Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences
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SHEDDING LIGHT ON ALTERNATIVE SHRIMP FISHING

– Development of shrimp pots with a focus on selection, attraction and behaviour

BELYSA ALTERNATIVA RÄKFISKE

– Utveckling av räkbur med fokus på selektivitet, attraktion och beteende

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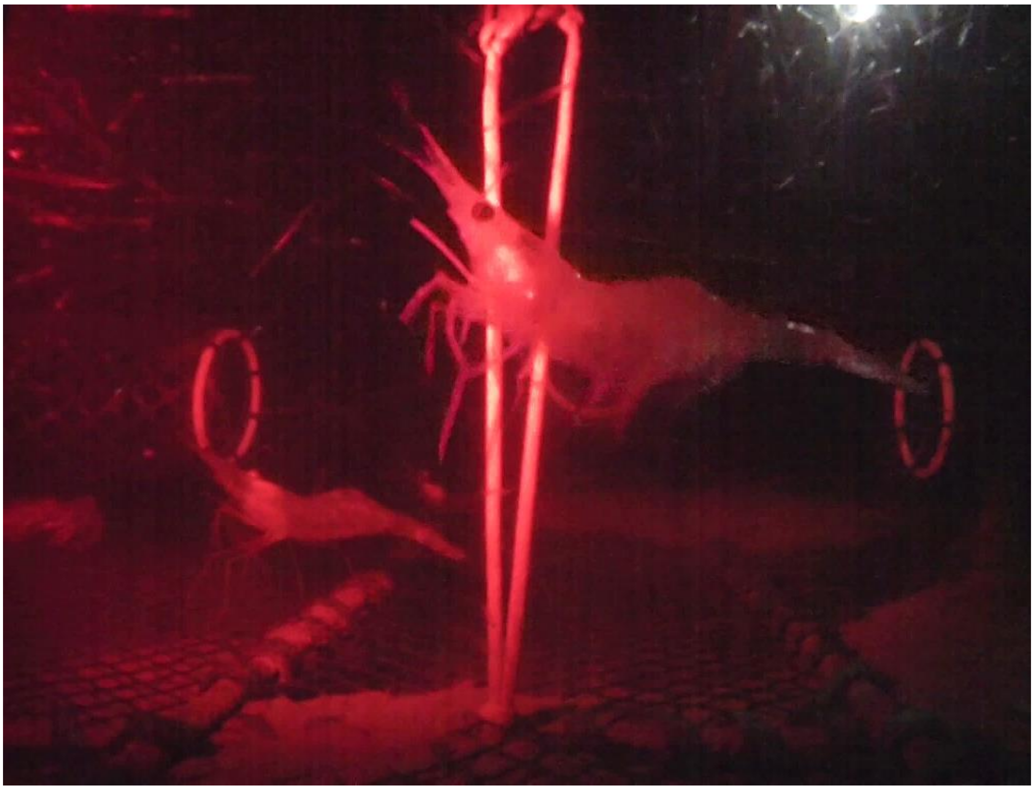

Department of Aquatic Resources

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René Bouwmeester
rene.bouwmeest.r@gmail.com

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Supervisor: Peter Ljungberg
Mail address supervisor: peter.ljungberg@slu.se
Department: SLU, Department of Aquatic Resources in Lysekil, Sweden

Examiner: Valerio Bartolino
Mail address examiner: valerio.bartolino@slu.se
Department: SLU, Department of Aquatic Resources in Lysekil, Sweden

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Keywords: Northern shrimp, Pandalus borealis, shrimp pot, fishing, bycatch, gadoid, attract, green light, white light, UV light, LED light, underwater camera, video recording, behaviour.

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Abstract

In search of a less destructive alternative to current shrimp fishing methods, both in terms of bycatch reduction and increasing shrimp-catch in pots, this study aims to analyse the catches and bycatches of different pot designs and alternative attractants for pot fishing on Northern shrimps (*Pandalus borealis*). There are three main objectives: (1. describe how the different pot designs and attractants affects shrimp catch and bycatch in abundance and composition, (2. describe how the different pot designs and attractants affects the shrimp size distribution of the catch, (3. Describe how the different pot designs and attractants affect the behaviour of shrimps and bycatch inside the pot by means of underwater video recordings. These objectives were met by conducting an experimental fishing study in Gullmarsfjord, Sweden. As alternative attractant lights in the colours green, white and ultra violet (UV) were tested together with four different pot design. The pots with the larger oval entrances caught significantly more shrimp in CPUE in comparison to the pots with the plastic funnel entrances. In terms of bycatch no significant difference was found between pot designs. The use of lights as an alternative to herring as attractant resulted into a 3.1 times higher shrimp CPUE. However the attractants also effected the bycatch. Especially green light resulted in many gadoids in the bycatch, white light resulted in fewer gadoids than green light, but UV light was found to be the most selective light with the best shrimp catch/bycatch ratio. The results from this study contributes to the development of fishing shrimps with pots by presenting how the tested methods increased shrimp catches and affected bycatches.

Sammanfattning

Studien syftar till att utvärdera räkburar som ett mindre destruktivt alternativ till nuvarande räkfiskemetoder efter nordhavsräka (*Pandalus borealis*) i svenska vatten. Studien hade tre huvudmål: 1. att analysera fångst och bifångst i förhållande till burdesign och typ av attraktion; 2. att analysera storleksfördelning av räkor i förhållande till burdesign och attraktion; 3. att utföra beteendeanalys av fångst och bifångst genom medel av video-inspelningar under vatten från insidan av burar. Bur ett och tre hade den högsta räkfångsten, troligen på grund av de större, ovala, ingångarna. Användningen av ljus som ett alternativ till sill som attraktion resulterade i en 3,1 gånger högre räkfångst. I jämförelse visade sig att typ av attraktion ha större inverkan än burdesign när det kom till mängden fångad räka. Kombinationen av vitt ljus och sill gav det bästa resultatet, följt av vitt ljus och UV-ljus. Däremot påverkade varje kombination av attraktorer fångs-kompositionen av framför allt bifångstarter på eget sätt.

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1 Introduction

Marine ecosystems are under pressure due to many human activities. Marine-food resources are dwindling (Ripple et al., 2017) and many ecosystems are shifting their balance. Fishing is one of the human activities that greatly affects the marine systems (Pauly et al., 2000). Not only overfishing affects marine ecosystems severely, but also many fishing methods we commonly use are destructive and catch a lot of unwanted organisms, called bycatch (Hall et al., 2000). In order to reduce bycatches, the EU has responded with the landing obligation also known as discard ban. The landing obligation requires that all catches of species regulated by Total Allowance Catch (TAC; species that are allowed to be caught until a set total amount) should be landed and counted against quota (https://ec.europa.eu/, 2017). This creates a motivation for increasing the selectivity of the fishing-gear and methods (Hall et al., 2000).

Sweden has an annual fishing economy worth of one billion SEK, the equivalent of 103 million EUR (European Parliament, 2010). Therefore economic stakes are high and changes in this industry can have large effects. Average annual landings of 2000 tons of shrimps are realised by Sweden (Ulmestrand et al., 2013), and with a landing value of 100 million SEK (10 million euros) they account for 10% of the annual Swedish fishing economy (European Parliament, 2010). Fishing for shrimps in Sweden is usually done with a bottom trawl. This is a weighted net that is dragged over the ocean floor with possibly devastating effects on marine ecosystems, especially benthic ecosystems (National Research Council, 2002; Jones, 1992). Shrimp trawlers are notorious for having extremely high bycatch rates. They are responsible for more than one-third of the world's total known bycatch, with bycatch ratios between 3:1 (three kg of bycatch per one kg shrimp) and 20:1 with an average of 6:1 (Clucas, 1997; Hall et al., 2000). Hence, my interest to investigate for alternative and more sustainable fishing methods for shrimp by means of using pots and alternative attractants.

Fishing with pots is considered to be more sustainable and of low impact on the ocean floor (Jennings et al., 2001; Moffett et al., 2012; Suuronen et al., 2012). Firstly, it allows undersized shrimps to escape through meshes of the nets, which helps to sustain the shrimp population. Secondly, bycatch is minimal compared to traditional catch methods: bycatches from a pot fishery in Maine 2010 and 2011 where 1.21% and 1.11% while in the same years the bycatch from trawling was 5 times higher (ASMFC, 2015a, 2015b; Clark et al., 2000). Thirdly, in pot fishing the survival rate of the bycatch is expected to be much higher compared to trawling because the catch remains undamaged in pot and could be released alive facilitating compliance with the landing obligation (Suuronen et al., 2012).

Next to environmental benefit there are several advantages for the fisherman as well: fishing with pots requires far less fuel and less manpower compared to trawling, on small boats it can even be a one man job. Pots can also be deployed at bottoms where it is difficult to trawl. Most importantly, in the case of bad weather conditions the pot can just stay on the seafloor and continue fishing since the catch is kept alive in the pots. Also in contradiction to using a trawl, shrimps remain undamaged in the pots and can therefore be sold with a higher quality.

One of these shrimp species that is fished on a large scale is the Northern shrimp (*Pandalus borealis*). They can be found in the Pacific and Atlantic ocean and the connected seas between 40ºN and 80ºN latitude (Squires, 1990), They are also known as Northern prawn, deep sea prawn, pink shrimp or cold water shrimp. They can be found at temperatures between 0 and 14ºC, but they prefer temperatures between 1 and 6ºC (Shumway et al 1985). Strong correlations are found between temperature and abundance (Koeller et al., 2007). Northern shrimps mostly live on soft bottoms with a high organic content between a depth of 20-500m, but are also found at greater depths (Squires, 1990; Bergström, 1992). It is known that Northern shrimps perform daily vertical migration. During the day they feed mainly on detritus and during their nocturnal migration they predate on krill, copepods and other zooplankton (Savenkoff et al., 2006). Northern prawns are protandric, meaning that they are hatched as males and after approximately four years they become females. However environment and mainly temperature has a larger effect on when they change sex (Savenkoff et al., 2006). For spawning and when the females release their eggs the shrimps move to shallow areas inshore. (Savenkoff et al., 2006). Once they have moved inshore they are accessible for pot fishers (Moffett et al., 2012). Northern prawns are usually caught with pots at a depth between 60 and 80m (Berggren, 2015-2016).

An example of a successful commercial pot fishery on northern shrimps can be found in the Gulf of Maine, since 1996 (Koeller et al., 2007). Catches are between 1 and 13kg per pot, with an average of 5.5kg. However catches can vary greatly throughout the fishing season, from 2000kg per landing down to below 100kg per boat. (ASMFC, 2015a, 2015b) Boats usually haul and set on average 100 pots. They are often placed individually, in pairs or in links (a row of multiple pots attached to the same string). Since pots can be deployed on almost any substrate, they are usually placed on soft bottoms between trawl areas and hard bottoms. This pot fishery has landed on average 5% of the annual landing of Northern shrimps with peaks up to 9% (Northeast Fisheries Science Center, 2003), for a corresponding value of half a million US dollars (calculated with data from Northern Shrimp Technical Committee 2014). Although there are examples of shrimp fisheries that uses pots in North America, it is generally still underrepresented in literature.

