Analyses of catch rates of important bycatch species in the Norwegian Coastal Survey north of Stad (62°N) 2003-2017: Do catch statistics and scientific surveys tell the same story?

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By

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Photo front cover: obtained from IMR webpage

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Abstract

Bycatch is always a present risk when conducting any kind of fisheries and an important potential resource loss we need to monitor. Four common bycatch species in Norwegian fisheries North of Stad (62^0N) are European plaice (*Pleuronectes platessa)*, European hake *(Merluccius merluccius*), rabbit fish (*Chimaera monstrosa*) and golden redfish (*Sebastes norvegicus*). Of these, golden redfish has strict regulations; ICES has advised a catch quota equal to zero as the stock is in danger of collapse. Both survey catch-per-unit-effort (CPUE) data and commercial landings data in the time period 2003-2017 are used in this thesis. Six statistical areas along the Norwegian coast north of 62°N are being examined; statistical area 7, 6, 0, 5, 4 and 3. The aim is to find what statistical/main areas these species mainly occur, and the trends of catch rates over time for both survey and commercial data. There shall also be a description of differences in catch in coastal and offshore areas using the survey data. In addition, I will identify areas and fisheries with the highest landings of the four species and evaluate whether survey catch rates can be used to identify trends in the development of the four bycatch species and thus general trends in commercial fisheries. In order to do that, exploratory data analysis were made, alongside with a forward selection modelling approach and correlation tests.

Based on survey catch rates, the data showed that the main area of occurrence for plaice was statistical area 4, for hake and rabbit fish statistical area 7, and golden redfish statistical area 5. All four species had highest catch rates in coastal areas in comparison to offshore. The data revealed Danish seine fisheries as the main fishery regarding plaice. For hake and golden redfish, the gillnet fishery was found to have the highest catch rates whereas for rabbit fish it was the longline fishery. The distribution of occurrence in landings closely resembled that from the surveys, with highest catch rates in statistical area 5 for plaice, statistical area 7 and 6 for hake and rabbit fish respectively, and statistical area 5 for golden redfish. The forward selection modelling approach revealed years, fishing depth and an interaction term between the two as significant variables for explaining the variation in CPUE regarding plaice. For hake and rabbit fish both years and fishing depth showed to be significant, whereas for golden redfish only fishing depth was a significant variable. The best models explained about 25.37%, 8.17%,

41.66% and 5.25% of the variance in CPUE for plaice, hake, rabbit fish and golden redfish, respectively.

The results from the correlation tests ranged from poor to good, both between species and areas. Regarding plaice, only statistical area 5 had a significant correlation between CPUE and landings. This showed to be strongly negative, meaning that landings were large when CPUE was low. Positive correlations were found in area 7 and 4 for hake and rabbit fish, respectively. This indicated large landings with correspondingly large CPUEs. No significant correlations were found for golden redfish. On a general basis the confidence intervals were very broad, indicating low degree of correlation between survey CPUE and commercial landings. With the exception of area 7 and 4 for hake and rabbit fish, none of the other correlations can be used as indicators when trying to identify general bycatch trends in the commercial fisheries.

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Introduction

Even though Norway has many regulations regarding discarding and bycatch (Norwegian ministry of fisheries and coastal affairs, n.d) it is always a present risk when conducting any kind of fishery. This is a problem as it results in unaccounted mortality rates, making stock assessment calculations difficult (Crowder & Murawski 1998). Regardless of types of fisheries, four common bycatch species in Norwegian fisheries North of Stad (62^0N) are European plaice (*Pleuronectes platessa)*, European hake *(Merluccius merluccius*), rabbit fish (*Chimaera monstrosa*) and golden redfish (*Sebastes norvegicus*). In an attempt to further our understanding regarding abundance trends of bycatch species, in this thesis I will analyze catch rates from scientific surveys and commercial fisheries landings to see if the surveys can be used in estimations regarding bycatch and to explain general trends observed in the commercial fishery.

1.1 Bycatch – a global phenomenon

In a fisheries context the term "bycatch" refers to discarded catch or the incidental catch of species not targeted. Discarded catch is the portion of the catch initially caught that is returned to the sea (Crowder & Murawski 1998) because of, for example, low economic value, illegal species or size, whereas the incidental catch represents the non-targeted species that accidently became part of the catch (Alverson et al., 1994). Through history the definition of bycatch has changed, and there are still some disagreements among scientist today regarding what should be included in the final definition. As many countries lack the capacity to adequately monitor and assess bycatch problematics, the scope of the problem remains largely undocumented. In an attempt to increase our understanding on the matter, Alverson et al., (1994) conducted a study commissioned by the United Nations Food and Agriculture Organization (FAO) looking at the discarding element of bycatch. They estimated that commercial fisheries on average discard 27 million tons each year. Kelleher (2005) applied another methodology and found an estimated discard of 7.3 million tons. If looking at bycatch simply as unused or unmanaged catches, a newer study estimates that global bycatch may represent more than 40% (38.5 million tons) of the global marine catches (Davies et al., 2009). Recognizing that the methodology applied in the different studies are different means that they are not directly comparable, nevertheless they all illustrate that discarding is a global phenomenon and problem.

Reasons for discarding bycatch might be illegal fish (e.g. undersized, not covered by quota etc.) in the catch, or a lot of low-value bycatch (Young & Muir 2002). Due to strongly driven economic considerations, discarding might also happen as a result of high-grading. This is when fishermen discard target species of low value due to small size only to be able to land larger, more valuable individuals (Jennings, Kaiser & Reynolds 2001). Survival of discarded bycatch is generally low, because the handling makes the fish more vulnerable to predation and diseases due to scale loss or other damages after encountering fishing gear. This can result in unaccounted mortality rates for the species involved. From both a management and scientific point of view, this challenges fisheries management (Alverson & Hughes 1996). Lack of precise mortality and ability to monitor the part of the catch going back into the sea makes it challenging to include when trying to do calculations for stock assessment (Crowder & Murawski 1998). Regardless, bycatch introduces a loss of resources for the society as a whole, and represents an additional cost for fishermen as they have to spend time and effort cleaning their gear (Young & Muir 2002).

1.2 Index for abundance - Catch per unit effort

Catch-per-unit-effort (CPUE) is a common index for abundance used in fisheries science. Despite that this index is one of the most used in abundance estimations, it has its challenges due to the assumptions it relies on (Harley, Myers & Dunn 2001): It is assumes that the CPUE is proportional to the population size/cohort size. If this were to be true this means that the catchability of fish must be constant, and effort stay the same per unit time (Jennings, Kaiser & Reynolds 2001). This is seldom true from a historical exploitation point of view, as there are several factors influencing catch rates (Maunder et al., 2006). In an equilibrium situation, there is a basic idea saying that each year's catch and effort data is in a steady state. This method assumes that the historical catch rates and the population are in an equilibrium (Hilborn & Walters 1992). When using this method it is necessary to remember that the CPUE reflects the ongoing reduction in the standing stock as effort might increase as fisheries develops. It is rarely the single reflector of density-dependent population responses to fishing mortality (Jennings, Kaiser & Reynolds 2001).

1.3 Management of fisheries in Norway – discarding

The main objective of Norwegian fisheries management is to maintain sustainable harvesting of the fish resources from both a biological and economical point of view. In order to deal with bycatch and discard problems, Norway has established both regulations and several management measures (Norwegian ministry of fisheries and coastal affairs, n.d; Norwegian ministry of fisheries and coastal affairs 2018). For instance, already in 1987 a discarding ban was established in Norway, which, accompanied with the Marine Resources Act from 2008 ("Havressursloven"), makes it obligatory to land all catches. The rest of the regulations are separated into four different categories; quotas, bycatch, change of fishing ground and closed areas (Norwegian ministry of fisheries and coastal affairs 2018).

When it comes to quotas, different fisheries are assessed and assigned species quotas after evaluating the anticipated species composition in the catches (Norwegian ministry of fisheries and coastal affairs 2018). Along with regular individual quotas per fisheries and boats, there are control regulations regarding bycatch quotas as Norwegian vessels have a certain maximum percentage of which the total catch can consist of bycatch (Directorate of Fisheries 2018). Some fisheries are managed to only catch the target species, while others are allowed a certain percentage of bycatch (Norwegian ministry of fisheries and coastal affairs, n.d). These numbers are not fixed, meaning that they can be changed at any point of time throughout the year if this is deemed necessary (Directorate of Fisheries, n.d). In addition to bycatch quotas and percentages, the regulations may include vessel size and species-selective gears (Næringskomiteen 2008; Norwegian ministry of fisheries and coastal affairs 2018). Regarding fishing grounds, the vessels are obligated to change their location if the species composition in the catches violates the quota regulations or bycatch percentage. Lastly, in closed areas or marine protective areas it is illegal to fish as these are closed to protect fry and small fish (Norwegian ministry of fisheries and coastal affairs 2018).

1.4 Commercial fisheries – Trawl, Danish seine, gillnet and longline

Bottom trawl fishery

Towed fishing gears such as bottom trawls are used all over the world on shelf seas (Jennings, Kaiser & Reynolds 2001), but McAllister et al. (cited in Roberts 2002) estimated that 40% of the worlds trawling grounds are located in areas deeper than the continental shelves. Such gears tend to cause dramatic changes on the sea floor, disrupting and damaging demersal fauna (Jennings, Kaiser & Reynolds 2001). In Norway this fishery has cod (*Gadus morhua*), saithee (*Pollachius virens*) and haddock (*Meranogrammus aeglefinus*) as target species. The selectivity of a trawl occurs in several stages, beginning at behavior responses to sound and visible indications of the gear or vessel. The trawl itself is selective due to mesh size and grids, allowing smaller individuals to escape the trawl before they reach the cod-end (O'Neill & Mutch 2017). Still, trawling gear has the potential to capture a wide variety of organisms in large quantities, which in turn can result in conflicts with other fisheries (Kennelly 1995).

Danish seine fishery

Danish seines are mainly used to fish demersal species, and are size-selective as mesh sizes are chosen based on the target. This form of fishing has a relatively low environmental impact (Australian Fisheries Management Authority, n.d), where bycatch is the main possible influence on other living organisms. Smaller individuals and non-target species can easily be caught in the net, and might be discarded (Sainsbury 1996). The Norwegian Danish seine fishery, located mostly north of Lofoten, has cod (*G.morhua*) and haddock (*M.aeglefinus*) as two main target species.

Gillnet fishery

Gillnets are both passive and selective fishing gears, with mesh sizes chosen to target different length groups within a stock. There is also discrimination between species due to morphology and activity levels. In addition, the use of this type of gear is habitat restricted, resulting in yet another influence regarding species selectivity (Næsje et al., 2007). Cod (*G.morhua*) and saithe (*P. virens*) are two main target species in the Norwegian gillnet fishery, but other species might get tangled, reducing the net area. As a result, there is a reduction in efficiency and extra work as the gear might be damaged. Also, the fish caught in the demersal gillnets are targets for crabs to feed on, resulting in reduced value and quality of the catch (Godøy, Furevik & Løkkeborg 2003).

Longline fishery

With low fuel consumption, minimum damage of fishing grounds, good quality and relatively low rate of discarding of undersized individuals and bycatch (Bjordal, cited in Løkkeborg & Bjordal 1992) the fisheries management might encourage the use of longlines due to their conservation-orientated aspects. In the Norwegian longline fishery, cod (*G. morhua*) and haddock (*M. aeglefinus*) are the two most important target species (Løkkeborg 1991). Several factors affect the longline catches, those being environmental, biological or technical aspects (Olsen & Laevastu 1983). The species selectivity and catch success is linked to horizontal and vertical distribution of fish (Løkkeborg & Bjordal 1992), and heavily influenced by the foraging behavior; hence, bait type is important (Løkkeborg, cited in Løkkeborg & Bjordal 1992). Chemical components in the bait might attract other species than the target species, resulting in bycatch. This causes incidental mortality of different species and bait loss, which leads to a reduction in gear efficiency (Løkkeborg 2001).

1.5 Commercial fishery history regarding European plaice- and hake, rabbit fish and golden redfish

Four of the most important bycatch species in the Norwegian fishery are European plaice, European hake, rabbit fish and golden redfish, all common along the Norwegian coast (Figure 1). While some are still commercially harvested, all have been targeted in the past in smaller or bigger scale.

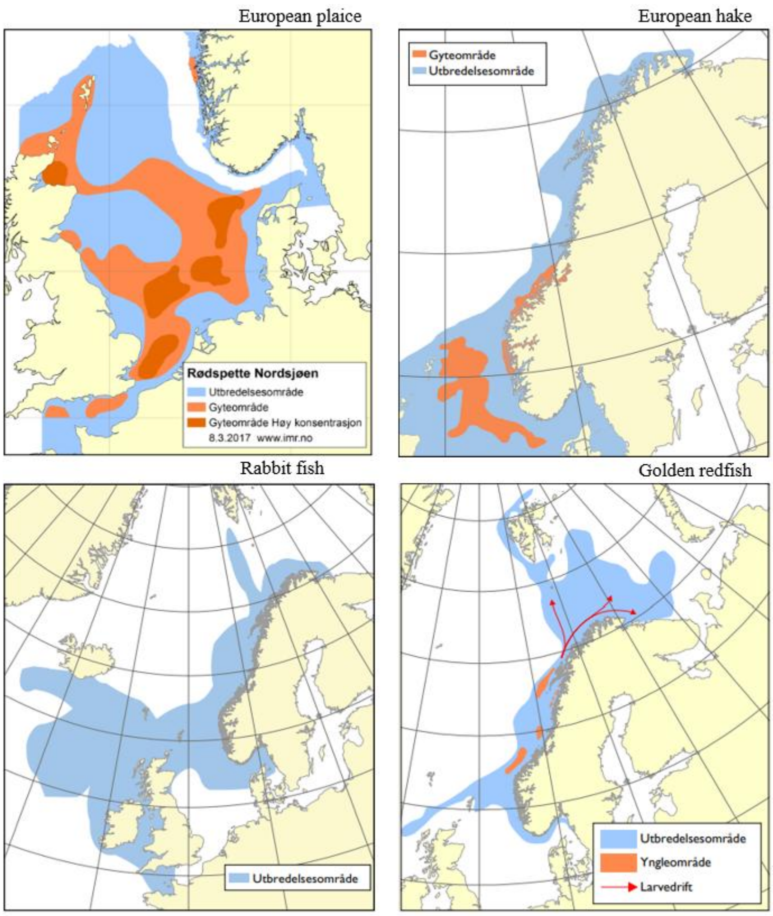

Figure 1 – Distribution maps for plaice, hake, rabbit fish and golden redfish. Area of distribution is marked with light blue, orange indicates spawning- and fry areas and red lines show larval drift (Bakketeig, Hauge & Kvamme 2017).

European plaice (*P. platessa)* (Fig. 2) is divided into several stocks, with the North sea stock estimated to be the largest. There is an ongoing commercial fishery on this stock and ICES estimates it to be in good shape and sustainably harvested. This estimation is valid regardless of the known fact that there is an extensive discard rate of undersized individuals (Bakketeig, Hauge & Kvamme 2017). There is no target fishery of plaice along the Norwegian coast today, mainly due to a large presence of the strongly regulated coastal cod in the catches when targeting flatfish (Bakketeig, Hauge & Kvamme 2017).

European hake *(M. merluccius*) (Fig. 3) is also divided into several stocks. The "northern" stock of hake consists of all individuals found north of the Bay of Biscay, west of Ireland and the entire North Sea and Skagerrak. Hake found along the Norwegian coast north of 62°N is not a part the same management unit (Bakketeig, Hauge & Kvamme 2017). Here, the species is mainly found in areas off Møre og Romsdal, where most of the catches are done using gillnets, but in the later years also by bottom trawls further offshore. Between 400 and 700 tons have been landed annually since 2004, but in the later years the total catches have been over 900 tons (Institute of Marine Research 2019b).

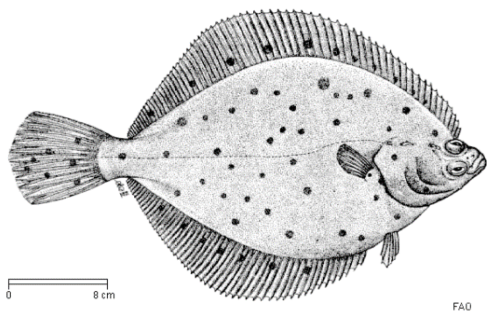

*Figure 2 – European plaice (*Pleironectes platessa) *illustration (Bauchot 1987b).*

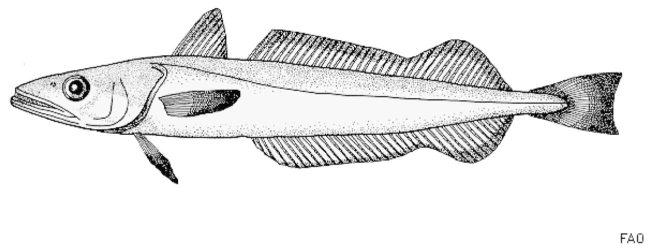

Figure 3 – European hake (Merluccius merluccius*) illustration (Cohen et al., 1990).*

Rabbit fish (*C. monstrosa*) (Fig. 4) was commercially harvested in the past, with the species' large liver as the main resource for oil production. Today there is no target fishery on rabbit fish in Norwegian areas, only catches made as bycatch in other fisheries, which are believed to be discarded (Bakketeig, Hauge & Kvamme 2017). Management and monitoring of the stock is not prioritized, hence we lack knowledge about the species biology. The limited information we have regarding discarding makes fishery data less reliable. As a precautionary approach the International Union for Conservation of Nature (IUCN) has labeled rabbit fish as "near threatened". However, rabbit fish has had a stable incidence in several of the scientific cruises done by the IMR (Bakketeig, Hauge & Kvamme 2017).

Golden redfish (*S. norvegicus*) (Fig. 5) has not always been separated from similar looking species regarding registration of landings. In 1999 a total catch equal to 30.201 tons was recorded for redfish species combined. Commercial fisheries peaked in 1937-1938 and 1951-1952, and between 1960-1990 the catches were fairly stable. Then, from 1990, the stock has experienced low recruitment, and is today said to be at a historically low level (Bakketeig, Hauge & Kvamme 2017). As a result, ICES has advised to ban all fishing activities regarding golden redfish, setting the quota equal to zero (ICES, 2016).

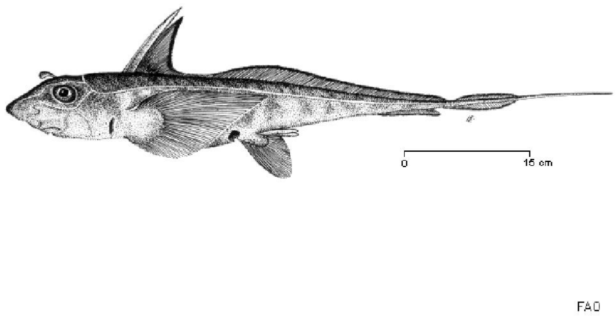

*Figure 4 – Rabbit fish (*Chimaera monstrosa*) illustration (Bauchot 1987a).*

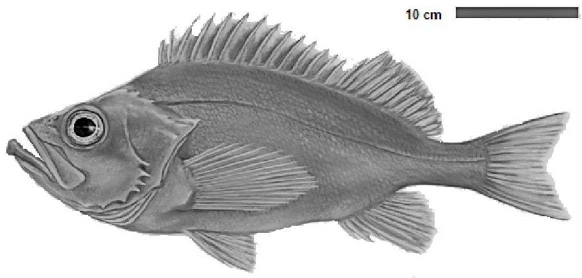

*Figure 5 – Golden redfish (*Sebastes norvegicus*) illustration (The Editors of Encyclopaedia Britannica 2017).*

1.6 Study area

The Norwegian Sea is categorized as a species rich and productive marine area between Norway, Iceland, Svalbard and Greenland (east of the mid-Atlantic ridge). One of the main reasons for why the Norwegian waters are so productive is the inflow of nutrient-rich warm water from the Atlantic, resulting in high rates of harvestable resources (Stenevik & Sundby 2007). There are large depth differences throughout the area (mean depth; 1600m), giving it a diverse demersal fauna (Ottersen, Mork & Huse 2016). Due to the depth differences, and the fact that there are several sites deeper than 3000m, there are only a few fishing grounds where it is practical to catch demersal fish. These aggregate on the continental shelf and on the “slope’’ along the shelf (Norwegian ministry of fisheries and coastal affairs 2017).

This study also takes place in the southern parts of the Barents Sea, which has a mean depth of 230m, making it a relatively shallow but highly productive area. It is an attractive area for fishing, with a high exploitation of several commercially important species. In these areas cold arctic waters meets and mixes with water of higher temperatures and salinity from the North Atlantic current. As a result, the temperature and the ice coverage varies greatly throughout the year. The Barents Sea is a specious area, with a rich life of everything from plankton to whales, but the great diversity is highly dependent on the influx of eggs- and larva (Institute of Marine Research, n.d).

On these fishing grounds, the average temperature in the water column has increased during the last decade, and this has the potential to affect the marine life in different ways (Norwegian ministry of fisheries and coastal affairs 2017). A change in temperature may alter productivity and cause fish species to alter their distribution and migration patterns. If so, this can change their visiting time in the Norwegian Exclusive Zone, which may affect fisheries management and quota setting (Stenevik & Sundby 2007).

1.7 Aims

This thesis will be an attempt to thoroughly describe trends in bycatch of plaice, hake, rabbit fish and golden redfish along the coast of Norway north of Stad (62°N) by comparing catch-data from Norwegian commercial fisheries with scientific cruise data. Catches from six statistical main areas along the coast are being examined (Table 1). Specific aims for this thesis will be:

- To describe the main areas of occurrence based on survey catch rates of the four species and the trends of catch rates over time.
- To describe differences in catch rates in coastal and offshore areas using the survey data
- To identify the areas and fisheries that have the highest landings (bycatch) of the four species.
- Compare the distribution of occurrence of both survey data and commercial fisheries landings
- Evaluate whether survey catch rates can be used to identify trends in the development of the four bycatch species and thus general trends in commercial fisheries

Materials and method

2.1 Data sources

This study of European plaice, European hake, rabbit fish and golden redfish is based on data from the Norwegian Coastal survey, and the commercial fishery landings. Additionally, reference fleet data was used to determine the selectivity of different fishing gears for the four species investigated. Survey data and data from the reference fleet is stored in IMRs S2Data Editor database. The commercial fishery landings data was extracted from official landings receipts/tickets which is made available to the Institute of Marine Researches (IMR) by the Norwegian Directorate of Fisheries. All data were provided by IMR.

2.1.2 Norwegian Coastal survey

The Norwegian Coastal survey has been conducted annually by the Institute of Marine Research since 1995. For the purpose of this thesis, survey catch-data for plaice and hake, rabbit fish and golden redfish from the period 2003-2017 is used. The survey design changed in 2003, making it difficult to compare data from earlier years. The survey covers coastal and offshore bank areas between Stad (62ºN) and Kirkenes (71ºN), and is carried out annually during October-November. The main aim of the cruise is to estimate abundance indices (number of fish) by age for saithe and coastal cod, and calculate the average weight and length at age for both species. The survey abundance indices are used in the stock assessment of both coastal cod and saithe (Mehl et al., 2016).

The main gear used for collecting data during the cruise is a standard shrimp trawl (Campelen 1800) (Fig. 6), with mesh size of 80mm in the front end and 22mm in the cod-end, and fitted with rock hopper gear to prevent damage to the trawl on rough bottom. Standard trawling duration is 30 minutes, and when trawling at a speed 3-3.5kn the opening/height of the trawl should be more than 3.6m and the door-spread

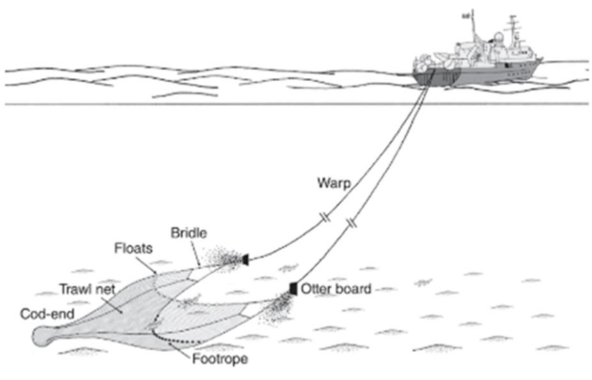

Figure 6 - Bottom trawl illustration. Otter boards (trawl doors and other gear) create mud clouds that herd the fish into the trawl (Fig. 3.6 in Salvanes et al., 2018).

50-55m. “Thyborøn” trawl doors with 40m sweeps are used to achieve the desired trawl width.

The cruise has a predetermined number of bottom trawl stations. In between the fixed stations several bottom trawl hauls are conducted for acoustic target identification purposes, adding a limited number of random samples each year. Following a standardized sampling protocol (Mehl et al., 2016), the total catch is first sorted and weighed by species. Thereafter either the total catch or a subsample of the total (in case of large catches) is used to obtain length, weight, sex- and gonad maturity data for target species, while length measurements are obtained for non-target species. Otoliths are removed for age estimation of target species.

2.1.2 Commercial fishery

When describing the size of the Norwegian fishing fleet several indicators can be used. Often the number of vessels registered, with vessels operating throughout the year representing the important part of the fleet, give a reliable indication. These vessels have a minimum of 30 weeks in active fishing operation. This part of the fleet is further divided into two main groups, coastal- and offshore fisheries, based on the area, size and gear used in the different vessels. Coastal fishing vessels operate within 12 NM from the shore, whereas fishery outside this boundary is regarded as offshore (Jakobsen & Lindkvist 2003). Typically, fisheries using various types of set nets / gillnets are coastal and operate inside the 12 NM zone, which is also the case for the purse seine, Danish seine and longline fisheries. The trawl fishery is largely an offshore fishery operating outside the 12 NM zone. In this thesis, total bycatch landings of the four species in the period 2003-2017 from both the coastal- and offshore fleet are examined.

