Universität Rostock

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Reduction of bycatch in the Baltic Sea Fishery:

An evaluation of alternative passive fishing gears and their comparison to the gillnet

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Abstract

Gillnets are the most common fishing gear of the passive fishery in the Baltic Sea. They are known to be size selective and efficient fishing gears, which show low interactions with the sea bottom and require low personnel expenditure. Nevertheless, gillnets are quite often in focus of criticism – due to the bycatch of marine mammals like harbor porpoise (*Phocoena phocoena* L.) which is endangered in the Baltic Sea and several diving seabirds. For some species, drowning in gillnets is said to be the key mortality factor. One option to reduce the incidental bycatch of mammals and birds is the use of alternative fishing gears.

This study tested several of those alternative gears: a modified gillnet, which was reduced in height, two types of fish pots (small Norwegian type and large Canadian type) and three jigging machines with different setups. Further, the catches of these gears were compared to the catches of a standard gillnet, which was set in the same area.

The lower gillnets caught about one fifth of the standard gillnets and offered problems during handling. However, both types of gillnets showed a good selectivity regarding cod. Less than 10% of the captured fish were undersized. The Norwegian pots were tested with different baits and modifications (herring, boilie, light, different entrance, camouflage netting cover, floating off the bottom). Pots, which were baited with herring, showed considerable better catches than unbaited or boilie baited pots. A further increase of catch efficiency was possible by using a light additional to herring, resulting in a predicted catch of 7.1 cod (*Gadus morhua* L.) per ten pots and day. This value is even higher than the catch per day of ~275m gillnets (4.5 individuals), which can be handled in the same time. However, the fish pots are less efficient than standard gillnets, because a) more than 60% of the fish captured by pots were undersized and b) fish pots need, contrary to the gillnet, two or more people to be handled. Furthermore, the fish pots caught a ringed seal (*Pusa hispida* L.). The Canadian fish pot caught zero fish. The jigging machines fished with different types of artificial lures and different fishing programs. All setups caught similar numbers of cod, implying that the catch efficiency is not affected by lure shape, lure color or program. For comparing jigging machines and gillnets, the average cod catch of three machines per hour was calculated and compared to the catch of the standard gillnet, because it needs about one hour per day to be handled. As a result, the jigging machines caught less than a quarter of the standard gillnet, whereby more than 50% of the fish were undersized.

Despite relatively low numbers of marketable fish, testing of alternative fishing gears should be continued since not only the quality of caught fish is very high and the dependence on weather is reduced, but also several modifications are able to raise efficiency and selectivity.

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List of abbreviations

ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas
AIC	Akaike Information Criterion
BLE	Bundesanstalt für Landwirtschaft und Ernährung (Federal Office for Agriculture and Food)
CP	Cod pot / Fish pot
CPnor	Cod pot / Fish pot - Norwegian type
CPcan	Cod pot / Fish pot - Canadian type
CPUE	Catch per Unit Effort
CTD	Conductivity, temperature, depth (hydrographic measurement equipment)
FRV	Fisheries Research Vessel
GLM	Generalized linear model
ICES	International Council for the Exploration of the Sea
ICES SD	ICES-Subdivision
IWLS	Iteratively Weighted Least Squares
JM	Jigging machine
MLS	Minimum Landing Size
LGN	Lower gillnet
LOA	Length Over All
LSF	Large Scale Fishery
SD	Standard deviation
SED	Seal Exclusion Device
SGN	Standard gillnet
SSF	Small Scale Fishery
TI-OF	Thuenen-Institute of Baltic Sea Fisheries

1 Introduction

1.1 The Baltic Sea Fishery

Fishing gears can be divided into two categories: a) active gears like trawls and b) passive gears like gillnets, fykes, longlines or traps. This classification is based on the behavior of target species and gear: The catch by active gears is generally based on an aimed chase of fish, whereas passive gears are waiting for the movement of fish towards the gear (BJORDAL, 2002).

Since active gears are towed through the water, their energy consumption is relatively high and they can cause environmental problems. For example, trawl doors, used by bottom trawls, are dragged along the seabed and can damage sessile organisms and fragile habitats. If the fishing grounds are characterized by soft sediments, sediment can be stirred up. This can lead to a release of nutrients and toxic compounds like Polychlorinated Biphenyls (BRADSHAW *et al.*, 2012) or – in shallower areas - to a light limitation of phototrophic organisms. Contrary to towed gears, passive methods are fuel-saving and show low interactions with the bottom. Main components of an interaction with bottom habitats are the anchors, fixing the gears on the seabed.

In the Baltic Sea both active and passive gears are in use but the major part of the catch is landed by active gears (Table 1). The most important target species are cod (*Gadus morhua* L.), herring (*Clupea harengus* L.) and seasonally different flatfish species like flounder (*Platichthys flesus* L.).

Table 1: Quantity of active vessels in the German Baltic Fleet and total landings for 2012 separated by gear type (BLE 2013).

Gear type	No. of active vessels	%	Total landing [t]	%
passive	880	92	9064	12
active	73	8	68153	88
Total	**1255**	**100**	**77220**	**100**

The most widely used passive gear for catching cod is the bottom-gillnet, a wall of netting which is anchored to the bottom and catches fish by wedging or entangling them (VON BRANDT, 1984). Other types of gillnets, so called “trammel nets”, consist of three walls of netting.

In addition to the low interactions with the bottom, common gillnets are known to be very size selective regarding the target species (HUSE *et al.*, 2000). Sufficiently small fish pass through the meshes and sufficiently large fish cannot wedge and have only a little chance to entangle in gillnets. Thus, selectivity curves of gillnets are represented by bell shaped curves (Figure 1).

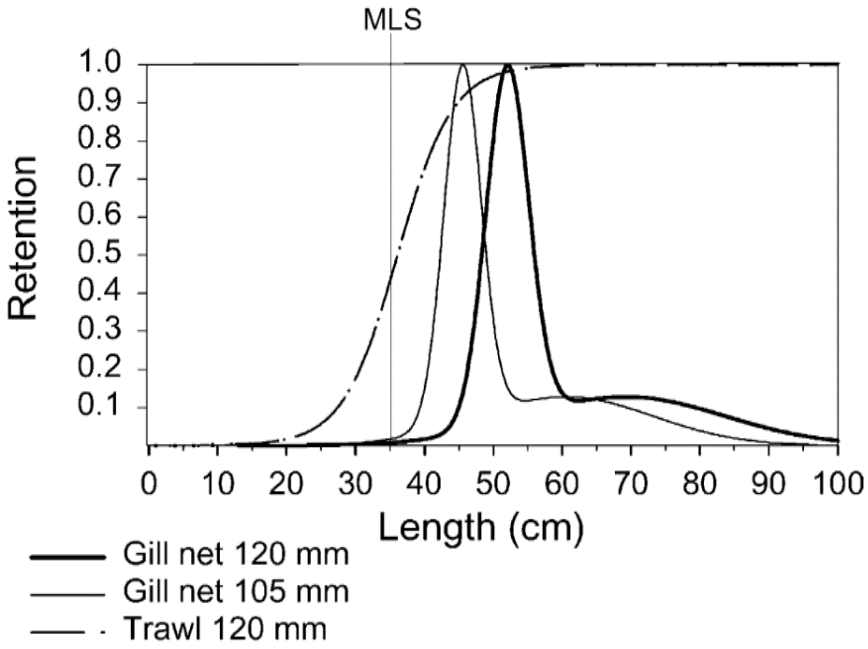

Figure 1: Examples of cod selectivity curves of two gillnets (mesh size 120 mm and 105 mm) and a trawl (mesh size 120mm). Gaussian Bell curve of both gillnets proves size selectivity of small and large fish (© HOLST *et al.* (2002), where Minimum Landing Size (MLS) was 35 cm).

It is important to protect small individuals since they have to be discarded if they were caught. But also larger or older individuals have to be protected because of their greater contribution to reproduction which is given due to "*…the higher fecundity and greater viability of eggs and larvae*" (MARTEINSDOTTIR & THORARINSSON, 1998).

1.2 The problem of bycatch

Despite the advantages, mentioned above, gillnets are criticized often because of the bycatch of marine mammals, especially harbor porpoise (*Phocoena phocoena* L.) (CASWELL *et al.*, 1998; COX *et al.*, 1998; HERR, 2009; KOSCHINSKI, 2001), and diving birds like the common eider (*Somateria mollissima* L.) (BELLEBAUM, 2011; SONNTAG *et al.*, 2012; ZYDELIS *et al.*, 2009).

1.2.1 Harbor porpoise

The harbor porpoise is the only cetacean species that occurs and reproduces in the Baltic Sea (AGUAYO, 1978). Morphometric studies found significant differences between animals of different parts of the Baltic Sea, indicating the existence of separate subpopulations (GALATIUS *et al.*, 2012; HUGGENBERGER *et al.*, 2002). However, other studies, such as an investigation by PALMÉ *et al.* (2004), did not find enough genetic differences to justify the separation of subpopulations in the Baltic Sea. Apart of this open debate, Baltic harbor porpoises are separated in two so-called management-units: a) Western Baltic and b) Baltic Proper (WIEMANN *et al.*, 2010).

Main reason for the separation, used by conservation agreements like ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas), is the considerable lower number of animals in the Baltic Proper. Regarding this group, no reliable data are available. More data are available for the western group: SVEEGAARD (2011) claimed a decrease of the harbor porpoise abundance in the Western Baltic from 27,767 in 1995 to 10,865 in 2005 and an increase to 18,495 individuals in 2012 (SVEEGAARD *et al.*, 2013). Nevertheless, these abundance estimates were not statistically different because of broad confidence intervals.

Beside natural factors like strong winters, also several human activities endanger harbor porpoises: a) pollution by chemicals, b) fishing of prey species, c) noise pollution (for example by boats, military maneuvers and offshore wind farms) and d) incidental bycatch by fishermen, especially in gillnets (KOSCHINSKI, 2001). The number of bycatches is uncertain. According to an estimation by KOSCHINSKI (2011), which used numbers of strandings and bycatches announced by fishermen, an annual number of at least 70 animal has to be assumed. However, the Jastarnia-Plan, a recovery plan for Baltic harbor porpoise, elaborated by a study group of ASCOBANS, demanded a decrease of bycatches to two individuals per year in the Baltic Proper and stated that a *"…maximum annual by-catch must be less than 1.7%..."* of the population size *"…to ensure a high probability of meeting the ASCOBANS objective*" (ASCOBANS, 2000). Aim of ASCOBANS is to keep or restore the population of the Baltic harbor porpoise to 80% of their carrying capacity (ASCOBANS, 2002; ASCOBANS, 2010).

The relative poor visual and acoustic visibility of the netting material for the eyes or the biosonar of whales (AU & JONES, 1991; DAWSON, 1991) is assumed to be one major cause for the entanglement of harbor porpoises in gillnets. Furthermore, the animals do not use their biosonar continuously to scan the water column (AKAMATSU *et al.*, 2007), but only in special cases like during foraging whereby the focus of the sonar beam is directed to the prey (KASTELEIN *et al.*, 1995), which is often on the seabed. Thus, harbor porpoises do not notice gillnets and can entangle in them. According to PFANDER & PFANDER (1997), particularly juvenile animals are affected. Possible explanations for this high bycatch rate of juveniles are that a) young harbor porpoises are more inquisitive than older individuals and want to explore their environment, b) young unexperienced animals do not react to echoes which signify potential danger and c) they have less precise control over their body movements, which can lead to swimming mistakes, when recognizing gillnets (KASTELEIN *et al.*, 1995).

1.2.2 Seabirds

In addition to the harbor porpoise, diving seabirds could entangle in gillnets if their foraging area overlaps with the fishing grounds (BELLEBAUM, 2011; SONNTAG *et al.*, 2012). In the Baltic Sea native birds and migrating birds, using the region as roosting place, are affected. According to ZYDELIS *et al.* (2009), the annual number of bird bycatches reaches up to 76.000 birds in the whole Baltic Sea, whereas the level of uncertainty is very high. Nevertheless, drowning in fishing nets was identified as one main cause of seabird mortality (MEISSNER *et al.*, 2001): along the Baltic coast of Poland in 1998–1999, drowning in gillnets accounted for up to 76.5% of beached marine birds.

1.3 Possible solutions to reduce bycatch

Several approaches are discussed to solve the problem of incidental bycatch of birds and mammals in the Baltic gillnet fishery (Figure 2). However, so far none of them is proved to be optimal and meaningful to be implemented immediately.

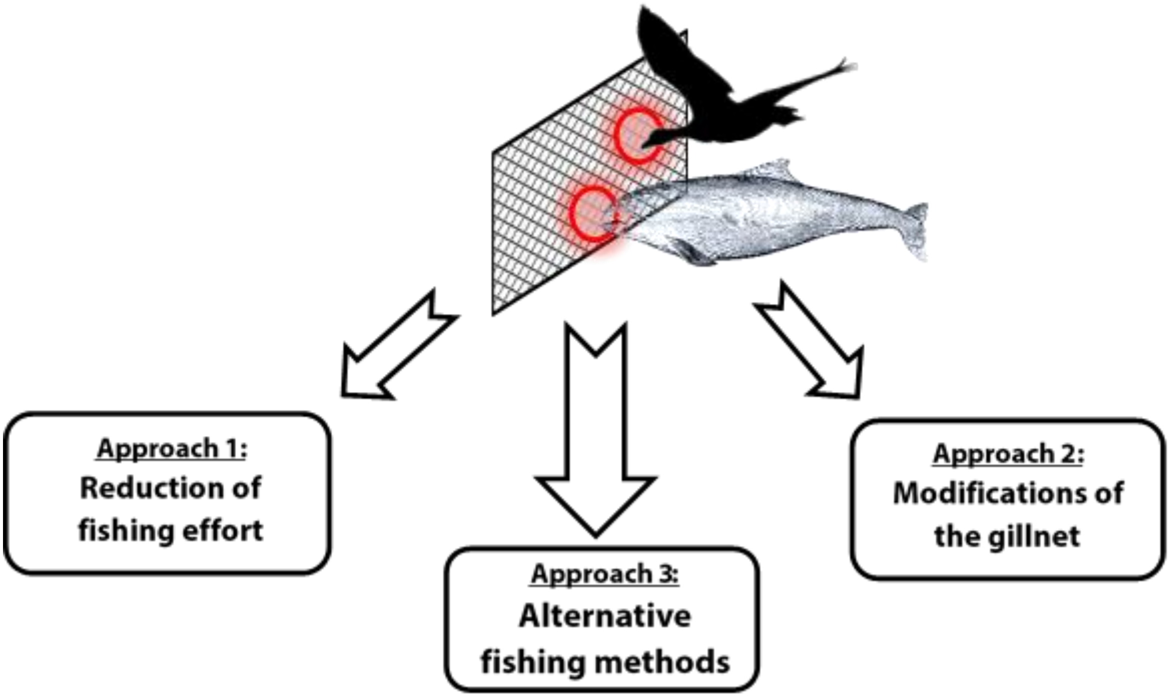

Figure 2: Classification of approaches to reduce bycatches of marine mammals and seabirds in passive fisheries.

1.3.1 Approach 1: Reduction of fishing effort

The Jastarnia-Plan calls for the reduction of fishing effort, for example by complete closures of special areas (e.g. Natura2000 areas) for determined periods or specific gears known to be associated with high porpoise bycatch such as gillnets (ASCOBANS, 2002). Another possibility could be to reduce the allowed length of gillnets per vessel.

All approaches that demand a reduction of fishing effort would lead to socioeconomic problems for fishermen and other people in the fishing industry because lower catches would have to be expected. Furthermore, fishing cutters and small fishing ports belong to the typical townscape of many coastal towns and attract many tourists. Thus, also other branches like the tourism would be affected if the fishermen and their vessels disappear and approaches which ensure their remaining have to be considered:

1.3.2 Approach 2: Modification of currently used fishing gear

A way to keep the cheap and efficient fishing with gillnets is to modify them. One passive method is to increase the visual and acoustic visibility of the netting for non-target species like harbor porpoises. MOONEY *et al.* (2002), TRIPPEL *et al.* (2003) and MOONEY *et al.* (2007) used a novel type of net material, including barium sulfate or iron oxide, to increase the ability of reflecting clicks of the biosonar. Since fish do not have a biosonar it was assumed that the catchability of fish would not be affected. During these investigations was observed that reflecting gillnets can be detected better by porpoises, but the net material is also stiffer than common material. However, MOONEY *et al.* (2007) assumed that this stiffness might also reduces the fish catches.

An active method is the usage of acoustic pingers. It is called active, because pingers are small electronic devices, which are attached to gillnets and actively emit a loud sound within the hearing sensitivity of harbor porpoises. This sound is intended to be unpleasant to porpoises, to keep them from entering the area of fishing or cause them to flee, if they are already there. As a result, harbor porpoises are actually excluded of areas where gillnets are set, but be retracted to areas which do not afford best conditions for the animals (CULIK *et al.*, 2001). Another problem can occur later through an effect called habituation (COX *et al.*, 2001). Habituation means that porpoises become accustomed to the sound and will not fear the noise anymore. It is even possible that the animals associate the sound with the presence of fish and become attracted by pingers. This effect is called dinner bell-effect (FRANSE, 2005)

To solve the problem of exclusion of harbor porpoises from their habitats by traditional pingers, so called PALs (“Porpoise ALarm”) were developed within a project, currently conducted by the Thuenen-Institute of Baltic Sea Fisheries (TI-OF). PALs are technical devices which use a “click-train” to induce harbor porpoise to be more careful. A “click-train” is a sequence of clicks, used by the animals to warn each other of danger. First results are promising and will be continued in autumn 2013 (pers. comm. Christian v. Dorrien, TI-OF).

MENTJES (2000) tried to reduce the bycatch of harbor porpoises and seabirds by the help of “shoo meshes” (big meshes in front of gillnets). The result of this investigation was a decrease of the fish catchability of about 70% at an increasing effort of handling the gear. During the investigation, no porpoise was caught.

One suggestion to reduce especially the bycatch of seabirds was the usage of opaque net material in the upper part of gillnets because this material is more visible than common netting. MELVIN & CONQUEST (1996) tested these meshes in different sizes and they actually caused lower bycatches of birds, but if the meshes had been too small, catches of fish would have been decreased as well.

Another idea is the reduction of the gillnet height to reduce the risk of entangling for non-target species. Since no investigations were conducted concerning these “lower gillnets” in the Baltic Sea, this modification should be tested within this study.

1.3.3 Approach 3: Alternative fishing gears

The third approach encompasses the implementation of alternative fishing gears that should:

a) be operational on common gillnet fishing vessels, which are mostly small;
b) supply economical catches;
c) be no danger for marine mammals and seabirds and
d) keep bycatch of unwanted fish low.

Fish pots

One alternative could be a baited fish pot, which is similar to a trap, *“...but a trap is different from a pot, in that it is equipped with one or two lead nets ending at a chamber, usually with two or more entrances of diminishing size mounted after each other. Also, traps are usually not baited.”* (FUREVIK, 1994)

Fish pots are assumed to be seabird- and sea mammal-safe fishing gears with low environmental interactions. Furthermore, they ensure a high quality of the catch because the fish are usually still alive when coming onboard. Associated with this higher quality is the advantage of a reduced dependence on weather. If gillnets cannot be hauled on one day due to bad weather, the quality of the catch could be quite poor (Figure 3a). Contrary, pots can be left in the water for several days with an unchanged good catch quality (Figure 3b). Thus, it could be possible to sell same amounts of fish at higher prices. This raise of the price could be supported by the information that this fish was caught in a sustainable way: According to a poll about certification of green products, 84% of those polled, would be willing to pay more for fish products that were caught in a sustainable way (DÖRING & WICHTMANN, 2007).

Several investigations considering fish pots were conducted in the Baltic Sea, especially by Swedish and German institutions, but their motivations differed. Main target of Swedish investigations (LJUNGBERG, 2007; OVEGÅRD, 2011) was to find a seal-proof fishing gear because the increasing number of seals along the Swedish coast leads to more and more damage of gears and catches in their gillnet fishery. German studies by LORENZ *et al.* (2009), HASSELMEIER *et al.* (2013) and smaller investigations of the TI-OF (pers. comm. Bernd Mieske, TI-OF) had the main aim to find a profitable fishing gear that is bird- and mammal-safe. One result of all pot investigations in the Baltic Sea was a low catch efficiency in relation to gillnets.

Figure 3: Comparison of different qualities of cod after a soak time of 24 hours captured in different gears. a) Gillnet. b) Fish pot.

Although there exist many types of fish pots, this study will focus on only two of them:
The first type (Figure 4c, Figure 7b), which was originally developed in Alaska for catching cod, was brought to Norway in 1975 (FUREVIK & LØKKEBORG, 1994) and refined by different experiments. This kind of fish pot was examination object of different investigations conducted in the Baltic Sea (HASSELMEIER *et al.*, 2013; LJUNGBERG, 2007; LORENZ *et al.*, 2009; OVEGÅRD, 2011).
The second type is a pot (Figure 4d, Figure 8a) which was developed in Newfoundland, where it is in general use (WALSH & SULLIVAN, 2010). Beside a larger size in relation to the Norwegian type, it is equipped with so called trigger mechanisms, which are implemented into each entrance (Figure 8b) to decrease the risk of escape through the entrance. This type of fish pot was not tested in the Baltic Sea yet, but the results of the Canadian studies have shown high catchabilities, even exceeding gillnet catches in some cases (WALSH & SULLIVAN, 2010).

Jigging machines

Jigging machines are automatic fishing gears, which were originally invented for squid fishing. Over time, those machines were modified and are in use for fishing cod and other species in several regions of the world. The machine moves the lures and sinker automatically according to a setup, set before.

According to STREHLOW *et al.* (2012), the recreational fishery accounted from 2005 to 2010 for an annual share of 34 - 70% of the commercial cod landings in the western Baltic Sea. This fact brings out that jigging machines, using similar lures as sport fishers, could be another alternative gear for the Baltic Cod Fishery. However, jigging machines were not tested in the Baltic Sea yet.

Apart from low environmental impacts of this fishing gear, the quality of the caught fish is quite high - every individual is alive.

1.4 Aim of this study

This study shall contribute to a reduction of the bycatch of seabirds and marine mammals of the passive fishery in the Baltic Sea. The focus was on the test of alternative fishing gears, especially a) modified lower gillnets, b) two types of fish pots and c) electronic jigging machines.

The gears were tested with several modifications to increase their efficiency and were compared to standard gillnets to enable an estimation of their efficiency in relation to the common gillnet. The results of this study shall provide a basis of data and knowledge for further discussions on use and improvement of alternative fishing gears and shall answer the question, if these gears could be potential alternatives to the common gillnet in the Baltic Sea.

2 Material and Methods

2.1 Equipment

Beside the standard gillnet, four alternative fishing gears were used in this study (Figure 4):

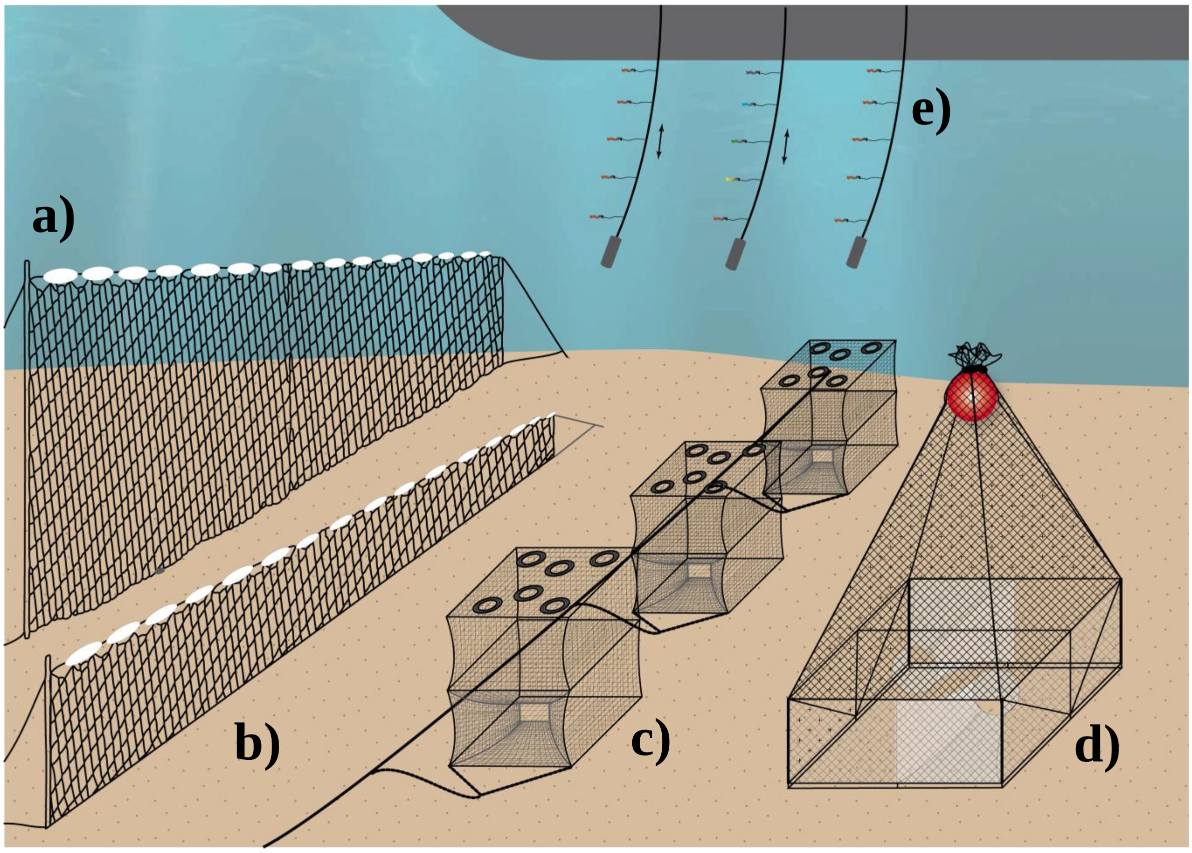

Figure 4: Overview of fishing gears used in this study (© TI-OF Annemarie Schütz). a) Standard gillnets. b) "Lower" gillnets c) Norwegian fish pots. d) Canadian fish pots. e) Jigging machines.