One important drawback is that catches in shrimp fishing with pots are generally lower compared to trawling (Suuronen et al., 2012). One potential strategy to increase the catch is the use of lights. Fishing with lights has been done for hundreds of years, back than with fire, nowadays mostly with electric light. That fish can be attracted and affected by lights has been known for centuries (Hasegawa, 1993; Marchesan et al., 2005). Lights can help fish differentiate food more clearly (Ben-Yami, 1988). Light has been used in the fishing industries, both as attractant and deterrent: In Sweden positive results where gained from attracting cod (Bryhn et al. 2014) and light has also been used as bycatch reduction device with positive results (Hannah et al., 2015). Furthermore, several studies have shown that lights of several different colours can work well as attractant in pots (Ahmadi, 2012; Bryhn et al. 2014; Doherty, 1987; Meekan et al., 2001). This is relevant since shrimps are able to differentiate colours like fish are able to do (Eaton, 1972). Therefore it might be valuable to experiment with different colours of light, also in relation to bycatch. Whether lights attract potential prey for shrimps or simply make them visible, or shrimps are attracted to lights itself is still unclear. Although there are currently no commercial shrimp fisheries that use light, there are indications for its potential: small scale fisheries in Canada and the USA have experience with trapping shrimps with lights, there are examples for recreational shrimp fishing with lights and there are several brands of shrimp lights for sale, indicating that there already is an existing market for the latter. However not much scientifically has been done to test its efficiency.

Aim

In search of a less destructive alternative to current shrimp fishing methods, both in terms of bycatch reduction and increasing shrimp catches in pots, this study aims to analyse the selectivity of different pot designs and alternative attractants for pot fishing on northern shrimps in Gullmarsfjord, Sweden.

There are three main objectives:

1. Describe how the different pot designs and attractants affects shrimp catch and bycatch in abundance and composition.
2. Describe how the different pot designs and attractants affects the shrimp size distribution of the catch.
3. Describe how the different pot designs and attractants affect the behaviour of shrimps and bycatch inside the pot by means of underwater video recordings.

2 Methods

2.1 Experimental setup

The study was conducted in Gullmarsfjord (figure 1), between the 20th of March and the 14th of April 2017. Four different pot designs and six combinations of attractants were tested. They were deployed to a depth between 50 and 80 meters on fine sediment with a soak time of one day. The locations of the fishing areas where determined based on the fisherman's experience about the locations, in relation to depth, sea floor characteristics and locations of trawling areas. Underwater cameras were placed in the pots for capturing the behaviour of the caught individuals to allow for determination of enter/exit rates of both shrimp and fish. Also the Carapace length of the caught shrimps was measured for 48 pots throughout the study.

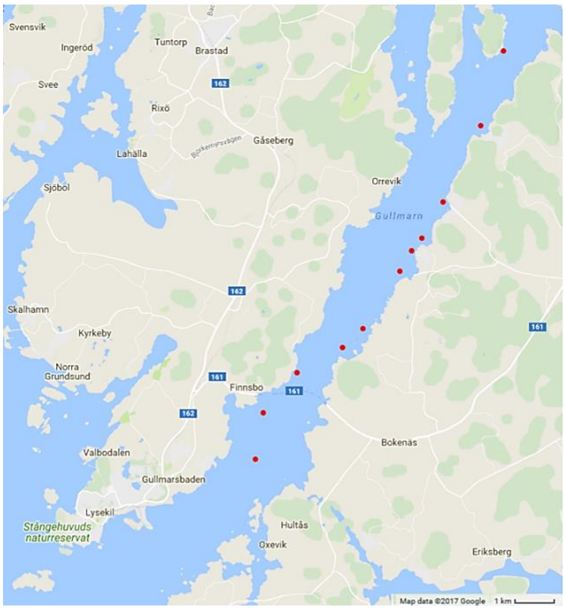

Figure 1: Map of Gullmarsfjord with red dots representing the fishing areas that were exploited during this study.

2.1.1 Pots

Out of eight pot designs four pot designs where selected for this study as best preforming based on fishing results from previous fishing season. The pot designs ''one'', ''three'', ''six'' and ''seven'' that where tested in this study included two different entrances designs: Wide oval entrances made out of nylon netting and an metal ellipse shaped ring in pot one and three, and black plastic funnel shaped entrances with a white plastic ring (commonly used in pots for Norway lobsters; *Nephrops norvegicus*) in pot six and seven. (figure 2, 3 and table 1). The pots one, three and seven have a V shaped top entrance made from white plastic and a horizontal net in the middle that divides the pots into two chambers.

Figure 2: Pot entrances. From top to botom: 1. V shaped top entrance in the roof of the pots one, three and seven, 2. Oval entrance at the long sides of pot one and three, 3. Funnel entrances at all sides of pot six and seven.

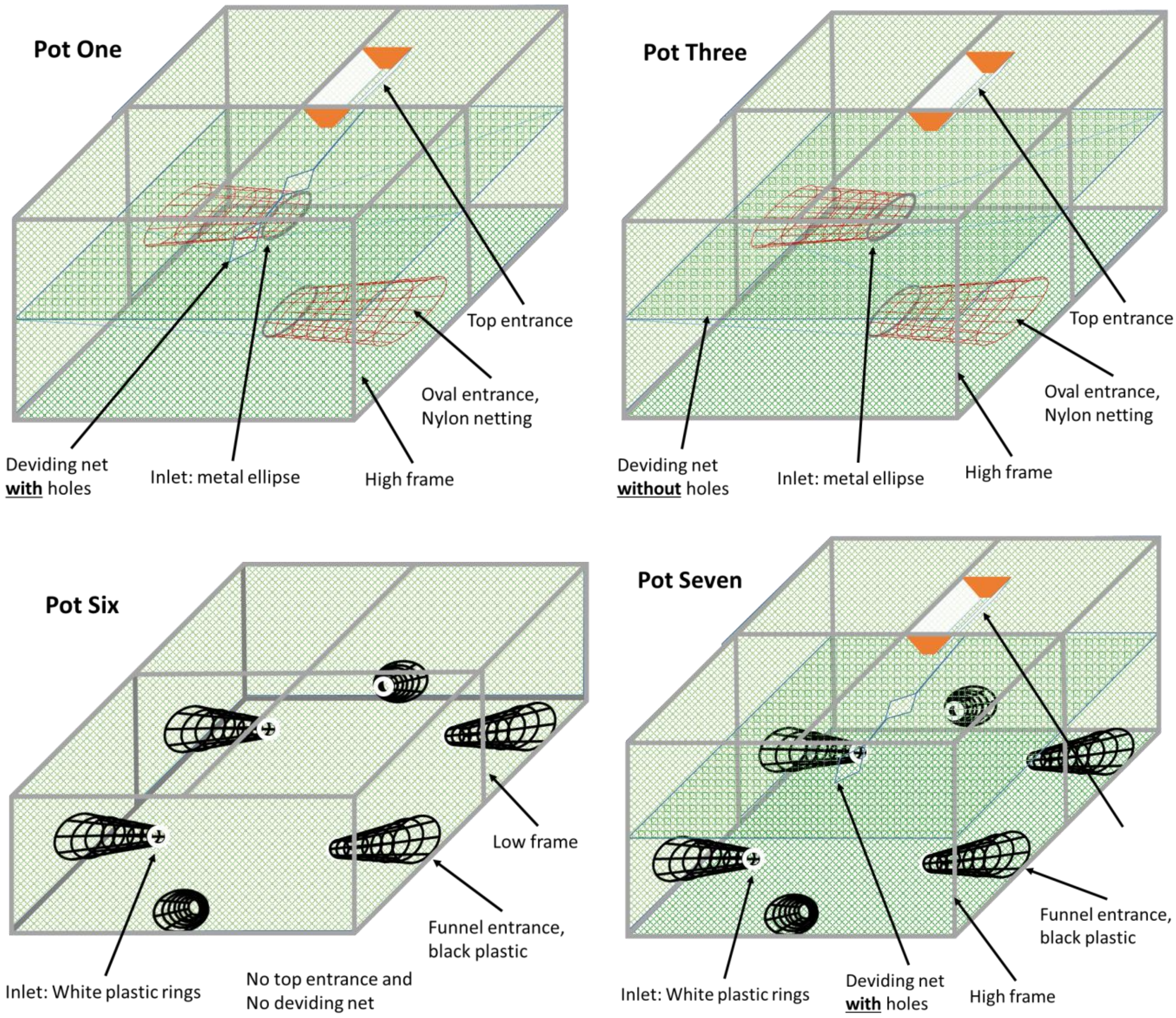

Figure 3: Illustrations of the four pot designs that were used for this study. Pot one (upper left picture): has two oval entrances, a top entrance and a horizontal net that devids the pot into two chambers with two holes which allows the shrimps to move between the chambers. Pot three (upper right picture): has also two oval entrances, a top entrance, but no holes in the deviding net. Pot six (lower left picture): Has six funnel entrances, no top entrance, no dividing net and is only half as high compared to the other pots. Pot seven (lower right picture): has also six funnel entrances, a top entrance, a horizontal dividing net with two holes, and the pot is twice as high as pot six.

Table 1: Pot characteristics. The sizes described in the entrance column are the sizes of the entrance opening on the side of the pot, while inlet describes the sizes of the entrance ring in the pot.

POT	SIZE (CM)	FRAME	NET TYPE AND MESH SIZE	ENTRANCE (LXW)	TOP ENTRANCE	INLET (LXW)
1	120x80x70	5mm steel rods	Nylon green net mesh size 14x12mm	2 oval entrances made of nylon netting 38x15 cm	Plastic V shaped 25x18 cm	38x9 cm
3	120x80x70	5mm steel rods	Nylon green net mesh size 14x12mm	2 oval entrances made of nylon netting 38x15 cm	Plastic V shaped 25x18 cm	38x9 cm
6	120x80x35	5mm steel rods	Nylon green net mesh size 14x12mm	6 black plastic funnel entrances 25x12 cm	No top entrance	Diameter of 7 cm
7	120x80x70	5mm steel rods	Nylon green net mesh size 14x12mm	6 black plastic funnel entrances 25x12 cm	Plastic V shaped 25x18 cm	Diameter of 7 cm

2.1.2 Attractants

Six different combinations of attractants where used: LED lights of the brand Trophy Torch in the colours white, green (520 – 565 nm), UV (365 - 385 nm), and the combinations white light with herring (*Clupea harengus*), green light with herring and herring without light as control. UV light in combination with herring was not tested due to a limited amount of lights. Green light was selected because it has been used as bycatch reduction device (Hannah et al, 2015) and green light reaches further through the water column compared to other colours. UV light and white light were selected because they were recommended by shrimp fisherman in North America (John Beath and Steve Kalek). The lights are powered by one AA battery and they emit a continuous light that lasted for seven days, but after day five the light becomes rather weak and therefore the batteries where changed every five days. The lights are rated for 600m depth and for this study were equipped with plastic clippers for an easy re-arrangement of the attractants between the pots (figure 4). The lights were clipped onto frame at the top of the pots in a way that the light hangs down in the centre.

