Evaluation of fish pot modifications in the western Baltic Sea

Christoph Wengerodt

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University of Rostock

Faculty of Mathematics and Natural Sciences

Institute of Biological Sciences

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First reviewer:

Dr. Daniel Stepputtis

Thuenen-Institute of Baltic Sea Fisheries

Alter Hafen Süd 2, 18057 Rostock, Germany

Tel.: +49 (0) 381 8116 136

Email: daniel.stepputtis@ti.bund.de

Second reviewer:

Dr. Helmut Winkler

University of Rostock, Institute of Biological Sciences, Department of Zoology

Universitätsplatz 2, 18055 Rostock, Germany

Tel.: +49 (0) 381 498 6272

Email: helmut.winkler@uni-rostock.de

Abstract

Gillnets are one of the most common fishing gears in the Baltic Sea. They are regarded as a cost-efficient, size selective and easy to handle gear, which can be used even on small vessels. Nevertheless, they are often criticised for the accidental bycatch of marine mammals and seabirds. Also, a growing seal population in the Baltic Sea raises the need for alternatives. Seals are already causing great economic damage on the Swedish coast, by catching fish out of the nets and damaging fishing gear.

Fish pots (Syn.: pots) are regarded as an alternative fishing gear with low environmental impact and other favourable characteristics. For example, pots have little interaction with the sea floor and are relatively safe for marine mammals and seabirds. They can also be modified to be proof against seal attacks. Moreover, their deployment is less weather dependent compared to gillnets, because they can stay in the water for several days, delivering alive fish.

In this study, 2 types of two-chamber pots were tested on a commercial fishing vessel. Additionally, 4 different baits were tested. Hereby, pots were baited with herring or shrimp as natural bait but also with the amino acid glycine and the amino acid derivative glutamate, as artificial baits. In preparatory studies, different methods were tested to make the artificial baits long lasting and to improve their usability. To evaluate the practicability of pots in the commercial fishery, their catches were compared to the catches of a common gillnet.

Pots caught almost exclusively cod (*Gadus morhua*). The gillnet also caught mainly cod, but also a large amount of flounder (*Platichthys flesus*). The cod catch per unit effort (CPUE, 10 pots equivalent to 200 m gillnet) of pot-type I was approx. 2.6-times lower compared to the cod CPUE of the gillnet. Pots of type II caught on average 15-times less cod than the gillnet. Moreover, pots caught mainly cod below the minimum landing size (pot-type I: 74 %, pot-type II: 67 %), whereas only a small percentage of the gillnet cod catches were undersized (7 %). There was no significant difference between the average catch obtained with the different tested baits but in general, cod catches of unbaited control pots were highest. The reasons for this unexpected finding are unclear. Furthermore, natural baits were superior to artificial baits. The effective handling of the pots needed more effort than the gillnet.

In their tested state, pots cannot be regarded as economic alternative to gillnets. Future studies on pot modifications as well as on long lasting baits should be conducted to increase the practicability and catchability of this promising alternative fishing gear.

Zusammenfassung

Stellnetze sind eines der am häufigsten verwendeten Fischfanggeräte in der Ostsee. Sie gelten als kostengünstig, größenselektiv, einfach zu handhaben und können selbst auf kleineren Booten eingesetzt werden. Allerdings wird oft kritisiert, dass sich marine Säuger und Seevögel in ihnen verfangen und verenden können. Ein anderes Problem ist die wachsende Robbenpopulation vor der deutschen Ostseeküste. Robben verursachen schon jetzt große wirtschaftliche Schäden vor der schwedischen Küste indem sie gefangenen Fisch anfressen oder gar Fanggerät beschädigen. Alternativen sind nötig um diesen Problemen zu begegnen.

Fischfallen (engl.: *fish pots*, *pots*) gelten als alternatives Fanggerät mit geringem ökologischen Einfluss. Sie haben nur geringe Auswirkungen auf den Meeresboden und sind relativ ungefährlich für marine Säuger und Seevögel. Zudem bieten sie für Fischer verschiedene Vorteile. Sie können z.B. so modifiziert werden, dass der Fang vor Robben geschützt ist. Die Arbeit mit Fischfallen ist generell weniger wetterabhängig im Vergleich zu Stellnetzen, da sie für mehrere Tage im Wasser bleiben können und trotzdem lebendigen Fisch liefern.

In dieser Studie wurden 2 Typen (*pot-type I*, *pot-type II*) von Fischfallen auf einem kommerziellen Fischkutter getestet. Außerdem wurden 4 verschiedene Köder erprobt. Fischfallen wurden mit natürlichen (Hering und Krabben) und künstlichen Ködern (Aminosäure Glycin und Aminosäurederivat Glutamat) bestückt. In Vorexperimenten wurden verschiedene Methoden erprobt, um die künstlichen Köder länger haltbar und praktikabel zu machen. Um die Tauglichkeit der Fischfallen in der kommerziellen Fischerei zu bewerten, wurden ihre Fänge und Praktikabilität mit einem herkömmlichen Stellnetz verglichen.

Fischfallen fingen fast ausschließlich Dorsch (*Gadus morhua*). Das Stellnetz fing zusätzlich größere Mengen Flunder (*Platichthys flesus).* Der *catch per unit effort* (CPUE, Fänge von 10 Fallen) von *pot-type I* war 2,6-mal geringer verglichen zum CPUE des Stellnetzes (Fänge von 200 m Stellnetz). Die Fänge von *pot-type II* waren 15-mal geringer im Vergleich zum Stellnetz. Zudem fingen Fischfallen vor allem untermaßigen Dorsch (*pot-type I*: 74 %, *pot-type II*: 67 %), wohingegen die Dorschfänge des Stellnetzes nur zu einem geringen Anteil untermaßig waren (7 %). Verschiedene Köder führten nicht zu signifikanten Unterschieden in den Fängen, aber generell wurde mit unbeköderten Fallen am meisten Dorsch gefangen. Die Gründe für dieses unerwartete Ergebnis sind unklar. Zudem fingen natürliche Köder im Durchschnitt mehr Dorsch als Künstliche. Der benötigte Arbeitsaufwand bei Fischfallen war generell größer als beim getesteten Stellnetz.

Die getesteten Fischfallen können momentan nicht als ökonomisch-sinnvolle Alternative zu Stellnetzen betrachtet werden. Zukünftige Studien zu Fallenmodifikationen und künstlichen Ködern sollten durchgeführt werden um die Praktikabilität und Fängigkeit dieses vielversprechenden alternativen Fanggerätes zu verbessern.

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ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
BLE	Bundesanstalt für Landwirstschaft und Ernährung (German Federal Office for Agriculture and Food)
CP I	Cod pot-type I
CP II	Cod pot-type II
CPUE	Catch per unit effort (for a detailed description, see chapter 2.3)
FAO	Food and Agriculture Organization of the United Nations
GN	Gillnet
ICES	International Council for the Exploration of the Sea
ICES-SD	ICES subdivision
LALLF M-V	Landesamt für Landwirtschaft, Lebensmittelsicherheit und Fischerei Mecklenburg-Vorpommern (State office for agriculture, food safety and fishery Mecklenburg-Western Pomerania)
LED	Light-emitting diode
n	sample size
p	probability-value in significance analyses
Pers. comm.	personal communication
SD	Standard deviation
TI-OF	Thünen-Institut für Ostseefischerei (Thuenen-Institute of Baltic Sea Fisheries)

1 Introduction

1.1 The fishery in the western Baltic Sea

Fishing gear can be categorized by their functionality. Active fishing gear, on the one hand, involves a movement of itself (and thou the boat) through the water to chase and capture fish. A widely used active fishing method is the bottom or pelagic trawl net. These nets are pulled over the sea bottom or through the open water, respectively. On the other hand, passive fishing gears like gillnets, traps and pots are often anchored at the sea floor and work by entangling or trapping fish in their structures.

In the commercial fishery of the western Baltic Sea, the most used passive gear is the gillnet. This net curtain is often around 2.5 m high and anchored at the sea floor. A floating upper line erects the netting in the water. Normally, fishermen use multiple panels and different kinds of these nets, forming a chain that can be up to several kilometres long.

In the German waters of the Baltic Sea, this traditional fishing method is mainly used by small vessels, often operated by 1 to 4 fishermen. They represented the large part of the German Baltic commercial fishing fleet in 2013 (ca. 92 % of the vessels) (Table 1). But this large part of the fleet only accounted for 27 % of the total commercial landings. The majority of fish was landed with active gears like trawl nets.

Main pelagic target species in the Baltic are Atlantic herring (*Clupea harengus*) and European sprat (*Sprattus sprattus*) (ICES 2013). Main demersal target species is Atlantic cod *(Gadus morhua*) and seasonally important flat fish like flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*) and turbot (*Scophthalmus maximus*). These species are mainly caught with bottom trawl nets. The target species for the passive (gillnet) fishery are cod, herring, Atlantic salmon (*Salmo salar*) and different flatfish species.

Table 1: Number and total landings of German fishing vessels in 2013 separated by fishing method (BLE 2013).

Gear type	Number of active vessels	%	Total landings [t]	%
passive	856	92	10062	27
active	72	8	27209	73
Total	928	100	37271	100

1.2 The need for alternative fishing gears

Figure 1: Satellite image of fish trawler in the northern Gulf of Mexico off the coast of Louisiana. The sediment plumes behind the vessels are likely caused by bottom trawl nets. © SkyTruth

Active fishing gears like trawls are regarded as profitable and size selective fishing technique. A clear disadvantage is the required movement of the gear and the associated high fuel consumption. Moreover, trawls are often criticised because of their high bycatch rates and negative effects on benthic ecosystems (De Groot 1983, Jennings & Kaiser 1998, Jones 1992). For example, often otter boards are used for bottom trawls to pull the net wide open. These heavy wooden or iron boards can dig up to 30 cm of sediment, which is often visible in form of plumes of suspended sediment (Krost *et al*. 1990) (Figure 1).

In contrast, passive gears like gillnets don´t require any movement of the gear nor the attendance of a fishing vessel over the whole fishing period. They just have to be checked regularly. Gillnets are also regarded as size and species selective and can be profitable operated on smaller vessels, compared to trawls. Besides many advantages, these passive fishing gears have also disadvantages. Although they don't require a permanent attendance of a fisher, they have to be checked and emptied frequently. Especially during summer, the catch has to be collected not later than 24 hours after setting the nets, because entangled fish often die and start to rod (pers. comm. Bernd Mieske, TI-OF). When the fish is not collected because of e.g. bad weather, the whole catch can be lost.

Although gillnets have a good selectivity towards the target species, they are often criticised for the accidental bycatch of unwanted species, such as sea birds and marine mammals. Modern gillnets can form walls of nearly invisible meshes which can be several kilometres long. These nylon curtains are hard to detect for the sonar of marine mammals, such as dolphins and harbour porpoises (*Phocoena phocoena*) and potentially they entangle and drown in them (Au & Jones 1991, Dawson 1991, Koschinski 2001). Koschinski (2011) estimated the number of bycaught harbour porpoises at the German Baltic coast to around 70 animals per year. These rare marine mammals are under special protection of a recovery plan (ASCOBANS 2002, ASCOBANS 2010). Additionally, diving sea birds like ducks and divers can entangle in gillnets when they search for food at the sea ground (Bellebaum 2011, Sonntag *et al*. 2012). Especially bays and coves are an important breeding area for numerous indigenous and migrating bird species. Off the German Baltic coast, an estimated number of 17500 seabirds is annually bycaught in gillnets (Bellebaum *et al*. 2013), whereas the real bycatch numbers are unclear and the estimates are subject of discussions. Investigations on gillnet modifications, to solve the problem of bycatch of bird and mammals, were not successful so far. Consequently, other fishing gears need to be considered as alternatives for gillnets.

An additional need for alternatives is raised by a growing grey seal (*Halichoerus grypus)* population on the German Baltic coast (Herrmann *et al.* 2007). Since many years, Swedish fishermen struggle with their local populations (Königson 2011, Lunneryd 2001, Lunneryd & Westerberg 1997, Westerberg *et al*. 2000). The seals feed on the fish that is caught in the gillnets or damage fishing gear. This can lead to a loss of the total catch and cause an enormous economic problem (Königson 2011). The seal population along the German Baltic coast is much smaller, compared to Sweden. Nevertheless, it is growing and the first German fishermen reported bite marks on fish, which were caught in their gillnets (pers. comm. Christian von Dorrien, TI-OF). This could be a first indication that German fishermen will face similar problems as in Sweden.

In the case of seals, it is now the time to look for solutions for this possible imminent problem, before they can cause large economic damages. In the case of bycaught marine mammals and seabirds, one solution is always to completely exclude the fishery from an area or at least to reduce the fishing effort. Most of the time, this leads to a direct economic loss for the fisher. In a long term view, it is more cost efficient to work on alternative fishing gears, as long as it is still time to counteract those problems. Alternative gears should be safe for marine mammals and seabirds, protect the catch against predation by marine mammals, as well as, they should be an economical reasonable option for fishermen.

1.3 Fish pots as a possible alternative

Fish pots (hereafter used: pots) are used since thousands of years worldwide (Becker-Nielsen 2002, Sainsbury 1996, von Brand 1984). According to the FAO fishing gear classification, pots are a subgroup of traps (Slack-Smith 2001), but the main difference between pots and traps (in their strict sense) is, "*that traps guide and then trap fish, while pots attract and then retain fish.*" (Pol *et al*. 2010). Generally, traps are static structures, which are placed in coastal areas and river estuaries (Figure 2). Hereby, fish are misled, attracted or drift into these enclosures and (ideally) won´t find their way out again. For example, in tidal zones, stone walls are build which are flooded during high tide. With the retreating water, the fish accumulate at this obstacle and can be collected. Ancient forms of these traps are up to 12000 years old and their remains can still be found all over the world (Claxton & Elliott 1994, Nishimura 1968, Sara 1980). Other types of traps are e.g. trap nets and pound nets. Typically, all of these traps don´t use any form of bait.

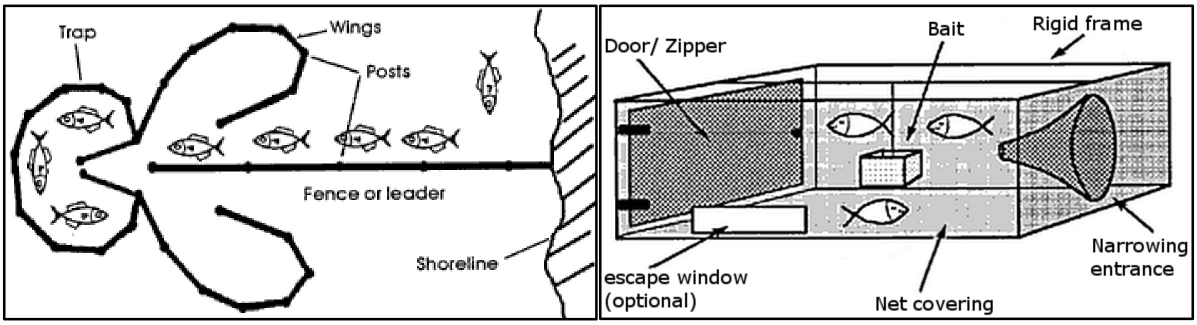

Figure 2: Scheme of the general working principle of a fish trap (left) and a fish pot (right) (from Slack-Smith 2001).

Normally, pots are portable basket- or boxlike enclosures (Figure 2), equipped with a type of bait (e.g. prey fish, light). They were invented independently all over the world in different types and are still used until today. Pots work after the principle of luring fish, crustaceans or cephalopods into the narrowing pot entrance, using bait. Once the animal is inside the pot, it´s difficult to find the way out again. Pots are common in the fishery for crustaceans like lobster and crabs. They are widely used for the small-scale fisheries in the tropics, e.g. for catching fish in reefs where nets can´t be used (von Brand 1984). They are also used in larger and economic important fisheries like the pot fishery for king crab (*Paralithodes camtschaticus*) in the Bering Sea (Falk-Petersen *et al.* 2011). In the German Baltic fishery, the commercial use of pots is virtually non-existent. They are mainly used to catch fish without harming for scientific sampling.

Fish pots are generally recognized as a fishing technique with a low environmental impact (Cole *et al*. 2003, Dayton *et al*. 1995, Jennings & Kaiser 1998). Possible harmful interactions with the benthos can be reduced by floating pots off the sea floor. Thus, only the anchors and the ground line touch the bottom. As a passive fishing gear, they can stay in the water without requiring the presence of a fishing vessel. Additionally, they can stay in the water for several days, because most fish stay alive inside (Thomsen *et al*. 2010). So, the pots don´t require daily emptying like it is the case with gillnets, which makes the fishermen less dependent on the weather. Moreover, unwanted fish can be returned to sea with low mortality and physical damage. These factors make pots a favoured technique to catch fish for scientific sampling or for the live fish market. Additionally, they are considered to be safe of accidental bycatch of seabirds and marine mammals. Fish pots are manufactured in various designs and sizes (Furevik & Løkkeborg 1994). Models ranging from small pots that can easily be handled by one person to large, heavy pots that can only be operated from large purpose-build vessels with special equipment (king crab fishery). Single components of pots like entrances, floats and bait can easily be modified (Furevik *et al*. 2008, Königson *et al.* 2014, Ljungberg 2007).

1.4 Chemical stimuli, chemoreception, and food search behaviour of fish

For a catch success, the target fish species has to be lured inside the pot first. Here, their natural food search behaviour is utilised. Fish are attracted by the bait in form of different types of stimuli. The stimuli pathways underwater differ greatly from those above the water. In a fluid medium, important stimuli such as sound (except low frequencies) and light attenuate rapidly. Especially in areas with limited visibility, because of e.g. high turbidity or great depths, chemical stimuli play an important role for the detection of possible food sources. This type of information pathway has two advantages over acoustic and visual stimuli. First, chemical stimuli disperse with the current over long distances. Hereby, the stimuli becomes diluted with an increasing distance to its source. Nevertheless, fish can detect these stimuli over long ranges. In a study from Løkkeborg (1998), cod could be attracted with bait from a distance of 700 m. The second advantage is that a chemical stimulus lasts for a long period of time, whereas acoustic und visual stimuli fade quite quickly after being emitted. For example, cod was able to locate bait 7 hours after setting it, which shows that the attractants stay detectable in the water for several hours (Løkkeborg 1998). These two unique characteristics make chemical stimuli superior to attract fish over long spatial and temporal ranges.

Visual signals are more suitable to attract fish over shorter distances. Artificial lights are able to attract prey, as well as target species and they are used in fisheries for thousands of years until today (Ben-Yami 1976, Gabriel *et al*. 2005).

Fish detect chemical signals with their olfactory and gustatory system (Hara 1994). Olfaction is enabled through two paired nostril structures which are located in the snout of the fish. By moving though the water, currents or respiratory pressure changes of the fish, water flows into the anterior inlet and out of the posterior outlet of these channels. Waterborne chemical stimuli are detected via specialised receptor cells of the nasal mucosa (Zeiske *et al.* 1992). From here, the signals are directly transferred to the olfactory bulb of the brain, were the information is processed (Hara 1992). The structural bases of the gustatory system are the taste buds. These specialised epithelial cells can be found on the lips, in the oral cavity, the pharynx, on the barbells, gills and sometimes even distributed over the body surface (in scaleless catfish). It is believed that olfaction has a lower detection threshold than the gustatory system (Johnstone 1980, Ishida & Kobayashi 1992). Therefore, olfaction is assumed to initiate food search behaviour for a variety of chemical stimuli. The gustatory system works probably more selective and provides the final sensory evaluation (Kasumyan & Døving 2003). Whether a food search behaviour is initiated in the first place depends on several interacting internal factors like hunger, reproductive status and diel patterns (Jobling *et al.* 2010) (Figure 3).