The marine areas off Norway, i.e. North Sea or Norwegian Sea, are divided into statistical main areas, which again are further divided into statistical fishing locations or rectangles (ICES, n.d). The main areas are defined by longitudinal and latitudinal boundaries covering specific parts of the coast. In this thesis, only six areas north of 62°N were covered (Table 1).

Table 1 - Latitudinal and longitudinal boundaries regarding the six statistical main areas examined in this thesis. All areas are standard ICES statistical areas.

Main area	Latitudinal boundary (°N)	Longitudinal boundary (°E)
7	62 - 64	-
6	64 - 67	-
5	67 - 70	-
0	67 - 68.5	11 - 17
4	70 - 71	-
3	69 - 72	26 - 33

When comparing the fishing fleet from different regions, there are major variations in size- and composition of coastal- and offshore vessels. Some groups of the fleet are even highly bound to certain areas. Looking at coastal vessels, the main groups are located in the most northern part of Norway, for example; Danish seine fisheries are mostly north of Lofoten and purse seines in both north and south. The gillnet fishery on the other hand is only patchy distributed north of Lofoten as this fishery is mainly off the coast of Møre and Helgelandskysten. The main county regarding the offshore fleet is Møre og Romsdal where most of the trawling operations are located. Still, some of this fishery is also located north of Lofoten. As a result, factors such as landings and target species might vary between fisheries. Regarding landings there are two main factors influencing this. First of all, the resource and population dynamics, and second, the quota settings (Jakobsen & Lindkvist 2003).

2.1.3 Reference fleet

The reference fleet is a part of the commercial fishing fleet, consisting of about 38 vessels that provide IMR with information from randomly selected fishing stations on a regular basis. The data gathered by this fleet gives more detailed information of species composition in the commercial catches and, extensive data regarding age- and length composition used in stock assessment of commercially important species. In addition, CPUE-data from this fleet has been used in fishery management. The fleet is renewed every fourth year and consists of vessels with both active gears such as trawls and purse seines, and passive gears like longline and gillnets. The vessels are equipped to take length and weight measurements and to collect otoliths using the same sampling procedures and data handling as the research vessels (Institute of Marine Research 2019a).

The gears used during scientific cruises do not have the same length selectivity as the commercial fleet, which are obliged to use larger meshes; hence, smaller individuals are often caught on surveys. To make sure that cruise and the commercial fleet comparison was based on the same part of the population, length data from the Reference fleet collected in 2017 North of 62°N was used. Cumulative length distributions for hake and golden redfish were made from the gillnet fishery, whereas for plaice and rabbit fish the length data came from Danish seine- and longline fisheries respectively. Cumulative length distributions from the reference fleet and the survey were compared to establish a minimum length, in order to eliminate survey stations containing mostly fish below this length. The selectivity analysis were done at IMR prior to this study and are therefore not included in the thesis.

2.2 Selection of data materials

All statistical data analyses were done using the statistical program R version 3.4.1 (R Core Team 2017). Data extractions and some preparations were done before any analyses of the catch-data from the survey could be conducted. All CPUE-data were standardized to kg/NM and Campelen 1800 standard shrimp trawls were selected as gear. The cruise stations allocated within the six main areas were further divided into subareas with regards to the location of the stations and their distance to shore. Stations closer than eight nautical miles to the main land were categorized as "coastal-stations", whereas those further offshore were categorized as "open ocean-stations". In total that gave 12 areas to consider, consisting of six main areas divided into two subareas each. Further, the mean CPUE per year was calculated for each subarea.

The total landings from the commercial fishing fleet came from seven different gear categories; trap, Danish seine, gillnets, longline, purse seine, trawl and 'other'. For all gear categories, total landings per year in all main areas were calculated along with total catch during the course of the time period studied. After comparing total catches with different gears for each species, the gear with the highest landing in total was selected for comparison with survey CPUE.

2. 3 Exploratory data analyses

To visualize patterns of both CPUE and landings different kinds of graphical illustrations were made using the package *ggplot* (Wickham 2016) in R. The line in figures such as Figure 8- and 9 were made with the command *geom_hline (aes(yintercept=mean(cpuew))* making a line representing the mean CPUE for all areas combined. In figures such as Fig. 13 and 14 on the other hand, the regression lines were made by fitting the best line to the data points with the command *geom_smooth(method=”lm”)*.

For plaice and redfish, there were large outliers in CPUE in some years between 2003-2017. In order to better show the main trend in the data for these two species, a new panel with a limited y-axis was made, visualised in the same figure as the original with all data points present (Fig. 8- and 32-33 and Appendix A.5).

To be able to compare and look at correlation between CPUE and landings, the datasets had to be combined in R. After being customised they were united by the following code; *full_join(data.x, data.y)* (Appendix A.5). Pearson correlations tests were conducted after the new dataset was filtered for each area, giving an individual correlation coefficient per main area (Appendix A.5). Correlation tests were also conducted when specific outliers were neglected to check to what degree they influenced the result.

2.4 Modelling approach

I used both simple and multiple linear regression models (LM) when modelling the relationship between response and explanatory variables. These models are described in this manner:

$$y_i = \beta_0 + \beta x_i + e_i$$

$$y_i = \beta_0 + \beta_i x_i + \beta_j x_j \ldots\ldots + e_p$$

where y equals the response variable CPUE (kg/NM) and x are the predictor variables year and fishing depth. e is the random variable representing the error term in the model, meaning random fluctuations, measurement errors or how factors outside our control can have an effect. The response variable CPUE (kg/NM) was log transformed using natural logarithm in order to look at relative and not absolute change. Both models were used to check if there were any reason to believe that the response variable was influenced by more than one predictor variable and if interactions between them were significant. Both of these models have several assumptions one has to take into consideration. There has to be a linear relationship between the response-and the predictor variable, there must be multivariate normality, no or little multicollinearity, no auto-correlation and homoscedasticity (Assumptions of Linear Regression, n.d; Assumption of Multiple Linear Regression, n.d).

The area with the highest landings in total was found for each species and filtered out as a new data frame along with coastal stations before the modelling approach started (Appendix 5). This was done to reduce the number of variables in question and to only focus on the most important main-and sub-area. The area with highest landings were used for all species with the exception of rabbit fish, where the area with the second highest landings was chosen (area 7). Approximately 14 tons separated the two main areas (6 and 7) (Appendix 3, Table 3.3) throughout the period studied, but due to a better time series in the coastal stations from the survey, area 7 was chosen for this species.

Two predictor variables were used when looking at the cruise data; fishing depth and year. Therefore, forward selection was used when finding the most parsimonious model to explain the variance in the response variable CPUE (kg/NM). First, a null model was made, only giving the mean value for the response variable for the entire time series. Second, two models were made by adding a single predictor variable before these were compared against the null model using a likelihood ratio test (the R command *anova(mod.0,mod.1,test="F")*). If more than one variable resulted in a significantly better model, the one reducing the residual sum of squares (RSS) the most was chosen as the new null model. This process was repeated with the remaining predictor, adding it to see if it would result in a significant reduction in RSS. The last step was to test for interaction between significant predictors to see if an interaction term gave a significant improvement on the model. One interaction was considered for cruise data, interaction year × fishing depth. The interaction term was added in the same way as predictors (Appendix 5).

When the best models were found, they were used to predict trends in CPUE for each species. The predicted values were plotted along side with observed means of CPUE to illustrate the model estimates. Since fishing depth is a continuous predictor variable a fixed depth needed to be determined in order to include it when making these figures. The fixed fishing depth was chosen to be 200m, a representative depth for the survey.

Results

3.1 European plaice

3.1.1 Scientific survey – CPUE-data

European plaice was a frequently caught species and present in all areas in the course of the study period, particularly in the coastal areas (Fig. 7). On the coastal stations, plaice was observed annually in area 0 and 3-5 (Fig. 8), whereas fewer observations were made in area 6 and 7. In area 0, 3 and 5 there was a more or less stable CPUE from 2003-2017, whereas the CPUE in area 4, 6 and 7 all showed a varying increasing trend.

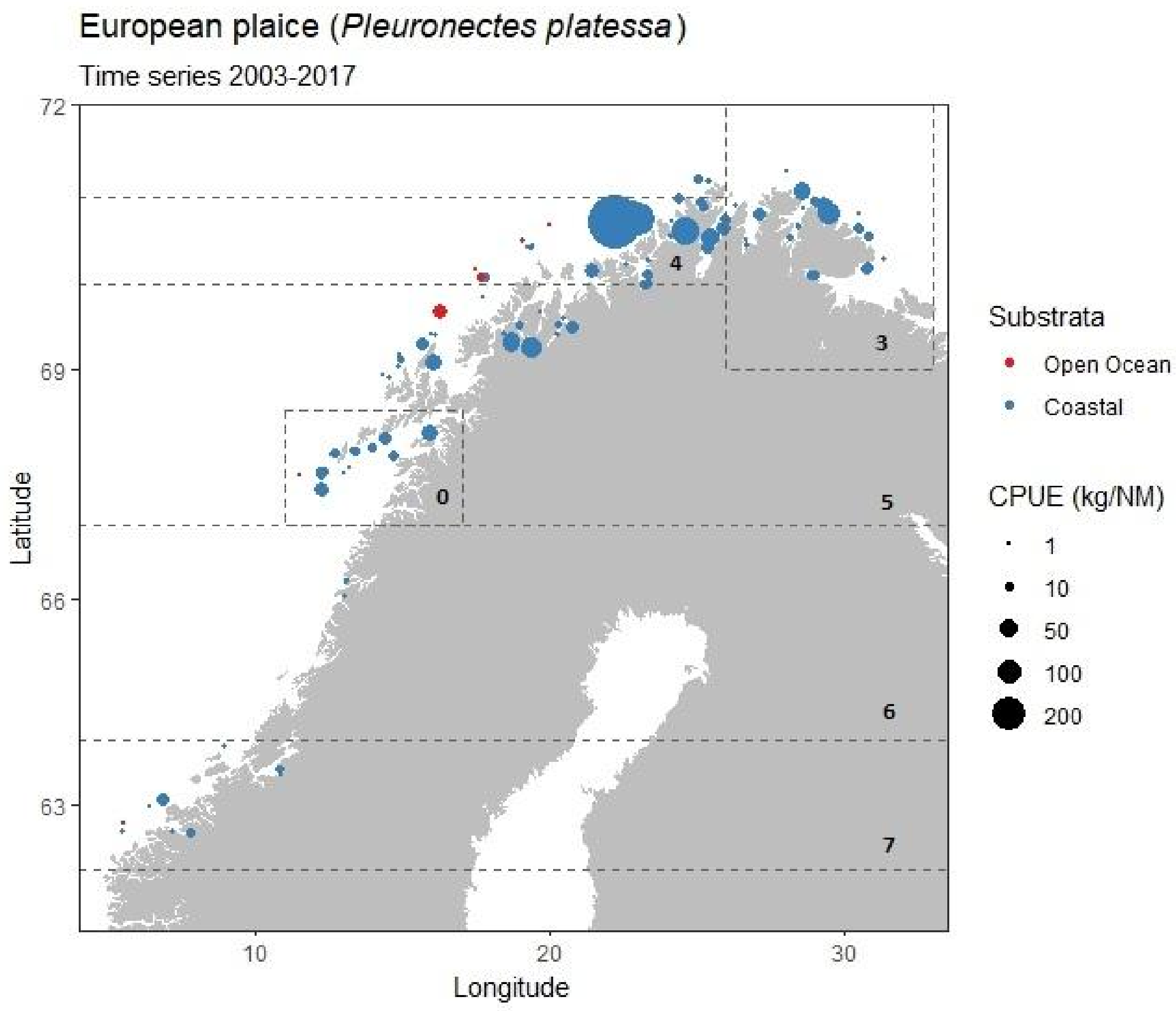

*Figure 7 – Catches from surveys of European plaice (*Pleuronectes platessa*) made during the study period along the Norwegian coast north of 62°N. Catch per unit of effort (CPUE) is proportional to circle size and coastal- and open ocean stations are indicated separately. Numbers on the map indicate areas corresponding to the main statistical fisheries area.*

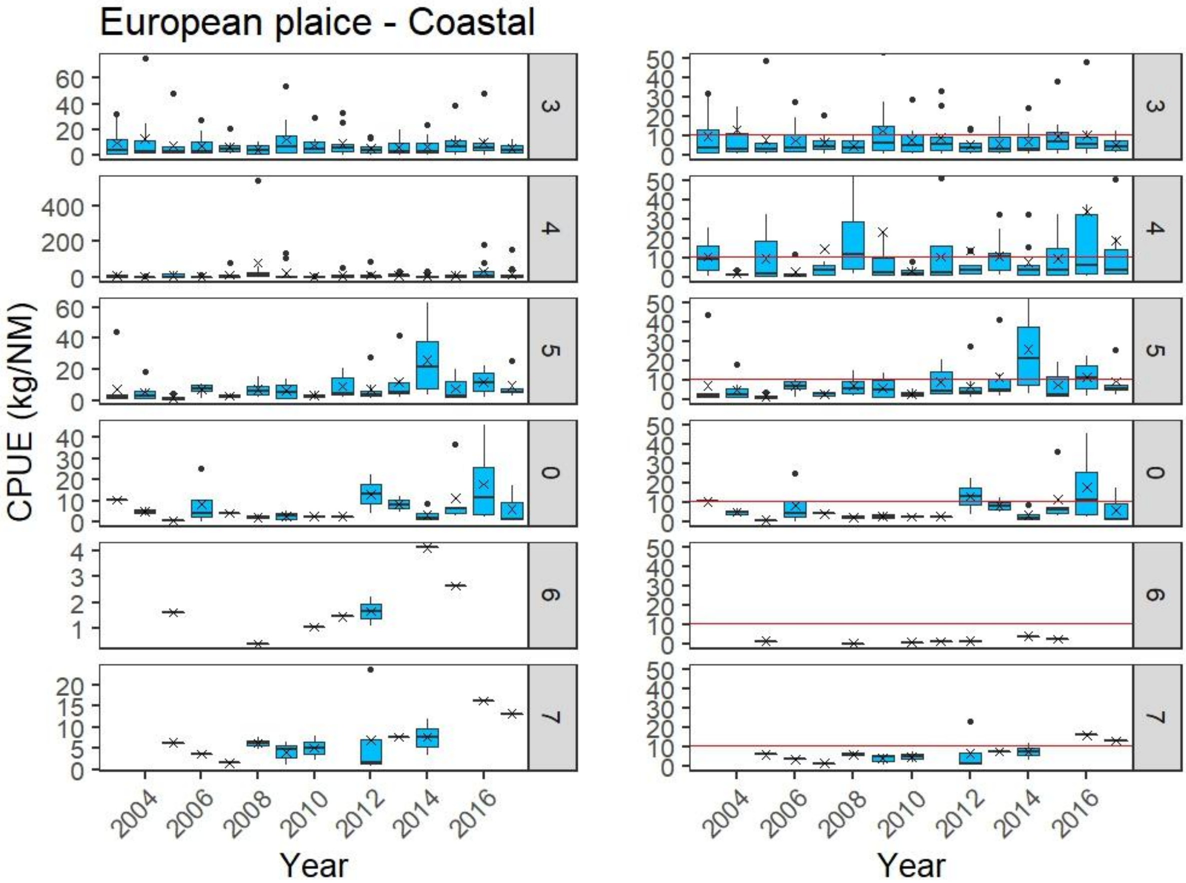

*Figure 8 - Annual average catch per unit of effort (CPUE) of European plaice (*Pleuronectes platessa*) based on coastal stations sampled by IMR where average CPUE is indicated by stars. The left panel includes all data points whereas the panel to the right has a limited y-axis excluding some outliers. The red line on the right panel illustrates the overall average CPUE for all areas combined.*

Offshore observations were only made in three areas, 4, 5- and 7. Out of these, plaice was most frequently caught in area 5 (Fig. 9) where the largest CPUE was in 2010. After 2010 catch rates decreased, and for example, in area 7 and 4, only one and two observations were made respectively the last 15 years. Combining the mean CPUE from both subareas, main area 4 was where the catch rate was found to be the highest (Appendix 1, Table 1.1), giving the largest total CPUE of plaice the last 15 years. Area 5 and 3 had the second and third largest CPUE found.

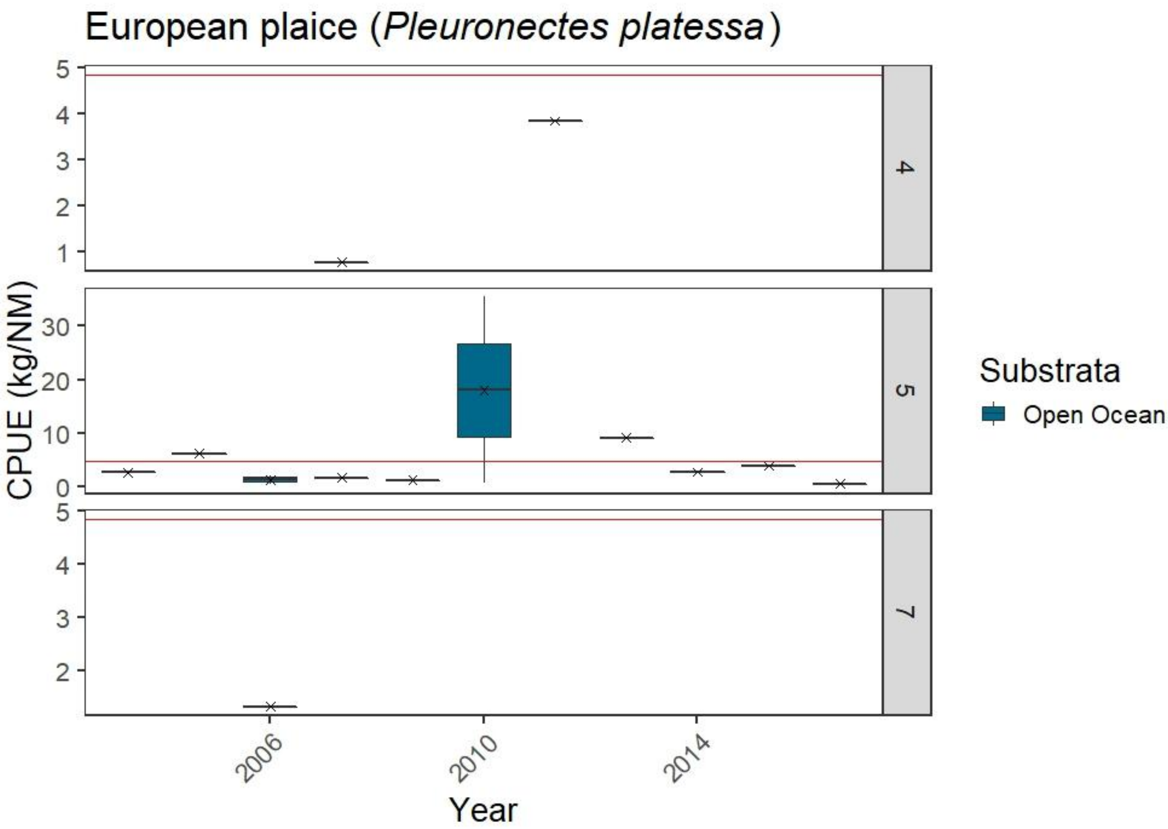

*Figure 9 - Annual average catch per unit of effort (CPUE) of European plaice (*Pleuronectes platessa*) based on open ocean stations sampled by IMR where average CPUE is indicated by stars. The red line illustrates the overall average CPUE for all areas combined.*

3.1.2 Commercial fisheries – landings data

The bycatch of plaice was mainly from the Danish seine fishery (Fig. 10), having caught around 8087 tons from 2003 - 2017 (Appendix 2, Table 2.1). For all fisheries combined, the highest landings of this species were made in areas 4 and 5. Looking at the time series of annual Danish seine catches only, variation over the last 15 years is evident (Fig. 11). Landings from areas 6 and 7 were comparatively low. The trends in areas 0-5 were very similar, all declining until 2010-2012 followed by a more or less stable trend with a slight increase. For the Danish seine fishery the overall largest catches were made in area 5, followed by areas 4 and 3 (Appendix 3, Table 3.1).

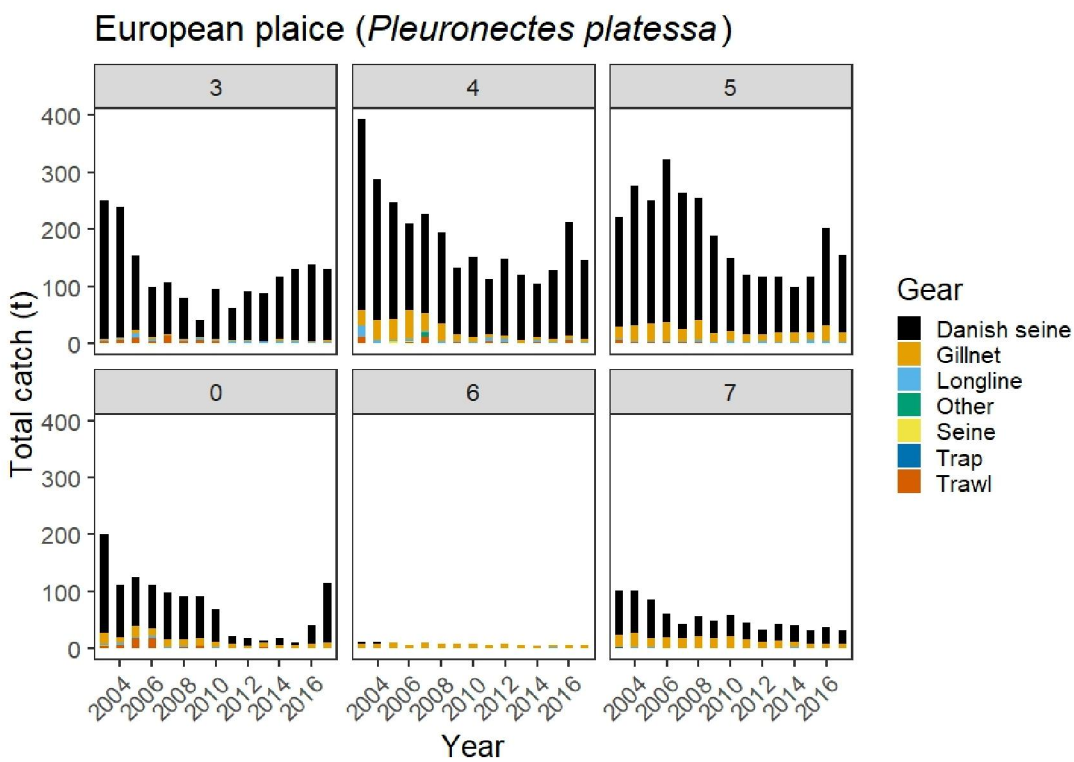

*Figure 10 - Total annual bycatch of European plaice (*Pleuronectes platessa*) by commercial fishing gear group / category and area between 2003 and 2017.*

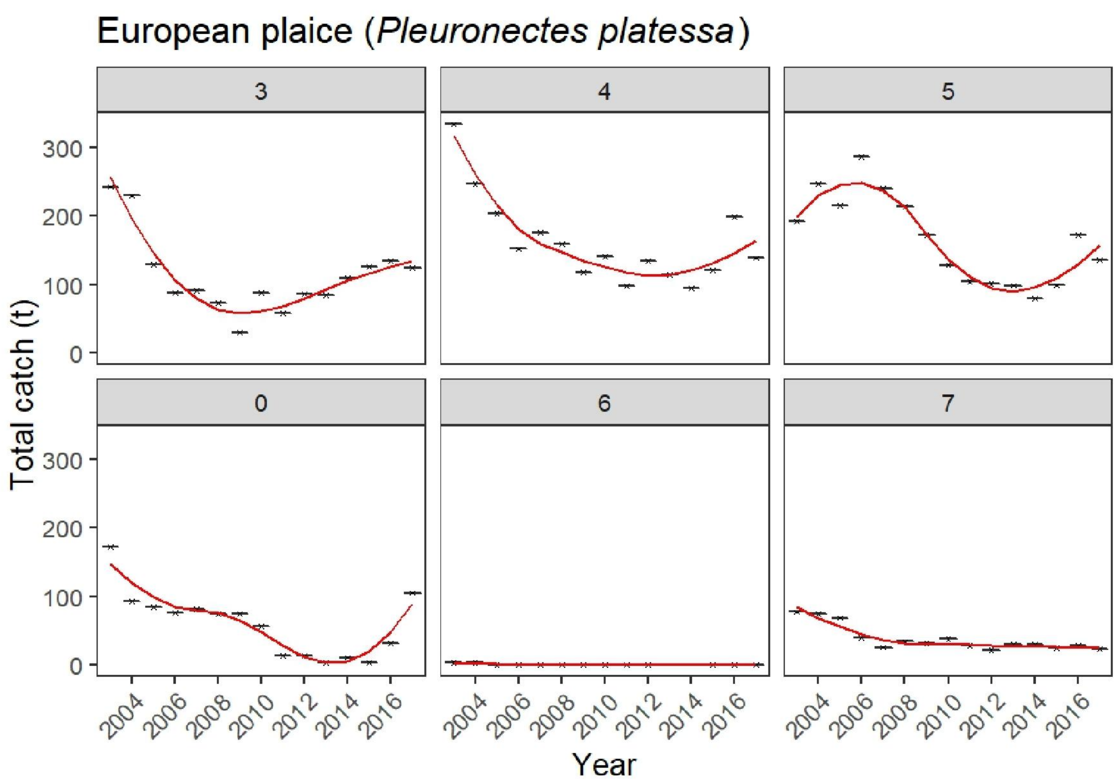

*Figure 11 – Annual total bycatch landings of European plaice (*Pleuronectes platessa*) in main statistical fisheries areas from the Danish seine fisheries. Stars indicate landings, and the red line represents a trend line following the yearly total catches.*

3.1.3 Model prediction

Area 5 was found to be the area with the highest landings in total. The two parameters, year and fishing depth, in addition to an interaction term between them were found to give the best model, explaining 25.37% of the variance in the CPUE-data (Fig 12, Model output in Appendix 4).