Figure 4: Trophy Torch LED lights in green, white and ultra violet with plastic clippers.

2.1.3 Setup on board

Four pots, one of each type were attached to a string with a distance of 25m between the pots, forming a link. The position of the pot in the link is randomly determined for each fishing day, as well as the distribution of the attractants over the pots. The links were also randomly distributed over the fishing areas. Within 5 links all the possible combinations of pot type and attractant occurred once and formed together a replica. Two replicas per fishing day were hauled during 18 fishing days. Soak time between each fishing day was one day, except for two occasions when the pots where out for three and four days. Each fishing day included hauling, record the data, retrieving and setting the cameras, swap positions of pots and attractants and deploying. Dates, times, positions, cloudiness, moon phase and depth of all set and hauled links where recorded. Catch was sorted by species and recorded as number of individuals per species, including bycatch. Which in this study is everything other than shrimps and Norway lobsters. In this study, Norway lobster is seen as positive bycatch due to its high market value.

2.1.4 Shrimp size and shrimp abundance.

For 12 links, including 48 pots throughout the study the carapace length of 549 shrimps was measured in order to determine the size distribution. An electronical WEL caliper with a USB connection to a field tablet was used on board to measure the carapaces of all the caught shrimps. Other than that, data from SLU's research trawler was used to determine shrimps density in the fjord. The research trawler took two hauls of 30min once at a depth between 20 and 37m with a speed of 1,9 knots and once between 78 and 87m with the same speed. The trawl is of type TV3, Model 3192A with a 16mm diagonal mesh size and a 6-7m trawl opening. Two times a surface area of approximately 11km2 was trawled. 880 shrimps were caught by the trawler measured in length of their carapaces.

2.1.5 Underwater cameras

In order to do a behavioural analysis and determine the enter and exit rate of the catch and bycatch, four underwater cameras where set out per day, on 13 fishing days and retrieved next hauling. The Cameras (GoPro Hero 3 White Edition) with battery backpack and SD memory card (200 or 128 GB) together with 2 power banks (12000- 15000 mAh) were placed in custom-made underwater housing. The housing was placed in the pots and fitted with a dive-light of the type Fisheye Fix Neo DX 800 and Fisheye Fish Neo DX 1200. The lights were adjusted with red filters as Northern prawns are unable to see red light (Eaton, 1972) and was set to 12% of their power output, which makes them last for approximately 30 hours. Each fishing day the SD card, power banks and dive light batteries were replaced before cameras were set out again.

Cameras were placed only in pot six and pot three in order to determine differences in the performance of the two entrance types. These pots were chosen due to the impossibility for the shrimps to reach the cameras field of vision via the top entrance. The pots were adjusted with a few pieces of wood in order to properly secure the cameras to the pots (figure 5). The cameras were directed towards the pot entrance(s) and the entrances that were outside of the camera's field of vison were closed off.

Figure 6: The Underwater cameras, with dive light set in pot six and three, strapped with a piece of wood onto the pots.

2.2 Statistical analysis

28 full replicas were hauled and in total 614 pots were included in the data analysis. All statistical analyses where performed with Rstudio Version 1.0.143 software.

2.2.1 Catch data

Catches were analysed as Catch Per Unit Effort (CPUE) in numbers per species, per fishing day. For this analysis, the data was divided in three groups: shrimp, Norway lobster and bycatch of TAC gadoids (cod like species with a set total allowance catch). The TAC gadoids were in this case saithe (*Pollachius virens*), Atlantic cod (*Gadus morhua*) and whiting (*Merlangius merlangus*). Only TAC gadoids were included in the catch data analysis due to that they represented 90% of the bycatch and they are of commercial value. However, to determine the species composition of the bycatch all bycatch species where included. Each species of bycatch was tested against pot design and attractant. Data were tested for normality with the Shapiro-Wilk test and with Levene's test for homogeneity of variance. None of the data were normally distributed or had a homogeneous variance. To make a comparison of the CPUE between the different pot designs the Kruskal-Wallis rank sum test was used with the Dunn's test as post-hoc. The same tests were used to analyse differences in CPUE between attractants. For testing the differences between entrance designs with the Wilcoxon rank sum test, the data was organized into two groups; pots with oval entrances and pots with funnel entrances.

2.2.2 Shrimp size

Shrimp size data is used to determine whether there is a size difference in caught shrimps between (1. pot designs, (2. attractants and (3. trawl and pot. To test the data for normality and homogeneity of variance again the Shapiro-Wilk test and the Levene's test are used. To test for significant size differences between trawl and pots, and between the two entrance types, a Wilcoxon rank sum test was used. To test between pot types and between attractants a Kruskal-Wallis rank sum test was done with a following up Dunn's post-hoc test.

2.2.3 Video data

In total 47 videos where recorded. Videos where analysed by means of the software BORIS (Friard & Gamba, 2016) and VLC Media player (VideoLAN Client, Software). Ten videos, recorded on five different days with one recording of pot six and pot three per day, where analysed in a playback speed of 4x. This way a comparison could be made between cameras placed on the same day and in the same link, but with different entrances. The number of entries and exits of the bycatch was determined and divided into gadoids and non-gadoids (only fish species included). Data was tested for normality with the Shapiro-Wilk test and with Levene's test for homogeneity of variance. The differences between means where tested for significance with a One way ANOVA and with a Wilcoxon rank sum test if the data was not normally distributed.

2.2.4 Variables in relation to shrimp CPUE

To analyse which variables might have affected shrimp CPUE a Generalized Linear Model (GLM) was used including 558 observations:

ShrimpCPUE ~ pottype + attractant + moonphase + depth, family = poisson

The model included the four different pot designs, the six combinations of attractants, the moon phase in percentage of moon illumination and depth of which pots were placed. A Poisson distribution was chosen as statistical family due to that the data contains integer and categorical data. An ANOVA was used in order to calculate p-values from the GLM and a final model was created with the ‘’step’’ function in Rstudio. The “step” function filters out non-significant variables and orders the variables based on AIC number from low to high.

3 Results

3.1 Catch data

3.1.1 Shrimp CPUE

For shrimp CPUE there was a significant difference between pot types (Kruskal-Wallis rank sum test, n = 614, x^2 = 30.7, df = 3, p < 0.001). Pot one with a mean catch of 8.5 shrimps per pot had a significantly higher catch compared to pot six and seven (Figure 6 and Table 2). Also pot three with a mean catch of 8.2 shrimps, had a significantly higher catch compared to pot six and seven. There are no significant differences between pot one and three (with both oval entrances) and also not between pot six and seven (with both funnel entrances). There was also a significant difference in the CPUE between the attractants (Kruskal-Wallis rank sum test, n = 614, x^2 = 82.2, df = 5, p < 0.001). The use of light resulted into average catch of 8 shrimps per pot which is, a 3.1 times higher CPUE in comparison with only herring as attractant (figure 7 and table 3). Between the different colours of light there was no significant difference in the shrimp CPUE, except for that UV light which had a slightly lower CPUE in comparison with white light. Combining light with herring had no significant effect on the CPUE in relation to only light.

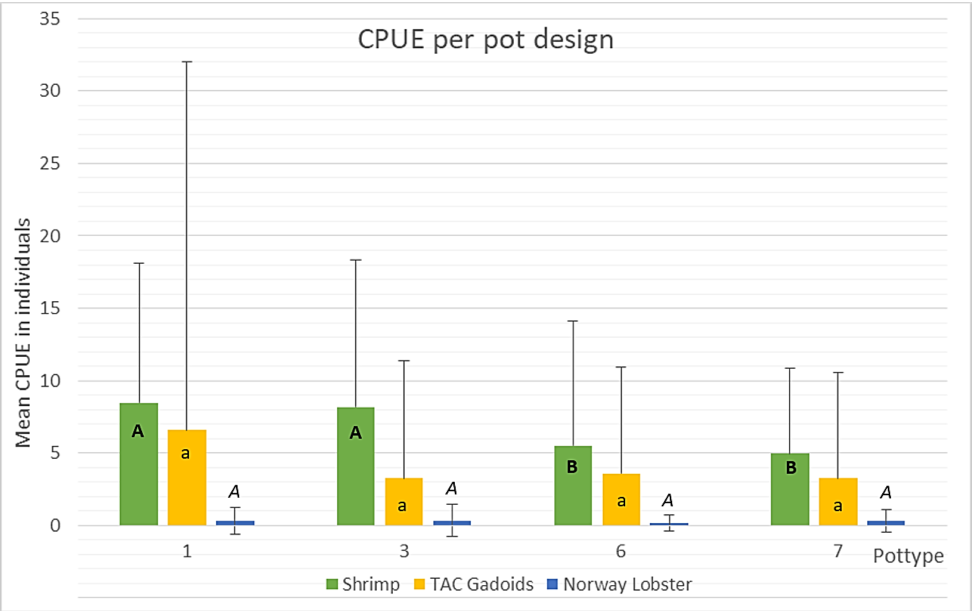

Figure 8: Mean CPUE per pot design for shrimps, TAC Gadoids and Norway lobsters. The error bars represent the standard deviations and the letters illustrate significant different means between the bars. Bars with different letters are significantly different from each other, bars with the same letter are not significantly different from each other.

Table 2: Differences in mean Shrimp CPUE between pot designs. Results Dunn's test.