The major driver for the dispersion of particles and substances in seawater is the current. This is because the rate of molecular diffusion in water is very low. Thus, a fish that detects an odour of a bait or prey, has to swim upstream to locate its source (Atema 1980). This behavioural orientation to water currents is called rheotaxis. Chemically stimulated rheotaxis is regarded as the most likely explanation for how fish and crustaceans locate an odour source (Carton & Montgomery 2003, Løkkeborg *et al.* 2010, Pawson 1977a). Field studies with several species have verified that most fish encounter bait from the downstream direction (Fernö *et al*.1986, Løkkeborg *et al*. 1989, Løkkeborg & Fernö 1999). An alternative theory for food location of fish is based on the increasing chemical concentration gradient as the distance to the odour source decreases. However, this explanation is rather unlikely because turbulences often weaken and mix up gradients, resulting in an inconsistent chemical signal, which would be hard to locate (Webster & Weissburg 2001; Carton & Montgomery 2003).

Visual and mechanosensory stimuli (via the lateral line system) become rather important at close range and may give additional clues, whether or not to attack (Kalmijn 1988, Guthrie & Muntz 1993).

Since olfactory and gustatory stimuli are the most important senses to initiate food search behaviour, even over a long range, chemical stimuli and their characteristics (long range, constant over time) should form the basis for developing new baits.

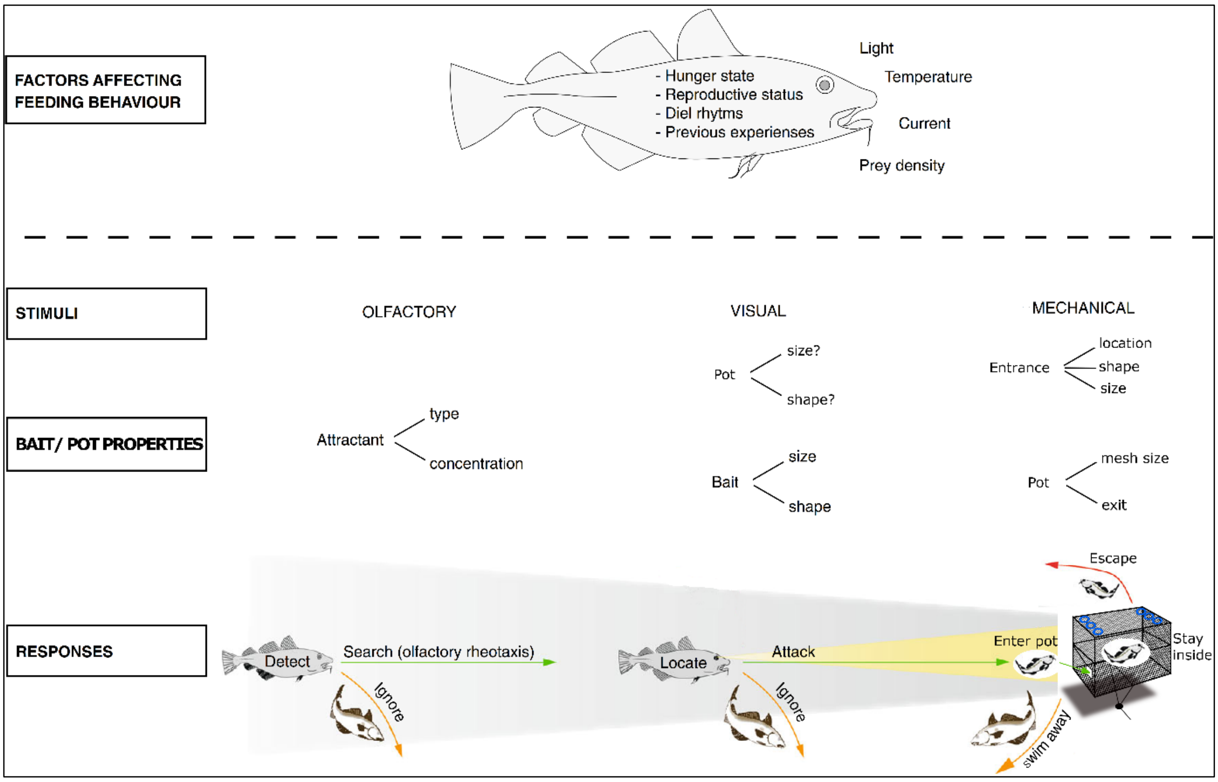

Figure 3: A multifactorial overview on fish behaviour to pots, that affect the catch success. Internal and external factors that affect fish behaviour are shown above the broken line. Type of stimuli, bait/ pot properties and fish responses are shown at different distances, down-current from the pot (grey shade: odour plume, yellow shade: visual range) (after Løkkeborg et al. 2014).

1.5 Bait for fish pots

Pots are usually baited to attract fish. Commonly, these baits consist of smaller prey fish like herring or mackerel. Amongst others, Martin & McCracken (1954) and Ljungberg (2007) have shown, that also shrimp and squid are suitable baits for catching cod. It is also known that food preferences differ greatly in different areas and among species. For example, squid resulted in good cod catches in the north Atlantic but caught poorly in the Baltic Sea (Ljungberg 2007). These traditional, natural baits have all in common that they are relatively cheap and easy to access. They can be caught by the fishermen themselves and, being frozen, stored for a long time. The disadvantage of natural baits is, that they release their attractants only over a relatively short time (Løkkeborg 1990). This directly affects the catch success. In trials with pre-soaked bait, Løkkeborg & Johannessen (1992) found out, that the catch rate of bait, soaked 24 h prior the trial, was 50 % less in comparison to fresh bait. Fish pots generally stay in the water for 1 – 3 days. Thus, it is desirable to have a constant release of attractants over the whole fishing period. To achieve this, artificial baits were developed and hereby two general methods have emerged. First, artificial baits can be made of surplus fish products like minced guts or whole fish (Løkkeborg 1991). The advantage of this type of artificial bait is, that the components are cheap and easily available. Løkkeborg (1991) found out, that a paste of minced herring led to a higher catch rate for haddock (*Melanogrammus aeglefinus*), torsk (*Brosme brosme*) and ling (*Molva molva*) in comparison to natural bait. One problem with such pastes is the necessity of a carrier. A carrier facilitates a constant release of the bait attractants over a long period of time. These carriers can be added directly to the (often fluid) bait to make it less soluble. For example, Løkkeborg (1991) added guar gum or gelatine to a paste of minced herring. Additionally, the bait-carrier mixture can be put into special containers, which release a certain amount of bait over a given time into the water (pers. comm. Bjarti Thomsen, Faroese Fisheries Laboratory).

The second method for producing artificial bait, is to extract attractants out of prey species or to synthesize attractive, chemical components. Several studies have shown that feeding behaviour in fish is stimulated by substances with a low-molecular weight and a high aqueous solubility such as amino acids, peptides and steroids (Carr & Derby 1986, Hara 1992, Hara 2011). Hereby, amino acids seem to comprise the most important group, and short-chained neutral amino acids (e.g. alanine, glycine, glutamic acid) appear to be most stimulating (Hara 2011, Kasumyan & Døving 2003, Marui & Caprio 1992). One associated adaptation of fish could be, that they are able to discriminate between different amino acids and are able to detect them, even in very low concentrations (Ellingson 1985, Friedrich 2006). For example, the response threshold for glycine was estimated to be less than 10^{-7} M in cod and whiting (Pawson 1977b). The advantage of artificial baits, made from isolated chemical attractants, is that they (ideally) only require a small amount of the substance, because of its high potency and the ability of most fish to detect chemical stimuli even in very low concentrations (Hara 1994). A disadvantage are the high costs of most of those chemical extracts because of the complex methods of identification, extraction and/ or synthesis. Like with artificial baits made from surplus fish products, the carrier is a crucial factor for the efficiency of synthetic artificial baits, because without one they would dissolve after a short time. Carr (1981) invented a carrier for artificial long line baits, made of a water-insoluble, hydrophilic matrix (a polyurethane foam) which is permeable (by diffusion) to the release of the incorporated synthetic attractants.

In contrast to baits for long line fishing (which should be swallowed by the fish), the texture of a bait for fish pots is rather unimportant. When the fish reaches the bait bag to attack it, it will already be trapped. Still, many internal and external factors interact in the process of attraction, capturing and retaining fish with pots, which have to be considered (Figure 3).

Following characteristics apply for an ideal bait (natural and artificial):

- release attractants over a long period of time
- release constant amount of attractants over a given period of time
- raw materials should be available and cost efficient
- easy to handle on deck ("ready-to-use")
- non-perishable (best without frosting)
- species selective
- non-hazardous and biodegradable

Regarding these features, an ideal bait would form an olfactory guidance that disperses with the current and attracts fish over a long range. This way, the rather small effective fishing area of a fish pot (because of its rather small size) would be compensated by a large attraction area of the bait (McQuinn *et al*. 1988, Miller 1990). In contrast, conventional passive fishing gears like gillnets have a large effective fishing area due to their length, but no attraction area (Figure 4).

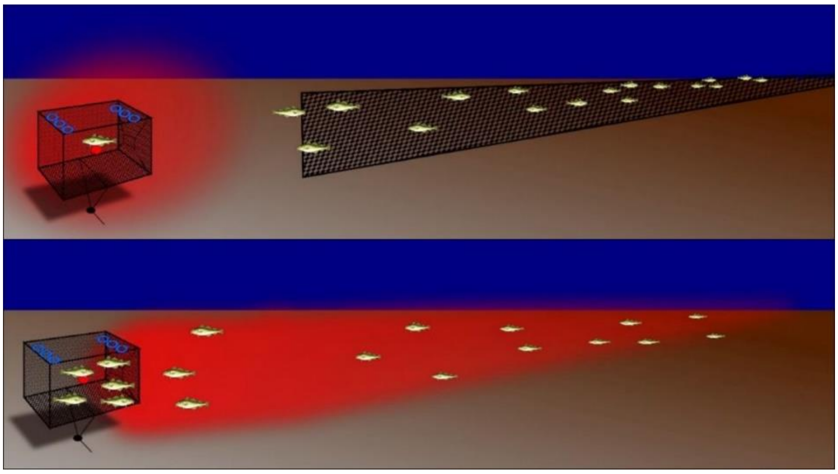

Figure 4: Illustration of the theory of an olfactory guidance. Top: A pot equipped with a low-potent bait has a small active fishing area and a small attraction area (red), whereas the gillnet has a large active fishing area. Bottom: The small effective fishing area of the fish pot is compensated by a large attraction area using a high-potent bait.

1.6 Aim of this study

Aim of this study is to test and evaluate modifications of fish pots as well as different baits for pots. Moreover, the handling und usability of fish pots on a commercial fishing vessel will be tested. Based on catch data and usability, it will be discussed if fish pots are a potential alternative for the common gillnet.

Following hypotheses shall be tested:

$[H_0]_1$: Different gears (pot-type I, pot-type II, gillnet) have no significant differences in catches.

$[H_0]_2$: Different baits for fish pots (herring, shrimp, glycine, glutamate, light only, unbaited control pots) have no influence on the catches of cod.

To test these hypotheses, following questions were stated:

1) Do the difference gears affect the catch composition?
2) Do the different gears affect the length distribution of caught cod and flounder?
3) How much cod can be caught by the different gears?
4) How much cod can be caught by pots of both types, when equipped with different baits?

The results of this study should contribute to the ongoing debate on the potential use of alternative fishing gears in the commercial fishery of the western Baltic Sea. With regard to the accidental bycatch of marine mammals, sea birds and a growing seal population as fishing competitor, there is an urgent need for research on alternative fishing gears, from the environmental and the economic point of view.

2 Material and Methods

2.1 Preliminary studies

A carrier was necessary to prevent a fast leaching of the artificial baits and to make them easier to handle. In general, that can be achieved by e.g. adding a binder to a fluid bait, making it more viscous. Thus, the bait dissolves slower and it releases its attractants over a longer period of time.

In first trials, the crystalline artificial baits glycine and glutamate were dissolved in water and filled in plastic bottles. A colouring agent was added to make a possible dilution visible. The bottles were then punctured with holes of different sizes (0.5 mm – 1.5 mm) and numbers (3 – 8) and put into a port basin. The theory was, that the glycine or glutamate-saturated water had a higher osmotic value compared to the surrounding seawater and would diffuse out of the bottle. However, the colour of the solution did not change for several hours (the experiment was checked up to 24 h after start), which indicated that there was no significant exchange of substances. One possible explanation for this is, that the bait solution had an osmotic value similar to the surrounding seawater. This way, diffusion would have occurred only in insufficient dimensions. Moreover, during the preliminary studies, it became clear that a fluid bait that is applied in a permeable container would be inconvenient to handle on board a fishing vessel.

To counter this problem, the bait solution was absorbed with a textile material, acting as a kind of reservoir for the fluid bait. The soaked fabric was enwrapped with a waterproof sheath, except for two area. Only there, an exchange of substances by diffusion was possible. However, the coloured bait solution remained in the textile unchanged for several days, making it arguable whether there was a sufficient exchange of substances. Another negative point of this type of bait application was, that it was hardly quantifiable. A similar idea was, to insert the bait solution under high pressure into a carrier material, after the principle of pressure impregnation. This way, the high concentrated attractants would leak out into the water over a long time in. This approach was not pursued any further, because of its high technical difficulty and its uncertain prospects.

Finally, a method from Løkkeborg (1991) was adopted, where guar gum was added to a paste of ground fish to make it more viscous and with it less soluble. In this study, a mixture of wheat flour and water (for detailed description see chapter 2.4.3) was chosen as a carrier.

The resulting paste could be produced in different viscosities, depending on e.g. the water current, temperature and the desired permanency of the bait. The crystalline artificial baits could be added easily to the mixture. To find the best trade-off between the durability of the bait and the release rate of its attractants, different concentrations of components were tested. Experiments conducted in a port basin near the TI-OF in Rostock, showed that a mixture of 215 g flour, 175 ml water and 125 glycine loses about 50 % of its original mass after 24 h (Figure 5). It was assumed that the artificial baits, which were incorporated in the paste, are released in a similar quantity as the mixture dissolves over the time. Regarding this, an hourly attractant-release-rate of 2.699 g/h could be estimated. Mixtures with a higher content of flour showed a lower rate of dissolubility. If the flour content was low, the mixture became runnier and did not last long. A bait container was necessary to make the paste transportable, easy to handle and more durable. For this, 500 ml PVC wide neck containers with holes on each side proved as suitable (Figure 36, for details see chapter 2.3.3).

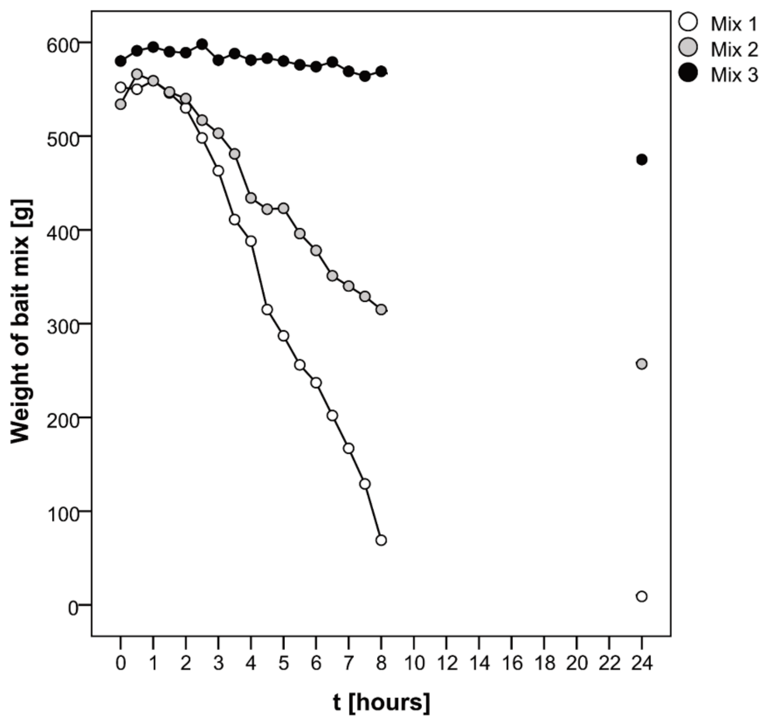

Figure 5: Mass loss of different artificial bait mixtures in g over the time in hours. The bait paste was put into a holey container which was submerged into a port basin (Mix 1: 175 g flour + 225 ml water + 125 g glycine, Mix 2: 215 g flour + 175 g water + 125 glycine, Mix 3: 250 g flour + 150 ml water + 125 g glycine).

2.2 Fishing trials

2.2.1 Study site

Experimental fishing trials were conducted between the 06th and the 26th of May 2014 in the western Baltic Sea, north-west of the island of Rügen, Germany (ICES-SD 24) (Figure 6). The original experimental set-up scheduled 25 fishing days between May and July but had to be drastically shortened down to 7 days, due to bad weather and technical difficulties with the vessel. The study was conducted in collaboration with the training school of the “Christlichen Jugenddorfwerk Deutschlands e.V.” in Stralsund, Germany. The fishing vessel “Lassan” (SAS112) (Figure 33) was operated by an experienced local captain. The fishing trials were conducted in areas with a structured sea floor (e.g. gravel, stones) and practicable depths from 11 m to 20 m.