All gears, except the jigging machines, are gears, which are set on the bottom and have to be controlled after a certain period. In the meantime, the vessel does not have to be at the fishing ground. Contrary, the jigging machines are gears that force the vessel to be in the fishing area during the whole time of fishing operation.

2.1.1 Gillnets

A standard gillnet of single netting (SGN; Figure 5), which is used in commercial cod fishery, represented the reference gear in this study. In total, two gillnets, each of five panels (=one gillnet-fleet) with a length of 55 m and a height of 2.5 m were used. The netting material was orange and had a nominal mesh size of 110 mm.

Figure 5: Setting of a standard gillnet with a height of 2.5 m (© TI-OF Kerstin Schumann).

The second type of gillnet, used in this study, is reduced in height and not common in the commercial fishery of the Baltic Sea (lower gillnet, LGN; Figure 6). Except the height of only 0.4 m, all other specifications are equal to the standard gillnet. Two gillnet-fleets, each of five panels, were applied.

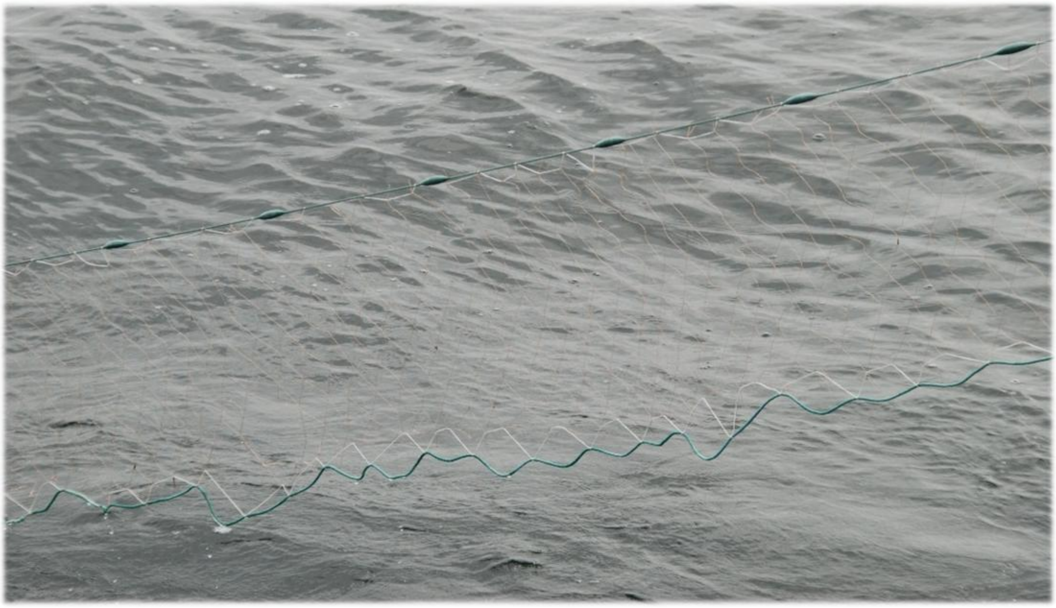

Figure 6: Setting of a lower gillnet with a height of 0.4 m (© Kim Detloff).

2.1.2 Norwegian Fish pots

Pots of the Norwegian type were manufactured by Norwegian Refa Frøystad group and had a mesh size of 50 mm (Figure 7a). The pots are collapsible (Figure 7b) and consist of two chambers. One pot is 150 cm long, 100 cm wide and 120 cm in height. It consists of two aluminum frames, which form the upper chamber and a steel frame at the bottom. The lower chamber has two facing entrances and a bait bag in its center, which is held by two plastic clips. Between both chambers, a single-ply net with a narrow opening is strained.

If a cod enters the pot through one of the entrances, it will be in the lower chamber. After the fish recognizes being trapped, its natural flight reaction is to swim upwards (pers. observation). Now it will pass the net between the chambers and come into the upper part of the pot, from where it is difficult to find a way out.

Both chambers have a zipper on the longer side to empty the pots and replace the bait bag. Further, each pot is equipped with eight floats (0.4 kg buoyancy) on the top to ensure the unfolding of the fish pots in the water. For anchoring the pot on a groundline, a holdfast (crowfoot) with a snap hook is added to the bottom frame of every pot. In total, 33 pots of this type were used.

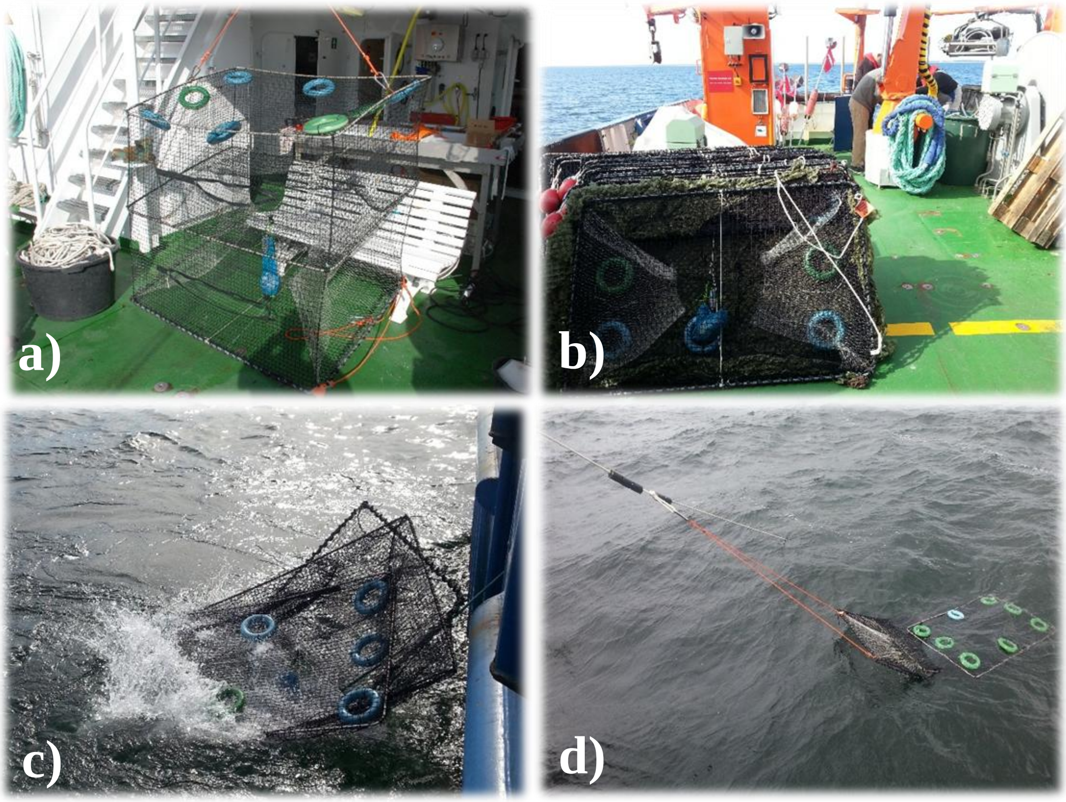

Figure 7: Norwegian fish pot. a) Folded on deck of the vessel. b) Unfolded (© Kim Detloff). c) Setting of one pot. d) Hauling of one pot.

2.1.3 Canadian fish pot

The second pot type (Figure 8a), that was used in this investigation, was built along the lines of a fish pot, developed in Codroy, Newfoundland (WALSH & SULLIVAN, 2010). It is a collapsible type, consisting of two bottom frames and three frames which can be putted up to establish the catch chamber. All frames are made of steel. When unfolded, the Canadian pot is 2 m long, 2 m wide and approximately 1 m in height. Furthermore, the net material (mesh size 100 mm), covering the frame, builds up “a tent” of approximately 3 m in height. A float is added to the top of this tent to keep it up. This type possesses also two entrances, but - contrary to the Norwegian type - they are staggered and contain a trigger-mechanism (Figure 8b) to prevent the escapement of caught fish.

Figure 8: Canadian fish pot. a) Hauling of a pot. b) Trigger mechanism which is implemented in each entrance to avoid escapes.

2.1.4 Jigging machines

The jigging machine BJ5000 is a product of the Swedish "Belitronic" company (Figure 9).

The gear is fixed to the railing of the vessel with a stand pole. Here, a box including all electronic units and a wheel for storing the line is mounted. A pole with pulley, which is added to the upper part of the machine, works as outrigger and guides the line from the wheel into the water. At the end of the line, different lures and sinkers can be added. For moving the lures automatically, the machine offers different programs. The program, which was used in this study is called "Bottom Fishing Program" (Figure 10), meaning that the lures are lowered until the sinker reaches the sea ground. Then the lures are pulled up to a given depth above the seabed and be jigged for a defined time until the seabed is found again. In this way, it is ensured that the lures are near to the seabed, for example if the vessel drifts into deeper areas.

In this study, three jigging machines BJ5000 were used.

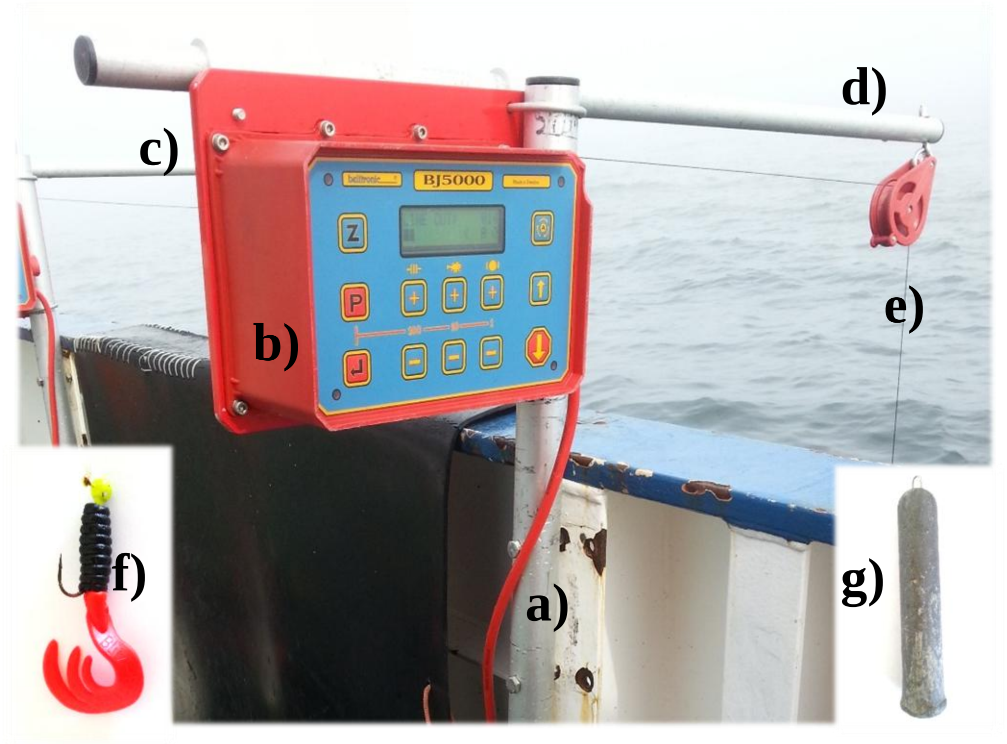

Figure 9: Jigging machine Belitronic "BJ5000". a) Stand pole. b) Control unit. c) Wheel (behind control unit, not seen in this picture). d) Pole with pulley (outrigger). e) Line. f) Main lure: Red-black twister. g) Sinker (1 kg).

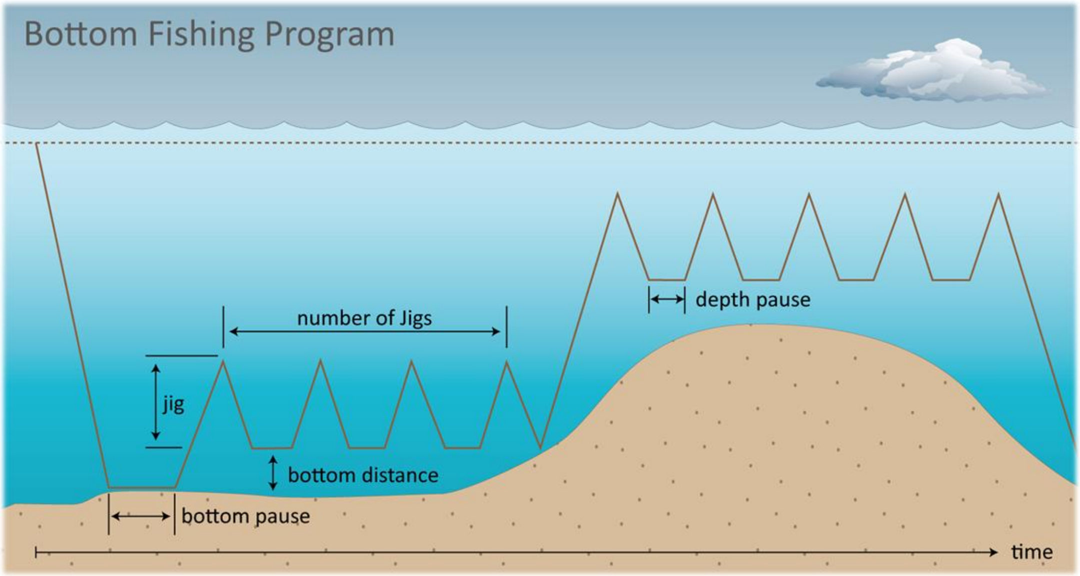

Figure 10: Schematic presentation of the „Bottom Fishing Program" after Manual "Belitronic BJ5000" (© TI-OF Annemarie Schütz).

2.2 Experimental setup

2.2.1 Gillnets

The static gears (for an overview see Figure 11) required an area of approximately 1500 m x 500 m, whereby the central part was represented by four gillnets. Each gillnet consisted of five panels, henceforth referred to as "lots". Two of those four lots consisted of standard gillnets (lot 1 and lot 3). Both other lots consisted of lower gillnets (lot 2 and lot 4). Referring to Figure 11, the outer lots (lot 1 and lot 4) were not flanked by fish pots, while lot 2 and lot 3 were flanked. Thus, lot 2 and lot 3 are potentially affected by pots, but lot 1 and lot 4 are unaffected. For clarity, each lot is described shortly:

- lot 1: standard gillnet, unaffected by pots
- lot 2: lower gillnet, potentially affected by pots
- lot 3: standard gillnet, potentially affected by pots
- lot 4: lower gillnet, unaffected by pots

Every panel of a lot and every lot was linked, resulting in a total gillnet length of about 1100 m. Both ends were anchored to the seabed with a grappling-hook and marked with a flag at the surface. An additional flag was attached to the line between lot 2 and lot 3.

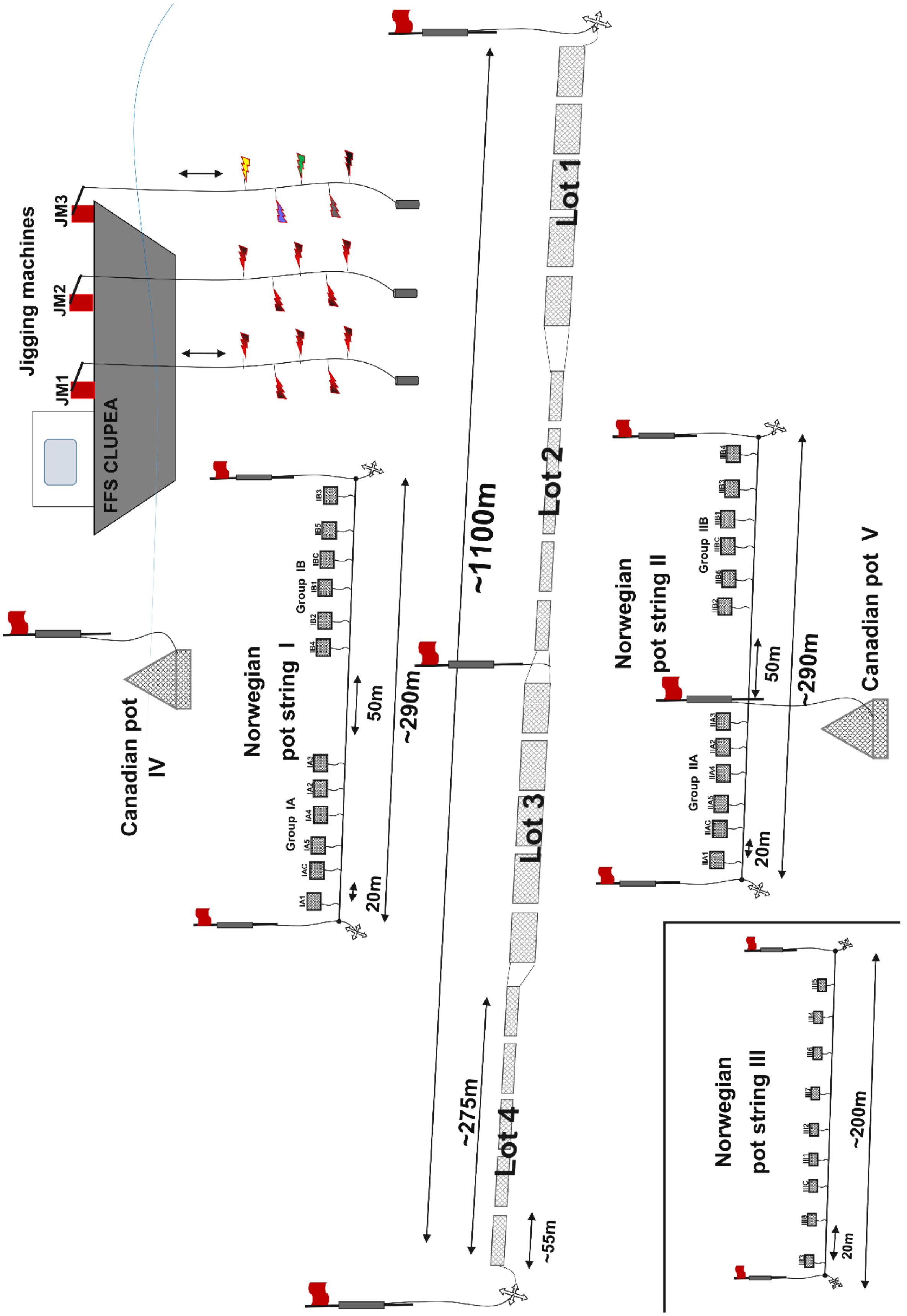

Figure 11: Experimental setup 270th cruise - part "passive fishery" of FRV Clupea from May to June 2013. String III of the Norwegian fish pots was set in more distance to gillnets than string I and II. Canadian fish pots were added to setup on 6th of June 2013.

2.2.2 Norwegian Fish Pots

The fish pots were set as two strings, twelve pots each, on both sides of the gillnets (string I and string II). An additional string of nine pots (string III) was set in more distance to the gillnets (Figure 11). This string acted as a reference for the other strings (because it was not affected by gillnets) and to test special modifications (Table 2). At the beginning of the study, two different approaches for the experimental setup of string I and string II existed, based on statistical considerations. The first setup consisted of six modified pots, each tested against an empty pot. This pairwise setup would allow more powerful statistics, but requires a certain quantity of caught fish. The second setup comprised of two groups per string, each with five modifications and one empty pot. This group-setup would be more able to work with many zero catches. After analyzing the first data (catch until 20/04/2013), the setup with the better approach (second setup) was selected for both strings.

Each pot was hooked with a snap hook into loops of a nylon rope in a distance of 20 m between the pots and 50 m between the pairs/groups. The loops were equipped with 5 kg of leaden weights to hold the pots in position. Furthermore, both ends were anchored with a grappling-hook in a distance of 20 m to the pots and marked with a flag at the surface (Figure 11). String I had a length of 290 m, string II had a length of 410 m (pairwise setup; 15/03/ - 20/04/2013) or 290 m like string I (group setup; 02/05/ – 23/06/2013) and string III was 200 m long.

To identify the pots, every pot was provided with a code, describing its modification. The position of the pots in their group/string was randomly alternated every day to avoid effects of the string position.

In total, eight types of modified fish pots (Table 2) were tested during this study.

Table 2: Pot modifications and corresponding codes. (I/II/III: string; A/B: group; 1/2/3/4/5/6/7/8/C: ID of pot modification; T/C: Test/Control).

ID	Modification					15/03/ - 20/04/2013				02/05/ - 23/06/2013				
	Light	Herring	Boilie	Entrance	Camouflage	StringI		StringII	StringIII	StringI		StringII		StringIII
C						IAC	IBC	II1C,II2C,II3C II4C,II5C,II6C	IIIC	IAC	IBC	IIAC	IIBC	IIIC
1	X					IA1	IB1	II1T	III1	IA1	IB1	IIA1	IIB1	III1 (+floats)
2		X				IA2	IB2	II2T	III2	IA2	IB2	IIA2	IIB2	III2 (+floats)
3			X			IA3	IB3	II3T	III3	IA3	IB3	IIA3	IIB3	III3 (+floats)
4	X	X				IA4	IB4	II4T	III4	IA4	IB4	IIA4	IIB4	III4 (+floats)
5	X	X		X		IA5	IB5	II5T	III5	IA5	IB5	IIA5	IIB5	III5 (+floats)
6	X		X			-	-	II6T	III6	-	-	-	-	III6 (+floats)
7	X		X	X		-	-	-	III7	-	-	-	-	III7 (+floats)
8	X	X		X	X	-	-	-	III8	-	-	-	-	III8

Light

Fish seek areas where the chance to find and catch food is high. Since light attracts the prey species, it is also likely that fish swim to the light. For this study, a fishing light of the Korean YM Fishing Corporation (type YML-1000; Figure 12) was attached to the center of the lower pot chamber.

Figure 12: Fishing light type YML-1000 (YM Fishing Corporation) used in fish pots.

Herring

Previous investigations showed that herring is a bait which is suitable to catch cod (FUREVIK & LØKKEBORG, 1994). More recent investigations, conducted in the Baltic Sea, found herring to be even the best bait (LJUNGBERG, 2007; LORENZ *et al.*, 2009). This is not a surprising result because herring is one of the main prey species of cod. In this study, the bait bag of herring baited pots contained two herrings (ca. 300 g), which were cut into four pieces to enhance odor release. The bait was kept frozen until it was about to be used.

Boilie

Boilies are small dough balls (Figure 13), actually developed as baits for recreational carp fishing. Today, they are also available with flavorings, which potentially attract cod, such as mussel, fish or crab flavor. The advantage of boilies is that they are produced industrially and therefore are available all year. The bait bag of boilie baited pots contained nine boilies (~50 g).

Figure 13: Nine boilies of flavor „Monsterfish“ produced by Starbaits company.

Entrance

Another option to influence the catch efficiency of pots, already noted by FUREVIK & LØKKEBORG (1994), is the shape of the entrance. Two modifications were tested in this study: a) replacing the white line, which keeps the entrance open, by a transparent monofilamentous fishing line to reduce its visibility (Figure 14a) and b) adding a fluorescent line to make the entrance more visible (Figure 14b). The second idea was suggested because some fishermen assumed that the fish are not able to find the entrance.

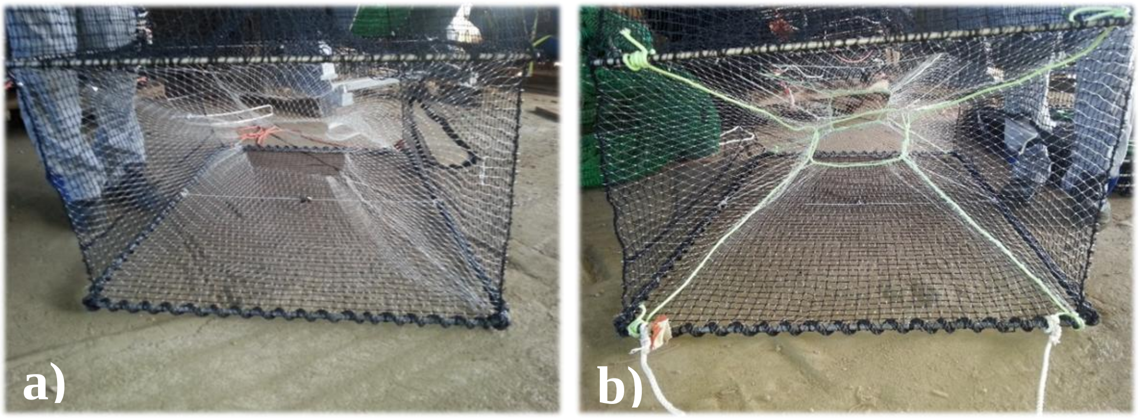

Figure 14: Different modifications of the entrance by use of a) a fishing line to reduce its visibility or b) a fluorescent line to increase visibility of the entrance.