Pot	One	Three	Six	Seven
One		z = 0.85	z = 4.41	z = 4.28
Three	p = 0.20		z = -3.41	z = -3.24
Six	**p < 0.001**	**p < 0.001**		z = 0.32
Seven	**p < 0.001**	**p < 0.001**	p = 0.38	

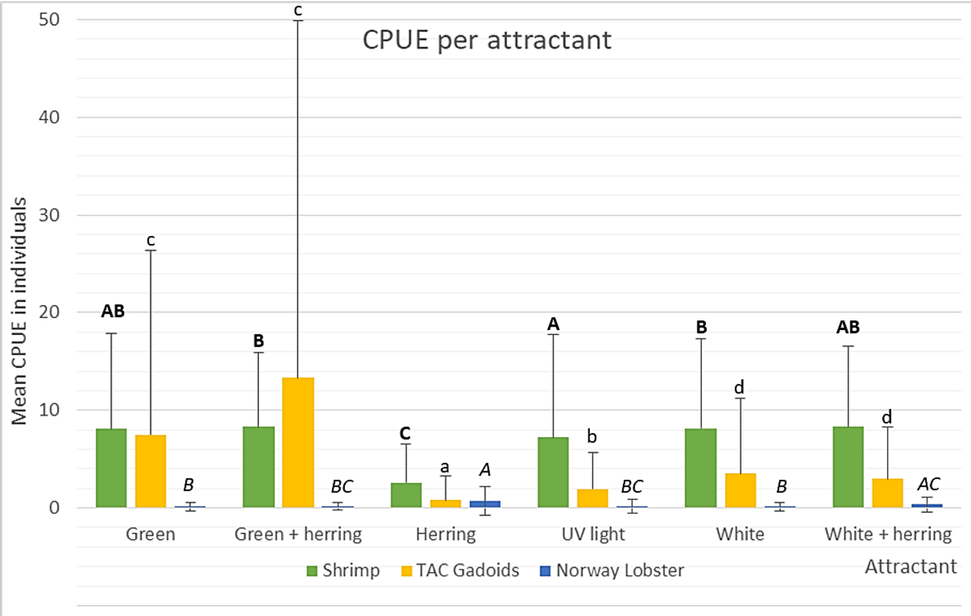

Figure 9: Mean CPUE per attractant for shrimps, TAC Gadoids and Norway lobsters. The error bars represent the standard deviations and the letters illustrate significant different means between the bars. Bars with different letters are significantly different from each other, bars with the same letter are not significantly different from each other. A bar with two letter has no significant difference with all the bars that has one or both of the letters.

Table 3: Differences in mean shrimp CPUE between attractants. Results Dunn's test.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		z = -0.43	z = 7.01	z = 1.52	z = -0.53	z = -0.25
Green + herring	p = 0.33		z = 6.01	z = 1.64	z = 0.01	z = 0.15
Herring	**p < 0.001**	**p < 0.001**		z = -5.50	z = -7.58	z = -5.90
UV light	*p = 0.06*	**p < 0.05**	**p < 0.001**		z = -2.07	z = -1.49
White	p = 0.30	p = 0.50	**p < 0.001**	**p < 0.05**		z = 0.17
White + herring	p = 0.40	p = 0.44	**p < 0.001**	*p = 0.07*	p = 0.43	

3.1.2 Norway lobster CPUE

For CPUE of the kept Norway lobsters there was no significant difference between pot types (Kruskal-Wallis rank sum test, n = 614, x^2 = 3.3, df = 3, p = 0.34). But there is a significant difference between attractants (Kruskal-Wallis rank sum test, n = 614, x^2 = 23.2, df = 5, p < 0.001). Using only herring as attractant resulted in a mean catch of 0.7 lobsters per pot, a significantly higher CPUE in comparison with the other attractants, except for white light plus herring (figure 7 and table 4). There was also a significant difference between white light and white light plus herring, but no significant difference between green light and green light plus herring.

Table 4: Differences in mean Norway lobster CPUE between attractants. Results Dunn's test.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		*z* = -1.29	*z* = -4.12	*z* = -0.83	*z* = -0.29	*z* = -1.97
Green + herring	*p = 0.10*		*z* = -1.97	*z* = 0.63	*z* = 1.06	*z* = -0.57
Herring	**p < 0.001**	**p < 0.05**		*z* = 3.29	*z* = 3.84	*z* = 1.32
UV light	p = 0.20	p = 0.26	**p < 0.001**		*z* = 0.54	*z* = -1.31
White	p = 0.38	p = 0.14	**p < 0.001**	p = 0.29		*z* = -1.73
White + herring	**p < 0.05**	p = 0.28	*p = 0.09*	*p = 0.10*	**p < 0.05**	

3.1.3 Bycatch of TAC gadoids

In bycatch there was no significant difference between pot designs (Kruskal-Wallis rank sum test, x^2 = 4.0, df = 3, p = 0.26). However there is a significant difference between attractants (Kruskal-Wallis rank sum test, n = 614, x^2 = 90.2, df = 5, p < 0.001). In general the use of light resulted in a mean bycatch of 5.8 individuals per pot in comparison to 0.8 individuals when using only herring as attractant (figure 7 and table 5). The use of green light, with or without herring, resulted in the highest bycatch with a mean of 10.4 TAC gadoids per pot, which was also significantly higher in comparison to the other lights. UV light had with a mean of 1.9 TAC gadoids, the least bycatch in comparison with the other lights.

Table 5: Differences in mean TAC gadoid bycatch between attractants. Results Dunn's test.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		*z* = -1.08	*z* = 7.83	z = 4.90	*z* = 2.52	*z* = 2.23
Green + herring	p = 0.14		*z* = 7.32	*z* = 5.00	*z* = 3.10	*z* = 2.84
Herring	**p < 0.001**	**p < 0.001**		*z* = -2.89	*z* = -5.30	*z* = -4.05
UV light	**p < 0.001**	**p < 0.001**	**p < 0.01**		*z* = -2.38	*z* = -1.72
White	**p < 0.01**	**p < 0.001**	**p < 0.001**	**p < 0.01**		*z* = 0.20
White + herring	**p < 0.05**	**p < 0.01**	**p < 0.001**	**p < 0.05**	p = 0.42	

3.2 Species composition of bycatch

14 different species of bycatch where caught during this study, excluding crab, sea/brittle star and sea feather species, and one common thornback ray (*Raja clavata*). Norway lobsters are considered positive bycatch and are therefore also excluded from this analysis. In general using light compared to using herring as attractant resulted in a substantially larger portion of gadoids in the bycatch (figure 8). When using light 93% of the bycatch where gadoids compared to 80% when using herring. Mainly saithe dominated the bycatch followed by cod and whiting.

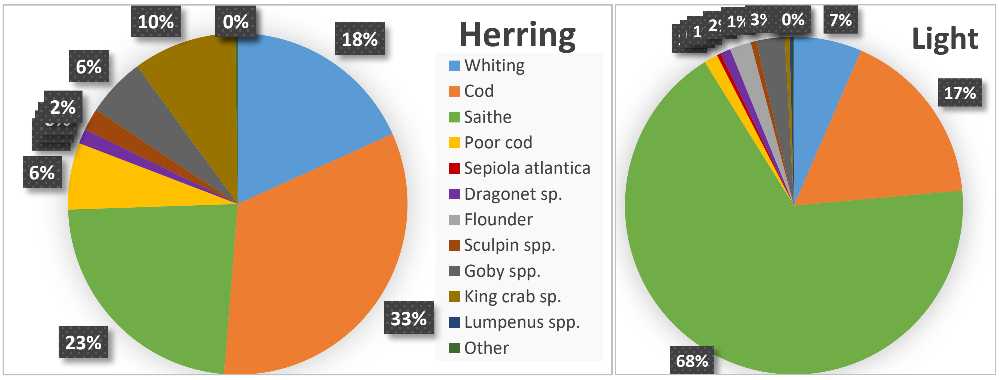

Figure 10: Species composition of the bycatch when using light (right) compared to using herring (left) as attractant. Keep in mind that the total bycatch when using light is much higher and that these charts purely illustrate the composition and states nothing about amounts. The group "Other" contains the species: true sole spp. (Soleidae spp.), wrasse spp. (Labridae spp.), and fourbeard rocklings (Enchelyopus cimbrius).

3.2.1 Saithe (*Pollachius virens*)

There were no significant differences in saithe catch between pot designs (Kruskal-Wallis rank sum test, n = 614, x^2 = 0.5, df = 3, p = 0.92). However, there were significant differences between attractants (Kruskal-Wallis rank sum test, n = 614, x^2 = 83.1, df = 5, p < 0.001). Using herring as attractant resulted in a significantly lower catch of saithe compared to all the other attractants (Dunn's test, p < 0.001; figure 9 and appendix, table 9). Using green light causes a significantly higher saithe catch in comparison to white light (Dunn's test, p < 0.05). Adding herring to the lights had no significant effect. UV light caught significantly less saithe compared to all other lights (Dunn's test, p < 0.05), except to white light with herring (Dunn's test, p = 0.11).

3.2.2 Cod (*Gadus morhua*)

There were no significant differences between pot designs in cod catch (Kruskal-Wallis rank sum test, n = 614, x^2 = 5.5, df = 3, p = 0.14). Nevertheless, there were significant differences between attractants (Kruskal-Wallis rank sum test, n = 614, x^2 = 31.4, df = 5, p < 0,001). Green light caught the most cod and significantly more compared to all other attractants (Dunn's test, p < 0.05; figure 9 and appendix, table 10) except green light with herring. Green light with herring caught significantly more cod compared to only herring and UV light (Dunn's test, p < 0.01), with a tendency towards catching more cod compared to white light (Dunn's test, p = 0.07). Using only herring resulted in the leased cod compared to all the other attractants (Dunn's test, p < 0.05). UV light caught significantly less cod compared to green light with or without herring (Dunn's test, p < 0.01), but also significantly more than only herring (Dunn's test, p < 0.05).

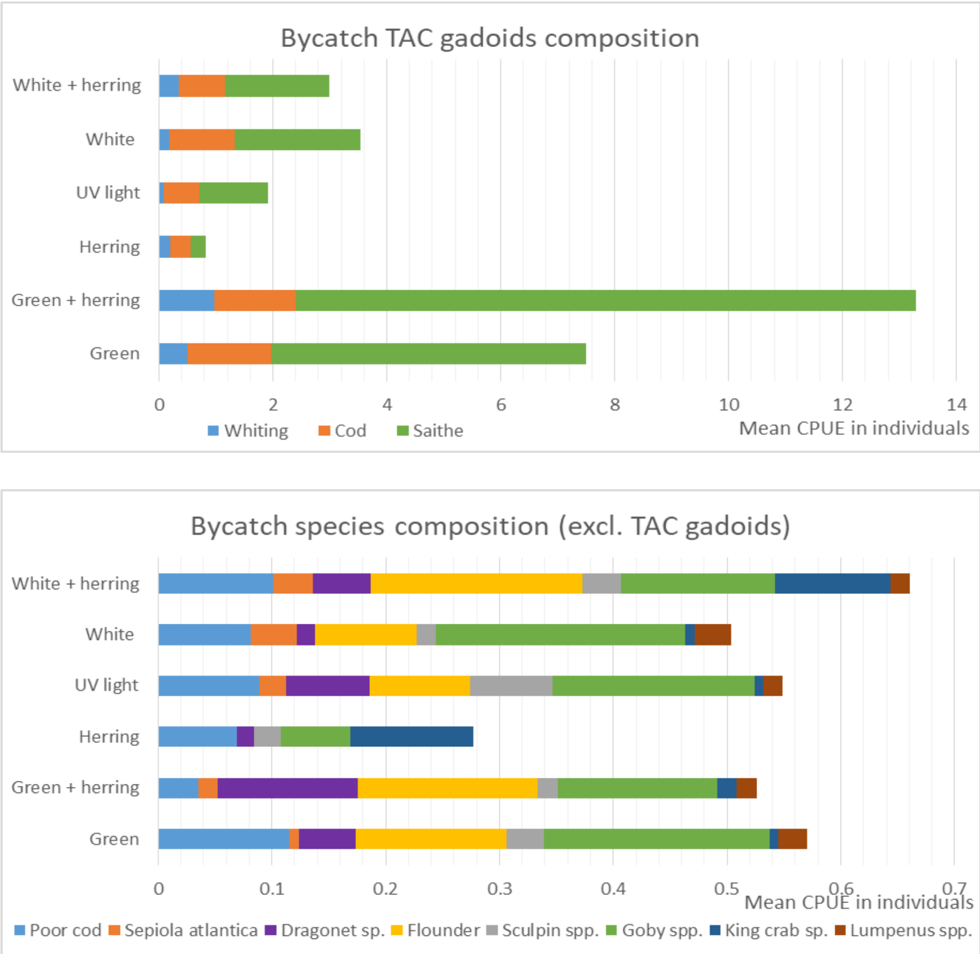

Figure 12: Bycatch composition in mean CPUE with attractant on the y-axis, divided into TAC gadoids (upper chart) and other bycatch (lower chart) due to large difference in amounts. In order not to compromise the clarity of the charts, error bars are excluded. Species like true sole spp. (Soleidae spp.), wrasse spp. (Labridae spp.) and fourbeard rockling (Enchelyopus cimbrius) where left out of the chart because they were caught only rarely.