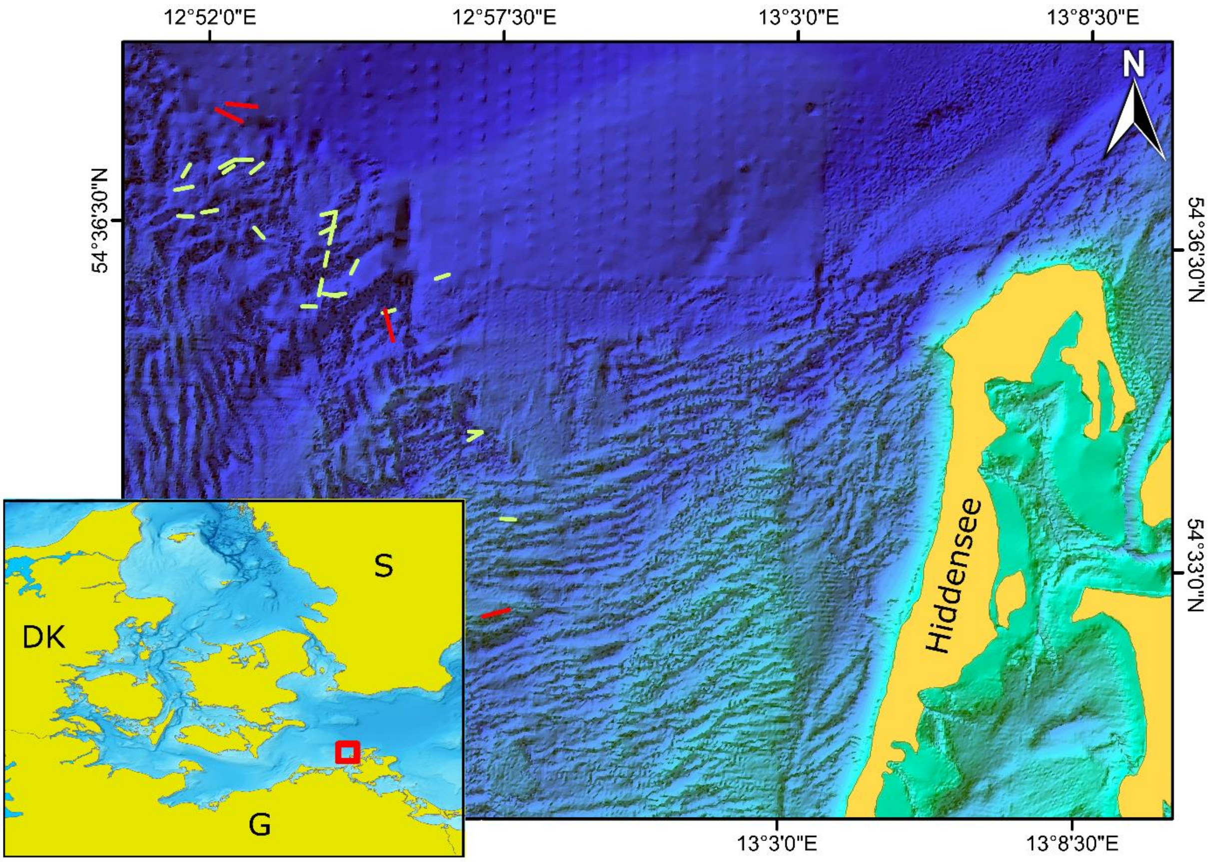

Figure 6: Study area in the western Baltic Sea with positions of the gillnet and pot strings (D: Denmark, G: Germany, S: Sweden, red lines: gillnet, yellow lines: pot strings) (Data from BSH 2014) © TI-OF (N.Plantener).

2.2.2 Gear used

Two types of cod pots were tested in this study, referred to as pot-type I and pot-type II. They had the same basic design of foldable rectangular net cages, consisting of 3 metal frames, which were spanned with netting. Unfolded they had a size of 1.5 m in length, 1 m in width and 1.2 m in height. Fish could enter the pots through one, respectively two (depending on the type of pot), funnel shaped entrances on the lower half of the short sides. Behind the entrance, a nylon bag for holding the different baits was fixed. Above the bait bag, all pots where equipped with a green LED fishing light (YML-1000, YM Fishing Corporation) (Figure 7), acting as a visual stimulus. Attracting fish with light is a known fishing practice (see chapter 1.4). Researches of the TI-OF have shown, that fixing a light into cod pots additional to normal bait leads to a higher catch of cod (Noack 2013). The used pots and lights were the same as in this study. Inside the middle metal frame, a single-ply net with a narrow slit-opening was fixed horizontally, dividing the pot into two chambers. Fish entered the pod through the entrance into the lower chamber. When realising they are trapped, most fish will swim upwards through the slid opening into the upper chamber, because of their natural flight behaviour. Here it is very difficult for the fish to escape again (Furevik & Skeide 2002). Each chamber could be accessed through two zippers on the long side of the trap to empty the pot and replace the bait. On top of all pots, 8 ring floats (each 0.4 kg buoyancy) were attached to unfold the pot underwater (Figure 8, Figure 9). All pots had a holdfast attached to one end with which they were connected to the ground line via a snap hook. Although pots of both types had the same basic design, they differed in some important characteristics which are explained in the following and are summarized in Table 2.

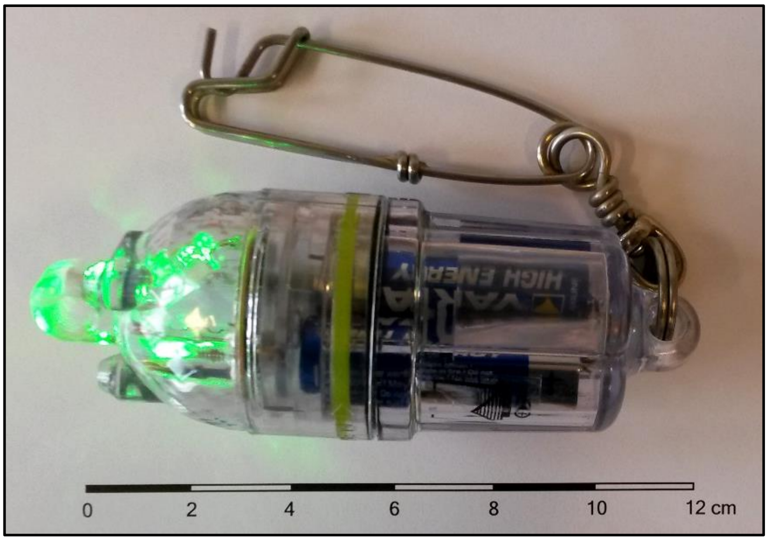

Figure 7: Fishing light which was used in addition to all baits in pots and as a singular bait (referred to as light only).

Table 2: Summary of the characteristics of cod pot-type I (CP I) and pot-type II (CP II).

	CP I	CP II
Dimensions	1.5 m x 1 m x 1.2 m	1.5 m x 1 m x 1.2 m
Design	rectangular, 3 metal frames, two chambers, foldable	rectangular, 3 metal frames, two chambers, foldable
Mesh size	20 mm (square mesh side length)	30 mm (square mesh side length)
Escape window	-	1 m x 0.6 m panel of 40 mm (square mesh side length)
Entrance	2 funnel-shaped entrances, facing each other in small sides of pot	1 funnel-shaped entrance in small side of pot + seal exclusion device (SED)
Floats	8 x ring floats (0.4 kg buoyancy)	8 x ring floats (0.4 kg buoyancy) 3 x floats (0.78 kg buoyancy)
Mode of operation	bottom set	float approx. 1 m above sea floor
Holdfast	2 strings attached to lower frame	4 strings attached to lower and middle frame (opposite entrance)
Fishing light	1 green LED fishing light in lower chamber	1 green LED fishing light in lower chamber
Quantity used	24 per haul (2 strings with 12 pots each)	24 per haul (2 strings with 12 pots each)

Cod pod-type I

Pots of type I were manufactured by the Norwegian Refa Frøystad group. One mesh of the circumfluent square netting had a side length of 20 mm. These pots were planned to rest on the sea floor (Figure 34). Furthermore, they had two tunnel-shaped entrances at the lower half of the short sides, facing each other (Figure 8). The holdfast of these pots consisted of two strings, which were attached to the lower frame. A total of 24 pots of this type was used. The general features of these pots are described in chapter 2.2.2.

Figure 8: Cod pot-type I. 2 funnel-shaped entrances were facing each other on the short sides of the lower chamber. The lower and upper chamber were separated by a roof-shaped single ply netting with a narrow slit opening. Both chambers could be accessed through horizontal zippers (dark lines in left picture). The blue bait bag was suspended in the middle of the lower chamber. 8 floats (0.4 kg buoyancy) were strapped on the top of the pot to unfold it underwater.

Cod pod-type II

Pots of type II were purchased from the Swedish company Kingfisher AB. Here, the square meshes of the pot netting had a side length of 30 mm.

Pots of type I were equipped with 3 additional floats (0.78 kg buoyancy each) to float them approx. 1 m above the sea floor (Figure 9). Furevik *et al.* (2008) found out that pots which floated of the bottom caught more fish of target species than bottom set pots. The reasons for that are probably the rheotaxive food search behaviour of cod in connection with the characteristics of particle dispersion under water (see chapter 1.4). Therefore, a self-aligning pot with an opposite-current facing entrance should have a higher chance of cod locating the entrance and swimming into the pot. The amount of floats, necessary to lift a pot off the sea floor, was investigated in preliminary studies. To ensure a horizontal floating position, additional leaden weights were attached to the lower metal frame at the entrance-side of the pot.

Because every entrance is a possible exit and the current-facing entrance is rarely used anyway, pots of type II had only one entrance. Another advantage of this design is, that the pot is less likely to get blocked with jelly fish. During high abundances of these planktonic organisms, they could be drifted into a current-facing entrance and block the whole pot (pers. comm. Daniel Stepputtis, TI-OF).

Another important modification was the escape window that was built in pots of this type. Each pot had a 1 m x 0.6 m panel of larger square meshes (length of mesh side 40 mm) build into one side of the upper chamber (Figure 9). These larger meshes should make it possible for cod below the MLS (minimum landing size), which can´t be sold legally, to escape the pot.

Additionally pots of this type were equipped with a seal exclusion device (SED). To prevent seals from entering the pots, a metal frame was placed in the entrance of each pot (Figure 9).Thus, seals and other marine mammals wouldn´t be able to enter the pots and possibly drown in them. This method was adopted from Königson *et al.* (2014), where seals have been repeatedly caught and drowned in fish pots. Also during fishing trials of the TI-OF in 2013, one seal was caught and drowned in a pot like the ones used in this study (Noack 2013). These unwanted bycatches of some also endangered and protected species should be countered with this measure. Pots of type I were not equipped with SEDs and acted as a control group to determine the influence of this modification.

The bait bags of pot-type II had a different colour than the ones from pot-type I and had two white nylon straps attached to it as additional visual stimuli. Königson (ICES 2009) found out, that fixing white plastic strips to bait bags leads to a higher catch of pots.

Another difference to pot-type I was the holdfast, which consisted of four strings and was affixed to the lower and middle frame of the pot (Figure 9). A fixation at two different levels of the pot should ensure an additional horizontal stability during strong currents. Also at the end of the holdfast, a 4 kg leaden weight was attached to hold the pot in position on the ground. In total, 24 pots of this type were used.

Figure 9: Cod pot-type II was equipped 8 ring floats (0.4 kg buoyancy) and 3 additional floats (0.78 kg buoyancy, yellow , top left picture) to float the pot off the sea bottom. A metal frame in the entrance acted as a seal exclusion device (SED) (bottom left picture). An escape window, consisting of a larger green mesh panel (40 mm square mesh side) was installed in the upper half of the pot. The four-string holdfast was attached on two levels of the pot and equipped with a 4 kg mooring weight (right picture).

Gillnet

To reference the catches of the pots, a conventional gillnet of single orange netting with a mesh size of 55 mm (one square mesh side) was used. The net consisted of twelve panels with a length of 50 m each (in total 600 m) and a height of 2.5 m. These nets are often used in the commercial cod fishery in the western Baltic Sea.

2.2.3 Experimental setup

Cod pots

In total, 24 pots of each type were used. One pot type was deployed in 2 strings with 12 pots on each ground line. The twelve pots on one ground line were arranged in two groups with 5 different baits and one empty pot in each group (Figure 10). This group-wise setup was more suitable to work with many zero catches (pers. comm. Juan Santos, TI-OF). Previous studies of the TI-OF with this alternative fishing gear have shown that often this is the case (Noack 2013).
The pots were attached to a loop in the ground line with a snap hook, in the distance of 20 m between each other and in a distance of 50 m between the two groups. Additionally, on each loop of the ground lines of pots of type I, a 5 kg leaden weight attached, to moor the pots on the ground. Pots of type II had a mooring weight attached to their holdfast.
The ends of a string were anchored with a grappling hook, which was attached to the ground line in a distance of 20 m to the last pot. The anchors were marked with flags at the surface. To identify the strings and their groups, the flags were marked with an ID. One string had a length of approx. 290 m in total.
As best as possible, the pots were set diagonally to the main current direction to avoid an overlapping of the odour plumes. The soak time of the fish pots ranged from one to six days, depending on factors like weather and fishing routine.
The arrangement of the baits inside the groups was randomised on each setting to avoid effects of the bait position. During the setting of the pots, the order of the baits was noted because after hauling the bait was not always in the bait bag.

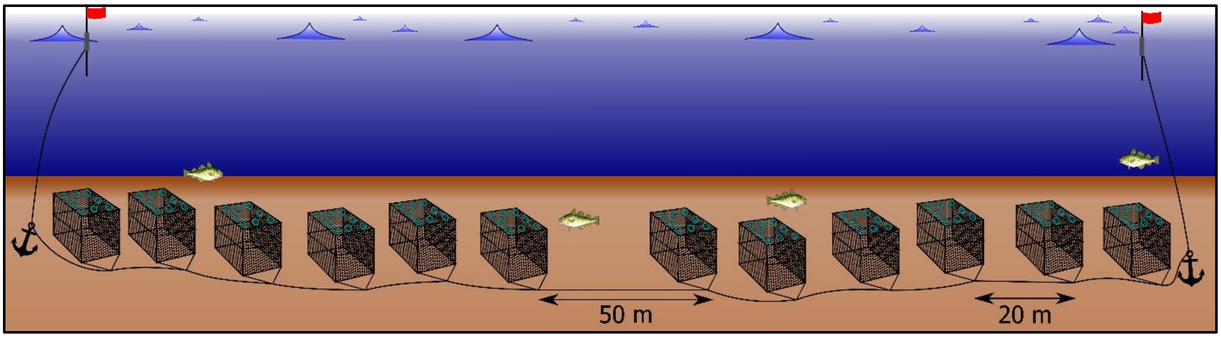

Figure 10: Scheme of the experimental setup of one pot string. Twelve pots were set in one string, clustered into 2 groups. In each group of six pots, the 5 different baits plus an unbaited control pot were used in randomized positions. Two of those strings where used for each of the two pot types (CP I, CP II), resulting in 24 pots of each type per haul. Scheme is not drawn to scale.

Baits

Herring

Herring (*Clupea harengus*) has been proven as suitable bait for cod pots in former studies (Ljungberg 2007, Ovegård 2011). Moreover, herring is naturally abundant in the western Baltic Sea and a typical prey species for larger cod (Sparholt 1994). In the present study, two whole, frozen herring (approx. 400 g) were used per pot.

Shrimp

Brown shrimp (*Crangon crangon*, Syn.: common shrimp, bay shrimp, sand shrimp) are also abundant in the Baltic Sea and are often found in the stomachs of cod. Because of terms of availability, 400 g of cooked, frozen shrimp were used as bait. On board, the shrimps were filled into a fine-meshed bag to prevent them from falling out of the coarse meshed bait bag of the pot (Figure 35).

Glycine

Glycine (NH_2CH_2COOH) is a water-soluble, non-essential, proteinogenic amino acid. It has proofed to induce food search behaviour in cod even in very low concentrations (10^{-4} mol/l = ca. 10^{-3} g/l) (Ellingson 1985). Pure, glycine is a colourless, crystalline solid. For the present experiments, 125 g glycine (SLI Chemicals) were mixed with 175 ml water and 215 g wheat flour (Type 405, Frießinger Mühle), acting as a carrier (see chapter 1.5), into a viscous paste(Figure 11). Preliminary studies have shown that ca. 500 g of this frozen paste, continuously dissolved into the water over 8 hours and probably even for more than 24 hours (see chapter 2.1.2, Figure 5). As container, 500 ml PVC wide neck containers (310 series, Kautex Textron) with a 20 mm hole on each side and the bottom were used (Figure 11, Figure 36). The holes were closed with tape and the prepared bait containers were kept frozen until being used on board. Before putting them into the bait bags, the tape was removed.

Figure 11: Bait paste made of glycine, wheat flour and water (left) and the same paste, filled into one of the used PVC containers (right). Flour paste was used as a carrier to make the artificial bait easier to handle and long lasting (see chapter 1.5). The prepared bait containers were sealed with tape and frozen until used.

Glutamate

Monosodium glutamate ($C_5H_8NO_4Na$; Syn.: sodium glutamate, glutamate) is the salt of the non-essential proteinogenic amino acid glutamic acid. Potential bait fish like herring and mackerel contain high concentration of glutamic acid (Oluwaniyi *et al.* 2010). In trials of Pawson (1977b), cod showed food search behaviour when glutamic acid was applied in low concentrations (10^{-1} µmol/l). Because of terms of availability and costs, glutamate was selected as a possible alternative for glutamic acid. Glutamate occurs naturally in high concentrations in foods like kelp, mushrooms, tomatoes, cheese and fish (Ikeda 2002). Pure, it is a colourless, crystalline solid. The preparation as bait was the same procedure as with glycine: 125 g glutamate (Fuchs) were mixed with 175 ml water and 215 g wheat flour (Type 405, Frießinger Mühle) into a paste. Also, the same 500 ml PVC wide neck containers (310 series, Kaudex Textron) (Figure 36) with a 20 mm hole on each side and the container bottom were used. Until use, the holes were closed with tape and the prepared containers were kept frozen. The prepared glutamate and glycine baits looked alike. To distinguish them, zip ties were attached to the glutamate containers.

Light only

All pots were equipped with a LED fishing light, acting as visual stimuli to attract fish (for details see chapter 2.2.2). To test the singular effects of this modification, pots with only a fishing light and no additional bait were deployed (referred to as light only).

Control

To test for potential effects of the pots themselves, unbaited pots without a fishing light were deployed. Since cod mostly hide and feed in a structured environment (Gotceitas & Brown 1993, Gregory & Anderson 1997), it is possible that they are attracted by the sheer structure of a pot.

Gillnet

The gillnet was set in a distance to the pots to avoid possible interactions between the pots and the net. To anchor the net at the sea bottom a grappling hook was attached to each end, which was marked with a flag at the water surface.
The soak time of the gillnet was one day as it is the code of practice in the local fishery.

Data collection

On board, each cod and flounder was measured by length on centimetres below. Each individual was weighed with a sea-stabilized scale (M1100 PL2060 Portable, Marel). Catches of other species were noted and their weight per pot or gillnet was determined.
For each haul, the GPS coordinates and the time of setting and hauling of the different gears were recorded by the vessel instruments.
On the 14.05.2014, one pot of each type was equipped with a camera (GoPro Hero 3+, GoPro Inc.) to analyse the proper functioning of the gear and the behaviour of fish in and around the pot.
Over the whole time of the experiment, a sensor and data logger (DST magnetic, StarOddi) was attached to one pot of each type to record their vertical and horizontal orientation in the water, based on the magnetic field of the earth. Data were measured hourly.

2.3 Data analyses

All data sets with $n > 50$ were checked for normal distribution via a Kolmogorov–Smirnov-test. Data sets with $n < 50$ were tested via a Shapiro–Wilk-test (Shapiro & Wilk 1965), because this test is more able to handle smaller sub samples (Brosius 2011). To test for a homogeneity of variances, a Levene's-test was conducted with the respective data set.

Comparisons of means of two samples were carried out using a Mann-Whitney-U-test (Mann & Whitney 1947). The catch comparison between pot types in chapter 3.2.2 was conducted via a Welch´s-test (Welch 1947), because the used subsets of data had inhomogeneous variances. For the comparisons of means of more than two samples, a Kruskal-Wallis-test (Kruskal & Wallis 1952) was used. All these non-parametric tests are suitable for non-normal distributed data, like the present count data in this study. The significance level for all statistical analyses in this study was set to $p \leq 0.05$.

In this study, the different analyses begin with an overview of the summed catches of the different gears. These pooled data don´t give a conclusion about the catch efficiency of pot-type I, pot-type II or the gillnet, because they were used in different quantities. To make a comparison between the gears possible, the catches were standardized to the catch per unit effort (CPUE). Here, the cod catch of 10 pots and 200 m gillnet was compared, because these quantities took the same time to handle. The handling time is a suitable basis for a comparison of the single gears, because of their different mode of operation (Noack 2013).

