2012). During the terminal phase of a prey capture event harbour porpoises broaden their biosonar beam up to 30° (Wisniewska et al. 2015). The size and properties of the melon are expected to affect the transmission beam of emitted signals from the head (Varanasi et al. 1975, Aroyan et al. 1992, Harper et al. 2008).

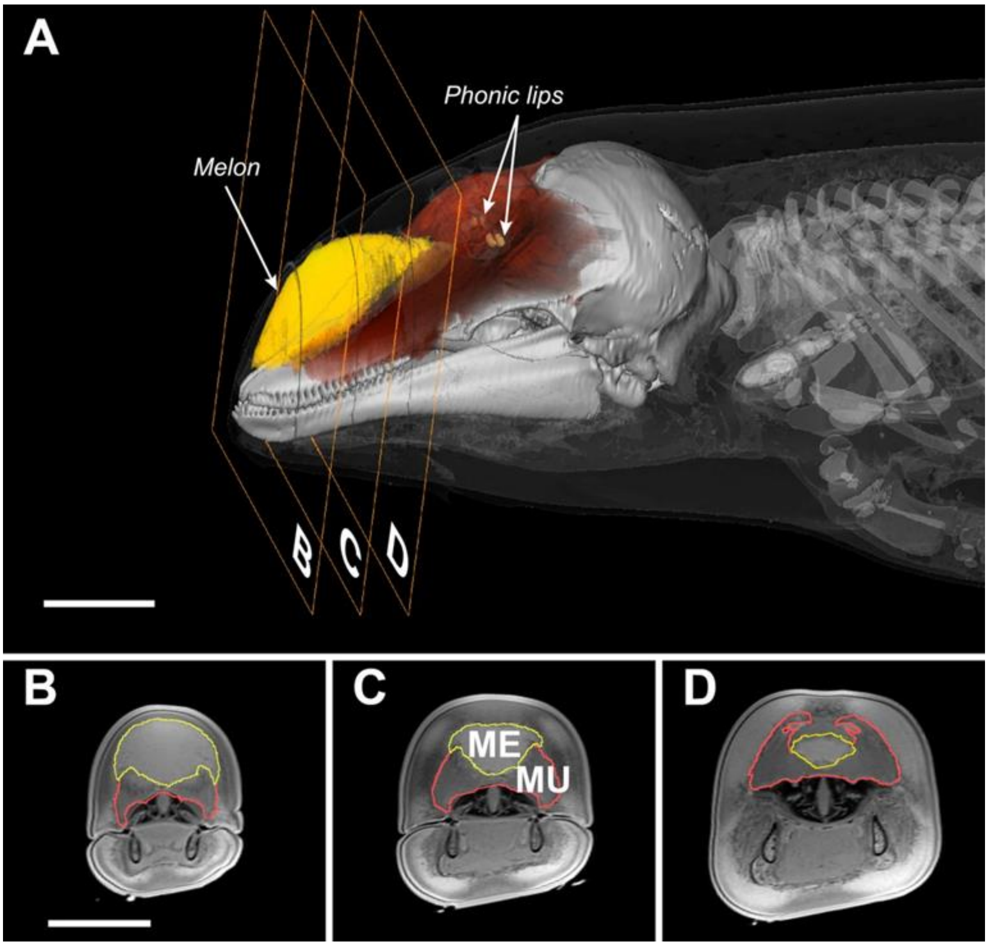

Figure 2: Cranium of a young harbour porpoise shown by a transverse MRI scan(Wisniewska et al. 2015). The white bars indicate 5 cm. The melon is highlighted in yellow and the phonic lips in light brown. Attached muscles are red colored.

Returning echoes can only be detected by the echolocating harbour porpoise if the emission level on a statistical basis is higher than the threshold in the auditory system for detections (Madsen and Surlykke 2013). This threshold can be defined by the typical and individual hearing threshold, clutter and ambient noise. Therefore a success in foraging with echolocation can only be guaranteed by the emission of sufficiently high SPL. Echolocating predators like toothed whales and bats are able to detect small prey targets at a distance of many body length in uncluttered spaces (Wisniewska et al. 2015) which could be achieved by the emission of biologically generated sounds with the very high SPL (Madsen and Surlykke 2013). In harbour porpoises the mean source level could be determined at 191 dB re 1 µPa pp at 1 m in free ranging animals (Villadsgaard et al. 2007). For captive animals, measured source levels are 30 dB lower (Møhl and Andersen 1973) (Møhl and Andersen 1973; Akamatsu et al. 1994; Teilmann et al. 2002). Harbour porpoises are known to echolocate almost constantly, emitting echolocation click trains on average every 12.3 s (Akamatsu et al. 2007, Linnenschmidt et al. 2013). A variability in the maximum period without recorded clicks could be shown for three free ranging harbour porpoises by analysing data of acoustic data loggers (Linnenschmidt et al. 2013). Maximum periods with no clicks or clicks with amplitudes below recording threshold of 142 dB (peak-to-peak re 1µPa) of between 99 s and 21.67 min could be shown for the three individuals.

Harbour porpoises use echolocation for orientation and foraging during daylight in relatively clear water conditions, independent of their ability to use eyesight or not when being blindfolded (Verfuss et al. 2009). Therefore echolocation is the most important sense for orientation.

In comparison to other toothed whales using broadband signals, the variability in the frequency of harbour porpoise vocalizations is small (Au et al. 1999). The emitted clicks of harbour porpoises are highly stereotypic with a peak frequency around 130 kHz, a duration of approximately 100µs (Figure 3) and a narrow bandwidth with no energy below 100 kHz (Møhl & Andersen 1973, Villadsgaard et al. 2007). Harbour porpoises are therefore well suited for such acoustic monitoring devices due to their highly stereotypical clicks (Villadsgaard et al. 2007).

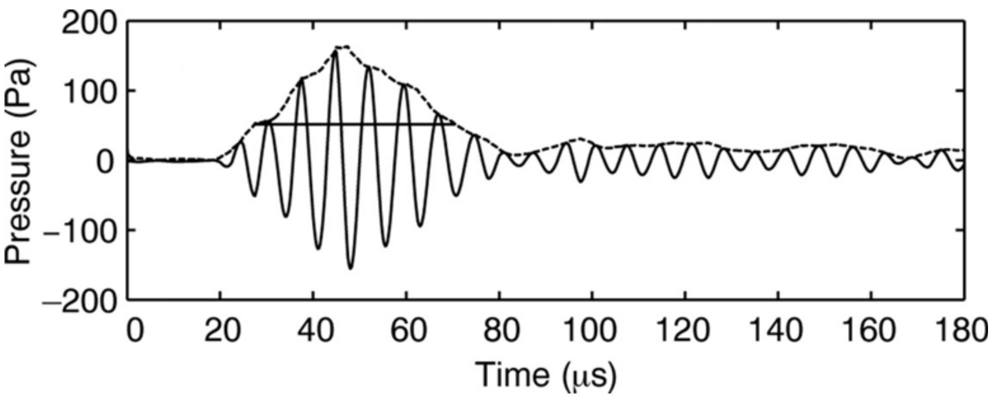

Figure 3: Single click of a harbour porpoise with signal envelope (dotted line) and the -10 dB duration of the click (horizontal line) (adapted figure from Villadsgaard et al. (2007)).

1.2.3.2. Communication of harbour porpoises

Harbour porpoises use specific click patterns for orientation and prey capture (Verfuss et al. 2005; 2009; DeRuiter et al. 2009), but also for intraspecific communication (reviewed in (Koschinski et al. 2008; Clausen et al. 2011). Behavioural categories could be discriminated by patterns in the inter click interval (ICI) this means the time between two clicks.

A minimum ICI of below 10 ms is believed to indicate sequences in the echolocation behaviour of harbour porpoises that are related to foraging (Carlström 2005, Todd et al. 2009, Verfuss et al. 2009, Linnenschmidt et al. 2013, Nuuttila et al. 2013). Communication sequences have been classified by simultaneous visual and acoustical observations (Clausen et al. 2011).

Intraspecific warning signals which made the confronted harbour porpoise immediately turn away were categorized as ‘aggressive behaviour’. The click trains of aggressive behaviour are characterized by upsweeping, high repetition rates with a length of about 1.3 s (0.4 – 2.3 s) associated with a rapid scanning movement of the head (Figure 4). Minimum click rates of 200 clicks / s and maximum click rates of approximately 1000 clicks / s could be measured. Aggressive communication signals consisted of one to four of these click trains per event. A female was observed emitting aggressive behaviour sequences in the direction of its calf at short distances of less than 1.5 m. The calf always reacted towards the signal by swimming away rapidly (Clausen et al. 2011).

Communication signals with high repetition rates suffer from physical limitations. Aggressive behaviour sequences could be determined at distances less than 1.5 m (Clausen et al. 2011) which could be a consequence of the high absorption in the water. Additionally, the emitting porpoise and the receiver must be close to each other because of the narrow echolocation beam (Koblitz et al. 2012, Wisniewska et al. 2015).

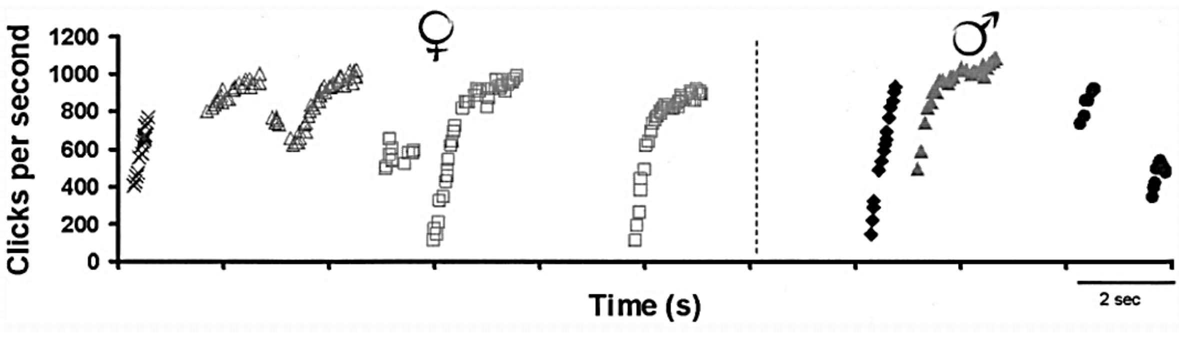

Figure 4: Several sequences of aggressive behaviour of harbour porpoises recorded at Fjord & Belt in Kerteminde (Clausen et al. 2011). Sequences are separated by different symbols for the female (left) and the male (right).

1.3. Fisheries

Different kind of gear types are used in fisheries which can be divided into the groups of active and passive fishing methods. Most common gear types used by German fisheries in the Baltic are trawls (active) and set-nets (passive). Bottom-set gillnets belong to the static gear types which are very common in German Baltic Sea fisheries. The net-row is placed on the bottom and anchored at both ends. A weighted ground line at the bottom and a buoyed float line at the top arrange the net in a vertical position on the seabed. In this thesis bottom-set gillnets are abbreviated as set-nets. This fishing gear is very common in small-scale fisheries along the coasts of the German Baltic Sea. The German fleet can be separated into six different classes.

1) Vessels <12 m with passive fishing gear
2) Vessels >12 m with passive fishing gear
3) Trawler <40 m
4) Beamtrawler
5) High Sea trawler, >40 m, pelagic
6) High Sea trawler, >40 m, bentic

A vessel monitoring system (VMS) was introduced for fisheries controls in EU fisheries. This system was established to provide information on location, course and speed of vessels larger than 12 m on regular intervals to the fisheries authorities. In addition an electronic recording and reporting system (ERS) was introduced to collect and provide data on catch, landing, sales and transshipment to the national authorities for all vessels larger than 12 m (European Commission Fisheries 2011). Vessels larger than 8 m and shorter than 12 m are obliged to fill out handwritten log books. The German fleet consists of 1,139 fishing vessels smaller than 12 m which are neither covered by the VMS nor the ERS. The total effort in set-net fisheries of the German fleet could not be assessed to date due to the fact that current EU fishery statistics do not cover boats with a length smaller than 8 m. Almost all of these vessels belong to the Baltic Sea coastal fisheries which use passive fishing gear like set-nets, fyke nets and longlines (Federal Ministry of Food and Agriculture 2014). These small boats represent the majority of fishing vessels along the German Baltic coast fishing with set-nets. (C.v.Dorrien, Thuenen Institute of Baltic Sea Fisheries, pers.comm.). The most important commercially used fish species in the German Baltic Sea are Baltic cod (*Gadus morhua*), Baltic herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) (ICES 2015). Baltic Sea cod has been divided into an eastern and a western stock which have been managed separately since 2004. The western Baltic cod stock decreased since the early 1980s to a low in 2010 and is still alarming low (ICES 2015).

1.4. Bycatches

The set-net as an arranged barrier blocks the pathway of larger animals while travelling close to the irrespective of target or non-target species (Žydelis et al. 2013), resulting in bycatches. A bycatch is the unintentional capture of non-target species during fishing operations. The probability of bycatch is dependent of multifaceted factors like location, depth and mesh size of set-nets, net-material and additionally depends on the range of species present (reviewed for seabirds in Žydelis et al. 2013). Compared to other fishing gear bycatch numbers are highest in set-net fisheries for seabirds (reviewed in Žydelis et al. 2013) and harbour porpoises (ASCOBANS 2002).

However, there is no practicable regulation to monitor bycatches of seabirds and harbour porpoises (Sonntag et al. 2012, COFAD 2014).

The population declines of seabird populations are faster compared to other bird groups (Croxall et al. 2012). This decline is suspected to be caused by incidental bycatches in fisheries (ICES 2008). 14,000 ducks, primarily common eiders were bycaught in one year in set-nets only along the eastern coast of Schleswig-Holstein which represents a proportion of up to 17 % of the wintering bird populations (Kirchhoff 1982). Skov (2011) described a decrease in bycatch numbers of seabirds for the last years which are, however a result of reduced population sizes. The potential of unintentional bycatches is affected by multiple factors like visibility, water depth, soaking time, weather conditions, abundance of seabirds, mesh size, twine diameter and time of day (Varennes et al. 2013, Žydelis et al. 2013).

Entanglement in gill nets is highest for seabirds that are diving for fish or benthic fauna (Žydelis et al. 2013).The species which are most affected in numbers in the Baltic Sea are seaducks (*Merginae*) (east and south), diving ducks (*Anatidae*) (south) and auks (*Alcidae)* (west). This composition represents generally the distribution of these species (Žydelis et al. 2009). Loons (*Gaviidae*), grebes (*Podicipedidae*), auks and cormorants (*Phalacrocoracidae*) are more vulnerable to bycatch in regard of their abundance (Dagys & Žydelis 2002) because of their foraging technique by pursuing their prey underwater. Benthivorous ducks in contrast perform straight dives to the bottom moving relatively little on a horizontal level and are therefore less affected (Žydelis et al. 2009).

To reduce incidental bycatches of diving seabirds numerous technical adaptions were investigated. Reduced net heights, additional preceding larger sized meshes or conspicuous bright lines had no effect on bycatches but led to decreased catch rates (Mentjes & Gabriel 1999). A reduction of the total allowable catches had no effect on bycatch numbers as shown for longtailed ducks (Bellebaum et al. 2013). On one side the temporal use of longlines during the winter when seaduck densities are highest could reduce seaduck bycatches. On the other side this fishing technique has to be improved to guarantee catch rates comparable to set-net fisheries (Mentjes & Gabriel 1999).

Stranded harbour porpoises along the coast of Schleswig-Holstein are collected and examined by the Institute for Terrestrial and Aquatic Wildlife Research since 1990. In the early 90s the number of delivered bycatches by fishermen was higher than the number of stranded individuals. In 2003 to 2009 there was an increase in the total number of animals collected from beaches while at the same time the number of animals delivered directly by the fishermen decreased rapidly due to the fact that fishermen are aware of a bad public perception. After 2009 the total number of stranded animals in Schleswig-Holstein decreased. Since 2000 there is an increase in stranded animals that could be categorized as bycatches (Siebert et al. 2009, Koschinski & Strempel 2012) with a maximum in 2009 (Wehrmeister et al. 2013; Figure 5).

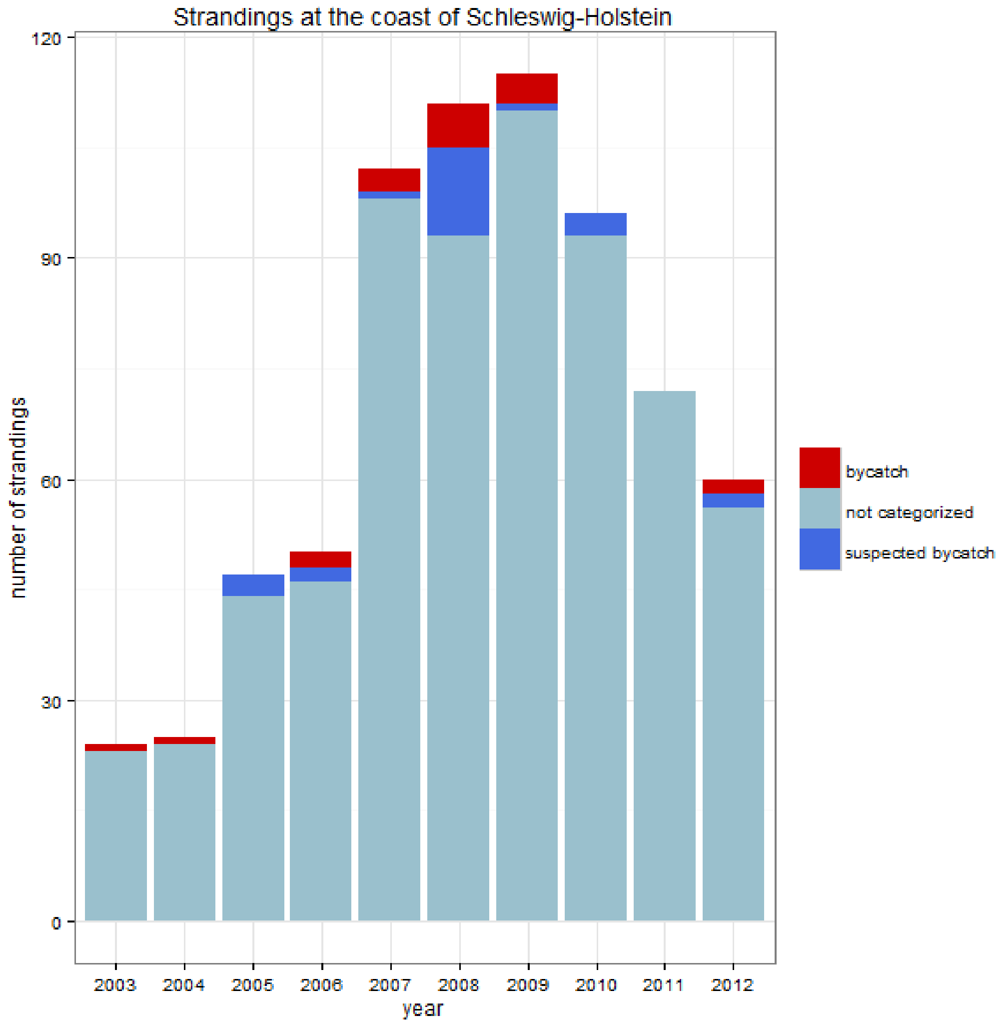

Figure 5: Number of strandings at the coast of Schleswig-Holstein from 2003-2012. Individuals have been examined for indications of being bycaught in set-nets except for the year 2011. The figure was created according to the results of Wehrmeister et al. (2013).

A recent analysis of stomach content lead to the assumption that the bycatch of harbour porpoises in bottom set gillnets occurs more often when feeding close to the bottom ('bottom grubbing') while standing vertically in the water column with the sonar beam directed on the seabed (Leopold et al. 2015). The introduction of monofilament nets enhanced the potential of possible bycatches in recent decades. These nets are indeed better to handle, longer lasting and much cheaper but they are also less visible to non-target species and lead therefore to higher numbers of bycatches (Žydelis et al. 2013). Boström et al. (2013) could show that the presence of a set-net has no effect on the distribution of harbour porpoises which could indicate, that set-nets are not recognized as a potential danger at larger distances. The weak received echoes from gillnets could be interpreted by the porpoise as not harmful and therefore penetrable although harbour porpoises are able to detect a gillnet at distances between 3-6 m (Kastelein et al. 2000a) or even at 13-26 m (Villadsgaard et al. 2007). Especially in situations with additionally entangled prey items in the net, the returning echoes from these stronger targets are likely to mask the weaker echoes from the gillnets (Au & Jones 1991). However, an improvement of net detectability could reduce the predisposition of bycatches. A reduction in bycaught individuals could be achieved by the use of net material with a higher density (Cox & Read 2004, Koschinski et al. 2006, Larsen et al. 2007, Mooney et al. 2007). This decrease was rather caused by the enhanced stiffness of the net than the acoustic reflectivity which could not be enhanced by this approach

Although both, barium sulphate and iron oxide-enhanced nets, showed increased reflectivity compared to control nets, the detection range was determined as too low to avoid an entanglement for harbour porpoises approaching the net from greater angles than 40°(Mooney et al. 2007). The calculation of a possible detection range, however, based on a maximum sound level of 160 dB (Mooney et al. 2007). Villadsgaard et al. (2007) reported maximum sound levels of 205 dB for harbour porpoise clicks. Consequently, harbour porpoises might be able to detect set-nets at larger distances as reported by Mooney et al. (2007) hence.