3.2.3 Whiting (*Merlangius merlangus*)

In whiting catch there were significant differences between pot designs (Kruskal-Wallis rank sum test, n = 614, x^2 = 9.3, df = 3, p < 0.05). Pot one caught significantly more whiting in comparison to the other pots (Dunn's test, p < 0.05; appendix, table 11). There were no significant differences between the other pot designs. Also between attractant there were significant differences (Kruskal-Wallis rank sum test, n = 614, x^2 = 19.3, df = 5, p < 0.001). Green light with herring caught the most whiting in comparison with the other attractants (Dunn's test, p < 0.05; figure 9 and appendix, table 12). Adding herring to green light doubled the catch in whiting (Dunn's test p < 0.001). UV light caught significantly less whiting compared to green light with herring and white light with herring (Dunn's test p < 0.05), but not significantly in comparison to the other lights.

3.2.4 Flounder (*Platichthys flesus*)

There were significant differences in flounder catch between pot designs (Kruskal-Wallis rank sum test, n = 614, x^2 = 9.8, df = 3, p < 0.05). Pot seven caught significantly less flounders compared to pot one and three (Dunn's test, p < 0.01; appendix, table 13). Pot six had a tendency towards catching less flounder compared to pot one (Dunn's test, p = 0.09). There were no significant differences between the other pot designs. However, there were significant differences between attractants (Kruskal-Wallis rank sum test, n = 614, x^2 = 15.0, df = 5, p < 0.01). Using herring as attractant resulted in catching no flounder at all and is significantly different from catches with the other attractants (Dunn's test, p < 0.01; figure 9 and appendix, table 14).

3.2.5 Goby spp. (*Gobiidae spp.*)

There were no significant differences between the pot designs (Kruskal-Wallis rank sum test, n = 614, x^2 = 6.8, df = 3, p = 0.08). However, between attractants there were significant differences (Kruskal-Wallis rank sum test, n = 614, x^2 = 11.0, df = 5, p < 0.05). Using herring resulted in significantly lower catches compared to all lights without herring (Dunn's test, p < 0.01; figure 9 and appendix 1, table 15). There were no significant differences found between the other attractants.

3.2.6 King crab sp. (*Lithodes maja*)

There were significant differences in King crab catch between pot designs (Kruskal-Wallis rank sum test, n = 614, x^2 = 14.8, df = 3, p < 0.001). Pot one and three caught significantly more king crabs compared to pot six and seven (Dunn's test: p < 0.05, appendix 1, table 16). Also between attractants there were significant differences (Kruskal-Wallis rank sum test, n = 614, x^2 = 19.8, df = 5, p < 0.001). only herring and white light with herring caught significantly more king crabs compared to the other attractants (Dunn's test, p < 0.01; figure 9 and appendix 1, table 17), with no significant difference between only herring and white light with herring.

3.2.7 Other species

Other species that where part of the bycatch where; poor cod (*Trisopterus minutus*), squid sp. (*Sepiola atlantica*), common dragonet (*Callionymus lyra*), sculpin spp. (*Cottoidea spp.*), true sole spp. (*Soleidae spp.*), wrasse spp. (*Labridae spp.*), Lumpenus spp. and fourbeard rockling (*Enchelyopus cimbrius*). For these species no significant differences were found between pot designs or attractants (appendix, other bycatch species).

3.3 Shrimp size and shrimp abundance

3.3.1 Pot design

A significant difference was found for carapace length between pot designs (Kruskal-Wallis rank sum test, n = 549, x^2 = 8.4, df = 3, p < 0.05). Pot seven caught the largest shrimps with a mean of 20.61mm. Pot one caught the smallest shrimps with a mean of 19.42mm, significantly smaller compared to pot seven and pot six (figure 10 and table 6). There was a tendency towards pot three catching larger shrimps compared to pot one and there was no significant difference between pots six, seven and three. When comparing the two entrance types (oval and funnel shaped) a significant difference in shrimp size was found (Wilcoxon rank sum test, n = 549, W =32052, p < 0.05). The funnel shaped entrances caught shrimps with a mean carapace size of 20.47 mm, 0.85 mm larger compared to the oval entrances.

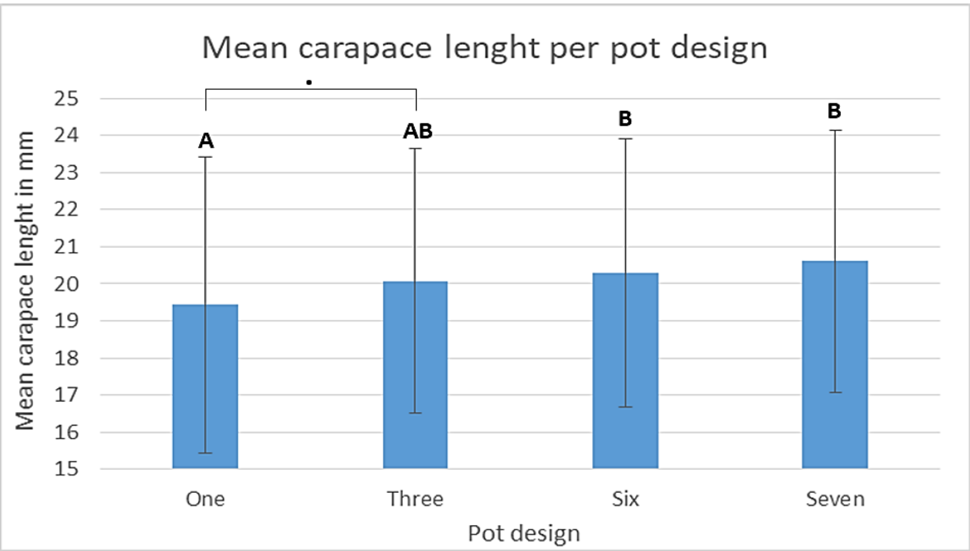

Figure 14: Mean shrimp carapace length per pot design. The error bars represent the standard deviations and the letters illustrate significant different means between the bars. The horizontal bracket with a dot shows a marginal significant difference.

Table 6: Differences in mean carapace length between pot designs. Results Dunn's test.

Pot	One	Three	Six	Seven
One		z = -1.31	z = -1.89	z = -2.69
Three	*p = 0.09*		z = 0.43	z = 0.99
Six	**p < 0.05**	p = 0.33		z = 0.55
Seven	**p < 0.01**	p = 0.16	p = 0.29	

3.3.2 Attractants

There was also a significant difference found in carapace size between different attractants (Kruskal-Wallis rank sum test, n = 549, x^2 = 42.4, df = 5, p < 0.001). White light with herring caught significantly larger shrimps compared to all the other attractants except herring, this was almost significant (figure 11 and table 7). White light with herring caught the largest shrimps with a mean size of 22.45 mm. Only herring as attractant caught shrimps with the second largest mean and UV light the smallest with a mean of 18.83mm. The use of light results in average on a 1.55 mm smaller shrimps compared to using herring as attractant (Wilcoxon rank sum test, n = 549, W = 14634, p < 0.001). There is also a significant difference between the use of light with herring and the use of light without herring. When herring was combined with green light the mean caught shrimps where significantly smaller compared to only using green light. However when white light was combined with herring the mean carapace size was significantly larger compared to using only white light.

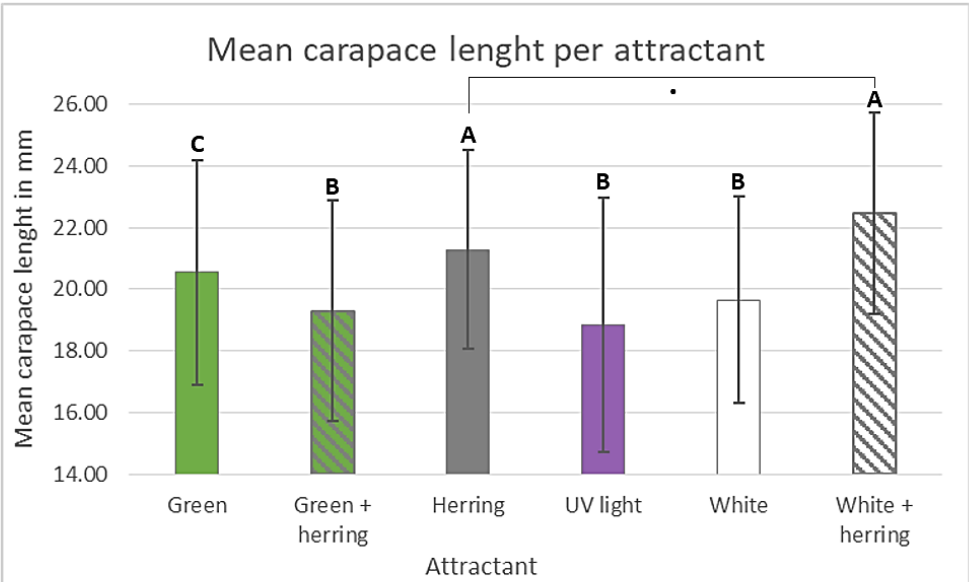

Figure 15: Mean shrimp carapace length per attractant. The error bars represent the standard deviations and the letters illustrate significant different means between the bars. The horizontal bracket with a dot shows a marginal significant difference.