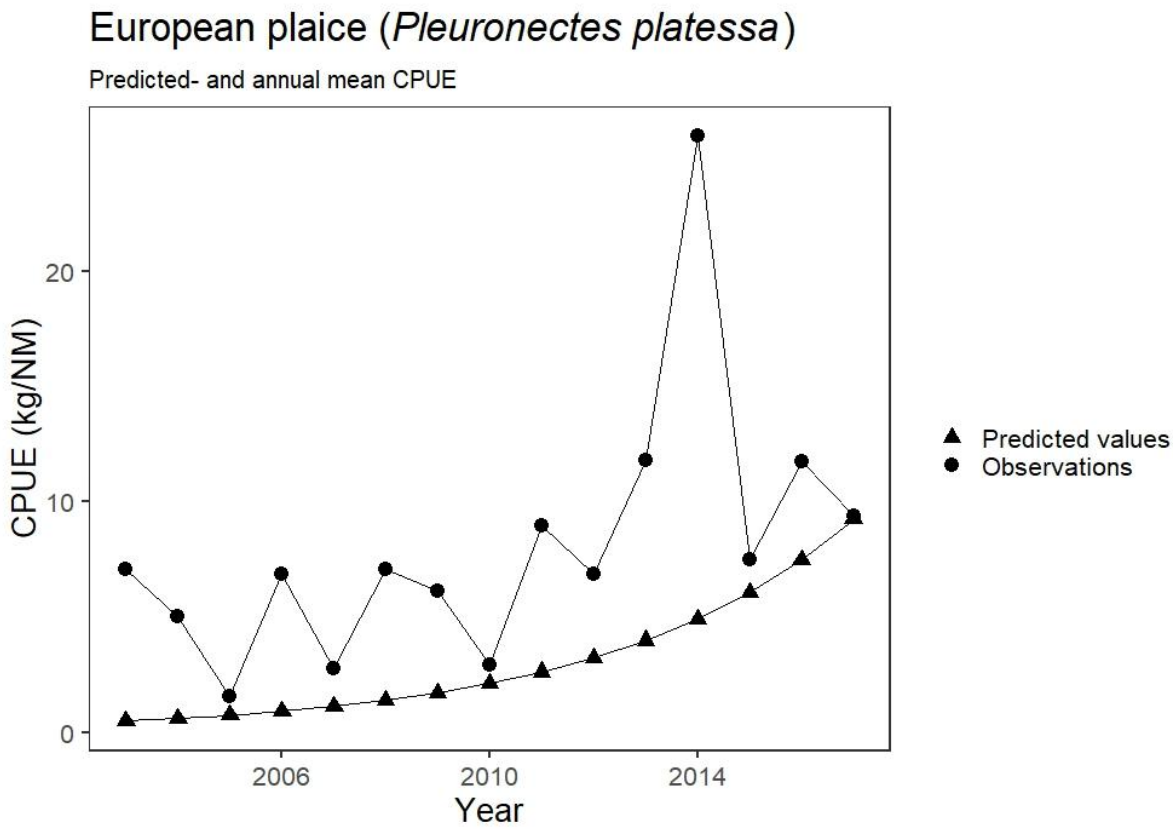

*Figure 12 – Visualization of predicted (triangles)- and observed mean annual CPUE (circles) for European plaice (*Pleuronectes platessa*) in main area 5, subarea coastal.*

3.1.4 Correlation between CPUE and landings

Comparing average annual survey CPUE with landings from fisheries by subarea (Fig. 13) revealed variation in correlation. In all areas, except for area 3, survey CPUE was negatively correlated with total catches from the commercial fishery. A significant correlation was only found in area 5, whereas for the other areas there were found no relationship between survey CPUE and commercial landings at all (Table 2). This was also the case when the data point with the highest CPUE in area 4 was neglected. With other words, most of the confidence intervals were very broad, indicating low degree of correlation. In area 5 the correlation coefficient was equal to -0.60, indicating large commercial landings when survey CPUE was low. When the data point with the highest CPUE was neglected in this area, the correlation was no longer significant or as strongly negative.

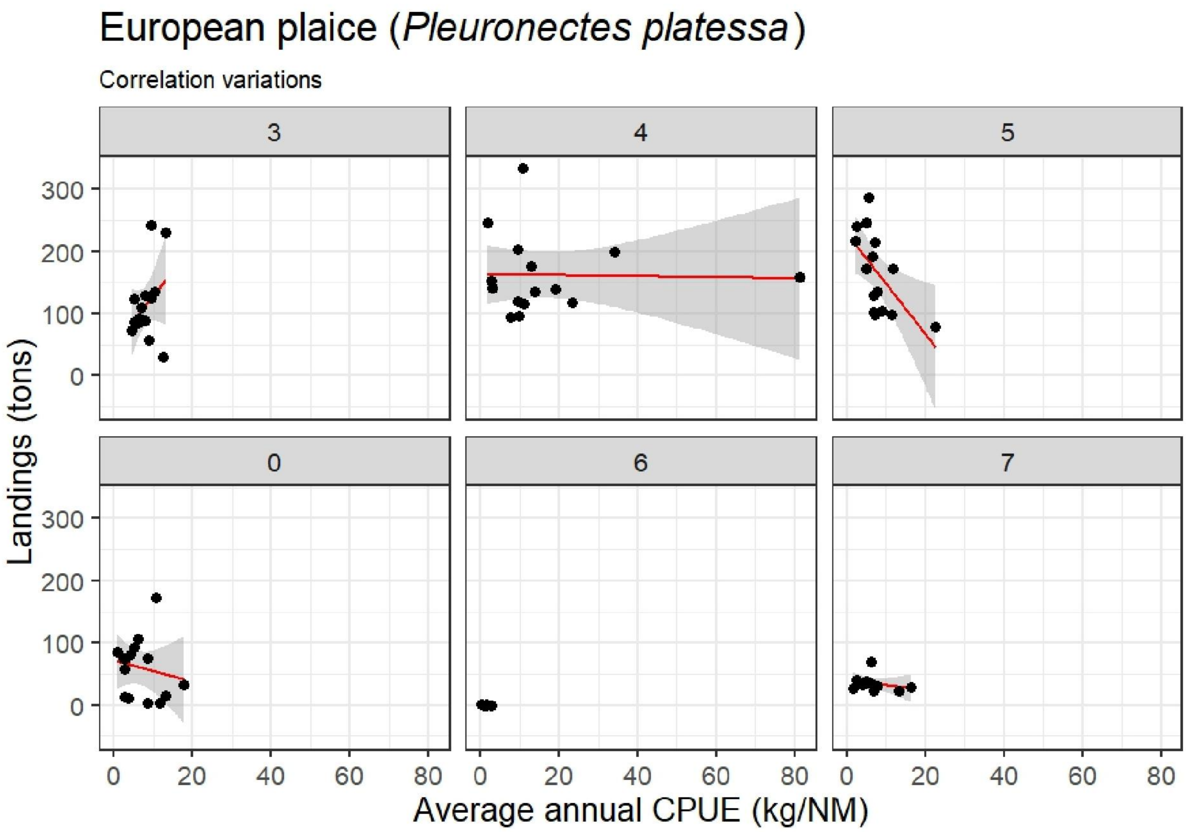

*Figure 13 - Correlation plot showing the dependence of survey CPUE (kg/NM) – calculated for both coastal and offshore areas - and landings (tons) for European plaice (*Pleuronectes platessa*).*

*Table 2 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for European plaice (*Pleuronectes platessa*), calculated for both coastal and offshore areas. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
0	-0.63	0.37	-0.17	0.54	-0.63	13
3	-0.20	0.73	0.35	0.20	1.35	13
4	-0.53	0.49	-0.03	0.93	-0.09	13
5	-0.85	-0.13	-0.60	0.02	-2.74	13
6	-0.93	0.54	-0.48	0.33	-1.11	4
7	-0.74	0.42	-0.24	0.47	-0.76	9

As there were almost no data of plaice from the open ocean stations, it was decided to further look only at the coastal areas separately and compare these with the landings data (Fig. 14). The only coefficient that differed from the combined comparison was for area 5, which changed to -0.53. The other correlation coefficients were the same (Table 3). This meant that for the rest of the areas there were no relationship between commercial landings and survey CPUE, and the negative correlation in area 5 indicated high landings when CPUE was low.

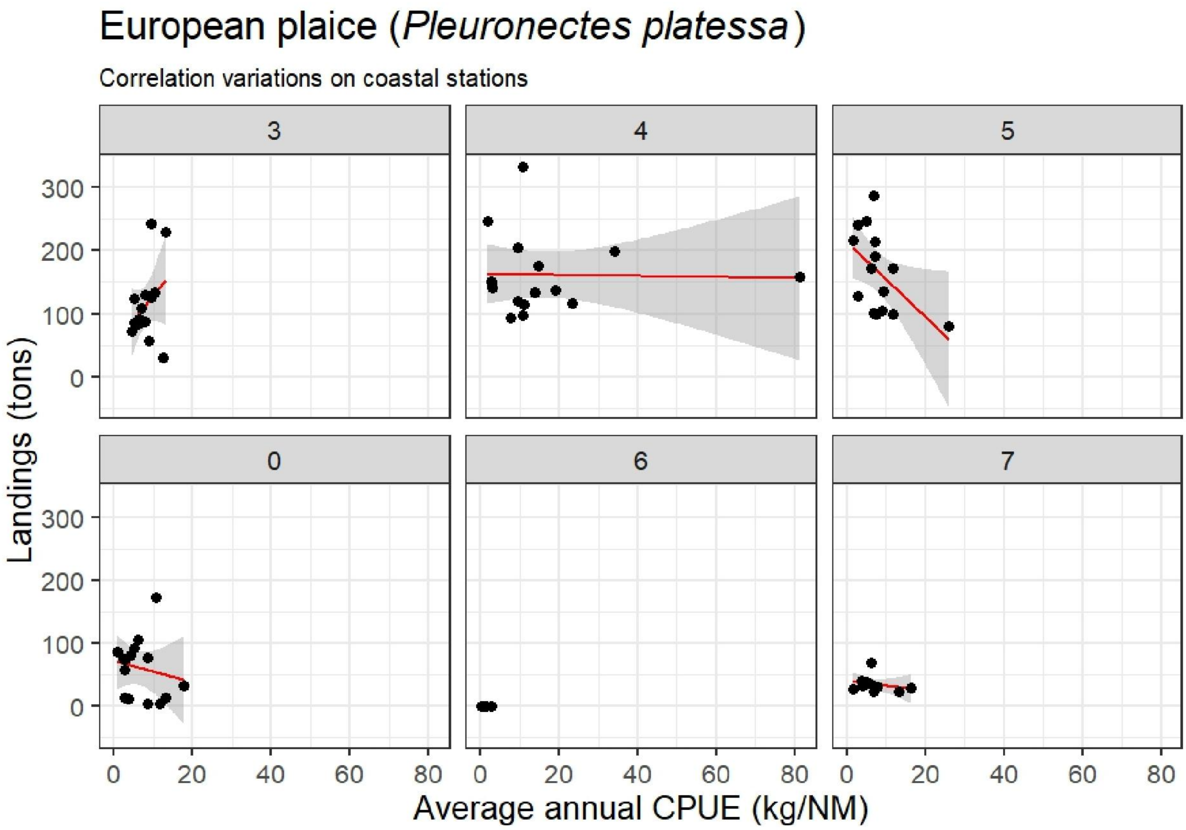

*Figure 14 - Correlation plot showing the dependency of survey CPUE (kg/NM) - calculated for coastal areas only - and landings (tons) for European plaice (*Pleuronectes platessa*).*

*Table 3 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for European plaice (*Pleuronectes platessa*), calculated for coastal areas only. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
0	-0.63	0.37	-0.17	0.54	-0.63	13
3	-0.20	0.73	0.35	0.20	1.35	13
4	-0.53	0.49	-0.03	0.92	-0.10	13
5	-0.82	-0.02	-0.53	0.04	-2.23	13
6	-0.93	0.54	-0.48	0.33	-1.11	4
7	-0.73	0.42	-0.24	0.48	-0.73	9

3.2 European hake

3.2.1 Scientific survey – CPUE-data

European hake, a common species along the coast off Møre, was frequently found in this area during the scientific cruises (Fig. 15). Hake was observed in area 0 and 5-7 on coastal stations, but was annually caught only in area 7 (Fig. 16). Area 0 and 5 had relatively few observations. Both area 6 and 7 showed a small, but overall increasing trend in CPUE, from 2003-2017.

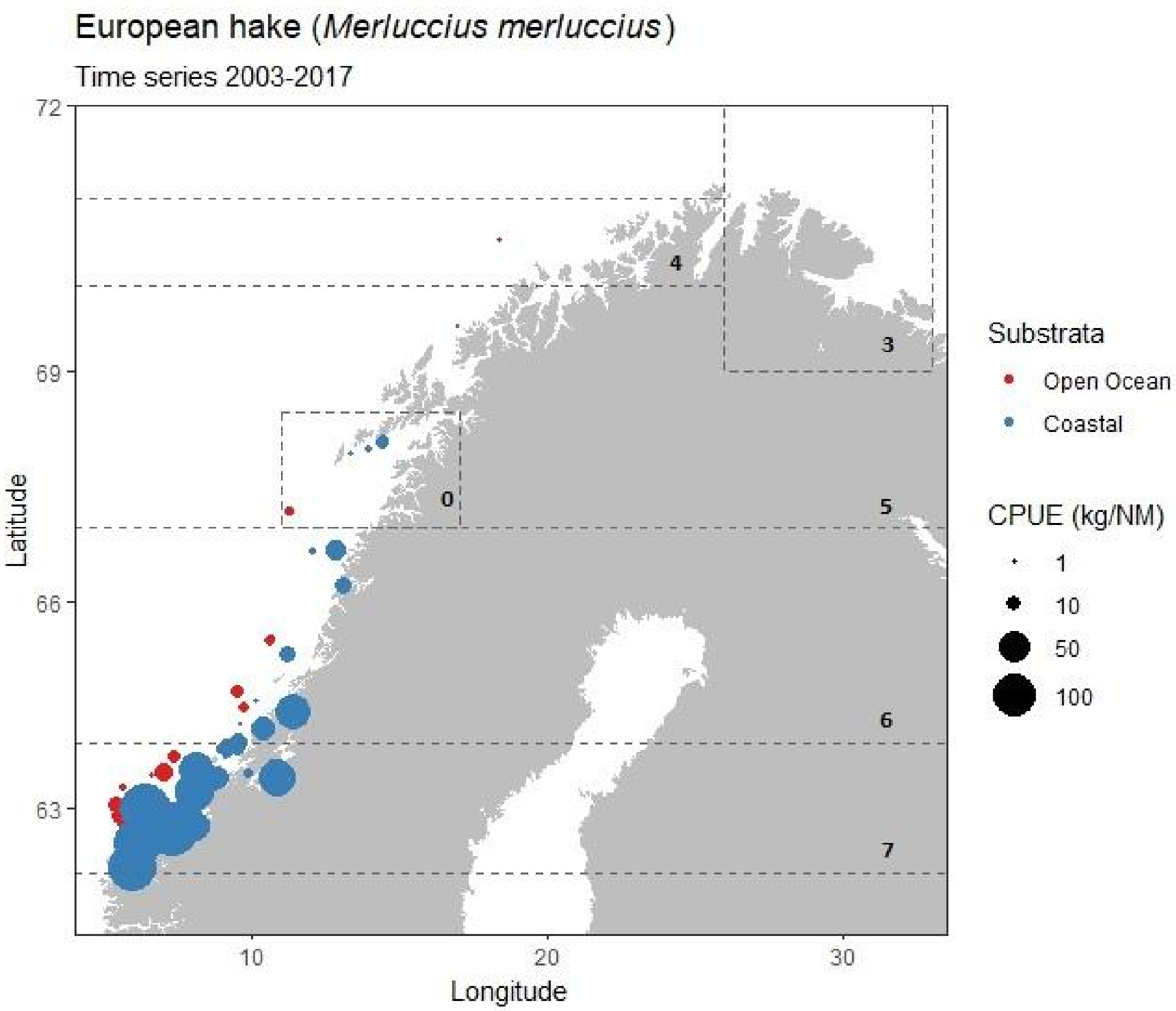

*Figure 15 – Catches from surveys of European hake (*Merluccius merluccius*) made during the study period along the Norwegian coast north of 62°N. Catch per unit of effort (CPUE) is proportional to circle size and coastal- and open ocean stations are indicated separately. Numbers on the map indicate areas corresponding to the main statistical fisheries area.*

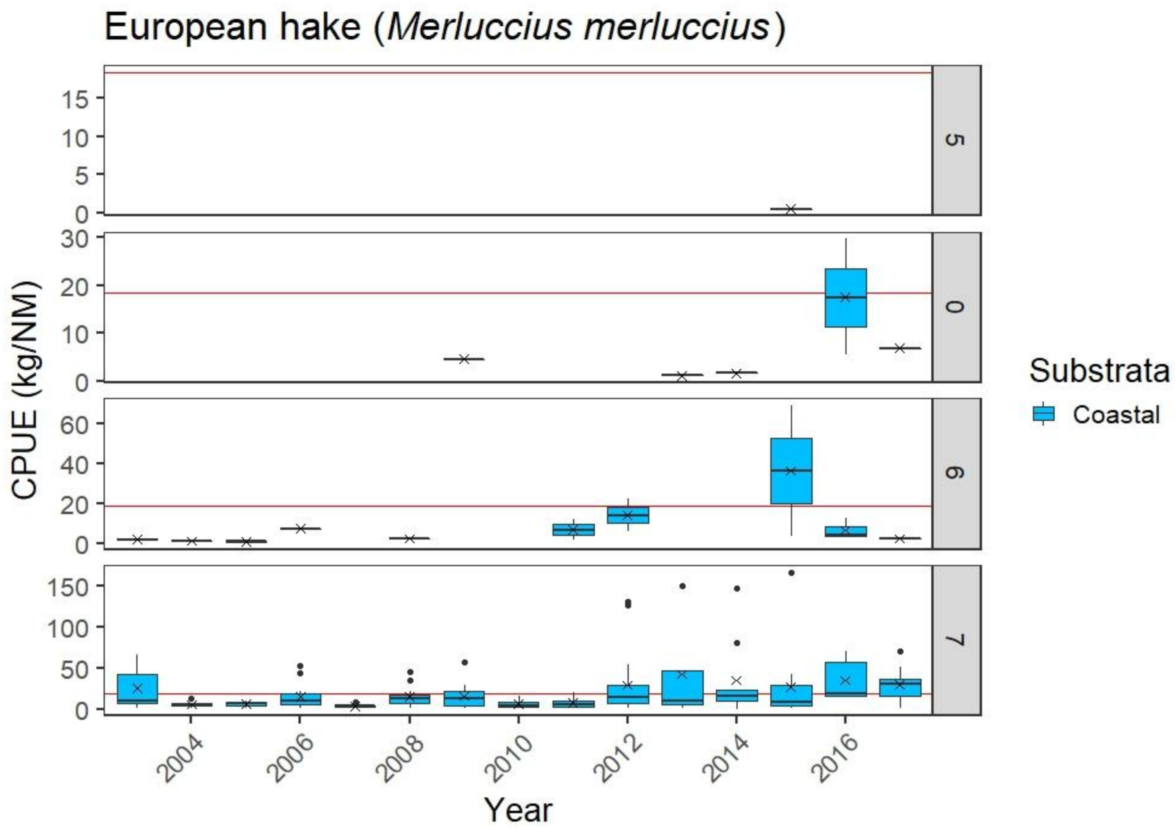

*Figure 16 - Annual average catch per unit of effort (CPUE) of European hake (*Merluccius merluccius*) based on coastal stations sampled by IMR where average CPUE is indicated by stars. The red line illustrates the overall average CPUE for all areas combined.*

Offshore observations of hake were made in area 0, 4, 6 and 7, with both the largest and most frequent observations in area 7 (Fig. 17). An increasing trend in CPUE was observed in this area, whereas there was a varying trend in area 6. In total, when both subareas were combined, it was area 7 that had the overall highest catch rate of hake, followed by area 6 and 0 respectively (Appendix 1, Table 1.2).

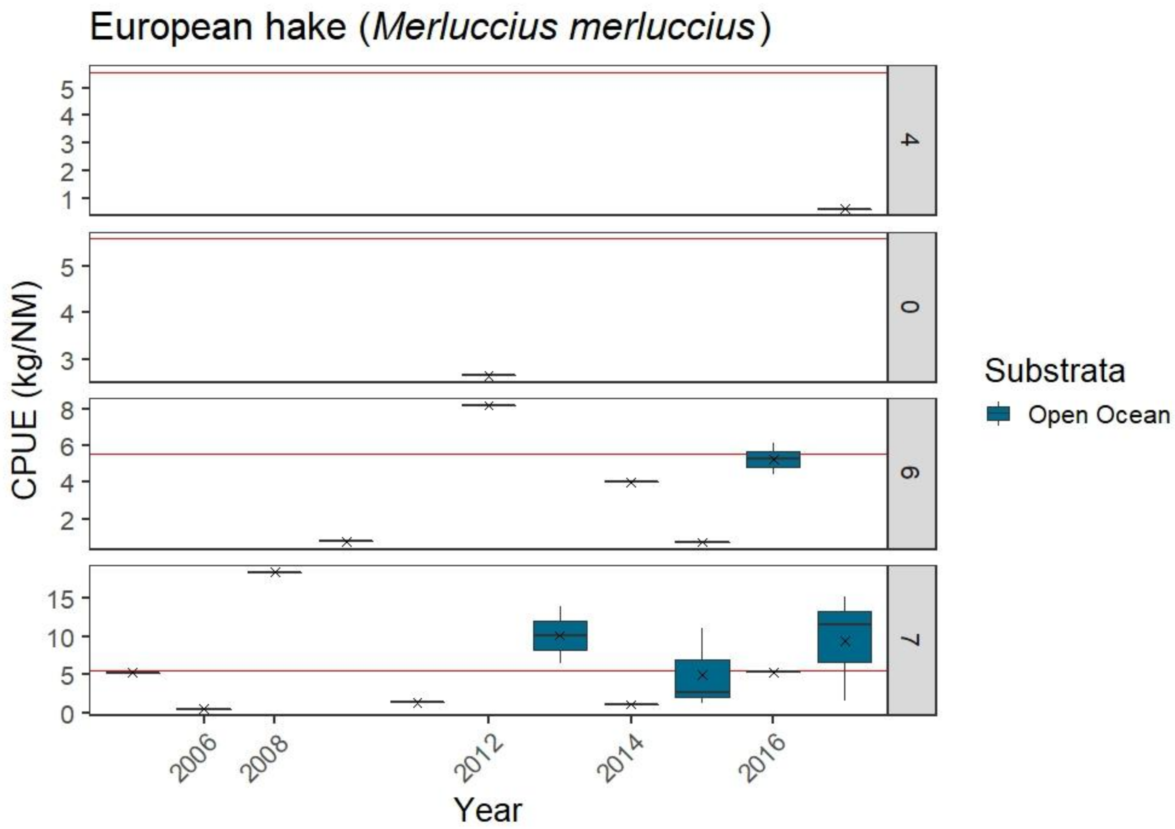

*Figure 17 - Annual average catch per unit of effort (CPUE) of European hake (*Merluccius merluccius*) based on open ocean stations sampled by IMR where average CPUE is indicated by stars. The red line illustrates the overall average CPUE for all areas combined.*

3.2.2 Commercial fisheries – landings data

In the commercial fisheries, the highest catches of hake were made in area 7 (Fig. 18). A total of 7240 tons were caught by gillnets (Appendix 2, Table 2.2), making it the main commercial fishing gear between 2003-2017. Annual gillnet-catches revealed that catches in area 0 and 3-4 were relatively low (Fig. 19). Area 6 and 7 showed an increasing trend from the beginning, but area 7 had both a steeper increase and overall bigger landings than area 6, representing a total of approximately 6254 tons alone (Appendix 3, Table 3.2).