1.5. Acoustic alarming devices

The approach to decrease bycatches of harbour porpoises by the use of acoustic deterrents seems attractive for the fishermen because substantial changes in their fishing gear or behaviour are not required. Therefore this could be a less expensive attempt compared to other approaches (Dawson et al. 2013). Sound emitters can be separated into two different groups regarding their acoustic properties and target. On the one hand so called acoustic harassment devices (AHDs) are generating high sound levels of over 180 dB (re 1 µPa at 1 m) to prohibit depredation of marine mammals from fishing gear (Quick et al. 2004, Harris et al. 2014) or to deter harbour porpoises from risky areas like zones of pile driving during offshore windpark constructions (Brandt et al. 2013). On the other hand acoustic deterrent devices (ADDs) which emit sounds of lower intensity (<150 db re 1 µPa at 1 m) are used to decrease bycatches. These devices are also called pingers (e.g. reviewed in Dawson et al. (2013)).

Flight reactions and an increase in the respiration rate could be shown by the introduction of several pingers (standard Dukane alarm, random Dukane alarm, Bird alarm, XP-10, 2MP, HS20-80) in a test tank with harbour porpoises (Kastelein et al. 2000b). Harbour porpoises reacted to all pingers in the same way but have shown the strongest reactions to the pinger with the highest source level (Kastelein et al. 2001). In addition to the described reactions a decrease in surface time and echolocation rate occurred when two harbour porpoises were exposed to pinger like sounds (100-1540 kHz, 200 ms, repeated once in every 4s, 153 dB re 1 µPa at 1 m) (Teilmann et al. 2006). A temporary habitat displacement by the use of two types of pingers (Airmar: 10 kHz tone; SaveWave Black Saver: 30-160 kHz sweep) of harbour porpoises was determined in an experiment that should simulate set-net fisheries (Kyhn et al. 2015).
Studies in commercial fisheries could prove decreased bycatch rates by the use of pingers (Carlström et al. 2009, Gönener & Bilgin 2009, Hardy et al. 2012, Larsen & Eigaard 2014). The AQUAmark100 pinger which has a wideband, frequency modulated ping at frequencies between 20 and 140 kHz and random pings at intervals between 4 and 14 seconds with a signal of 0.4 s, could significantly decrease the probability of harbour porpoise bycatches in set-net fisheries on monk fish (*Lophius americanus*) in Cornwall (Hardy et al. 2012).
Furthermore, the input of noise can have effects on the animal that do not compromise the acoustic perception directly. These masking effects reduce the ability to detect, recognize, or understand sounds of interest by acoustic interferences which can lead for example to decreased communication distances of animals. The masking power is dependent on the intensity of the noise signal, its direction, frequency and time. The more similar the two signals, the higher the masking effect. Shipping noise is unlikely to mask harbour porpoise communication because it contains much lower frequencies (Wright et al. 2007, Au & Hastings 2008, Tasker et al. 2010).
The effectiveness of pinger sounds on the decrease of harbour porpoise bycatches could be related to many different factors. Four main hypotheses are reviewed in Dawson et al. (2013) to explain how pingers could deter harbour porpoises:

1. Pingers are generally deterring and scaring off animals from the area of the emitted signals.
2. The echolocation activity could be enhanced by alarming sound of the pingers which enables the harbour porpoise to detect the net autonomously.
3. Pinger signals lead to interferences with the animals’ own echolocation clicks which confuses the animal and causes it to leave the area

4. The distribution of prey is changed by the pinger and therefore less porpoises are present in the area resulting in less entanglements

To improve the functionality of a pinger it is important to understand how the signal influences the harbour porpoise.

It could be shown that pingers lead to a decrease in echolocation activity which contradicts point 2 for standard pingers. Echolocating toothed whales are able to discriminate individuals by their clicks and do not suffer from masking effects by other individuals while travelling in a group (Branstetter et al. 2013) as well as assemblages of several odontocete species possibly feeding together (Au et al. 2013, Hodge et al. 2013, Au et al. 2014, Lin et al. 2015) therefore it is unlikely that an artificial signal could mask echolocation clicks or confuse the animal. Due to the fact that the main prey items in the Baltic Sea, herring and cod, are unable to hear pinger like sounds (Astrup & Mohl 1993, Schack et al. 2008), point 4 can also be rejected. Consequently, the effectiveness of pingers is most likely caused by a deterring function.

1.6. Limits in the use of pingers as bycatch mitigating devices

However, there are also limits in the functionality of pingers as a device for the mitigation of bycatches. Although general aversive reactions to pinger like sounds have been determined for captive animals, which were accompanied by decreased surface time and echolocation activity, a clear habituation occurred after several playbacks of the sound (Teilmann et al. 2006). Additionally a displacement of 208 m away from the introduced pingers (Dukane NetMarkTM 1000) could be determined for free-ranging harbour porpoises (Cox et al. 2001). However, the flight distance was halved within four days and the probability of porpoise detections within an area of 125 m around the pinger returned to the basal line within 10-11 days (Cox et al. 2001). A reduction in effectiveness of pingers over a period of about 50 days was also observed at 2 out of 9 stations in Carlström et al. (2009). Their findings indicate that habituation is more likely to happen if porpoises were confronted with pinger signals repeatedly (Carlström et al. 2009) which could occur especially in inshore areas where set-net fisheries is conducted in the Baltic Sea and harbour porpoises are at least seasonally resident (Dawson et al. 2013). Tendencies for a gradual habituation could be shown in an experiment simulating set-net fisheries with periodically occurring pinger signals while there was no evidence for a habituation for continuous signals (Kyhn et al. 2015). Consistently, no habituation occurred in a 12 month period to pinger signals in Hardy et al. (2012).

Alterations of the emitted signal may delay the habituation but could also be unnecessary if a porpoise only occasionally gets in contact with pinger signals (Teilmann et al. 2006). A large-scale utilization of pingers would increase the probability for an individual for the repeated receiving of pinger signals which could induce a habituation. In contrast, Palka et al. (2008) could not find evidence for habituation to pinger signals over a period of 10 years. Furthermore, the impact of habitat exclusion by the use of pingers must be considered simultaneously with a decrease in bycatches when conducted in marine protected areas (Kyhn et al. 2015).

Increased bycatch rates during pinger usage could be observed for set-nets with an incomplete acoustic coverage by pinger signals due to device failure (Palka et al. 2008). Acoustic gaps could be caused either by too large spacing of the pingers or damaged devices. Zones without pinger signals in pinger equipped nets could be classified by harbour porpoises as gaps to flight. This could explain the 2-10 fold increase of bycatches in net-rows with failed devices compared to net-rows without pingers (Palka et al. 2008, Carretta & Barlow 2011).

In summary, the convergence of fisheries and harbour porpoises is most likely because both are driven by fish abundance. The effectiveness of pingers could decrease over time if a habituation occurs. However, deterring signals which cause flight reactions could increase stress levels resulting in a possible cascade of secondary stressors and unpredictable physiological and psychological effects which could also have effects on fertility and survival rate an therefore on the population level (Beale & Monaghan 2004, Wright et al. 2007). An incorrect usage could even increase bycatches. Under these circumstances the best solution following Dawson et al. (2013) would be a device that stimulates echolocation activity to detect set-nets autonomously without excluding individuals from areas of fishing activities

1.7. Anti-bycatch device: Porpoise alarm (PAL)

In this thesis the effect of a new type of pinger (PAL = Porpoise alarm; Figure 6) on harbour porpoise bycatches in commercial set-net fisheries in the Western part of the German Baltic Sea was tested.

The data in this study was gathered within a larger project funded by the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV, Grant Nr.

2819100612 to F³, Boris Culik and Grant Nr. 2819100512 to Thünen Institute, Christian von Dorrien) in collaboration of the Thünen Institute of Baltic Sea Fisheries in Rostock and ‘F³-Forschung, Fakten, Fantasie’ in Heikendorf.

The transmitter emits synthetic clicks and click trains of harbour porpoises. It has a centroid frequency of 133 kHz and a source level of 158 dB (peak to peak re 1µPa 1m).

The PAL housing is conical shaped with a length of 19 cm, a diameter of 6 cm and a weight of 184 g. It can be attached horizontally or vertically to the float line of the net-row by either attaching one or both ends. Two different sized holes can be found at each end for the attachment with a rope (Figure 6).

This enables the fisher to adjust the attachment to his individual fishing gear and fishing operations. The air-filled housing has a low buoyancy to guarantee that bottom-set nets would not be carried away. The transmitter of the cone-shaped PAL emits omni-directional signals around its transverse-axis but not around the longitudinal-axis because of the air-filled housing containing the batteries. Therefore it is necessary to point all PALs in the same direction when attaching them horizontally to guarantee an acoustical coverage of the whole net-row.

The PAL can be programmed to generate up- or downsweep chirps, individual click rates or combined signals with freely programmable repetition rates and pauses (Culik et al. 2015). The emitted signal is species specific and should have no effect on seabirds or fish. Although Atlantic cod is able to hear frequencies of about 38 kHz (Astrup & Mohl 1993) it does not show flight reactions when hearing high frequency sounds (Schack et al. 2008).

Furthermore, it could be shown that the catch rate of cod, pollock and other fish species was not affected by the use of common pingers (Carlström et al. 2002) but has to be verified for the PAL also.

The warning signal, emitted by the PAL is not in the region of acoustical sensitivity of diving birds and therefore unlikely to be heard by seabirds (see chapter Seabirds).

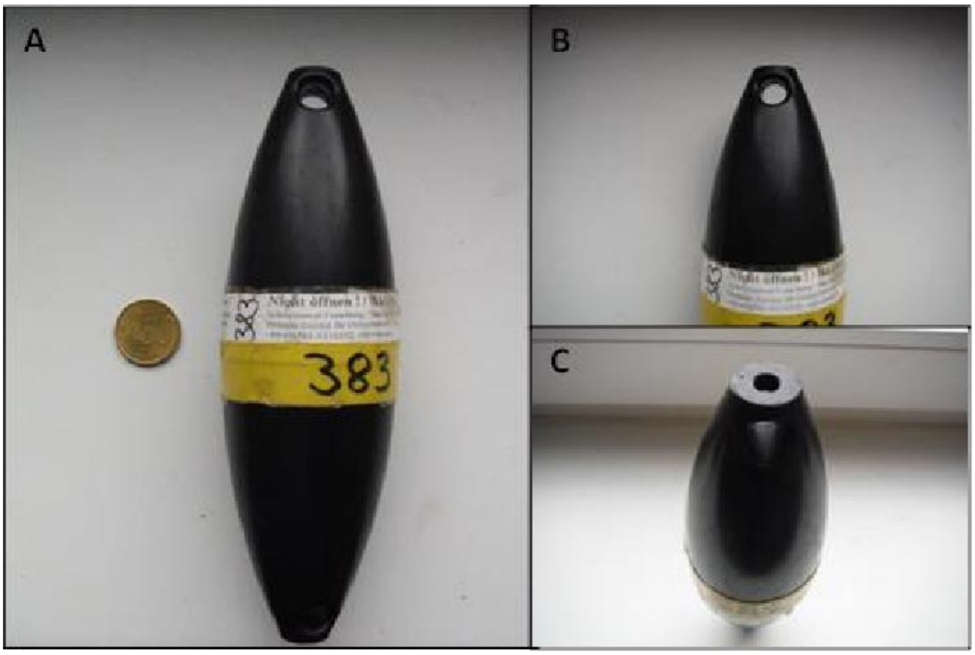

Figure 6: Pictures of the PAL which has a length of 19 cm, a diameter of 6 cm and a weight of 184 g. (A). PAL housing with two different sized holes for the attachment to the floating line at a lateral (B) and distal (C) position.

In addition to the emitted signal, reactions towards the PAL can also arise from the housing or the labelling. In comparison to gillnets, the housing has a much higher acoustic reflectivity due to its larger surface and air-filled body and should be better detected by an echolocating harbour porpoise.
The utilized signal is called ‘F3’ and simulates the so called ‘aggressive behaviour’ communication sequences that serve as an intraspecific warning signal (Clausen et al. 2011). ‘F3’ consists of two upsweep chirps over a total length of 1.22 s with a click rate of 173 clicks per second in the beginning up to 959 clicks per second in the end. In detail, the PAL generates a signal every 20 s, thus three signals per minute. One signal consists of about 1500 clicks resulting in 4,500 clicks per minute produced by the PAL.

In behavioural experiments, this intraspecific communication signal led to an increase in the distance from the harbour porpoise to the PAL while simultaneously increasing its echolocation activity (Culik et al. 2015).
The working hypothesis in this thesis is that an increase in echolocation activity should enhance porpoise attention and therefore their ability to detect set-nets autonomously. A reduced risk of entanglement in set-nets should be measurable. Previous experiments in

the field revealed increased click rates (+68 %) and a slightly increased distance to the PAL transmitter (+ 32 m) (Müller 2013, Culik et al. 2015).

1.8. Human dimensions of wildlife management

Conservation issues contrast with fisheries interests. An enlargement of monitoring programmes in areas of sensible habitats, as well as spatial and temporal restrictions or even an abandonment of set-net fisheries (BUND magazin , 2013) could lead to deteriorated competiveness of German fisheries resulting in negative economic and socioeconomic effects on the 1,400 crew members of the 1,139 German coastal fishing vessels (Sonntag et al. 2012, Federal Ministry of Food and Agriculture 2014).
Germany is a member of the ASCOBANS and therefore obliged to be active in the conservation of harbour porpoises and provide annual reports on bycaught individuals. The development and improvement of alternative fishing methods to reduce the bycatch of small cetaceans is one major aim in the JASTARNIA plan of ASCOBANS. The recovery of harbour porpoises should be achieved by following recommendations (ASCOBANS 2002):

1) Reduce fishing effort in certain fisheries
2) Involve stakeholders in the work of reducing bycatch of harbour porpoises
3) Replace fishing methods known to be associated with high porpoise bycatch (i.e. set nets) and introduce alternative gear that is considered less harmful
4) Implement a pinger programme on a short-term basis

The PAL has the potential to serve as a wildlife management tool following the 3rd and most challenging approach of Dawson et al. (2013) to solve conflicts between wildlife and fisheries by altering the animal’s behaviour and allowing fishers to continue gillnet use.

2. Material and methods

2.1. Experimental design

Fishermen using bottom-set gill-nets were asked to volunteer to test the new alarming device during their normal commercial fishing operations. Under real conditions approximately one half of the nets were equipped with alarming devices while the other half was equipped with dummies during the first period of investigation. These dummies consisted of the same housing as the PAL but had no sound emitter. The nets with dummies served as a control sample to guarantee that possible effects on bycatch rates are not induced by the housing but rather by the emitted signal. No dummies were used in the second period of investigation

In view of the observed increase in bycatches caused by a wrong spacing or failure of devices (Palka et al. 2008, Carretta & Barlow 2011), fishermen had to check the devices every day especially because this was its first usage in commercial fisheries.

2.2. Period of investigation

Data was gathered during two periods of investigation. The first period lasted from August 8th to November 30th in 2013. The second period started on March 7th and ended on October 14th in 2014. The number of fishing trips for each fisher was dependent on many different factors like weather conditions, seasonal restrictions regarding target species and functioning of fishing vessels. Fishing trips were only conducted under convenient sea state conditions. This evaluation was carried out by the fishermen and was therefore subjective. Generally no fishing trips have been conducted if a wind speed higher than 5 Beaufort was forecasted with no account on direction or if a wind speed higher than 3 Beaufort coming from the east was forecasted.

2.3. Observed parameters and data collection

Data was gathered on board of set-net fishery vessels in the Baltic Sea in an area where conflicts between set-net fisheries and harbour porpoises are expected. The abundance of harbour porpoises is highest in the Western part of the Baltic Sea (Benke et al. 2014), therefore bycatches are assumed to occur more often in this area. Fishermen could take part in this study if they fulfilled several criteria:

a) The fishing vessel needed to be large enough to take a scientific observer along.
b) The fishing effort had to be higher than five net-kilometres per day.

Finally, two German fishermen fulfilled these criteria and participated voluntarily in this study in the first period. In the second period only one of these fishers continued his participation.

The names of the fishermen are anonymised for privacy reasons and represented by the letters A and B to respect their personal rights. The participating fishers in this study collected data about their fishing trips in standard protocols (see Appendix). For each day data on fishing sites, net characteristics, effort, catch and bycatches of birds and marine mammals – if occurred - were collected. The fishers participating in this study were accompanied on a regular basis on their fishing trips by a scientific observer who kept an eye on the tested anti-bycatch devices and supported the fishermen in data collection.

Protocols with missing deployment or retrieval times were excluded for the analysis of fishing effort and catch rates.

2.4. Study area

The study area was restricted to the regions of normal fishing operations of those two fishermen who participated in this study. Figure 7 gives an overview of the study area. Detailed information on home ports of the vessels or net-positions are not shown because of data privacy reasons.

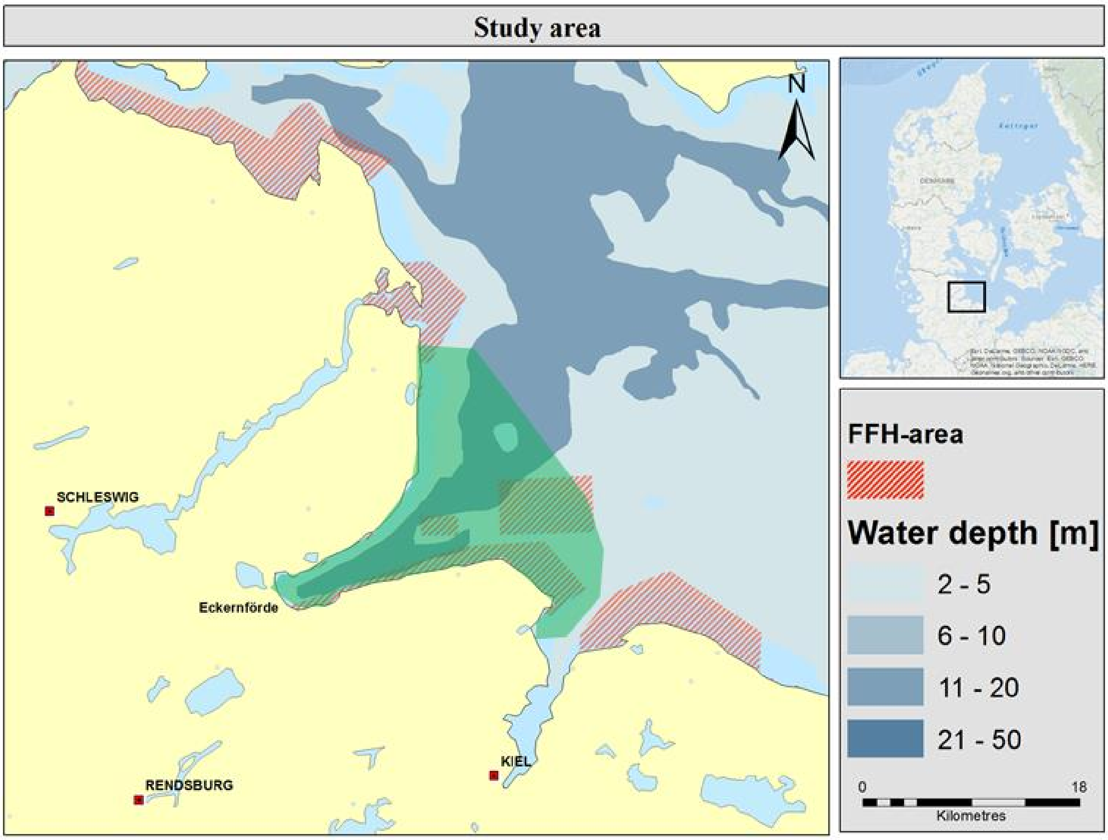

Figure 7: Overview of the study area (right, top) and fishing area of the 2 involved fishermen (left, green coloured). Differences in the water depth are represented by different shades of blue. FFH-areas are represented by red dashed areas.

2.5. Passive acoustic monitoring (PAM)

2.5.1. Cetacean-Porpoise detector (C-POD)

C-PODS are self-contained devices providing information on harbour porpoise presence and acoustic behaviour by logging echolocation-like clicks with the time of their occurrence and duration (Tregenza 2015). The advantage of acoustic data loggers in comparison to visual surveys from planes or vessels is that data can be gathered continuously over longer periods with no limitations in terms of daylight and weather conditions. Additionally, static devices that are moored at sea can gather information in challenging habitats without causing disturbance (Mellinger et al. 2007).

Harbour porpoises are well suited for such acoustic monitoring devices due to their highly stereotypical clicks (Villadsgaard et al. 2007). An omni-directional hydrophone records data of frequencies between 20–160 kHz. Click events and their time of occurrence, bandwidth, envelope, intensity and frequency can be logged. The setting of a C-POD can be adjusted according to the experimental design. For instance a limit can be set which delimits the maximum number of recorded clicks per scan. One scan has a length of 10 s and consists of 9.17 s of recording and 0.23 s processing time.

The C-POD has a buoyancy of 0.7 kg and is standing vertically in the water column with the hydrophone at the top. The upwards directed hydrophone leads to an acoustically 'blind spot' beneath it caused by the tube holding the electronics and batteries. The data is stored on a removable 4 GB SD card.

2.5.2. Classification of harbour porpoise click trains

After the retrieval of the C-POD the data can be read out and analysed by the software C-POD.exe. The data can be downloaded from the SD card and transferred into CP1 files. This is a raw format which enables a visualisation of several parameter of the recorded data. These are for example the inter click interval, click rate, sound pressure level, frequency or the envelope.