Table 7: Differences in mean carapace length between attractants. Results Dunn's test.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		*z* = 1.75	*z* = -1.63	*z* = 3.23	*z* = 2.16	*z* = -2.75
Green + herring	**p < 0.05**		*z* = -2.90	*z* = 0.43	*z* = -0.21	*z* = -3.67
Herring	**p < 0.05**	**p < 0.01**		*z* = 4.65	*z* = 3.61	*z* = -1.59
UV light	**p < 0.001**	p = 0.33	**p < 0.001**		*z* = -0.94	*z* = -4.75
White	**p < 0.05**	p = 0.41	**p < 0.001**	p = 0.17		*z* = -4.10
White + herring	**p < 0.01**	**p < 0.001**	*p = 0.06*	**p < 0.001**	**p < 0.001**	

3.3.3 Trawl compared to pots

Also between the pots and trawl a significant size difference was found (Wilcoxon rank sum test, n = 1429, W = 191370, $p < 0.001$). The mean carapace size caught by trawl was 21.51 mm, with a size range between 10mm up till 28mm. This was 1.54 mm larger compared to the shrimps caught by the pots with a mean of 19.97 mm. Even though the pots caught shrimps between a very similar size range of 10 mm up till 27mm. However the pots caught a higher percentage of smaller shrimps compared to the trawl (figure 12). In the paper of Ljungberg & Berggren (2016) this was the other way around, then the trawl caught on average smaller shrimps compared to the pots.

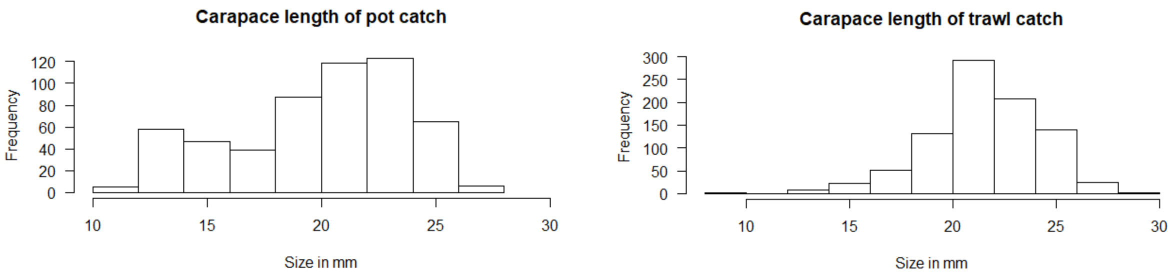

Figure 16: Shrimps divided into size classes, showing the frequency of how many of each class were caught.

3.3.4 Shrimp abundance

The shrimp density was calculated from the trawler catch, including 880 individuals and a trawled surface area of 22km2. The population size was estimated to 0.04 shrimps/m2, which is double as much compared to last year, 0.02 shrimps/m2 (Ljungberg & Berggren, 2016).

3.4 Video data

Two different entrance types were compared in order to find a difference in entries and exits of the bycatch. The oval entrance had and enter exit rate of 22:1 (22 gadoid entries per exit), and the funnel shaped entrance had an enter/exit rate of 12:1. However, no significant differences were found for gadoid and non-gadoid entries between the two entrance types (One way ANOVA, n = 10, $F(2,8) = 0.92$, $p = 0.37$; Wilcoxon rank sum test, n = 10, W =19, $p = 0.18$). Also no significance for gadoid exits (Wilcoxon rank sum test, n = 10, W = 12.5, $p = 1$). Only two shrimp exits where observed and no non-gadoid exits.

3.5 Variables in relation to shrimp CPUE

The GLM produced the following best model including all the variables that were entered and all variables had a strong significant effect on shrimp CPUE:

ShrimpCPUE ~ attractant + moonphase + pottype + depth, family = poisson

Table 8: Result GLM on shrimp CPUE in relation to four variables, n = 558

Variable	x^2	df	p	sig. level	AIC
Pot type	143.86	3	2.2e-16	***	4393.8
Attractant	349.36	5	2.2e-16	***	4595.3
Moon phase	200.15	1	2.2e-16	***	4454.1
Fishing depth	62.55	1	2.6e-15	***	4316.5

The relation between shrimp CPUE and pot design or attractant was as illustrated in figure 6 and 7 on page 14 and 15, and are discussed in the thereto belonging paragraphs. With only a small percentage of the moon illuminated, shrimp CPUE is higher in comparison to having a larger percentage of the moon illuminated (figure 13). The difference was on average approximately 3 shrimps per pot. As illustrated in figure 14 shrimp CPUE seems to be increasing with fishing depth with an average difference of approximately 2 shrimps per pot.

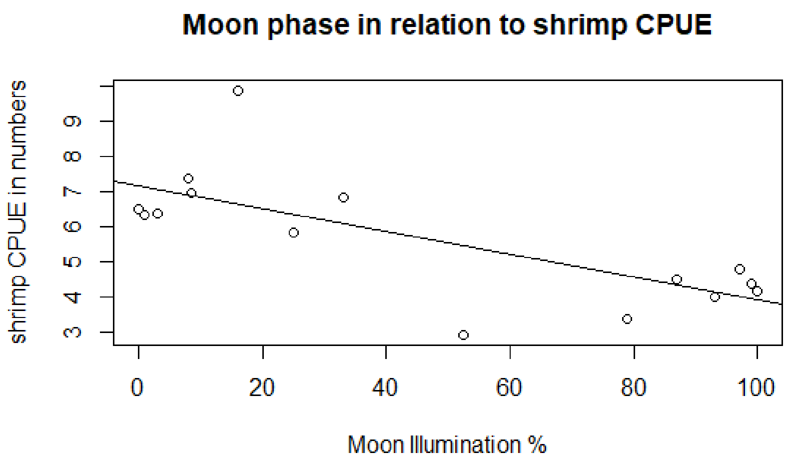

Figure 18: Moon phase in relation to shrimp CPUE in numbers. Showing that the more the moon is illuminated the lower the shrimp catch.

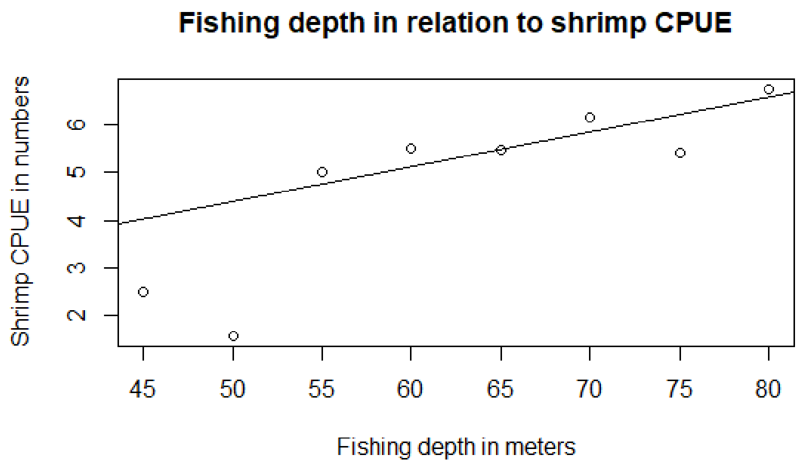

Figure 19: Fishing depth in relation to Shrimp CPUE, Showing a positive relation with depth.

4 Discussion

This study assesse the effects of pot design and attractants on the catch of shrimps, Norway lobster and bycatch. By analysing catch data, carapace length measurements and underwater video recordings, first-hand information was collected for development of alternative shrimp fishing methods and especially focussed on using light as attractant. The results are specifically interesting for the development of less destructive fishing methods, reducing bycatch and increasing shrimp CPUE. The results illustrate that pot design and attractant type has large effects on catches of target species and bycatch.

4.1 Catch data

4.1.1 Shrimp CPUE

Pots with an oval entrances (pot one and three) caught on average 1.6 times more shrimps compared to pots with funnel shaped entrances (pot six and seven) and with a significant difference between pots with different entrance designs but not between pots with the same entrance design (figure 6 and 7, page 14 and 15). Entrance design is therefore most likely responsible for the CPUE difference. The oval entrances are much larger than the funnel shaped entrances and probably therefore easier to find for shrimps. Possibly the material of the entrance also plays a role. The funnel shaped entrances are made of black plastic, which does not allow much light to pass through and could shade the area in front of the entrance. This could make it harder for shrimps to find the entrance, since it is assumed that they are attracted to the light. Since the oval entrances are made with netting, shading is not an obstacle. Pot one and three are identical except for the holes in the net that horizontally divides pot one. This is different for pot six and seven, with pot six being only half as high as pot seven. However it did not result into a significant catch difference.

In future studies with these pot designs it is recommended to close off the top entrances of the pots for a better comparison between pot designs. Experience from previous studies and this study point to the poor performance of the top entrances and therefore these were not considered in this study. Even though the top entrances where not closed off, it did not affected the catch significantly. Pot six was the only pot without a top entrance, but had the same funnel shaped entrances as pot seven. Tests between pot six and seven showed no tendencies towards or significant differences between the pots.

Using light as attractant resulted in a 3.1 times higher CPUE compared to using herring as attractant. Shrimps leave the ocean floor at night to predate on planktonic organisms (Shumway et al., 1985) and therefore might orientate by swimming towards the light or, alternatively, get attracted to other organisms that come towards the lights. Since Northern shrimps predate on copepods, the lights could be mistaken for the bioluminescence substance that deep sea copepods can release when attacked. However, this should be studied in future research. UV light had a slightly lower CPUE compared to the other colours, possibly because UV light does not reach as far through the water column as blue and green light does (Lalli & Parsons, 1995; Smith, 1974; Wolken, 1995). When light attenuates in water not every colour is absorbed at the same rate. Colours with a wavelength around 480 nm (blue/green) reaches furthest through the water column depending on suspended particles and substances (Loew & Lythgoe, 1985). The combination of UV with herring was not tested during this study due to a limited amount of lights and it would reduce the number of possible replicates remarkably.

4.1.2 Norway lobster CPUE

There was no significant difference between pots for Norway lobster CPUE, however between attractants there was (figure 7, page 15). Using herring as attractant resulted in a 3.4 times higher CPUE compared to using light. The combination of light and herring resulted in a lower CPUE compared to using only herring. Possibly lights have a repelling effect on the Norway lobsters even though bait is present. This is a difficulty when aiming to catch both shrimps and Norway lobster. However, white light with herring caught a higher mean Norway lobster CPUE compared to the other lights. Possibly the colour of light has a slight influence on Norway lobster CPUE, however not significantly in this study.