Camouflage netting

All fish have a behavior that may be explained as “reef-effect” (LJUNGBERG, 2007), meaning they seek protection in structured environment (GOTCEITAS & BROWN, 1993; GREGORY & ANDERSON, 1997). Therefore, a textile camouflage netting (Figure 15a) was applied to imitate a natural structure, such as rock caves and algae, to attract fish. With exception of the bottom and the entrances, the complete pot was covered by camouflage netting (Figure 15b).

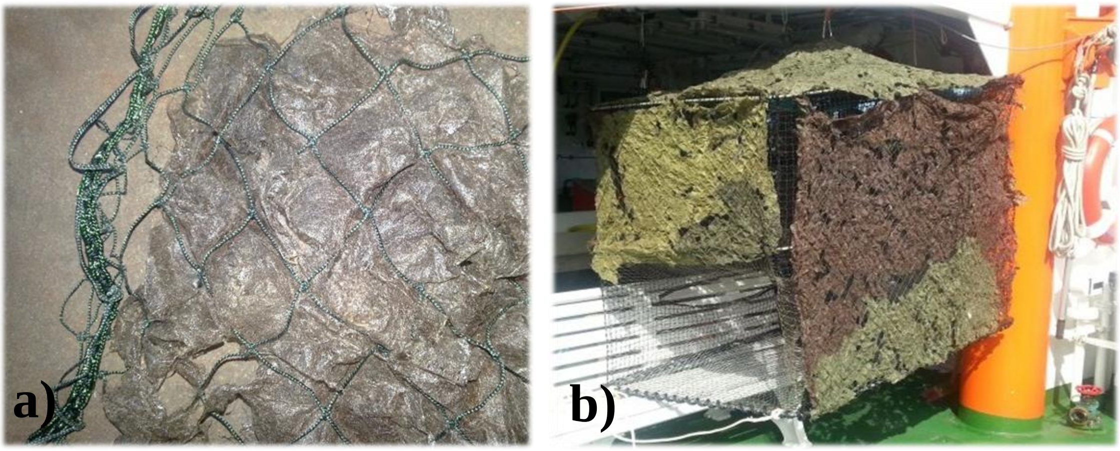

Figure 15: Camouflage netting, used as one modification of fish pots. a) Close-up of textile material. b) Pot III 8 covered with camouflage netting.

Additional Buoyancy

The last modification, tested in this study, is the application of additional floats to make pots hover off the bottom (Figure 16). This pot modification was also used during an Norwegian investigation to reduce the bycatch of king crab (*Paralithodes camtschaticus* L.) in fish pots (FUREVIK *et al.*, 2008). Among an elimination of the crab bycatch, a significant increase of the cod catches was observed. For that reason, six pots of string III (pots III1-III7 in Table 2) were equipped with four additional floats (0.78 kg buoyancy) and tested between the 24th of May and the 23rd of June.

Figure 16: Two additional floats (0.78 kg buoyancy), which were attached to the upper frames on both sides of a fish pot between 24th of May and 23rd of June to float them off the bottom.

2.2.3 Canadian Fish Pots

From the 6th of June until the 23rd of June, two fish pots of the Canadian type were tested. These pots were placed solitary outside of pot string I and pot string II.

Due to their larger volume, each of the Canadian pots was baited with two bait bags (also used in Norwegian pots). Each bag was filled with about 500 g of cut herring.

Due to their weight of ca. 60 kg, an additional use of anchors was not necessary and only a line to a marking flag at the surface was mounted to each pot.

2.2.4 Jigging Machines

Three jigging machines were mounted to different sides of the vessel to minimize the risk of raveling. Different setups were used for each jigging machine (Table 3):

Table 3: Experimental setup used for jigging machines. (JM: jigging machine). For explanation of Bottom Fishing Program see chapter 2.1 and Figure 10.

JM	Setup		Location on vessel
	Bottom Fishing Program	Lures	
1	Yes	Red-black Twister	Starboard
2	No	Red-black Twister	Backboard
3	Yes	Various	Astern

The choice of red-black Twisters (made by different companies, Figure 9f) (jigging machine 1 and jigging machine 2) originated from a small experimental fishing, conducted prior to this study in December 2012, where this type of lure was the most efficient one (pers. observation). Jigging machine 2 fished directly above the bottom, but without moving the lures, to investigate, if it is possible to catch similar amounts of fish by lures which are moved only by the movement of the vessel, caused by waves.

Jigging machine 3 was equipped with different lures (Figure 17) to investigate the catch efficiency of other lure shapes and lure colors (Figure 9f).

Fishing with jigging machines took place primarily as close as possible to the static gears (Figure 11, Figure 18) to keep relationship to the pots and gillnets, but also in deeper areas in proximity of wrecks or other structures. Furthermore, areas were visited, where sport fishing boats or vessels that offer fishing trips fished because their captains knows the local waters and potential hot spots of fish best.

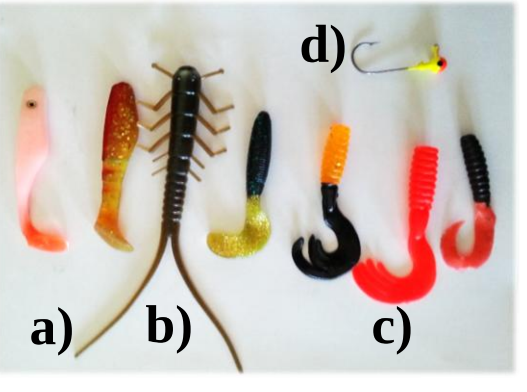

Figure 17: Selection of lures used on jigging machine 3. a) Shads. b) Hellgie. c) Twisters. d) Jighead to mount soft lures to hook and line. It was not possible to take a photo of an also used Cod fly, because it was lost during the study.

2.3 Data collection

The study was conducted during the 270th cruise of the FRV "Clupea" (28.8 m LOA, 478 kW, stern trawler; Figure 18) between the 14th of March and the 23rd of June 2013 in the waters around Rügen (ICES SD 24)

The soak time of pots ranged from one to seven days (Norwegian type) and one to eleven days (Canadian type), dependent on weather condition and available vessel time. The soak time of gillnets was typically one day, whereas all gears were set for two days on the 20th of June 2013. The haul duration of the jigging machines ranged from 9 minutes to 3.54 hours, whereby up to four hauls were conducted per day. An overview about temporal activation of all fishing gears can be seen in Table 5.

Every day of the study started with heaving and setting the static fishing gears. The remaining day was used to test the jigging machines.

The experiments took place in areas with structured grounds (stones, wrecks, etc.) and a suitable depth from 11.0 m to 17.3 m regarding pots and gillnets or from 12.7 m to 34.9 m regarding jigging machines.

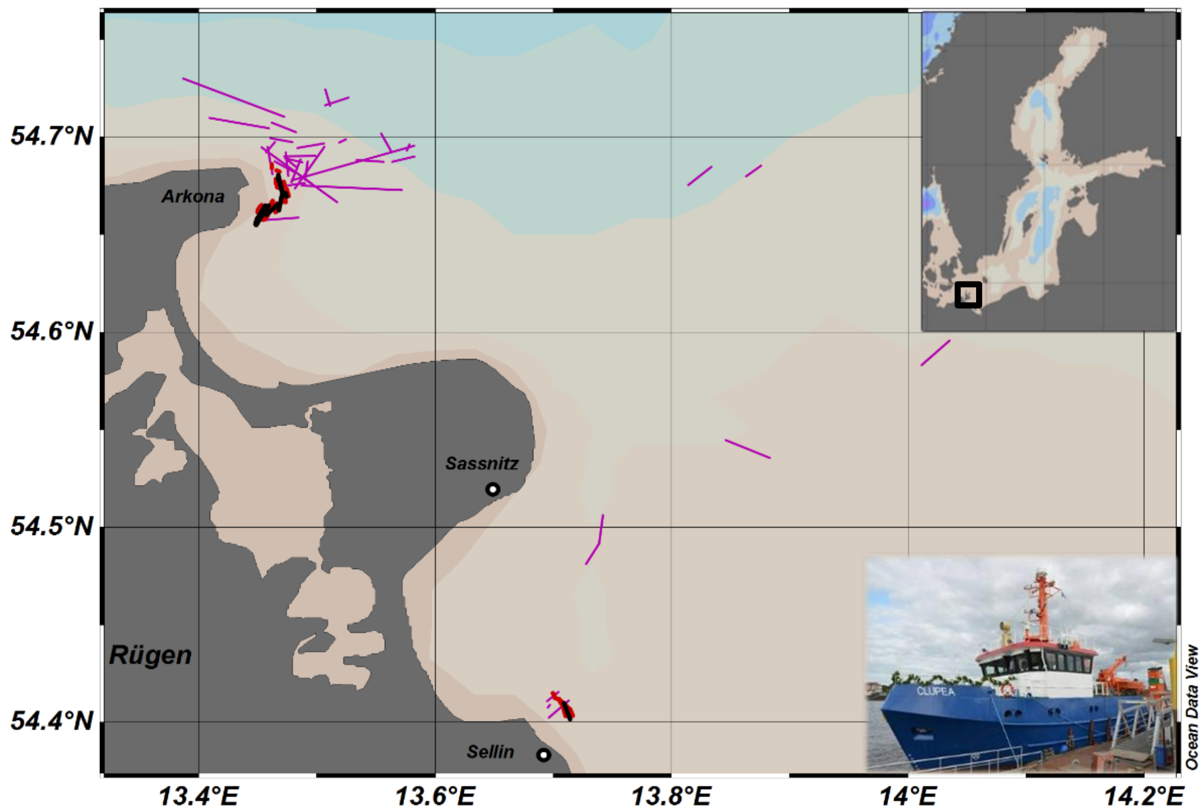

Figure 18: Study area to test passive fishing gears during 270th cruise of FRV Clupea (red lines: pot strings, black lines: gillnets, purple lines: drift tracks during fishing with jigging machines).

Several parameters were recorded by the internal data recording tool (DATADIS) in an interval of 10 s. These data included vessel position, depth, temperature of sea surface (ranging from 0.4 °C to 16.6 °C) and meteorological data like air temperature, wind direction and wind speed. Additional hydrographic parameters were obtained using a CTD (conductivity, temperature, depth) water sampler (Figure 19). Every day, a profile of different factors (e.g. temperature, oxygen, salinity) was created for the area of the static gears and for each haul of the jigging machines.

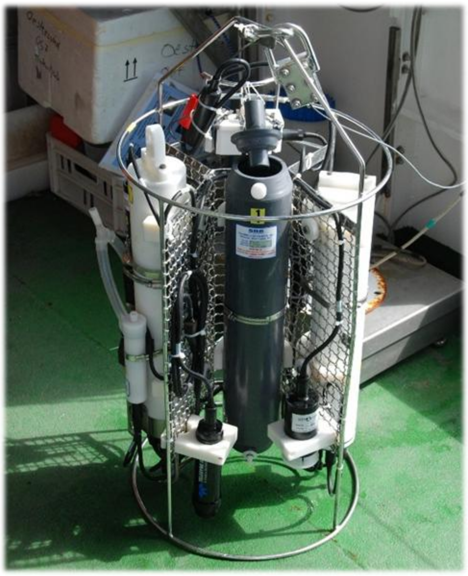

Figure 19: CTD (conductivity, temperature, depth) water sampler to obtain several hydrographical data (© Kim Detloff).

The fish, caught by the respective gears, were measured on centimeter below and the total weight per species per lot of gillnet or pot was determined. Furthermore, the individual weight of cod was measured to the nearest gram using a sea stabilized scale.

From the 6th to the 7th and from the 20th to the 22th of June, one Canadian pot and one Norwegian pot (No. III6) were equipped with a camera (GoPro Hero 3) to investigate the behavior of fish in relation to the fish pots.

2.4 Data analysis and statistics

Since this study considers several modifications of alternative gears, as well as efficiencies of alternatives versus standard gillnets, the analysis of each gear will be divided into two parts: a) assessing each gear and its settings and b) comparing the alternative gears to standard gillnets. Since the analyses have different requirements, it was necessary to choose different subsets of the haul data for different analyses. The requirements and number of valid hauls are mentioned at the respective parts.

All analyses and statistical tests were done with Excel 2013 or the statistical computer software R (R DEVELOPMENT CORE TEAM, 2012).

All comparisons of means were done using a Mann Whitney U-test (MANN & WHITNEY, 1947). This non-parametric test was chosen because the data were not normally distributed and thus, did not meet the requirements of parametric tests.

The Canadian pots did only get a little consideration because they were added later to the setup and no fish were caught.

2.4.1 Assessment of gear settings

This part of analysis will consider each gear itself by considering the catch generally and by considering the tested modifications, such as different baits in fish pots or different lures on jigging machines. Aim of this part is to get an overview of the catch and to find the best modification of the alternative fishing gears.

First, a descriptive analysis of weight and length was conducted for each gear, except the Canadian fish pots since they did not catch any fish. An additional comparison of fish above MLS (Minimum Landing Size) and fish below MLS was done for cod and flounder.

For further analyses, it was necessary to test, if different static gears affect among each other (standard gillnets versus fish pots, lower gillnets versus fish pots and vice versa). One case could be, if fish swim through the fishing area and change their swimming direction because they were attracted by the fish pots. Actually, the fish would have been caught by gillnets, but due to the change of the swimming direction, the encounter with the gillnets would be prevented. The other case would be that a fish is attracted by a fish pot (e.g. by odor or light) and wants to swim towards it but on the way the gillnets were set and it can entangle.

If there exist interactions, the following analyses would have to regard the different parts of the gears individually, meaning lot 3 (standard gillnet, potentially affected by pots), lot 2 (lower gillnet, potentially affected by pots) and string I and string II would have to be treated different to their unaffected counterparts (lot1 1, lot 4 or string III, see Figure 11).

To test the effect of fish pots on the catch efficiency of gillnets, the particular parts of gillnet were compared:

- Lot 1 as “standard gillnet, unaffected by pots” versus lot 3 as “standard gillnet, potentially affected by fish pots” and
- Lot 4 as “lower gillnet, unaffected by pots” versus lot 2 as “lower gillnet, potentially affected by fish pots”.

To test, whether gillnets influence the catchability of fish pots, the mean catches of pots in string I and string II were compared to the catches of their equivalents in string III.

The next step of this analytical part was to identify the best modification and to figure out the expected catch per pot. This was done by a modeling approach. In a modeling approach, different distributions are tested to describe the data. When one type of model is chosen as the model, which describes the data best, it is possible to compute predicted means or probabilities. One option could be the standard linear model, but if certain prior assumptions, like a normal distribution of the errors or an equal variance are not met by the data, the application of this model would lead to systematical errors. Furthermore, standard linear models have no restriction of zero values.

Count data, such as the number of caught individuals per pot and day, are usually modeled with a model, belonging to the family of generalized linear models (GLMs). GLMs also assume a linear relationship between predictors and responses, but, in contrast to standard linear models, the estimation of predictors via maximum likelihood is not done directly, but using an algorithm known as Iteratively Weighted Least Squares (IWLS) (MAC CULLAGH & NELDER, 1989).

The most common model of this family is the Poisson regression model, where the variance = Φ * mean. Φ is the so called scale parameter, describing the spread of the distribution and it is assumed that the mean is equal to the variance ($\Phi = 1$). However, if the response variable exceeds the mean ($\Phi > 1$), a special case occurred, which is called overdispersion.

The problem of overdispersion can be faced with a) so called quasi-Poisson models by relaxing the assumption of $\Phi = 1$ or with a more formal way b) by assuming different variance structures available in other likelihoods such as the negative binomial with an additional shape parameter

Θ or the geometric distribution, a special case of the negative binomial, assuming that the shape parameter is equal to one (Θ = 1).

Another problem might be the occurrence of more zero values than would be allowed by the Poisson, the negative binomial or the geometric model. To counteract this problem, a second part had to be added to the model which describes zero counts. One model that adds a component like this, is the so called zero-inflated model (LAMBERT, 1992), which splits the zero values up to "true zeros" and "excess zeros".

Another way of modeling many zero counts is a so called two-part (HEILBRON, 1994) or hurdle model (MULLAHY, 1986). This type of count model combines a count data model f_{count}, describing all positive values and a zero hurdle model f_{zero} which is employed for zero versus positive values (Equation 1). Thus, the hurdle model consists of two components.

$$\log(\mu_i) = x_i^{\top}\beta + \log(1-f_{zero}(0;z_i;\gamma)) - \log\left(1 - f_{count}(0;x_{i,}\beta)\right) \qquad \text{(Equation 1)}$$

The advantage of this model is, that both components can use different family distributions (Table 4) and the model parameters β and γ are estimated separately.

For further information to count models see ZEILEIS *et al.* (2008).

Table 4: Possible distributions to use in hurdle model.

Distributions of positive values	Distribution of zero values
Poisson Negative Binomial Geometric	Binomial Poisson Negative Binomial Geometric

The choice of the model, which describes the data best, was done by considering the AIC (Akaike information criterion)-value (AKAIKE, 1973). The AIC is a quality criterion, which balances the number of parameters and fits it to the log likelihood of the data. A small AIC-value indicates a better description of the data. Thus, the model with the lowest AIC has to be chosen.

The next step was to make inferences of the predicted values by using bootstrap confidence intervals. Since the experiment was based on a multistage sampling design, where the experimental unit (fish) is nested in different upper experimental units (pots, groups, strings

and hauls), the standard inference cannot be used here. This fact of nested samples is called pseudoreplication (HURLBERT, 1984). Pseudoreplication is widely discussed by LAZIC (2010), but briefly it means that there are more degrees of freedom than there actually are.
To avoid the problem of pseudoreplication, a non-parametric block bootstrapping was used. Bootstrap in general is a type of Monte Carlo resampling methods (EFRON & TIBSHIRANI, 1993), but the block bootstrap is a method especially designed for clustered data. This special feature fitted with the data herein analysed. Assuming correlation within clusters of same level and independence between them, the block bootstrap performs a nested resampling scheme with replacement as shown in the next steps:

1. Based on the observed hauls (representing the first block), $H = (h_1, \ldots, h_n)$, a random sample $H^{*b} = \left(h_1^{*b}, \ldots, h_n^{*b}\right)$ was artificially simulated by resampling with replacement. In other words, after the extraction of an element, this is replaced in the original sample so that it can be chosen again.
2. For each $h_i^{*b}, i = (1, \ldots, n)$, a random sample of string as second block, $S = (S_1, S_2))$, was taken with replacement $S^{**b} = \left(S_1^{**b}, S_2^{**b}\right)$.
3. The resampling technique is subsequently used for group as third block within string within haul as in previous steps, giving $G^{***b} = \left(G_1^{***b}, G_2^{***b}\right)$.
4. Step 1 to 3 were repeated for a large number of times (B=3000), giving B different sets of data to simulate the natural variability of the data.
5. The model, described in the previous section, was used on each of the $b = (1, \ldots, B)$ datasets obtained using the steps 1-4. The predicted catch abundance $\hat{\mu}^{***b} = X^T \beta^{***b}$ was extracted from the model, giving $\widehat{\mu}^{***1}, \ldots, \hat{\mu}^{***B}$.

Now the bootstrap percentile confidence intervals for the predicted abundance per pot were produced by following the next steps:

1. For each pot $p \in \{C, 1,2,3,4,5\}$ the previous resampling scheme yielded the vector of predictions $X^P {\beta_p}^{***1}, \ldots, X^P {\beta_p}^{***B}$.
2. The distribution of the asymptotic prediction $X^P \beta_p$ was approximated by an histogram obtained on the basis of $X^P {\beta_p}^{***1}, \ldots, X^P {\beta_p}^{***B}$.

3. Finally, the confidence intervals were constructed by using the ∝-percentiles of the histogram from step 2 ($X^P\beta_{p(1/\propto)}{}^{***}, X^P\beta_{p(1-1/\propto)}{}^{***}$), where ∝ was previously set to 0.005., giving the 95% confidence intervals.

In addition to effects of modifications on the catch efficiency, influences of the additional parameters “seasonal trend” and “soak time” were investigated.

The analysis of the jigging machine catch efficiency was conducted as comparisons of different machine setups (Table 3) and of different lures, used on jigging machine 3.

2.4.2 Comparison of alternative gears and standard gillnets

The second part of the analysis had the aim to compare catch efficiencies of the alternative gears to the standard gillnet. To compare different gears, the catches of each gear had to be standardized. In this study, the standardization of the different gears was done by the time to handle the gear, which is one type of the so called catch per unit effort (CPUE).

The CPUE comparisons were limited by the number of valid hauls, when both gears were in use at the same time. Days considered as valid hauls, are noted in each part of the statistical analysis.

At first, lower gillnets were compared to standard gillnets. Since both types of gillnets were handled almost equally, the total catch amount of lot 1 and 3 were compared to the total amount of lot 2 and 4 without any standardizations.

The second aim of this part to compare pots and the standard gillnet, was more complex. For doing this, the predicted number of individuals per pot and day of the best modification was extrapolated to a quantity of ten pots. The reason for choosing ten pots was that the time to handle five gillnet panels (= one lot) matches with the time to handle ten pots. This value represents the CPUE and was compared to the mean catch of one standard gillnet lot with the same fishing duration.

For comparing jigging machines and standard gillnets, the catch of the three jigging machine was converted to catch per hour. The resulting value was compared to the catch of one standard gillnet lot because it took about one hour to haul one lot, clean it and set it out again.

3 Results

3.1 Total catch

In total, 616.7 kg of fish were caught during in this study. More than half of all fish were caught by standard gillnets (332.6 kg), followed by Norwegian fish pots (175.2 kg), lower gillnets (63.1 kg) and jigging machines (45.9 kg). All gears showed varying catches during time of the study, whereby most fish were caught from the end of April until the beginning of May. The Canadian pots caught no fish (Table 5).

The total catch was composed of 16 species. Thereby, different species were caught solely by specific gears (Table 6). Dab (*Limanda* L.) and saithe (*Pollachius virens* L.), for example, were caught only by gillnets and species like eelpout (*Zoarces viviparus* L.) or hooknoose (*Agonus cataphractus* L.) only by fish pots. Species like herring (*Clupea harengus* L.*),* plaice (*Pleuronectes platesa* L.*)* and turbot (*Psetta maxima* L.) were caught by gillnet and pots and whiting (*Merlangius merlangus* L.) were caught by gillnet and jigging machine. Cod (*Gadus morhua* L.), flounder (*Platichthys flesus* L.) and shorthorn sculpin (*Myoxocephalus scorpius* L.) were caught by all gears. Thus, the number of species found in different gears differed: eleven in standard gillnets, seven in lower gillnets, twelve in fish pots and four by jigging machines.

Cod represented the main part of the total catch with a total weight of 404.7 kg (65.6% of total catch; Table 7) and was the dominant species in all gears, representing 50% or more of total catch of each gear (Figure 20). The second most common species was flounder with 103.2 kg (16.73% of total catch, Table 7).

Table 5: Catch composition [kg], separated by day and gear. Colored cells show the use of each gear. Catch is shown at haul day (SGN: standard gillnet; LGN: lower gillnet; CP_{nor}: Norwegian pot; CP_{can}: Canadian pot; JM: jigging machine).