Harbour porpoise presence could be ascertained either by scanning the CP1 files visually or by transferring the CP1 into the CP3 format. For this purpose C-POD.exe uses an algorithm for the categorisation of harbour porpoise click trains. This algorithm is called 'KERNO classifier'. This algorithm assigns click trains into different categories the so called train-filters (Table 1). This categorization is based on the frequency and chronology of the detected click trains and has proved to be efficient in finding harbour porpoise detections.

Table 1: Description of the click train filters of the harbour porpose classifier in C-POD.exe:

Train-filter	description
High	click trains that have a high probability to originate from harbour porpoises
Moderate	click trains that have a moderate probability to originate from harbour porpoises
Low	there is a high risk that these click trains have been generated randomly and do not originate from harbour porpoises
Q	click trains are presumably generated randomly
No category	no harbour porpoise click trains

In areas of high density the KERNO classifier is used to find porpoise detections automatically with train filters set to ‘high’ and ‘moderate’. This is a conservative approach as the algorithms refuses more porpoise click trains than it categorizes ‘false positive’ click trains that do not originate from harbour porpoises. Whereas in areas of low harbour porpoise density train filters from ‘Q’ to ‘High’ are set to find all sequences with potential harbour porpoise click trains. All these classified sequences are scanned visually afterwards to find all harbour porpoise click trains.

2.5.3. Experimental set-up

Passive acoustic monitoring (PAM) has been carried out to measure the abundance of harbour porpoises in the study area. For this purpose, C-PODs have been attached to the end of a net-row (Figure 8; Figure 9). C-PODs were deployed randomly on 31 days in the second period of investigation. The effort of C-POD deployment was equal for PAL- and control-nets. In PAL-nets, the distance between C-POD and the first PAL in the net-row was short (approximately <5m). It was ensured, however, that no other net-row with PALs was at a distance shorter than 200m.

In this study the click limit was set to a maximum of 65,536 clicks per minute, resulting in 10,923 clicks per scan, to guarantee the detection of harbour porpoises while the PAL is simultaneously emitting signals. One PAL signal consists of approximately 800 clicks and is repeated at most once per scan. Even if echoes of the PAL signal, reflected by the surface and the bottom are recorded, the limit is unlikely to be reached just by the PAL clicks.

The GPS position and water depth were taken from the protocols. A mean depth for the whole net-row was calculated when exact depth for the CPOD position was missing. C-PODs were not deployed when water depth was shallower than 5 m due to expected echoes from the surface and equipment loss by passing vessels.

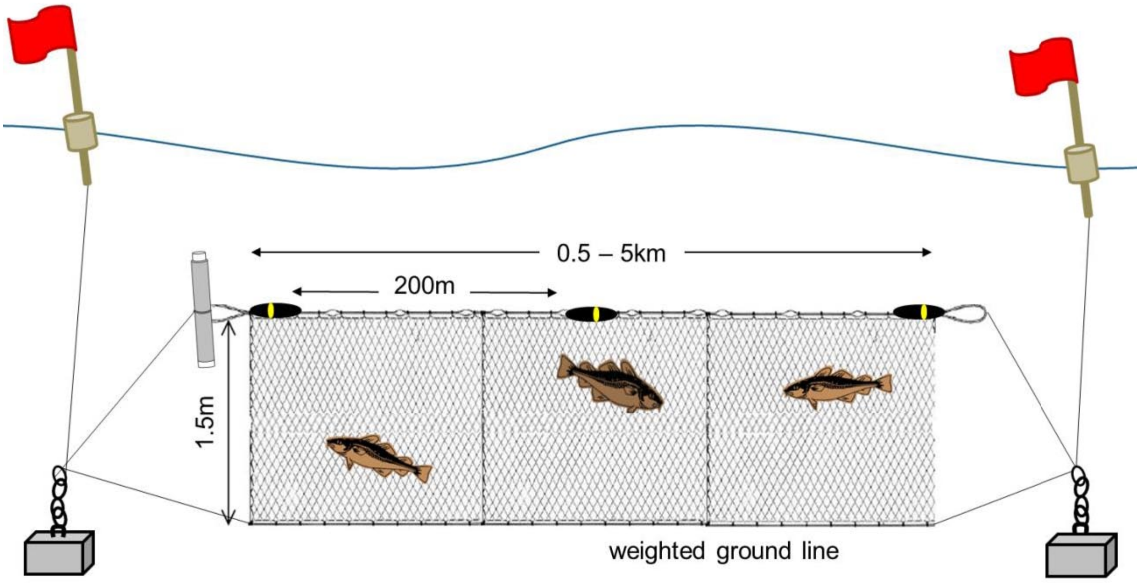

Figure 8: Experimental set-up with the net row standing vertically on the ground, fixed by an anchor at each end and a weighted ground line. Red flags are attached to the anchors to mark the end-positions of a net-row at the surface. Net-rows had a length between 0.5 and 5km and a height of 1.5m. The figure shows a net-row with attached PALs (black ellipses with a yellow line) on the head rope. The distance between PALs was determined at not exceeding 200m. C-PODs (grey cylinder) were attached randomly at the end of a net-row. In PAL-nets, as shown in this figure, the C-POD was attached at short distances to the PAL (www.engelnetze.com, edited).

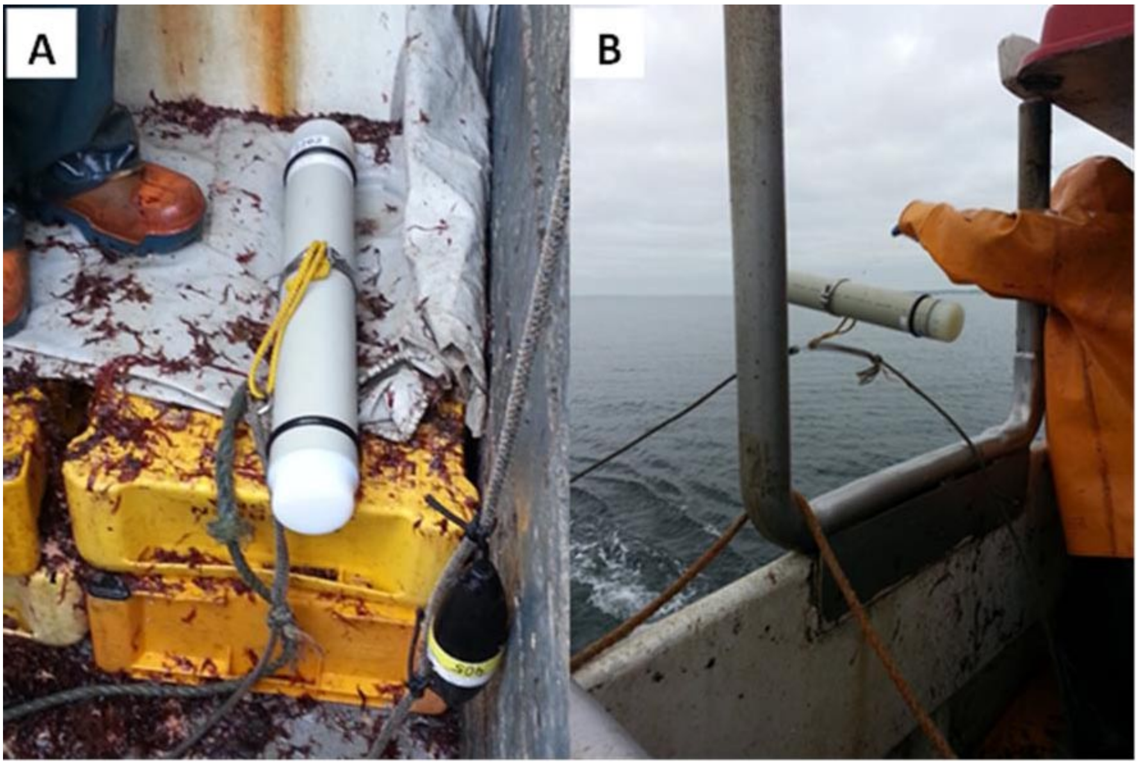

Figure 9: Attachment of the C-POD to the rope at the end of a net-row (A). Deployment of a C-POD (B).

2.5.4. Analysis of C-POD data

2.5.4.1. Visual screening

In this study, all CP1 files were screened visually to detect all porpoise like clicks. Data of both experimental groups was analysed using the same settings and method.

Click filters were set to exclude recordings which were not in the frequency range of harbour porpoise clicks. The minimum frequency was set at 110 kHz and the maximum frequency at 145 kHz.

The progression of ICI and the duration of individual clicks were used to verify clicks as being produced by a harbour porpoise (see Koschinski et al. (2008) for examples of detected harbour porpoises). Sequences containing a minimum of at least 5 clicks have been classified as a porpoise click sequence (Verfuss et al. 2007, Gallus et al. 2012).This approach was chosen to find all click trains originating from harbour porpoises because the period of investigation was short.

Any 10-minute period that contained at least one visually confirmed porpoise click sequence was classified as a porpoise-positive-10-minute-period (pp10min) resulting in a binary coded data set with zeros for absence and ones for presence. Due to a limited detection range and angle of the PAM approach, it is possible that harbour porpoises have been present without being detected. Consequently no conclusion is possible on absence data in terms of harbour porpoise detections. No information about the proportion of false negatives is available. Therefore, only minimum estimates of porpoise detections can be assessed

2.5.4.2. Automatic screening with the KERNO classifier

In addition, C-POD data was analysed by the KERNO classifier to test if the synthetic clicks, emitted by the PAL, would have been classified as being produced by a harbour porpoise.

Harbour porpoise presence could be overestimated in case of false classification of PAL signals.

The results of the automatic classification should be compared to the visually categorized porpoise detections.

For this purpose C-POD.exe (Version 2.044) was used with species selection set at 'NBHF' (narrowband high frequency) only, which corresponds to harbour porpoise echolocation trains. The quality of the train filters was set to high and moderate. Standard settings were used for the train filters (Table 2). According to the visual analysis, pp10min were exported.

Table 2: Train filter settings for the analysis of harbour porpoise detections with the KERNO classifier

Train-filters	Minimum	Maximum
Modal kHz	0	255
N in train	5	99
Clicks / s	1	2000
Mean SPL	1	999

2.6. Analysis of the PAL signal

The PAL signal was recorded in the harbour basin of Büsum to analyse the emitted signal in detail, targeting at the maximum source level (SL in dB re p-p 1µPa at 1m) and a spectral analysis. The experiment was conducted standing on the pier during high tide in a water depth of 4 m. A TC 4014 (Reson, USA) hydrophone with a measured sensitivity of -186.5 dB re 1V/µPA was used for the recording. The hydrophone and the PAL were deployed in a depth of 2 m. The hydrophone was fixed at a distance of approximately 1.5 m away from the pier. The PAL was attached to a rope, weighted by an anchor and buoyed at the surface by a floating body. Thus, the PAL could be moved and deployed at different distances to the hydrophone. The PAL was also deployed at a distance of approximately 1.5 m away from the pier.

A custom made program (written in LabView) was used for the recording at a sample rate of 400 kHz (16 bits) and a clipping level (c) of 1 V. The recording was amplified by 40 dB by a B1501 hydrophone amplifier (etec, Denmark). Additionally, the recording was filtered by -3dB with a highpass filter (1st order) at 1kHz and with a lowpass filter (1^{st} order) at 360kHz. The signal was recorded at different distances from 1 to 52 m. The distance was determined via laser rangefinder (Nikon Laser 550A S, Japan).

The recordings were afterwards edited in Adobe Audition (Version 3.0) and filtered again by a Butterworth highpassfilter (8^{th} order) at 10kHz and a Butterworth lowpassfilter (8^{th} order) at 180 kHz.

It was ensured that during all recordings no vessels were passing by and weather was stable with no rain and low swell.

The recordings were analysed in R (version 3.1.0) (R Core Team 2014) to determine the SL and analyse the frequency of the emitted signal.

The measured voltage (x=peak-to-peak value of signal) was converted into dB using following formula*(Au & Hastings 2008)*:

$$PAL\ dB = 20*\log_{10}(x)$$

The transmission loss over distance (r) was calculated using following formula(Au & Hastings 2008):

$$TL=20*\log_{10}(r)$$

The SL [dB re 1µPa] was calculated with respect to the amplification (A), hydrophone sensitivity (S) and transmission loss over distance (TL) with following formula:

$$SL=PAL\ dB - S - A + TL$$

2.7. Data analysis

The protocol data was edited in Microsoft Excel 2010 and then analysed with the software R (version 3.1.0) (R Core Team 2014). Graphics were generated with the CRAN package 'ggplot2' in R (Wickham 2009). Maps of the study area and positions of bycatches were created using the ArcMap software (version 10.2.2.) under license (ESRI 2011). For the case that the exact position of a bycatch was missing, it was assumed that the bycatch took place in the centre of the net-row. The start and end positions of the net-rows were determined respectively by the fishers via GPS. The centre was calculated as a mean position for longitude and latitude each: $\text{row} - \text{center} = \frac{\text{start} + \text{end position}}{2}$. A value for minimum and maximum water depth for each net-row was collected and the mean water depth was calculated. For comparative reasons a standardized unit for CPUE (catch per unit effort) was calculated, the net-kilometer day (NKD) which corresponds to a net-string of 1 km and a soaking time of 24 h.

Although fisher A used three-layered nets infrequently, only single–layer nets were included in the analysis of catch- and bycatch rates. The sample size of three-layered nets was too low for an analysis for fisher A. Fisher B in contrast, used three-layered nets in most of the cases targeting at flatfish species and single-layer nets infrequently. To maintain the experimental conditions and exclude variations caused by different net properties data of three-layer nets was excluded for fisher A and data of single-layer nets was excluded for fisher B.

Data of caught fish was also standardized and transformed into kg per net-kilometer-day (kg/NKD). Data of caught fish was also restricted for fisher A who generally catches cod as a main target species but occasionally catches several flatfish species. Accordingly, due to the small sample size, only cod was included in the catch rate analysis.

A comparison of catch rates between Fisher A and B is not possible due to different target species and fishing gear.

2.8. Statistics

The statistical analysis was conducted with the software R (version 3.1.0) (R Core Team 2014). Several hypotheses were tested to verify that both experimental groups, PAL- and control-nets, are comparable:

1) The mean water depth at which set-nets were deployed shows no differences between PAL- and control-nets
2) The effort between set-nets in the two experimental groups shows no differences
3) The water depth at which C-PODs were deployed shows no differences between the two experimental groups
4) The effort in C-POD deployment shows no differences between PAL- and control-nets

In case that no differences between experimental groups could be detected we tested a series of hypotheses to analyse the possible effect of the PAL:

5) The catch rate between set-nets in the two experimental groups shows no differences
6) The relative bycatch rate between set-nets in the two experimental groups shows no differences
7) The presence of harbour porpoises at set-nets of the two experimental groups shows no differences

Additionally, the effect of the presence of a scientific observer on reported bycatch numbers was tested:

8) The presence of an scientific observer has no effect on the number of reported bycatches (separated for harbour porpoises and seabirds)

A Wilcoxon signed rank test was used to test the hypotheses 1-7. This test is suited for data that is not distributed normally and paired (the experimental groups are paired because set-nets were deployed in the same area, at the same time and at the same water depth).

A Mann-Whitney U test for unpaired samples was used for hypothesis 8. This test can be applied to unknown distributions and is comparably efficient like the t-test on normal distributions.

3. Results

3.1. Practicality of the PAL attachment

In the beginning of the study the PAL was attached vertically and at one end. This attachment was not firm enough resulting in intense hits against the edge of the vessel during the deployment of the set-nets. One consequence of this was a temporal disconnection of the batteries which led to a restart of the PAL. The first batch of built PAL could not restart autonomously after a strong hit. These hits usually happened during the deployment of set-nets but caused no damages on the housing. A correct restart was prevented by a software problem, resulting in PAL failure. This problem was solved in the second batch, after September 8, 2013. All data prior to this date were therefore excluded from data analysis.

Figure 10: Entanglement of a PAL in meshes. The PAL has been attached in a horizontal position to the floating line of a set net. Due to its tapered ends meshes could be caught resulting in twists which could lead to damages of the net material.

The second PAL batch was also attached differently. All fishermen found a horizontal attachment to be more practical. With this attachment, fewer meshes were entangled by the tapered ends of the PAL (Figure 10) resulting in a decrease of twists or damages of the net material. However, twists could not be prevented entirely.

Additionally, the probability of intense hits could be also decreased by a horizontal attachment. A few PALs were cracked during the retrieval due to too tight attachment to the rope. Therefore one side of the PAL was attached with a flexible rope. By this improved attachment PALs worked reliably over a period of approximately 45 days before the batteries had to be changed.

3.1.Data collection

In total, the study was conducted over 340 days resulting in 225 days with protocols for fisher A and 51 days with protocols for fisher B (three-layered nets only; Figure 11). Data was filtered for further analyses to exclude data gathered prior 8th of September 2013 and data on three-layered nets for Fisher A or single-layered nets for fisher B.

Additionally, only days with protocols for PAL- and control-nets per day were chosen for further analysis.

After filtering data, protocols of 186 days were available for fisher A and protocols of 29 days for fisher B.

Fisher A collected data in both periods of investigation but provided detailed information about catch rate for the second period only. Fisher B collected data only in the first period but provided detailed information about catch rates.

Data on harbour porpoise presence was collected between June and August in the year 2014 at set-nets of fisher A.

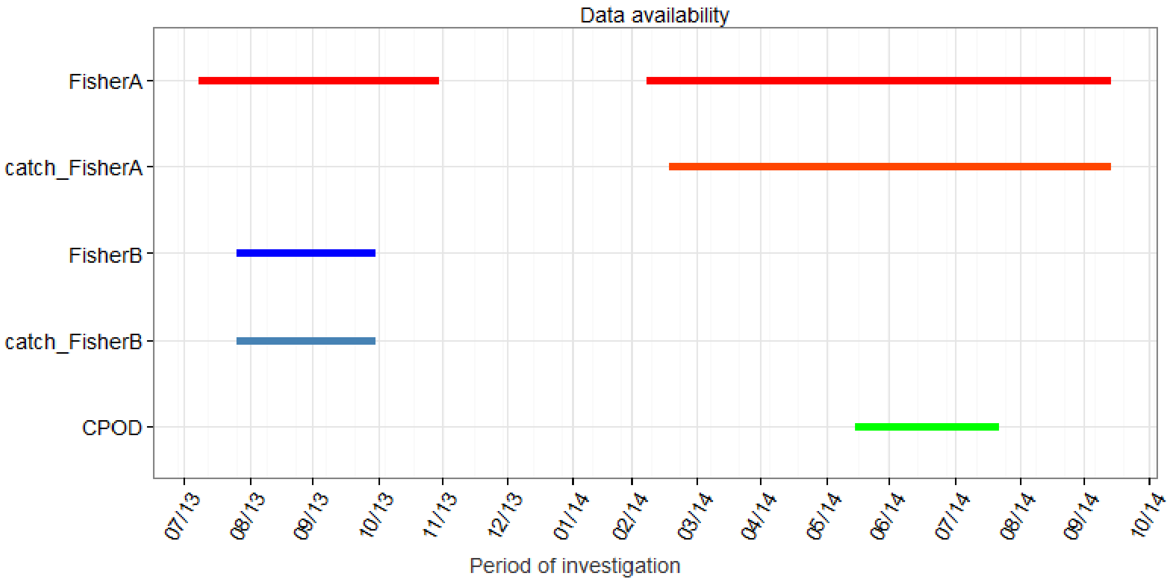

Figure 11: Data availability of fisher protocols, catch rates of the fishers and C-POD data for the whole period of investigation separated by different colouration.

The fishing area of fisher B was close to a harbour with relatively high levels of noise due to ship traffic and touristic activities. No bycatches were recorded for Fisher B and were not expected in the future due to expected low harbour porpoise abundance. Therefore this vessel was not selected for the second period of investigation.

3.2. Water depth

The mean water depth at which nets were deployed was calculated for each fishing trip and fisher (Table 3).

Table 3: Mean water depth (m) at which nets were deployed for both fishers with no account on experimental group

depth (m)	Fisher A (n=193)	Fisher B (n=30)
Minimum	2.5	10.0
Median	6.0	14.0
Mean	6.5	13.8
Maximum	19.0	19.5

Data was separated into the two experimental groups (Table 4; Table 5; Figure 12). Additionally, data was filtered for fishing trips after September 8, 2013 and days with net-rows for both experimental groups.

Table 4: Mean water depth (m) at which nets were deployed for fisher A:

depth (m)	control (n=193)	PAL (n=193)
Minimum	2.5	2.8
Median	6.0	6.0
Mean	6.4	6.6
Maximum	16.0	19.0

The mean water depth at which nets were deployed similar for control- (6.4 m) and for PAL-nets (6.6 m; Table 4). The deepest PAL-nets were deployed at a depth of 19.0 m whereas control-nets reached a maximum depth of 16.0 m.

Table 5: Mean water depth (m) at which nets were deployed for fisher B:

depth (m)	control (n=30)	PAL (n=30)
Minimum	10.00	10.00
Median	14.00	14.00
Mean	13.93	13.67
Maximum	19.50	16.00

Fisher B deployed PAL- and control-nets at similar mean water depth (PAL=13.67 m, control=13.93 m, Table 5). The minimum water depth of deployed nets was the same for both experimental groups (10 m). The maximum water depth at which nets were deployed differed by 3.5 m and was higher for control-nets (19.50 m) than for PAL-nets (16.00 m).

Data of water depth of deployed net-raws was tested for differences between PAL and control nets for fisher A and B by a Wilcoxon signed rank test for paired samples. Significant differences in mean water depth of deployed set-nets could be neither found for fisher A (p=0.1851), nor for fisher B (p=0.6555).