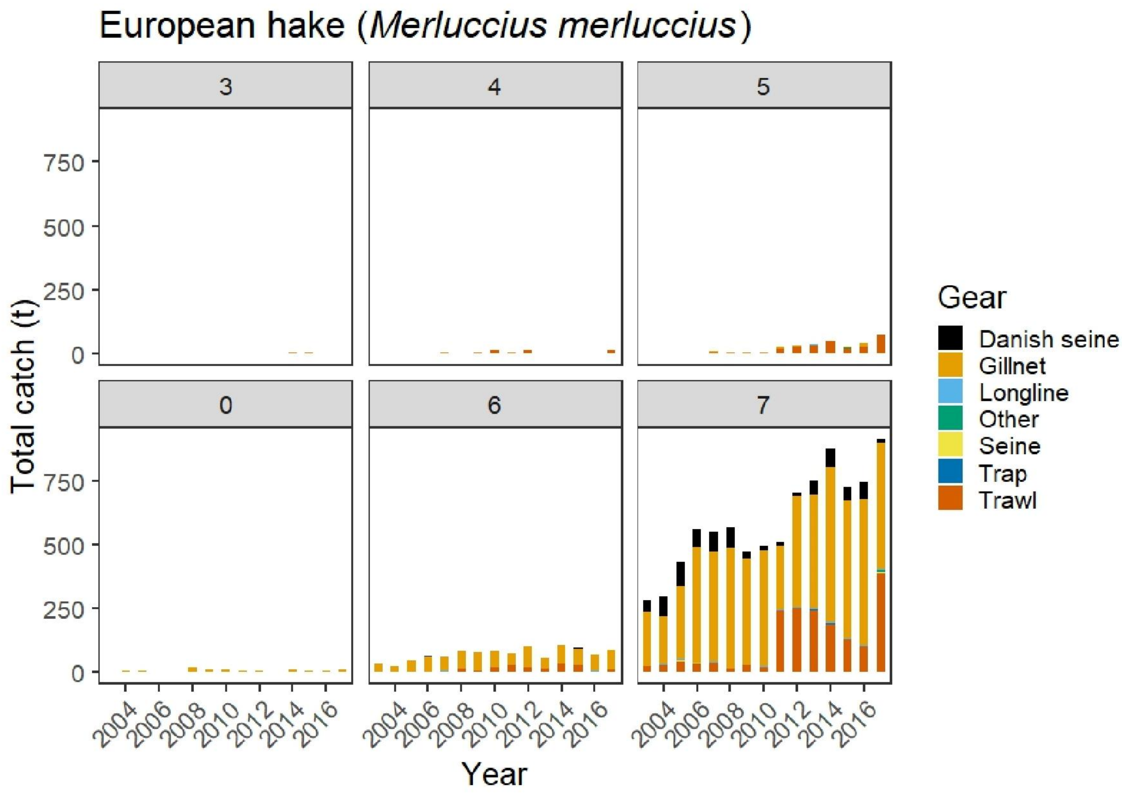

*Figure 18 - Total annual bycatch of European hake (*Merluccius merluccius*) by fisheries and area between 2003 and 2017.*

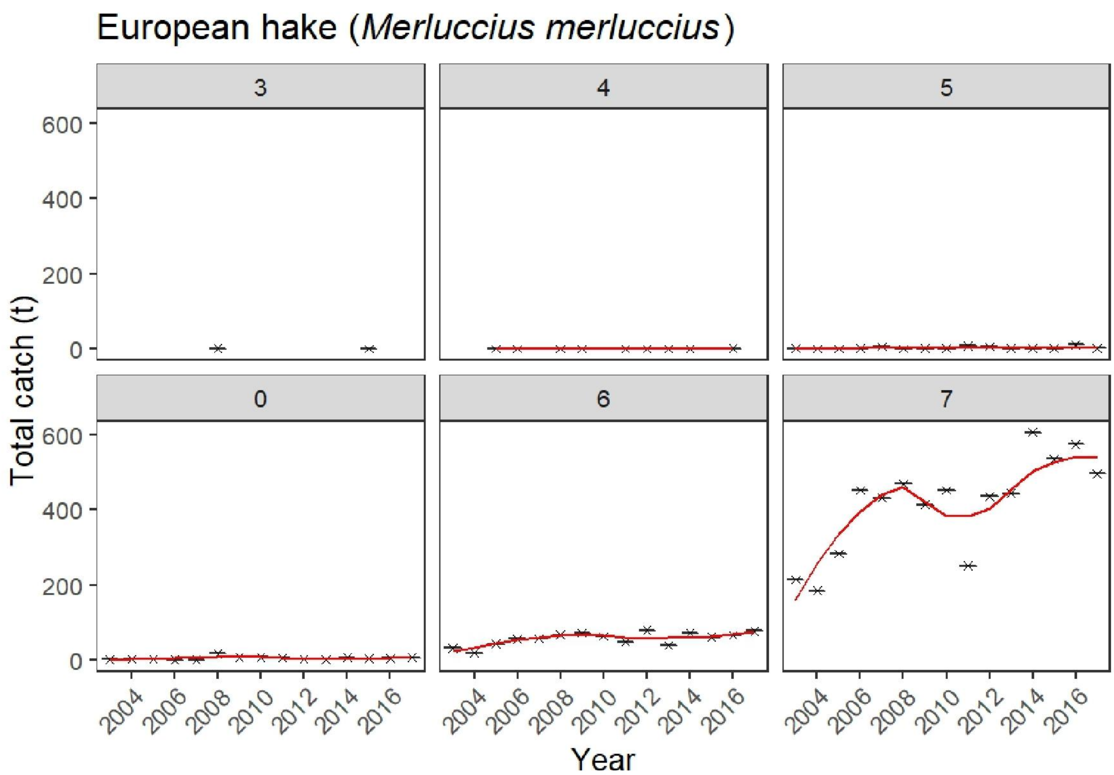

*Figure 19 - Annual total bycatch landings of European hake (*Merluccius merluccius*) in main statistical fisheries areas from the gillnet fisheries. Stars indicate landings, and the red line represents a trend line following the yearly total catches.*

3.2.3 Model prediction

The area with the highest landings was found to be area 7. The model explaining most of the variance in the CPUE-data included both year and fishing depth (Model output in Appendix 4). This model explained 8.17% of the total variance, indicating large variance in the data (Fig. 20).

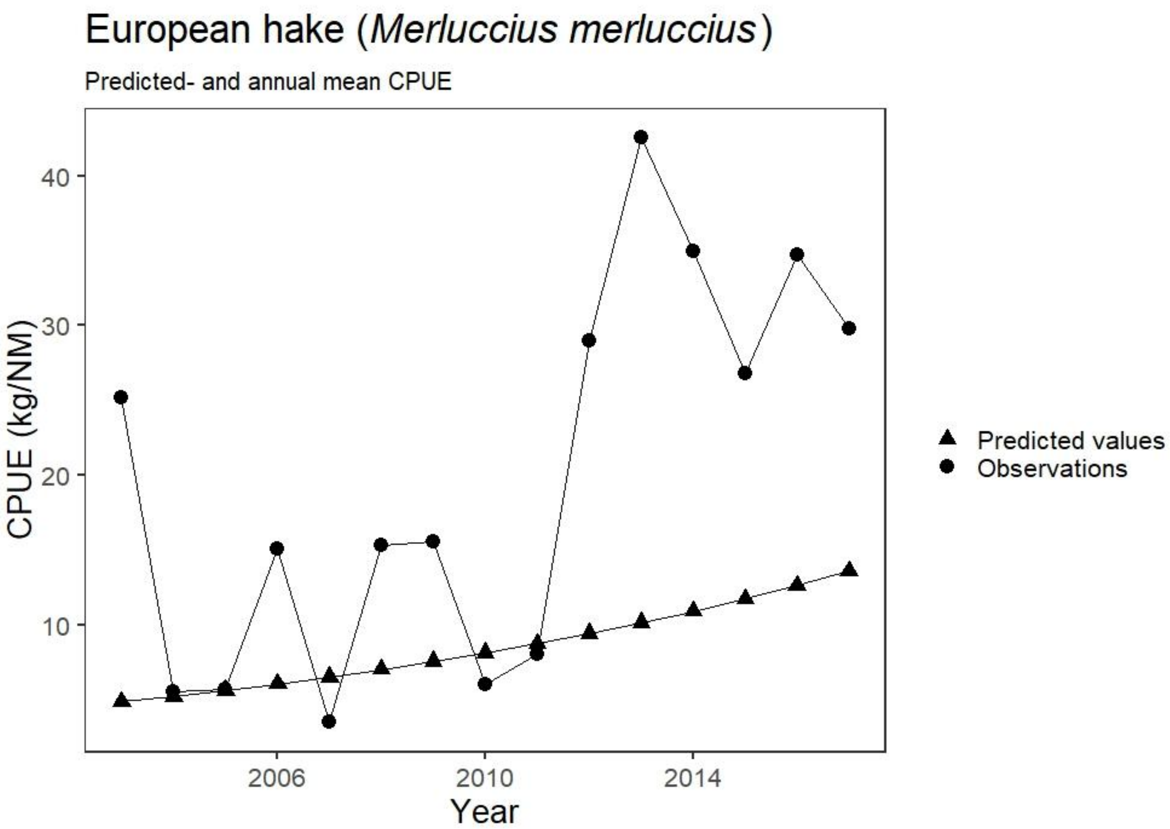

*Figure 20 - Visualization of predicted (triangles)- observed mean annual CPUE (circles) and for European hake (*Merluccius merluccius*) in main area 7, subarea coastal.*

3.2.4 Correlation between CPUE and landings

Average annual survey CPUE and landings could only be compared for three areas in total, area 0, 6 and 7 (Fig. 21). In these areas CPUE was positively correlated with landings, but it was only for area 7 the correlation was significant (Table 4). A positive correlation indicates large commercial landings when the survey CPUE is correspondingly large. With generally broad confidence intervals, there was no significant correlation between CPUE and total catches in the other areas. The same was true when the data point with the highest CPUE in area 6 was neglected.

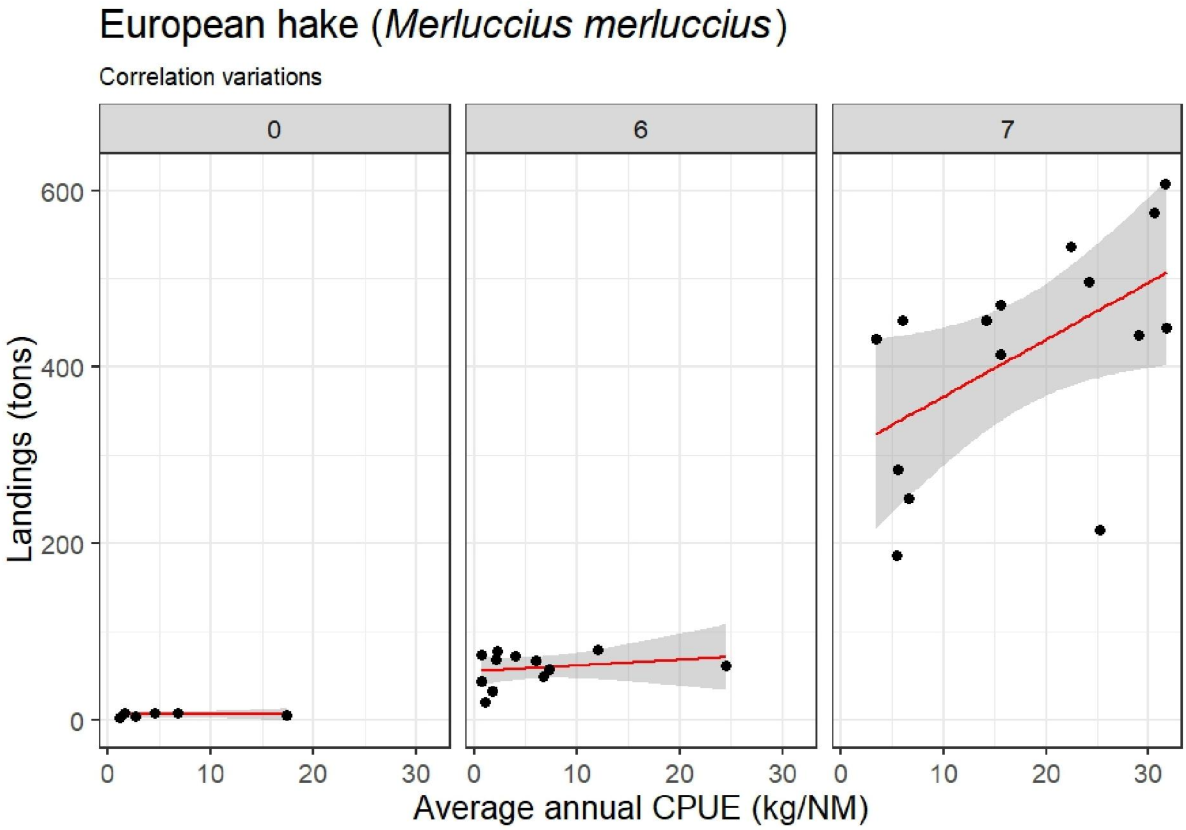

*Figure 21 - Correlation plot showing the dependency of survey CPUE (kg/NM) – calculated for both coastal and offshore areas - and landings (tons) for European hake (*Merluccius merluccius*).*

*Table 4 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for European hake (*Merluccius merluccius*), calculated for both coastal and offshore areas. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
0	-0.80	0.82	0.03	0.96	0.06	4
6	-0.39	0.71	0.24	0.46	0.77	10
7	0.04	0.82	0.54	0.04	2.30	13

Being most frequently observed on the coastal stations, a second correlation test was computed with data only from the coastal subarea (Fig. 22). Survey CPUE was positively correlated with total catches in all areas (Table 5). Only for area 7 the p-value was significant at 0.03, meaning that high landings were correlated with high CPUE. The confidence intervals were broad, indicating low degree of correlation between commercial- and survey data in the other areas. The same was true when the same data point as mention before in area 6 was neglected.

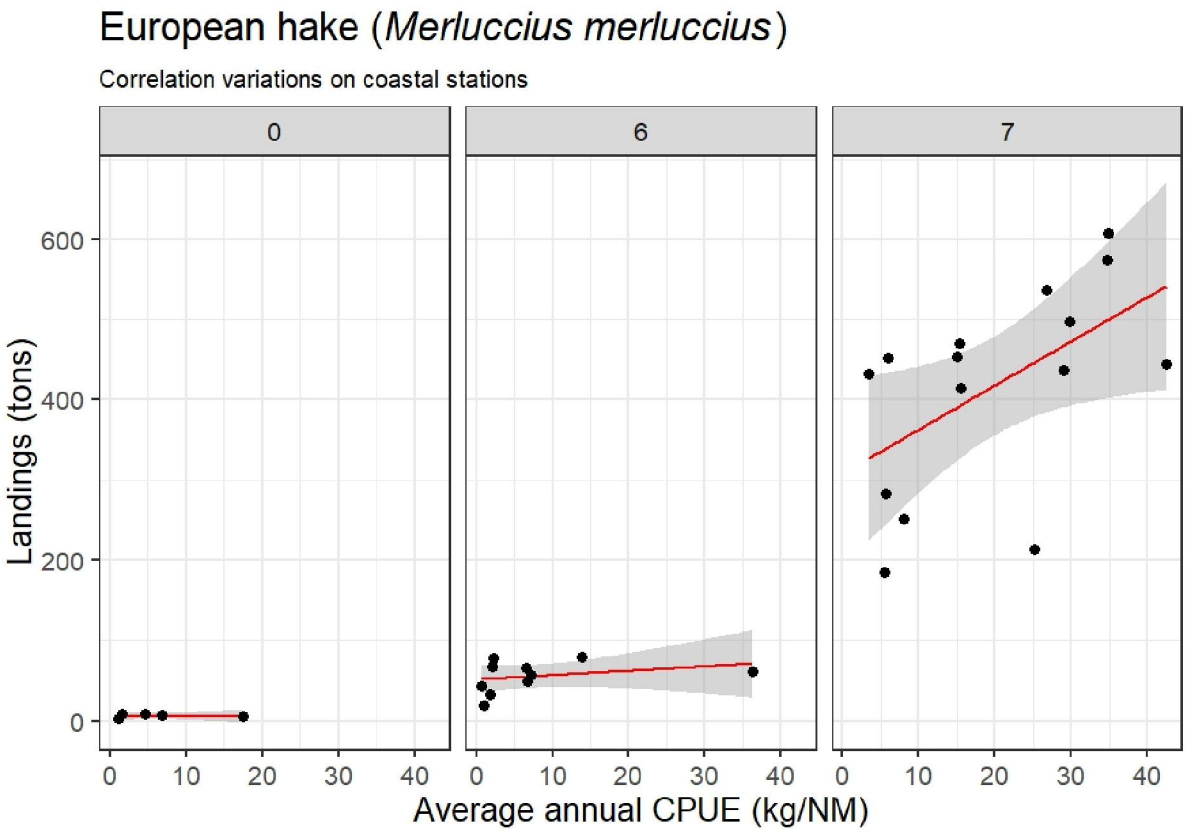

*Figure 22 - Correlation plot showing the dependence of survey CPUE (kg/NM) – calculated for both coastal areas only - and landings (tons) for European hake (*Merluccius merluccius*).*

*Table 5 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for European hake (*Merluccius merluccius*), calculated for coastal areas only. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
0	-0.90	0.86	-0.09	0.88	-0.16	3
6	-0.40	0.78	0.30	0.39	0.90	8
7	0.05	0.83	0.55	0.03	2.38	13

3.3 Rabbit fish

3.3.1 Scientific survey – CPUE-data

Rabbit fish is a common bycatch species along the coast and was present in all but one area in the time period studied. The species was also well represented in both subareas (Fig. 23). On the coastal stations, rabbit fish was observed almost annually in area 4, 5 and 7, where all displayed a slight but seemingly stable increase (Fig. 24). Fewer observations were made in area 0 and 6. The mean CPUE in area 0 remained relatively stable, whereas it showed an overall increasing trend in area 6 from 2003-2017.

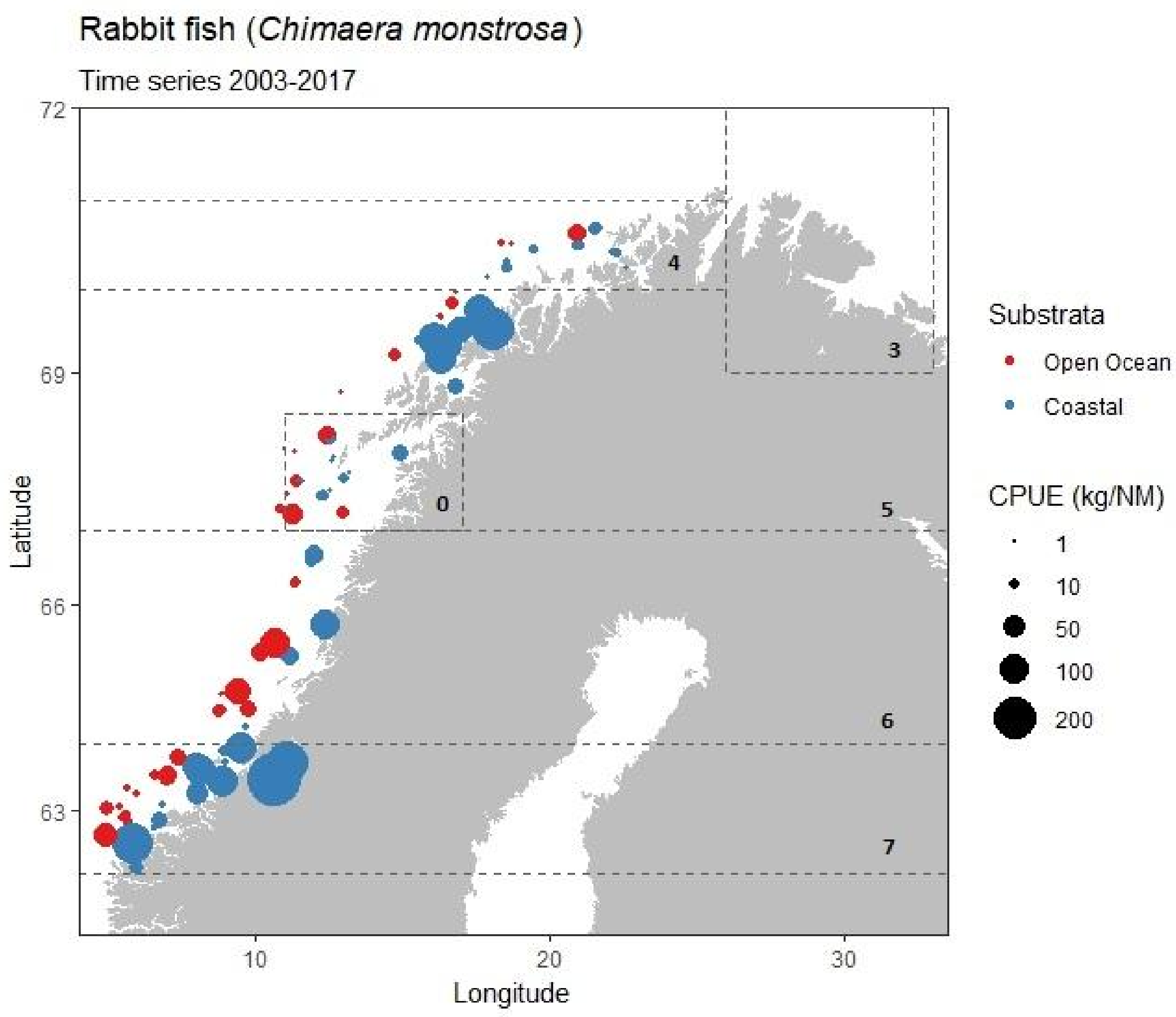

*Figure 23 - Catches of rabbit fish (*Chimaera monstrosa*) made during the study period along the Norwegian coast north of 62°N. Catch per unit of effort (CPUE) is proportional to circle size and coastal- and open ocean stations are indicated separately. Numbers on the map indicate areas corresponding to the main statistical fisheries area.*

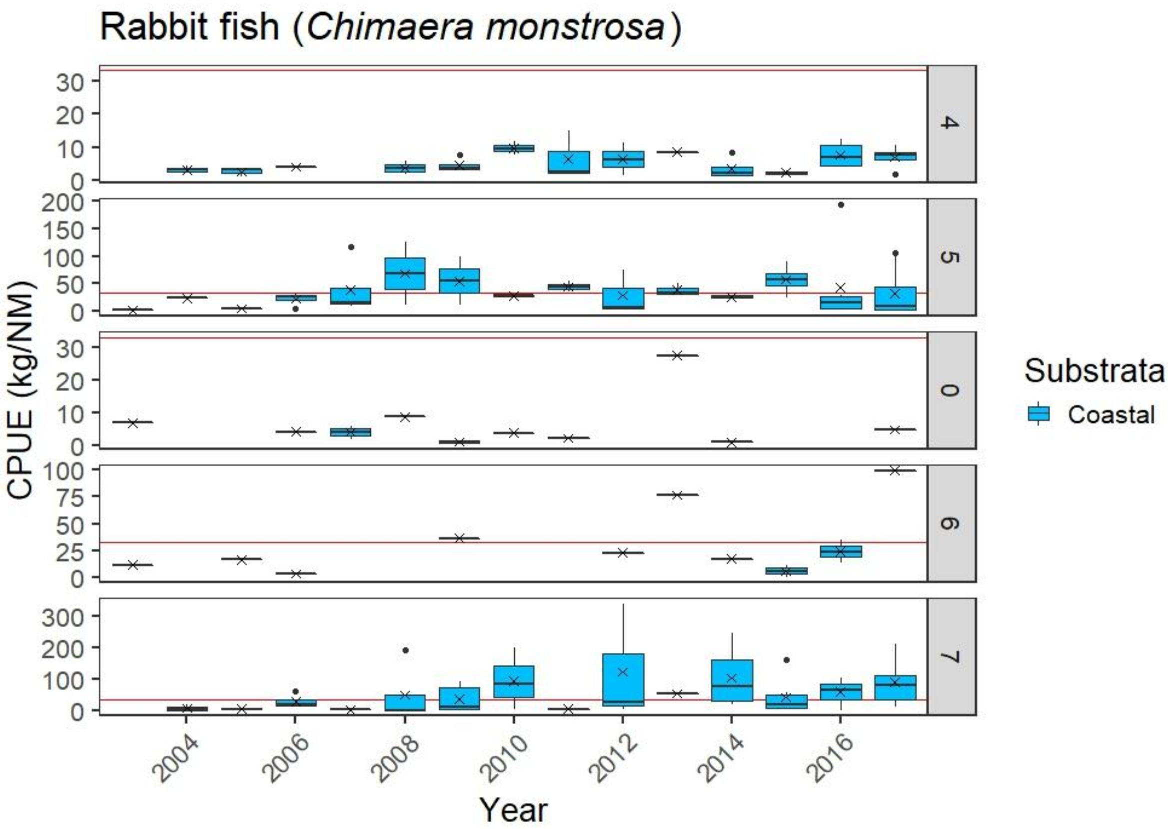

*Figure 24 - Annual average catch per unit of effort (CPUE) of rabbit fish (*Chimaera monstrosa*) based on coastal stations sampled by IMR where average CPUE is indicated by stars. The red line illustrates the overall average CPUE for all areas combined.*

The offshore observations of rabbit fish varied within the different areas (Fig. 25). Area 7 had an overall stable trend in CPUE, whereas area 4-6 has had a varying increase in CPUE towards the end of the time series. Fewest observations were made in area 0, but also here there was an increase in CPUE. Combining mean annual CPUE from both subareas showed that area 7 had the highest CPUE with area 5 and 6 having the second and third highest CPUE, respectively (Appendix 1, Table 1.3).