	Static gears										JMs							
Date	Depth [m]	Temp [° C]	SGN	LGN	CP_{nor}I	CP_{nor}II	CP_{nor}III	CP_{can}1	CP_{can}2	Total static gears	Depth [m]	Temp [° C]	Duration [h]	JM1	JM2	JM3	Total JM	Total catch
15/03/2013											13.8 - 25.1	1.0	4.99	0	0	0.2	0.2	0.2
16/03/2013	16.5	1.0	4.3		0.3	0.5				5.1	23.0 - 28.4	1.2	3.47	0	0	0	0	5.1
17/03/2013																		
18/03/2013																		
19/03/2013																		
20/03/2013																		
21/03/2013																		
22/03/2013																		
23/03/2013																		
24/03/2013											14.1 - 19.4	0.4	3.27	0	0	0	0	0
25/03/2013																		
26/03/2013																		
27/03/2013																		
28/03/2013																		
29/03/2013																		
30/03/2013																		
31/03/2013																		
01/04/2013																		
02/04/2013																		
03/04/2013																		
04/04/2013																		
05/04/2013																		
06/04/2013											12.7 - 31.7	1.3	2.76	0	0	0.3	0.3	0.3
07/04/2013	13.7	1.6	7.6	2.2	2.7	2.0	1.7			16.2								16.2
08/04/2013																		
09/04/2013																		
10/04/2013											NA	1.3	1.28	0	0	0	0	0
11/04/2013	11.0	1.9			4.2	4.7	1.3			10.2								10.2
12/04/2013																		
13/04/2013																		
14/04/2013																		
15/04/2013																		
16/04/2013																		
17/04/2013																		
18/04/2013	12.5	2.2			6.3	3.5	2.2			12.0	15.6 - 23.7	2.1	2.50	0.3	0	0	0.3	12.3
19/04/2013	16.6	3.5	50.5	7.0	1.7	1.1	2.5			62.8	21.9 - 24.6	2.7	3.05	0.3	0	0.8	1.1	63.9
20/04/2013	13.9	3.3	38.0	8.5	0.3	0.3	1.0			48.1	25.1 - 26.9	2.8	2.94	0	0	0	0	48.1
21/04/2013											20.8 - 22.3	2.1	2.56	0	0	0	0	0
22/04/2013																		
23/04/2013																		
24/04/2013																		
25/04/2013																		
26/04/2013																		
27/04/2013																		
28/04/2013																		
29/04/2013																		
30/04/2013																		
01/05/2013																		
02/05/2013											25.5 - 34.7	3.0	4.94	3.7	0.9	4.8	9.4	9.4
03/05/2013	15.4	4.2	45.3	9.9		10.3	7.6			73.1	24.1 - 19.8	4.6	2.97	3.2	5.9	1.0	10.1	83.2
04/05/2013	15.4	3.9	17.9	1.0	22.9	8.6	3.5			53.9	21.6 - 22.9	4.6	1.26	0	1.2	1.7	2.9	56.8
05/05/2013	14.3	3.8	16.3	6.0	4.5	5.7	3.2			35.7								35.7
06/05/2013																		
07/05/2013																		
08/05/2013																		
09/05/2013	17.3	3.8			2.7	11.0	2.3			16.0	NA	4.4	3.73	0.4	2.4	0	2.8	18.8
10/05/2013	13.4	4.0	9.4	1.8	2.0	1.9	4.4			19.5	21.8 - 23.0	4.0	2.60	0	0	0	0	19.5
11/05/2013	13.2	7.0	15.0	0.9	2.5	2.7	0.4			21.5	15.6 - 20.2	3.3	2.94	0.5	3.4	1.6	5.5	27.0
12/05/2013	15.1	5.6	8.2	1.4	5.2	5.6	2.5			22.9								22.9
13/05/2013																		
14/05/2013																		
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22/05/2013																		
23/05/2013																		
24/05/2013											22.5 - 32.0	8.0	4.32	0	1.0	1.7	2.7	2.7
25/05/2013	13.3	8.4	14.7	8.8	2.7	2.8	3.4			32.4	22.2 - 34.9	4.7	4.13	0	0	0.6	0.6	33.0
26/05/2013											21.1 - 21.9	3.5	1.61	0	0	0	0	0
27/05/2013																		
28/05/2013																		
29/05/2013																		
30/05/2013																		
31/05/2013																		
01/06/2013																		
02/06/2013																		
03/06/2013																		
04/06/2013																		
05/06/2013																		
06/06/2013											30.1 - 34.8	6.8	3.54	0.6	0	0.5	1.1	1.1
07/06/2013	13.5	10.1	12.9	0.9	1.8	3.1	1.8	0	0	20.5	31.2 - 33.8	6.4	1.81	0	0	0.7	0.7	21.2
08/06/2013	13.2	10.5	18.9	4.6	1.0	2.2	0	0	0	26.7	19.4 - 22.1	8.4	1.39	1.0	0	0	1.0	27.7
09/06/2013	13.5	10.4	23.8	2.1	0.7	1.3	1.7	0	0	29.6								29.6
10/06/2013																		
11/06/2013																		
12/06/2013																		
13/06/2013																		
14/06/2013																		
15/06/2013																		
16/06/2013																		
17/06/2013																		
18/06/2013																		
19/06/2013																		
20/06/2013	13.4	14.6						0	0	0	25.1 - 30.6	5.7	3.26	2.8	0.5	3.2	6.5	6.5
21/06/2013																		
22/06/2013	13.3	13.3	39.8	6.4	0.9	2.8	1.7	0	0	51.6	21.0 - 21.2	13.0	1.39	0	0	0.9	0.9	52.5
23/06/2013	13.3	13.0	10.1	1.5	0.5	0.4	0.6	0	n.a.	13.1								13.1
Total			**332.6**	**63.1**	**63.0**	**70.4**	**41.8**	**0**	**0**	**570.9**				**12.8**	**15.2**	**17.8**	**45.8**	**616.7**

Table 6: Fraction of single species caught in different gears, based on weight (SGN: standard gillnet; LGN: lower gillnet; CP: pot (Norwegian type); JM: jigging machine).

Gear	[%]																Number of species
	Cod	Dab	Eelpout	Flounder	Herring	Hooknose	Lumpfish	Perch	Plaice	Round goby	Ruffe	Saithe	Sea trout	Shorthorn sculpin	Turbot	Whiting	
SGN	49.43	100	0	66.72	15.64	0	63.33	0	74.65	0	0	100	83.58	35.93	86.51	1.21	11
LGN	8.75	0	0	13.43	0	0	17.26	0	8.36	0	0	0	16.42	11.94	9.58	0	7
CP	32.36	0	100	19.66	84.36	100	19.41	100	16.99	100	100	0	0	47.97	3.91	0	12
JM	9.46	0	0	0.19	0	0	0	0	0	0	0	0	0	4.15	0	98.79	4
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**16**

Table 7: Catch composition [kg], separated by day and species and percentage of total catch.

Date hauled	Cod	Dab	Eelpout	Flounder	Herring	Hooknose	Lumpfish	Perch	Plaice	Round goby	Ruffe	Saithe	Sea trout	Shorthorn sculpin	Turbot	Whiting	Total
15.03.2013	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0.2
16.03.2013	3.4	0	0	0	0	0	1.4	0	0	0	0	0	0	0.3	0	0	5.1
06.04.2013	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3
07.04.2013	3.7	0	0.2	10.6	1.1	0	0	0	0	0.1	0	0	0	0	0.5	0	16.2
11.04.2013	0	0	0	8.1	0.2	0.2	0.3	0	0.6	0.3	0	0	0	0.5	0	0	10.2
18.04.2013	2.0	0	0.3	5.0	1.2	0	0	0.1	0.9	1.3	0.1	0	0	1.4	0	0	12.3
19.04.2013	41.4	0	0	6.0	0	0	13.8	0	1.5	0	0	0	0	0.9	0.3	0	63.9
20.04.2013	19.9	0	0	13.6	0	0	12.0	0	0.7	0	0	0	0	0.4	1.4	0	48.2
02.05.2013	9.1	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	9.4
03.05.2013	74.3	0	0	6.1	0	0	1.2	0	1.4	0	0	0	0	0	0	0	83.0
04.05.2013	52.7	0	0	3.5	0	0	0	0	0.6	0	0	0	0	0	0	0	56.8
05.05.2013	24.7	0	0	6.7	0	0	2.9	0	0.4	0	0	0	0	1.0	0	0	35.6
09.05.2013	15.3	0	0	0	0	0	1.7	0	0	0	0	0	0	1.7	0	0	18.7
10.05.2013	14.5	0	0.8	0.6	0	0	2.4	0	0	0	0	0	0	1.3	0	0	19.5
11.05.2013	23.1	0.3	0	1.3	0	0	1.2	0	0	0	0	0	0	1.2	0	0	27.1
12.05.2013	19.2	0	0	0.1	0	0	2.6	0	0.2	0	0	0	0	0.8	0	0	22.9
24.05.2013	2.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.6
25.05.2013	23.0	0	0	2.0	0	0	5.4	0	0.1	0	0	0	0	1.3	0.4	0.6	32.9
06.06.2013	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0.5	1.1
07.06.2013	10.6	0	0	7.0	0	0	2.0	0	0.8	0	0	0	0	0	0	0.7	21.2
08.06.2013	16.9	0	0	5.0	0	0	1.5	0	0.1	0	0	0	3.7	0.4	0	0	27.7
09.06.2013	20.7	0	0	6.1	0	0	1.5	0	0.6	0	0	0	0	0.2	0.4	0	29.6
20.06.2013	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.1	6.5
22.06.2013	19.4	0	0	15.4	0	0	0	0	1.4	0	0	0.3	5.3	1.4	9.4	0	52.6
23.06.2013	6.2	0	0	5.9	0	0	0	0	0.2	0	0	0	0	0.4	0.4	0	13.1
Total	**404.7**	**0.3**	**1.2**	**103.2**	**2.6**	**0.2**	**50.1**	**0.1**	**9.7**	**1.7**	**0.1**	**0.3**	**9.1**	**13.8**	**12.9**	**6.9**	**616.7**
% of total catch	**65.60**	**0.05**	**0.19**	**16.73**	**0.42**	**0.03**	**8.12**	**0.02**	**1.57**	**0.28**	**0.02**	**0.05**	**1.48**	**2.24**	**2.09**	**1.12**	**100**

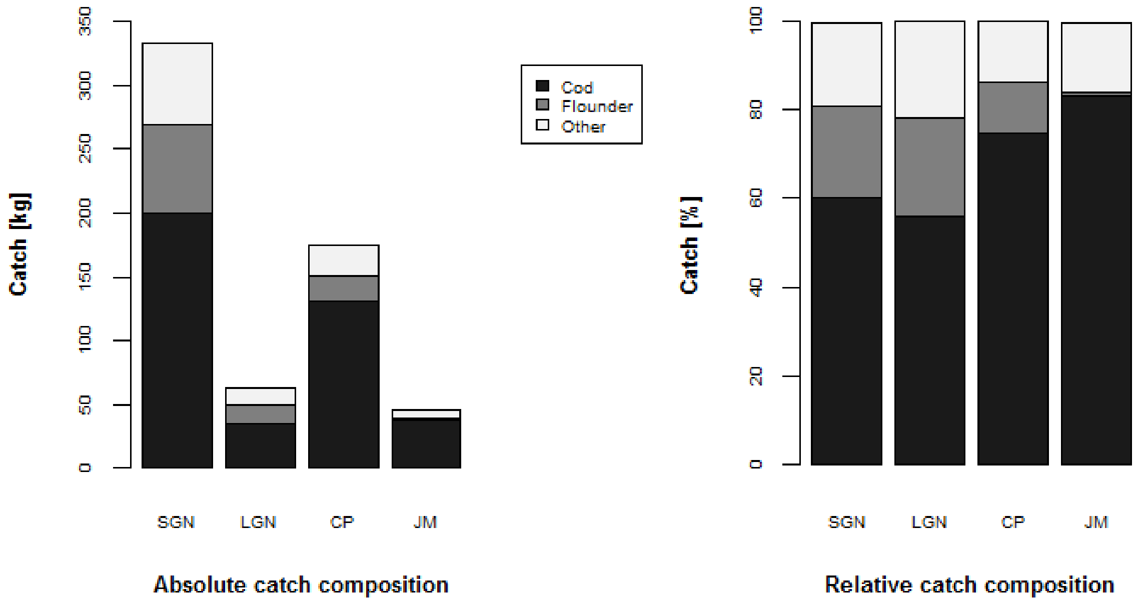

Figure 20: Catch composition of each gear. (SGN: standard gillnet; LGN: lower gillnet; CP: pot (Norwegian type); JM: jigging machine).

3.2 Length distribution

Since only cod and flounder were caught in considerable numbers, length distribution is only shown for these species.

3.2.1 Cod

Total length of cod ranged from 21 cm to 74 cm with a mean value of 40.3 cm. The mean length of fish, caught in both types of gillnet, was similar: 46.2 cm for standard gillnets and 46.8 cm for lower gillnets. The mean size for alternative gears were lower, 35.3 cm for fish pots and 38.6 cm for jigging machines (Table 8). Furthermore, the alternative gears showed larger length ranges than both types of gillnets (see boxes in Figure 21 and SDs in Table 8).

Table 8: Summary of length distribution for cod, separated by gears (SGN: standard gillnet; LGN: lower gillnet; CP: pot (Norwegian type); JM: jigging machine, SD: Standard deviation).

Gear	Individuals	Length [cm] - Cod		
		Min	Max	Mean ± SD
SGN	192	26	62	46.2 ± 5.8
LGN	32	38	53	46.8 ± 3.4
CP	245	21	74	35.3 ± 8.4
JM	60	27	58	38.6 ± 7.2
Total	**529**	**21**	**74**	**40.3 ± 8.8**

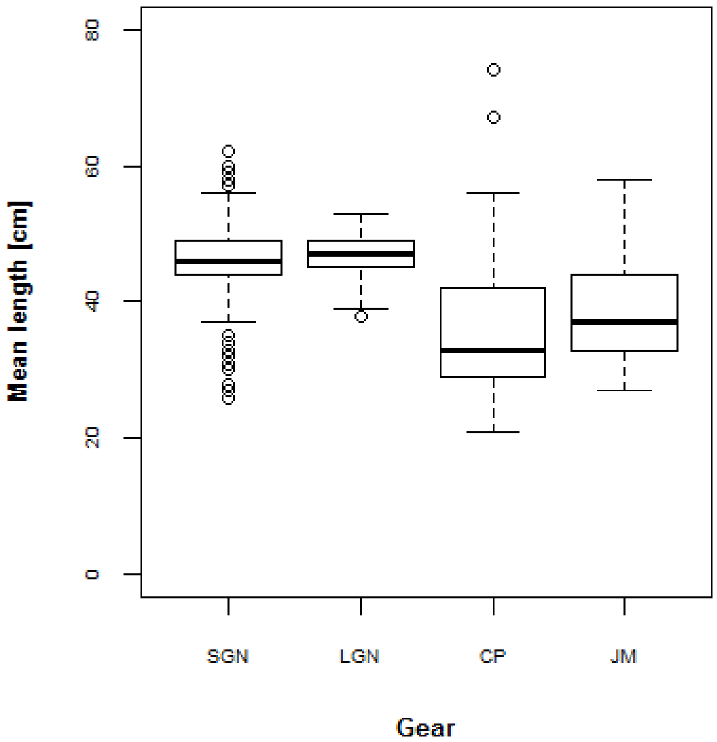

Figure 21: Summary of length distribution for cod, separated by gears. Line shows median, whereas the box represents lower and upper quartile. Whiskers show values within 1.5 of interquartile range. Small circles are outliers (SGN: standard gillnet; LGN: lower gillnet; CP: pot (Norwegian type); JM: jigging machine).

Both, individuals above MLS (minimum landing size) of 38 cm (COASTAL FISHERIES REGULATION MECKLENBURG VORPOMMERN, 11TH NOVEMBER 2008, § 2) and individuals below MLS were caught, whereby almost all individuals caught by gillnets had a size above MLS (91.7% in SGN, 100% in LGN; Figure 22). In contrast to the gillnet, the number of caught cod above MLS in both alternative gears was quite low, 36.33% in fish pots and 48.33% by jigging machines.

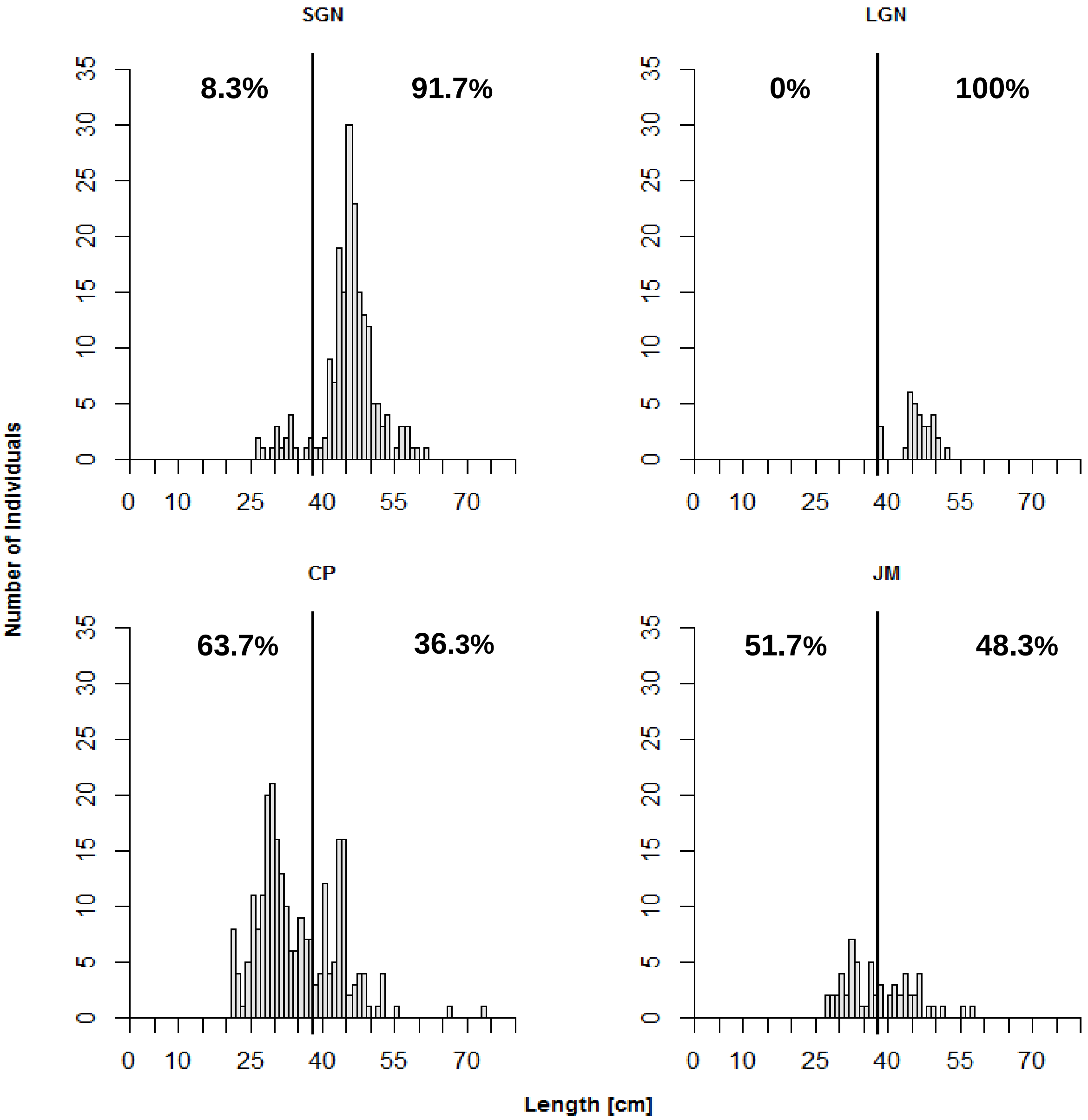

Figure 22: Length distribution of cod and percentages of fish below and above MLS (black line), separated by gears. (SGN: standard gillnet; LGN: lower gillnet; CP: pot (Norwegian type); JM: jigging machine).

3.2.2 Flounder

Total length of flounder ranged from 10 cm to 41 cm with a mean value of 23.5 cm. The mean value of standard gillnets was 25.8 cm. The jigging machines caught only one flounder with a length of 26 cm. The mean values of the lower gillnets and fish pots were 24.1 cm and 19.3 cm (Table 9). The length ranges of all static gears were similar (see boxes in Figure 23 and SDs in Table 9).

Table 9: Summary of length distribution for flounder, separated by gears. (SGN: standard gillnet; LGN: lower gillnet; CP: pot (Norwegian type); JM: jigging machine; SD: Standard deviation).

Gear	Number	Length [cm] - Flounder		
		Min	Max	Mean ± SD
SGN	349	15	41	25.8 ± 4.3
LGN	93	17	37	24.1 ± 3.4
CP	209	10	41	19.3 ± 4.8
JM	1	26	26	26
Total	652	10	41	23.5 ± 5.2

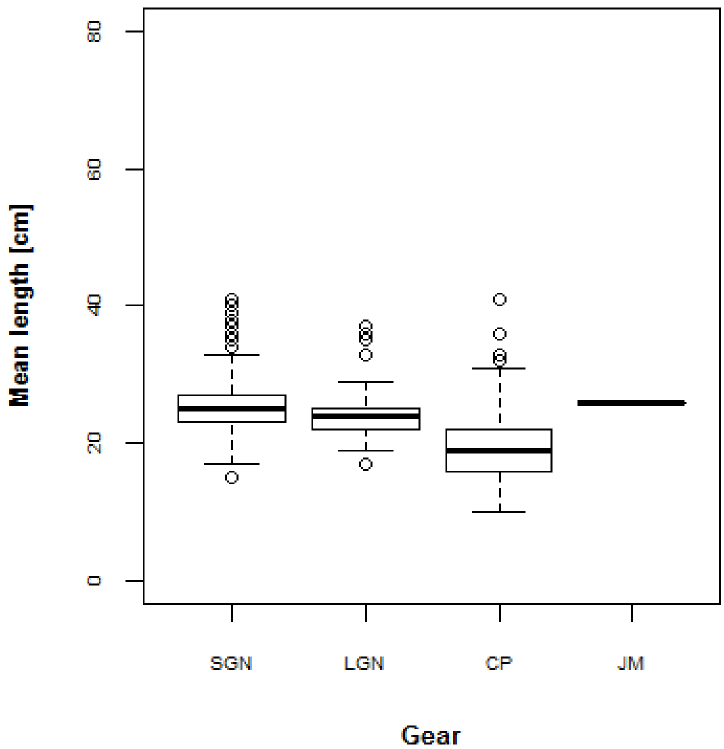

Figure 23: Summary of length distribution for flounder, separated by gears . Line shows median, whereas the box represents lower and upper quartile. Whiskers show values within 1.5 of interquartile range. Small circles are outliers (SGN: standard gillnet; LGN: lower gillnet; CP: pot (Norwegian type); JM: jigging machine).

A large number of caught flounder (~61 %) did not reach the MLS, which is 25 cm in the research area (Coastal fisheries regulation, Mecklenburg Vorpommern 11th November 2008, § 2). 45.27% of the individuals in standard gillnets, 63.44% of the fish, caught in lower gillnets, and 87.08% of the fish, caught in fish pots, were below 25 cm (Figure 24). The single flounder, caught by the jigging machines, was above MLS.

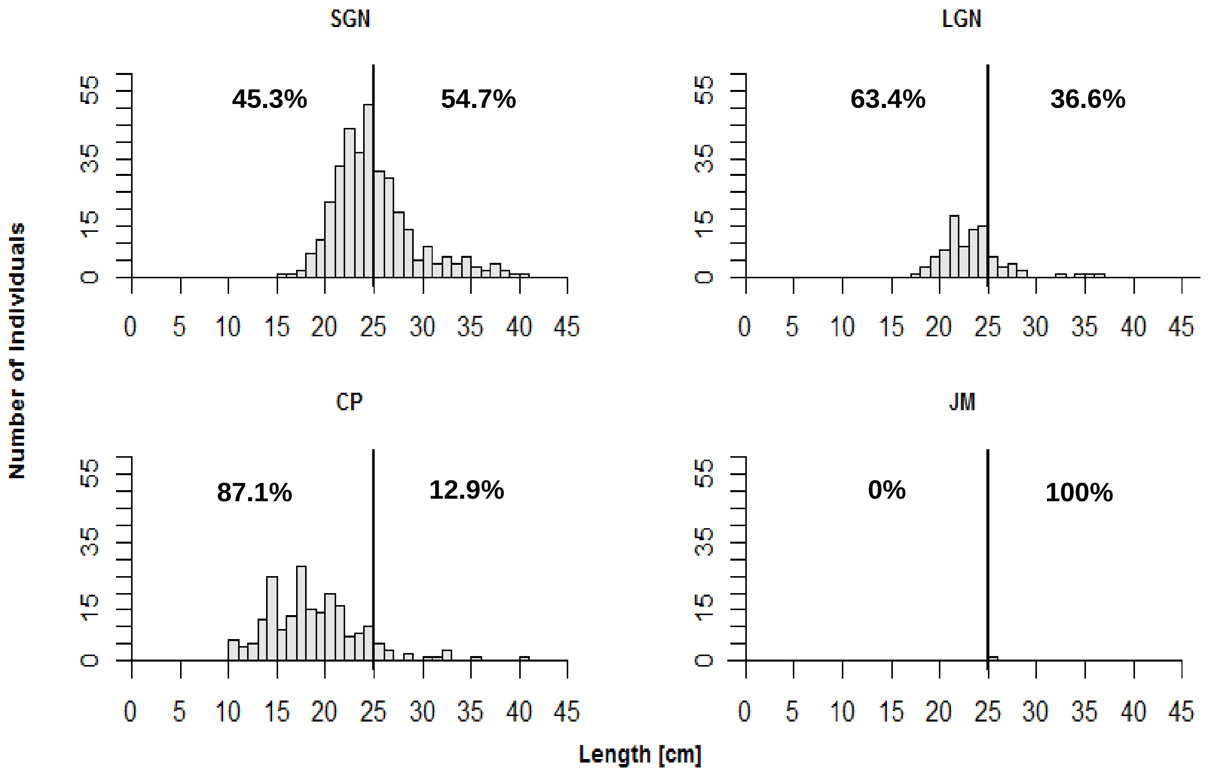

Figure 24: Length distribution of flounders and percentages of fish below and over MLS (black line). (SGN: standard gillnet; LGN: lower gillnet; CP: pot (Norwegian type); JM: jigging machine).