The relative catch efficiency of the different gears was estimated by comparing the cod CPUE, measured in individuals, of a certain length class ($CPUE_l$), that was caught with a certain gear ($gear1/2$) (Equation 1). Catch data were pooled over all days, and for pots additionally over all baits.

$$\textit{Relative catch efficiency} = \frac{CPUE_{lgear1}}{CPUE_{lgear1} + CPUE_{lgear2}} \qquad \text{(Equation 1)}$$

The selection curve of the escape window of pot-type II was estimated via a generalized linear model with a binomial distribution.

A possible relationship between catches and the soak time of the pots was checked via a linear regression analysis.

All data were processed with Excel 2013 (Microsoft) and analysed with SPSS 22 (IBM) or R (R Development Core Team).

3 Results

3.1 Catch composition

In total, 661.4 kg fish were caught during this study. The majority was caught with the gillnet (357.4 kg/ 54.07 % of total catch) followed by fish pots of type I, which caught 259.7 kg (39.26 %). Pots of type II only fished 44.3 kg, which corresponds to 6.70 % of the total catch (Table 3).

Table 3: Overview of total catch in kg separated by date and gear. Catch is shown at day of haul (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, grey cells: gear in use (soak days).

Date	Total catch [kg]		
	CP I	**CP II**	**GN**
06.05.2014			
07.05.2014			112.4
08.05.2014	9.5	1.9	
09.05.2014	3.2	0	60.5
10.05.2014			
11.05.2014			
12.05.2014			
13.05.2014			
14.05.2014			
15.05.2014	41.1	6.7	91.3
16.05.2014			
17.05.2014			
18.05.2014			
19.05.2014			
20.05.2014			
21.05.2014	111.8	24.4	
22.05.2014	26.7	5.9	93.2
23.05.2014			
24.05.2014			
25.05.2014			
26.05.2014	67.4	5.4	
Total	**259.7**	**44.3**	**357.4**

During the fishing trials, 9 different species were caught (Table 4). The number of caught species was similar between the different gears. Pots of type II only caught one species more than the other gears (Table 6).

Some species were only caught by one type of gear. Hook-nose (*Agonus cataphractus*), lumpfish (*Cyclopterus lumpus*), sea scorpion (*Myoxocephalus scorpius*) and plaice (*Pleuronectes platessa*) were only caught by fish pots. Whereas dab (*Limanda limanda*) and salmon (*Salmo salar*) were only fished with the gillnet.

Moreover, virtually all flounder and turbot where caught with the gillnet. Cod (*Gadus morhua*) was fished with all gears. Also, cod represented the main part of the total catch with 528.2 kg, accounting for ca. 80 % of the total catch. Additionally, cod was the dominant species in all gears, representing more than 95 % of the total catch (weight) in both types of pots and 64 % of the total catch of the gillnet (Figure 12,Table 5, Table 6).The second most abundant species was flounder, representing 16.8 % (111.1 kg) of the total catch. The other 7 species combined, only made up a minor fraction of the total catch (3.23 %/ 22 kg).

Table 4: List of caught species (sorted alphabetically).

Latin name	English name	German name	FAO Taxocode
Agonus cataphractus L.	Hook-nose	Steinpicker	1781904401
Cyclopterus lumpus L.	Lumpfish	Seehase	1782000301
Gadus morhua L.	Atlantic cod	Kabeljau, Dorsch	1480400202
Limanda limanda L.	Common dab	Kliesche	1830202405
Myoxocephalus scorpius L.	Short-spined sea scorpion	Seeskorpion	17813012XX
Platichthys flesus L.	European flounder	Flunder	1830204802
Pleuronectes platessa L.	European plaice	Scholle	1830200405
Salmo salar L.	Atlantic salmon	Atlantischer Lachs	1230100401
Scophthalmus maximus L.	Turbot	Steinbutt	1830509201

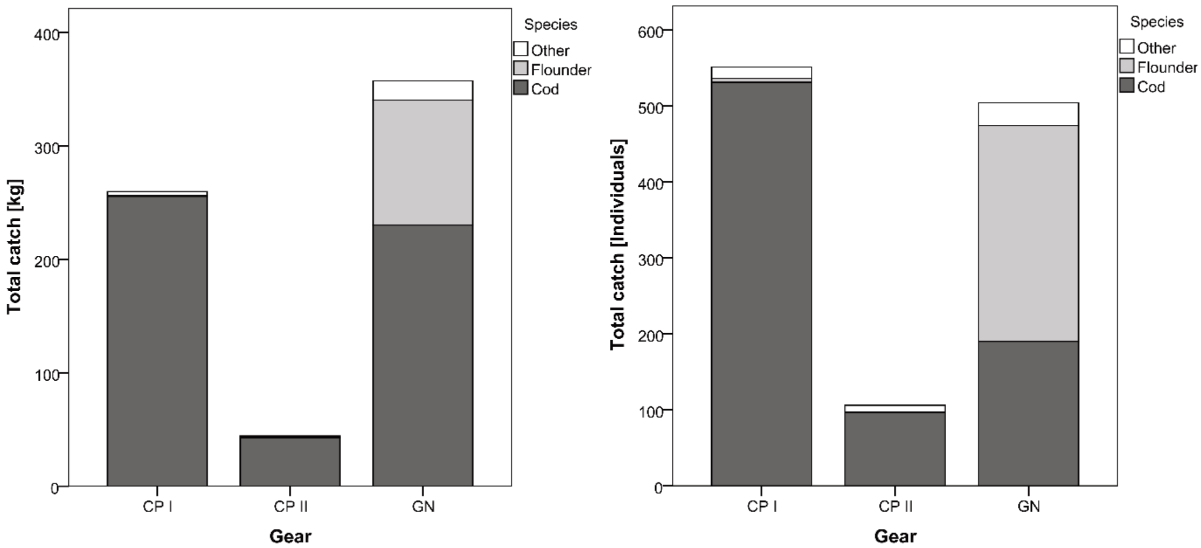

Figure 12: Catch composition in kg (left) and individuals (right), separated by gear. Data were summed over all hauls, and for pots additionally over all baits and thus don´t give a conclusion about the catch efficiency of the single gears (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet).

Table 5: Total catch in kg, separated by gear and species. Data were summed over all hauls, and for pots additionally over all baits and thus don´t give a conclusion about the catch efficiency of the single gears (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet).

	Total catch [kg]									
Gear	**Cod**	**Dab**	**Flounder**	**Hook-nose**	**Lumpfish**	**Plaice**	**Salmon**	**Sea Scorpion**	**Turbot**	**Total**
CP I	255.4	0	0.8	0	2.0	1.4	0	0.1	0	259.7
CP II	42.8	0	0.1	0.2	0.9	0	0	0.1	0.2	44.3
GN	230.1	0.5	110.2	0	0	0	1.5	0	15.1	357.4
Total	**528.3**	**0.5**	**111.1**	**0.2**	**2.9**	**1.4**	**1.5**	**0.2**	**15.3**	**661.4**
% of total catch	**79.88**	**0.08**	**16.80**	**0.03**	**0.44**	**0.21**	**0.23**	**0.03**	**2.31**	**100**

Table 6: Relative percentage and number of species caught by different fishing gears. Numbers are based on weight. Data were pooled over all hauls, and for pots additionally over all baits. (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet).

	Total catch (weight) [%]									
Gear	**Cod**	**Dab**	**Flounder**	**Hook-nose**	**Lumpfish**	**Plaice**	**Salmon**	**Sea Scorpion**	**Turbot**	**Number of caught Species**
CP I	48.35	0	0.72	0	68.97	100	0	50.00	0	5
CP II	8.09	0	0.09	100	31.03	0	0	50.00	1.31	6
GN	43.56	100	99.19	0	0	0	100	0	98.69	5
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**9**

3.2 Length distribution

Since cod and flounder were the only species caught in sufficient numbers, length data were only taken from these species.

3.2.1 Length distribution of cod

The size of cod ranged from 13 cm to 70 cm with a mean of 38 cm over all gears. Cod, which were caught with pots, showed significantly smaller ($p < 0.05$, Mann-Whitney-U-test) mean lengths of 35.4 cm (pot-type I) and 35.2 cm (pot-type II) compared to cod caught with the gillnet (46.5 cm) (Table 7). There was no significant difference ($p > 0.05$, Mann-Whitney-U-test) in mean length between the two pot types (Figure 13).

Table 7: Summary of cod length data separated by gear. Data were pooled over all hauls, and for pots additionally over all baits (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, n: number of individuals, SD: standard deviation).

Gear	*n*	Cod length [cm]		
		min	max	Mean ± SD
CP I	531	20	61	35.4 ± 5.6
CP II	96	13	51	35.2 ± 5.0
GN	190	28	70	46.5 ± 6.2
Total	**817**	**13**	**70**	**38.0 ± 7.4**

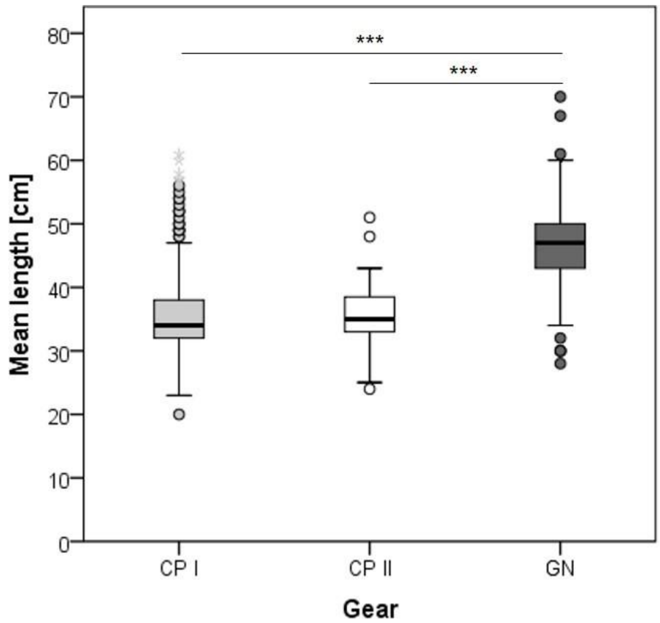

*Figure 13: Summary of cod length data in cm, separated by gear (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, ***: $p \leq 0.001$ in Mann-Whitney-U-test, line: median, box: lower and upper quartile, whiskers: values within 1.5 of interquartile range, circles: outlier-values with 1.5 - 3 of interquartile range, stars: extreme-values larger than 3 times box range).*

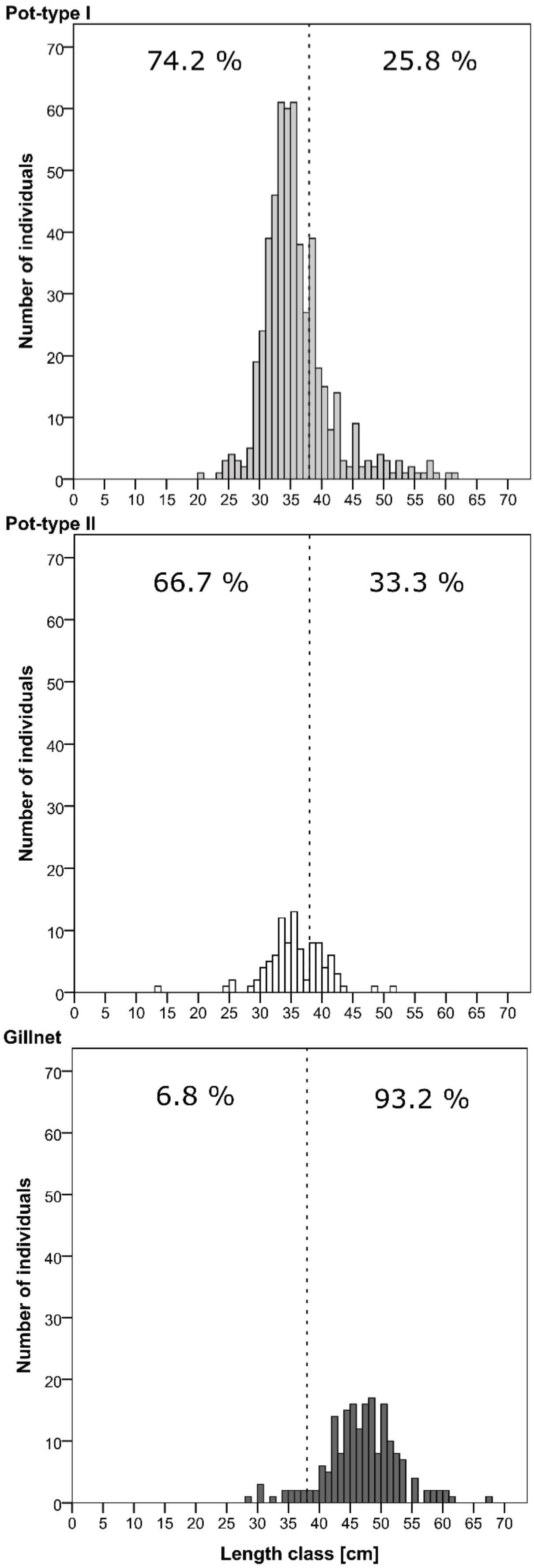

Figure 14: Length distribution of cod for pot-type I (top), pot-type II (middle) and the gillnet (bottom) with percentages of fish below and above the MLS (spotted line: MLS of 38 cm).

All used gears caught cod below and above the minimum landing size (MLS) of 38 cm (LALLF M-V 2014). The cod catches of pot-type I consisted to 74.2 % of undersized fish and the catches of pot-type II were to 66.7 % under the minimum landing size. In contrast, the gillnet caught a low portion of undersized cod, with only 6.8 % (Figure 14).

3.2.2 Length distribution of flounder

Size of flounder ranged from 18 cm to 44 cm with a mean length of 28.1 cm over all gears. Flounders, which were caught with pots of type I, had a slightly smaller mean length of 27.2 cm, compared to flounders caught with a gillnet (29.0 cm). Pots of type II caught only one individual of 27 cm (Table 8, Figure 15). There were no significant differences in mean lengths of flounder ($p > 0.05$, Mann-Whitney-U-test) caught with the different gears.

Table 8: Summary of flounder length data, separated by gear. Data were pooled over all days, and for pots additionally over all baits (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, n: number of individuals, SD: standard deviation).

Gear	***n***	**Flounder length [cm]**		
		min	**max**	**Mean ± SD**
CP I	5	18	33	27.2 ± 6.0
CP II	1	-	27	-
GN	284	20	44	29.0 ± 4.3
Total	**290**	**18**	**44**	**28.1 ± 5.2**

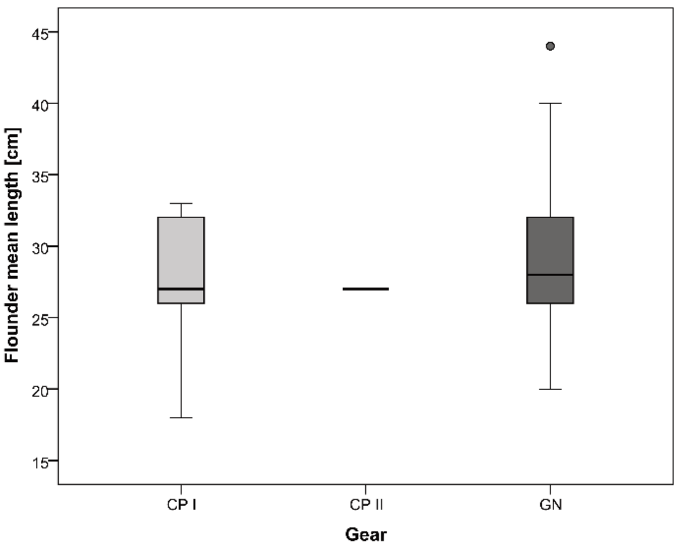

Figure 15: Summary of flounder length data in cm, separated by gear (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, line: median, box: lower and upper quartile, whiskers: values within 1.5 of interquartile range, circles: outlier-values with 1.5 - 3 of interquartile range).

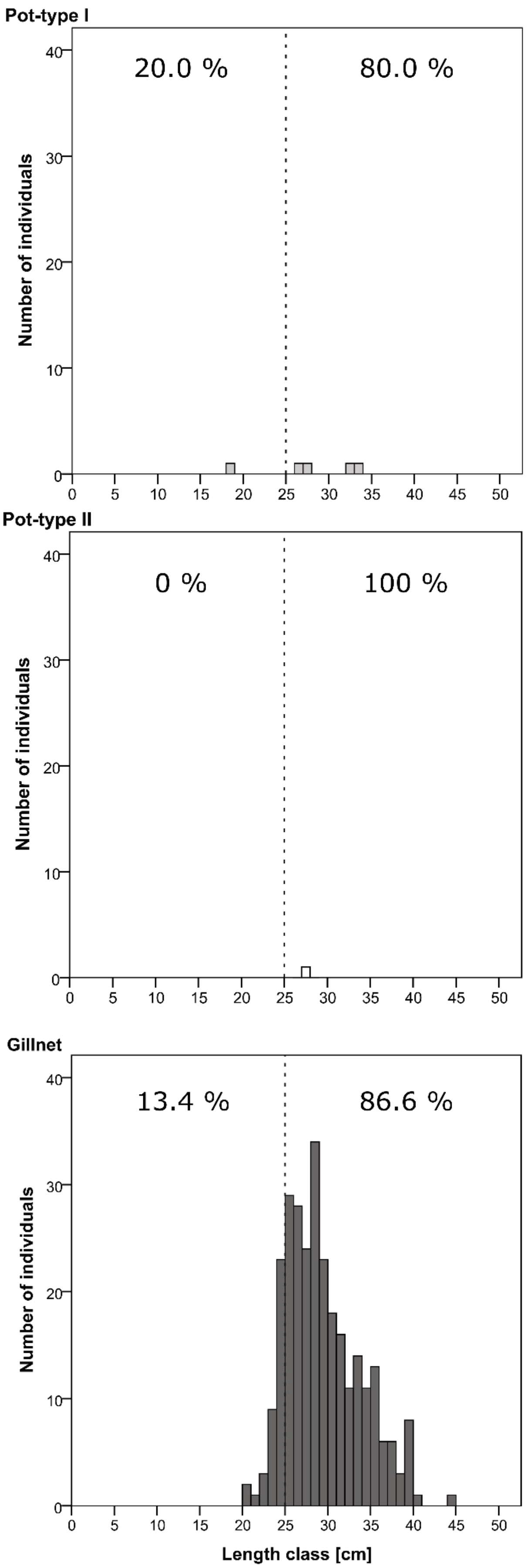

Figure 16: Length distribution of flounder for pot-type I (top), pot-type II (middle) and the gillnet (bottom) with percentages of fish below and above the MLS (spotted line: MLS of 25 cm).

The percentage of over- and undersized flounder that were caught with pots is not representative, because of the few caught individuals. These few fish (pot-type I: 5, pot-type II: 1) were mainly above the MLS of 25 cm (LALLF M-V 2014). The gillnet caught considerably more flounder, from which 86.6 % were above the MLS (Figure 16).