4.1.3 Bycatch of TAC gadoids

Pot design had no effect on the TAC gadoid bycatch, however attractants did have effect. Green light attracted significantly the most bycatch and UV light attracted significantly the least bycatch in comparison with the other lights. Possibly gadoids are unable to see UV light, since UV light normally does not reach to these depths due to light attenuating in water. Fish that live mainly in deeper waters have a maximised visual contrast in the blue and green band, because these colours reach deepest, therefore many fish are not sensitive to red and UV light (since these colours attenuate fastest in water; Loew & Lythgoe, 1985; Villamizar, 2010). Animals with colour vision usually have several types of receptors in their eyes which are sensitive to different specific wavelengths. For example cod has its optimal spectral sensitivity peaking at 490 nm (blue/green light) and at 550 nm (green/yellow; Anthony and Hawkins, 1983).

4.2 Species composition of bycatch

Since several species show a clear preference to certain attractants, results of the bycatch species composition in relation to the attractants can be useful for developing other pot fisheries, like cod pot fishing. In general, using light compared to using herring as attractant resulted in a substantially larger portion of gadoids in the bycatch (figure 8, page 17). From the TAC gadoids the colour of the light had the strongest effect on saithe, which formed the largest proportion of the bycatch when using light. For most other bycatch species the colour of light did not affect, only the presence of light affected. This was different for king crab, the attractants affected the catch of king crab in a similar way as the Norway lobster catch was affected. For flounder and king crab pot design affected the catch. Pots with oval entrances caught on average more of these species compared to the funnel entrances. The reason behind this is that the oval entrances are much larger in width compared to funnel entrances. Larger specimens of these species are also broader than tall and therefor can enter pots with oval entrances but not pots with funnel entrances.

4.3 Shrimp size

Pots with funnel entrances caught significantly larger shrimps compared to pots with oval entrances (figure 10, page 20). Even though both inlets are large enough for the largest shrimps to enter and therefore it cannot be a limiting factor. Possibly the material of which the entrances are made could have made a difference. However the difference in carapace length was only 0.85mm.

White light with herring caught the largest shrimps, only herring caught shrimps with the second largest mean and UV light the smallest (figure 11, page 21). White light with or without herring resulted in significantly larger shrimps compared to green light with or without herring. Therefore it seems that white light in general attracts larger shrimps compared to green light. Why adding herring to white light results in larger shrimps and adding herring to green light results in smaller shrimps is unclear, as well as why different sizes are attracted to different colours.

4.4 Video data

No significant difference in gadoid or non-gadoid entries or exits between entrance designs are found. Possibly more videos would need to be analysed to observe a significant difference. Because the analysis of video data is heavily time-consuming, this analysis was limited to ten videos. Moreover, there were only five pairs of videos within the same link and day that had a substantial number of fish bycatch. No reliable results on shrimp entries and exits could be acquired due to the poor light conditions in combination with the shrimps transparent bodies.

However, the cameras did capture some other possibly relevant events. A lot of arrow worms (*Chaetognatha*) and krill where attracted to the lights. Also some copepods and Tomopteris species (taxonomic group of free swimming polychaetes) were seen. Fish predate in the pots on those worms, krill and the shrimps. No attacks by fish towards the lights where observed, but a lot of shrimps were attacked. This demonstrates another incentive to reduce bycatch. It seems that fish are most likely more attracted to the possible preys around the lights rather than the lights itself. Also some bioluminescent activity was observed, possibly caused by copepods. Deep sea copepods are known for releasing a bioluminescent decoy when attacked. Since the bioluminescence decoys are used to distract predators like fish and shrimp, it could be for the same reason why shrimp and fish are attracted to the lights. The shrimps were occasionally swimming towards the light and repeatedly bumping into it, the reason for this is still unclear. No shrimp attacks on other organisms were observed, possibly due to the poor visibility in the pots and the size of their prey.

On the boat many difficulties where encountered with the cameras. Out of the 47 placed cameras more than half had technical issues, but nevertheless 32 recordings where good enough for analysis. The main problems were that the cameras shut down or the dive lights run out of battery. In future studies it is recommended to place two dive lights on the cameras. This will optimize light conditions and if one battery fails the another light prevents total loss of visibility. Another suggestion is to use other cameras than Gopros. Mobius Action cams have been used for similar studies with hardly any difficulties.

4.5 Recommendations on pot design

Based on this study recommendations can be given in order to optimize the pot designs. This study illustrated that there was no difference between using a low pot frame like pot six or a high pot frame like pot one, three and seven. Therefore it is advised to use a low pot frame, because they are more manageable and take less space on deck, allowing more pots to be stored on deck at the same time. For the entrance designs it is advised to use a horizontally elongated inlet like the oval entrance, with sizes that limits larger fish to enter the pot without limiting larger shrimps or Norway lobsters. In the inlet a cable tie can be added in vertical manner in order to prevent larger flatfishes, king crabs and rays from entering (figure 15). The entrance, in front of the inlet, should be as large as the side of the pot, to make it easier for shrimps to find the entrance, and it should be made out of fine netting, in order to let through the maximum amount of light. Top entrances can be added but they caught poorly during this study, possibly due to their small size. If added, it is important that they are made from white or transparent plastic therefore it does not block the light. They should cover a larger surface of the roof to increase the chance of shrimps finding the entrance. And could be located along the sides of the pot, (to catch shrimps that crawl from the roof to the side of the pot or from the side to the roof) or close to the light (since it is assumed they are attracted to the light). How these adjustment exactly affect the catch should be experimented with.

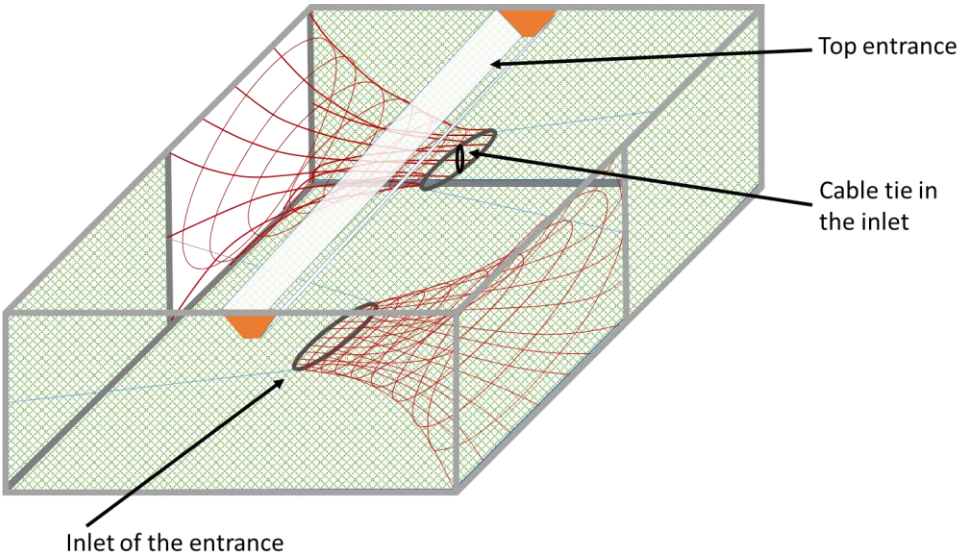

Figure 20: Optimized pot design with a low frame like pot six, two oval inlets, two maximized entrances made out of nets and an enlarged top entrance made out of transparent plastic.

4.6 Considerations for attractant choice

In order to choose which attractant to use a few considerations should be made. Each of the attractants resulted in a different catch composition. Using herring resulted in a 3 times lower shrimp CPUE, however the shrimps where on average larger, the Norway lobster CPUE was higher and there was not much bycatch. Using a light in general resulted into a higher shrimp CPUE, on average smaller shrimps, a lower Norway lobster CPUE and a higher bycatch. Light colour mostly affected the amount of bycatch. However, in the case of using UV light it also affected shrimp CPUE and combining white light with herring resulted in larger shrimps. UV light had a catch/bycatch ratio of 1:3 (one individual of bycatch per three shrimps). For white light this was 1:2.5 and for green light this was 1:0.8. Since the catch composition influences income and market prices fluctuate from place to place, it is important that each fishery makes its own considerations on what attractant to use. For some fisheries it is prioritized to catch a larger amount of shrimps than catching more Norway lobsters. For others it is the opposite.

4.7 Variables in relation to shrimp CPUE

The GLM showed that all the included variables (pot design, attractant, moon phase and depth) had a clear significant effect on shrimp CPUE. The variables pot design and attractant are discussed in the above paragraphs and therefore not discussed here. There was a negative relation between moon illumination and shrimp CPUE (figure 13, page 23). Shrimp light suppliers advised to go shrimp fishing with lights during dark nights with little moonlight in order to increase the contrast between the attracting light and the surroundings. Koeller et al. (2007) also described a relation between shrimp catch and the lunar cycle, however they observed higher catches during full moon. In their study, tidal difference was also an influential factor, which is negligible in Gullmarsfjord. In this study, only one full cycle was taken into account. To determine the effect of the lunar cycle on shrimp CPUE, several cycles should be taken into account. The GLM showed that shrimp CPUE increased with depth (figure 14, page 24), which is coherent with the knowledge that Northern shrimps spend most of their lives in deeper parts (>100m). In order to find the optimum depth for fishing shrimps greater depth than 80m should be included.

4.8 Conclusion

This study analysed the selectivity of four pot designs and six combinations of attractants used for shrimp fishing in order to develop an alternative fishing method. This study shows that pot design and especially entrance design can result in significant differences in shrimp CPUE. The pots with the larger oval entrances caught significantly more shrimp in CPUE in comparison to the pots with the plastic funnel entrances. Compared to the impact of pot design on the entire catch, the impact of type of attractant was even larger. The use of lights as an alternative to herring as attractant resulted into a 3.1 times higher shrimp CPUE. However the attractants also affected the bycatch. Especially green light resulted in many gadoids in the bycatch, white light resulted in fewer gadoids than green light, but UV light was found to be the most selective light with the best shrimp catch/bycatch ratio. Which was less than one individual of bycatch per three shrimps. However, white light in combination with herring is also a well preforming attractant, since this combination resulted in larger shrimps and more Norway lobsters in comparison to the other lights. The results from this study contributes to the development towards more sustainable fishing methods by presenting how the tested methods increased shrimp catches and affected bycatches in pots. However, further development is still needed for more optimization.

4.9 Recommendations for future studies

There are various ways in which to take this research further. For example, to experiment with different colours like blue, yellow or optimize the colours in a way that the lights emit colours that peak in the same wavelengths as the visual spectrum of the target species. According to shrimp light suppliers the amount of lumen is an important factor, therefore it is recommended to experiment with stronger lights and pulsing lights, Light could also be interesting for gadoid fisheries since they are strongly attracted to light.

Another suggestion is to study what attracts shrimps to light. Are they attracted to the light itself or to something that is attracted to light? In his study, Eaton (1972) concluded that adult Northern shrimps do not respond to light in his experiment, which makes it more likely that shrimps are attracted to possible prey that are attracted to light. Fish are attracted to light in the same way (Marchesan et al, 2004; McConnell et al, 2010). In this study underwater cameras showed that potential prey are attracted to the lights but no shrimps that tried to catch it where observed. However small planktonic species are hard to capture on camera. An experiment in a controlled environment could show if shrimps are attracted to light when there are no other organisms.