3.3 Gears interactions

The analysis of interactions between pots and gillnets was conducted for the total catch of all hauls when both pots and gillnets were in use at the same time (Table 5).

The p-value of both U-tests, comparing the unaffected standard gillnet (lot 1) with the potentially affected standard gillnet (lot 3) and comparing the unaffected lower gillnet (lot 4) with the potentially affected lower gillnet (lot 2), are considerable greater than the threshold of 0.05 (Figure 25, Figure 26). This indicates no significant differences between their catches and thus, no influence of pots on gillnets. An equal evaluation of the corresponding lots was given.

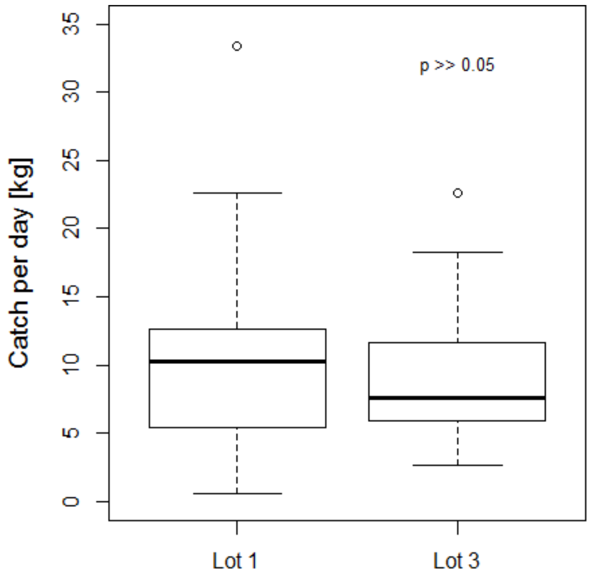

Figure 25: Comparison of gillnet lot 1 (standard gillnet, unaffected by pots) and lot 3 (standard gillnet, potentially affected by pots) to test for influence of fish pots on standard gillnets. Line shows median, whereas the box represents lower and upper quartile. Whiskers show values within 1.5 of interquartile range. Small circles are outliers. P-value (Mann Whitney U-test) indicates no significant differences.

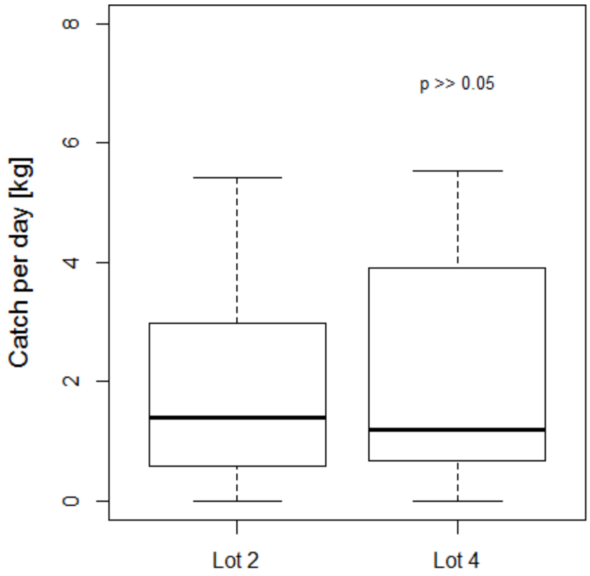

Figure 26: Comparison of gillnet lot 4 (lower gillnet, unaffected by pots) and lot 2 (lower gillnet, potentially affected by pots) to test for influence of fish pots on lower gillnets. Line shows median, whereas the box represents lower and upper quartile. Whiskers show values within 1.5 of the interquartile range. Small circles are outliers. P-value (Mann Whitney U-test) indicates no significant differences.

To test, if gillnets influence the catch of fish pots, the mean catches per day and pot of string I and II, which were placed near the gillnets, were compared to string III, which was set in more distance to the gillnets (Figure 11). Only pot modification 1, 2, 3, 4, 5 and C were considered because modifications 6, 7, and 8 were either not used the whole period or not used in string I and II at all (for explanation of pot modifications, see Table 2).

No significant differences were found between the pot catches of string I and string III or string II and string III (Mann Whitney U-test, p-values>0.05; Figure 27). Thus, the gillnets did not influence the fish pots and an equal evaluation of the corresponding pot strings was given.

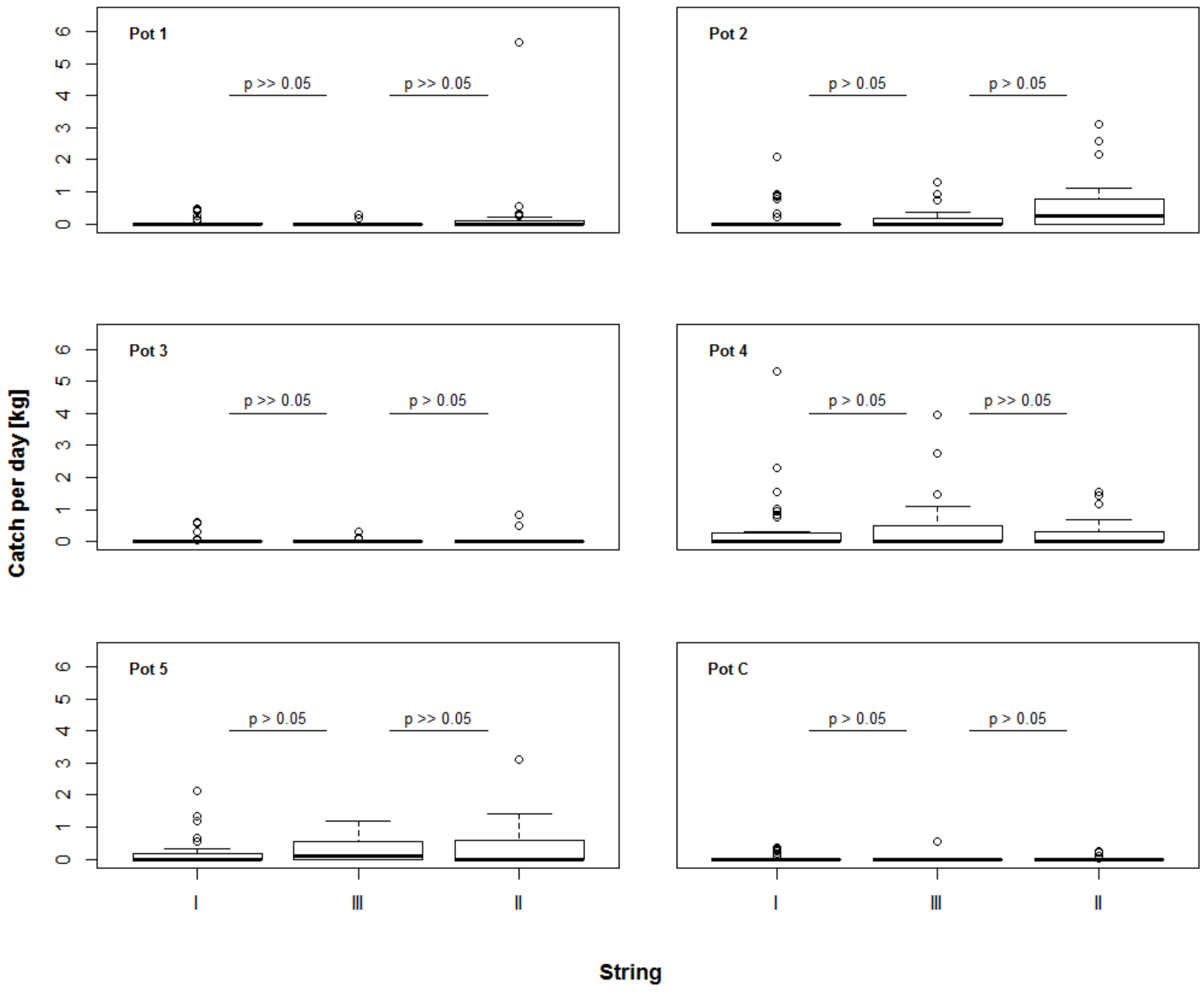

Figure 27: Comparison of pot modification 1-5 and C of string I and II versus string III (in the middle) to test for influence of gillnets on fish pots. Line shows median, whereas the box represents lower and upper quartile. Whiskers show values within 1.5 of interquartile range. Small circles are outliers. P-values (Mann Whitney U-test) indicate no significant differences between corresponding pots of different strings.

3.4 Gillnets

3.4.1 Descriptive analysis

Large variability of catches was found between different days. In some cases, the differences in both lots of one type of gillnet were bigger than ten kilograms (Table 10). Nevertheless, the mean total catches per day of lots of one gillnet type were similar. Standard gillnets (10.9 kg and 9.9 kg) caught around 5 times more fish than lower gillnets (2.2 kg and 2.0 kg). Regarding the mean catch of cod per day, the results are similar. Standard gillnets (6.4 kg or 6.1 kg) caught 5-6 times more cod than lower gillnets (1.4 kg or 0.8 kg). However, both types of gillnets show also catches of zero or near zero and a high standard deviation of the catch per day (Table 10).

Table 10: Catch comparison of standard and lower gillnets for total catch and catch of cod in weight [kg], separated by lot. (NA: lot was not in use; SD: Standard deviation).

	Standard gillnet				Lower gillnet			
	Lot 1		Lot 3		Lot 2		Lot 4	
	Total	Cod	Total	Cod	Total	Cod	Total	Cod
16/03/2013	1.6	0.8	2.7	1.9	NA	NA	NA	NA
07/04/2013	4.9	1.9	2.7	0	2.2	0.7	0	0
19/04/2013	33.3	21.2	17.1	12.0	4.9	3.5	2.2	0
20/04/2013	19.7	8.7	18.3	8.4	3.0	1.3	5.5	1.2
03/05/2013	22.6	18.8	22.6	18.8	5.4	5.4	4.5	4.5
04/05/2013	11.4	10.1	6.5	5.9	0	0	1.0	0
05/05/2013	11.5	7.1	4.8	1.3	2.1	2.1	3.9	2.1
10/05/2013	2.0	0.9	7.4	6.3	1.8	1.1	0	0
11/05/2013	11.9	9.7	3.1	2.1	0.9	0.9	0	0
12/05/2013	0.6	0	7.6	6.6	1.0	0.7	0.5	0
25/05/2013	5.9	2.9	8.7	7.5	5.4	3.1	3.4	2.2
07/06/2013	6.7	2.8	6.2	1.6	0.2	0	0.7	0
08/06/2013	10.2	5.2	8.6	6.9	0.5	0	4.1	1.0
09/06/2013	13.3	8.4	10.4	8.5	0.7	0	1.4	0.6
22/06/2013	13.8	1.7	25.9	7.0	4.6	3.7	1.9	1.2
23/06/2013	4.4	1.5	5.7	3.4	0.6	0	0.9	0
Total	**174.1**	**101.9**	**158.5**	**98.2**	**33.2**	**22.5**	**29.9**	**12.8**
Mean ± SD	**10.9 ± 8.7**	**6.4 ± 6.3**	**9.9 ± 7.2**	**6.1 ± 4.7**	**2.2 ± 2.0**	**1.4 ± 1.7**	**2.0 ± 1.8**	**0.8 ± 1.3**

3.4.2 Standard gillnets versus lower gillnets

For comparing both types of gillnets, the catches of all days, when both gillnets were in use, were chosen (Table 10). The analysis was conducted for total catch, catch of cod and catch of flounder. In order to test for differences in catch between both gillnets, lot 1 and lot 3 were combined to "standard gillnet" and lot 2 and 4 to "lower gillnet" and compared, showing that standard gillnets gave significantly better catches than lower gillnets (U-test, $p<0.05$ in all cases, Figure 28).

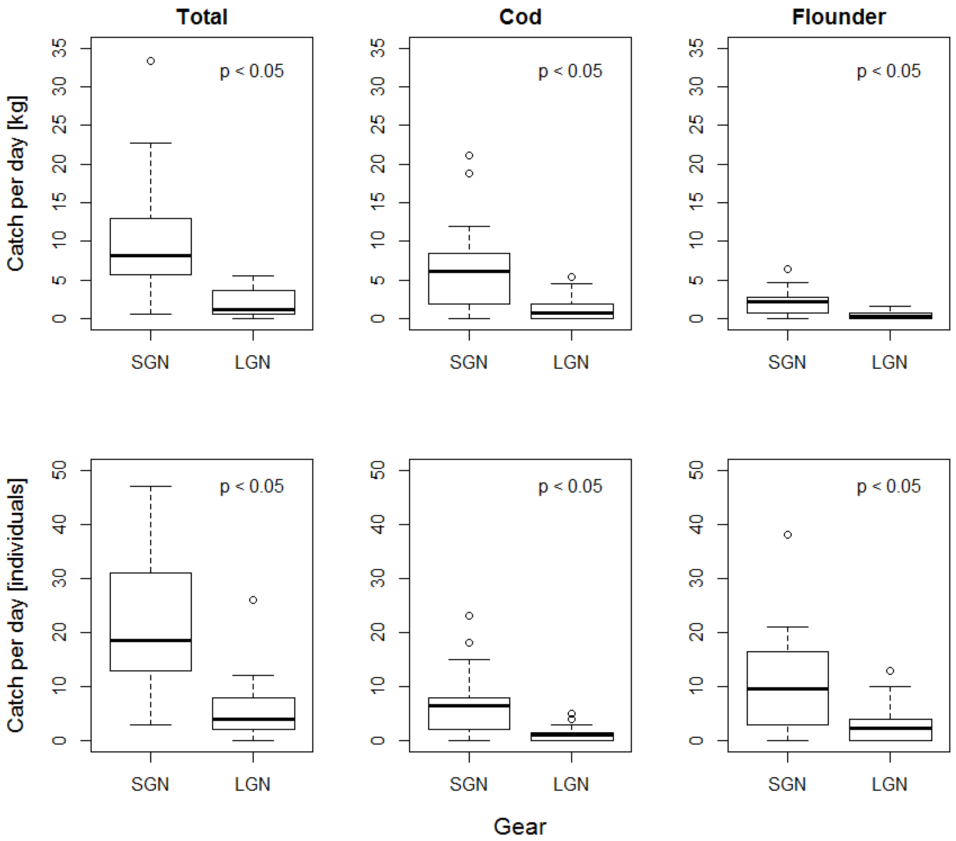

Figure 28: Total catch, catch of cod and catch of flounder by SGN and LGN. Line shows median, whereas the box represents lower and upper quartile. Whiskers show values within 1.5 of interquartile range. Small circles are outliers. P-values (Mann Whitney U-test) indicate significant differences. (SGN: standard gillnet; LGN: lower gillnet).

Since the length distributions of cod and flounder were similar in both types of gillnets (Figure 22, Figure 24), a further analysis of fish below and above MLS was not conducted.

3.4.3 Handling

The standard gillnets were easy to handle because the crew was experienced in using this gear and because utilities, such as gillnet hauler are well adapted to this type of gillnet.

By contrast, lower gillnets had two technical disadvantages: a) the gillnet hauler (Figure 29a) tore them because the hauler was developed for gillnets of a larger height and b) cleaning of gillnets by using a common gillnet cleaner (Figure 29b) took more time because the clamps of this device were also made for larger gillnets. When cleaning lower gillnets, they often moved to one side of the cleaner and had to be adjusted manually.

Another disadvantage of the lower gillnets was that fish, swimming into it, did not entangle like they do in standard gillnets. As a result, many were lost during hauling.

Setting all gillnets (lot1 – lot 4) took ca. 20 minutes, whereas hauling needed approximately 30 minutes. The time, necessary to clean one lot of gillnets, depended on the amount of caught fish and ranged from some minutes up to half an hour.

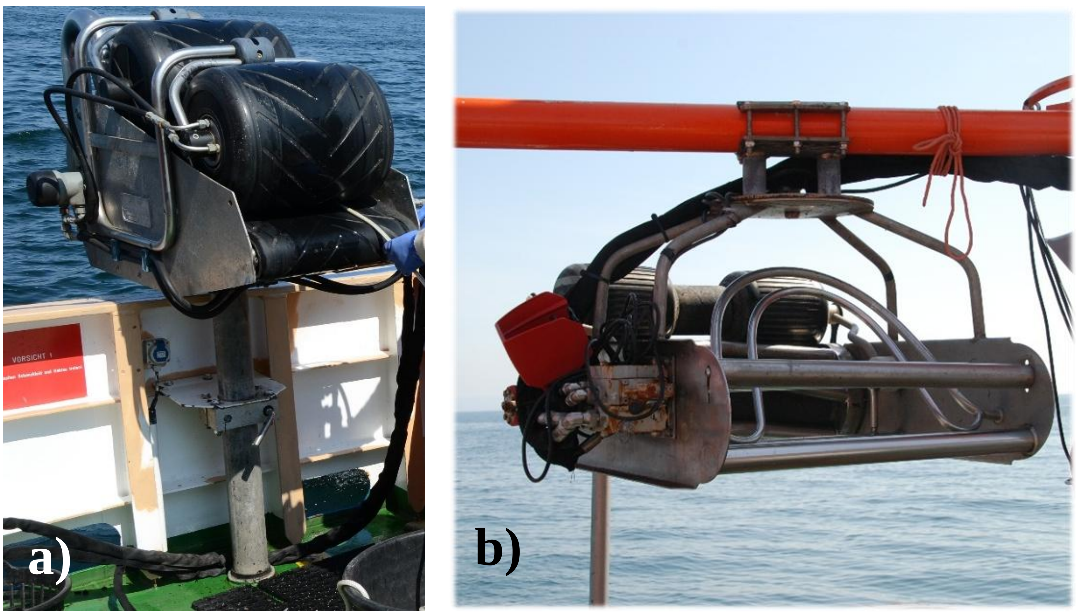

Figure 29: Utilities to handle gillnets. a) Gillnet hauler. b) Gillnet cleaner

3.5 Fish pots - Norwegian type

The first aim was to choose one pot order for string I and string II, either the pairwise setup (tested in string II), which allows a more powerful statistic or the setup in groups (tested in string I), which could handle many zero catches better (see chapter 2.2.2). Since the first hauls showed many zero catches, the group setup was chosen and string II was adapted to string I.

3.5.1 Descriptive analysis

The catch per day was different for the tested pot modifications (Figure 30). Regarding all species, catches of herring baited pots (pot modifications 2, 4, 5 and 8) and pots with only a light (pot modification 1) were higher than catches of pots, baited with boilie (pot modifications 3, 6 and 7) and unbaited pots (pot C). The catches of cod were highest in all pots, which contained herring (pot modifications 2, 4, 5 and 8). The caught flounder did not prefer one specific pot modification. Although the number of caught individuals was similar to cod, the weight was lower, indicating the occurrence of smaller individuals. The median of the total catch was zero for all pot modification, except modification 8 (Figure 30).

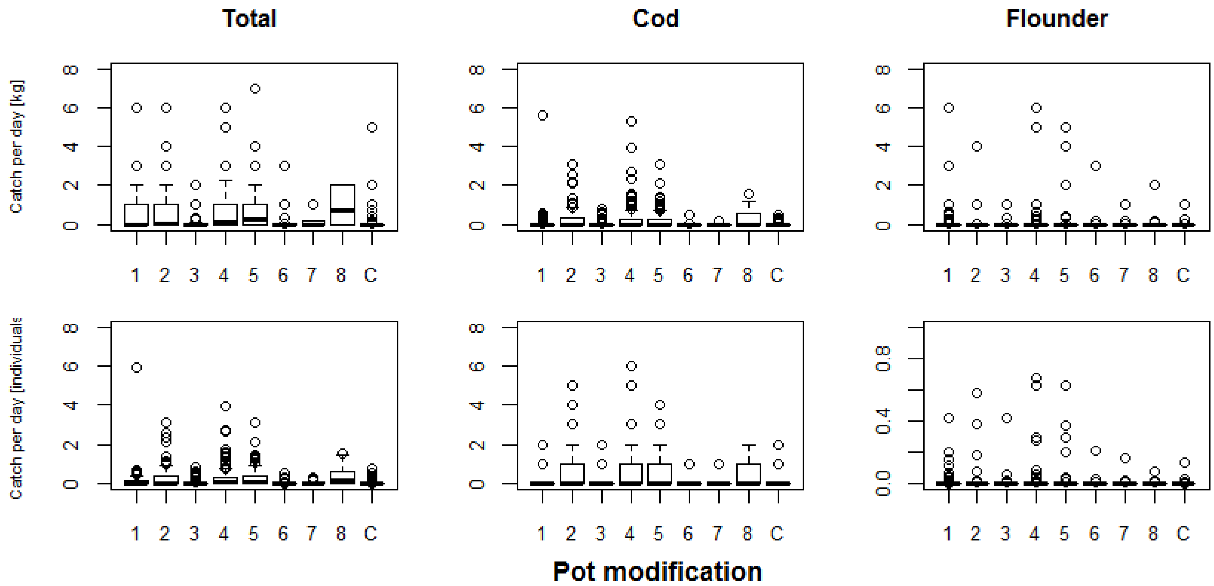

Figure 30: Catches of different pot modifications in weight [kg] and individuals for total catch, cod catch and flounder catch. For explanation of pot modifications see Table 2. Note different scale for catch per day of flounder. Line shows median, whereas the box represents lower and upper quartile. Whiskers show values within 1.5 of interquartile range. Small circles are outliers.

Due to many zero catches, the mean catch of fish pots was quite low and the standard deviation was high. The mean catch per day and pot of all species ranged from 0.21 individuals with 0.04 kg for pot modification 6 (boilie and light) to 1.1 individuals with 0.47 kg for pot modification 4 (herring and light; Table 11).

The mean catch per day of cod ranged from 0.04 individuals with 0.02 kg for pot modification 6 (boilie and light) or 0.06 individuals with 0.01 kg for pot modification 7 (boilie, light and entrance) up to 0.59 individuals with 0.39 kg for pot 4 (herring and light) or 0.61 individuals with 0.33 kg for pot modification 8 (herring, light, entrance and camouflage netting; Table 12).

The average catch per day of flounder ranged from 0.01 individuals with less than 0.01 kg per pot and day for the unbaited pot C up to 0.32 individuals and 0.04 kg for pot modification 4 (herring and light; Table 13).

Table 11: Total catches of different pot modifications in number of individuals (ind) and weight [kg] (weight in brackets; NA: pot was not in use; SD: Standard deviation).