3.2 Cod catches by pot type

3.2.1 Overview

In total, pots of type I caught 255.4 kg cod. Pots of type II caught 6-times less, with only 42.8 kg cod (Table 5, Figure 17). Looking at individuals, 531 single cod were caught with pot-type I, whereas pots of type II only caught 96 individuals. The cod catches of pots fluctuated between the different days. The first two days of deployment (08.05.2014 and 09.05.2014) showed especially low catches (Figure 18).

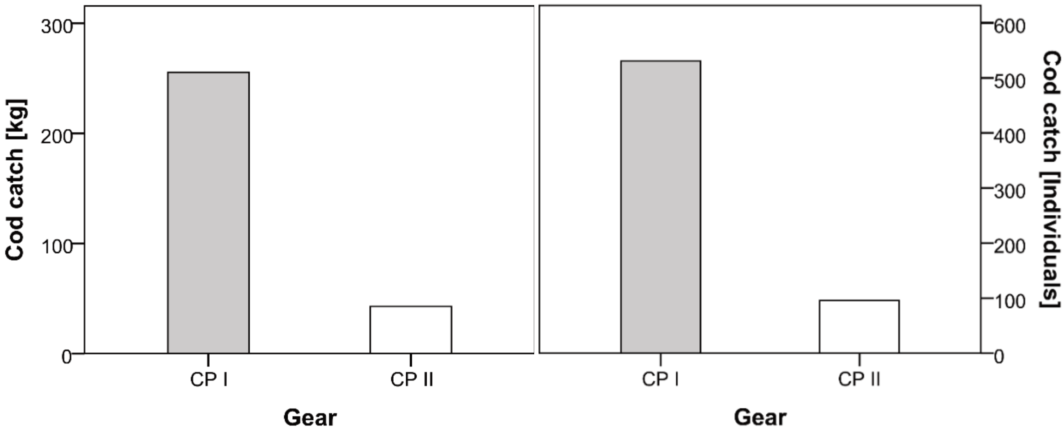

Figure 17: Summed cod catches in kg (left) and individuals (right), separated by gear. Data were pooled over all days and baits. For data in numbers see Table 5 (n=144 pots per type) (CP I: cod pot-type I, CP II: cod pot-type II).

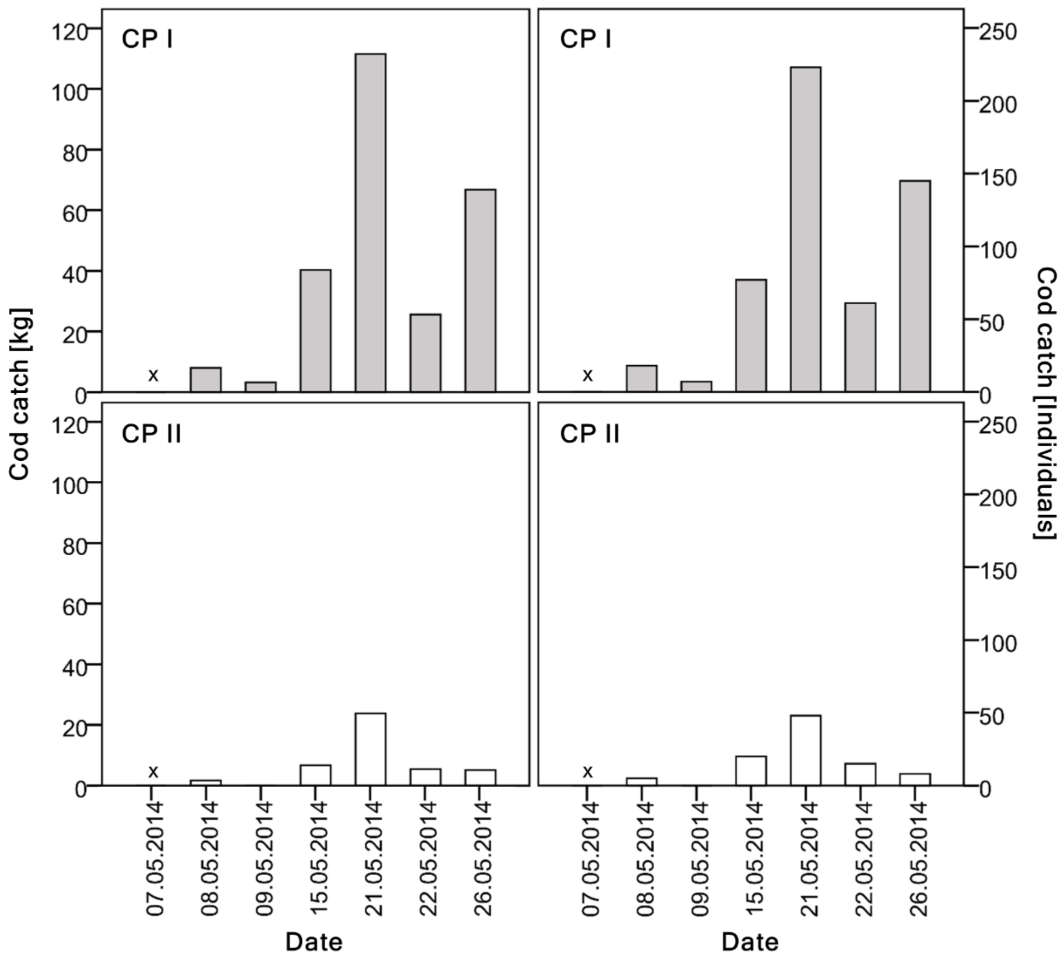

Figure 18: Cod catch in kg (left) and individuals (right) over the single days and for the different gear. Data were pooled over all baits (n= 24 pots per pot-type per day) (CP I: cod pot-type I, CP II: cod pot-type II, x: gear not in use).

3.2.2 Catch comparison

The cod catches of the different pot types had to be standardized for each haul to be comparable and to emphasise the catchability of a single pot. For that, the cod catch of a single pot during one haul was divided by the number of soak days resulting in the cod catch per pot per day (Table 9).

Table 9: Mean cod catch per pot per day in kg and number of individuals, for the two types of pots. Data were pooled over all baits (n: number of pots, CP I: cod pot-type I, cod pot-type II, SD: standard deviation).

Gear	***n***	**Cod catch per pot per day**	
		Mean weight [kg] ± SD	**Mean number of fish ± SD**
CP I	144	0.75 ± 1.13	1.58 ± 2.22
CP II	144	0.13 ± 0.25	0.33 ± 0.76

The mean catches per pot per day for pot-type I were significantly higher ($p < 0.05$, Welsh´s t-test) compared to those of pot-type II (Figure 19). On average, one pot of type I caught 0.62 kg and 1.25 individuals more on a single day, than one pot of type II. When separated by date, the first two days of deployment (08.05.2014 and 09.05.2014) showed significantly lower cod catches ($p < 0.05$ in Kruskal-Wallis-test). The differences between the other days were not significant (Figure 20).

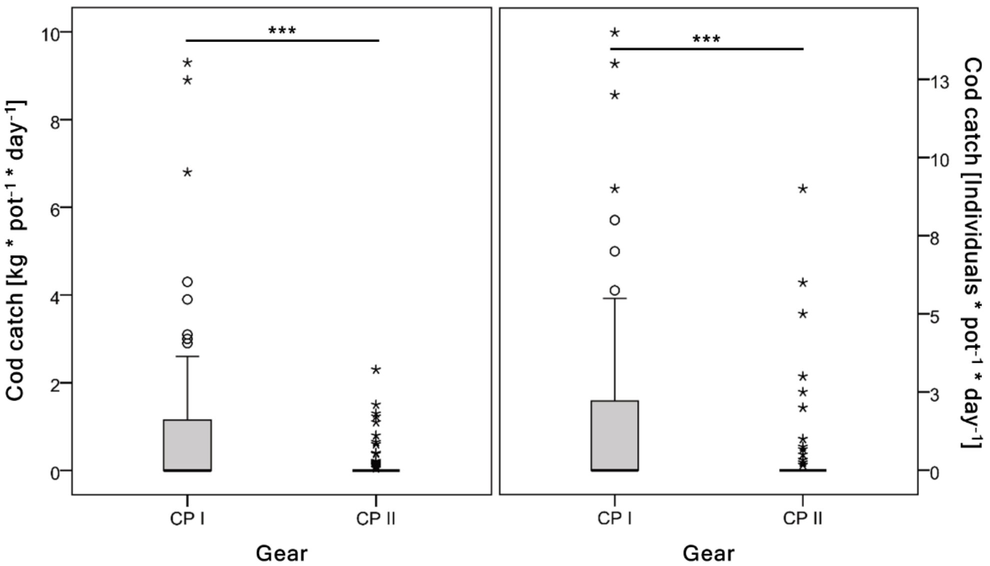

*Figure 19: Summary of cod catch per pot per day in kg (left) and caught individuals (right) for the two tested pot types. Data were pooled over all baits (n= 144 pots per type) (CP I: cod pot-type I, CP II: cod pot-type II, <u>***</u>: $p \leq 0.001$ in Welch´s t-test, line: median, box: lower and upper quartile, whiskers: values within 1.5 of interquartile range, circles: outlier-values with 1.5 - 3 of interquartile range, stars: extreme-values larger than 3 times box range)*

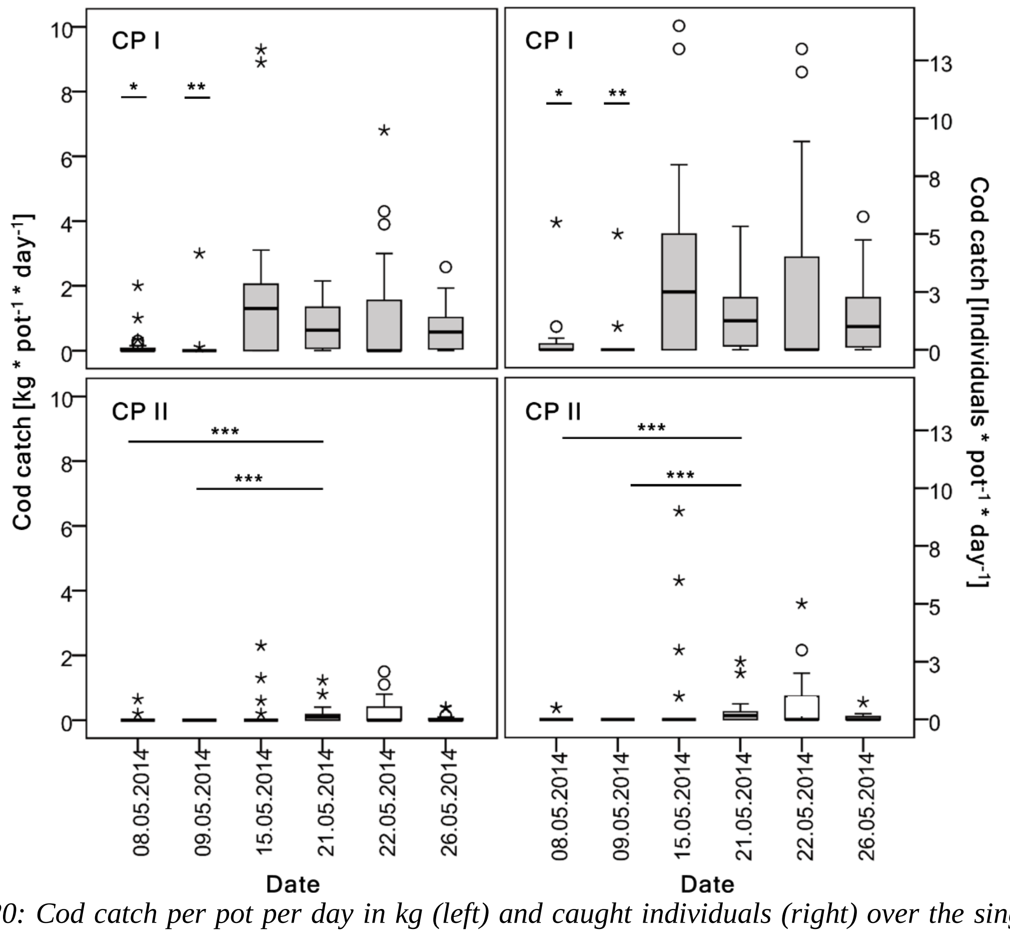

*Figure 20: Cod catch per pot per day in kg (left) and caught individuals (right) over the single days and for the two tested pot types. Data were pooled over all baits (n=24 pots per type per day) (<u>***</u>: $p \leq 0.001$, <u>**</u>: $p \leq 0.01$, <u>*</u>: $p \leq 0.05$ in Kruskal-Wallis-test, CP I: cod pot-type I, CP II: cod pot-type II, line: median, box: lower and upper quartile, whiskers: values within 1.5 of interquartile range, circles: outlier-values with 1.5 - 3 of interquartile range, stars: extreme-values larger than 3 times box range).*

3.2.3 Comparison to gillnet (CPUE)

The comparison of catches with standardized efforts presented a suitable way to distinguish differences in the catch success of the different gears. To make a comparison between fish pots and gillnet possible, the catches had to be standardized. For this, the catch of one pot per day was extrapolated to 10 pots, resulting in the catch per unit effort (CPUE) for pots. The CPUE for the gillnet was calculated from the catch of the used 600 m gillnet per day, to the theoretical catch of a 200 m gillnet. These units of effort originate in the equal handling time of 10 pots and 200 m gillnet. This common effort of handling time was an applicable base of comparison because of the different modes of operation of pots and gillnets.

Table 10: Mean cod catch per unit effort (CPUE) for the different gears. Pot and gillnet data were pooled over all days. Pot data was additionally pooled over all baits (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, SD: standard deviation).

Gear	**Cod CPUE**	
	Mean weight [kg] ± SD	**Mean number of fish ± SD**
CP I	7.53 ± 14.35	15.79 ± 27.22
CP II	1.27 ± 3.65	3.20 ± 10.94
GN	19.18 ± 5.25	15.83 ± 5.48

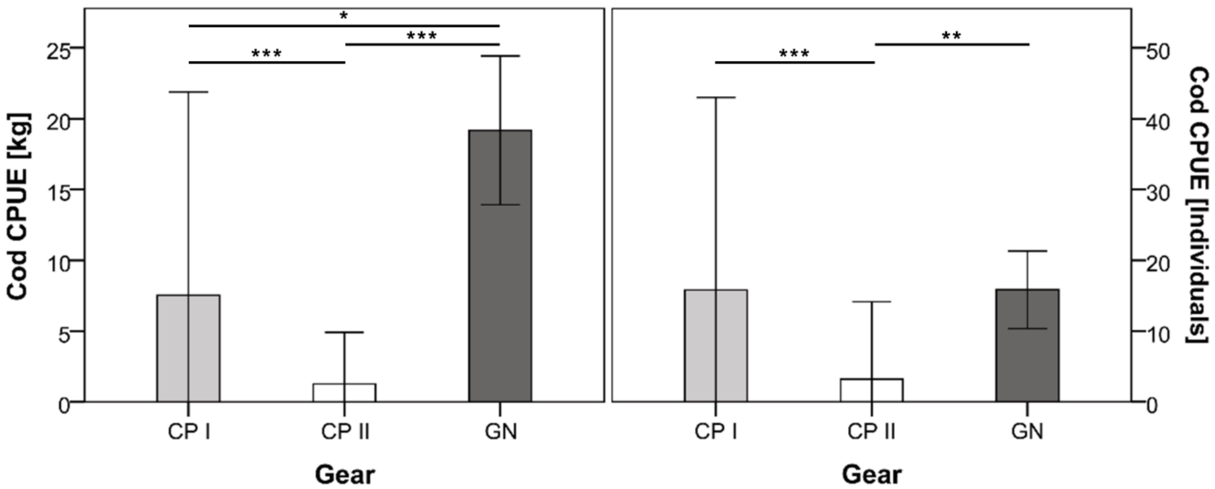

Figure 21: Mean cod catch per unit effort (CPUE) in kg (left) and individuals (right) for the different gears. Standardized effort for CP I and CP II: 10 pots, standardized effort for GN: 200 m gillnet. Pot data were pooled over all baits. Pot and gillnet data were pooled over all days (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, $\underline{***}$: $p \leq 0.001$, $\underline{**}$: $p \leq 0.01$, $\underline{*}$: $p \leq 0.05$ in Kruskal-Wallis-test, bars: standard deviation).

Since the cod CPUE for pots was calculated from the cod catch per pot per day, the differences in means between the pot types were akin to these numbers. Like in chapter 3.2.2 (Table 9), pots of type I caught significantly more cod (weight and individuals) than pots of type II (Table 10). But in this analysis, it was also cognizable that the gillnet had significantly higher catches of cod (weight) when standardized to a common effort ($p < 0.05$ in Kruskal-Wallis-test). The gillnet caught on average 2.6-times more cod (weight) than pot-type I and 15.1-times more cod than pot-type II. When looking at the number of caught cod, there were no significant differences between the CPUE of pot-type I and the gillnet. Nevertheless, pot-type I and the gillnet caught significantly more individuals than pot-type II ($p < 0.05$ in Kruskal-Wallis-test). Pots of type I and the gillnet caught on average 4.9-times more individuals than pot-type II.

3.2.4 Relative catch efficiency

The relative catch efficiency of the different gears was estimated by comparing the cod CPUE, measured in individuals, of a certain length class that was caught with a certain gear (for details, see chapter 2.3). For this, the number of caught cod per length class was standardised to the respective CPUE of the gear (10 pots and 200 m gillnet). Catch data were pooled over all days, and for pots additionally over all baits. The analysis suggests that, pots of type I caught cod more efficient in almost every length class than pots of type II (Figure 22). Especially, larger cod (from 44 cm and bigger) were only caught with pots of type I. Compared to the gillnet, pot-type I caught more small cod (20 cm - 30 cm), whereas the gillnet caught larger cod (40 cm - 70 cm) more efficiently. Values larger than 0.0 for these larger length classes indicate, that pot-type I still caught a few bigger cod. When comparing the length class specific catches of the gillnet to the catches of pot-type II it becomes clear that, the gillnet was superior in catching larger cods (length class of 39 cm and bigger). The almost continuous 0.0 values for length classes larger than 39 cm indicate that pots of type II caught virtually no larger cod, as it was also visible in the comparison of pots type I and II.