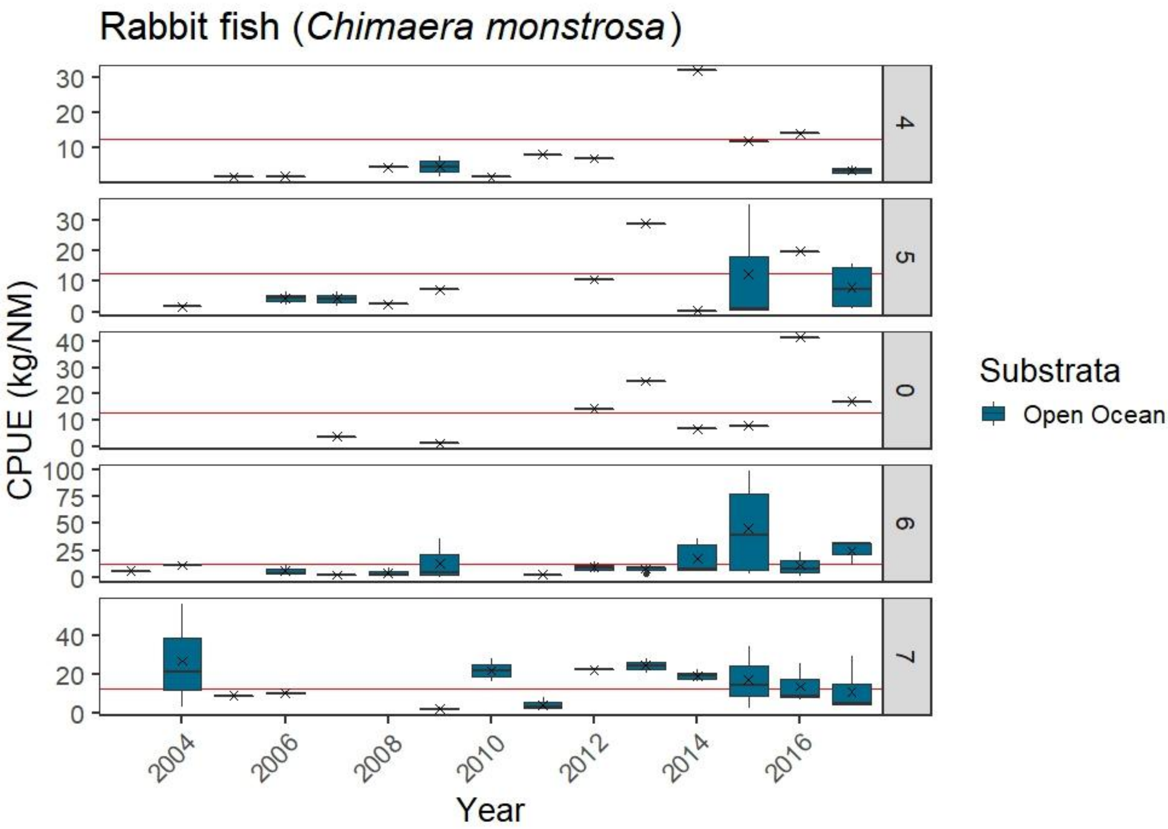

*Figure 25 - Annual average catch per unit of effort (CPUE) of rabbit fish (*Chimaera monstrosa*) based on open ocean stations sampled by IMR where average CPUE is indicated by stars. The red line illustrates the overall average CPUE for all areas combined.*

3.3.2 Commercial fisheries – landings data

With a total of 901 tons, longline was the main commercial gear catching rabbit fish (Appendix 2, Table 2.3). The highest landings of this species were made in area 6, 7 and 5, respectively (Fig. 26). The same applied for catches done only by longline (Fig. 27, Appendix 3, Table 3.3). In area 5, 6, and 7 there were annual catches of rabbit fish. Area 5 and 6 both had an increase in catches until 2010, followed by a subsequent decrease, whereas in area 7 there was an overall increasing trend in landings from 2003-2017. In area 0, 3 and 4 there were relatively few and low catches.

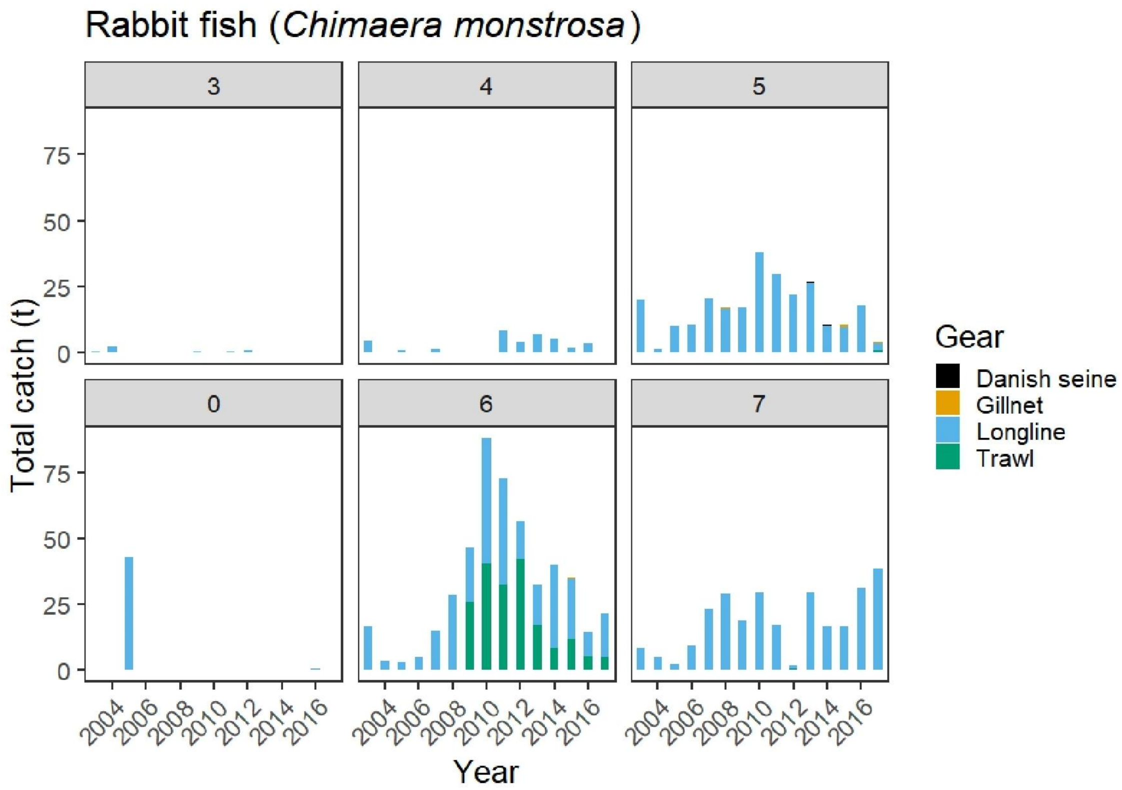

*Figure 26 - Total annual bycatch of rabbit fish (*Chimaera monstrosa*) by fisheries and area between 2003 and 2017.*

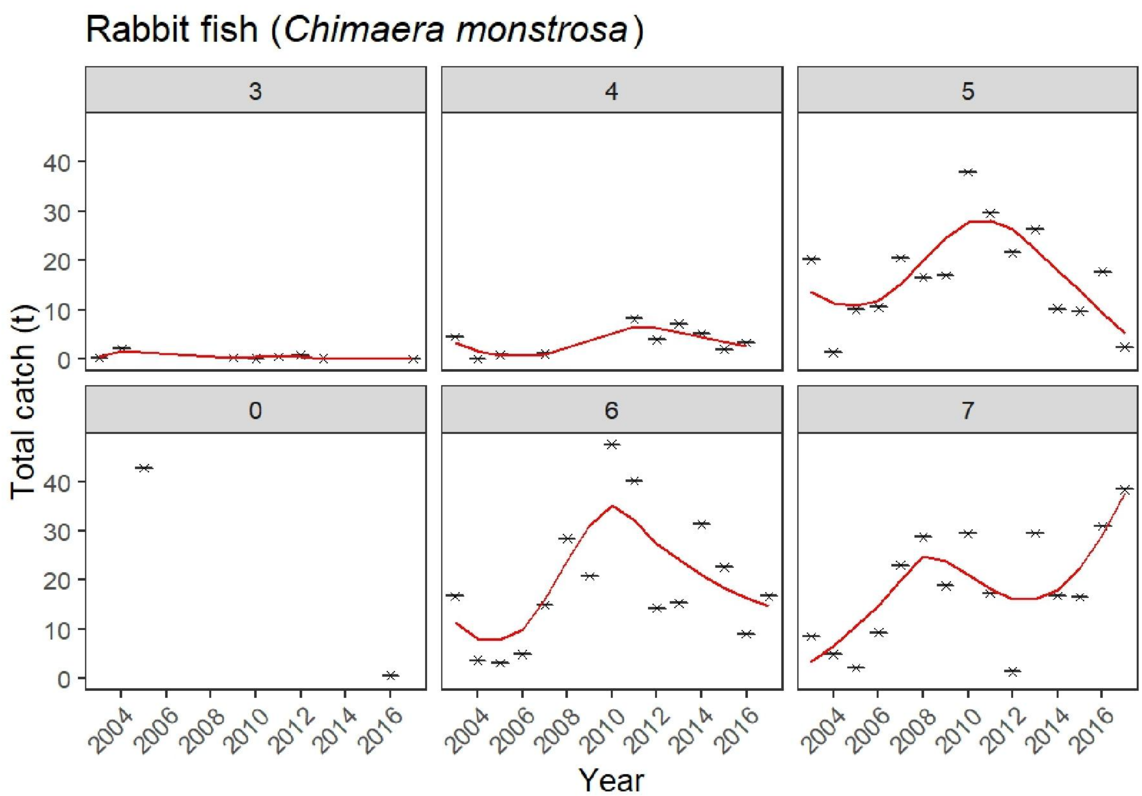

*Figure 27 - Annual total bycatch landings of rabbit fish (*Chimaera monstrosa*) in main statistical fisheries areas from the longline fisheries. Stars indicate landings, and the red line represents a trend line following the yearly total catches.*

3.3.3 Model prediction

It was in area 6 the highest commercial landings were done, but the model was based on area 7 due to a better time series. The two parameters, year and fishing depth, were found to be significant when trying to explain the variation in CPUE-data (Model output in Appendix 4). This model had an explanation percentage equal to 41.66% (Fig. 28).

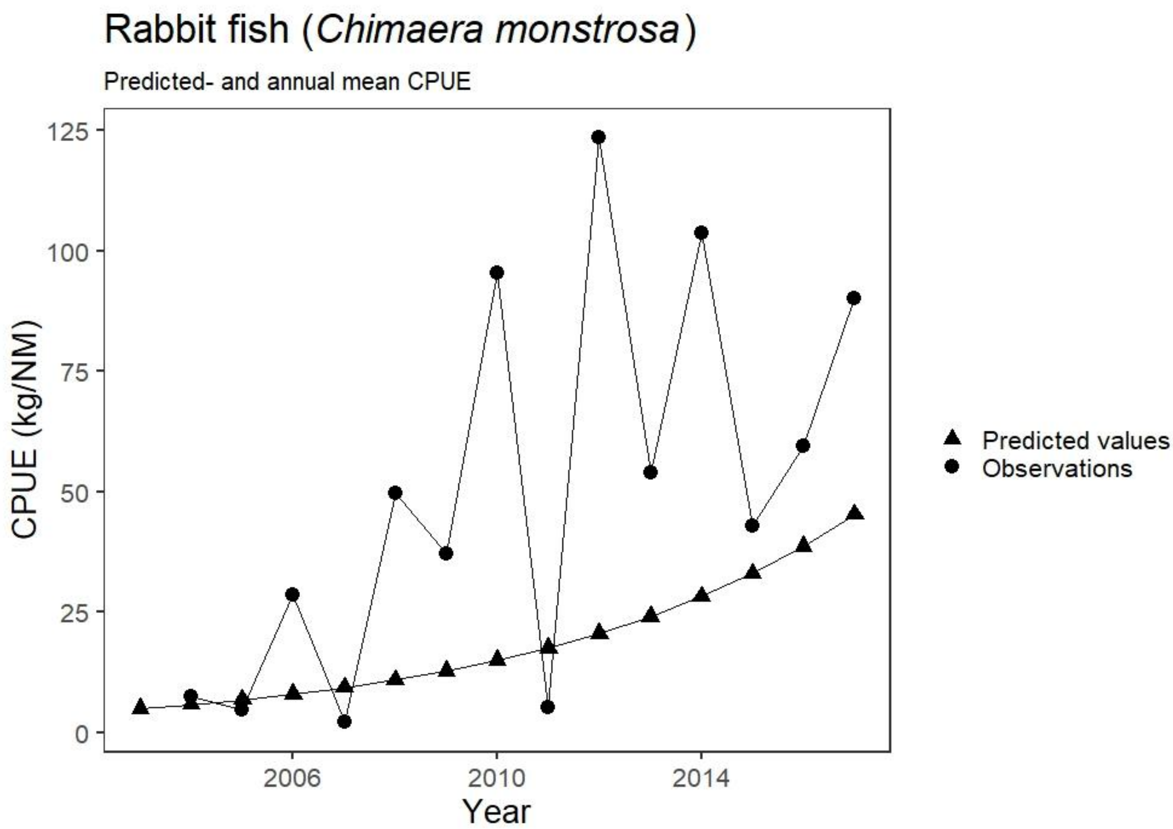

*Figure 28 - Visualization of predicted (triangles)- and observed mean annual CPUE (circles) for rabbit fish (*Chimaera monstrosa*) in main area 7, subarea coastal.*

3.3.4 Correlation between CPUE and landings

Comparing average annual survey CPUE with landings by subarea revealed variation in correlation where all but one correlation coefficient were positive (Table 6). The only significant correlation was found in area 4, indicating a strong correlation between large commercial landings and high survey CPUE. The other areas had generally broad confidence intervals, giving few indicators of correlation on a general basis.

*Table 6 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for Rabbit fish (*Chimaera monstrosa*), calculated for both coastal and offshore areas. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
4	0.02	0.94	0.71	0.05	2.50	6
5	-0.17	0.74	0.37	0.17	1.44	13
6	-0.58	0.48	-0.07	0.80	-0.25	12
7	-0.47	0.59	0.09	0.77	0.30	12

Rabbit fish was well represented in both subareas, which was a cause to look at both subareas separately when comparing CPUE with landings. For the coastal stations all correlation coefficients were positive (Fig. 29, Table 7). Neglecting the outlier having the largest CPUE and lowest landings makes the correlation in area 7 significant and positive (p-value 0.02, and coefficient equal to 0.62). For the open ocean stations (Fig. 30) one out of four correlation coefficients turned out negative (Table 8). With the exception mention above, non of the p-values were significant, neither for coastal nor open ocean stations. The confidence intervals were generally broad, indicating low correlation between CPUE and landings.

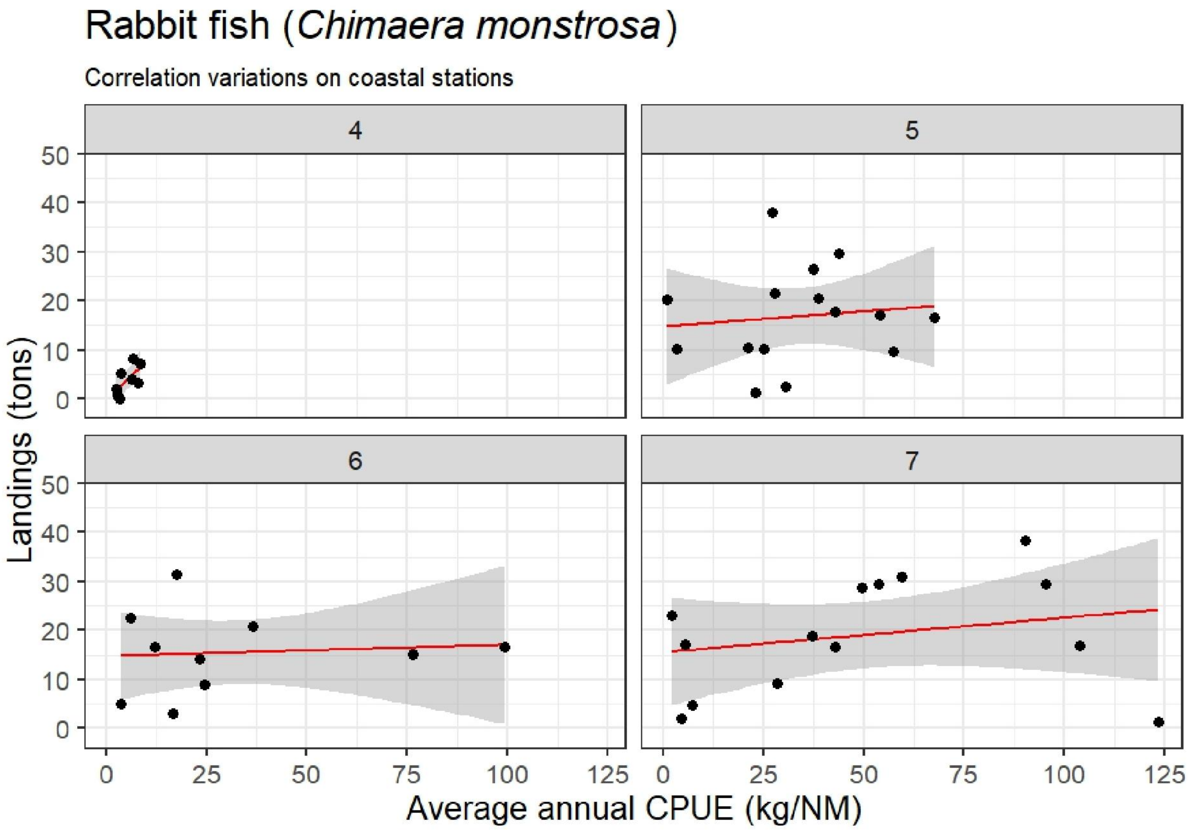

*Figure 29 - Correlation plot showing the dependence of survey CPUE (kg/NM) – calculated for coastal areas only - and landings (tons) for rabbit fish (*Chimaera monstrosa*).*

*Table 7 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for rabbit fish (*Chimaera monstrosa*), calculated for coastal areas only. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
4	-0.05	0.94	0.68	0.06	2.26	6
5	-0.42	0.59	0.11	0.68	0.42	13
6	-0.57	0.68	0.09	0.81	0.25	8
7	-0.33	0.69	0.24	0.40	0.87	12

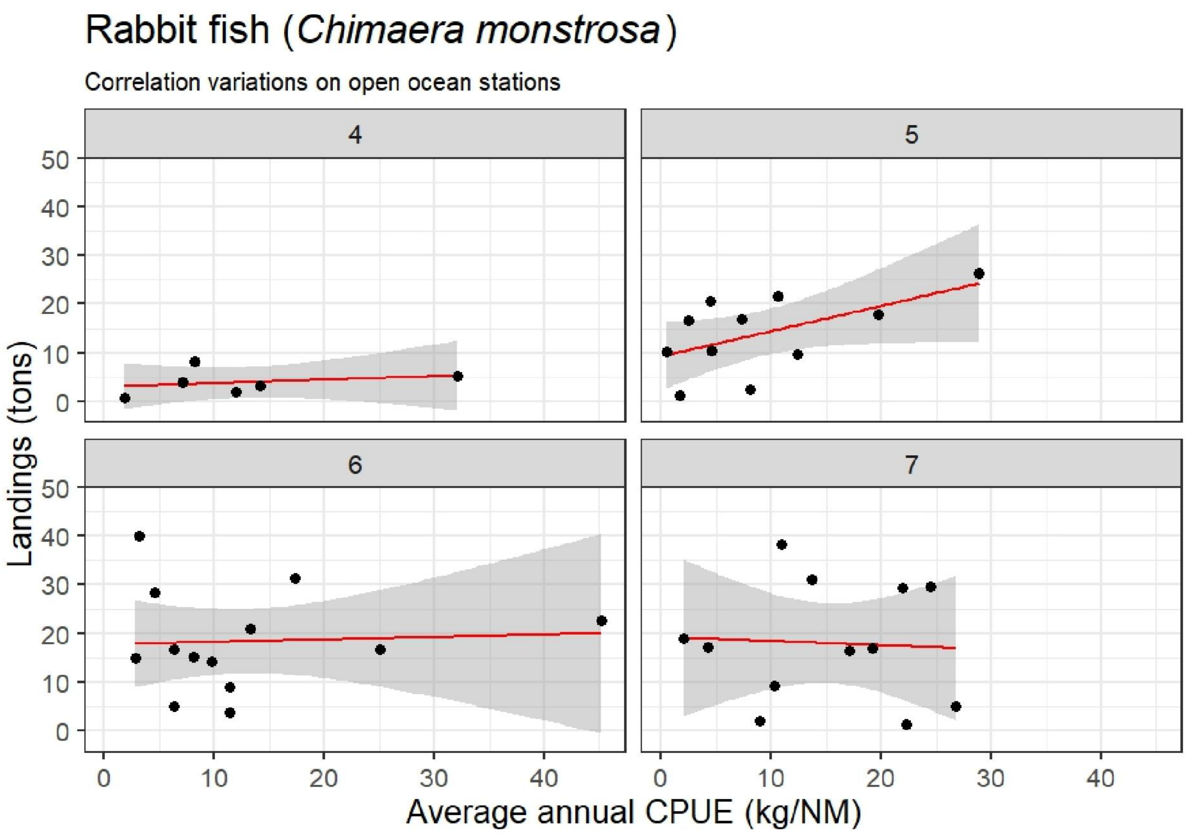

*Figure 30 - Correlation plot showing the dependence of survey CPUE (kg/NM) – calculated for offshore areas only - and landings (tons) for rabbit fish (*Chimaera monstrosa*).*

*Table 8 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for rabbit fish (*Chimaera monstrosa*), calculated for offshore areas only. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
4	-0.68	0.89	0.29	0.58	0.60	4
5	-0.05	0.87	0.57	0.07	2.06	9
6	-0.51	0.59	0.05	0.86	0.18	11
7	-0.61	0.53	-0.06	0.86	-0.18	10

3.4 Golden redfish

3.4.1 Scientific survey – CPUE-data

On the scientific cruises, golden redfish was frequently observed along the coast in both coastal and offshore areas (Fig. 31). Regarding the coastal stations, golden redfish had annual observations in all areas (Fig. 32). In area 0, 5 and 7 an overall stable trend in CPUE was observed, compared to an increasing trend in CPUE in area 4 and 6. The CPUE in area 3 varied throughout the study period.