Catch per pot and day										
Date	**String**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**C**
16/03/2013	**I**	0	1.0 (0.2)	0	0	1.0 (0.1)	NA	NA	NA	0
	II	0	1.0 (0.2)	0	0	0	0	NA	NA	0
	III	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/04/2013	**I**	3.0 (0.2)	8.0 (1.0)	1.0 (0.1)	10.0 (0.9)	7.0 (0.6)	NA	NA	NA	0
	II	3.0 (0.2)	1.0 (0.1)	0	3.0 (0.1)	2.0 (0.1)	1.5 (0.1)	NA	NA	2.5 (0.4)
	III	0	3.0 (1.1)	0	0	2.0 (0.4)	0	1.0 (0.2)	2.0 (0.1)	0
11/04/2013	**I**	4.8 (0.3)	0.8 (0.2)	0.5 (0.0)	2.0 (0.3)	3.0 (0.2)	NA	NA	NA	0.1 (0.0)
	II	1.4 (0.1)	0.3 (0.0)	0.8 (0.0)	1.3 (0.1)	0.8 (0.1)	0.2 (0.0)	NA	NA	0.9 (0.1)
	III	0.8 (0.0)	0.3 (0.0)	0	0.3 (0.0)	1.5 (0.1)	0	0.8 (0.1)	1.0 (0.1)	0
18/04/2013	**I**	1.4 (0.2)	0.1 (0.0)	0.6 (0.1)	2.3 (0.4)	0.9 (0.1)	NA	NA	NA	0.2 (0.0)
	II	0.2 (0.0)	0.2 (0.0)	0.1 (0.0)	0.1 (0.0)	0.2 (0.0)	0.03 (0.00)	NA	NA	0.6 (0.1)
	III	0.7 (0.0)	0.3 (0.0)	0.3 (0.1)	0.4 (0.0)	0.3 (0.0)	0.1 (0.0)	0.1 (0.0)	0.7 (0.0)	0
19/04/2013	**I**	1.0 (0.2)	1.0 (0.8)	0	2.0 (0.2)	1.0 (0.2)	NA	NA	NA	0.3 (0.1)
	II	0	0.5 (0.1)	0.5 (0.4)	0	0	0	NA	NA	0
	III	0	1.0 (0.2)	1.0 (0.4)	0	3.0 (1.3)	1.0 (0.3)	1.0 (0.3)	0	0
20/04/2013	**I**	0	1.0 (0.3)	0	0	0	NA	NA	NA	0
	II	0	0.5 (0.1)	0	0.5 (0.1)	0	0	NA	NA	0
	III	0	0	1.0 (0.3)	0	1.0 (0.4)	0	1.0 (0.3)	0	0
03/05/2013	**I**	NA	NA	NA	NA	NA	NA	NA	NA	NA
	II	1.5 (3.0)	3.0 (1.2)	0	0.5 (0.2)	1.0 (0.7)	NA	NA	NA	0.5 (0.1)
	III	0	1.0 (1.3)	1.0 (0.1)	6.0 (4.0)	3.0 (0.9)	1.0 (0.5)	0	1.0 (0.3)	2.0 (0.5)
04/05/2013	**I**	1.3 (0.4)	0.8 (0.5)	0	4.0 (3.9)	1.0 (0.9)	NA	NA	NA	0.8 (0.2)
	II	1.0 (0.2)	3.0 (1.9)	0	1.0 (0.7)	1.5 (1.6)	NA	NA	NA	0
	III	1.0 (0.3)	0	0	2.0 (1.5)	1.0 (0.2)	0	0	2.0 (1.5)	0
05/05/2013	**I**	1.0 (0.2)	0.5 (0.4)	0	1.0 (0.5)	2.5 (1.1)	NA	NA	NA	0
	II	0	0.5 (0.4)	0.5 (0.1)	3.0 (1.7)	1.0 (0.6)	NA	NA	NA	0
	III	0	0	0	2.0 (1.1)	3.0 (0.7)	0	0	2.0 (1.4)	0
09/05/2013	**I**	0.3 (0.1)	0	0.1 (0.0)	0.1 (0.0)	0.1 (0.1)	NA	NA	NA	0.4 (0.1)
	II	0.6 (0.1)	0.5 (0.5)	0.1 (0.0)	1.0 (0.3)	0.5 (0.2)	NA	NA	NA	0.5 (0.1)
	III	0	0.3 (0.2)	0.5 (0.1)	0.3 (0.2)	0	0	0	0.5 (0.0)	0
10/05/2013	**I**	0	0	0	1.5 (0.8)	0.5 (0.1)	NA	NA	NA	0.5 (0.1)
	II	0.5 (0.2)	1.0 (0.4)	0	1.0 (0.4)	0	NA	NA	NA	0
	III	1.0 (0.2)	2.0 (1.0)	1.0 (0.4)	1.0 (0.4)	2.0 (1.2)	0	0	1.0 (1.2)	0
11/05/2013	**I**	0.5 (0.0)	0	0.5 (0.1)	0.5 (0.4)	0.5 (0.7)	NA	NA	NA	0
	II	0.5 (0.3)	1.0 (0.5)	0	0.5 (0.1)	1.5 (0.5)	NA	NA	NA	0
	III	0	0	0	2.0 (0.4)	0	0	0	0	0
12/05/2013	**I**	1.0 (0.3)	1.5 (0.4)	0	1.5 (1.2)	1.0 (0.5)	NA	NA	NA	0.5 (0.1)
	II	1.5 (0.3)	1.0 (1.6)	0	0.5 (0.1)	1.5 (0.8)	NA	NA	NA	0.5 (0.1)
	III	2.0 (0.3)	1.0 (0.3)	0	1.0 (0.3)	3.0 (0.9)	0	1.0 (0.2)	2.0 (0.5)	0
25/05/2013	**I**	0	1.0 (1.0)	0	0	0.5 (0.1)	NA	NA	NA	0.5 (0.2)
	II	1.0 (0.3)	1.5 (0.5)	1.0 (0.2)	1.5 (0.4)	0	NA	NA	NA	0
	III	0	0	0	3.0 (2.7)	1.0 (0.3)	0	0	2.0 (0.4)	0
07/06/2013	**I**	0.5 (0.1)	0	1.0 (0.3)	1.0 (0.3)	0.5 (0.2)	NA	NA	NA	0.5 (0.1)
	II	0.5 (0.1)	1.0 (0.3)	1.0 (0.3)	0.5 (0.8)	0.5 (0.1)	NA	NA	NA	0
	III	1.0 (0.3)	1.0 (0.2)	0	0	1.0 (1.0)	0	0	0	1.0 (0.4)
08/06/2013	**I**	0	0	1.0 (0.3)	0.5 (0.1)	0	NA	NA	NA	0.5 (0.1)
	II	1.0 (0.3)	0.5 (0.4)	0.5 (0.2)	0	0.5 (0.2)	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
09/06/2013	**I**	0.5 (0.1)	0	1.0 (0.3)	0	0	NA	NA	NA	0
	II	1.0 (0.2)	0	0	0	0.5 (0.4)	NA	NA	NA	0
	III	0	1.0 (0.2)	1.0 (0.3)	0	1.0 (0.5)	0	0	2.0 (0.6)	0
22/06/2013	**I**	0	0	0.3 (0.0)	0.3 (0.1)	0.5 (0.1)	NA	NA	NA	0
	II	0	0	0	0.8 (0.4)	0.5 (0.4)	NA	NA	NA	0
	III	0	0.5 (0.1)	0	0.5 (0.5)	0	0	0	1.0 (0.2)	0
23/06/2013	**I**	0	0	0	0.5 (0.2)	0.5 (0.1)	NA	NA	NA	0
	II	0	0.5 (0.2)	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	2.0 (0.6)	0
Mean ± SD										
I	ind	0.84 ± 1.24	0.87 ± 1.85	0.33 ± 0.42	1.51 ± 2.37	1.14 ± 1.67	-	-	-	0.23 ± 0.26
	weight	0.12 ± 0.13	0.27 ± 0.35	0.07 ± 0.11	0.51 ± 0.91	0.28 ± 0.33	-	-	-	0.06 ± 0.07
II	ind	0.72 ± 0.77	0.89 ± 0.84	0.24 ± 0.36	0.80 ± 0.90	0.63 ± 0.63	0.28 ± 0.60	-	-	0.29 ± 0.60
	weight	0.28 ± 0.66	0.45 ± 0.53	0.06 ± 0.11	0.28 ± 0.41	0.30 ± 0.40	0.02 ± 0.04	-	-	0.05 ± 0.09
III	ind	0.36 ± 0.58	0.63 ± 0.82	0.32 ± 0.45	1.02 ± 1.55	1.27 ± 1.15	0.12 ± 0.32	0.27 ± 0.44	1.07 ± 0.85	0.17 ± 0.51
	weight	0.06 ± 0.11	0.26 ± 0.40	0.10 ± 0.15	0.62 ± 1.09	0.44 ± 0.45	0.05 ± 0.14	0.05 ± 0.09	0.39 ± 0.51	0.05 ± 0.15
∑	**ind**	**0.64 ± 0.91**	**0.80 ± 1.24**	**0.30 ± 0.40**	**1.10 ± 1.70**	**1.00 ± 1.22**	**0.21 ± 0.46**	**0.27 ± 0.44**	**1.07 ± 0.85**	**0.23 ± 0.48**
	weight	**0.15 ± 0.40**	**0.33 ± 0.44**	**0.07 ± 0.12**	**0.47 ± 0.84**	**0.34 ± 0.39**	**0.04 ± 0.09**	**0.05 ± 0.09**	**0.39 ± 0.51**	**0.05 ± 0.10**

Table 12: Cod catches of different pot modifications in number of individuals (ind) and weight [kg] (weight in brackets; NA: pot was not in use; SD: Standard deviation).

Date	String	1	2	3	4	5	6	7	8	C
Cod - catch per pot and day										
16/03/2013	**I**	0	1.0 (0.2)	0	0	0	NA	NA	NA	0
	II	0	1.0 (0.2)	0	0	0	0	NA	NA	0
	III	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/04/2013	**I**	0	0	0	0	0	NA	NA	NA	0
	II	0	0	0	0	0	0	NA	NA	0.5 (0.1)
	III	0	2.0 (0.9)	0	0	0	0	0	0	0
11/04/2013	**I**	0	0	0	0	0	NA	0	0	0
	II	0	0	0	0	0	0	0	0	0.3 (0.1)
	III	0	0	0	0	0	0	0	0	0
18/04/2013	**I**	0	0	0	0	0	NA	NA	NA	0
	II	0	0	0	0	0	0	NA	NA	0
	III	0	0	0.0 (0.1)	0	0	0	0	0	0
19/04/2013	**I**	0	1.0 (0.8)	0	1.0 (0.2)	1.0 (0.2)	NA	NA	NA	0
	II	0	0.5 (0.1)	0.5 (0.4)	0	0	0	NA	NA	0
	III	0	0	0	0	2.0 (1.0)	0	0	0	0
20/04/2013	**I**	0	1.0 (0.3)	0	0	0	NA	NA	NA	NA
	II	0	0	0	0	0	0	NA	NA	0.5 (0.1)
	III	0	0	0	0	0	0	0	0	2.0 (0.5)
03/05/2013	**I**	NA	NA	NA	NA	NA	NA	NA	NA	1.5 (0.4)
	II	1.0 (2.8)	2.5 (1.1)	0	0.5 (0.2)	1.0 (0.7)	NA	NA	NA	0
	III	0	1.0 (1.3)	1.0 (0.1)	6.0 (4.0)	1.0 (0.3)	1.0 (0.5)	0	1.0 (0.3)	0
04/05/2013	**I**	1.0 (0.3)	0.8 (0.5)	0	3.8 (3.8)	1.0 (0.9)	NA	NA	NA	0
	II	0.5 (0.1)	3.0 (1.9)	0	0.5 (0.3)	1.5 (1.6)	NA	NA	NA	0
	III	1.0 (0.3)	0	0	2.0 (1.5)	1.0 (0.2)	0	0	2.0 (1.5)	0
05/05/2013	**I**	1.0 (0.2)	0.5 (0.4)	0	1.0 (0.5)	2.5 (1.1)	NA	NA	NA	1.5 (0.5)
	II	0	0.5 (0.4)	0	1.5 (1.3)	1.0 (0.6)	NA	NA	NA	2.0 (0.6)
	III	0	0	0	2.0 (1.1)	3.0 (0.7)	0	0	1.0 (1.1)	0
09/05/2013	**I**	0.3 (0.1)	0	0.1 (0.0)	0.1 (0.0)	0.1 (0.1)	NA	NA	NA	0
	II	0.4 (0.1)	0.5 (0.5)	0	0.3 (0.1)	0.4 (0.2)	NA	NA	NA	0
	III	0	0.3 (0.2)	0	0.3 (0.2)	0	0	0	0	0
10/05/2013	**I**	0	0	0	0.5 (0.5)	0	NA	NA	NA	0
	II	0	1.0 (0.4)	0	0.5 (0.3)	0	NA	NA	NA	0
	III	1.0 (0.2)	1.0 (0.8)	0	1.0 (0.4)	2.0 (1.2)	0	0	1.0 (1.2)	0
11/05/2013	**I**	0.5 (0.0)	0	0	0.5 (0.4)	0.5 (0.7)	NA	NA	NA	0.5 (0.1)
	II	0.5 (0.3)	1.0 (0.5)	0	0.5 (0.1)	1.5 (0.5)	NA	NA	NA	0.5 (0.1)
	III	0	0	0	0	0	0	0	0	0
12/05/2013	**I**	0.5 (0.2)	1.5 (0.4)	0	1.5 (1.2)	0.5 (0.3)	NA	NA	NA	0
	II	1.0 (0.1)	1.0 (1.6)	0	0.5 (0.1)	1.5 (0.8)	NA	NA	NA	0
	III	1.0 (0.2)	1.0 (0.3)	0	1.0 (0.3)	2.0 (0.5)	0	1.0 (0.2)	1.0 (0.3)	0
25/05/2013	**I**	0	1.0 (1.0)	0	0	0.5 (0.1)	NA	NA	NA	0.5 (0.1)
	II	0.5 (0.1)	1.5 (0.5)	0	1.0 (0.3)	0	NA	NA	NA	0
	III	0	0	0	3.0 (2.7)	1.0 (0.3)	0	0	0	0
07/06/2013	**I**	0.5 (0.1)	0	1.0 (0.3)	1.0 (0.3)	0.5 (0.2)	NA	NA	NA	0.5 (0.1)
	II	0	1.0 (0.3)	1.0 (0.3)	0.5 (0.8)	0.5 (0.1)	NA	NA	NA	0
	III	1.0 (0.3)	1.0 (0.2)	0	0	1.0 (1.0)	0	0	0	0
08/06/2013	**I**	0	0	1.0 (0.3)	0.5 (0.1)	0	NA	NA	NA	0
	II	0.5 (0.2)	0.5 (0.4)	0	0	0.5 (0.2)	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
09/06/2013	**I**	0.5 (0.1)	0	0.5 (0.1)	0	0	NA	NA	NA	0
	II	0.5 (0.1)	0	0	0	0.5 (0.4)	NA	NA	NA	0
	III	0	1.0 (0.2)	1.0 (0.3)	0	1.0 (0.5)	0	0	2.0 (0.6)	0
22/06/2013	**I**	0	0	0.3 (0)	0	0.5 (0.1)	NA	NA	NA	0
	II	0	0	0	0.8 (0.4)	0.5 (0.4)	NA	NA	NA	0
	III	0	0.5 (0.1)	0	0.5 (0.5)	0	0	0	1.0 (0.2)	0
23/06/2013	**I**	0	0	0	0.5 (0.2)	0	NA	NA	NA	0
	II	0	0.5 (0.2)	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	2.0 (0.6)	0
Mean ± SD										
I	ind	0.24 ± 0.35	0.38 ± 0.52	0.16 ± 0.33	0.58 ± 0.92	0.4 ± 0.63	-	-	-	0.25 ± 0.49
	weight	0.06 ± 0.10	0.20 ± 0.31	0.04 ± 0.1	0.39 ± 0.90	0.2 ± 0.34	-	-	-	0.07 ± 0.15
II	ind	0.26 ± 0.34	0.76 ± 0.84	0.08 ± 0.25	0.34 ± 0.42	0.47 ± 0.56	0	-	-	0.20 ± 0.48
	weight	0.20 ± 0.64	0.43 ± 0.53	0.04 ± 0.11	0.21 ± 0.34	0.29 ± 0.41	0	-	-	0.05 ± 0.14
III	ind	0.22 ± 0.43	0.43 ± 0.59	0.11 ± 0.32	0.88 ± 1.56	0.78 ± 0.94	0.06 ± 0.24	0.06 ± 0.24	0.61 ± 0.78	0.11 ± 0.47
	weight	0.05 ± 0.10	0.22 ± 0.38	0.03 ± 0.08	0.60 ± 1.10	0.32 ± 0.41	0.03 ± 0.12	0.01 ± 0.04	0.33 ± 0.49	0.03 ± 0.13
∑	**ind**	**0.24 ± 0.37**	**0.53 ± 0.68**	**0.12 ± 0.30**	**0.59 ± 1.07**	**0.55 ± 0.73**	**0.04 ± 0.20**	**0.06 ± 0.24**	**0.61 ± 0.78**	**0.19 ± 0.47**
	weight	**0.11 ± 0.38**	**0.29 ± 0.43**	**0.04 ± 0.09**	**0.39 ± 0.84**	**0.27 ± 0.38**	**0.02 ± 0.10**	**0.01 ± 0.04**	**0.33 ± 0.49**	**0.05 ± 0.14**

Table 13: Flounder catches of different pot modifications in number of individuals (ind) and weight [kg]. (weight in brackets; NA: pot was not in use; SD: Standard deviation).

Flounder - catch per pot and day										
Date	**String**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**C**
	I	0	0	0	0	0	0	0	0	0
16/03/2013	**II**	0	0	0	0	0	0	0	0	0
	III	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I	3.0 (0.2)	8.0 (1.0)	1.0 (0.1)	10.0 (0.9)	5.0 (0.3)	NA	NA	NA	0
07/04/2013	**II**	3.0 (0.2)	0.5 (0.0)	0	3.0 (0.1)	2.0 (0.1)	1.5 (0.1)	NA	NA	0.2 (0.0)
	III	0	0	0	0	2.0 (0.4)	0	1.0 (0.2)	2.0 (0.0)	0
	I	4.3 (0.3)	0.5 (0.0)	0.3 (0.0)	2.0 (0.3)	3.0 (0.2)	NA	NA	NA	0.1 (0.0)
11/04/2013	**II**	0.3 (0.0)	0	0.2 (0.0)	0.3 (0.0)	0.2 (0.0)	0.1 (0.0)	NA	NA	0.0 (0.0)
	III	0.2 (0.0)	0.1 (0.0)	0	0.1 (0.0)	0.4 (0.0)	0	0.2 (0.0)	0.2 (0.0)	0
	I	0.3 (0.0)	0.0 (0.0)	0	0.4 (0.1)	0.1 (0.0)	NA	NA	NA	0
18/04/2013	**II**	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0	0.0 (0.0)	NA	NA	0.0 (0.0)
	III	0.1 (0.0)	0	0	0.1 (0.0)	0	0.0 (0.0)	0.0 (0.0)	0.1 (0.0)	0
	I	0	0	0	0	0	NA	NA	NA	0
19/04/2013	**II**	0	0	0	0	0	0	NA	NA	0
	III	0	0	1.0 (0.4)	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
20/04/2013	**II**	0	0	0	0	0	0	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/05/2013	**II**	0	0.5 (0.1)	0	0	0	NA	NA	NA	0
	III	0	0	0	0	2.0 (0.6)	0	0	0	0
	I	0.5 (0.1)	0	0	0.5 (0.2)	0	NA	NA	NA	0
04/05/2013	**II**	0.5 (0.1)	0	0	0.5 (0.3)	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
05/05/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
09/05/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
10/05/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
11/05/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
12/05/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
25/05/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0.5 (0.1)	0	0	0	0	NA	NA	NA	0
07/06/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0.5 (0.1)	0	0	0	0	NA	NA	NA	0
08/06/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
09/06/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
22/06/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	NA	NA	NA	0
23/06/2013	**II**	0	0	0	0	0	NA	NA	NA	0
	III	0	0	0	0	0	0	0	0	0
Mean ± SD										
I	ind	0.47 ± 1.25	0.53 ± 1.99	0.08 ± 0.25	0.77 ± 2.51	0.51 ± 1.41	-	-	-	0.01 ± 0.02
	weight	0.03 ± 0.08	0.06 ± 0.24	0.00 ± 0.01	0.08 ± 0.24	0.03 ± 0.1	-	-	-	0.00 ± 0.00
II	ind	0.26 ± 0.73	0.06 ± 0.17	0.01 ± 0.05	0.20 ± 0.73	0.13 ± 0.48	0.27 ± 0.60	-	-	0.01 ± 0.04
	weight	0.03 ± 0.06	0.01 ± 0.02	0.00 ± 0.00	0.01 ± 0.03	0.01 ± 0.00	0.02 ± 0.04	-	-	0.00 ± 0.01
III	ind	0.02 ± 0.05	0.00 ± 0.02	0.06 ± 0.25	0.01 ± 0.02	0.27 ± 0.68	0.00 ± 0.01	0.08 ± 0.25	0.14 ± 0.50	0.00 ± 0.00
	weight	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.11	0.00 ± 0.00	0.06 ± 0.20	0.00 ± 0.00	0.01 ± 0.04	0.01 ± 0.02	0.00 ± 0.00
∑	**ind**	**0.25 ± 0.82**	**0.18 ± 1.11**	**0.05 ± 0.20**	**0.32 ± 1.46**	**0.28 ± 0.91**	**0.07 ± 0.31**	**0.07 ± 0.24**	**0.13 ± 0.48**	**0.01 ± 0.03**
	weight	**0.02 ± 0.06**	**0.02 ± 0.13**	**0.01 ± 0.06**	**0.04 ± 0.14**	**0.03 ± 0.10**	**0.01 ± 0.02**	**0.01 ± 0.04**	**0.01 ± 0.02**	**0.00 ± 0.00**

3.5.2 Modeling approach

Since this kind of analysis required serious balance of data and a further comparison to gillnet catches was needed, only eleven hauls were regarded as valid hauls. The following requirements were applied to identify valid hauls:

- same setup (not applicable for initial setup until 4^{th} of May)
- gillnets were used in parallel (not applicable for 9^{th} of May)

Only string I and string II were regarded, since amount and order of specific pot modifications in string III were different. The analysis was done exclusively for catches of cod because this was the only marketable species, which occurred in sufficient amounts during the study period of these hauls.

The first task was to find a model to predict the catch per pot and day (subsequent process of model selection is widely discussed in chapter 2.4.1).

A standard linear model cannot be used, since different prior assumptions of this type are violated by the data (e.g. normal distribution). Thus, a model of the GLM family had to be used, especially one type of model, that accounts for extra zeros because the pot catch data contained more zeros, than would be recommended for the use of a single Poisson, negative binomial or geometrical model. A zero-inflated model was not used, since the pot catch data did not provide any information of the nature of “excess” zero counts, which this type of model assumes. Instead, a hurdle model with logit link and a binomial distribution to model the zero counts was used. To describe the count data, a geometric model was chosen because it showed the smallest AIC-value (Table 14). However, different distributions, used in the hurdle model, had similar AIC-values, meaning that the predicted catch values of other models would also be similar. This similarity is also supported by similar log likelihood values and the number of predicted zeros. This number expresses the number of zero counts, predicted by the model. All models predict a number of 184 zeros (Table 14), which is equal to the observed value.

Table 14: Comparison of AIC (Akaike Information Criterion, (AKAIKE, 1973)), Log likelihood and number of predicted zeros as quality criterions for selection of count distribution in hurdle model.

Distribution		AIC	Log likelihood	Predicted zeros
Zero values	**Positive values**			**(184 observed)**
Binomial	Poisson	459.46	-217.73	184
Binomial	Negative Binomial	460.32	-217.16	184
Binomial	Geometric	458.61	-217.26	184

The mean values of predicted cod catches per day differed greatly between different pot modifications (Table 15, Figure 31). Pot C (with no bait) showed the lowest number of predicted individuals per day with a value of 0.14. All pots, which were equipped with herring as bait, showed the highest catch predictions: Pot modification 5 (herring, light and entrance) had a value of 0.61, pot modification 2 (herring) had a value of 0.64 and pot 4 (herring and light) had the highest value of 0.71 individuals per day and pot.

Since the mean values of the original data ($Mean_{asymptotic}$) and the mean values of the bootstrapped data ($Mean_{Bias\ corrected}$) are similar (Table 15), all results of the bootstrapping can be regarded as statistically robust. However, the confidence intervals, which result from the bootstrapped data, are broad (Figure 31), indicating a high amount of uncertainty for the predicted mean catches of each pot.

Table 15: Predicted number of individuals per day and pot ($Mean_{asymptotic}$) for pot modification 1-5 and C. Predicted number multiplied with ten is the predicted catch of a pot string of ten pots, representing the Catch Per Unit Effort (CPUE) for fish pots used in this study (underlined: highest value). Confidence intervals (CI) and $Mean_{Bias\ corrected}$ resulting from block bootstrapping with 3000 repetitions.

	Pot modification					
	C	**1**	**2**	**3**	**4**	**5**
$Mean_{asymptotic}$	0.14	0.36	0.64	0.18	0.71	0.61
$Mean_{asymptotic}$ * 10 (~ CPUE)	**1.40**	**3.60**	**6.40**	**1.80**	**<u>7.10</u>**	**6.10**
Lower CI	0.02	0.14	0.25	0.02	0.34	0.27
$Mean_{Bias\ corrected}$	0.14	0.36	0.64	0.19	0.71	0.61
Upper CI	0.34	0.64	1.11	0.45	1.23	1.07

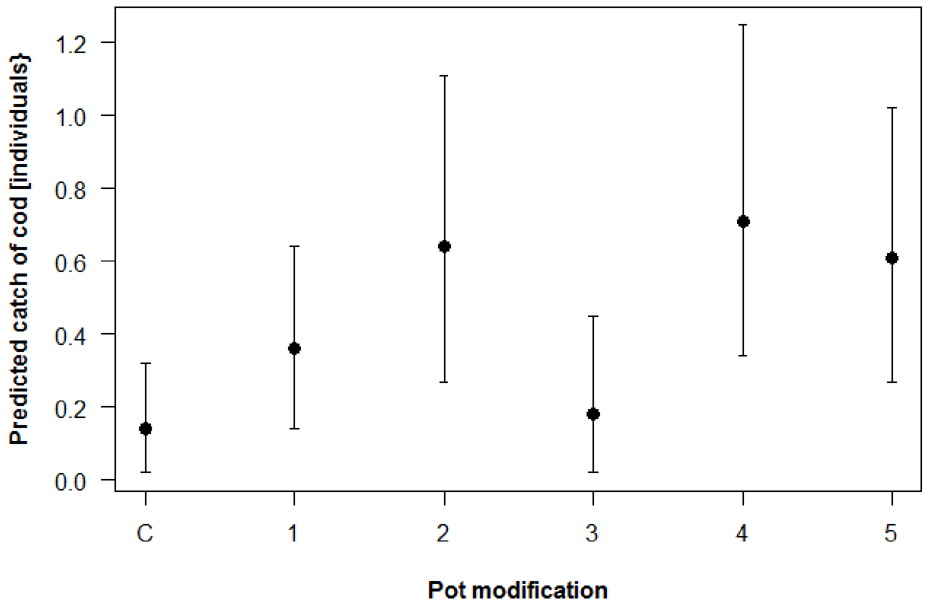

Figure 31: Predicted cod catches in number of individuals for pot modifications 1-5 and C. Error bars showing lower and upper confidence limits of bootstrapping (3000 repetitions).