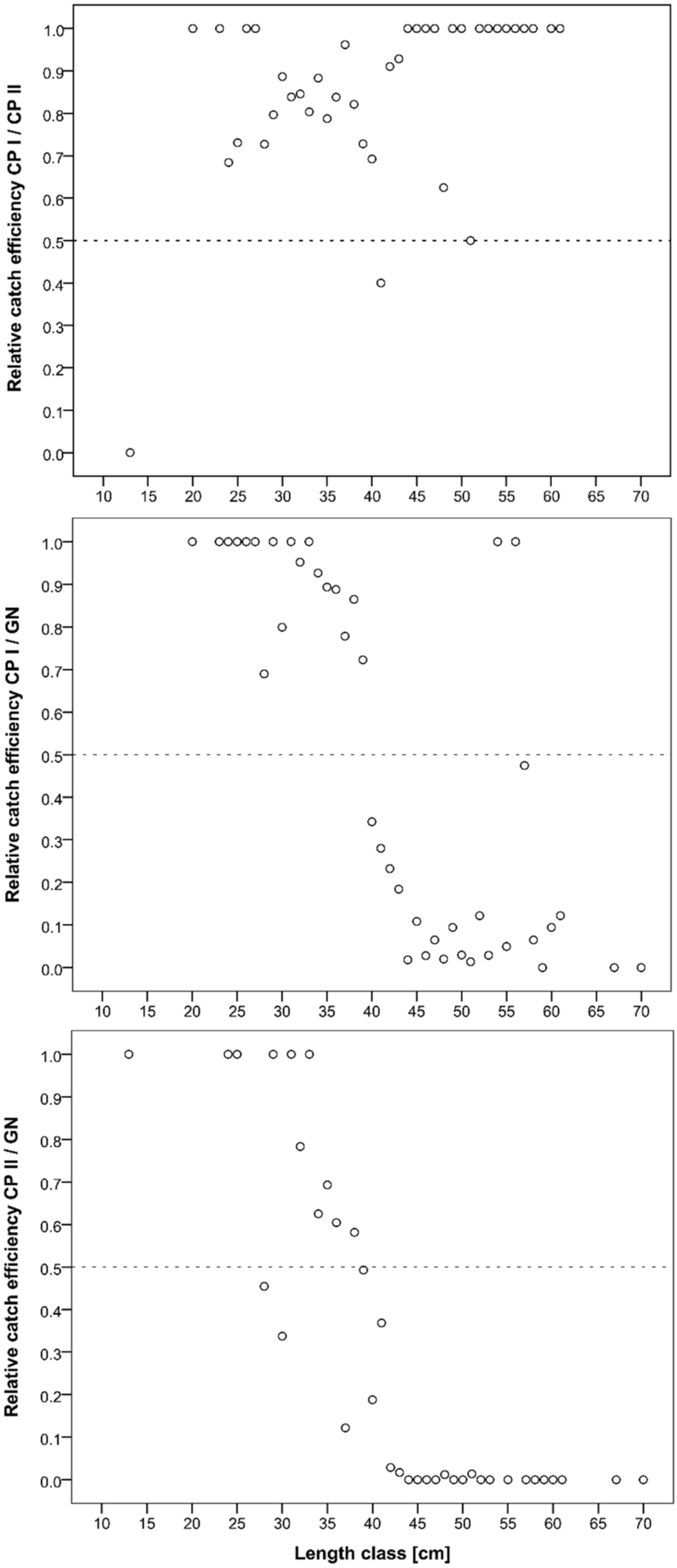

Figure 22: Relative catch efficiency of pot-type I compared to pot-type II (top), pot-type I to gillnet (middle) and pot-type II to gillnet (bottom), based on the CPUE in individuals. Data were pooled over all days and for pots additionally over all baits (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, spotted line: equal catch efficiency (same number of fish in length class for both gears)).

3.3 Cod catches by bait type

3.3.1 Overview

In this overview the catches of the 5 different baits and of the unbaited control pots were pooled over the days. In each haul, one bait was tested in 2 pots per string, with 2 strings of each of the 2 pot types (resulting in 4 pots per bait per haul). The same experimental design applies for the unbaited control pots, which were deployed on the same strings to test for potential effects of the pot structure itself. Pots of type I caught the most cod (weight and individuals) with these unbaited control pots (66.3 kg/ 127 individuals) (Figure 23, Table 16). The artificial bait glutamate caught the least amount of cod in pots of type I (23.3 kg/ 60 individuals). The two natural baits herring and shrimp combined caught 87.3 kg (172 single cod), which was 43.2 % more mass and 30.2 % more individuals compared to the artificial baits glycine and glutamate, which caught combined 49.6 kg (120 individuals) cod.
Cod pots of type II caught the most cod with shrimp-baited pots (9.6 kg/ 22 individuals). Pots of type II which were only baited with a light caught only 3.1 kg of cod and glycine-baited pots of this type caught only 7 single cod, which was the minimum. Like in pots of type I, the artificial baits caught less cod than the natural baits.

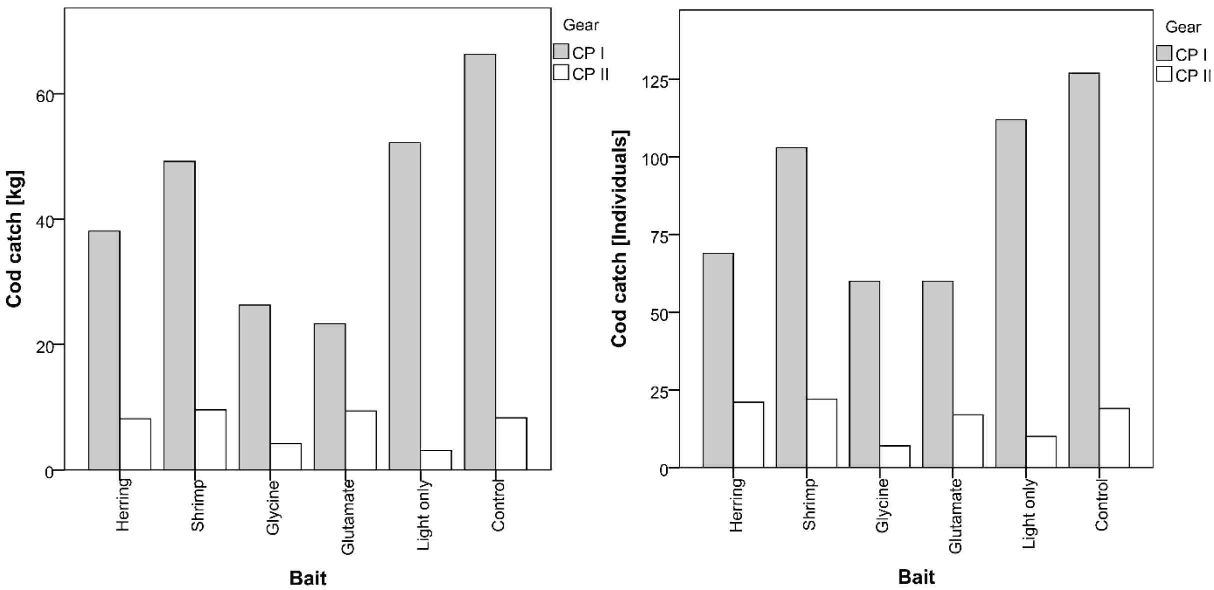

Figure 23: Total cod catch in kg (left) and individuals (right) for the different baits summed over all 6 hauls. For data see Table 16 (n= 24 pots of each pot-type and each bait) (CP I: cod pot-type I, CP II: cod pot-type II)

3.3.2 Catch comparison

Because of many zero catches, the mean value for the catch of one pot per day was quite low (Table 11). Moreover due to of high catch variability between single days and between single pots, which were baited alike, (Figure 25) the standard deviation was relatively high. Consequently, for the cod catch per pot per day, there are no significant differences between the baits ($p > 0.05$, Mann-Whitney-U-test) (Figure 24). Looking at the means of cod pot-type I, which were pooled over all days, empty control pots caught the most cod (1.15 kg ± 1.24/ 2.42 individuals ± 2.98 per pot per day) (Table 11). Pots of type I, baited with glycine caught the least amount of cod with 0.35 kg ± 0.62/ 0.84 individuals ± 1.49 per pot per day. The mean catches per pot per day for pots of type II were much lower and here, herring-baited pots caught the most cod (0.19 kg ± 0.48/ 0.58 individuals ± 1.85 per pot per day). Also pots baited with glutamate caught the least amount of cod for this gear (0.07 kg ± 0.25/ 0.12 individuals ± 0.51 per pot per day).

Table 11: Mean cod catches per pot and day for the different tested baits and pot types. Data were pooled over all days (n: number of pots, CP I: cod pot-type I, cod pot-type II, SD: standard deviation).

Bait	*n*	Cod catch per pot per day			
		Mean weight [kg] ± SD		Mean number of fish ± SD	
		CP I	CP II	CP I	CP II
Herring	24	0.79 ± 1.57	0.19 ± 0.48	1.44 ± 2.57	0.58 ± 1.85
Shrimp	24	0.86 ± 1.80	0.08 ± 0.19	1.79 ± 2.96	0.20 ± 0.47
Glycine	24	0.35 ± 0.62	0.15 ± 0.51	0.84 ± 1.49	0.26 ± 0.85
Glutamate	24	0.41 ± 0.94	0.07 ± 0.25	1.09 ± 2.83	0.12 ± 0.51
Light only	24	0.96 ± 1.95	0.10 ± 0.30	1.90 ± 3.15	0.35 ± 1.27
Control	24	1.15 ± 1.24	0.18 ± 0.35	2.42 ± 2.98	0.41 ± 1.04

When looking at the cod catch per pot per day separated by date, the same temporal fluctuations like in 3.2.2 (Figure 20) were visible. Additionally, it was cognizable that unbaited control pots had rather constant catches over the single days and did not have especially low catches on the first two days of deployment, like it was the case with baited pots (Figure 25).

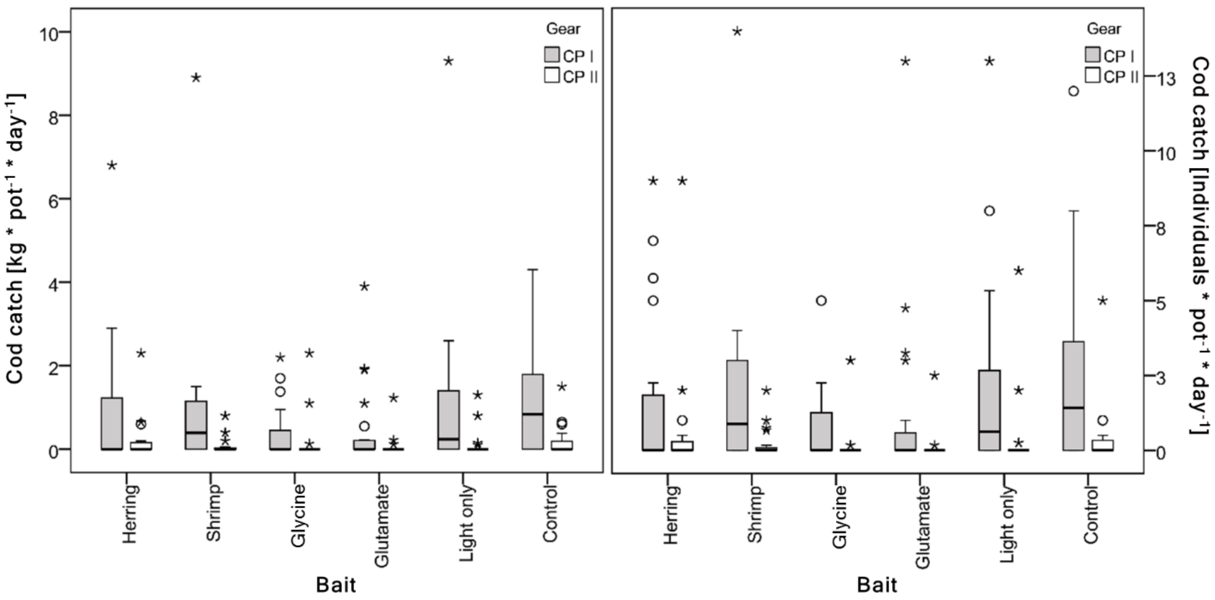

Figure 24: Cod catch per pot per day in kg (left) and individuals (right) for the different baits. Catches were pooled over all days (n=24 pots per gear per bait, CP I: cod pot-type I, CP II: cod pot-type II, line: median, box: lower and upper quartile, whiskers: values within 1.5 of interquartile range, circles: outlier-values with 1.5 - 3 of interquartile range, stars: extreme-values larger than 3 times box range).

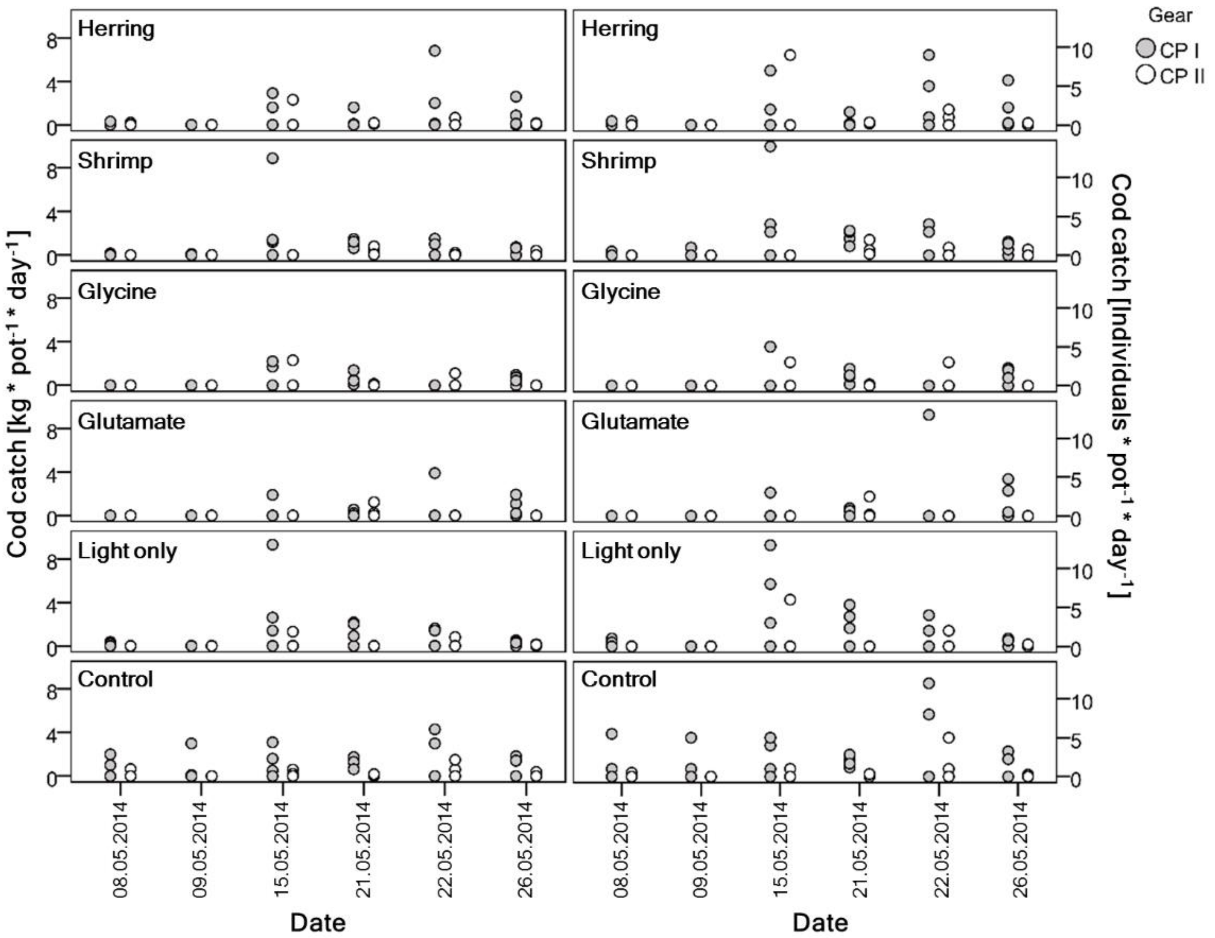

Figure 25: Cod catch per pot per day in kg (left) and caught individuals (right) for the different baits, separated by day and gear. (n=4 pots per day per bait per gear, CP I: cod pot-type I, CP II: cod pot-type II).

These results and trends were strongly influenced by temporal and spatial catch variations, because of the different haul days and haul locations (e.g. lower catches of first two hauls, see Figure 20). To eliminate these variations, the cod catch for a single bait was put into relation with the daily cod catch of the respective gear. This results in a temporal and spatial corrected percentage of the daily cod catch for the single baits (Table 12, Figure 26).

Table 12: Mean percentage of daily cod catch, based on weight and individuals, of the different baits and for the respective gear (n: number of pots, CP I: cod pot-type I, CP II: cod pot-type II, SD: standard deviation).

Bait	*n*	Percentage of daily cod catch [%]			
		Mean based on weight ± SD		Mean based on individuals ± SD	
		CP I	CP II	CP I	CP II
Herring	6	13.92 ± 12.28	18.98 ± 11.52	11.59 ± 10.09	20.42 ± 14.87
Shrimp	6	13.57 ± 10.48	11.30 ± 16.16	15.87 ± 8.66	13.61 ± 18.68
Glycine	6	5.80 ± 6.44	9.65 ± 14.41	6.75 ± 7.41	6.18 ± 8.95
Glutamate	6	7.23 ± 8.13	6.58 ± 16.13	8.86 ± 10.66	5.90 ± 14.46
Light only	6	15.40 ± 12.46	8.95 ± 9.96	15.92 ± 12.89	11.39 ± 13.60
Control	6	44.09 ± 33.61	27.88 ± 27.55	41.03 ± 30.36	25.83 ± 29.69

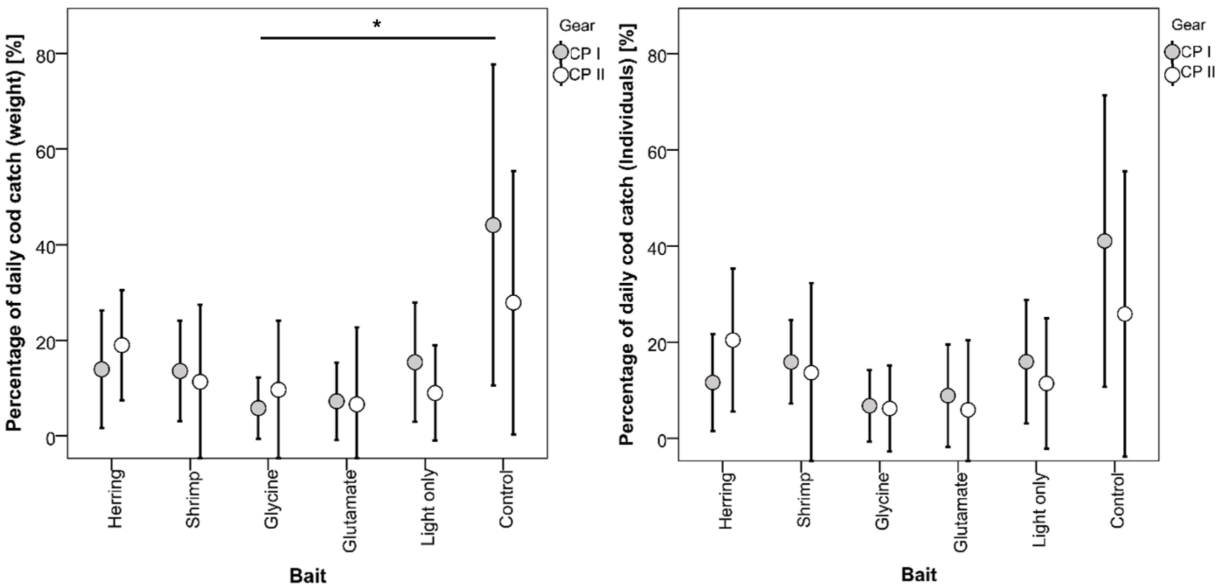

Figure 26: Percentage of daily catch based on weight (left) and based on individuals (right), caught with different baits, separated by gear (n=6 pots) (: $p \leq 0.05$ in Mann-Whitney-U-test, CP I: cod pot-type I, CP II: cod pot-type II, circles: mean, bars: standard deviation).*

This approach amplified the differences in cod catches between the baits. In pots of type I, empty control pots accounted for a significantly larger part of the cod catch than glycine-baited pots. Control pots accounted for 44 % (± 33.61) of the cod catch (weight) and for 41 % (± 30.36) of the caught individuals. Whereas glycine only accounted for approx. 6 % (± 6.44) of the caught cod mass and for about 7 % (± 7.41) of the caught individuals. Other differences were not significant. Nevertheless, it was clearly visible that on average the artificial baits (glycine and glutamate) made up the smallest part of the catch, with only 5.8 % - 7.2 % of the daily cod catch (weight). The natural baits (herring and shrimp) made up a larger part of the daily catch, but pots which were only baited with a fishing light or not baited at all, composed the largest part, with an average percentage of 14.4 % to 44 % of the daily cod catch.