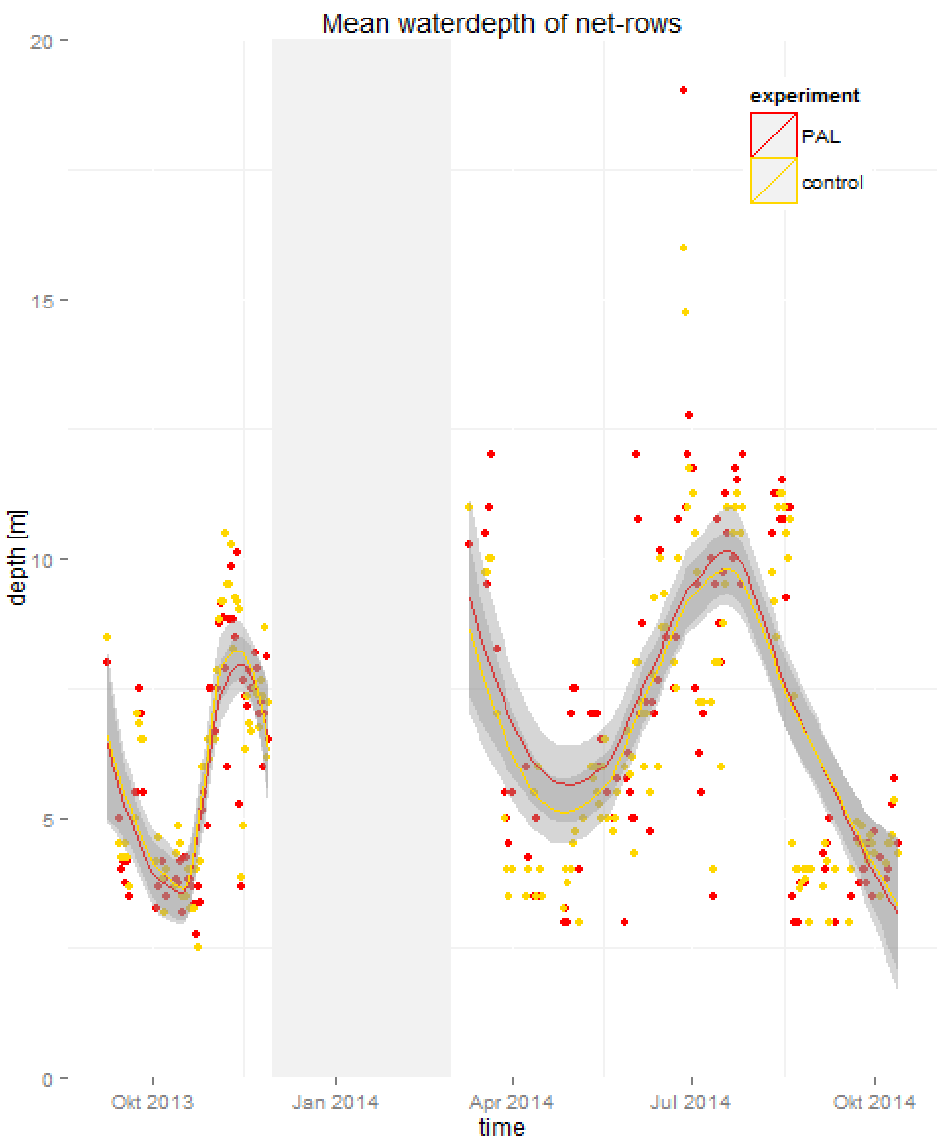

Figure 12: Scatterplot of mean water depth for each day and experimental group (PAL=yellow, control=red). The white bar indicates a gap in data. A locally weighted linear regression was used to smooth data. The regression was calculated for each period of investigation and type of experiment. The grey area indicates the confidence interval of 95%.

3.3. Fishing effort

The fishing effort varied between fishermen and over time. The fishing effort of Fisher A was higher with respect to NKD 1,328.10 and number of fishing trips (n=186) compared to fisher B (85.54 NKD; 29 fishing trips;Table 6). Mean effort per fishing trip of Fisher A was higher 7.14 NKD than for fisher B (2.95 NKD).

Table 6: Fishing effort of all fishers measured in NKD

NKD	Fisher A (n=186)	Fisher B (n=29)
Minimum	1.19	1.78
Median	7.17	2.79
Mean	7.14	2.95
Maximum	12.14	4.74
Total	1,328.10	85.54

In order to test whether the effort of each fisher was the same for PAL- and control-nets, data was separated by experimental type (Table 7).

Table 7: Fishing effort of all fishermen measured in NKD separated by experimental group:

NKD	Fisher A (n=186)		Fisher B (n=29)	
	Control	PAL	Control	PAL
Minimum	0.52	0.66	0.62	1.10
Median	3.66	3.56	1.39	1.39
Mean	3.60	3.54	1.21	1.74
Maximum	7.80	6.91	1.86	3.11
Total	669.77	658.33	35.10	50.45

Data was further analysed for differences in effort between PAL- and control-nets with a Wilcoxon signed rank test for paired samples.

No differences could be found in the fishing effort of fisher A between the two experimental groups ($p=0.4624$). In contrast, fisher B used more PAL-nets ($p<0.0011^{**}$).

3.4. Relative catch rate

The fishers collected data on fish catch per net-row which was standardized as CPUE (catch in kg per NKD). For this analysis mean relative catch rates were calculated for each fishing trip (fisher A=112; fisher B=29) separated into the two experimental groups (Table 8).

The mean relative catch rate of cod between PAL- and control-nets was similar for fisher A (control=23.71 kg/NKD; PAL=22.49kg/NKD), whereas differences in maximum of mean relative catch rates could be determined between the two experimental groups (control=163,90 kg/NKD; PAL=226.40kg/NKD).

The mean relative catch rate of fisher B was higher for control-nets (control=16.31kg/NKD; PAL=13.61kg/NKD), as same as the maximum relative catch rate (control=40.40kg/NKD; PAL=34.41kg/NKD).

Table 8: Catch rate (kg) of cod for fisher A and catch rate of flatfish per net-kilometre day summarised for each fishing trip. Data is separated by experimental type:

catch (kg) / NKD	Fisher A (n=112)		Fisher B (n=29)	
	Control	PAL	Control	PAL
Minimum	0.00	2.62	2.33	3.85
Median	15.33	15.16	13.68	14.33
Mean	23.71	22.49	16.31	13.61
Maximum	163.90	226.40	40.40	34.41

Data of relative catch rates was further analysed for differences between PAL- and control-nets with a Wilcoxon signed rank test for paired samples.

The relative catch rate did not show any differences between Pal- and control-nets for fisher A ($p=0.2521$) and B ($p=0.1577$)

3.5. Bycatches

All bycatches occurred in set-nets of fisher A. The most frequently bycaught species were common eiders (n=154), cormorants (n=31) and harbour porpoises (n=2; Table 9). Additionally, four birds were bycaught, which could not be classified (Figure 13). No bycatches of seals were observed in this study and fishers claimed to have never seen one.

Figure 13: Bycatch of unknown seabird (upper row). Bycaught harbour porpoise with netmarks (lower row).

Table 9: Total amount of bycaught species of fisher A, after the September 8, 2013

Bycatches	total	control	PAL
Common eider	154	53	101
Cormorant	31	12	19
Harbour porpoise	2	2	0

The small sample size of bycaught harbour porpoises until late 2014 was too small for further statistical analysis.

Absolute number of bycatches per month showed a high variability (Figure 14). The number of bycaught common eiders was highest in November 2013 (n=70), followed by October 2013 (n=61) and relative low for the rest of the year. These 132 common eiders, bycaught in two months, account for 85 % of all bycaught common eiders in the whole period of investigation.

Absolute bycatch numbers of cormorants were highest in September 2014 (n=11) followed by October 2013 (n=8).

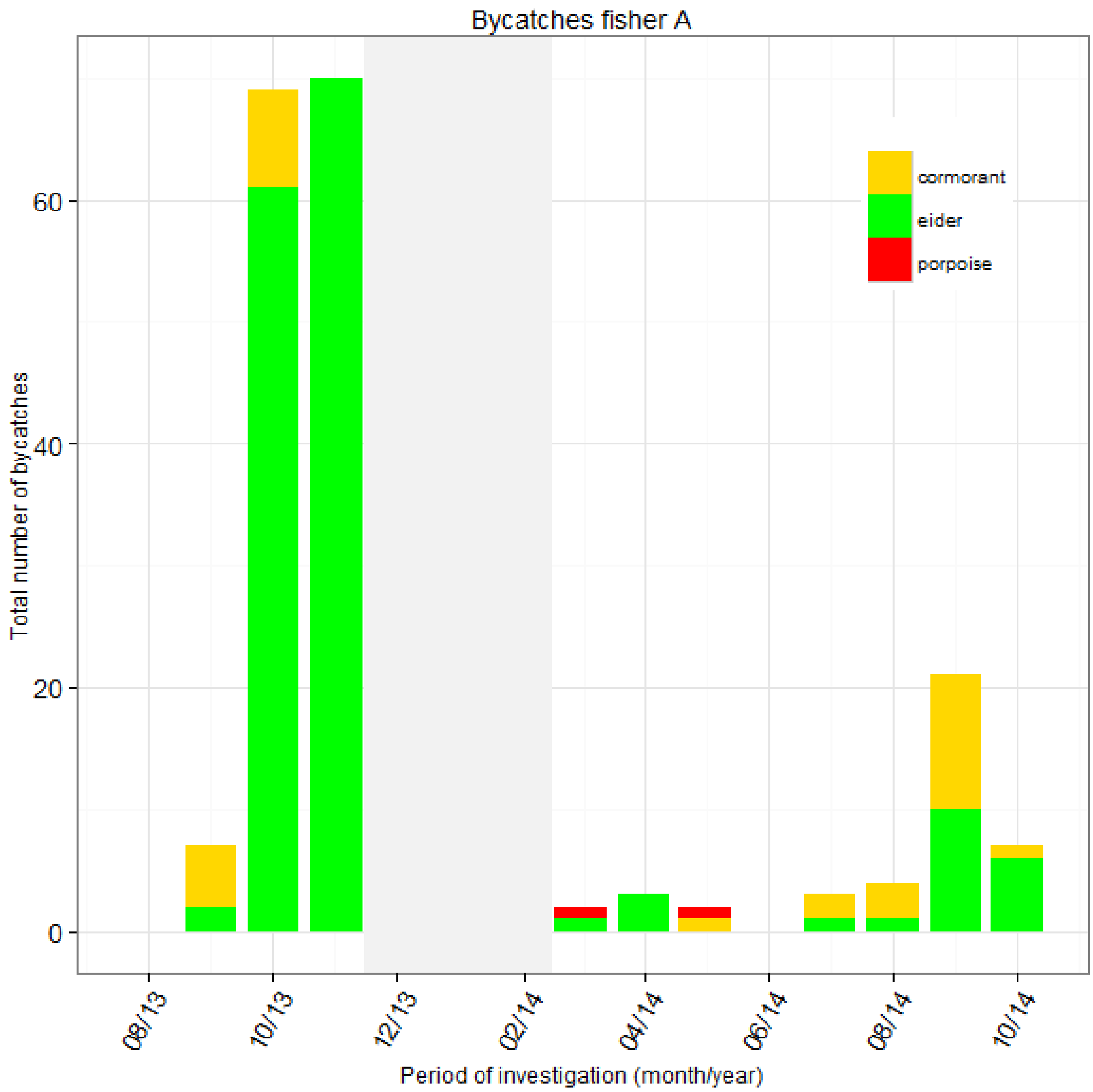

Figure 14: Annual distribution of all bycatches of Fisher A separated by species. Each bar represents the sum for one month with no account on experimental group and fishing effort. The grey bar indicates the gap in data between the two periods of investigation.

Both bird species were bycaught more by absolute number in PAL-nets.

For a further analysis, absolute numbers of bycaught individuals per net-row were divided by the NKD to correct for the fishing effort (net-length plus soaking time), according to Bellebaum et al. 2013, under the assumption that there is a linear relationship between the probability of bycatches and the net-length. A Wilcoxon signed rank test for paired samples was used to find differences in relative bycatches between PAL- and control nets. This test was chosen to be able to compare single days which are assumed to have the most influence on the occurrence of bycatches (Manly 2007) instead of pooling the data for the whole period of investigation.

It could be shown that the probability of bycatches was significantly higher in PAL-nets for cormorants (p=0.0284*) and common eiders (p=0.0038**).

Afterwards mean water depth for net-rows with bycatches was analysed for both experimental groups each.

Mean water depth of all net-rows with no account for experimental group was 6.6 m. Mean water depth of net deployments with bycaught harbour porpoises was 8.0 m (n=2), for cormorants 4.6 m (n=31) and for common eiders 5.2 m (n=154; Table 10). The maximum water depth at which bycatches occurred was similar for harbour porpoises (11.0 m), cormorants (12.5 m) and common eiders (11.5 m). The median water depth at which bycatches occurred was lower for cormorants (4.0 m) and common eiders (4.5 m), in contrast to harbour porpoises (8.0 m; Figure 15).

Table 10: Summary of measured water depth for net-rows with bycatches separated by species

depth	porpoise (n=2)	cormorant (n=31)	eider (n=154)
Minimum	5.0	3.0	2.5
Median	8.0	4.0	4.5
Mean	8.0	4.6	5.2
Maximum	11.0	12.5	11.5

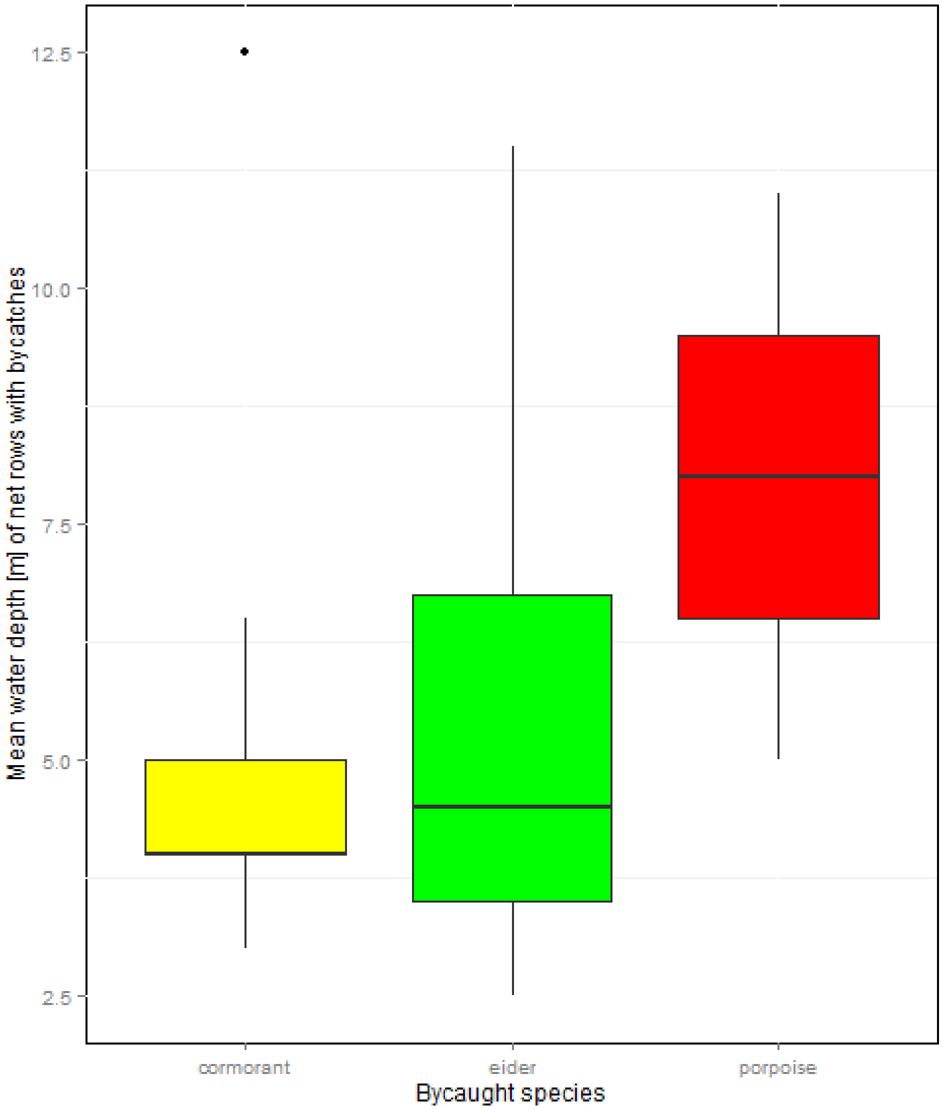

Figure 15: Boxplot of measured water depth for all occurred bycatches separated by species (shown by colouration). The box represents the interquartile range with 50% of data. The whiskers range from the median to the highest value that is within the 1.5 interquartile range. The black horizontal line within the box represents the median of each group.

3.6. Effect of Scientific observer attendance on reported bycatches

Data gathered within this study was further analysed for a possible effect of the presence of a visual observer on board of a fisher A on the number of reported bycatches.

The total numbers of bycatches per day was separated in two groups (presence and absence of observer) with no account on experimental group. A Mann Whitney U test for unpaired data was used for this analysis because data is not distributed normally. An observer accompanied in total 88 out of 217 fishing trips (40.5 %).

Table 11: Absolute number of bycatches for fishing trips with the presence of a visual observer and for fishing trips without

species	observer on board (n=88)	No observer on board (n=129)
Porpoise	1	1
Cormorant	14	17
Common eider	75	79

The presence or absence of an observer had no effect on the number of reported bycatches for harbour porpoises (p=0.7902), cormorants (p=0.5749) and common eiders (p=0.3532).

3.7. Harbour porpoise presence near set-nets

C-PODs were deployed for 31 days between July 15, 2014 and of August 21, 2014 in set-nets of fisher A only.

Mean water depth at which C-POD were deployed was compared between the two experimental groups (Table 12).

Table 12: Mean water depth in metres of net-rows with attached C-PODs

Mean water depth	control-nets	PAL-nets
Minimum	3.50	6.00
Median	10.00	10.00
Mean	9.50	9.52
Maximum	12.50	13.00

Mean water depth as same as maximum water depth at which C-PODs were deployed were similar between PAL- and control-nets. A Wilcoxon signed rank test for paired samples confirmed that there were no differences in water depth between the deployment of C-PODs in PAL and control-nets (p= 0.3469).

3.7.1. Visual Screening

Daily relative values for harbour porpoise presence, corrected for the observation time, were calculated for both experimental groups.

Harbour porpoise presence determined by a visual screening was low. In 80 10-minute intervals harbour porpoise like clicks could be verified (Table 13). Recorded clicks, visually classified as stemming from a harbour porpoise, are shown in Figure 16.

Harbour porpoise presence, determined as pp10min, was higher around control-nets (n=69) than PAL-nets (n=11). This corresponds to a relative amount of 1.47% porpoise positive 10-minute intervals for C-PODs near to control nets and 0.25% for C-PODs in the near of control-nets for the whole observation time (Table 13).

Table 13: Effort in C-POD deployment and detection positive 10-min intervals separated by experimental group

C-POD	control-nets	PAL-nets
Effort (trips)	34	29
Number of recorded 10min periods	4680	4322
Pp-10min (visual)	69	11
Rel. pp10min per observation time	1.47%	0.25%

Harbour porpoise detections were about 7 times higher in the vicinity of control-nets (Table 13). Data was further analysed for differences in harbour porpoise presence between C-PODs near PAL- and control-nets by a Wilcoxon signed rank test for paired samples. This test was chosen because the effect of a single day in the period of investigation was assumed to have the highest influence on porpoise detections caused by a study area with low harbour porpoise density. Therefore, relative values of harbour porpoise presence, corrected for period of observation, were calculated for each day. Only days with a C-POD in a PAL- and a control-net were analysed.

It could be shown that harbour porpoises detections were significantly higher near control-nets ($p<0.001$***).

PAL signals could be separated from harbour porpoise clicks due to their stereotypic pattern (Figure 17), regularly occurrence (every 20 s) and low ICI below 5 ms.

The visual screening of C-POD data revealed that a simultaneous recording of signals from two different PALs occurred just occasionally for short periods of time. Generally only signals of one PAL were recorded. The C-POD in a PAL net was attached at the end of a net-row at a distance of <5 m to the first PAL in the row. The distance between PALs was set at not more than 200 m to guarantee a complete acoustic coverage of the set-net. A C-POD is able to receive clicks generated by the PAL at distances of at least 240-460 m (Culik et al. 2015). Therefore signals of at least two PALs are expected in the C-POD recordings with this experimental design Consequently this gives evidence that the detection range of the C-POD could be decreased and therefore harbour porpoises could only be detected at shorter distances than expected.