Northern shrimps could be attracted to activity in the water that might mean that there is food around. Placing lure shrimps in the pot might increase attractiveness, also because Northern shrimps live in groups. On the video recordings an increased rate of entries was observed when other shrimps where present in the pot.

Another potential study is to research the effect of soak time on the catch. Is it necessary to haul the pots every day or can they be hauled every two days or three days without losing on catch? If pots have to be hauled only half of the time possibly more pots could be placed and hauled interchangeably every other day. On two occasions in this study the pots had a soak time of three and four days. A soak time of three days resulted a three times higher catch compared a soak time of one day, however a soak time of four days resulted in a only two times higher catch instead of four times higher. This where only two occasions, more replicates should be made in order to show the effect of soak time.

Moreover, one could study the impact of the environmental factors like cloud cover and temperature on the shrimp CPUE, and go deeper into moon phase, depth. In this study the GLM pointed out that moon phase and depth had an significant effect on shrimp CPUE, but only one moon cycle and a limited depth was taken into account. In the study of koeller et al., (2007) a clear co-relation was found between catch and temperature. These factors have shown to effect shrimp CPUE, but data over a longer time period is needed to find out to what extend they affect the CPUE per study area.

It is recommended to study the survival rate of bycatch and undersized shrimps. They seem undamaged and were released, however they are displaced from their natural environment and no longer under cover of the darkness of the deep sea. It is still unclear if bycatch finds its way back to the deep and survives.

A part of the gadoid bycatch does not survive the pressure difference form hauling the pots. These individuals can be used as bait. In this study they were used to bait the lobster pots of the fisherman, but not shrimp pots because it might influence the results. It would be interesting to know if the dead bycatch can be used this way without affecting the catch negatively. This would increase the sustainability of the fishing method and the dead bycatch is used purposely, and no herring has to be caught and bought only for baiting pots.

With environmental awareness growing, the supply on eco-labelled food cannot keep up with the demand. In the fishing industry eco-labels are an underexplored area. An almost damage-free sustainable fishery like pot fishing could mean a higher market value. This, taken together with the improved quality of the shrimps, provides ample incentive for this niche to be further explored.

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Appendix, Results from statistical analysis on bycatch species

Saithe CPUE

Table 9: Differences in mean saithe CPUE between attractants. Results Kruskal-Wallis rank sum test ($n = 614$, $x^2 = 83.1$, $df = 5$, $p < 0.001$) with Dunn's test as post-hoc.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		*z* = 0.74	*z* = 8.40	*z* = 4.90	*z* = 3.01	*z* = 2.73
Green + herring	p = 0.22		*z* = 5.93	*z* = 3.16	*z* = 1.65	*z* = 1.69
Herring	**p < 0.001**	**p < 0.001**		*z* = -3.47	*z* = -5.38	*z* = -4.00
UV light	**p < 0.001**	**p < 0.001**	**p < 0.001**		*z* = -1.89	*z* = -1.21
White	**p < 0.01**	**p < 0.05**	**p < 0.001**	**p < 0.05**		*z* = 0.31
White + herring	**p < 0.01**	**p < 0.05**	**p < 0.001**	p = 0.11	p = 0.38	

Cod CPUE

Table 10: Differences in mean cod CPUE between attractants Results Kruskal-Wallis rank sum test ($n = 614$, $x^2 = 31.4$, $df = 5$, $p < 0{,}001$) with Dunn's test as post-hoc.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		*z* = 0.09	*z* = 4.97	*z* = 3.19	*z* = 1.93	*z* = 1.57
Green + herring	p = 0.46		*z* = 3.86	*z* = 2.46	*z* = 1.45	*z* = 1.26
Herring	**p < 0.001**	**p < 0.001**		*z* = -1.75	*z* = -3.22	*z* = -2.41
UV light	**p < 0.001**	**p < 0.01**	**p < 0.05**		*z* = -1.26	*z* = -1.01
White	**p < 0.05**	*p = 0.07*	**p < 0.01**	p = 0.10		*z* = 0.01
White + herring	*p = 0.06*	p = 0.10	**p < 0.01**	p = 0.15	p = 0.50	

Whiting CPUE

Table 11: Differences in mean whiting CPUE between pot designs. Results Kruskal-Wallis rank sum test ($n = 614$, $x^2 = 9.3$, $df = 3$, $p < 0.05$) with Dunn's test as post-hoc.

Pot	One	Three	Six	Seven
One		*z* = 2.29	*z* = 2.60	*z* = 2.39
Three	**p < 0.05**		*z* = -0.31	*z* = -0.01
Six	**p < 0.01**	p = 0.38		*z* = 0.31
Seven	**p < 0.01**	p = 0.50	p = 0.38	

Table 12: Differences in mean whiting CPUE between attractants. Results Kruskal-Wallis rank sum test (n = 614, x^2 = 19.3, df = 5, p < 0.001) with Dunn's test as post-hoc.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		*z* = -3.39	*z* = -0.12	*z* = 0.78	*z* = -0.26	*z* = -1.32
Green + herring	**p < 0.001**		*z* = 3.40	*z* = 4.10	*z* = 3.26	*z* = 1.86
Herring	p = 0.45	**p < 0.001**		*z* = 0.92	*z* = -0.14	*z* = -1.24
UV light	p = 0.22	**p < 0.001**	p = 0.18		*z* = -1.05	*z* = -1.96
White	p = 0.40	**p < 0.001**	p = 0.44	p = 0.15		*z* = -1.11
White + herring	*p = 0.09*	**p < 0.05**	p = 0.11	**p < 0.05**	p = 0.13	

Flounder CPUE

Table 13: Differences in mean flounder CPUE between pot designs. Results Kruskal-Wallis rank sum test (n = 614, x^2 = 9.8, df = 3, p < 0.05) with Dunn's test as post-hoc.

Pot	One	Three	Six	Seven
One		*z* = 0.22	*z* = 1.31	*z* = 2.84
Three	p = 0.41		*z* = -1.05	*z* = -2.48
Six	*p = 0.09*	p = 0.15		*z* = -1.37
Seven	**p < 0.01**	**p < 0.01**	*p = 0.09*	

Table 14: Differences in mean flounder CPUE between attractants. Results Kruskal-Wallis rank sum test (n = 614, x^2 = 15.0, df = 5, p < 0.01) with Dunn's test as post-hoc.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		*z* = -0.75	*z* = 2.79	*z* = 0.36	*z* = 0.34	*z* = -0.66
Green + herring	p = 0.22		*z* = 2.97	*z* = 1.04	*z* = 1.02	*z* = 0.08
Herring	**p < 0.01**	**p < 0.01**		*z* = 0.92	*z* = -0.14	*z* = -1.24
UV light	p = 0.36	p = 0.15	**p < 0.01**		*z* = -0.02	*z* = -0.96
White	p = 0.37	p = 0.15	**p < 0.01**	p = 0.49		*z* = -0.94
White + herring	p = 0.25	p = 0.47	**p < 0.01**	p = 0.17	p = 0.17	

Goby spp. CPUE

Table 15: Differences in mean goby spp. CPUE between attractants. Results Kruskal-Wallis rank sum test (n = 614, x^2 = 11.0, df = 5, p < 0.05) with Dunn's test as post-hoc.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		*z* = -0.98	*z* = 2.47	*z* = 0.16	*z* = -0.45	*z* = 0.76
Green + herring	p = 0.16		*z* = 0.97	*z* = -0.86	*z* = -1.35	*z* = -0.20
Herring	**p < 0.01**	p = 0.17		*z* = -2.33	*z* = -2.94	*z* = -1.22
UV light	p = 0.44	p = 0.19	**p < 0.01**		*z* = -0.61	*z* = 0.64
White	p = 0.33	*p = 0.09*	**p < 0.01**	p = 0.27		*z* = 1.12
White + herring	p = 0.22	p = 0.42	p = 0.11	p = 0.26	p = 0.13	

King crab sp. CPUE

Table 16: Differences in mean king crab sp. CPUE between pot designs. Results Kruskal-Wallis rank sum test (n = 614, x^2 = 14.8, df = 3, p < 0.001) with Dunn's test as post-hoc.

Pot	One	Three	Six	Seven
One		*z* = -0.88	*z* = 2.41	*z* = 2.19
Three	p = 0.19		*z* = -3.13	*z* = -2.95
Six	**p < 0.01**	**p < 0.001**		*z* = 0.31
Seven	**p < 0.05**	**p < 0.01**	p = 0.38	

Table 17: Differences in mean king crab sp. CPUE between attractants. Results Kruskal-Wallis rank sum test (n = 614, x^2 = 19.8, df = 5, p < 0.001) with Dunn's test as post-hoc.

Attractant	Green	Green + herring	Herring	UV light	White	White + herring
Green		*z* = -0.34	*z* = -2.87	*z* = 0.01	*z* = 0.01	*z* = -2.85
Green + herring	p = 0.37		*z* = -1.94	*z* = 0.35	*z* = 0.35	*z* = -2.14
Herring	**p < 0.01**	**p < 0.05**		*z* = 2.90	*z* = 2.90	*z* = -0.57
UV light	p = 0.50	p = 0.36	**p < 0.01**		*z* = -0.00	*z* = -2.87
White	p = 0.50	p = 0.36	**p < 0.01**	p = 0.50		*z* = -2.87
White + herring	**p < 0.01**	**p < 0.05**	p = 0.28	**p < 0.01**	**p < 0.01**	

Other bycatch species

Poor cod CPUE

Between pot designs: Kruskal-Wallis rank sum test (n = 614, x^2 = 6.8, df = 3, p = 0.08)
Between attractants: Kruskal-Wallis rank sum test (n = 614, x^2 = 1.7, df = 5, p = 0.89)

Squid sp. CPUE

Between pot designs: Kruskal-Wallis rank sum test (n = 614, x^2 = 4.1, df = 3, p = 0.25)
Between attractants: Kruskal-Wallis rank sum test (n = 614, x^2 = 4.7, df = 5, p < 0.44)

Common dragonet CPUE

Between pot designs: Kruskal-Wallis rank sum test (n = 614, x^2 = 1.9, df = 3, p = 0.58)
Between attractants: Kruskal-Wallis rank sum test (n = 614, x^2 = 9.1, df = 5, p = 0.1)

Sculpin spp. CPUE

Between pot designs: Kruskal-Wallis rank sum test (n = 614, x^2 = 7.8, df = 3, p = 0.08)
Between attractants: Kruskal-Wallis rank sum test (n = 614, x^2 = 7.7, df = 5, p = 0.17)

There were not enough observations for the species, true sole spp., wrasse spp., Lumpenus spp. and fourbeard rockling in order to do a meaningful statistical analysis.