3.3.3 Comparison to gillnet (CPUE)

Like in chapter 3.2.3, the catch per unit effort (CPUE) was estimated by extrapolating the catch of 10 pots of one pot-type – bait combination from the cod catch per pot per day (Table 11, Figure 24). The differences in CPUE between the single baits, where alike to the cod catch per pot per day from the prior chapter. In this analyses, it was distinguishable which pot-type – bait combination was the most competitive to the gillnet and in which extent. The CPUE (weight) of the gillnet was significantly higher ($p < 0.05$ in Kruskal-Wallis-test) to all CPUEs of all baits used in pot-type II (Table 13, Figure 27). Looking at the caught cod individuals, the same significant differences were verifiable, except for the comparison gillnet – herring. The gillnet caught between 12.5-times (glutamate) and 10.2-times (herring) more cod in weight, and between 13.4-times (glutamate) and 2.7-times (herring) more individual cod than pots of type II.

Looking at the comparison of the CPUE of the gillnet and pot-type I, the contrasts were not as considerably as between gillnet and pot-type II. The only significant ($p < 0.05$ in Kruskal-Wallis-test) difference was detectable between the CPUE (weight) of the gillnet and pots of type I that were baited with glycine. There were no significant differences in the number of caught cod, when comparing the CPUE of the gillnet with the CPUE of all baits used in pot-type I. Nevertheless, on average the gillnet caught between 5.5-times (glycine) and 1.7-times (unbaited control pots) more cod (weight) than pots of type I. Although standardized, pots of type I, which were baited with shrimp or only a fishing light and unbaited control pots, still caught 12 % to 35 % more individual cod than the gillnet.

Table 13: Mean cod catch per unit effort (CPUE) for the different baits, in kg (top) and individuals (bottom), compared to the CPUE of the gillnet. Pot and gillnet data were pooled over all days (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, SD: standard deviation).

Bait	Mean cod CPUE [kg] ± SD		
	CP I	**CP II**	**GN**
Herring	7.88 ± 15.66	1.89 ± 4.83	19.18 ± 5.25
Shrimp	8.65 ± 18.01	0.79 ± 3.04	
Glycine	3.48 ± 6.17	1.47 ± 5.11	
Glutamate	4.08 ± 9.36	0.65 ± 2.53	
Light only	9.60 ± 19.52	0.98 ± 3.04	
Control	11.50 ± 12.36	1.82 ± 3.52	
Bait	**Mean cod CPUE [Individuals] ± SD**		
	CP I	**CP II**	**GN**
Herring	14.41 ± 25.66	5.83 ± 18.47	15.83 ± 5.48
Shrimp	17.92 ± 29.57	1.98 ± 4.72	
Glycine	8.37 ± 14.91	2.57 ± 8.46	
Glutamate	10.90 ± 28.31	1.18 ± 5.10	
Light only	18.95 ± 31.46	3.54 ± 12.70	
Control	24.20 ± 29.80	4.06 ± 10.36	

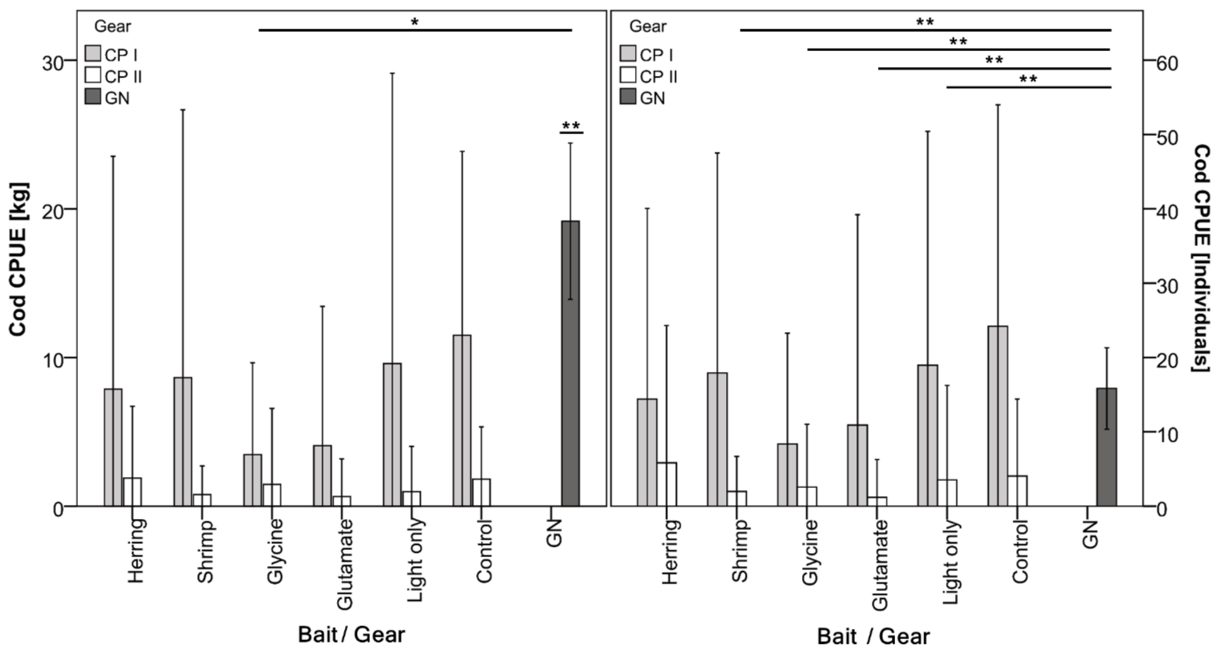

Figure 27: Mean cod catch per unit effort (CPUE) in kg (left) and individuals (right) for the baits and pot types in comparison to the gillnet. Standardized effort for CP I and CP II: 10 pots, standardized effort for GN: 200 m gillnet. Pot and gillnet data were pooled over all days (CP I: cod pot-type I, CP II: cod pot-type II, GN: gillnet, <u>**</u>: $p \leq 0.01$, <u>*</u>: $p \leq 0.05$ *in Kruskal-Wallis-test, bars: standard deviation).*

3.4 Assessment of soak time

On three out of six fishing days, the pots were left in the water for longer than one day (Table *3*). Because of the overall few fishing days, the analysis of the impact of soak time on the cod catch was limited. A regression analyses of the cod catch of one pot per haul suggested that there was a significant relationship between the catch amount and the number of soak days for some baits. The cod catch of pots of type I and II that were baited with shrimp increased with a prolonged soak time (Figure 28, Table 14). The same relationship was cognizable in pots of type I which were baited with glycine and in unbaited pots. Also, in pots of this type which were baited only with a fishing light, a prolonged soak time lead to an increase in cod individuals but not in weight. There were no significant changes in the cod catches per pot of one haul for other gear – bait combinations.

To see possible effects of a prolonged soak time on the daily catch of one pot, the cod catches of one pot per haul were divided by the number of soak days, resulting in the standardized cod catch per pot per day (Figure 29). Their regression analysis suggests that there was a significant positive correlation between the catch (weight) of pot-type II, which were baited with shrimp and an increasing number of soak days (Table 15). This would mean, that the daily cod catch of these pots increased with every day they stayed in the water. Besides that, the regression analyses showed no other significant correlations between the cod catch per pot per day and the number of soak days.

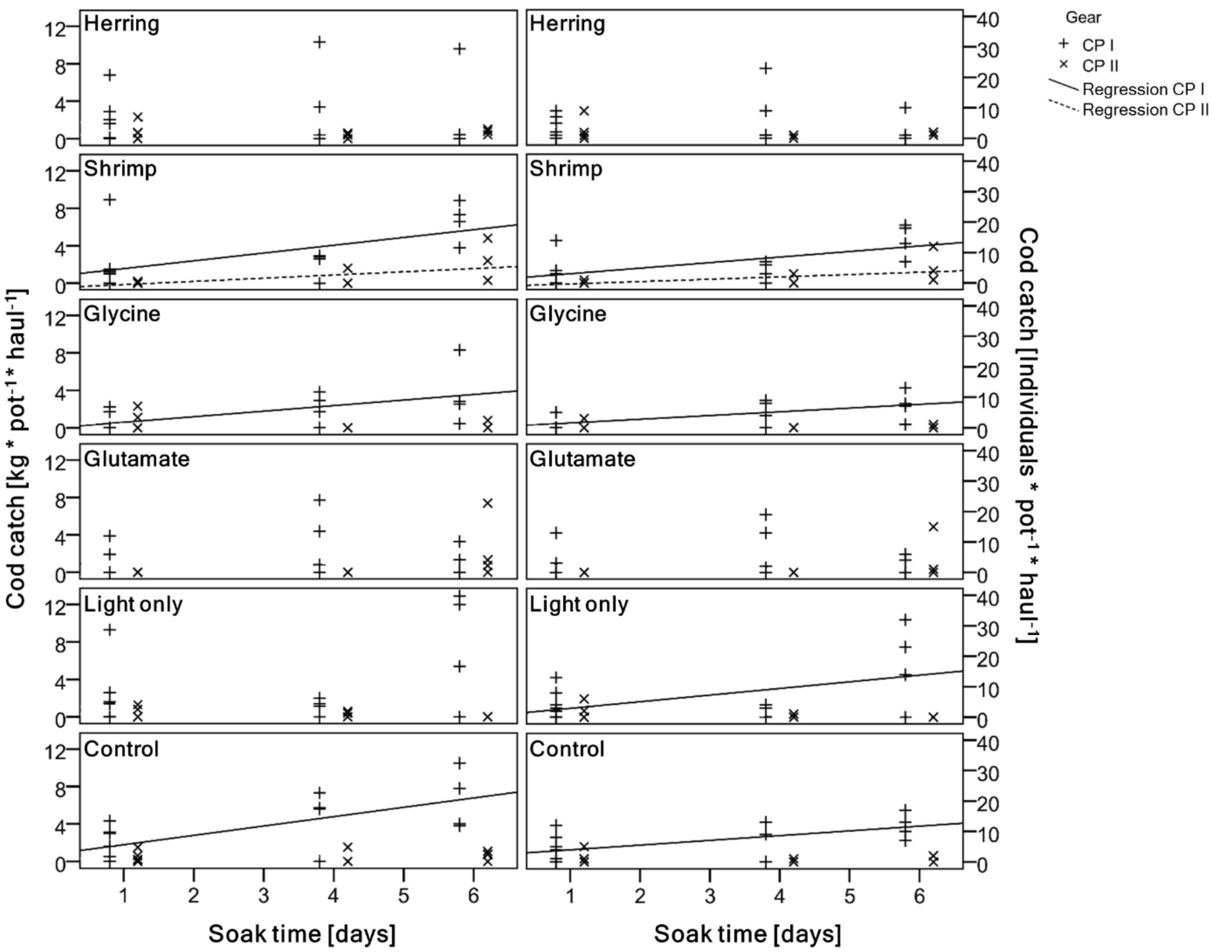

Figure 28: Cod catch per pot per haul in kg (left) and individuals (right) in relation to the soak time in days of both pot-types. Lines indicate significant linear regression between the number of soak days and the cod catch of the respective gear (for data of significant regression see Table 14). Data from the 08.05.2014 and 09.05.2014 were not included in this analysis because of their exceptional low catches.

Table 14: Summary of significant linear regression data between cod catch per pot per haul in kg (top) and individuals (bottom) and soak time (CP I: cod pot-type I, CP II: cod pot-type II, n: number of pots, R^2: coefficient of determination, t: quotient of regression coefficient and its standard error, p:significance)

Linear regression cod catch [kg * pot^{-1} * haul^{-1}] – soak time [days]					
Gear	**Bait**	***n***	**R^2**	**t**	***p***
CP I	Shrimp	16	0.334	2.647	0.019
CP I	Glycine	16	0.347	2.727	0.016
CP I	Control	16	0.466	3.494	0.004
CP II	Shrimp	16	0.326	2.599	0.021
Linear regression cod catch [Individuals * pot^{-1} * haul^{-1}] – soak time [days]					
Gear	**Bait**	***n***	**R^2**	**t**	***p***
CP I	Shrimp	16	0.394	3.019	0.009
CP I	Glycine	16	0.401	3.059	0.008
CP I	Light only	16	0.263	2.233	0.042
CP I	Control	16	0.380	2.932	0.011
CP II	Shrimp	16	0.298	2.439	0.029

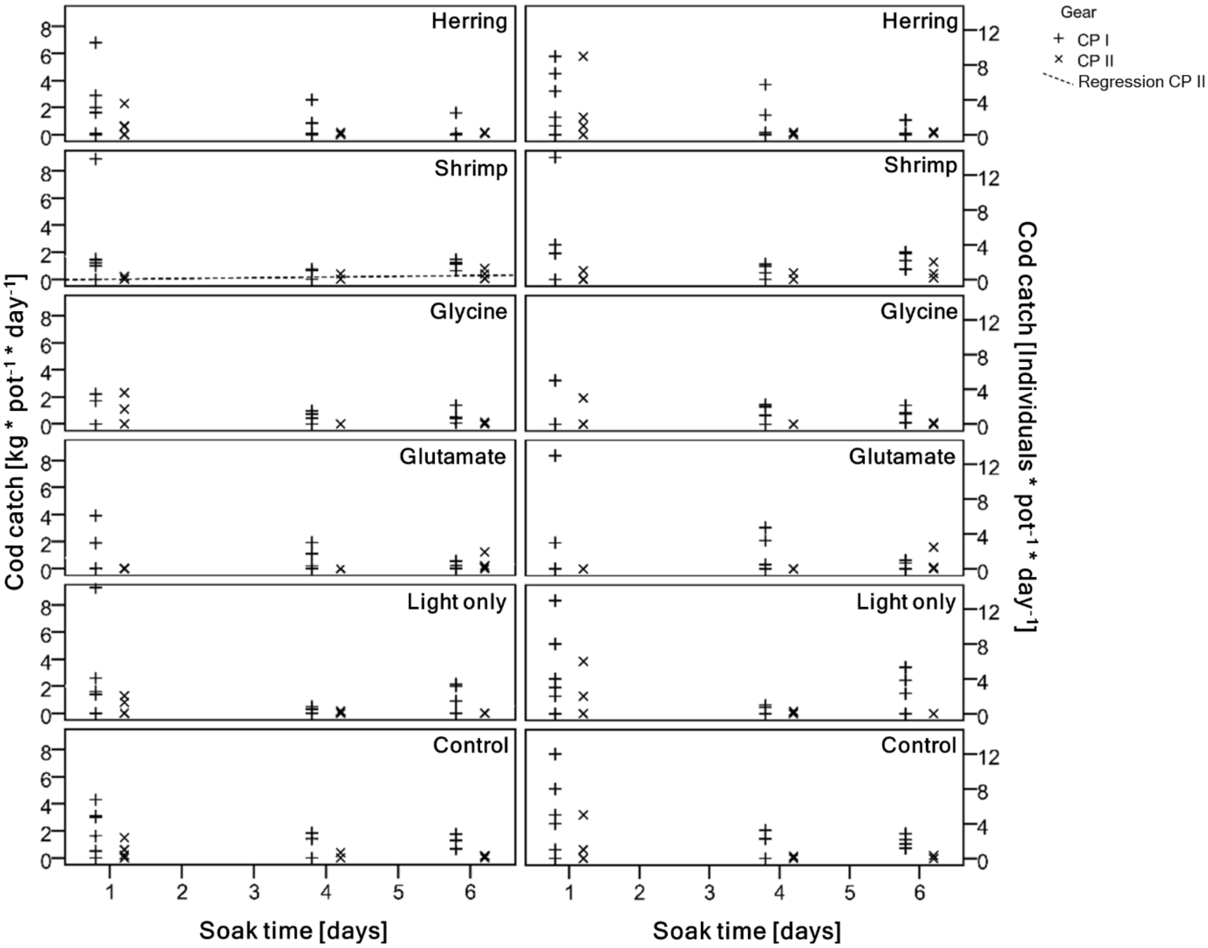

Figure 29: Cod catch per pot per day in kg (left) and individuals (right) in relation to the soak time in days of both pot-types. Lines indicate significant linear regression between the number of soak days and the cod catch of the respective gear (for data of significant regression see Table 15). Data from the 08.05.2014 and 09.05.2014 were not included in this analysis because of their exceptional low catches.

Table 15: Summary of significant linear regression data between cod catch per pot per day in kg and soak time (CP I: cod pot-type I, CP II: cod pot-type II, n: number of pots, R²: coefficient of determination, t: quotient of regression coefficient and its standard error, p: significance)

Linear regression cod catch [kg * pot^{-1} * day^{-1}] – soak time [days]					
Gear	**Bait**	***n***	**R^2**	**t**	***p***
CP II	Shrimp	16	0.271	2.282	0.039

3.5 Assessment of escape window of pot-type II

To test the functionality of the escape window (length of square mesh side: 40 mm), which was installed in pots of type II, cod of different size were manually tried to pass through the mesh. The results suggests that the window had a high retention probability even for smaller cod (Figure 30). A small cod with a body length of 32 cm had a 99.9 % probability to not pass through the escape window. The L_{50} (50 % chance for cod to be retained) was estimated to around 29.5 cm. That means that cod, which were several centimetres below the MLS of 38 cm, were not able to pass through escape window. The selection range (length classes between L_{25} and L_{75}) was with approx. 27.5 cm to 29.5 cm quite narrow and can be estimated in the steepness of the selection curve.

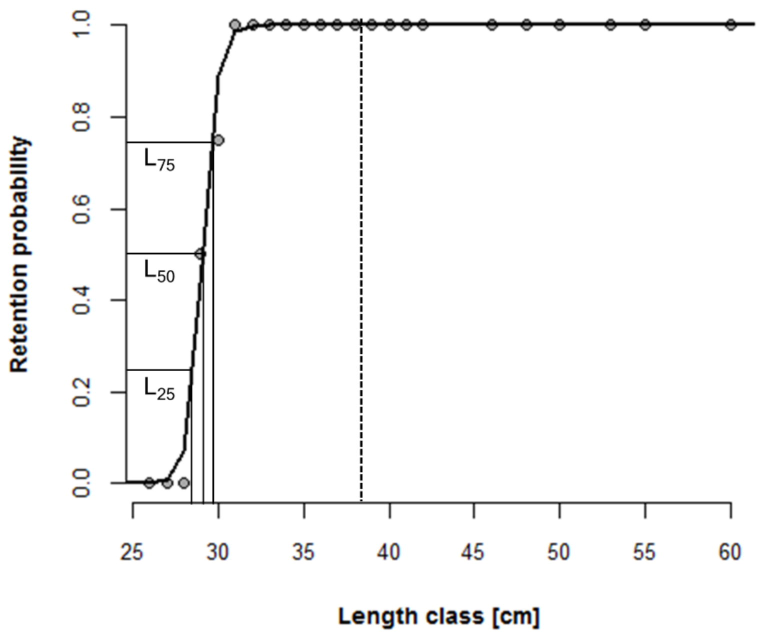

Figure 30: Estimated selection curve for the escape window in pots of type II using a generalised linear model (L_x: length class with a x chance to not pass the netting, spotted line: MLS of cod of 38 cm).