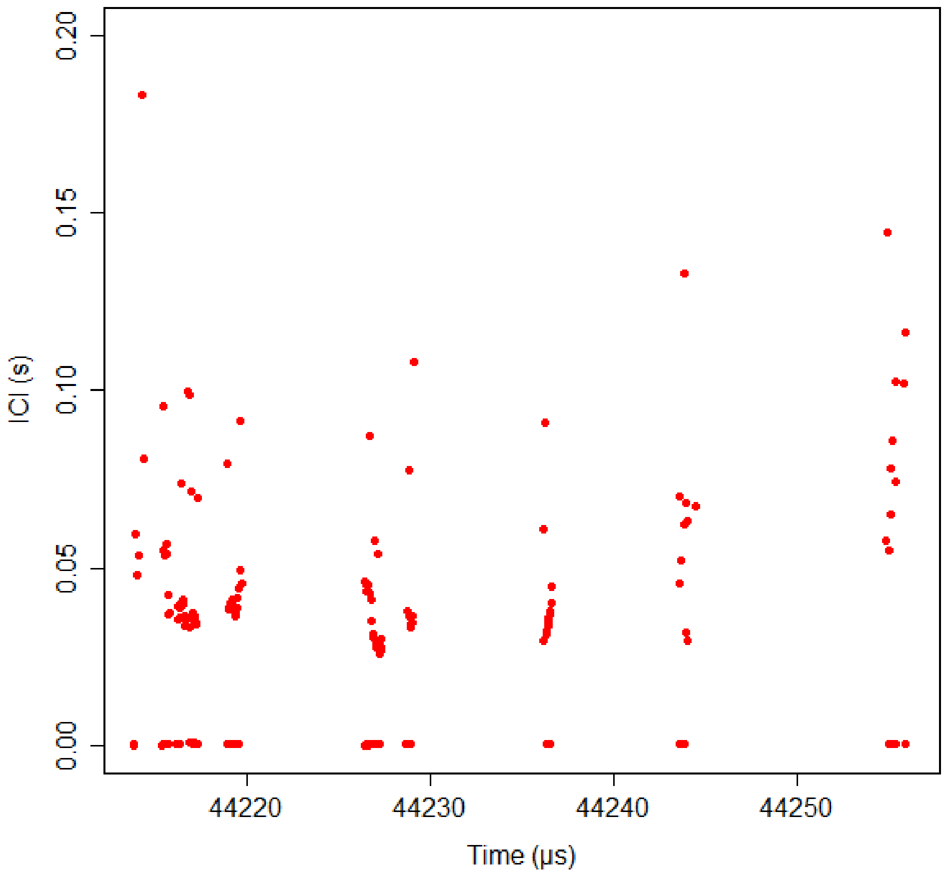

Figure 16: Harbour porpoise clicks recorded by a C-POD at a control net on August 14, 2015 at 12:16h.

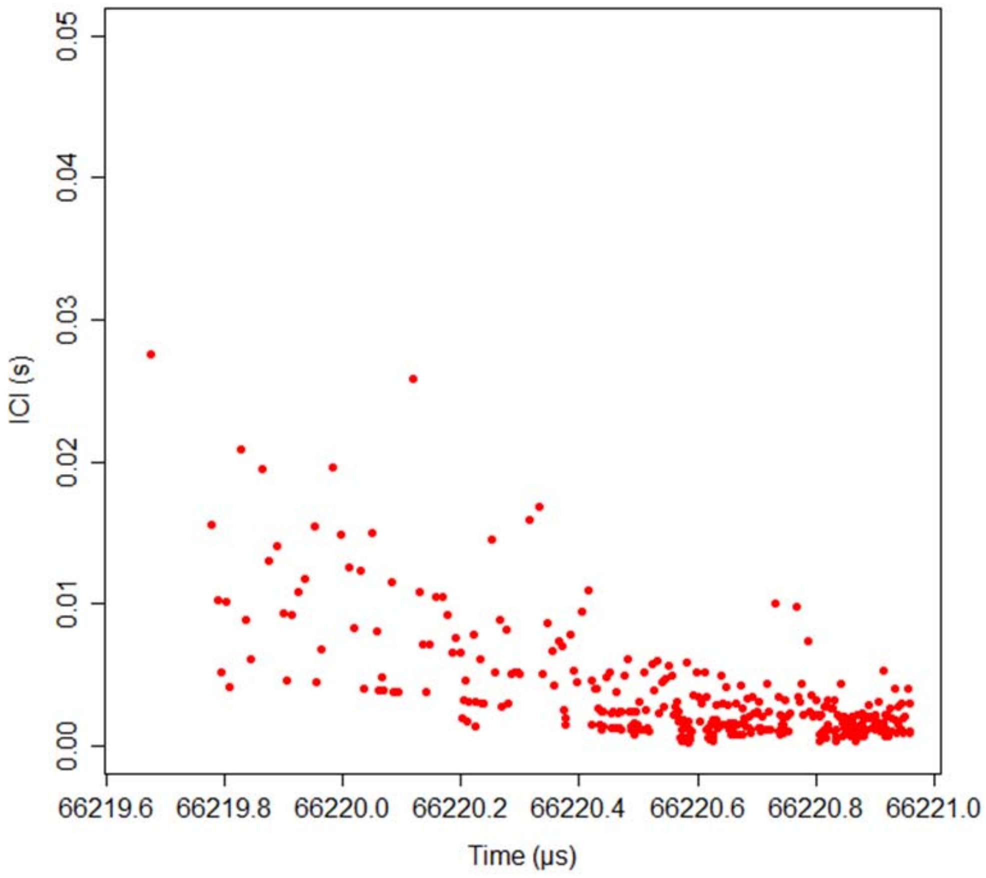

Figure 17: Stereotypic PAL signal recorded by a C-POD.

3.7.2. Automatic screening with KERNO classifier

C-POD data was additionally screened by the KERNO classifier to test, if PAL signals could be categorized as harbour porpoise click. Harbour porpoise presence was determined by the KERNO classifier in 31.1 % of 10-min intervals for the whole period of investigation and was 10 fold higher for PAL nets (Table 14).

Table 14: Effort in C-POD deployment and detection positive 10-min intervals, categorized by the KERNO classifier and separated by experimental group

C-POD	control-nets	PAL-nets
Effort (trips)	34	29
Number of recorded 10min periods	4680	4322
Pp-10min (KERNO)	237	2565
Rel. pp10min per observation time	5.1%	59.3%

PAL signals were not categorized continuously as porpoise like click trains. No clear pattern in the categorization of PAL signals by the KERNO classifier could be determined. Figure 18 shows four PAL signals recorded by a C-POD and visualized in C-POD.exe in the CP1 (raw; Figure 18B) and CP3 (KERNO processed; Figure 18A) file format. Both visualisations show the ICI of recorded clicks (CP1) or click trains (CP3) over time. In this example all signals look similar in the CP1 format but were categorized by the KERNO classifier differently. The first two signals were classified as porpoise click trains of high quality (red coloured), whereas the third signal was classified as a porpoise click train of moderate quality. Moreover, the fourth signal was not categorized as being produced by a harbour porpoise.

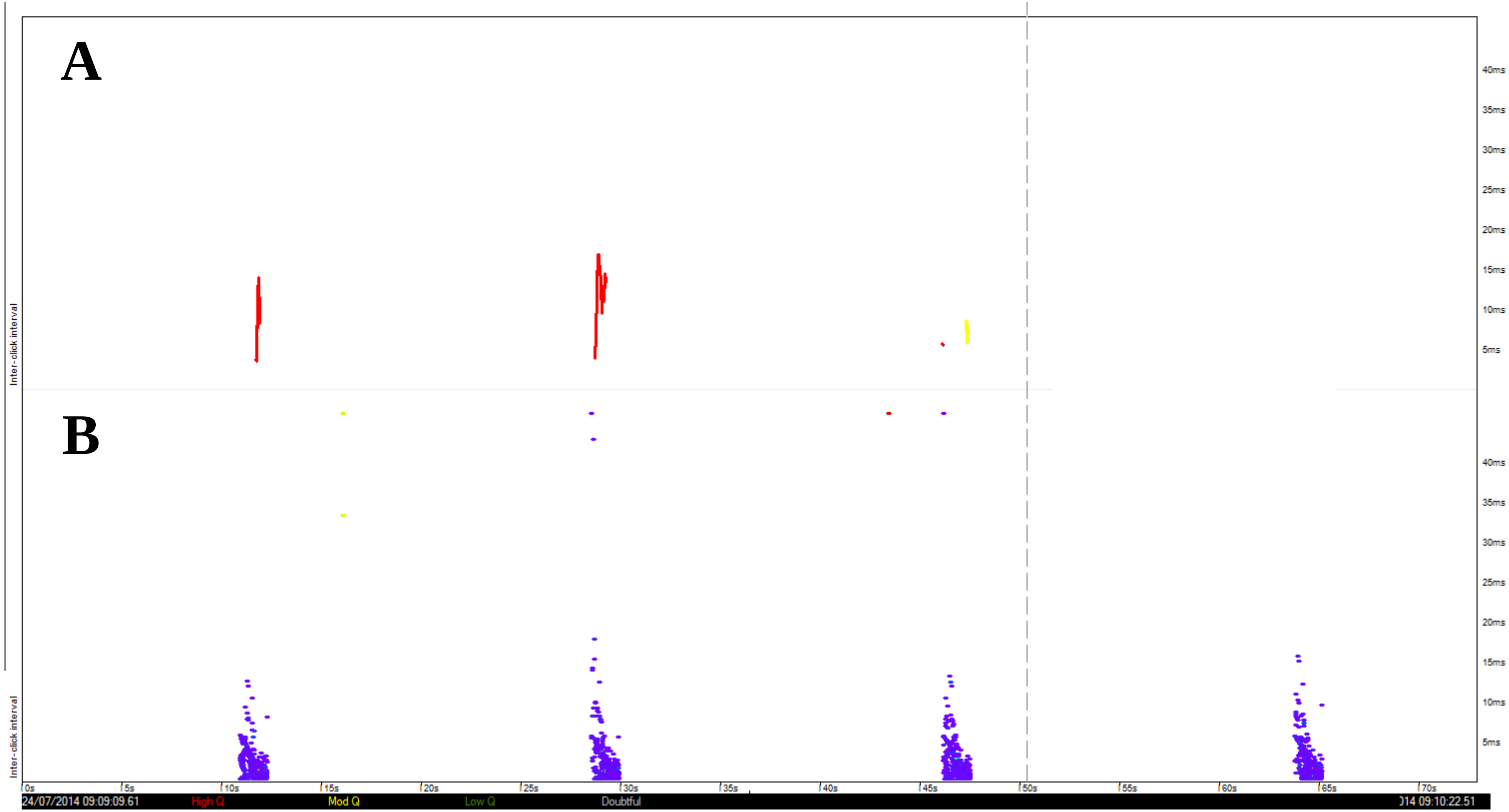

Figure 18: Recording of 4 PAL signals shown in C-POD.exe in the ICI view. A) PAL signals in a CP3 file format, categorized as porpoise like click trains colour coded for quality (red=high; yellow=moderate). B) PAL signals in a CP1 file format.

It could be also shown, that the KERNO classifier recognized harbour porpoise clicks in the presence of PAL signals which were, on the other hand, not categorized as beeing produced by a harbour porpoise (Figure 20A).

In a further analysis it was tried to use the filters in C-POD.exe to avoid PAL signals to be categorized as harbour porpoise clicks.
For this purpose, train and click filters were adjusted in C-POD.exe for a short recording of PAL signals.

The recorded clicks, emitted by harbour porpoises or synthesised by the PAL, were similar in peak frequency. In addition, high variations in ICI could be found for both click types.
However, the number maximum clickrate (clicks/s) was higher in PAL signals compared to harbour porpoise clicks. Furthermore, the duration of PAL clicks, represented as the number of cycles at the dominant frequency was higher than harbour porpoise clicks. Therefore the train filter was adjusted to a maximum of 20 clicks/s. The click filter was also adjusted by defining a maximum of 15 cycles per click.

This setting could filter out PAL signals effectively, which were categorized before, without adjusted filters, as harbour porpoise clicks (Figure 19). Afterwards this filter was tested for harbour porpoise clicks also, which should not be filtered out.
Although this adjusted filter eliminated several click trains, harbour porpoise clicks could be still found by the KERNO classifier with adjusted settings (Figure 20).

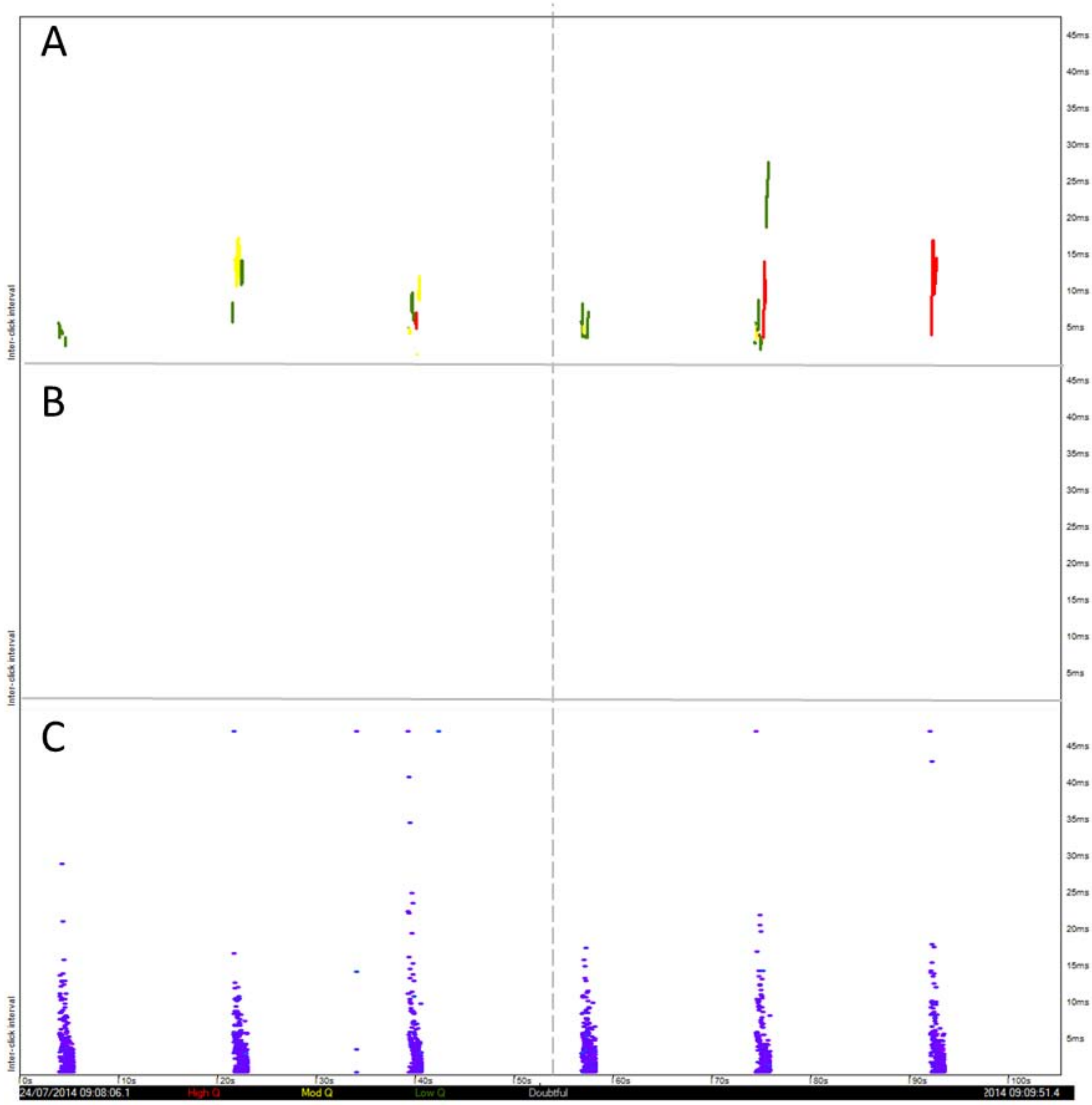

Figure 19: Sequence with PAL signals recorded by a C-POD. A) KERNO classifier processed view (CP3) without filter adjustment. PAL signals were categorized as being produces by a harbour porpoise. B) Same sequence as A with adjusted filter settings in C-POD.exe. Maximum click rate was set at 20 and maximum cycles were set at 15. C) Raw format (CP1) of the sequence with PAL signals, shown in ICI over time.

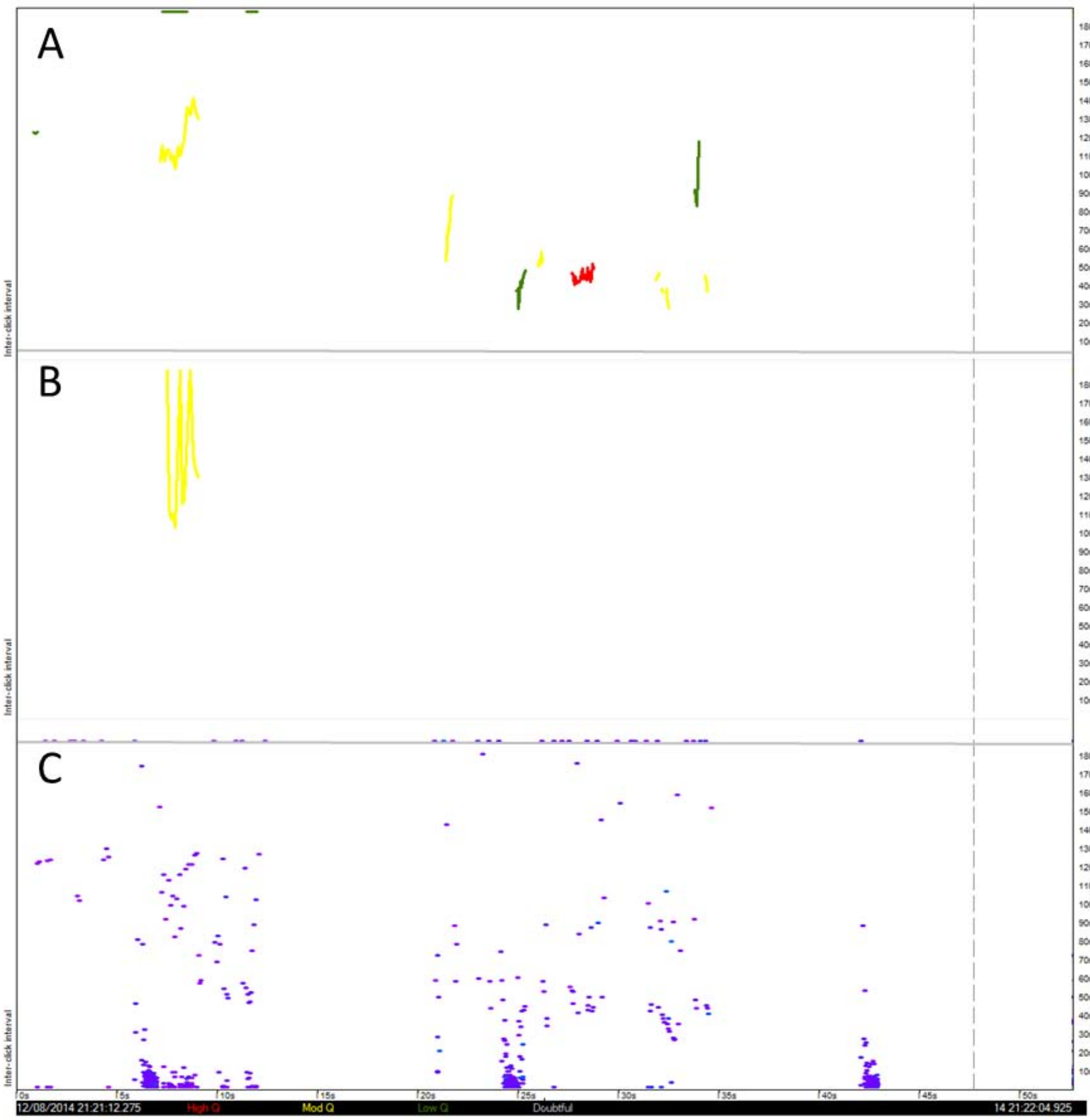

Figure 20: Sequence with harbour porpoise clicks and PAL signals recorded by a C-POD. A) KERNO classifier processed view (CP3) without filter adjustment. PAL signals were not categorized as being produces by a harbour porpoise but harbour porpoise clicks were recognized. B) Same sequence as A with adjusted filter settings in C-POD.exe. Maximum click rate was set at 20 and maximum cycles were set at 15. C) Raw format (CP1) of the sequence with PAL signals and harbour porpoise clicks, shown in ICI over time.

3.8. PAL-recordings

The PAL-signal was recorded at six different distances (1m, 10m, 21m, 30m, 40m, 52m). Data was visualized in R using the package 'seewave' (Sueur et al. 2008).

Figure 22 shows a single click emitted by the PAL and recorded at a distance of 1 m.

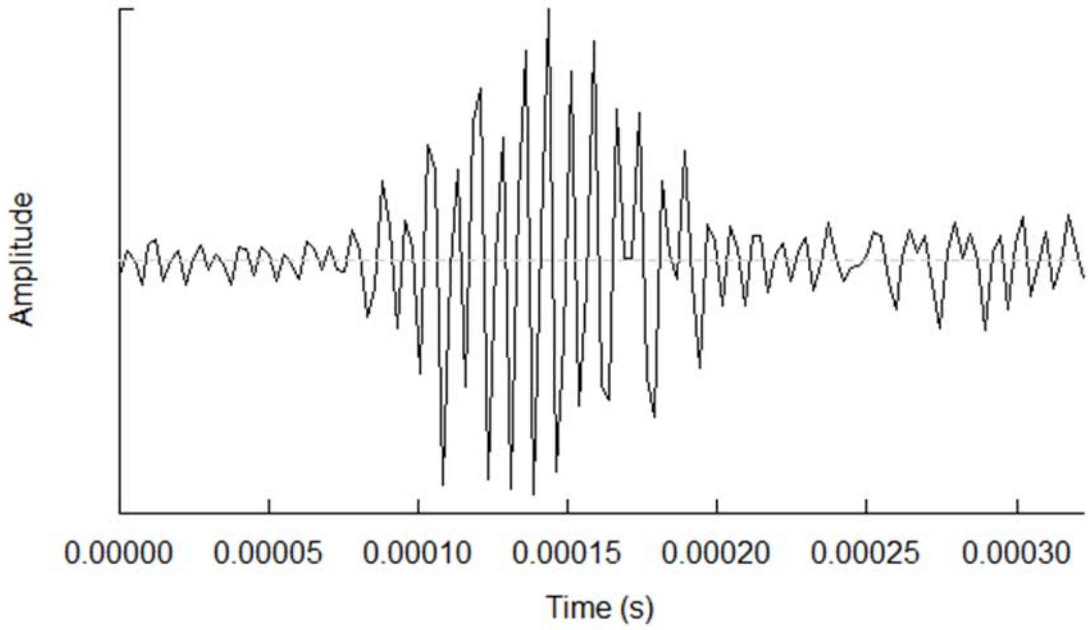

Figure 22: Relative Amplitude of a single PAL-click recorded at a distance of 1 m.