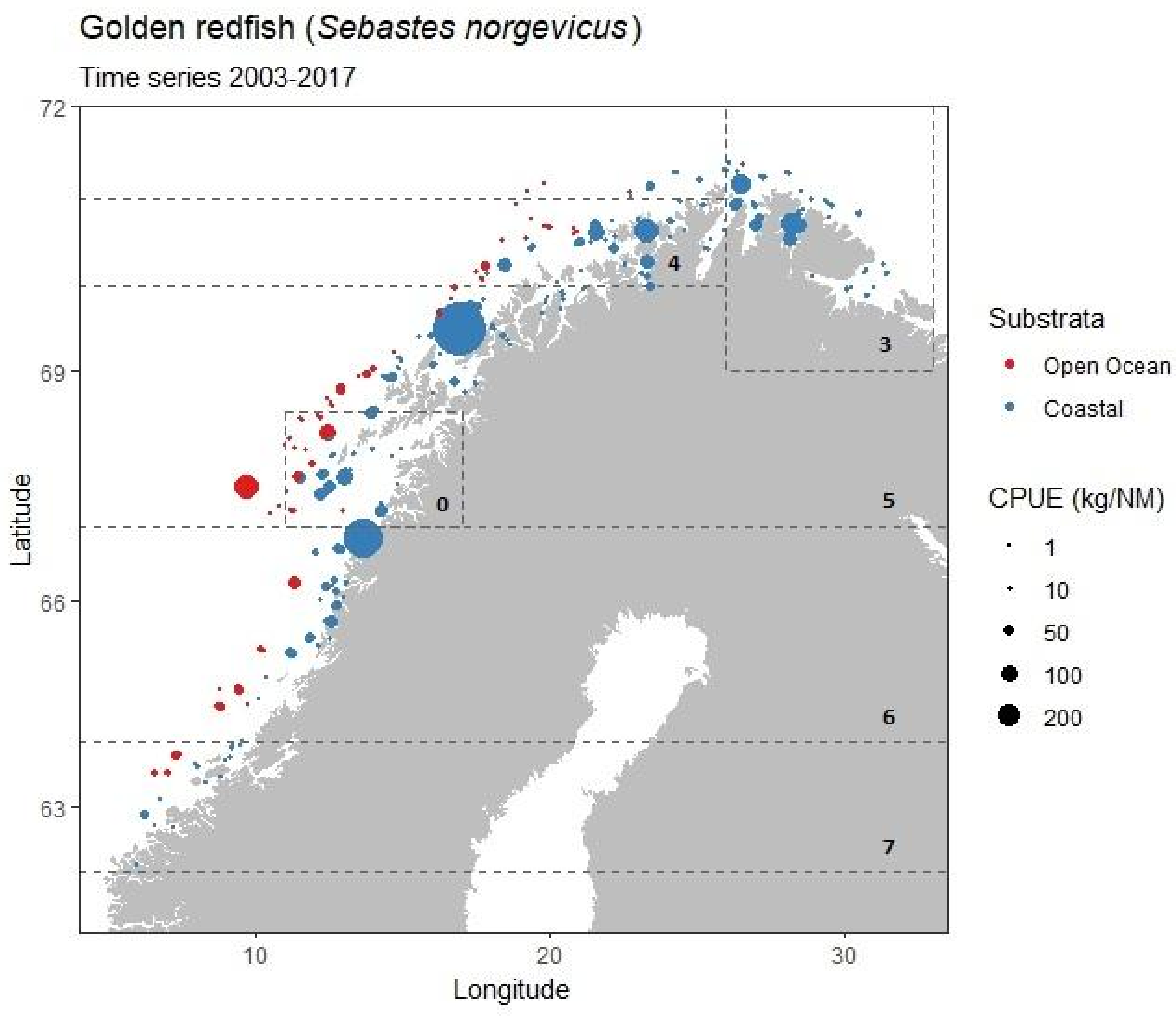

*Figure 31 - Catches of golden redfish (*Sebastes norvegicus*) made during the study period along the Norwegian coast north of 62°N. Catch per unit of effort (CPUE) is proportional to circle size and coastal- and open ocean stations are indicated separately. Numbers on the map indicate areas corresponding to the main statistical fisheries area.*

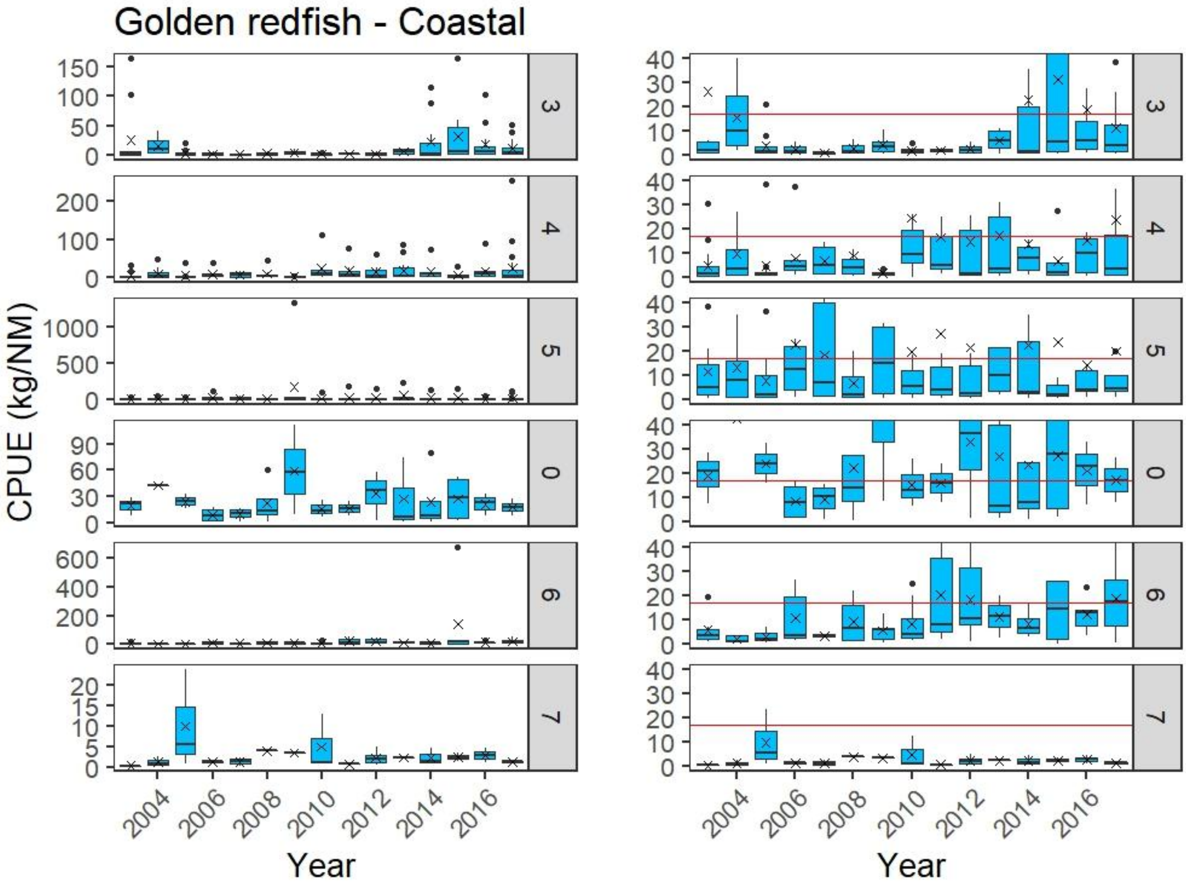

*Figure 32- Annual average catch per unit of effort (CPUE) of golden redfish (*Sebastes norvegicus*) based on coastal stations sampled by IM average CPUE is indicated by stars R. The left panel includes all data points whereas the panel to the right has a limited y-axis excluding some outliers. The red line on the right panel illustrates the overall average CPUE for all areas combined*

Fewer offshore observations were made in area 0, 3 and 4 (Fig. 33). In area 7 there was a decreasing trend in CPUE from 2003-2017, whereas in area 5 and 6 CPUE remained stable during the study period. In total when both subareas were combined, area 5 seemed to have the highest CPUE of golden redfish, followed by area 6 and 0 respectively (Appendix 1, Table 1.4).

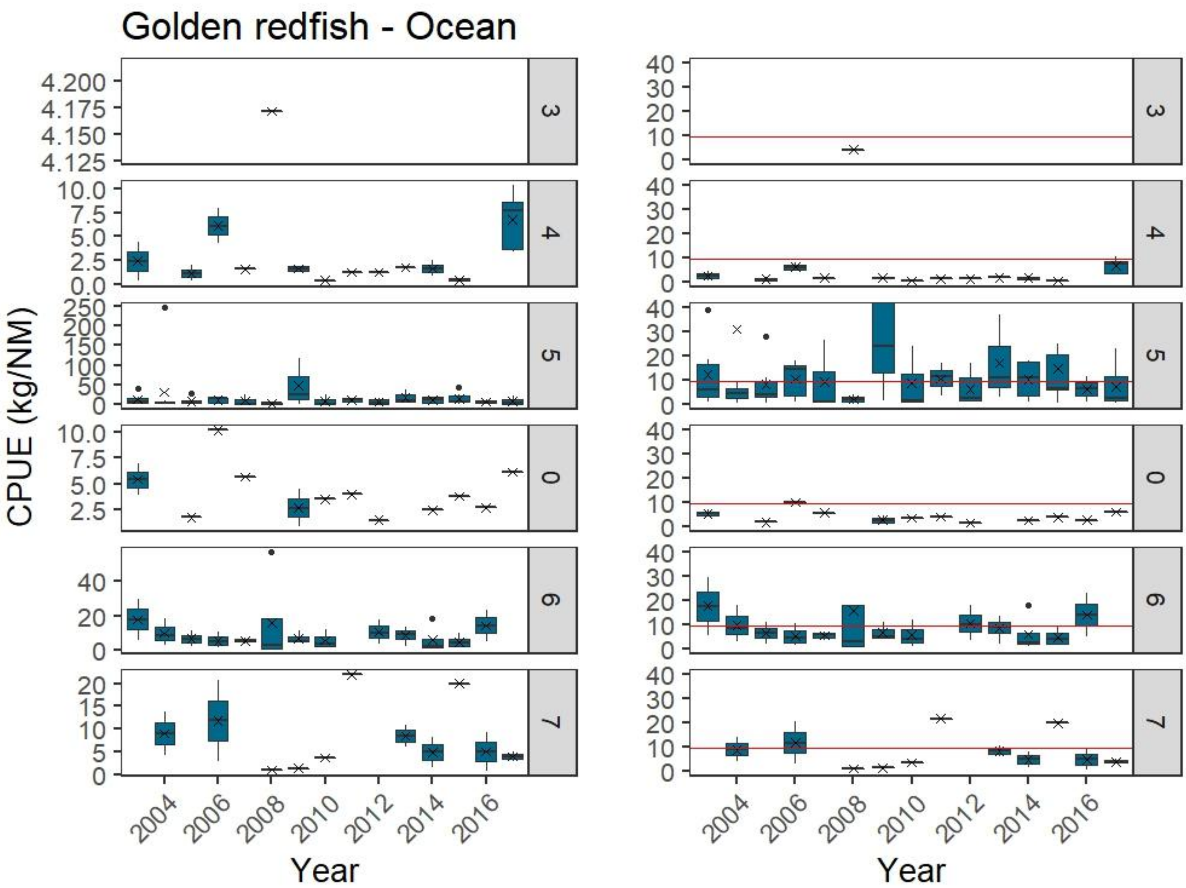

*Figure 33 - Annual average catch per unit of effort (CPUE) of golden redfish (*Sebastes norvegicus*) based on open ocean stations sampled by IMR where average CPUE is indicated by stars. The left panel includes all data points whereas the panel to the right has a limited y-axis excluding some outliers. The red line on the right panel illustrates the overall average CPUE for all areas combined*

3.4.2 Commercial fisheries – landings data

Gillnet fisheries had the highest landings of golden redfish with 32932 tons throughout the time series (Appendix 2, Table 2.4), whereas trawl fisheries caught most golden redfish in both area 3- and 4 (Fig. 34). Looking at gillnet fisheries only (Fig. 35) there was a decrease in landings in all areas from 2003-2017. Area 5 had the highest catches in total during the time period studied, followed by area 4 and 6 (Appendix 3, Table 3.4).

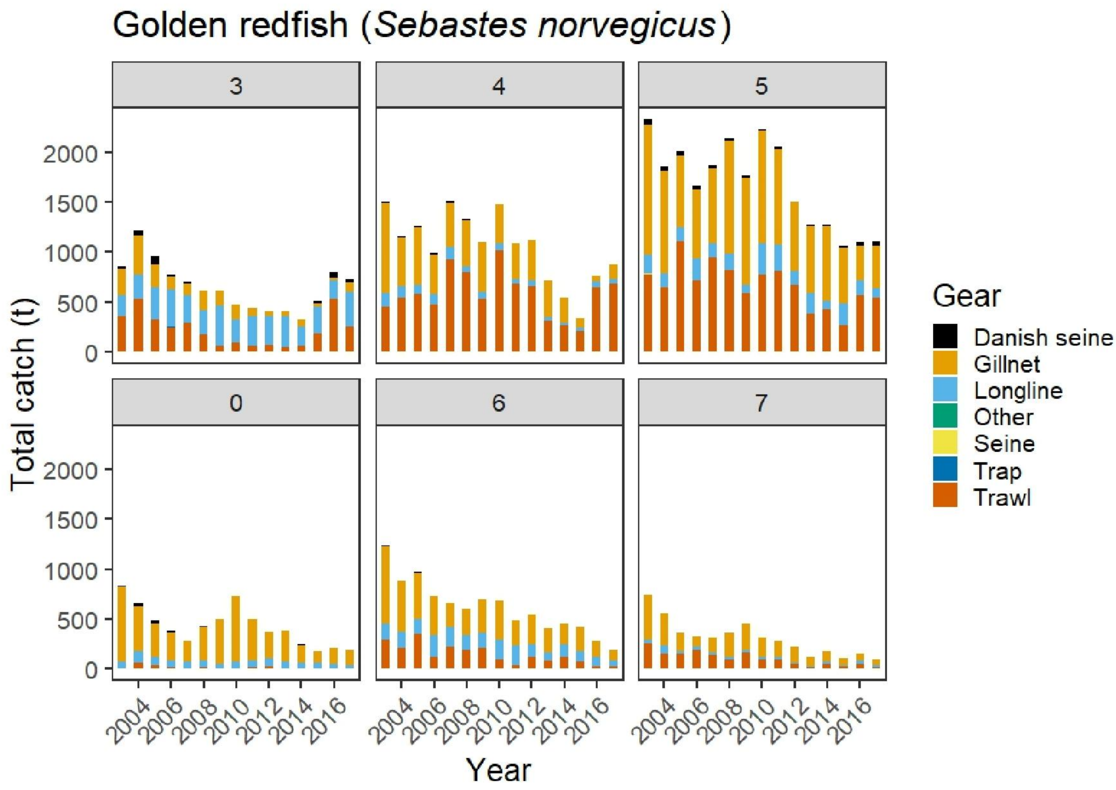

*Figure 34 - Total annual bycatch of golden redfish (*Sebastes norvegicus*) by fisheries and area between 2003 and 2017.*

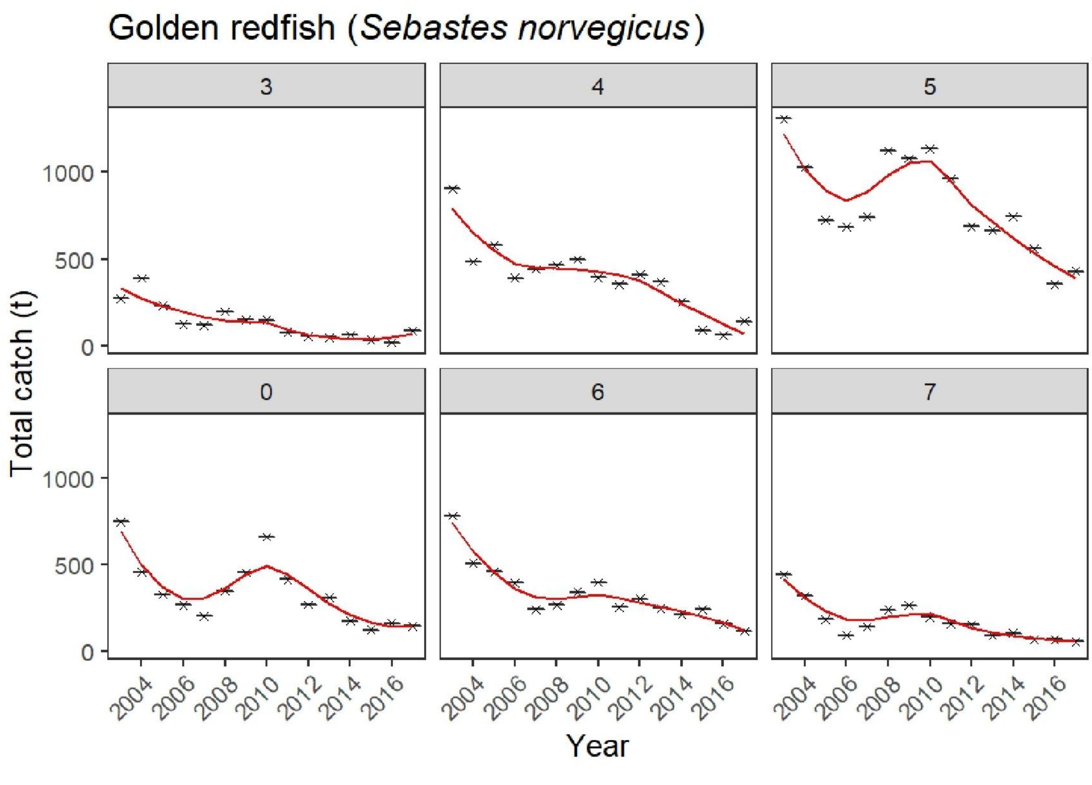

*Figure 35 - Annual total bycatch landings of golden redfish (*Sebastes norvegicus*) in main statistical fisheries areas from the gillnet fisheries. Stars indicate landings, and the red line represents a trend line following the yearly total catches.*

3.4.3 Model prediction

For golden redfish the area whit the highest total landings was area 5 (Model output in Appendix 4). The best model had only fishing depth as a significant variable, and explained 5.25% of the variance in CPUE (Fig. 36).

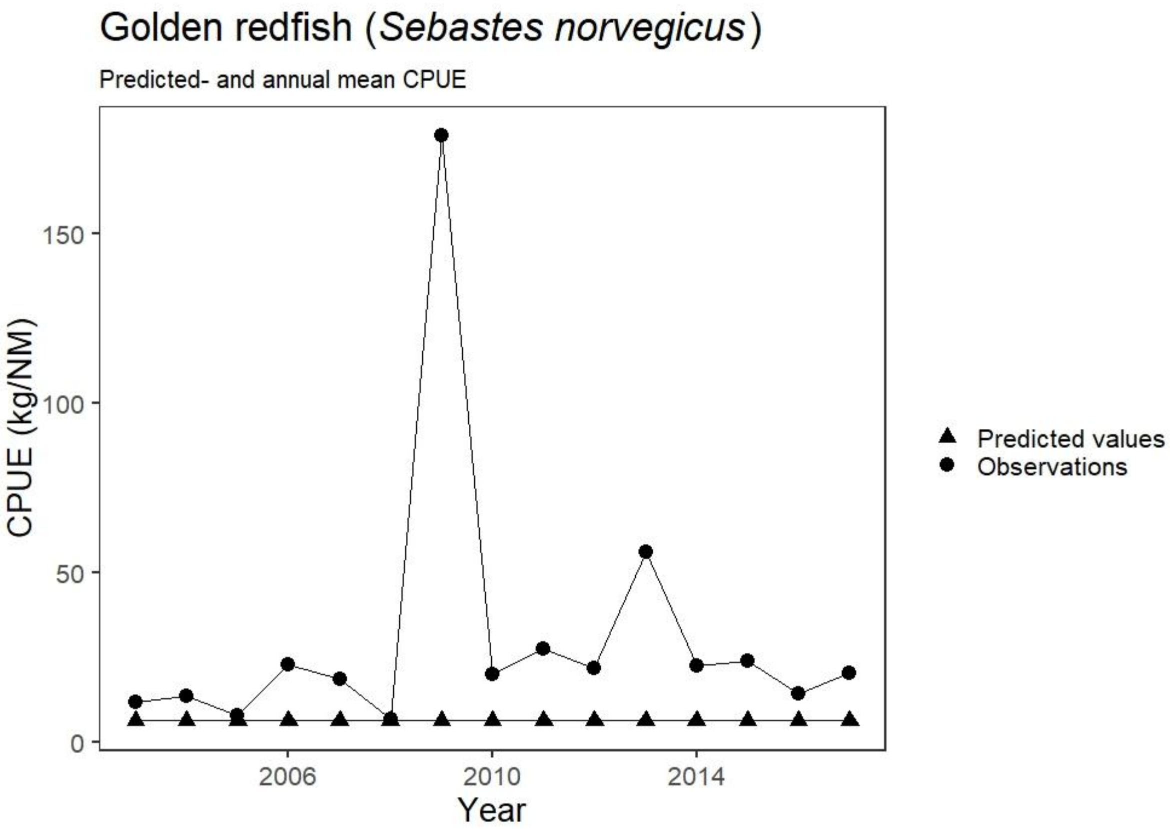

*Figure 36 - Visualization of predicted (triangles)- observed mean annual CPUE (circles) for golden redfish (*Sebastes norvegicus*) in main area 5, subarea coastal.*

3.4.4 Correlation between CPUE and landings

Comparison of average annual CPUE with total landings of golden redfish showed that four out of six correlation coefficients were negative (Table 9). None of the correlations were significant, meaning that no relationship between commercial landings and survey CPUE was found for this species.

*Table 9 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for golden redfish (*Sebastes norvegicus*), calculated for both coastal and offshore areas. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
0	-0.45	0.57	0.08	0.79	0.27	13
3	-0.52	0.51	-0.01	0.98	-0.03	13
4	-0.79	0.05	-0.47	0.08	-1.93	13
5	-0.33	0.66	0.22	0.43	0.82	13
6	-0.68	0.29	-0.26	0.35	-0.97	13
7	-0.73	0.19	-0.36	0.19	-1.37	13

Golden redfish was frequent in both subareas, which made it possible to compare average CPUE from both of them separately with the landings. For the coastal stations (Fig. 37) this meant that three out of six coefficients were negative (Table 10). For the open ocean stations (Fig. 38), three out of five coefficients were negative (Table 11). No p-values were significant for neither coastal, nor open ocean stations even when some data points were removed. The broad confidence intervals gave low indications of correlation.

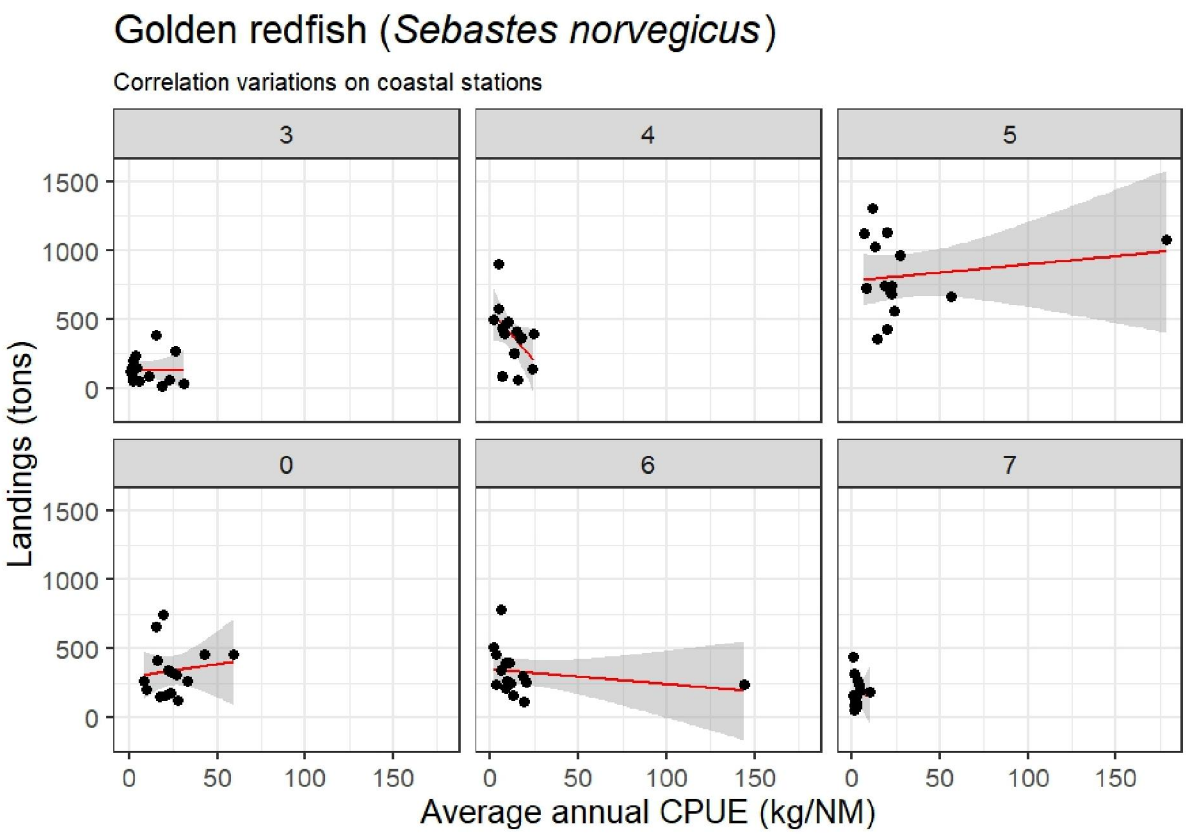

*Figure 37 - Correlation plot showing the dependence of survey CPUE (kg/NM) – calculated for coastal areas only - and landings (tons) for golden redfish (*Sebastes norvegicus*).*

*Table 10 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for golden redfish (*Sebastes norvegicus*), calculated for coastal areas only. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
0	-0.41	0.60	0.13	0.64	0.48	13
3	-0.52	0.51	0.01	0.98	-0.03	13
4	-0.80	0.04	-0.48	0.07	-2.00	13
5	-0.36	0.64	0.18	0.52	0.67	13
6	-0.66	0.32	-0.23	0.41	-0.84	13
7	-0.54	0.48	-0.04	0.89	-0.15	13

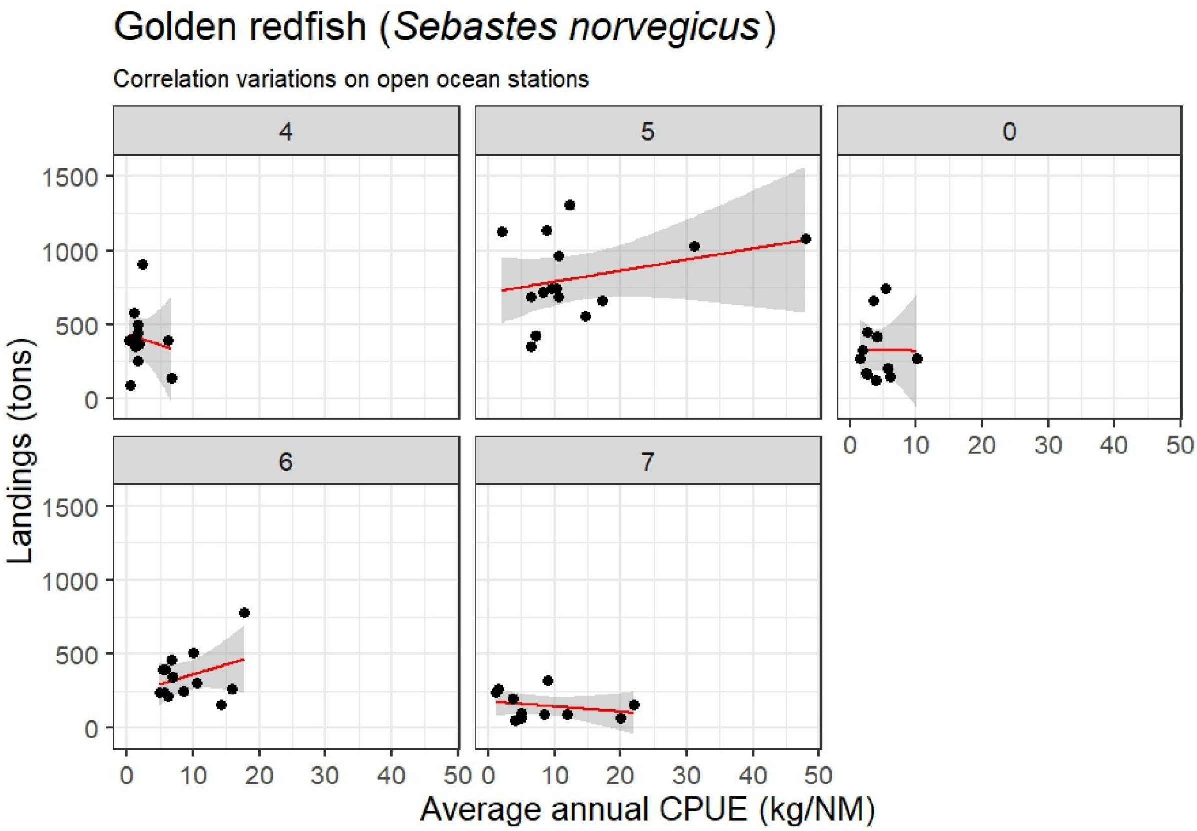

*Figure 38- Correlation plot showing the dependence of survey CPUE (kg/NM) – calculated for offshore areas only - and landings (tons) for golden redfish (*Sebastes norvegicus*).*

*Table 11 - Output from correlation test between survey CPUE (kg/NM) and landings (tons) for golden redfish (*Sebastes norvegicus*), calculated for offshore areas only. *Degrees of freedom*

Area	95% confidence intervall		Correlation coefficient	p - value	t - value	DF *
0	-0.58	0.57	-0.01	0.97	-0.04	10
4	-0.66	0.47	-0.15	0.65	-0.46	10
5	-0.24	0.71	0.31	0.26	1.18	13
6	-0.25	0.75	0.35	0.24	1.23	11
7	-0.75	0.39	-0.27	0.41	-0.85	9

Discussion

Based on the survey catch rates for the four species the main areas of occurrence was found to be area 4, 7, 7 and 5 for plaice, hake, rabbit fish and golden redfish, respectively. The highest catch rates were observed in the coastal subarea for all four species. Danish seine was found to have the highest catch-rate of plaice, for hake and golden redfish it was gillnets, whereas longline fisheries was found to have the largest landings of rabbit fish. Even though there were some variation, the distribution of occurrence in the main areas was fairly similar for all species when landings and survey data were compared. The areas with the highest landings were area 5, 7, 6 and 5 for plaice, hake, rabbit fish and golden redfish, respectively. It was found significant correlations between CPUE and landings in one area each for plaice, hake and rabbit fish, whereas for golden redfish there was none.