3.6 Assessment of seal exclusion device (SED)

To prevent seals from entering, all pots of type II were equipped with a metal frame SED, which was installed in the pot entrances. Since no seals were bycaught in pots with SEDs but also not in pots without the SEDs (pot-type I worked as a control group), it can´t be determined if the SEDs actually prevented seals from entering the pots or if there was no encounter between the pots and seals.

3.7 Handling

The crew of 6 man fulfilled different tasks in operating the cod pots. For hauling, the ground line was retrieved with the gillnet hauler, which was operated by one man. Two men pulled the pot over the rail, which was passed to the next two men who stacked the pots out of the way. After all pots of one string were hauled, the fish were collected, the bait exchanged and the pots restacked, ready for setting.

For setting, two men threw the pots over the side of the ship. It took around 30 min to retrieve and reset one pot string, depending on the amount of caught fish. The handling of pot-type II was more laborious, because the attached mooring weight. Collecting the single fish out of the pot took a large part of the handling time. The limited space on the vessel was an additional problem, causing a circuitous work flow (Figure 31).

There were no problems handling the gillnet, because the crew was experienced in using this gear and it did not require as much space as the pots.

Figure 31: Hauling of a pot on board the fishing vessel.

3.8 Video observation

To observe the functionality of the pots and possible fish that move around and in the fishing gear, cameras were attached on one pot of each type on the 14.05.2014. The video analysis showed, that pots of both types unfolded properly in the water. However, it also showed that the pot of type II did not float off the sea bottom like it was supposed to. This finding was backed by recordings of the magnetic field data logger which was fixed on another pot of type II. Its analysis showed that this pot did not change its horizontal orientation after being deployed at all times, which means that it did not align itself in the water current. Therefore, this finding was also assumed for all other pots of type II.

The video analysis also showed that the metal frame SEDs tilted when a stronger current occurred (Figure 32). In this time, the pot entrance was collapsed and presumably no fish could have entered the pot.

No fish were caught with the camera equipped pots. Also no fish could be observed entering and leaving the pots. Only two flatfish were observed, which tried to enter the pot from the downstream direction unsuccessfully (Figure 32).

Figure 32: Tilting metal frame SED (left) and flatfish trying to enter the pot (right).

4 Discussion

Due to the reduced fishing days and the resulting small sample size, it is uncertain whether the results of this study are representative. Furthermore, it is not possible to distinguish whether a difference in catchability was caused by a bait or by a potential attraction effect of the pot structure. There is the danger of misinterpreting these different factors. That is why the results of this study in terms of the catch success of different baits as well as the impact of the soak time should be used with caution.

The results of this study showed substantial quantitative and qualitative differences in the catches of pot-type I, pot-type II and the gillnet. Because of this, the first null hypothesis $[H_0]_1$ of this study ("Different gears have no significant differences in catches.") has to be rejected.

The analyses of the different baits, used in pot-type I and II, did not show significant differences in the average cod catches, attained with those baits. This is probably due to the overall low catches and the resulting high standard deviations. Although not significant, the differences in cod catches were clearly existent and thus the second null hypothesis $[H_0]_2$ ("Different baits for fish pots have no influence on the catches of cod.") has to be rejected, too.

The total catch was dominated by cod in all gears. This was expected because the tested fishing gears were designed to catch cod. Pots of both types caught virtually no flatfish. One possible explanation for this is, that flatfish could hardly enter the pots because of their relative wide cross section and the rather narrow funnel-shaped entrances of the pots. Especially the non-flexible SEDs of pot-type II may have detained flatfish from entering the pots. These findings correspond to the results from Lorenz *et al.* (2009), where similar pots caught almost no flatfish.

However, flatfish are often not unwanted bycatch but an important secondary source of income. It is common practice to catch flounder, turbot and plaice together with cod in gillnets (pers. comm. Dirk Beggerow, fisherman). The high species selectivity of cod pots would probably be unfavourable for fishermen. To make pots also selective for flatfish, the entrances would have to be modified (e.g. different shape and size).

The CPUE comparison of the different gears, showed that the gillnet caught on average more than twice as much cod (weight) than pot-type I, and even 15-times more than pot-type II. Nevertheless, pot-type I caught as many individual cod as the gillnet. The reason for the bigger catch (measured at the weight) of the gillnet can be found in the length distribution of the caught cod. More than 66 % of cod, which were caught with pots, were under the minimum landing size of 38 cm. In contrast, the gillnet caught mainly (> 90 %) cod above the MLS, resulting in the significantly higher cod catch. There was also a significant difference in the catches of pot-type I and II. Pot-type I caught on average six times more cod (weight) than pot-type II and five times more individuals.

The finding, that fish pots had a poor catchability compared to gillnets, is confirmed by other studies (e.g. Furevik & Løkkeborg 1994; Ljungberg 2007, Lorenz *et al*. 2009). Pots, similar to the ones of this study, caught between 75 % – 50 % of the referenced gillnet catches. It is generally remarkable, that trials with fish pots which were conducted off the Swedish coast were more successful compared to trials from the German Baltic coast. The Swedish archipelago coastline is characterized by a complex sea floor with many natural reefs (Voipio 1981). In contrast, the sea floor off the German Baltic coast is less structured, mainly consisting of sand with only scattered areas of bedrock and gravel (Emeljanov *et al.* 1993). Likewise, the locale cod stock is probably less aggregated. Fishing gears which have a small active fishing area like pots (see chapter 1.5) have a clear disadvantage when the target species is distributed over larger distances.

An explanation for the poor catches of pot-type II is most likely to be found in the SEDs (seal exclusion device). Since the video analysis and the data from the magnetic field sensor suggested that it was not possible to raise pots of type II off the sea floor, the only difference between the pots, which could significantly affect the catchability, were the SEDs. This assumption is supported by the video analysis, which has shown how the metal frame tilts in the presence of a strong current. The resulting collapse of the entrance would make it impossible for fish to enter the pot. This result is contrary to a study from Königson *et al.* (2014), where almost identical SEDs led to an increase in cod catches, compared to pots without SEDs. Different studies suggest that the entrance is a crucial factor that directly affects the catchability of pots (Furevik & Løkkeborg 1994, Munro 1974). If used in in future studies, this modification has to be improved in terms of stability in stronger currents, e.g. by a more stable attachment to the pot structure.

In addition to the relative low catchability, another problem of the pots was the large number of undersized cod. This problem was also encountered in other studies (Ljungberg 2007, Lorenz *et al.* 2009). One solution for this problem is to replace on panel of the standard pot netting with an escape window of larger square meshes. Ovegård *et al*. (2011) showed that the bycatch of undersized cod could be reduced by 90 % in pots that were equipped with an escape window with a square mesh size of 45 mm. In this study, pots of type II had such a window in the upper half of one short side. Nevertheless, there was no difference in mean length of cod, which were caught with pots of type I or type II. Also, the percentage of undersized cod in pot-type II was only slightly lower than in pot-type I. Thus, it can be assumed that the escape window had no significant effect on the size selection of pot-type II. A likely explanation for that is, that the mesh size of 40 mm (square mesh length) was too small for undersized cod to pass through. This assumption was confirmed by the manual selection trials. They showed that cod, which were several cm below the MLS could not pass through the netting. The narrow selection range of the escape window probably resulted in the relative inelastic square meshes and their fixation at the metal frames. A narrow selection range is economically desirable for most fishermen, but ideally should cover the length classes around the MLS, which was not the case in this study

The high percentage of cod above the MLS in the gillnet met the expectations. The used gillnet mesh size was designed for allowing undersized cod to slip through.

In future studies, pots with an escape window of 45 mm square mesh size and equipped with cameras should be tested against pots without such a window, to investigate possible effects. Minimizing the number of undersized individuals could decrease the handling time, which would lead to an increase of the CPUE.

The analyses of the different baits presented a paradox. Pots which were neither equipped with bait nor light (control) caught the most cod. In prior studies, cod were repeatedly caught with unbaited control pots and it was assumed that cod were attracted by the structure of the pot (“reef effect” in Ljungberg 2007, Lorenz *et al.* 2009). Nevertheless, no previous study showed a higher catchability of control pots compared to baited pots. Even if there is a kind of “reef effect” of the pot structure, all used pots would have had this feature. An unlikely explanation for this unusual finding is, that all baits acted as a repellent. This would mean, the structure of the pot was the only attracting factor while all baits had a different degree of repellent effect on cod.

This would contradict the findings of former studies, where all baits used in this study (with the exception of glutamate) have been identified as attractants for cod (e.g. herring/ shrimp: Ljungberg 2007, glycine: Ellingsen & Døving 1986, light: Bryhn *et al.* 2014). However, studies showed that synthetic mixtures of amino acids seldom attained the effectiveness of extracts from natural prey (Carr & Derby 1986, Hara 2011, Jones 1992b). Moreover, Løkkeborg *et al.* (1989) found that cod were not attracted towards a prey (or bait), which they did not encounter before. That could be a possible explanation for the poor catches of the artificial baits, because cod did not know them as a source of food. It is also possible that the wheat paste, used as a carrier in this study, had a repellent effect on cod. This form of bait additive was not used in previous studies and the reaction of cod is unknown.

Despite a possible non-attracting or even repellent effect of the baits, another possible shortcoming could be a fast leaching of them (Løkkeborg 1990). This was expected for the unmodified natural baits herring and shrimp. It is possible that the wheat paste did not prevent a quick leaching of the artificial baits. The theory of an olfactory guidance (see chapter 1.5) would not have been applicable, if this crucial factor (a constant release of attractants over a long time period) was missing. Therefore, the gillnet would have had a clear advantage, because of its large active fishing area.

Although glycine and glutamate did not proof as suitable baits in this study, artificial baits should be subject to further investigation, because they have the potential to act as a highly potent bait. Thereby, a focus should be on extracts of prey organisms. With a suitable carrier, artificial baits can release their attractants over a long time and the rather expensive extracts or chemicals would have to be used in only small amounts. The singular effects of wheat paste on cod have to be investigated first before it can be used as a cost efficient, available and easy to modify agent (see chapter 2.1.2) for crystalline or fluid artificial baits.

Another key aspect should be the improvement of natural baits in terms of persistence. Prey species like herring are a proven, cost-efficient and often easy available bait for cod.

To make natural baits longer lasting, Swedish colleagues developed an automatic rebait system which consists of a vacuum box that opens after a certain time via an attached timer (pers. comm. Sarah Königson, Swedish University of Agricultural Sciences). Multiple of these boxes can rebait a pot automatically for several days.

Moreover it is possible that cod were repelled by a high density of small cod inside the trap (“saturation effect” in High & Beardsley 1970).

All in all, to increase the long-term catchability of pots, these crucial factors have to be considered: attraction of baits, leaching time of baits, a possible repellent effect of leached bait or carriers and a possible saturation effect due to a high fish density in the pots.

The limited effect of the fishing lamps on the catch could be related to the relative short night periods during the time of this study (May). Trials from Bryhn *et al.* (2014) and Noack (2013), where this modification led to a significant catch increase, were conducted over a longer time span and during months with longer night periods. During this time, cod is likely more attracted to light sources than during the day. Nevertheless, this modification can be recommended for future studies, because fishing with light is a known practice and special fishing LEDs provide a cost efficient and convenient method to potentially increase the catch of fish pots.

It can´t be determined if the SEDs in this study prevented seals from entering the pot or if there was no interaction between pots and seals at all. Still, during a study of the TI-OF in 2013, one seal was caught and drowned in a pot that wasn´t equipped with a SED (Noack 2013). Although it is uncertain what prevented an accident like this in the present study, all measures should be taken to prevent unnecessary casualties of marine mammals in future studies.

The analysis of the impact of soak time was limited due to the overall few fishing days. It suggested for some baits a positive linear relationship between the number of soak days and the cod catch. For shrimp and glycine, it would mean that these baits had a constant attracting effect up to six days, and did not leach out. However, unbaited control pots showed the same positive correlation. So it could be that the baits leached out after one day and the cod were permanently attracted by the empty pot. These different attracting factors are not distinguishable and the results should be used with caution.

When testing baits for fish pots in future studies, it should be considered to use only one type of bait per pot string. This way, an overlapping and mixing of the bait plumes could be avoided and potential differences between the baits should be clearly distinguishable. Moreover, experimental fishing trials with pots should be conducted over a longer term to include seasonal variances. Fishermen often report that cod prefer different baits over the year (pers. comm. Christopher Zimmermann, TI-OF). Furthermore the effect of floating pots on the catchability should be investigated more comprehensive to verify the results from Furevik *et al.* (2008), where floating pots caught more cod than bottom set pots. Certain conclusions about the proper functioning of the pots and possible problems can only be attained via a comprehensive video observation.

Hereby, a continuous recording is recommended. Although, this is strongly limited by the battery of the camera at the moment, a non-stop observation is the best way to detect possible interactions between fish and pots, which are often only for a short moment (pers. observation).

Finally, fish pots like they were used in this study, cannot be fully recommended as an economic alternative to the gillnet. Pots are virtually non-existent in the German Baltic commercial fishery. Fishermen who would want to use this alternative fishing gear would have to pay asset costs for the new gear first. For the Swedish coast, it is suggested that fishermen would have to use approx. 120 pots to achieve viable catches (pers. comm. Sarah Königson, Swedish University of Agricultural Sciences). To be able to handle this large number of gears, fishing vessels would have to be adapted. Lorenz *et al*. (2009) conducted fishing trials with pots on a commercial vessel which had a special ramp for an easy deployment of pots. But more important would be a convenient system for pot hauling, because this took much more time than the setting. It is unknown if the mostly small vessels of the German fishing fleet would provide enough space for these modifications and for handling a large number of pots.

Nevertheless, many characteristics of fish pots are favourable for the small scale commercial fishery. For example, the weather independency of the pots could lead to a reduction of the fuel consumption in a long term view. Awareness has to be raised, that a high quality product, like fresh fish which was caught with an environmental friendly fishing gear, can be sold for a higher prize (Döring & Wichtmann 2007). At the moment, most fish in Germany is sold for the same prize, regardless of its catching method (pers. comm. Harry Strehlow, TI-OF). Further incentives for fishermen could be given in form of subventions from EU or national authorities. This way, potential lower catches could be compensated.

Further studies are necessary to improve this promising alternative fishing gear. Hereby, the fishermen should be directly included because their experience and expertise is essential for the process of development. Current problems like the problematic of bycatch as well as possible future problems like interactions with seals should be emphasised to fishermen to reconsider the usage of alternative fishing gears. The seal populations of the German Baltic coast are not as big as the Swedish ones yet, and interactions between seals and fishermen are still limited. So now is the time to develop solutions for this imminent problem, before it is too late.

Although the results of this study have to be viewed sceptically, they contribute to the ongoing process of the improvement of pots as alternative fishing gear. It was shown that the entrance is a crucial factor of the pot design and that artificial baits need further investigations to be effective. Regarding that fish pots are a relative new gear in the commercial fishery, they are likely to exploit their already promising advantages in the future.

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Appendix

Figure 33: The fishing vessel "Lassan" (SAS112) with which this study was conducted. ©Dirk Beggerow

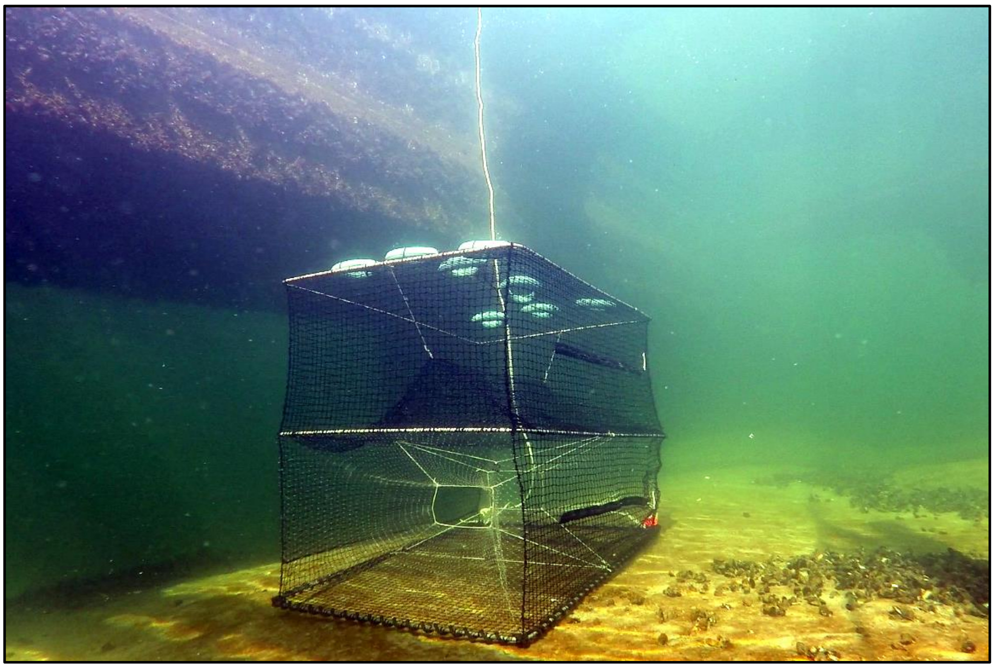

Figure 34: Pot-type I under water. Pots of this type were designed to rest on the sea floor.

Figure 35: Shrimps (Crangon crangon) were filled in a fine mesh bag to prevent them from falling through the larger meshes of the bait bag.

Figure 36: 500 ml PVC wide neck container (310 series, Kautex Textron) were used as container for the artificial baits glycine and glutamate.

Table 16: Cod catch in kg and individuals for the different baits summed over all 6 hauls. Data corresponding to Figure 23 (n= 24 pots of each pot-type and each bait).

Bait	**Cod catch**					
	CP I		**CP II**		**Total weight**	**Total individuals**
	Weight [kg]	Individuals	Weight [kg]	Individuals		
Herring	38,10	69	8,15	21	**46,25**	**90**
Shrimp	49,20	103	9,60	22	**58,80**	**125**
Glycine	26,30	60	4,20	7	**30,50**	**67**
Glutamate	23,30	60	9,40	17	**32,70**	**77**
Light only	52,20	112	3,10	10	**55,30**	**122**
Control	66,30	127	8,30	19	**74,60**	**146**
Total	**255,40**	**531**	**42,75**	**96**	**298,15**	**627**

Declaration of Authorship

I, Christoph Wengerodt, hereby certify that the thesis I am submitting was written only with the assistance and literature cited in the text. Only the sources cited have been used in this work. Parts that are direct quotes or paraphrases are identified as such. The figures and photographs in this work have been prepared by me, if not labelled otherwise. The thesis has not been previously submitted whether to the University of Rostock or to any other university.

Rostock, 16th of September 2014 Christoph Wengerodt