Clicks emitted by the PAL show a high similarity to real harbour porpoise clicks in amplitude and duration (Figure 3; Figure 22).
Ambient background noise was also recorded to assess the noise level without a PAL signal.
The background noise was dominated by broadband noise and not by specific frequencies (Figure 23; Figure 24).

For the calculation of the SL, the recording of a single PAL signal at a distance of 10 m was used. This recording was chosen because no noise artefacts, which were louder than the signal itself, could be determined within in the recording (Figure 25; Figure 26). Therefore, the maximum measured voltage was used to calculate the SL.
The maximum SL of the PAL signal was determined at 154 dB p-p re 1µPa at 1m.
Afterwards, a single PAL signal was visualized in a spectral plot and a spectrogram for each distance (Figure 25-Figure 36)

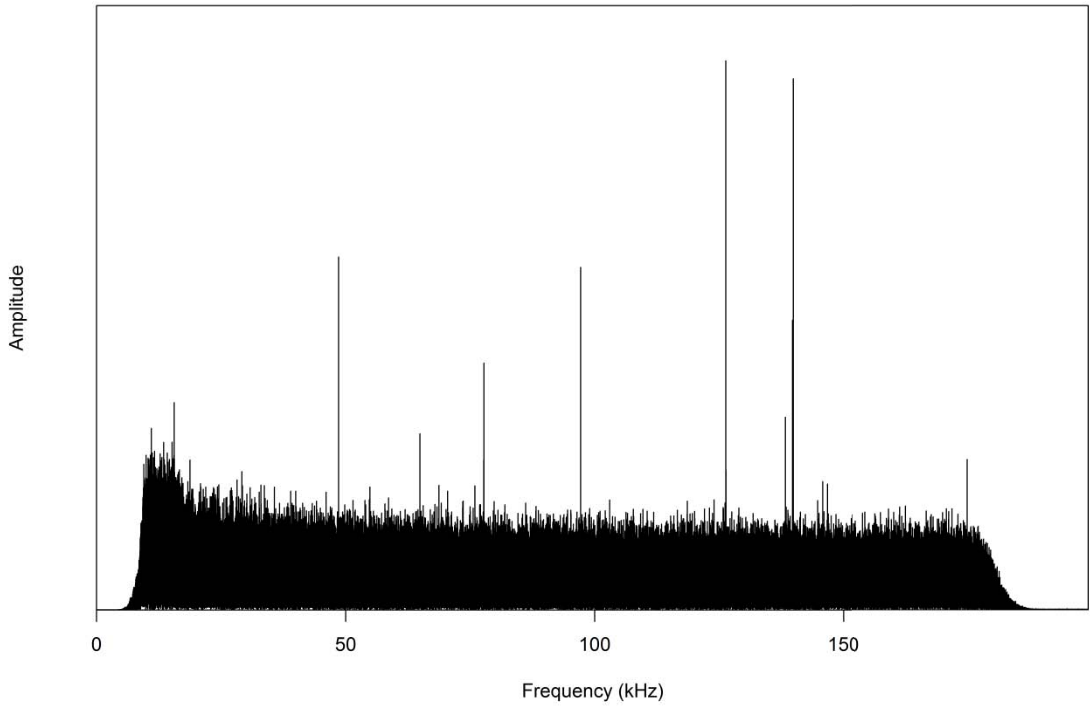

Figure 23: Frequency spectrum of ambient noise during the recordings without recorded PAL signal.

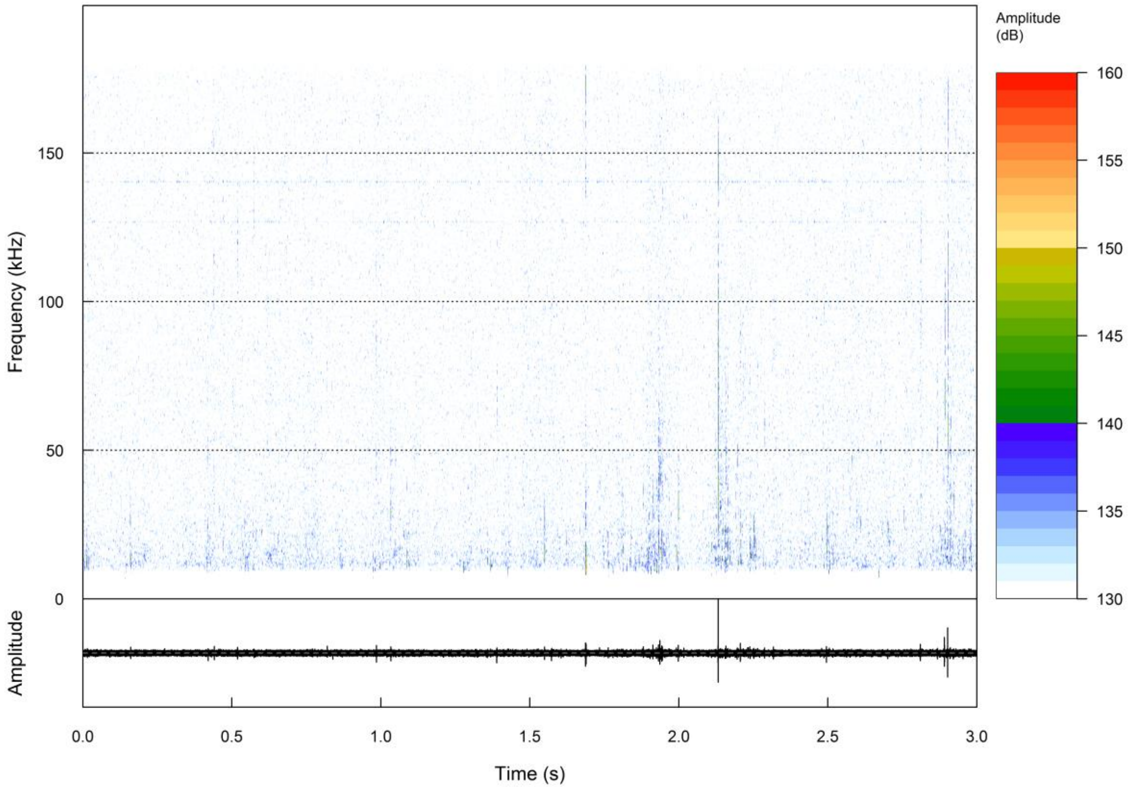

Figure 24: Spectrogram of ambient noise recording colour coded for SPL with relative amplitude below.

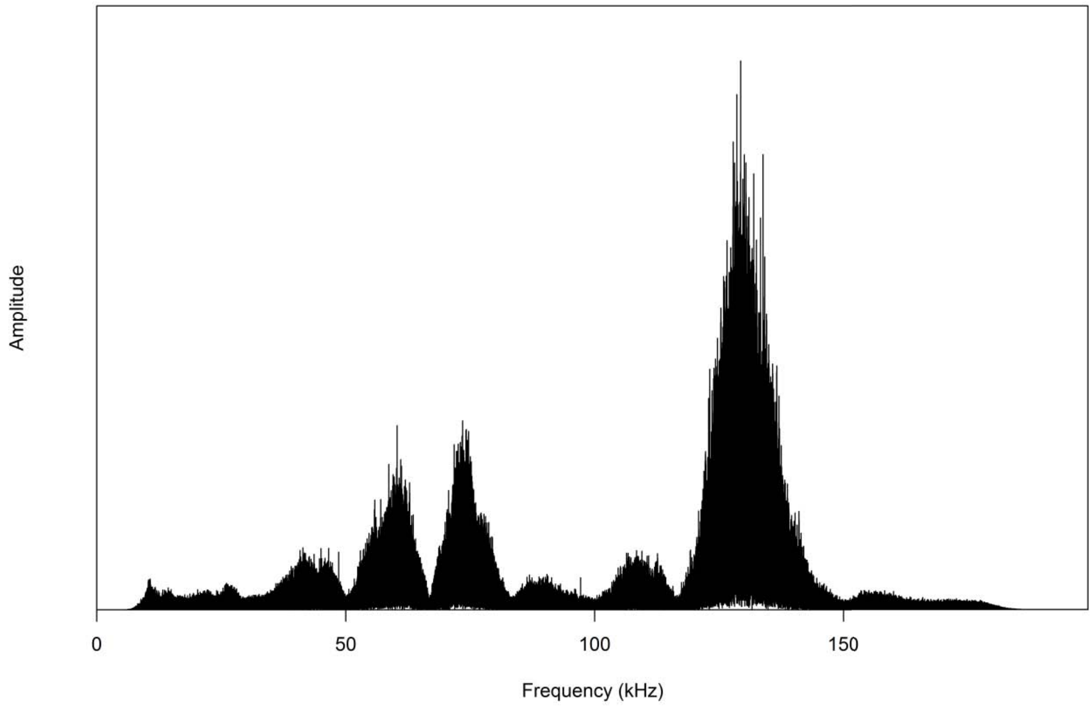

Figure 25: Frequency spectrum of a PAL signal recorded at a distance of 1m.

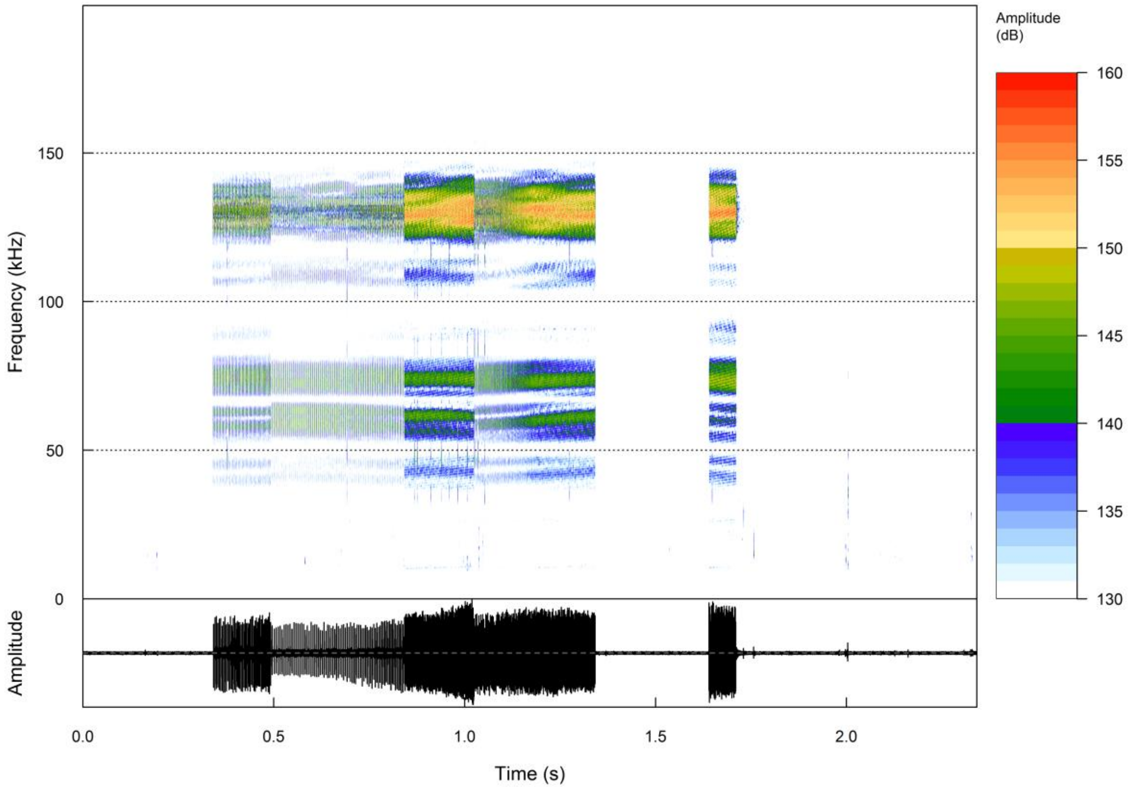

Figure 26: Spectrogram of a PAL signal recorded in a distance of 1m, colour coded for SPL and the relative amplitude below.

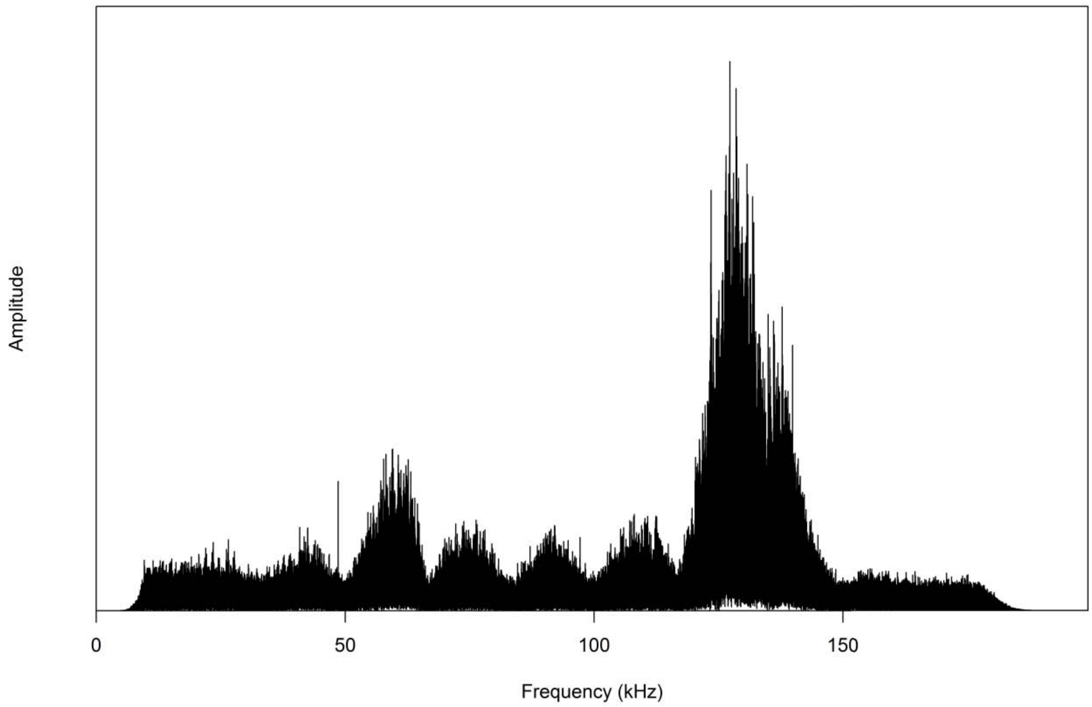

Figure 27: Frequency spectrum of a PAL signal recorded at a distance of 10m.

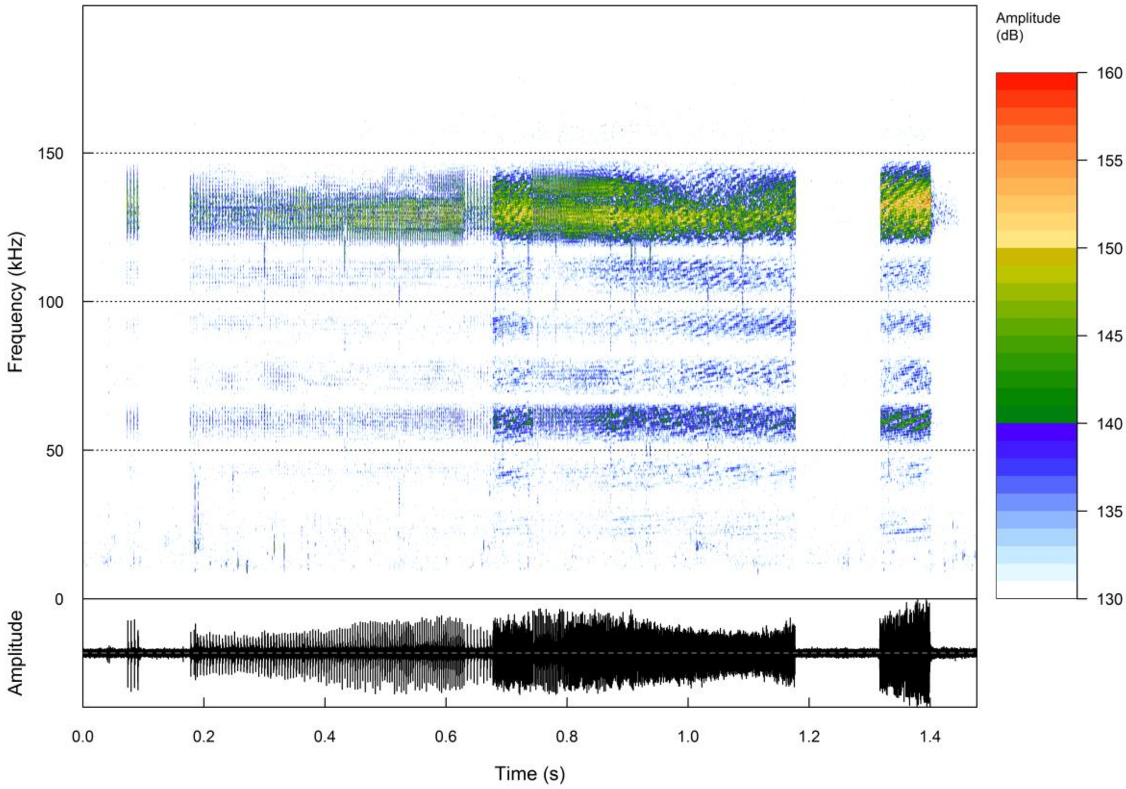

Figure 28: Spectrogram of a PAL signal recorded in a distance of 10m, colour coded for SPL and the relative amplitude below.

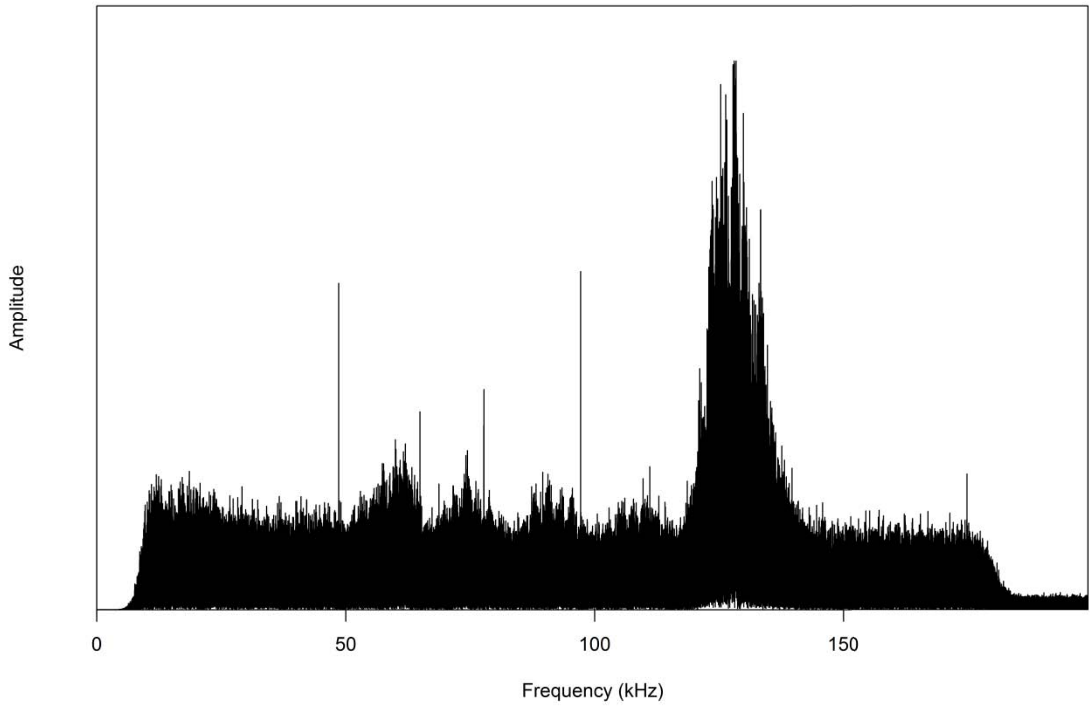

Figure 29: Frequency spectrum of a PAL signal recorded at a distance of 21m.