4.1 Limitations

CPUE- and fishery data

CPUE-data is a commonly used indicator in population dynamics, used in several studies for comparing catch rates, catch locations, determine spatial and temporal distributions and more (Fox & Starr 1996; Verdoit, Pelletier & Bellail 2003; Petitgas, Poulard & Biseau 2003). Common for several of the studies is that they have catch-data from both fishery dependent- and fishery independent data sources. Both scientific surveys and records from commercial fisheries are vital sources of information when assessing stocks (Verdoit, Pelletier & Bellail 2003). There are a lot of regulations regarding bycatch in the Norwegian fishery and it is commonly thought to be reliable. Still, it is justified to question how accurate landings actually are as there are many factors influencing these, for example storage space at sea and unknown discard rates. The advantage of scientific survey data is that it is collected based on protocols that are both standardized and controlled. The survey data used in this thesis comes from a trawl survey along the coast of Norway, and CPUE has been standardized to kg/NM. When conducting trawl surveys there is a critical assumption linked to the fishing efficiency, hence the catchability; an assumption saying that the catchability is constant in the time period studied. This might be valid in short periods, but it is probably not true over longer periods. It has been reported that improved roller gear and echo sounders can double the estimated efficiency of commercial vessels for instance (Kimura 1981). To guarantee that CPUE estimates are comparable between years, catchability should be studied every so often (Fox & Starr 1996).

Temporal survey data and cumulative commercial data

In management, fishery independent data is particularly important, but regardless of the quality of the data, scientific cruises are generally conducted only once a year. As a result, there is a lack of seasonal data; The Norwegian Coastal cruise only provides CPUE insight from October-November. In this study, the commercial fishery data lacked temporal data entirely, also it lacked information regarding exact fishing locations as only main areas were listed. Such information would have made it possible to evaluate the geographical co-occurrence in catches and to see whether the catches had been made within the coastal or offshore subareas from the cruise. Temporal data would have made it possible to compare trends from landings and surveys in the same period of time, making the estimates more reliable. In the commercial fishery, the distribution of fishing effort is not evenly dispersed (Fox & Starr 1996), and might vary between years. As a result, landings might differ too. The fact that the landings data lacked information regarding variables like soak time (effort) and fishing depth, made the comparison foundation weaker. Such effort measurements are often essential explanatory variables and vital for bycatch studies (Kaschner 2003).

Fishing effort – positive bias

A positive bias in the survey data was introduced through the elimination process of stations. One could therefore argue that the comparison between survey- and landing data only reflects the situation near the stations, and not the general trends. This was outweighed by the assumption that also fishermen have a positive bias in where they actually go fishing. Different ecological processes can generate aggregations and are commonly considered to be responsible for the variation in catches (Petitgas, Poulard & Biseau 2003). Fishermen take advantage of these aggregations and change both their fishing effort- and pattern accordingly in order to increase catches. In addition, as the same stations are being used yearly, the annual effort invested in each area during the scientific cruises is somewhat stable. This is also a factor minimizing the positive bias.

4.2 European plaice

4.2.1 Scientific survey – CPUE-data

Plaice was found to have the highest catch rate in area 4, followed by area 5 and 3, which all had variating trends in CPUE. The coastal areas had the highest catch rate, which was expected as this species is commonly found in the tidal zone and down to 200m depth (Bakketeig, Hauge & Kvamme 2017). The modelling process supported this as fishing depth was found to be a significant parameter explaining the variation in CPUE along with year and an interaction term between the two. This indicates variations in abundance between both years and fishing depth, in addition to variating CPUE depending on when and how deep one would fish. The interaction term could be explained by the fact that plaice seems to change depth preferences at different life stages (Freyholf 2014). This could mean that there are annual variations in recruitment and that the catches are from different cohorts found at different depths. As the model explained approximately 25% of the variance, there are indications of other factors, such as climate, contributing to the variation. Rijnsdorp et al. (2009) mainly focused on temperature effects and found climate related changes in recruitment for plaice, as both the quantity and quality of nursery habitats changed. In addition, Teal et al. (2008) found that the temperature in spawning periods influence the timing of spawning. This could in turn influence the timing of aggregation behavior, hence the catchability at different times of the year.

4.2.2 Commercial fisheries – landings data

The highest landings of plaice were from main area 5, followed by area 4 and 3. Those are the same areas as for the survey data, indicating that the distribution of occurrence is very similar. These results may also imply that there are one or several stocks aggregating along the northern coast of Norway. Based on plaice's depth preference, it could also be assumed that the commercial catches of plaice were made in more coastal areas. Due to overlapping habitat preferences (Bakketeig, Hauge & Kvamme 2017), high bycatches of plaice in the Danish seine fishery, which has cod, saithe and haddock as target species, can be expected. Another parameter influencing bycatch rates is that benthic communities might suffer due to bycatch and gear usage. Several studies have found that the ground gear mounted on trawls can penetrate 6cm into the sediments in addition to the 0.3m penetration caused by the otter boards (Caddy & Iles; Arntz & Weber; Krost et al., cited in Alverson et al., 1994). Danish seines, which can cause similar types of disturbances, might increase mortalities due to injuries, making benthic species more vulnerable for predation. Plaice being not only a demersal, but also a bottom dwelling species, might be more susceptible to such disruptions in addition to being captured when such gears are used.

4.2.3 Correlation between CPUE and landings

The only significant correlation in both combined- and coastal subareas was in area 5. Both being negative indicates high landings when observed CPUEs are low. Usually, high CPUE are observed when the resource is in good condition and low when the resource is depleted with corresponding high landings. Several factors such as outliers, migrations, gear usage- and selectivity in addition to spawning time may influence the correlation between CPUE and landings, resulting in the generally poor correlation indications found in this study.

Cod and haddock has overlapping spawning periods (Bakketeig, Hauge & Kvamme 2017), which in turn might overlap with the spawning time of plaice assuming that the stock located along the northern coast of Norway spawns in the same period as the one in the North Sea (Bakketeig, Hauge & Kvamme 2017). During spawning time fish are most likely to be caught as bycatch due to larger aggregations. Even if plaice was most frequently observed in area 4 during the cruise it is likely that it can migrate further south to spawn, for example to area 5 where haddock has an important spawning area (Bakketeig, Hauge & Kvamme 2017). The plaice stock located in the North Sea take advantage of selective tidal streams to migrate from feeding grounds in the north to spawning areas further south (Walker, Jones & Arnold 1978). It could therefore be a valid assumption that the stock located along the northern cost of Norway do the same thing. Since the survey is conducted in October-November and the landings data are a total landing from the entire year, it is likely that a large amount of plaice was caught earlier in the year, thus not corresponding to the catches made during the cruise. In addition, an observation from 2014 seems to have a rather big impact on the correlation (Fig. 14). This year had the largest mean CPUE from the entire period and the lowest recorded landings, resulting in an outlier that drives the correlation downwards (Fig. 14). Without this data point the correlation is neither significant, nor as strongly negative.

Plaice is found to be a nocturnal species, only leaving the bottom at night (Arnold & Cook, cited in Gibson 1997) where changes in light intensities work as a cue for the timing. This is true for a range of animals, whit flatfishes such as plaice making no exception (Gibson 1997).

A behavioral change induced by light might in turn have an effect on their catchability (De Groot, cited in Gibson 1997). Danish seiners are most efficient during daytime as the herding process of seines are heavily dependent on visual stimuli (Noack et al., 2017). In contrast, trawls can be operated during day- and nighttime (He & Winger, cited in Noack et al., 2017), hence the cruise can conduct hauls more randomly throughout a 24-hour period. If we assume that the behavior traits mentioned above are valid for the stock in question here, it might be that the catch rate of plaice is altered during nighttime. This could in turn affect the correlation.

Trawls and Danish seines have several differences in both selectivity, fishing procedures and design, hence also where it is optimal to use them. Whereas trawls are equipped with trawl doors, shorter sweeps and bobbins or rockhopper gear (He & Winger, cited in Noack et al., 2017), the seine have long sweeps, lack doors and are equipped with lighter ground gear (Sainsbury 1996). Trawlers can therefor operate on all sorts of substrate whereas seines are restricted to flat areas (even or sandy) to avoid damaging the gear (Noack et al., 2017). Plaice has a clear preference for sandy sediments (Freyholf 2014) and Noack et al. (2017) found that compared to trawls, seines had a higher catch rate of flatfish. The differences between survey and landings could therefore be due to substrate preferences, which are reflected in differences between bottom trawls and Danish seines. This implies that the survey does not adequately cover the area of distribution for plaice, explaining partly why the model explained comparatively little of the variance. In addition, seines are typically towed with a slower speed than trawls (Institute of Marine Research 2015) which might make plaice more vulnerable of being caught. All these parameters might be influencing the correlation between the two data sets.

4.2.4 Concluding paragraph for plaice

Even though the magnitude and order differed, it was found a complete overlap in main areas of occurrence between CPUE and landings with the highest observations in area 4, 5 and 3. For main area 5 the model explained approximately 25% of the variance in CPUE, indicating large degree of variation. The only significant correlations were found in area 5; being negative, they indicate large landings when observed CPUE is low. One data point in area 4 seems to drive the correlation, but has no effect after testing. In area 5 a data point from 2014 is of significance as this is the only reason for the significant correlation. The available data and results suggest that the correlation between commercial landings and survey CPUE is generally low, hence not to be used when trying to identify general commercial trends and the development of plaice bycatch.

4.3 European hake

4.3.1 Scientific survey – CPUE-data

European hake is known to be a Lusitanian species as it prefers warmer sea temperatures (Jiming 1981). In addition, important spawning areas for hake are found along the coast of Møre and in the North Sea (Werner, Staby & Geffen 2016), hence it was expected to find the highest catches and CPUE in these areas. Based on the survey data, the main area of occurrence was found to be area 7, the most southern area examined, followed by area 6 and 0. Regarding subareas, hake was clearly most common in the coastal stations. Being a demersal and pelagic species it is most commonly found at depths of 70-370m, but is also observed in coastal waters as shallow as 30m (Lloris et al.,; Meiners, cited in Korta et al., 2015). Hence, both of these results coincide with the already known distribution of the species.

In area 7 there has been an overall increasing trend in CPUE, but variations between years has been observed with some large observations in the coastal areas (Fig. 16). Years, in addition to fishing depth, was found to be significant parameters explaining the variation in CPUE through the modelling process. The model itself explained only 8% of the variation in the data, indicating a high degree of variance. Fishing depth might be significant due to the depth preference of the species, still it did not explain much of the variance. A reason for this might be that hake is known to have dial vertical migrations, bringing them closer to the surface at night due to feeding opportunities (Korta et al., 2015). Thus, depending on timing, the trawl might not be able to catch hake, resulting in a poor representative depth-profile, hence a low explanation contributor.

4.3.2 Commercial fisheries – landings data

The highest landings from the gillnet fishery were from the exact same areas as for the survey, area 7, 6 and 0, respectively. One difference between commercial and survey data is that in area 5, there have been limited annual catches of hake, whereas the survey has only observed hake once in the same area the last 15 years. Hake has a wide distribution in the north-east Atlantic, from northern Norway to the Guinea Gulf, throughout the Mediterranean and into the Black Sea, but is most abundant from the British Isle to southerly parts of Spain (Casey & Pereiro 1995). Large densities as far north as area 5 are therefore not that common, hence the relative low catch rates.

Hake is common off the coast of Møre og Romsdal, which also is believed to be a spawning area for the species (Werner, Staby & Geffen 2016). In addition to Helgelandskysten, this is also the area where most of the gillnet fishery takes place, with cod and saithe as the main target species. Looking at the distribution of these three species (hake, cod and saithe), there is a substantial overlap in distribution along the coast and the same is true for spawning areas (Bakketeig, Hauge & Kvamme 2017). The spatial behavior of hake is linked to its biology, and during spawning season mature fish tend to aggregate (Casey & Pereiro 1995; Poulard 2001). Larger aggregations tend to increase the catch rate, and even though hake spawn at different times during the year than both saithe and cod, they seem to inhabit the same areas making hake susceptible of being caught in the fishery.

4.3.3 Correlation between CPUE and landings

Newer studies have found that the spawning season for some hake stocks are very protracted with spawning activity year around (Murua & Motos 2006; Murua et al., 2006). Assuming that this is true for the stock in question here, this would mean that there is a somewhat steady recruitment throughout the year. In addition, the last decade larger and mature individuals of hake have been observed moving into more northern areas of the Northern Sea, contributing to increased abundance especially during summer and fall (Staby et al., 2018). This, in addition to the recruitment, might explain why an increasing trend in both CPUE and landings were observed. Such migrations might also influence the correlation in a positive way, especially since the cruise is conducted during the later fall. As mentioned, hake is a common species off the coast of Møre, which is largely covered by main area 7. Here correlation coefficients equal to 0.54 and 0.55 for combined subareas and the coastal subarea respectively were calculated. These are strong indications of correlation between commercial catches and survey CPUE, and both being positive indicate large landings with respectively high CPUEs. For hake the correlation result for area 7 would potentially be suitable to identify developing bycatch trends, hence also general trends in the commercial fishery.

For the other areas, no correlation was found to be significant. One data point in area 6 could be believed to have an impact on the correlation, but it was found not to. As for area 3 and 4 there were no co-occurrences of data points, making the comparison impossible. As mentioned, there has been yearly observations of hake in the commercial fisheries, and also a relatively large amount of landings from area 5 and 0. In these two areas there have been close to no observations from the cruise resulting in a poor comparison. These inconsistencies might be explained by that the cruise has had insufficient coverage in those areas. It could also be seasonal differences in abundance from when the survey is conducted and when the landings are being made.

Gear usage might affect the correlation as the survey used an active trawl, whereas passive gillnets were used in the fishery. Depending on effort, these two types of gears can have a very different catch rates and selectivity. Mesh size is the main character regarding selectivity in gillnets, whereas other factors such as visibility, tangling capacity, hanging coefficients and morphology affect the efficiency of the net (Clark; Brandt, cited in Hamley 1975). In addition to vertical migration (Korta et al., 2015), hake is also observed to make horizontal migrations in spawning seasons (Persohn, Lorance & Trenkel 2009). Depending on depth and area, gillnets might have an increased chance of interactions with hake. The length distribution in trawls and gillnets do not necessarily have to be the same either. An attempt to reduce this limitation was made as only stations with the same mean length was chosen, but gillnets tend to catch larger individuals either way. Hence, this could be an explanation for the differences in CPUE and landings.

4.3.4 Concluding paragraph for hake

The only complete time series for the survey was found in the coastal stations in area 7, whereas the commercial fishery had annual catches of hake in area 5, 0, 6 and 7. In area 7 an increasing trend was observed in both data sets, and the best model could explain only 8% of the variation in CPUE. This was also the only area found to have a significant correlation between CPUE and landings. The correlation was positive, 0.55 and 0.54 from combined and only coastal stations, respectively. These results suggest that CPUE can supplement landings data when trying to identify and estimate bycatch trends, at least in area 7.

4.4 Rabbit fish

4.4.1 Scientific survey – CPUE-data

The survey data showed that rabbit fish occurred in all areas except area 3. The area found to have the highest catch rate was area 7, followed by area 5 and 6, respectively. In general, these three areas had a stable catch-trend with a slight increase. Through the modelling process fishing depth and years were found to be significant explanation parameters regarding the variation in CPUE. With an explanation percentage of 42% it was the most explanatory model in this study. Rabbit fish is a bentho-pelagic species, and is common along the coast of Norway at depths of 300-1250m (Durán et al., 2010). Even so, other factors than depth can influence CPUE, for example segregating behaviors based on sex, size and maturity, which can differ between grounds and depth (Calis et al., 2005). Depending on the location and depth of the extra hauls conducted by the survey, these might influence the catch rate, hence also the explanation contribution regarding the variation.

Despite being regarded a deep-water species, rabbit fish was most frequently observed in the coastal stations, which have a mean depth of approximately 234m. This result might indicate that rabbit fish is inhabiting shallower waters during this time of year. According to Wheeler (cited in Calis et al., 2005), the species tends to migrate and spawn in waters shallower than 100m, but the spawning areas along the Norwegian coast are to this day not known (Bakketeig, Hauge & Kvamme 2017). More information regarding its reproductive biology and life history is required in order to fully understand the variations found in this study.

4.4.2 Commercial fisheries – landings data

The highest landings of rabbit fish in the longline fishery were made in the same areas as the survey, only with a slightly different order of magnitude, area 6, 7 and 5, respectively. Whereas the catch rate in area 7 was found to be steadily increasing, the catch rates from both area 5 and 6 declined after a peak in 2010. The total landings from 2010 in area 7 were also relatively large. This could either be a result of favorable conditions (food availability for instance) and strong recruitment that year (high abundance), increased effort directed at the target species of the longline fishery, or better market prices. The degree discard and bycatch related impacts varies between species, depending on factors like quantities taken, survival rate and life history traits in addition to population characteristics for the species in question (Alverson et al 1994). Species that are more vulnerable to elevated mortalities typically have long generation times, slow body growth and low natural mortality rates (Reynolds, Jennings & Dulvy 2001). Calis et al. (2005) suggest that rabbit fish is a typical "k-selected" species, characterized by all the traits mention above. If this is to be true, it is extremely important that the management regarding rabbit fish take appropriate precautions.

Rabbit fish was most frequently caught in fisheries where cod and haddock is the main target species. Looking only at distribution it is evident that from 62°N rabbit fish and haddock inhabit the same areas along the coast as well as some areas further into the Barents Sea towards Svalbard (Bakketeig, Hauge & Kvamme 2017). Comparing survey data and commercial landings, some of the largest observations has been found in areas known to be used as spawning areas for haddock. This could therefore indicate that rabbit fish is susceptible to capture in longline fishing due to the same preference in habitat as the target species.

4.4.3 Correlation between CPUE and landings

When subareas were combined, correlation tests revealed one significant correlation coefficient of 0.71 in area 4. This is not an area with neither the highest CPUE nor landings, but it is a relatively strong correlation making it a beneficial indicator for bycatch trends in the commercial fisheries. When subareas were separated on the other hand, neither costal nor open ocean stations showed a correlation of significance. Looking at the coastal stations one can recognize that there is a lot of uncertainty connected to the correlation (Fig. 29). In area 6 there are two data points that could be believed to drive the correlation, but these were found not to have any impact in the correlation when neglected. In area 7 on the other hand, an observation from 2012 have the largest CPUE observed correlated with the lowest landing recorded. Neglecting this actually makes the overall correlation significant and positive (0.62). Such data points are also seen for the open ocean stations, but non of them have any impact on the correlation (Fig. 30). In the end none of the two later mentioned areas, nor any others (expect area 4) has any indication of correlation between CPUE and landings and can therefore not be used when talking about trends in bycatch.

Compared to the other species, rabbit fish had the lowest landings on a general basis during the period studied. This might be explained by the size of the stock or it could be the difference in efficiency and selectivity of the gears used. Longlines are baited passive gears that rely on the foraging behavior of fish (Løkkeborg, cited in Løkkeborg & Bjordal 1992). The bait is selected based on the diet preference of the target species, so chemical components in the bait attracts the right species (Løkkeborg 2001). The diet of rabbit fish is taxonomically diverse and seems to change with season and size (Wik, in Calis et al., 2005). It could be that rabbit fish is attracted to the same chemical components as cod and haddock, resulting in rabbit fish catches. In longline fishery bait- and hook-size is also used as a selective measure in order to target a certain length/size group. It could therefore be that the rabbit fish landings are more homogenous in length-distribution from longlines than trawls, only capturing animals of a certain size. Even though trawls are equipped with certain mesh sizes and grids in order to be size selective (O'Neill & Mutch 2017), there is a chance of capturing a great amount of other individuals as well (Kennelly 1995). In addition, trawls are active gears chasing organisms along the seabed. Based on its anatomy, rabbit fish is not the fastest swimmer (Flammang 2014), hence it is plausible that it does not have extended swimming endurance. In comparison to longlines where an active choice is made by hooking, rabbit fish are more susceptible to trawl gear. Factors such as these affect the efficiency/catchability, hence also the correlation.

4.4.4 Concluding paragraph for rabbit fish

The main areas of occurrence overlapped between CPUE and landings (7, 6 and 5), but the magnitude of observations and order of main areas differed. Rabbit fish was most common in the coastal subarea and the model for area 7 explained approximately 42% of the variance in CPUE. The only significant correlation was strongly positive and derived from area 4, hence useful in identifications of bycatch trends. Still, more information regarding this species is needed to get indications of how factors such as bycatch trends affects the population dynamics (total mortality levels, estimation of natural- and fishing mortality components etc.).

4.5 Golden redfish

4.5.1 Scientific survey – CPUE-data

The golden redfish is a deep water species found in depths of 100-500m (Bakketeig, Hauge & Kvamme 2017), and is common along the coast of Norway (Barsukov, Litvinenko & Serebryakov 1984). In this study, golden redfish was the only species found in all areas and the respective subareas, with the highest catch rates observed in the coastal ones. The main area of occurrence was area 5, with area 6 and 0 following, respectively. The annual mean CPUE in each of these areas has mainly been below 40 kg/NM, but there are large- to extreme outliers resulting in yearly variations. The following modelling process for area 5 revealed years to be the single significant parameter explaining the variation in CPUE, but the model itself explained only 5.25% of the actual variance. These data suggest that there are other factors affecting the variation in CPUE.

One explanation for the variation might be diel vertical migrations (DVM) and pelagic shoaling behavior. Gauthier and Rose (2002) found evidence of packed aggregations of redfish either in direct contact with the bottom or pelagic shoals gathering near or close to the seabed during daytime. At night, the pelagic shoals dispersed further up in the water column, before the fish again aggregated and returned to the bottom at dawn. The behavior seemed to be induces by time of day, indicating that light intensity played an important role (Neilson & Perry 1990). Either this behavior trait could be linked to feeding opportunities or reducing the risk of individual predation (Pitcher & Parrish, cited in Gauthier & Rose 2002; Romey 1997) or it could be an anti-predator function (Clark & Levy 1988). Being both a demersal and a semi-pelagic species, its catchability would differ according to daytime. Another reason could be temperature as this affects the distribution and occurrence. Pikanowski et al. (1999) found two other redfish species to be most abundant when the bottom temperature was ranging between 4 and 13°C in autumn, where samples were collected from 125-200m depths. Assuming that golden redfish has somewhat of the same temperature- and depth preference at the timing of the cruise, it might be that there is insufficient coverage in areas fulfilling those criteria.

4.5.2 Commercial fisheries – landings data

When comparing main areas of occurrence from the survey and landings, there are some inconsistencies as the highest landings of golden redfish are from main area 5, 4 and 6, respectively. One explanation might be that golden redfish inhabit the same areas as cod and saithe along the coast. Saithe and cod are commercially important species targeted in the Norwegian gillnet fishery, which also had the largest catch rate of golden redfish. In addition to general distribution of the three species, there are also some overlapping regarding depth preferences and spawning areas (Bakketeig, Hauge & Kvamme 2017). All these co-occurrences make golden redfish susceptible for bycatch. Due to geographical preferences when trying to catch the target species and the fact that golden redfish seems to prefer the same locations, the survey and commercial fishery data might not show the same main areas of occurrence.