Another result of this modeling approach was the probability of catching a certain number of individuals n per day and pot (Table 16, Figure 32).

The highest probability to catch no fish was found for pot C and pot 3 with ~90% and also the most efficient modification 4 (herring and light) has a chance of ~52% to catch no fish. This order of probabilities changed for the probability to catch a single fish. For this case, the most efficient modifications were "herring, light and entrance" with 32.6%, followed by "herring and light" with 30.5%. The higher the number of individuals is, the lower is the probability to catch this number. However, in most cases the modifications including herring (2, 4 and 5) showed a higher probability than other modifications.

Table 16: Probability (between 0 and 1) of pot modifications 1 to 5 and C to catch n individuals of cod per day and pot (bold: highest value).

Number of potential caught individuals per day and pot n	Pot modification					
	C	1	2	3	4	5
0	**0.886364**	0.704545	0.636364	**0.886364**	0.522727	0.545455
1	0.093586	0.236382	0.182825	0.065091	0.305077	**0.325659**
2	0.017615	0.050905	0.114015	0.033433	**0.127676**	0.103162
3	0.002210	0.007308	**0.047402**	0.011448	0.035622	0.021786
4	0.000208	0.000787	**0.014781**	0.002940	0.007454	0.003451
5	0.000016	0.000068	**0.003687**	0.000604	0.001248	0.000437

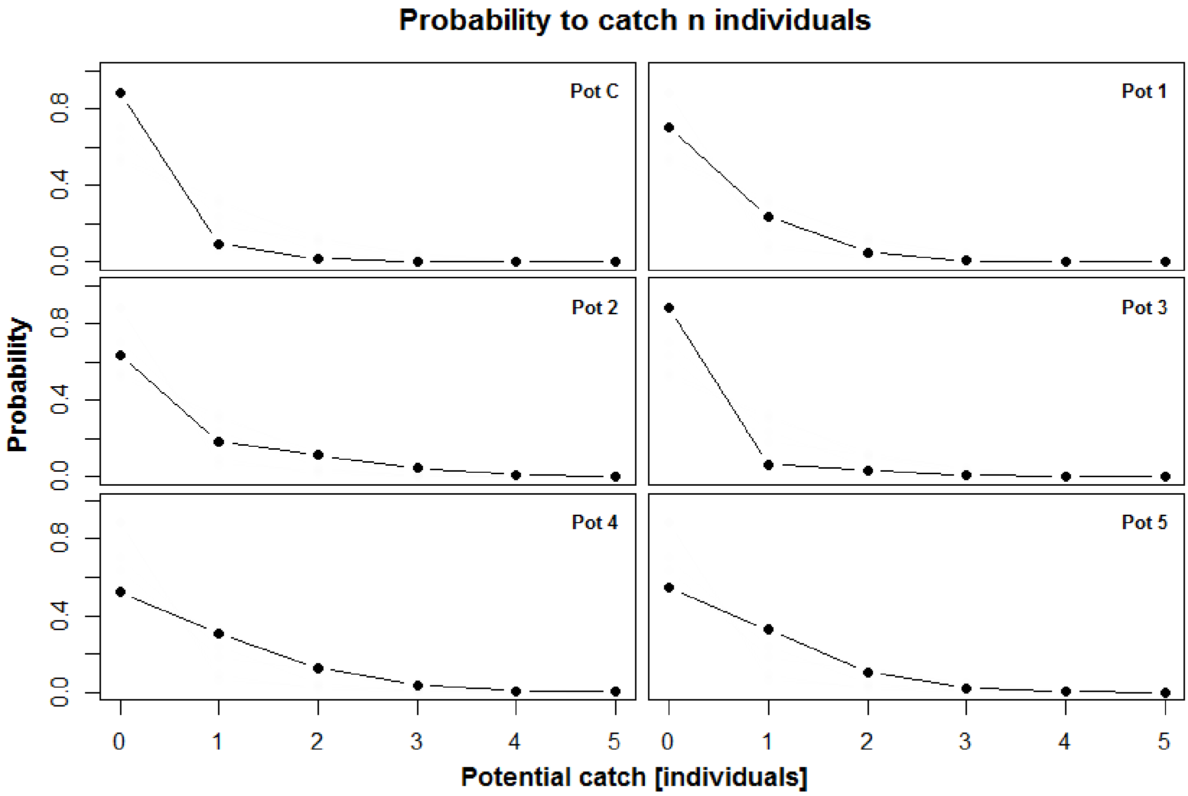

Figure 32: Probability of pot modifications 1 to 5 and C to catch n individuals of cod per day and pot.

3.5.3 Seasonal fluctuations of pot catches

The pot catches of cod are characterized by strong fluctuations (Figure 33). The catches were low in March, increased at the beginning of May to their maximum, but showed a rapid decrease subsequently. After a little increase, the values stabilized on moderate values from the end of May until the end of the study.

During the entire period of investigation, many zero catches occurred, resulting in a low mean curve. The smallest values were at level zero all times.

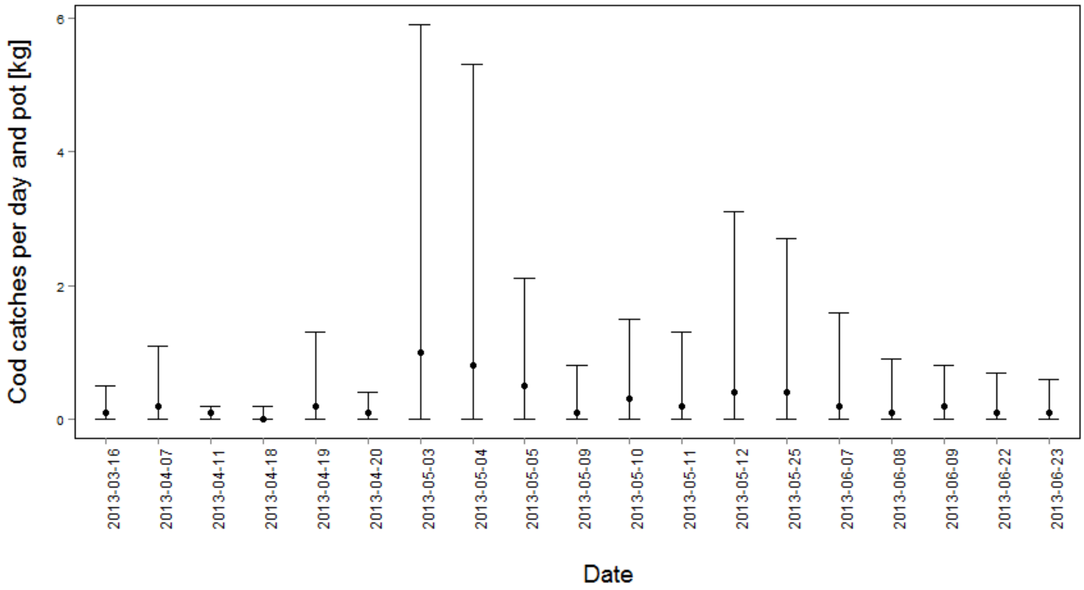

Figure 33: Cod catches of cod per pot and day [kg] over time. Dots represent mean. Error bars show minimum and maximum.

3.5.4 Impact of soak time

Four times, the fish pots were left in the water for more than one day (Table 5). Due to this fact, the analysis of the impact of soak time was limited.

The result of this analysis indicated no effects of a prolonged soak time on the total catch of fish pots (Figure 34). Consequently, the total catch of longer soaked pots, standardized by days of fishing (catch per day) is lower than the catch of pots, which were left in the water for one day (Figure 35).

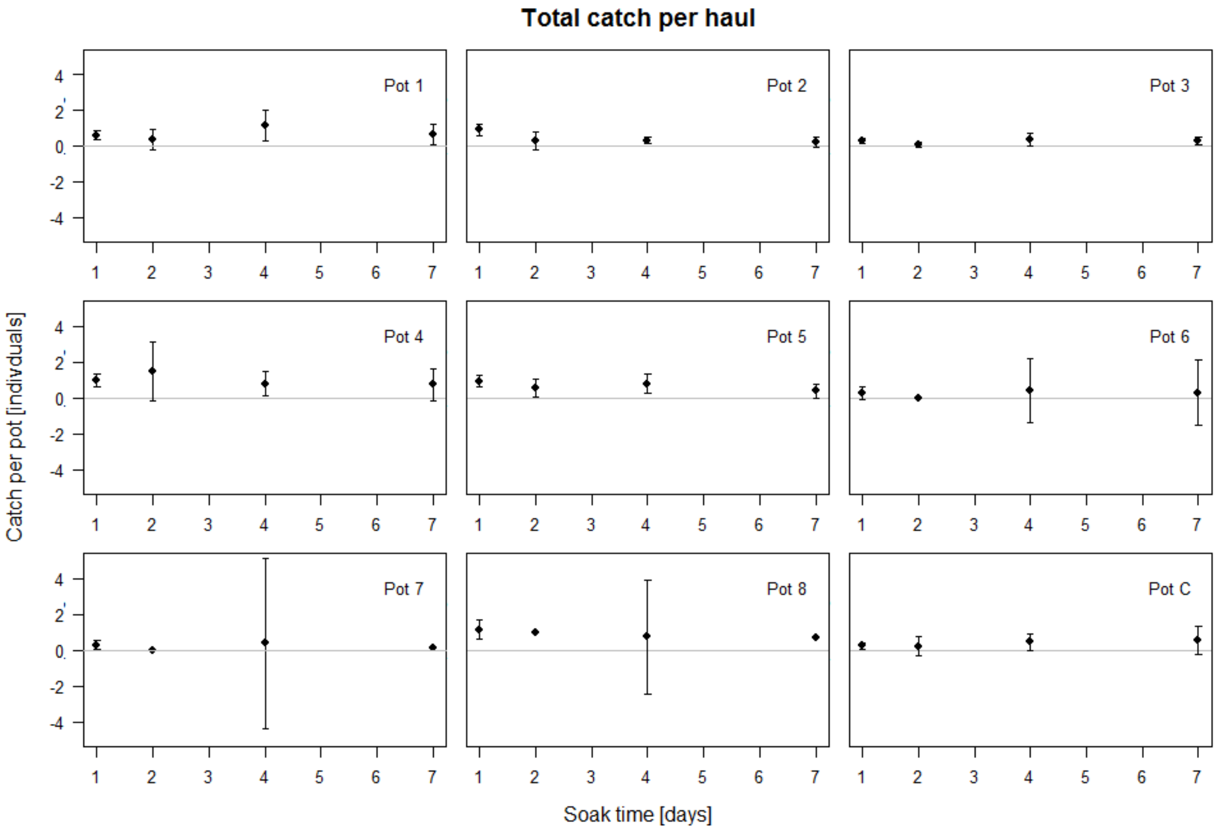

Figure 34: Impact of soak time on pot catches per haul separated by pot modifications. Error bars show standard deviation.

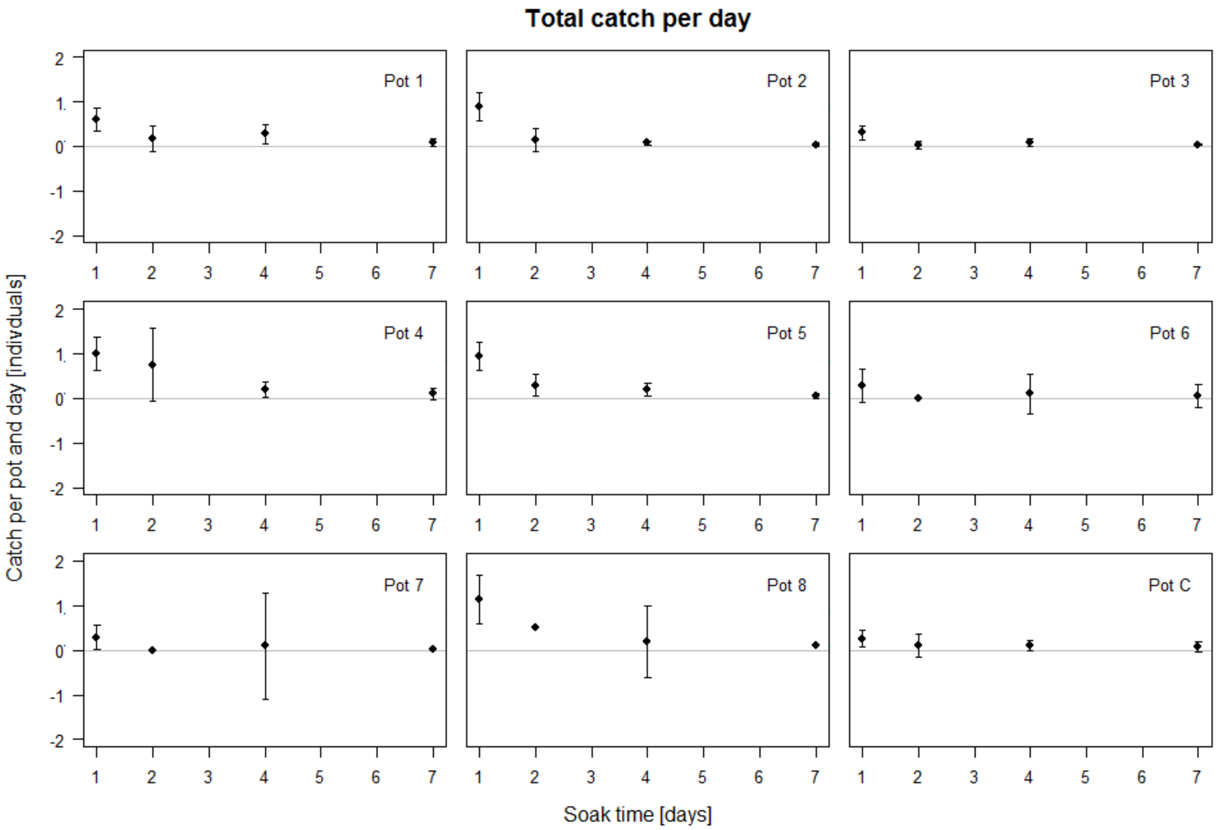

Figure 35: Impact of soak time on catches per pot and day separated by pot modifications. Error bars show standard deviation.

3.5.5 Fish pots versus standard gillnet

The cod catches of fish pots used for the comparison of pots and standard gillnets are based on the values, obtained by the modeling approach (see chapter 3.5.2). The predicted value for the catch of cod per day and pot of the best pot modification (modification 4 which used herring and light) was raised to ten pots, since this is the amount of pots that can be handled in the same time as one lot (4x55 m) of a standard gillnet. This estimated catch of ten pots was compared to the mean catch of cod per day and lot of a standard gillnet, whereby these values represent the CPUE of each gear in this study.

Since the predicted catch values for the pot are based on the number of individuals of eleven hauls, the catches of gillnets were also taken in the units “individuals per day and lot” from these eleven hauls (for description of these hauls see chapter 3.5.2).

A modeling approach for individuals above MLS, caught in fish pots, was not possible due to too few catches. Instead, the proportion of individuals above 38 cm, caught in fish pots, combined with the CPUE from the modelling approach, was compared to the number of individuals above 38 cm, caught in the standard gillnet (Table 17).

Table 17: Caught individuals per day of standard gillnets of days, relevant for comparison of standard gillnets and fish pots and resulting mean catch per day and lot (SD: Standard deviation).

Date	Individuals per day		Mean catch per day and lot [numbers] (~ CPUE)
	Lot 1	Lot 3	
04/05/2013	8.00	7.00	7.50
05/05/2013	7.00	2.00	4.50
10/05/2013	1.00	7.00	4.00
11/05/2013	8.00	2.00	5.00
12/05/2013	0	7.00	3.50
25/05/2013	3.00	7.00	5.00
07/06/2013	2.00	2.00	2.00
08/06/2013	5.00	6.00	5.50
09/06/2013	7.00	7.00	7.00
22/06/2013	1.00	3.50	2.25
23/06/2013	2.00	4.00	3.00
Mean ± SD	4.00 ± 3.07	4.95 ± 2.26	**4.48 ± 1.78**

Based on the modeling approach (see chapter 3.5.2), 7.1 individuals of all length classes are expected to be caught in a pot string, consisting of ten pots that are baited with herring and light. This value is 1.59 times higher than the mean number of individuals, caught in one lot of gillnet (4.48 individuals per day, Table 18).

Considering individuals above MLS, the CPUE decreased to 2.57 individuals per ten fish pots and 4.11 individuals per one lot of standard gillnets (Table 18).

Table 18: CPUE comparison fish pot and standard gillnet for cod. CPUE considering all length classes ($CPUE_{all\ length\ classes}$) based on values of Table 18 for standard gillnets and on results of the modeling approach for fish pots (Table 15). $CPUE_{>38cm}$ based on $CPUE_{all\ length\ classes}$ and ratio of individuals above MLS ($\%_{>38cm}$) (Figure 22).

	Individuals		
	Fish pot		Standard gillnet
$CPUE_{all\ length\ classes}$	7.10	>>	4.48
$\%_{>38cm}$	36.30	<<	91.70
$CPUE_{>38cm}$	2.57	<<	4.11

3.5.6 Handling

Onboard FRV Clupea, three people were needed for setting and hauling the pots.
After a certain settling-in period, handling did not cause any problems. Setting of a string of twelve fish pots took five minutes on average, whereas hauling required approximately twelve minutes. Clearing the pots depended on the amount of caught fish and ranged from some minutes up to half an hour per string.
The most difficult part was to haul the pot which was covered with camouflage netting (modification III8, Figure 15). Since the netting material became saturated with water, the weight of the pot increased enormously and resulted in a more difficult handling.
From the 3rd to the 4th of May, a strong current was apparent, which pushed the marking flags of pot string I under the water surface. To recover the pot string, two grappling-hooks were towed behind the vessel until they “found” the groundline of the string.

3.5.7 Video observations

During the observation of pots, very few fish were seen in the proximity of the fish pots. Some small fish entered and left the pots through the entrance (Figure 36), as well as through the meshes and some larger fish swam far outside the traps. Consequently, it is not possible to evaluate the behavior of larger fish in relation to the entrance.

Nevertheless, the video footage revealed three facts about the pots: a) the unfolding of the chambers worked without any problems, b) the pots stood stable on the sea bottom and c) the attempt to raise the pots (pots III1-III7, see Table 2) over the seabed failed. Also, pots equipped with floats did not float over the seabed. Thus, all pots of string III were handled equal in all analyses.

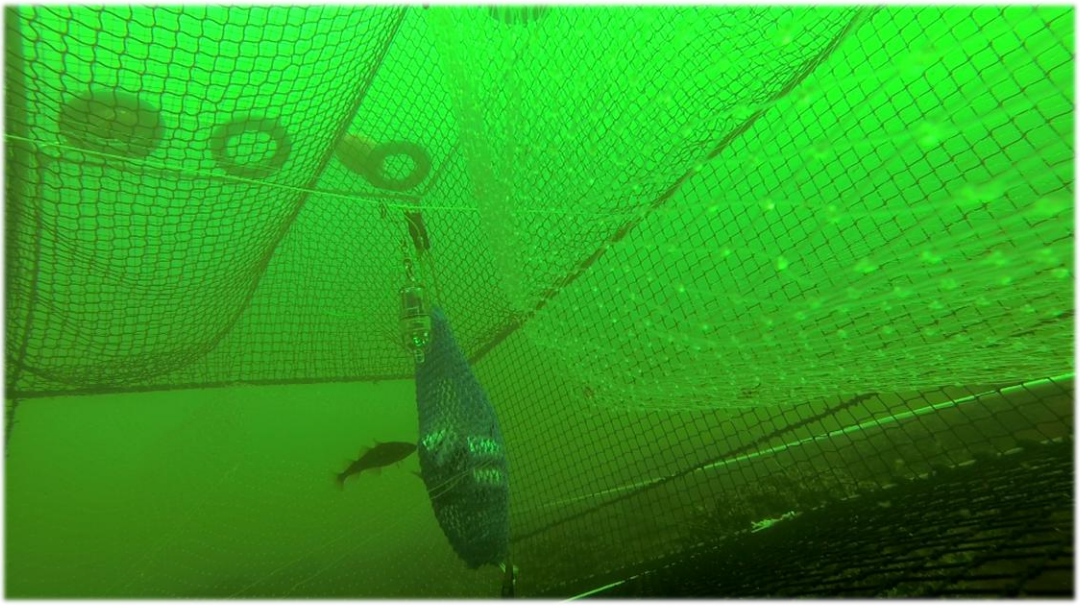

Figure 36: Small cod in Norwegian fish pot with modification 6 (herring, light and entrance) during video observation on 20th of June 2013.

3.6 Fish pots - Canadian type

The Canadian fish pots did not catch any fish during this study (Table 5). Thus, no further statistical analyses were conducted.

The handling of this pot type ran without any problems from the beginning. For checking the pots, two people and a crane were necessary. In total, checking of one pot needed approximately 5 minutes. If the bait had to be replaced, additional five minutes were needed.

Since these pots do not have a groundline and only one line connected it to the marking flag at the surface, it is difficult to find and recover lost pots. On the last day of this study, the marking flag of one Canadian pot was not detectable, probably due to strong current and even after two hours searching for the pot with grappling hooks, it was not possible to find it.

During video observation, very few fish were seen in the proximity of the fish pots. Some small fish entered and left the pot through the meshes. Some larger fish swam in the near of the pot, but none entered it (Figure 37). An evaluation of their behavior in relation to the pots, especially the trigger mechanism, was therefore difficult.

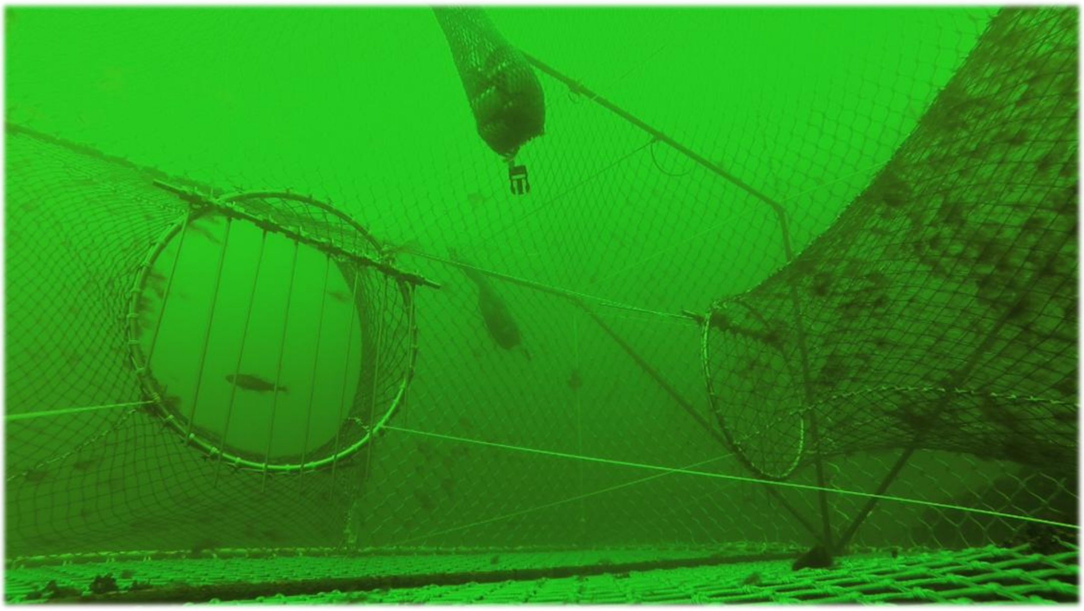

Figure 37: Small cod in front of an entrance of a Canadian fish pot during video observation on 20th of June 2013.

3.7 Jigging machines

3.7.1 Descriptive analysis

Comparison of different machine setups

In general, all setups of jigging machines caught few fish at similar levels (Table 5). Beside one flounder, two shorthorn sculpins and twelve whitings, cod represented the main species of the catch with 60 individuals. Therefore, further analysis will focus on cod.

All three machines were in use for 66.7 hours in parallel and caught almost the same amount of cod, round about 20 cod per machine (Table 19). Consequently, the catch per hour (=CPUE) of ~0.3 individuals and ~0.19 kg was similar for all setups (Table 19). The p-values (Mann Whitney U-test), higher than 0.05, indicate no significant differences between all three machine setups.

However, the machines caught different ratios of fish below and above MLS (Figure 38). Most cod above MLS were caught by jigging machine 2 (55.00% > MLS), followed by jigging machine 3 (52.38%) and jigging machine 1 (36.84% > MLS) (Table 19; Figure 38).

Table 19: Cod catches of jigging machines in number of individuals and weight [kg] (weight in brackets), percentage of fish above MLS and p-values of Mann Whitney U-test, made between different setups (see Table 3 for explanation of setups).