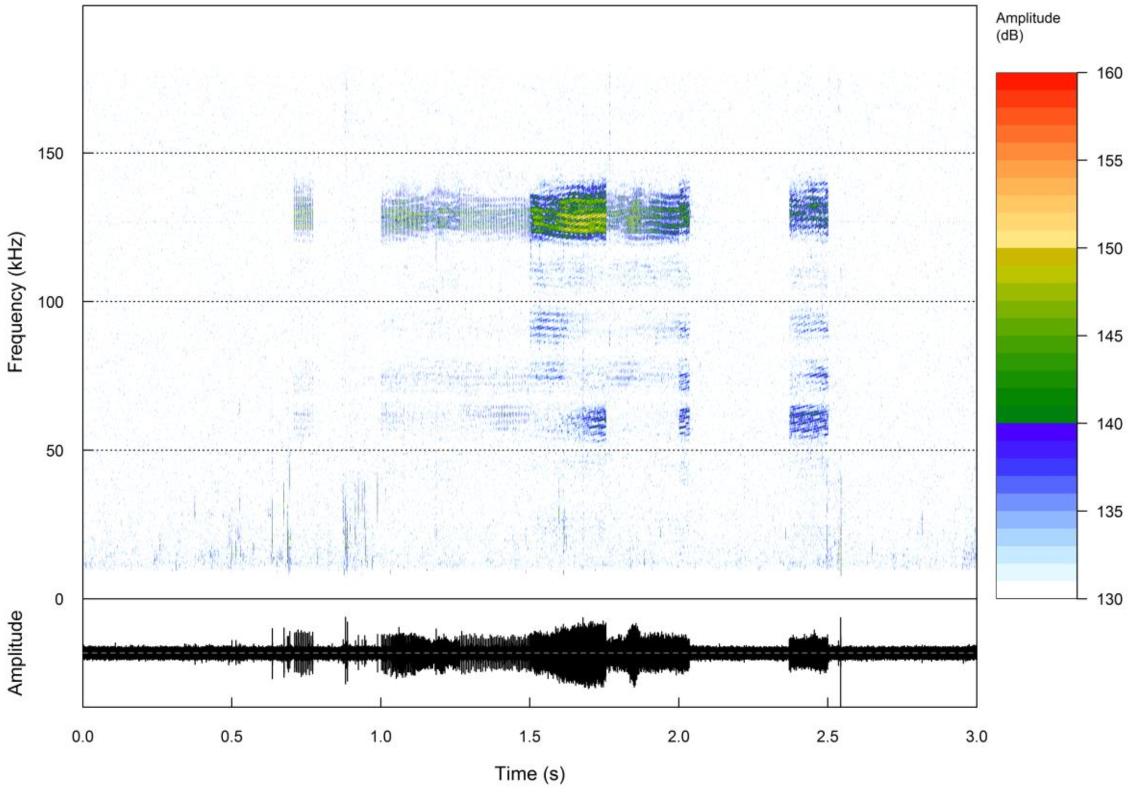

Figure 30: Spectrogram of a PAL signal recorded in a distance of 21m, colour coded for SPL and the relative amplitude below.

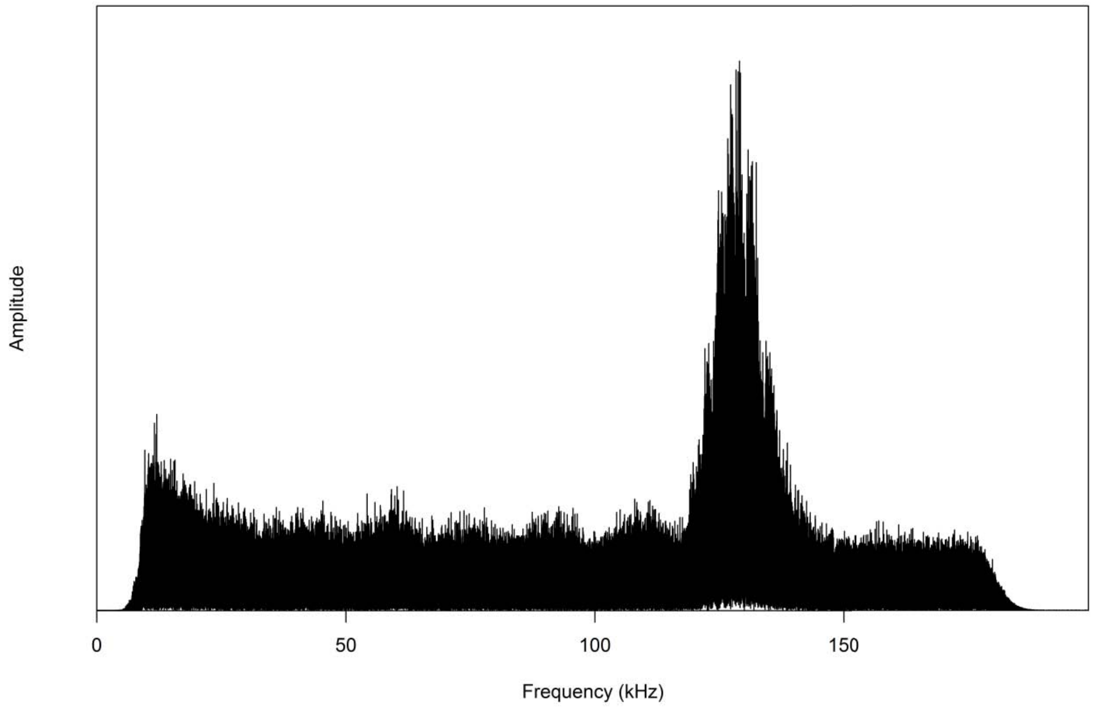

Figure 31: Frequency spectrum of a PAL signal recorded at a distance of 30m.

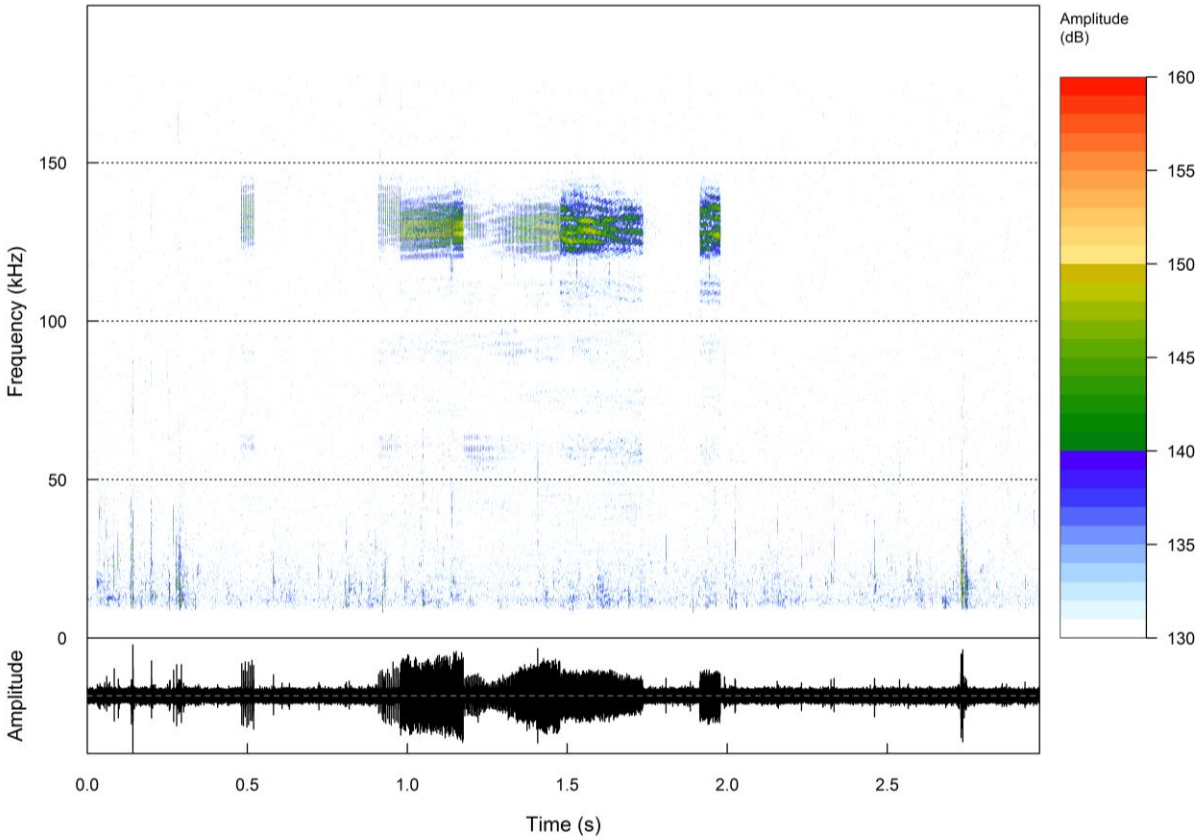

Figure 32: Spectrogram of a PAL signal recorded in a distance of 30m, colour coded for SPL and the relative amplitude below.

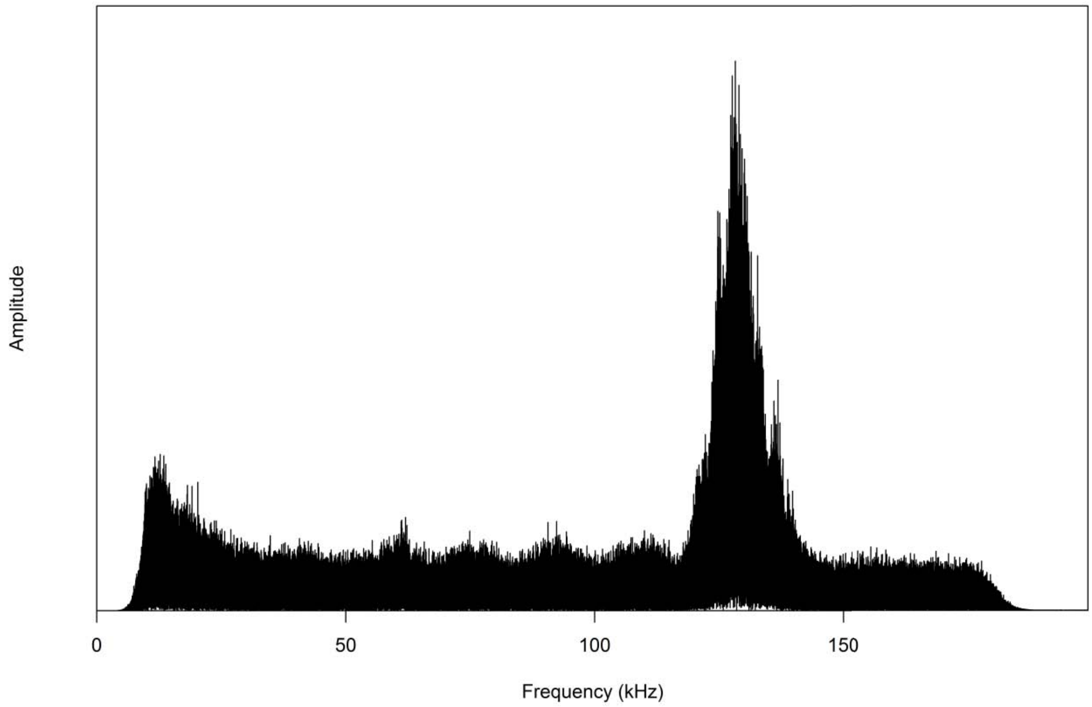

Figure 33: Frequency spectrum of a PAL signal recorded at a distance of 40m.

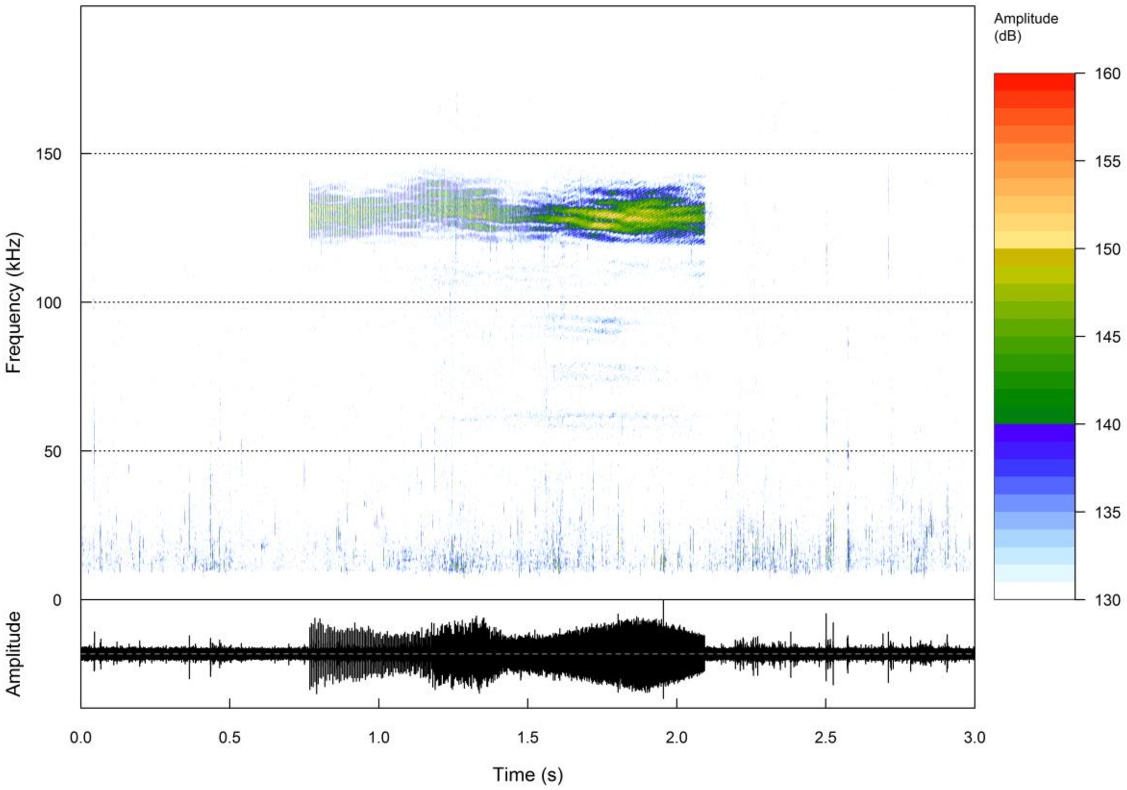

Figure 34: Spectrogram of a PAL signal recorded in a distance of 40m, colour coded for SPL and the relative amplitude below.

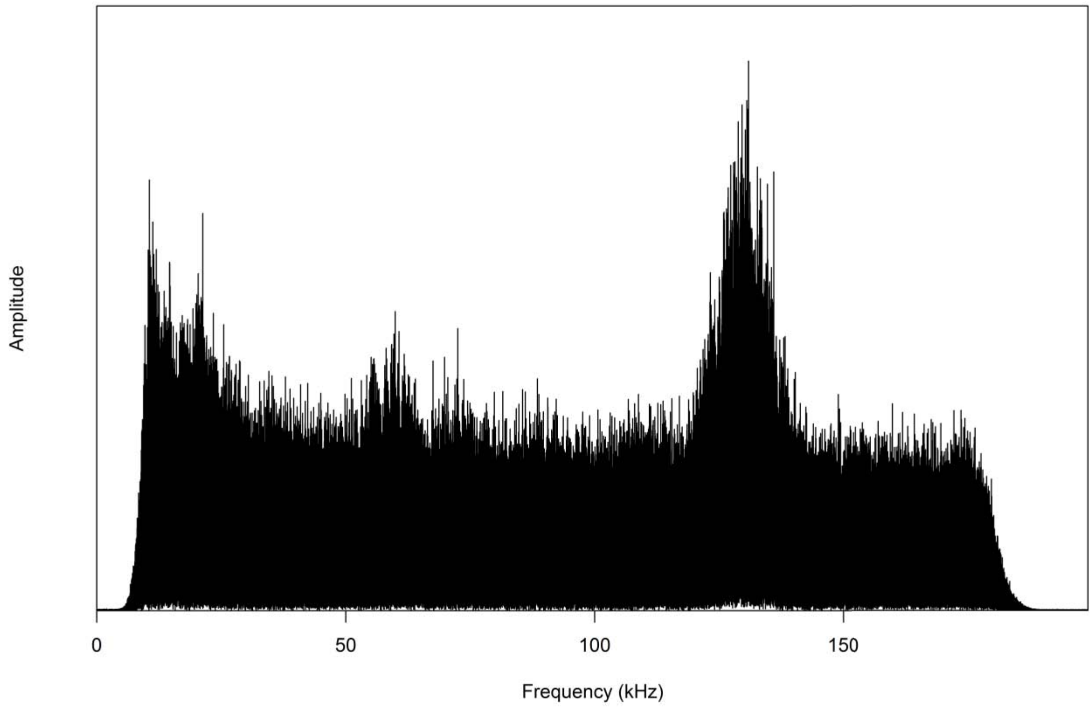

Figure 35: Frequency spectrum of a PAL signal recorded at a distance of 52m.

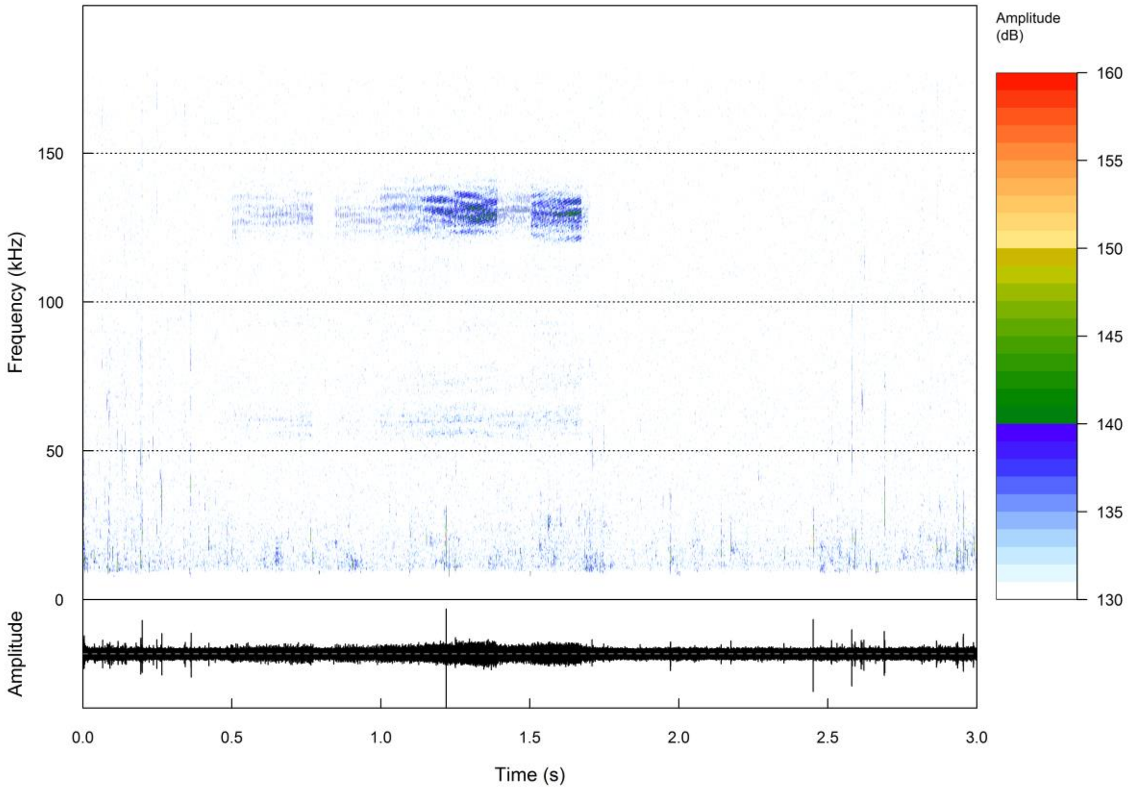

Figure 36: Spectrogram of a PAL signal recorded in a distance of 52m, colour coded for SPL and the relative amplitude below.

The recordings at different distances proved that the main energy of the PAL signal is at 130 kHz. It could be shown that the PAL signal contained also minor energy peaking at 60 and 70 kHz. This could be also shown at a distance of 10 and 21 m but not at a distance of 30 m. At a distance of 30 m the energy content at 60 and 70 kHz disappeared in background noise.

4. Discussion

4.1. Filtering of PAL signals by the use of C-PODs

PAL signals were classified as harbour porpoise clicks by mistake. Harbour porpoise positive 10 minute intervals around control-nets were determined in 57 % of the whole observation time by the KERNO classifier. The visual classification, in contrast, determined a harbour porpoise presence of 0.25 % near to PAL-nets

In general, the PAM approach cannot discriminate between the absence of animals and a change (decrease of clicks) in echolocation behaviour. Accordingly only possible changes in the echolocation behaviour can be evaluated, but not changes in the behaviour itself. Moreover no information on the number of individuals recorded at a PAM station is available.

No differences could be found in the water depth at which C-PODs were deployed between PAL- and set-nets. Both groups were in the same area very close to each other and control-nets were additionally equipped with the housing of the PAL, at least for the first period of investigation. A comparison of PAL- and control-nets with respect to relative harbour porpoise detections is therefore acceptable.

An increase of false positive detections caused by the PAL, would be a problem in areas where passive acoustic monitoring is conducted to asses harbour porpoise presence. In this case an overestimation of harbour porpoise detection would be caused by the PAL signal.

This thesis could confirm that PAL sequences, recorded by a C-POD, can be separated from harbour porpoise clicks by a visual screening. Furthermore, also the train and click filter settings within C-POD.exe proved to be suitable to filter out PAL signals. This could be achieved by limiting the maximum click rate in a train to 20 clicks per second and as well delimiting the maximum cycles per click to 15. These settings could remove PAL signals in the recordings while simultaneously maintaining harbour porpoise clicks.

The click rate limit at 20 clicks per second would eliminate harbour porpoise clicks also. Due to this restriction, all clicks with a click rate above 20 clicks per second, which corresponds to an ICI of 50 ms, would be also removed. Harbour porpoise click trains containing clicks below an ICI of 50 ms are assigned to foraging (Deruiter et al. 2009, Verfuss et al. 2009) or communication behaviour (Clausen et al. 2011). The proposed filter settings would therefore prohibit an investigation of harbour porpoise foraging or communication behaviour like shown in Nuuttila et al. (2013). However, raw files (CP1 format) are not affected by this filter and would be still suitable for further behavioural examinations.