Regardless of main area, the landings from the gillnet fishery all show the same decreasing trend in catch rates. One explanation of this might be that ICES has advised a total ban of any fishing activity regarding golden redfish. The population has been experiencing low recruitment since the early 1990's, and since the mid-2000s, the mortality rate has increased due to fishing activities (ICES 2016). The findings found in this study coincide with stock assessments of golden redfish done in the Barents- and Norwegian Seas: a declining trend in the early 2000s, followed by a slight increasing trend or a period of leveling out before yet another decline (ICES 2018). In 2010 it was classified as "highly endangered" and put on the Norwegian red list of endangerment, but the stock it is estimated to collapse within 2020 if mortality rates and low recruitment continues (Bakketeig, Hauge & Kvamme 2017). The golden redfish is a slow-growing species, having long generation times and low natural mortality rates (Hart & Reynolds 2002). Such species are more vulnerable to elevated fishing mortalities, which can result in declining populations if not properly managed.

Golden redfish is a non-targeted species in the Norwegian fishery, but is mistakenly captured as bycatch which could lead to economic losses. One might raise the question of what kind of costs or losses catching such species could have, neglecting the interaction between species (Alverson et al., 1994). Bycatch might alter the availability of prey and therefore predators, which in turn could affect both the marine ecosystem and fishery productivity (NOAA, n.d). Golden redfish is known to be prey for species like cod and pollock (Gauthier & Rose 2002), and by removing such resources as a result of bycatch one could alter the productivity, growth rate and survival of the exploited target-species. This could in turn lead to big economic effects in the commercial fisheries. Another more practical cost of bycatch is that it takes time to sort it from the target catch, cleaning the gear and storing at sea. There is also a loss in the forgone value if the bycatch was exploited and managed in a better way (Alverson et al,, 1994).

4.5.3 Correlation between CPUE and landings

No areas were found to have a significant correlation between CPUE and landings for golden redfish. When looking at the coastal stations (Fig. 37), there are one data point in both area 5 and 6 that could seem to have an impact on the correlation. It is in the same two areas such observations are made for the open ocean stations as well (Fig. 38). None of these data points had any impact on the correlation. With other words, the data suggest that the CPUE-data cannot be used to identify trends in bycatch of golden redfish in the commercial fisheries.

There could be several factors affecting the correlation between the two data sets, either technical measures regarding gear usage, temporal differences or biological explanations. Identification problematics might also influence the correlation and the reducing trends observed in both data sets. Several species in the genus *Sebastes* share many of the same morphology traits, resulting in difficulties in identification (Pampoulie & Danielsdottir 2008; ICES 2016). For golden redfish, *Sebastes mentella* is the most similar looking, and the identification problematics are pronounced in the juvenile life stages. The result of this is poor estimations of recruitment to the golden redfish stock as there is a high degree of uncertainty (ICES 2016).

The DVM and pelagic aggregation behavior may also influence the catch rate, hence the correlation. In addition to those two, it has been found that the size of redfish is positively correlated with depth (Brown & Hennemuth, cited in Pikanowski et al., 1999). This might be due to the identification difficulties mentioned above, or it could be factors such as size- and/or gender specific migrations, differential growth rates of stocks or a combination of all or some of these factors (Pikanowski et al., 1999). Resultantly, depending on timing and depth, the catch could differ as the stock is segregated both by depth in general, but also due to vertical migrations up the water column at different times a day. As bottom trawls are used in the survey this would mean that the catch rate would be lower during the night. Pikanowski et al. (1999) also found this as the stock is more dispersed in the pelagic zone at that time (Gauthier & Rose

2002). Gillnets are passive gears, so depending on both the location, depth and soak time the catch rate of golden redfish would differ.

4.5.4 Concluding paragraph for golden redfish

Main areas of occurrence did not completely overlap between CPUE and landings as the survey had most observations in area 5, 6 and 0 and the fishery in area 5, 4 and 6, respectively. The highest catch rates from the survey were observed in the coastal stations, and the best model explained only 5.25% of the variance in CPUE in area 5. In all main areas a declining trend in landings was observed, and no significant correlation between survey and commercial landings were found. This suggest that the data collected by the survey cannot be used in identifying commercial bycatch trends and developments. These findings coincide with the decision of not using coastal survey CPUE-data in assessments for golden redfish. It has been found that commercial catch trends capture the overall biomass trends more efficiently than survey CPUE as CPUE is more affected by the movement from inshore to offshore areas conducted by this species (Howell, pers.com).

4.6 Conclusion

The results in this study suggest that all species are most commonly observed in the coastal subareas during the Coastal survey. It was found extensive overlap in main areas of occurrence between the survey CPUE and fishery landings, and three different fisheries where found to have the largest catch rate; Danish seine – plaice, gillnet – hake and golden redfish, Longline – rabbit fish. The results regarding the correlation ranged from good to poor depending on species. For plaice, the only significant correlation was found to be negative in area 5. This means that landings were large when observed CPUE was low, which is turn suggest that the CPUE-data cannot be used to identify bycatch trends in the commercial fishery. For hake and rabbit fish it was found strong positive correlations in area 7 and 4 respectively, indicating large landings and correspondingly large CPUEs. Such results can be used as indicators when trying to identify the development of bycatch and thus general trends in the commercial fishery. No areas were found to have significant correlations between survey- and commercial landings data regarding golden redfish, hence the data is not suitable for use in identifying commercial bycatch trends.

The fishery dependent data can in many instances supplement research data in questions regarding spatial distribution and catch rate trends, but CPUE can in many instances also have little informative value regarding the development of fish resources. In comparison to the target species for the survey, these four species have a set of different behavior traits and biology, so it might be that the survey is unable to capture all the variability and aspects. Future work could include surveys with more focus on these species, more extensive sampling and temporal data to see when bycatch is most prominent. Further monitoring and management is required to fully understand and manage the bycatch problematics.

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Appendix 1 – Survey CPUE tables

The areas with the most catches were based on these tables

Table 1.1 - Mean CPUE (kg/NM) for European plaice per year in all areas when divided into subareas ocean and coast.

	0	3	4		5		6	7	
Year	Coast	Coast	Ocean	Coast	Ocean	Coast	Coast	Ocean	Coast
2003	10.59	9.47	-	10.70	2.67	7.06	-	-	-
2004	4.99	13.05	-	1.77	-	5.02	-	-	-
2005	0.91	7.80	-	9.54	6.23	1.58	1.60	-	6.29
2006	8.53	7.38	-	2.65	1.32	6.84	-	1.32	3.66
2007	4.19	6.43	0.77	14.69	1.71	2.78	-	-	1.54
2008	2.32	4.55	-	81.35	-	7.07	0.36	-	6.22
2009	2.87	12.42	-	23.51	1.26	6.12	-	-	4.13
2010	2.66	7.86	-	3.10	18.02	2.93	1.04	-	5.05
2011	2.70	8.81	3.84	10.62	-	8.98	1.44	-	-
2012	13.14	5.09	-	13.75	-	6.87	1.65	-	6.86
2013	8.47	6.04	-	11.09	9.11	11.79	-	-	7.70
2014	3.48	6.86	-	7.75	2.76	25.83	4.13	-	7.63
2015	11.50	9.43	-	9.56	3.85	7.47	2.63	-	-
2016	17.84	10.30	-	34.02	-	11.72	-	-	16.28
2017	6.17	5.08	-	19.12	0.58	9.37	-	-	13.23

Table 1.2 - Mean CPUE (kg/NM) for European hake per year in all areas when divided into subareas ocean and coast.

	0		4	5	6		7	
Year	Ocean	Coast	Ocean	Coast	Ocean	Coast	Ocean	Coast
2003	-	-	-	-	-	1.78	-	25.19
2004	-	-	-	-	-	1.04	-	5.50
2005	-	-	-	-	-	0.74	5.22	5.67
2006	-	-	-	-	-	7.27	0.52	15.10
2007	-	-	-	-	-	-	-	3.46
2008	-	-	-	-	-	2.16	18.37	15.32
2009	-	4.57	-	-	0.75	-	-	15.54
2010	-	-	-	-	-	-	-	5.99
2011	-	-	-	-	-	6.69	1.33	8.01
2012	2.67	-	-	-	8.20	13.94	-	29.01
2013	-	1.11	-	-	-	-	10.10	42.53
2014	-	1.58	-	-	4.00	-	1.07	34.93
2015	-	17.44	-	0.48	0.71	36.32	5.00	26.76
2016	-	-	-	-	5.27	6.52	5.29	34.70
2017	-	6.81	0.60	-	-	2.21	9.39	29.77

Table 1.3 – Mean CPUE (kg/NM) for rabbit fish per year in all areas when divided into subareas ocean and coast.

	0		4		5		6		7	
Year	Ocean	Coast	Ocean	Coast	Ocean	Coast	Ocean	Coast	Ocean	Coast
2003	-	6.93	-	-	-	0.91	6.33	12.16	-	-
2004	-	-	-	3.32	1.75	23.06	11.40	-	26.84	7.41
2005	-	-	1.81	2.72	-	3.29	-	16.71	8.98	4.67
2006	-	4.34	1.93	4.17	4.55	21.33	6.29	3.64	10.26	28.52
2007	3.66	4.10	-	-	4.42	38.69	2.85	-	-	2.14
2008	-	8.80	4.46	3.80	2.51	67.60	4.54	-	-	49.61
2009	1.05	1.18	4.74	4.62	7.34	54.19	13.30	36.66	2.07	37.10
2010	-	3.95	1.77	9.67	-	27.32	-	-	21.93	95.42
2011	-	2.34	8.20	6.58	-	43.83	3.19	-	4.20	5.36
2012	14.36	-	7.08	6.44	10.62	27.69	9.79	23.22	22.28	123.41
2013	24.86	27.50	-	8.65	28.93	37.36	8.12	76.41	24.47	53.85
2014	6.60	1.07	32.05	3.60	0.47	25.20	17.36	17.62	19.20	103.76
2015	7.76	-	11.93	2.44	12.36	57.24	45.16	6.19	17.07	42.84
2016	41.78	-	14.16	7.84	19.80	43.00	11.41	24.50	13.74	59.48
2017	17.14	4.87	3.64	7.06	8.09	30.67	24.99	99.18	10.91	90.13

Table 1.4 - Mean CPUE (kg/NM) for rose fish per year in all areas when divided into subareas ocean and coast.

	0		3		4		5		6		7	
Year	Ocean	Coast	Ocan	Coast	Ocean	Coast	Ocean	Coast	Ocean	Coast	Ocean	Coast
2003	5.41	19.18	-	26.30	2.42	4.61	12.34	11.56	17.74	5.71	-	0.41
2004	-	42.58	-	15.52	-	9.81	31.12	13.28	9.96	2.03	9.02	1.30
2005	1.81	24.13	-	3.58	1.13	4.69	8.28	7.92	6.67	3.15	-	10.05
2006	10.14	8.49	-	2.15	6.11	8.03	10.56	22.85	5.49	10.86	11.85	1.39
2007	5.66	9.47	-	0.88	1.59	6.67	9.44	18.47	5.64	3.32	-	1.37
2008	-	22.42	4.17	2.53	-	8.92	2.04	6.79	15.91	9.34	1.07	4.01
2009	2.67	59.15	-	4.13	1.63	1.61	47.84	178.71	6.91	5.61	1.42	3.52
2010	3.54	15.29	-	1.83	0.39	24.52	8.73	19.72	5.79	8.41	3.68	5.00
2011	4.00	16.15	-	1.92	1.25	16.56	10.61	27.42	-	20.26	21.90	0.81
2012	1.53	33.17	-	2.35	1.25	14.87	6.38	21.54	10.65	18.37	-	2.40
2013	-	27.20	-	5.95	1.76	17.40	17.11	55.96	8.54	11.47	8.49	2.42
2014	2.49	23.69	-	22.81	1.62	13.66	10.34	22.55	6.09	8.31	4.93	2.38
2015	3.82	-	-	31.34	0.45	6.59	14.64	23.85	4.88	143.65	20.00	2.52
2016	2.71	21.12	-	18.66	-	15.29	6.37	14.21	14.19	12.49	5.03	2.97
2017	6.14	17.25	-	11.36	6.79	23.80	7.18	20.09	-	19.01	3.97	1.38

Appendix 2 – Gears used in commercial fisheries

Table 2.1 - Total catches (tons) of European plaice with different gear types, showing that Danish seine has the highest catches of this species in total when looking at the time series as a howl.

				Gears			
Year	Gill net	Trawl	Long Line	Seine	Danish Seine	Cage	Other
2003	100.13	25.32	26.77	1.49	1021.67	1.42	-
2004	108.68	15.50	12.73	0.31	892.88	0.05	0.06
2005	119.48	29.31	18.03	3.18	703.87	0.17	0.11
2006	126.93	25.54	14.07	1.11	642.87	0.05	-
2007	92.66	25.84	8.33	-	614.61	0.55	7.92
2008	106.89	10.01	10.71	0.00	555.98	0.40	0.01
2009	66.68	12.17	8.16	-	425.78	0.13	-
2010	66.77	5.00	8.47	-	451.88	0.53	0.05
2011	52.31	3.59	11.00	-	301.14	0.78	0.03
2012	40.85	2.01	14.14	-	357.37	0.68	0.05
2013	50.10	1.86	7.13	-	329.98	0.89	-
2014	45.58	1.90	11.50	-	323.11	1.21	-
2015	36.70	0.62	12.30	-	372.92	1.01	0.31
2016	56.10	6.62	8.27	0.21	566.41	0.17	-
2017	49.72	0.12	6.48	0.56	526.43	0.22	-
Total	**1119.58**	**165.42**	**178.09**	**6.86**	**8086.89**	**8.26**	**8.55**

Table 2.2 - Total catches (tons) of European hake with different gear types, showing that gillnet has the highest catches of this species in total when looking at the time series as a howl.

				Gears			
Year	Gill net	Trawl	Long Line	Seine	Danish Seine	Cage	Other
2003	250.20	26.64	1.79	0.00	42.88	0.15	0.13
2004	208.90	27.77	8.19	-	77.09	0.34	-
2005	330.80	46.10	7.95	0.83	94.88	0.13	2.40
2006	512.05	33.95	4.37	2.78	71.61	0.06	-
2007	497.49	42.65	5.62	-	75.50	0.70	-
2008	556.35	31.17	3.03	-	82.00	0.02	-
2009	496.64	38.66	3.66	0.01	28.14	0.26	-
2010	525.66	57.82	6.36	-	16.77	0.45	-
2011	315.11	287.36	4.03	-	13.65	0.66	-
2012	525.29	309.41	4.70	-	15.91	0.61	-
2013	487.86	286.25	8.47	-	54.64	4.98	-
2014	688.84	270.70	6.36	-	70.74	6.37	-
2015	603.20	181.35	7.44	-	60.60	0.61	3.51
2016	657.79	130.98	3.39	0.81	67.33	0.20	-
2017	583.61	479.46	5.89	0.36	14.17	0.41	9.74
Total	**7239.78**	**2250.26**	**81.26**	**4.79**	**785.92**	**15.95**	**15.79**

Table 2.3 - Total catches (tons) of rabbit fish with different gear types, showing that longline has the highest catches of this species in total when looking at the time series as a howl.

	Gears			
Year	Gill net	Trawl	Long Line	Danish Seine
2003	-	-	50.18	-
2004	-	-	12.01	-
2005	0.01	-	58.93	-
2006	-	-	24.77	-
2007	-	-	59.60	-
2008	0.24	-	73.77	0.00
2009	-	25.74	56.81	-
2010	0.09	40.49	115.07	-
2011	-	32.26	95.73	-
2012	-	42.65	42.04	-
2013	-	16.90	78.39	0.07
2014	-	8.52	63.58	0.13
2015	1.33	11.88	50.84	-
2016	-	5.34	61.66	-
2017	0.44	5.65	57.58	-
Total	**2.12**	**189.43**	**900.97**	**0.20**

Table 2.4 - Total catches (tons) of rose fish with different gear types, showing that gillnet has the highest catches of this species in total when looking at the time series as a howl.

				Gears			
Year	Gill net	Trawl	Long Line	Seine	Danish Seine	Cage	Other
2003	4451.43	2134.75	800.13	3.06	94.71	1.59	0.29
2004	3173.22	2144.27	853.44	2.33	121.21	0.34	2.87
2005	2504.95	2539.07	821.83	2.29	162.52	0.46	0.28
2006	2246.19	1758.81	1035.13	0.22	113.75	2.94	-
2007	1888.37	2509.04	857.38	3.06	89.72	1.99	0.39
2008	2638.78	2090.16	699.15	0.01	35.75	0.40	2.21
2009	2788.10	1565.17	764.48	0.75	18.42	1.11	0.06
2010	2928.93	2067.44	901.79	-	14.15	0.39	0.66
2011	2223.15	1697.20	905.56	0.05	21.64	0.56	0.61
2012	1880.02	1582.62	704.57	0.19	12.57	0.60	0.07
2013	1730.56	841.30	713.91	-	23.30	0.54	0.49
2014	1556.73	931.54	493.06	-	25.35	0.39	-
2015	1119.71	774.75	666.97	-	48.56	0.25	-
2016	825.41	1816.39	565.17	-	97.16	0.16	0.05
2017	976.18	1527.84	586.31	0.49	98.80	2.08	-
Total	**32931.74**	**25980.34**	**11368.87**	**12.44**	**977.60**	**13.81**	**7.98**

Appendix 3 – Total catch per year by main gears

Table 3.1 - Yearly catches (tons) of European plaice from the commercial fisheries in different areas using Danish seine

Year	0	3	4	5	6	7
2003	172.76	242.61	333.99	191.85	3.17	77.30
2004	92.64	229.51	246.64	246.47	3.24	74.37
2005	85.35	129.70	203.72	215.74	0.47	68.89
2006	76.02	87.91	151.61	286.31	0.51	40.50
2007	81.21	91.36	174.99	240.46	0.79	25.81
2008	75.37	72.86	158.70	214.16	0.65	34.24
2009	74.59	29.17	117.26	171.83	0.60	32.34
2010	57.14	88.20	140.54	128.16	0.06	37.78
2011	13.61	57.74	97.00	104.44	0.03	28.32
2012	14.07	85.87	134.37	101.00	0.01	22.05
2013	2.93	83.73	114.78	98.29	-	30.25
2014	10.90	108.95	93.80	79.36	-	30.09
2015	3.36	126.00	120.32	98.53	0.15	24.56
2016	32.28	134.19	198.60	172.37	0.66	28.30
2017	105.46	124.06	138.37	135.14	0.48	22.93

Table 3.2 - Yearly catches (tons) of European hake from the commercial fisheries in different areas using gillnets

Year	0	3	4	5	6	7
2003	2.41	-	-	0.40	32.97	214.43
2004	3.39	-	-	0.08	19.92	185.50
2005	3.30	-	0.00	0.10	43.68	283.71
2006	1.43	-	0.08	0.75	56.70	453.09
2007	1.68	-	-	6.18	57.33	432.30
2008	17.31	0.64	0.00	0.12	68.25	470.02
2009	8.09	-	0.02	1.26	73.04	414.23
2010	8.69	-	-	0.61	63.99	452.36
2011	6.83	-	0.00	7.98	48.89	251.40
2012	3.60	-	0.13	5.59	79.62	436.36
2013	2.65	-	0.01	0.44	40.06	444.71
2014	7.98	-	0.03	0.68	72.74	607.42
2015	4.64	0.10	-	0.82	61.31	536.33
2016	5.03	-	0.63	10.63	66.74	574.76
2017	7.19	-	-	1.67	77.72	497.03

Table 3.3 - Yearly catches (tons) of rabbit fish from the commercial fisheries in different areas using longline

Year	0	3	4	5	6	7
2003	-	0.24	4.47	20.21	16.74	8.52
2004	-	2.09	0.01	1.32	3.68	4.92
2005	42.80	-	0.82	10.06	3.11	2.14
2006	-	-	-	10.49	4.95	9.33
2007	-	-	1.10	20.53	14.92	23.05
2008	-	-	-	16.57	28.42	28.78
2009	-	0.20	-	16.97	20.81	18.83
2010	-	0.04	-	38.01	47.57	29.45
2011	-	0.49	8.18	29.66	40.16	17.25
2012	-	0.81	3.90	21.64	14.31	1.39
2013	-	0.06	7.14	26.38	15.29	29.53
2014	-	-	5.16	10.23	31.36	16.84
2015	-	-	1.92	9.74	22.63	16.55
2016	0.58	-	3.29	17.79	9.01	30.99
2017	-	0.01	-	2.41	16.73	38.42

Table 3.4 - Yearly catches (tons) of rose fish from the commercial fisheries in different areas using gillnets

Year	0	3	4	5	6	7
2003	746.46	271.77	904.87	1306.43	780.20	441.71
2004	441.71	388.41	485.46	1028.78	508.20	320.67
2005	327.79	232.03	577.93	723.47	458.67	185.06
2006	266.66	124.36	391.19	685.23	685.23	93.53
2007	204.03	118.03	440.94	742.66	240.84	141.88
2008	345.29	198.68	464.00	1124.64	266.67	239.49
2009	453.87	150.40	496.65	1079.90	342.03	265.26
2010	658.65	148.13	393.04	1134.64	396.88	197.60
2011	413.92	78.00	355.74	964.12	253.48	157.90
2012	268.15	54.03	411.30	687.87	303.70	154.97
2013	310.37	47.79	368.09	665.96	247.67	90.67
2014	176.21	64.05	253.34	745.22	213.52	104.40
2015	124.23	34.41	90.50	558.86	242.43	69.29
2016	161.98	19.13	60.40	355.02	158.88	70.01
2017	146.71	87.36	141.89	429.31	114.96	55.95

Appendix 4 – Outputs from the forward selection modelling approach

Table 4.1 – Modelling outputs for all four species. For the significant parameters, year represents a regression variable, whereas area and subarea are categorical variables with six and two categories respectively.

Species	Significant parameters	Degrees of freedom	P-value	Explanation percentage (%)
European plaice	Year, fishing depth, year:fishing depth	3 and 88	< 0.01	25.37
European hake	Year, fishing depth	2 and 127	< 0.01	8.17
Rabbit fish	Fishing depth, year	2 and 53	< 0.01	41.66
Golden redfish	Year	1 and 135	< 0.01	5.25

Appendix 5 – Extractions from script

```
rspette <- sBT %>%
  filter(strat2 %in% c("K"))


plott.bp <- ggplot(data=rspette, aes(x=as.factor(year.x), y=cpuew, fill=strat2)) +
  geom_hline(aes(yintercept=mean(cpuew)), color="red") +
  geom_boxplot() +
  facet_wrap(~area, scales="free_y", ncol=1, strip.position="right") +
  scale_x_discrete(breaks = c(2004,2006,2008,2010,2012,2014,2016), labels = c("2004", "2006", "2008", "2010", "2012", "2014", "2016")) +
  theme_bw(base_size=20) +
  labs(x="Year", y="CPUE (kg/NM)", title=expression('European plaice ('*italic('Pleuronectes platessa')*')')) +
  #scale_fill_manual(name="Substrata", labels=c("H"="Open Ocean"), values=c("H"="deepskyblue4")) +
  scale_fill_manual(name="Substrata", labels=c("K"="Coastal"), values = c("K"="deepskyblue"), guide=FALSE) +
  stat_summary(fun.y = "mean", geom="point", size=2, shape=4, position=position_dodge(width=0.75), show.legend = F) +
  theme(axis.text.x=element_text(angle=45, hjust=1), panel.grid.major = element_blank(), panel.grid.minor = element_blank())

plott.bp


plott.bp_zoom <- plott.bp+
  geom_hline(aes(yintercept=mean(cpuew)), color="red") +
  coord_cartesian(ylim=c(0,50)) +
  labs(y="", title="")

gridExtra::grid.arrange(plott.bp, plott.bp_zoom,ncol=2)
```

Figure 5.1 - Overview of CPUE-changes throughout the study period. The two lower part made it possible to make a "double figure" (Fig. 8 and 33) such as for European plaice and Golden redfish. These two parts were not added for hake and rabbit fish.

Correlation and combining datasets

```
la <- lan %>%
  filter(art %in% c("rødspette")) %>%
  filter(gear%in% c("Danish seine"))

#la
la2 <- la %>%
  select(land_aar, fangst_homr, sumv) %>% #plukke ut kolonnene vi trenger
  rename(year=land_aar, area=fangst_homr) %>% #endre navn på kolonnene
  group_by(year, area) %>% #grupperer utifra year og area
  summarise(sumv=mean(sumv))
#splitte opp kolonnen
head(la2)



#rspette
rspette2 <-rspette %>%
  select(year.x, area, cpuew) %>% #plukke ut kolonnene vi trenger
  rename(year=year.x, area=area) %>% #endre navn på kolonnene
  group_by(year, area) %>% #grupperer utifra year og area
  summarise(cpuew=mean(cpuew))
#splitte opp kolonnen
head(rspette2)



nytt.datasett <- full_join(la2, rspette2)
```

Figure 5.2 - Combining datasets from landings (la) and survey (rspette)

```
omr <- nytt.dataset %>%
  filter(area %in% c("0"))

cor.test(x=omr$cpuew, y=omr$sumv, method = c("pearson", "kendall", "spearman"), use = "complete.obs")
```

Figure 5.3- Correlation test for each main area

Modelling – forward selection process

```
spbox.df <- spbox.df1 %>%
  filter(area%in% c("5")) %>%
  filter(strat2 %in% c("Coastal"))


mod.0 <- lm(log(cpuew)~1, data=spbox.df)

mod.1 <- lm(log(cpuew)~year.x, data=spbox.df)

mod.2 <- lm(log(cpuew)~fish_depth, data=spbox.df)

anova(mod.0,mod.1,test="F")

mod.3 <- glm(log(cpuew)~year.x + fish_depth, data=spbox.df)

mod.4 <- lm(log(cpuew)~year.x + fish_depth + year.x:fish_depth, data=spbox.df)

anova(mod.4,mod.5,test="F")
```