Cod catch	**Jigging machine**			**Total**
	1	**2**	**3**	
all length classes	**19 (9.91)**	**20 (15.23)**	**21 (13.13)**	**60 (38.27)**
<38 cm	12 (4.06)	9 (3.13)	10 (3.43)	31 (10.62)
>38 cm	7 (5.85)	11 (12.10)	11 (9.70)	29 (27.65)
% cod >38 cm	**36.84%**	**55.00%**	**52.38%**	**48.33%**
p-values	**>>0.05**		**>>0.05**	
		>>0.05		
CPUE	**0.28 (0.15)**	**0.30 (0.23)**	**0.31 (0.20)**	**0.9 (0.57)**

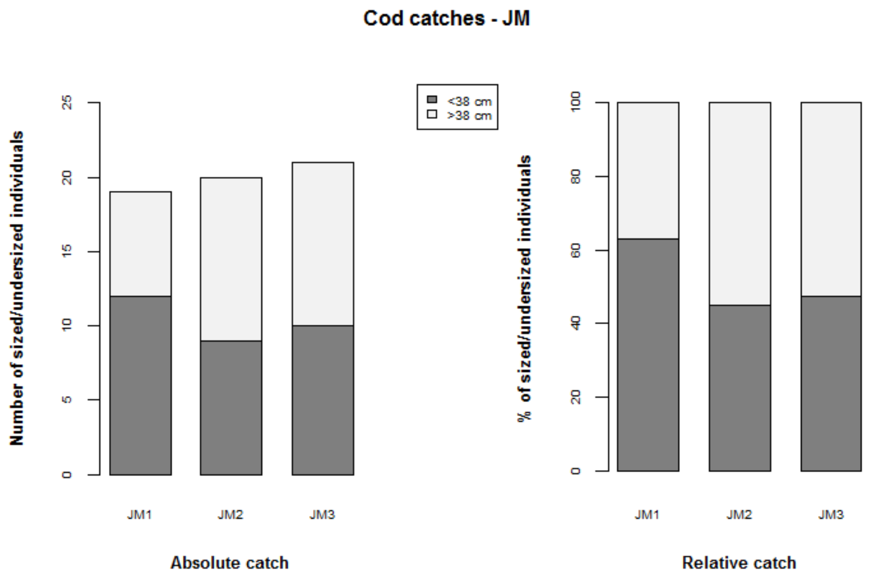

Figure 38: Absolute and relative cod catches based on number of individuals caught different jigging machine setups (for explanation of jigging machines setups see Table 3).

Comparison of different lures

To test, if different lures have different catch efficiencies, jigging machine 3 was equipped with different colored and different shaped lures. Thus, the analysis of different lures is limited to the catches of jigging machine 3, whereas all hauls were considered as valid. Since the time of fishing duration is not available for different lures, an estimation of the CPUE was not able to be done for each lure.

Nevertheless, the results indicate that all colors and all shapes of lures caught fish (Table 20). Contrary to shape and color of lure, the position on the line was very important: almost every fish was caught by the lure which was nearest to the sea bottom.

Table 20: Cod catches of jigging machine 3 in number of individuals and weight [kg], separated by lure type (Figure 17).

Lure	Catch – cod [individuals]	Catch – cod [kg]
Cod fly (green)	2	1.5
Shad (pink)	3	2.2
Shad (red-yellow)	3	1.2
Hellgie (green)	5	2.4
Twister (blue- green)	3	2.4
Twister (orange-black)	1	0.2
Twister (red)	1	0.9
Twister (red-black)	3	2.4

3.7.2 Jigging machine versus standard gillnet

For comparing the catch efficiencies, only the days of jigging were regarded, when gillnets were set simultaneously. Thus, 16 hauls remained for the analysis, which was only done for cod. It was the only marketable species that was caught in sufficient numbers in both gears. Since a) the durations of reaching fishing grounds were equal and b) hauling, clearing and setting of one lot of gillnets took about one hour, the aggregated catches of all three jigging machines per day were transformed to catch per hour. The resulting values were compared to the mean catches of one lot of standard gillnets, which were hauled one day later (Table 21).

The total catch per hour of three jigging machines ranged from zero to five fish. The mean catch of jigging machines (1.26 individuals) was less than a quarter of the mean catch of one lot of standard gillnets (5.86 individuals). Proved by a p-value (Mann Whitney U-test), which was less than 0.05, the standard gillnet caught significantly more cod per unit effort than the jigging machines (Figure 39).

Table 21: Comparison of CPUE of jigging machine (JM) and standard gillnet (SGN). CPUE of JM calculated as total catch per day divided by duration of jig fishing at this day. CPUE of SGN as mean catch per day of lot 1 and lot 3. (SD: Standard deviation).

		JMs		SGN
Start	**Jigging-duration [h]**	**Catch per day [numbers]**	**Catch per hour [numbers] ~ CPUE**	**Mean catch per lot and day [numbers] ~ CPUE**
15/03/2013	4.99	0	0	1.50
06/04/2013	2.76	1	0.36	1.00
18/04/2013	2.50	1	0.40	17.50
19/04/2013	3.05	2	0.66	8.00
02/05/2013	4.94	17	3.44	16.50
03/05/2013	2.97	15	5.05	7.50
04/05/2013	1.26	3	2.38	4.50
09/05/2013	3.73	4	1.07	4.00
10/05/2013	2.60	0	0	5.00
11/05/2013	2.94	6	2.04	3.50
24/05/2013	4.32	3	0.69	5.00
06/06/2013	3.54	1	0.28	2.00
07/06/2013	1.81	0	0	5.50
08/06/2013	1.39	3	2.16	7.00
20/06/2013	3.26	3	0.92	2.25
22/06/2013	1.39	1	0.72	3.00
Mean ± SD	2.97	3.75 ± 5.07	**1.26 ± 1.42**	**5.86 ± 4.82**

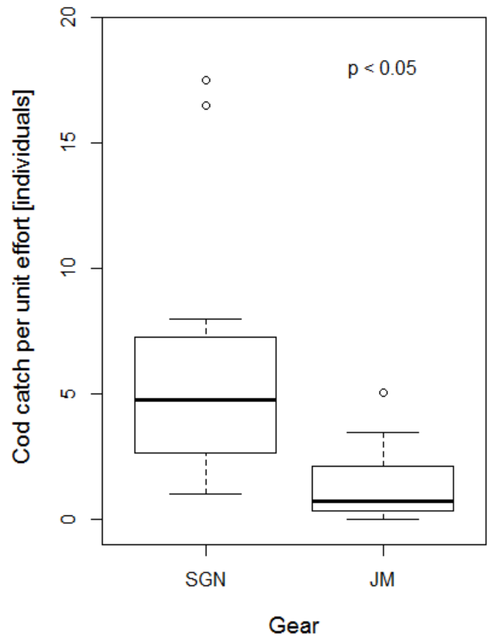

Figure 39: Comparison of cod catches per unit effort in number of individuals by jigging machine (JM) and standard gillnet (SGN) based on values of Table 21. Line shows median, whereas the box represents lower and upper quartile. Whiskers show values within 1.5 of interquartile range. Small circles are outliers. P-value (Mann Whitney U-test) indicates significant differences between CPUE of standard gillnets and jigging machine.

3.7.3 Handling

It was easy to operate three machines with one person because jigging machines work automatically. Nevertheless, the machines offered a number of problems: almost no caught fish was detected by the machine itself. Trying to solve this problem by adjusting catch sensitivity and reducing the sinker weight did not work because the lures drifted away when the sinker was not heavy enough.

Another problem was that the adjustment of the brake was intricate: if it was too soft, the sinker would pull the line out very fast and would hit the bottom very hard while the spool would continue to unwind the line. This could lead to a snarl, which would take time to be cleared. Additionally, the uncontrolled unwinding results in problems with the automatic depth detection. As a result, the zero-point, where the machine stops hauling the line, would be shifted and the lures would be pulled through the pulley. In the worst case, all lures and the sinker could tear off.

If the brake strength was adjusted too strong, the machines started the jigging program somewhere in the water column because no line was pulled out, which signalizes the machine the sea bottom.

Another observation was the frequent appearance of fish, injured by barotrauma. Barotrauma is an injury, occurring in physoclisti (fish which do not have a direct connection between their swim bladder and their gut to react on rapid decreases in ambient pressure). These fish were not able to adjust their internal pressure as fast as necessary and had an inflated body or even their stomach was everted, often signifying the soon death. When releasing these injured fish, many were not able to submerge for a couple of time, resulting in the additional danger of being eaten by seabirds. Furthermore, it was not possible to remove the hooks, without inflicting lethal damages to the caught fish in some cases.

3.8 Bycatch of marine mammals and seabirds

Only one bycatch of a marine mammal and no bycatch of seabirds occurred during this study. When the pots were hauled on the 18th of April after seven days of soak time, pot III8 (herring, light, entrance and camouflage netting) contained a ringed seal (*Pusa hispida* L., Figure 40).

Figure 40: A ringed seal was caught in fish pot III8 on 18th of April 2013 (© Rolf Singer).

The animal was collected by colleagues of the "South-East Rügen's Biosphere Reserve" and brought to the Meeresmuseum Stralsund, where the dissection of the seal took place on the 11th of June. The species was identified by molars and coat pattern (pers. comm. Klaus Harder, Meeresmuseum Stralsund; Figure 41). Furthermore, other basic information were gathered:

- Length: 116 cm
- Weight: 39 kg
- Health Condition prior to death: good
- Sex: female
- Age: 3 – 4 years

Figure 41: Bycaught ringed seal during dissection. a) coat pattern (© Klaus Harder). b) molars (© Klaus Harder).

4 Discussion

The amount of fish, available for the analytic part in this study, was quite low. A potential reason therefore could be the unusual springtime. The water was very cold over a long period, which may restrained cod from moving to shallower areas. At the beginning of May, when the bottom temperature reached values of more than 4° C, the catch rates increased notably, indicating that the fish came to the fishing grounds of this study. This could be explained by the optimum temperatures for rearing cod eggs, which ranges from 4° C to 8° C (WESTERNHAGEN, 1970).

Nevertheless, the catches decreased after a short time. Since the water did not reach temperatures, which are avoided by cod, the absence of prey species like herring might be an explanation.

4.1 Gillnets

The standard gillnet was the most efficient gear, used in this study, and caught about five times more fish than the lower gillnet (Figure 28). This result can be explained by the area of netting material because the amount of captured fish is related to it. In this case, the surface of the lower gillnets is less than one sixth of the standard gillnets.

The fraction of undersized cod was low in both types of gillnets (standard gillnets: 8.3% < MLS, lower gillnets: 0% < MLS), indicating a good size selectivity of gillnets regarding cod. This result corresponds to other investigations, which regarded the size selectivity of gillnets (HUSE *et al.*, 2000; SALVANES, 1991).

Beside reduced catches, lower gillnets also offered problems during handling. Utilities to get and clean gillnets are not adapted to this lower type. If lower gillnets should be used further on, these devices have to be modified.

On the basis of these two findings (a) low catch efficiency of lower gillnets in contrast to the standard gillnets and b) the difficult handling), it can be stated that this kind of modification cannot be regarded as an alternative for catching cod to standard gillnets under conditions like in this study. Nevertheless, lower gillnets could be a potential alternative to standard gillnets for other species, in other areas or in other seasons.

4.2 Fish pots - Norwegian type

A central part of this study was to test different modifications of the Norwegian fish pots. These pots showed the highest catches of the alternative gears, used in this study. After a short settling-in period, handling did not offer any problems and underwater observation showed that the pots functioned properly.

The results of testing different pot modifications indicate that herring as bait increased the catches. This outcome meets the expectations, based on previous investigations of fish pots in the Baltic Sea (LJUNGBERG, 2007; LORENZ *et al.*, 2009). For future investigations, it would be interesting to use uncut herring, since COLLINS (1990) has observed an increase of catches in pots, which were baited with whole clupeids – most likely because this kind of presenting the bait looks more naturally. An additional advantage is the work simplification due to a reduced preparation time when using uncut fish as bait.

Contrary to herring, the use of boilies as alternative bait is not recommendable because boilie baited pots caught as few fish as the unbaited control pots. Perhaps the boilies did not release odor as strong as herring.

Additional to herring, a light should further be used to raise the catch because pots with a light caught more fish than pots without. For future investigations, the use of different light colors could be interesting because different colors are supposed to catch different species and different amounts of fish (pers. comm. Thomas Lorenz, Verein Fisch und Umwelt).

Pots with modified entrances did not catch more fish than pots with standard entrances, whereby the design of the entrance is said to be one major factor, affecting the pot catch efficiency (FUREVIK, 1994). Future investigations should test other modifications of entrances because in this study only two modifications were tested and other changes may affect the catch efficiency more. One option might be to change the size of the funnel.

Also, the overall modification of a pot, consisting of herring, light, entrance and camouflage netting, did not show any positive effect on the catches. Considering the increased effort of handling this pot, the use of pots which are covered with this textile material is not recommended. Instead, other materials which do not become saturated with water could be used in future studies to imitate natural structure.

It was not successful to raise the pots off the bottom because the number of additional floats was not sufficient. Although floated fish pots can potentially catch more fish than bottom-set pots (FUREVIK *et al.*, 2008), they are associated with another problem. If jellyfish are in the fishing area, they can be drifted into the pots and make the handling more difficult (pers. comm.

Daniel Stepputtis, TI-OF). During this study, no jellyfish were caught, but in case of large catches of jellyfish, it might be difficult to heave the pots on deck and the jellyfish have to be picked out by hand. Additionally, it is a time-consuming and maybe dangerous job, if stinging species like hair jelly (*Cyanea capillata* L.) belong to the catch. Since one entrance of floated pots is automatically orientated towards the current, the probability to catch jellyfish is higher in floated pots than in pots which are set to the bottom. One solution of this problem could be the closure of this entrance. Thereby, a decrease of fish catches is not expected, since almost every fish approach baited pots from downstream, where the bait plume disperses (FUREVIK, 1994).

The catches of fish pots fluctuated during the study period. The first reason is probably the exceptionally long and cold winter, as already mentioned above. A second point is that, contrary to gillnets, where fish only have to be in the area of fishing or rather have to swim through it, fish have to enter the pots voluntarily, for example to get the bait inside the pot. According to HE (2005), natural prey must not be too plentiful when fishing with baited pots. Otherwise, fish could be satisfied and lose the interest in the bait. Therefore, lower catches of baited gears should be expected.

In contrast to the expectation that soak time affects the amount of catch, which was based on other investigations (BAGDONAS *et al.*, 2012; OVEGÅRD, 2011), this study did not find a direct relation of soak time and catch. Therefore, it is beneficial to empty pots every day, but if this is not possible due to bad weather, it is also no problem because the caught fish are usually still alive after several days (pers. observation).

This result of no dependence on soak time is contrary to studies of BAGDONAS *et al.* (2012), who observed a higher occurrence of cod on the second day, and OVEGÅRD (2011), who recommended a soak time of three days, whereby the catch efficiency for different soak times is potentially effected by several factors, such as the bait. If the bait is leached after one day, an increase of the catch is unlikely. Furthermore, fish which are already captured could attract (LJUNGBERG, 2007) or scare (HE & LODGE, 1990) other fish.

The comparison of the CPUE between standard gillnets and fish pots may primarily convey the impression that fish pots are more efficient than gillnets because the number of predicted individuals in pots (7.1 individuals) is 1.59 times higher than the mean value of gillnet catches per day (4.48 individuals) when considering all length classes. Nevertheless, the comparison of these numbers has to consider three other facts. a) The large confidence intervals of pots give an indication of high variability concerning the predicted CPUE values, calculated by the model. b) The corrected CPUE for length classes above MLS differed from the actual numbers. In this case, the CPUE of pots decreased enormously to 2.57 individuals per day, which is below the number of gillnets (4.11 individuals per day). c) The use of fish pots need more manpower than gillnets, which are often used by a single person (GABRIEL, 2005). Therefore, the proceeds must be divided.

Additionally to the lower CPUE considering fish above MLS, the bycatch of undersized cod poses other problems. Beside the longer handling time, many released fish were not able to survive. The reason for not surviving might be differences in temperature and pressure, injuries from handling the fish or gear contact. An efficient method to improve the selectivity of pots is the use of square mesh escape windows, as OVEGÅRD et al. (2011) did. During their study, one pot entrance and the net above this entrance was replaced by an escape window. Thus, undersized fish can escape from both chambers and the bycatch of undersized cod was reduced by 90%. Since a discard ban will potentially be established in the Baltic Sea also for cod, a use of these escape windows is recommended for all future use of fish pots to catch as few as possible undersized cod.

Another addition, which should be used in future pot fishing are special timed escape mechanisms like Galvanic Timed Releases (KRUSE *et al.*, 1993) or destruct panels of cotton web (BLOTT, 1978). Galvanic Timed Releases are small devices, which open a part of the pot if it is not hauled after a certain time and allow caught fish to escape. Cotton web panels work similar. If the pots are left in the water for a longer time, the material cotton material degrades and opens an escape window. The use of these options is important because pots can be lost from several causes, e.g. storms or strong currents, but lost pots (ghost pots) would continue fishing, which is called ghost fishing (MATSUOKA *et al.*, 2005).

The results of the effectiveness of fish pots, as observed in the present study, are supported by others studies (FUREVIK & LØKKEBORG, 1994; LJUNGBERG, 2007; LORENZ *et al.*, 2009). LORENZ *et al.* (2009), for example, observed gillnet catches which were more than twice as high as catches of fish pots in the water around Rügen. Furthermore, the fish pots caught most fish, when they were baited with herring and set in the near of wrecks or other structural elements. The idea of better catches in structured areas can be consolidated by regarding the results of an investigation of LJUNGBERG (2007). They compared pot and gillnet catches in the southeast of Sweden, where the coast is characterized by many natural structures. Indeed, the pots showed less catchability than gillnets, but better catches than the investigations, conducted in German waters. The pots caught 75% of the gillnet catches. Furthermore, shrimps were used as baits and found to be as efficient as herring. A study of FUREVIK & LØKKEBORG (1994), which was conducted in northern Norway, found squid and crab as best bait, both giving higher catches for cod than herring bait. Thus, different baits show varying efficiencies in different regions, possibly depending on the prey species of the target species.

All in all, it is not possible to fully recommend fish pots for the relatively scanty southern Baltic Sea at this time, because they had a relative low catch rate of sized fish and the handling effort is greater than for gillnets. Nevertheless, they could be a potential alternative in more structured areas or at different times to reduce the bycatch of mammals and sea birds.
Also, fish pots can be used in parallel to gillnets, since gillnets showed no effect on pots nor vice versa.

4.3 Fish pots - Canadian type

This study is the first, which tested this type of fish pot in the Baltic Sea so far. The result of exclusively zero catches could be explained by two suppositions: After the first hauls, it was assumed that the netting material frightened the fish because there was no time to soak them before the study started. This kind of soaking is a common procedure to adapt the smell of new materials to nature.
The other supposition concerns the trigger mechanism, which was used to prevent potentially caught fish from escaping through the entrance. The mechanism was maybe too strong. Due to the “fingers”, which are made of steel, it could be frightening for fish to swim through them into the pot. That would explain, why the fish, which was seen in the video footage, did not enter the pot and after several days in the water still no fish was caught.
Nevertheless, the investigations with this kind of fishing gear should be continued because results of other studies are promising (WALSH & SULLIVAN, 2010) and the experiments of this study were limited to the standard type without any modification, for example of the entrance or the color of netting material.

4.4 Jigging machines

This first attempt of describing the catch efficiency of jigging machines in the Baltic Sea showed that different jigging machine setups caught similar amounts of fish. Different lure types with different shapes and different colors showed similar results, indicating that fish are attracted by everything looking like prey. Similar results were demonstrated by a few previous studies, which considered the catch rates of different artificial lures. MACDONALD (2007) tested different artificial baits, which are used in commercial jig fisheries around Shetland to catch cod and found no significant differences of their catch efficiency. HSIEH *et al.* (2001) observed same results for another species. They compared different colors of lures, which are used to catch horse mackerel (*Pneumatophorus tapeinocephalus* L.) in north-eastern Taiwan and observed similar catches of all colors. Therefore, the assumption that red twisters are the best lures for cod could be withdrawn.

The calculated CPUE of cod for the jigging machines (1.26 individuals) was less than a quarter of the value for gillnets (5.86 individuals), whereby more than 50% of the caught fish were undersized. One suggestion to improve the selectivity might be to use larger hooks, but small fish also take large hooks and large fish also take small hooks (pers. observation). LØKKEBORG & BJORDAL (1992) found similar results when reviewing several publications that consider species and size selectivity of longlines.

One technical problem of the machines is that many hooked fish were not detected by the machine itself duo to poor sensitivity. Another problem (which also occurred in fish pots) is the condition of caught fish. Although, every fish was still alive when coming on board, many fish had strong injuries caused by hooks or by changes of ambient pressure. Since cod belong to the group of physoclisti, they are not able to adjust their internal pressure quickly to the ambient pressure (TYTLER & BLAXTER, 1973). To counteract this fact, it would be possible, to reduce the speed of hauling the fish after biting, but this would result in a higher chance to lose fish.

Nevertheless, the investigations of jigging machines should continue - maybe models of other companies can be used or deeper fishing grounds could be tested.

However, the use of these machines cannot be recommended so far as economic alternative gears. Due to low catches, a high amount of undersized fish and many undetected catches, the machines must be modified and further investigations are necessary to attain economic catch amounts in the Baltic Sea by using jigging machines.

4.5 Bycatch

Although incidental catch of marine mammals and seabirds is known as a great problem of gillnets (BELLEBAUM, 2011; COX *et al.*, 1998; KOSCHINSKI, 2001; PFANDER & PFANDER, 1997; ZYDELIS *et al.*, 2009), no bycatches of mammals or birds occurred in gillnets during this study. The only incident was achieved by one of the Norwegian fish pots, which caught a ringed seal. The pot was baited with herring and equipped with a light, modified entrances and a camouflage netting.

This problem was also observed in Swedish waters (pers. comm. Mikael Ovegård, Lund University). To solve it, the so called seal exclusion devices (SEDs) were tested by the Swedish colleagues. These SEDs are metal frames or nets in the entrance of the pot. An evaluation of these Swedish trials has not been finished yet.

Since also birds were caught in fish pots during other investigations (LORENZ *et al.*, 2009), it becomes clear that gears like pots, which are suggested to reduce or avoid the bycatch of mammals and birds are no mammal- and seabird-safe alternatives in their standard configuration.

4.6 Conclusion

All alternative gears, which were tested in this study, are not as efficient as gillnets to catch cod and other important species in the Baltic Sea. The lower gillnets caught less fish than standard gillnets and handling of them was problematic. The Norwegian fish pots, which were baited with herring and a light, showed the highest predicted catches of the pot modifications - at first appearance, even higher than the mean catches of a standard gillnet. Nevertheless, when considering other important factors, like amount of work and number of marketable fish, the pots cannot be regarded as a general economic alternative to gillnets in the southern Baltic Sea to date. The Canadian fish pots caught no fish during this study, but should be tested further because they are quite efficient fishing gears in other regions. The jigging machine caught less fish than gillnets, whereby the use of a program and type of lure did not affect the catchability significantly.

This study shows that none of the tested alternative gears can be regarded as an efficient alternative to common gillnets at this time. However, it might be possible to use them in other regions, to other times or with other modifications and if actually certain areas or periods become closed for gillnets, the use of alternative fishing gears is inevitable.

4.7 Outlook

Since the observations of each alternative gear indicated that different modifications can contribute to an increase of their catch efficiencies, investigations like this should continue.
The fish pots should be tested with other modifications and other natural baits. For example LJUNGBERG (2007) and FUREVIK & LØKKEBORG (1994) identified shrimps as a promising bait for cod. LØKKEBORG (1991) observed large cod catches by squid baited pots in other regions. Beside these natural baits, the use of artificial baits should be considered, which are already in use for longlining (LØKKEBORG, 1994). The idea of artificial baits is to develop a bait, which is based on the amino acid composition of the target´s prey species and releases an odor for several days. This may contribute to an increase of the catches with longer soak times. Furthermore, mechanical modification should be reconsidered because several ideas exist, for example the use of leading panels between pots (LORENZ *et al.*, 2009).
Jigging machines should also be tested again, for example with glowing lures during dawn or dusk, since feeding activity of cod is higher during this time (LØKKEBORG *et al.*, 1989).
Beside the improvement of alternative gears, which show relative low catches until today, modifications of gillnets should also be considered again in future. Additionally to persistent experiments with Porpoise Alarms by the TI-OF, the use of reflective net material seems to be one of the most promising ideas and should be regarded again in future experiments.
Since this study did not account for the economic view of this problem, a consideration of these aspects should be done in future, for example by an observation of the sale of fish. Thereby, it would be interesting, if fish, which were caught in a sustainable way, could be actually sold at higher prices. If this is the case, a fisherman could get same money for less fish.

In conclusion, the investigations to date are a good start to reduce interactions of marine mammals and seabirds with fishery, but much more research needs to be done before substantial success can be achieved. This research can establish on many ideas to modify the gillnet or potential alternative gears like fish pots and jigging machines.

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Declaration of Authorship

I, Thomas Noack, hereby declare that this thesis entitled

“Reduction of the bycatch in the Baltic Sea Fishery: An evaluation of alternative passive fishing gears and their comparison to the standard gillnet“

and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

Rostock, 10/09/2013 **Thomas Noack**