Moreover, harbour porpoise click trains which belong to general spatial orientation contain of clicks with ICI higher than 50 ms (Verfuss et al. 2005, Villadsgaard et al. 2007). Consequently, the proposed filter settings are likely to filter out PAL signals while harbour porpoise clicks could be still detected.

4.2. Harbour porpoise presence

The detection of harbour porpoises near control-nets, verified by a visual screening, was six times higher than for PAL-nets. No difference between the deployment depths of control- and PAL-nets with C-PODs could be determined. Only days with a deployment of C-PODs in both experimental groups were analysed.

Depending on individual variation of the devices and the presence of background noise, the detection range of a C-POD may vary within a maximum of several hundred metres (Kyhn et al. 2008, Kyhn et al. 2012). In this study C-PODs were attached to set-nets under suboptimal conditions in terms of C-POD performance. The low water depth results in short distances to the water surface which is a good reflector due to the higher sound velocity in the water compared to air and therefore likely to cause multiple echoes. Generally the bottom is a poor reflector although fishers have set nets on hard substrate (gravel) which is also capable to generate echoes (Au & Hastings 2008). Acoustic recordings in the field at low water depth may also be disturbed by bubbles in the upper layer which are caused by the swell and could lead to scattering and absorbing effects (Clay & Medwin 1977, Leighton 2012).

Nevertheless, the conditions for C-POD recordings near to PAL- and control-nets were the same.

The lower detections around PAL-nets could be explained by at least two different behavioural changes of harbour porpoises.

Harbour porpoises could be either deterred by the PAL signal at least out of the detection range of the C-POD or react towards the PAL signal with a decrease in echolocation activity.

Culik et al. (2015) could show that the PAL signal has the potential to enhance the produced clicks per minute of harbour porpoises by 10 %. The results in this study can also exclude the possibility that less harbour porpoises are detected due to changes in prey availability because no effects on the catch rate of cod could be revealed by the use of the PAL. Therefore a change in harbour porpoise detections is rather caused by a change in the animal's behaviour.
Harbour porpoises are able to detect standard nets at short distances between 3 and 6 m (Kastelein et al. 2000a). The reported increase in echolocation activity induced by the PAL signal has the potential to enlarge the detection range of harbour porpoises for set-nets (Culik et al. 2015). However, this effect would not result in decreased detection rates. A detection of a set-net could induce the harbour porpoise to leave the potentially dangerous area. But even an improved detection range would be still within the detection range of the C-POD and would not result in decreased harbour porpoise click trains on C-POD recordings.

The decrease in detection rates in the vicinity of the PAL is more likely to be caused by a deterring effect. It is not possible to estimate the distance from harbour porpoise to the net-row from data of a single C-POD but Culik et al. (2015) found increased minimum ranges of 32 m to the PAL. Although this deterring distance is lower than for regular pingers (300 m for Dukane NetMark 1000; Carlström et al. 2007), the distance could be too high to detect the net, even if echolocation activity increased. Therefore an effect of the PAL that would enable the porpoise to detect the net would not be seen in C-POD detection rates.
However, avoidance reactions of harbour porpoises towards modified gillnets at distances >80 m could be also shown (Nielsen et al. 2012) but are suspected to be a result of pseudo-replications (Dawson & Lusseau 2013).

Due to suboptimal conditions the detection range of the C-POD could be decreased and consequently harbour porpoises could only be detected at shorter distances than expected.
Experimental conditions were, however, the same for PAL- and are unlikely to be the reason for a decrease in harbour porpoise detections around PAL-nets.

4.3. Bycatches

The absolute number of bycatches as observed on one of the two vessels investigated, was highest for common eiders (n=154), followed by cormorants (n=31) and harbour porpoises (n=2). Due to a small sample size of bycaught harbour porpoises no statistical analysis could be conducted.

Common eiders were bycaught more often, by absolute numbers, in the winter season. The number of bycatches per month showed an increase in absolute numbers from August to the end of November until the data collection was interrupted until March, 2014. This missing data would have been very interesting in conservational issues as common eider abundance was still increasing in the wintering area. However, this could be a result of less fishing trips in October 2014.

Information on common eider occurrence by number over years would also be important to evaluate bycatches of different years. However, the most driving factor seems to be seasonal occurrence of ducks.

Mean depth at which bycatches of common eiders (5.2 m) and cormorants (4.6 m) occurred was low. This effect could be related to the diving behaviour of visually hunting predators which hunt in shallower waters with a higher visibility range during the day. In terms of reduced energetic costs by performing shallower dives, the majority of diving birds prefer depth shallower than 20 m for foraging grounds (Stempniewicz 1994). However, water depth of set-net deployments could also be a proxy for seasonal variations. The water depth at which fishers deployed set-nets varied throughout the year but was more or less the same for different net-rows of a single day. A bycatch at a lower water depth could be correlated therefore with the depth directly or indirectly with the depth at which nets were deployed in a certain period of time.

Cormorants (61.3 %) as well as common eiders (65.6 %) have entangled significantly more often in set-nets which were equipped with PALs. The emitted signal is not in the frequency of hearing sensitivity (Therrien 2014). An effect of the bright coloured labels of the PALs on the bycatch of diving birds is unlikely because visibility in the Baltic Sea is relative low and bycatches did not occur more concentrated close to PALs. Certainly this effect would have stronger effects on visual hunters pursuing prey under water like cormorants, because common eiders only conduct steep dives to the ground. On contrary, the effect was stronger for common eiders.

The determined differences between bycatches in PAL- and control-nets could also be a result of single events with up to 8 bycatches in a single net row in a zero inflated dataset. Certainly, outliers influence the determined mean values that have been tested by the Wilcoxon signed rank test. These outliers may be better explained by the variability of the day and location of the net than by the effect of the PAL. Moreover the data on bycatches was corrected for effort, resulting in relative numbers of bycatches per NKD (according to Bellebaum et al. 2013) under the assumption that there is a linear relationship between net-length and the probability of bycatches. It was also assumed, that the probability of bycatches was the same for every single bycatch. This assumption could not been tested within this study due to missing abundance data.

Sonntag et al. (2012) could show that the vulnerability and potential conflict was highest in winter and spring in coastal and shallow offshore waters for diving birds. Bird density in combination with fishing effort was found to be a better predictor for common eider bycatch than water depth (Degel et al. 2010). For common eiders, occurring in big aggregations on the water, the probability of bycatches could be correlated to abundance. In case that the probability of a bycatch increases after the first occurrence of a bycatch in a net-row, using the total number of bycatches could lead to a pseudo-replication. This could induce an overestimation of the probability of bycatches for the affected experimental group.

In contrast, cormorants are hunting generally solitarily (Nelson 2005) and the occurrence of two bycatches in one single net-row is more likely to be independent.

Overall 31 cormorant bycatches occurred in 30 single net-rows, whereas in total 152 common eiders were bycaught. These bycatches of common eiders occurred in 88 net-rows with a maximum of 8 individuals in a single net-row. In 64.8 % (n=57) of these net-rows, only 1 common eider was bycaught.

A different approach to test the effect of the PAL on the probability of bycatches could be a binary coded data set, with 0 for “no-bycatch” and 1 for bycatch with no account on the absolute number. However, this approach allows no correction for fishing effort. This different approach would have no effect on the data of cormorants which have been bycaught as single individuals per net-row almost exclusively. A correlation between seabird density and altered probability of bycatch should be investigated in further studies on bycatches with simultaneous estimates of bird abundance.

The study was focused on the bycatch of harbour porpoises and especially designed to test the effectiveness of the PAL. It should be ascertained that PAL- and control-nets were deployed with the same effort, in the same area and at the same water depth. This study design is therefore not applicable for a deeper analysis of other variables affecting the probability of bycatches. To evaluate the effect of water depth, net-length, soaking time and location there should have been more variation in the gathered data.

The fishermen in this study often deployed net-rows at the same position for several days. A near located mussel bank which functions as a feeding ground for common eiders could increase the probability of bycatches. Data on mussel abundance was not available for this study but is assumed to have a strong effect on the distribution of common eiders (Gulllemette et al. 1996). The deployment of the same net-row on a mussel bank repeatedly for several days could have a strong effect on the probability of bycatches for the corresponding experimental group.

In the field recordings of the PAL much lower frequencies could be determined in the PAL signal around 60 and 70 kHz, which could be still distinguished from background noise at a distance of 21 m. By reason that little is known about under water hearing abilities of seabirds it cannot be excluded that some content of the PAL signal can be perceived.

Increased seabird bycatch rates for set-nets equipped with pingers were also found by Manly (2007). There is no information on type of pinger and the frequency of the tested signal but generally the high frequency signal of a pinger is not assumed to be audible for most seabirds (Therrien 2014). The results of Manly (2007) could be ascribed mainly to bycatches of common murres of the *Alcidae* family.

On the contrary, a decrease in the bycatch of murres by the use of pingers could be shown by Melvin et al. (1999). Therefore, Manly (2007) suspects that this effect could be correlated with another parameter like the presence of good feeding grounds that attract murres in the vicinity of the nets.

Additionally it could be proved that the presence of a scientific observer has no effect on the reported number of bycatches. This supports the experimental design with protocols and trips with a scientific observer on a regular basis.

Due to the limited number of fishermen that participated and the small size of the study area, this study is not representative for the German and even less the whole Baltic Sea. Conclusions about fisheries impact for the German or the whole Baltic Sea based on the results of this study could lead to an overestimation of bycatches because fisheries and area were selected by high conflict potential.

4.4. Implications of PAL deployment on set-net fisheries

The tested PAL signal had neither an effect on the catch rate of cod for fisher A nor an effect on the catch rate of flatfish for fisher B.

The results of this study do not allow an evaluation of a possible habituation from harbour porpoises to the tested signal because harbour porpoise detections were rare and the period of investigation too short. Generally habituation effects are expected to occur if the toleration of a disturbing signal is rewarded with food. This is for example the case for depredation of seals or bottlenose dolphins at set-nets but not typically for harbour porpoises (Königson 2011, Dawson et al. 2013). A repeated hearing of the signal could also lead to habituation effects but harbour porpoises in inshore areas at most seasonally resident (Dawson et al. 2013). The effect of a possible habituation should be analysed in further studies but is generally not expected because the PAL follows a different approach. The emitted signal should not be deterring but warning.

4.5. Implication for conservation management

An effective prevention of bycatches should reduce human induced mortality but should be evaluated also on economic viability and versatility (Bull 2007) to maintain both, conservation and fisher's subsistence aspects. There is no technical solution available that universally mitigates seabird bycatch in gillnets because of the large variety of configurations on board of fishing vessels and affected seabird species. A combination of an alerting device for seabirds and harbour porpoises is difficult because it would have to include visual and acoustic warning features for both groups. Although the amount of bycatches depends on fishing gear there is no perfect alternative to set-nets. Alternatives like longline fisheries could result in increased numbers of fish-eating seabirds (Anderson et al. 2011).

In the case that the impact of set-net fisheries on the population, by accidental bycatches, is higher than allowed by the calculated potential biological removal rate, further management steps must be considered.

The fishers are concerned that fishing may become economically unviable while using alternative fishing methods which are less efficient than set-nets. Although fish traps and set-nets are considered to have fewer environmental impacts than active fishing gear, these fishing methods still cause unaccounted mortalities (Uhlmann & Broadhurst 2013). In addition to the catch of target species, unwanted mortalities can result from fishing with traps and set-nets by a) ghost fishing of derelict gear, b) discarding, c) escaping or dropping out of gear, d) depredation, e) habitat damage and f) infection of injuries caused by the fishing gear (Uhlmann & Broadhurst 2013).

One alternative fishing method which has a low predisposition for marine mammal bycatches is the use of fish traps. On a seasonal level so called cod pots could be as efficient as gillnets (Königson et al. 2015).

In addition fuel costs could be reduced drastically as the best soaking time was estimated at six days (Königson et al. 2015), whereas set-nets have to be checked every day (Ljungberg 2007). The catch of living fish leads to an increase in the quality and therefore to higher selling prices.

Accessorily, visual stimuli could be utilized in cod pods to enhance the catch rate. The introduction of a green lamp increased catch rates by 74-80% for cod larger than 38 cm in the Swedish fisheries in the Bay of Hanö and the Karlskrona Archipelago (Bryhn et al. 2014). This could be also beneficial in the German fisheries with fish traps.

Five-fold higher catch rates of cod could be shown for cod pots close to a Norwegian salmon farm compared to pots at a distance of 100 m to the farm (Bagdonas et al. 2012). Additionally, pots which were deployed underneath the salmon cages caught larger cods. However, legal fishing around aquacultures could create circumstances that result in the establishment of ecological traps. On the one hand the high quality and quantity of food below the salmon farm could be high attractive as a habitat for fish while on the other hand a high fisheries pressure could be generated (Dempster et al. 2002, Dempster et al. 2009). However, in Germany aquaculture farms in natural waters are mostly forbidden due to environmental protection regulations (Aquafima online assessed 12th of November, 2015). Accordingly, this approach to enhance the fishing success with cod pots is not transferable to German fisheries to date.

On the contrary an adjustment in the mesh size of fish traps can enhance selectivity to reduce undersized discard (Ovegård et al. 2011). These finding could make fish traps more competitive with set-nets in future.

In this study, bycatch rates of common eiders peaked simultaneously with highest catch rates of cod which contradicts a management approach with temporal limitations. It could be shown that seabird bycatches occurred within a proposed special area for conservation which is proposed for the protection of seabirds. However, it should be noted that only one fishing vessels was investigated during this study. Thus, any generalization of the results should be considered with great care.

Mean water depth of set-nets with bycaught seabirds was much lower than the total mean of set-nets. In this study cormorants were bycaught in a mean water depth of 5.2 m and common eiders in a mean depth of 4.6 m. No bycatches occurred in a mean depth larger than 12.5 m for cormorants and 11.5 m for common eiders. Therefore, a temporal regulation of the minimum depth at which set-nets are deployed could possibly reduce the number of seabird bycatches. This could be in the period of highest seabird abundance which is in the winter. However, an approach of regulations in water depth of deployed nets has to be tested in further studies. The set-up in this study does not allow an interpretation of water depth on the probability of bycatches because water depth was also a proxy for seasonal variations.

Cormorants seem to be visual hunters that are dependent from light (White et al. 2008) therefore a prevention of bird bycatches by visual signals seems to be the best approach. An improved net visibility and simultaneous use of acoustic alerts were found to reduce seabird bycatches (Melvin et al. 1999).

The most promising approach for an overall solution could be a combination of PAL, increased detectability and visibility of the net.

5. Outlook

The PAL was tested simultaneously in Danish set-net fisheries by two Danish fishermen. Their vessels were observed under the Danish Remote Electronic Monitoring Programme via on board video camera surveillance instead of written protocols. The analysis of the collected data from Danish fisheries was not completed prior to the deadline of this thesis.

A total of 12 harbour porpoises were bycaught by Danish fishermen (Table 15) after September 8, 2013. 10 individuals were bycaught in control and 2 in PAL equipped set-nets. Unfortunately, there are uncertainties in the categorization of experimental groups in the Danish fisheries that could not be solved yet. The first visual screening of the video protocols of all Danish fishing trips resulted in a more than doubled effort in the control group. The fishermen themselves reported that they conducted a study with similar effort in control and PAL nets. Therefore it is assumed, that the visual classification of experimental groups has to be improved. Better visual markings of set-nets with PALs could be an approach to solve this problem. In conclusion, a statistical analysis of bycatches in Danish fisheries is not possible.

The bycatches from the Danish fishermen gave evidence for differences between the North and the Baltic Sea. In the North Sea 2 harbour porpoises were caught in control-nets and 3 in control nets. In the Baltic Sea, all reported harbour porpoises were bycaught in control-nets. This could give evidence for the effectiveness of the PAL.

Table 15: Total amount of harbour porpoises bycaught by Danish fishermen separated by experimental group and area:

Bycatches	total	control	PAL
Baltic Sea	7	7	0
North Sea	5	3	2

In total, 14 bycaught harbour porpoises have been reported by all participating fishermen. Figure 37 shows the occurrence of all bycatches separated by experimental group by different colouration (PAL=yellow, control=red). Each dot represents the approximate position of a set-net with a bycatch with no account on number of bycaught animals.

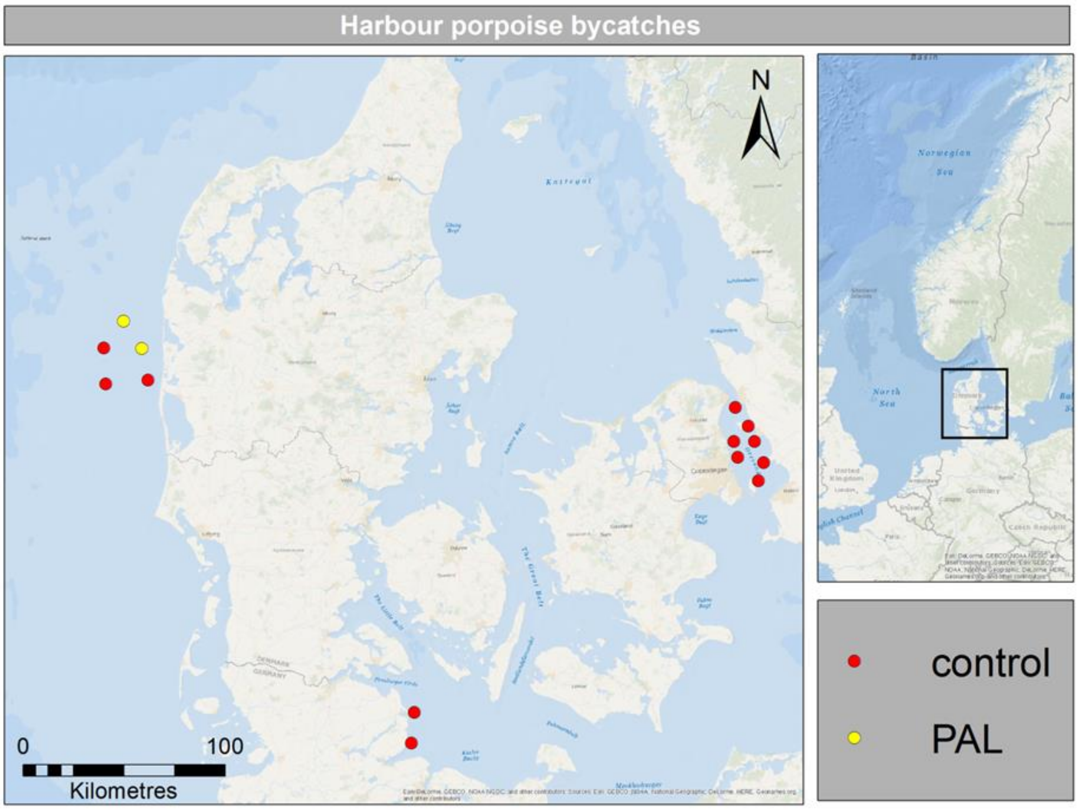

Figure 37: Total amount of harbour porpoise bycatches by German and Danish fishermen after September 8, 2013 separated by experimental group (control=red, PAL=yellow).

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vom Fischer auszufüllen

Bitte alles ausfüllen !

Schiff		
	Name	
	Fischereikennzeichen	
	Auslaufen Datum / Uhrzeit	
	Einlaufen Datum / Uhrzeit	

Für jede PAL-Farbe und jeden Hol bitte einen eigenen Schein ausfüllen - Danke!

	Fanggerät	Eingehängte PALs	
Netzbezeichnung (z.B. Dreiwandnetz)		Farbe	
Netztyp (siehe Rückseite; GNS, GTR)		Anzahl	
Netzlänge	m		
Netzhöhe	m	Abstand zw den PALS (max 200m)	
Maschenöffnung	mm	in m	m
Anzahl der Netze		in Netzlängen	Anz

Fangdaten				
	Zeitzone		UTC, MEZ, MESZ	
	Aussetzen	Datum	Tag.Monat.Jahr	
		Uhrzeit	Stunde : Minuten	
	Hieven	Datum	Tag.Monat.Jahr	
		Uhrzeit	Stunde : Minuten	
Geogr. Breite	Beginn	Grad°Minuten.MM' (54°25.05')		
Geogr. Länge				
Geogr. Breite	Ende			
Geogr. Länge				

Defekte PALs	
Nummer	Grund

Wassertiefe Minimum		m
Wassertiefe Maximum		m
Zielfischart	Name	
geschätztes Gesamtgewicht des Hols (Discard+Anlandung+Probe)		kg

Tragen Sie bitte hier unten die Fangmenge des Hols ein

Anlandung aus dem beprobten Hol (ohne Probe)	Fischart	Produkt (z.B. ausgenommen, rund)	Kisten (Anzahl)	Kistengewicht (kg)	Gesamtgewicht (kg)	keine Anlandung
	Dorsch					☐
	Flunder					☐
	Scholle					☐
	Kliesche					☐
	Wittling					☐
	Hering					☐
	Sprott					☐
weitere Arten						

Beifang-Bericht	Bitte pro Zeile nur einen Schweinswal eintragen. Bitte auch Seevögel eintragen			PAL-Geräte links/rechts vom Punkt im Netz, wo der Beifang aufgetreten ist	
Art	Anzahl	Abstand in Meter (ca)	gemessen vom Anfang/Ende	Farbe/Nummer links	Farbe/Nummer rechts

PAL 130819

Figure 38: Standardized protocol for data collection on board of the fisher's vessels.