Can catch data from small meshed gears in shallow waters be used to estimate recruitment indices of Norwegian coastal cod, Northeast Arctic saithe and pollack along the Norwegian coast?

by

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SUMMARY

Shallow waters (<30 meters) are important nursery areas for coastal cod, saithe and pollack, before they recruit to their respective fisheries at an age around 3 years old. Still, no study provides information on fish abundance in these nearshore habitats. This study has analysed a time series of catch data from fyke- and trammel nets in the sublittoral between 62ºN-68ºN from 2013-2018. The aims were to evaluate the gear's ability to catch recruits (0-2 years old) and to examine if these data could be used to establish recruitment indices for Norwegian coastal cod (*Gadus morhua* L.), Northeast Arctic saithe (*Pollachius virens* L.) and pollack (*Pollachius pollachius* L.). Results showed that 68% of the cod catch was under 3 years old, most of them caught by fyke net. The fyke nets were also able to catch recruits of saithe (68%) and pollack (35%), but these catches were irregular, with a small number of stations contributing to most of the catch. A generalized linear mixed effect model was used to estimate recruitment indices for cod, while this modelling approach failed to provide indices for saithe and pollack, due to the patchy distribution in the data sets. Overall, the indices of cod showed a higher level of recruitment further north, and there was a great annual variation, particularly for the 0-group. To evaluate the indices, mean CPUE of the shallow-water survey were compared to the index of the same year classes as 3-year-olds in IMR's acoustic coastal survey, operating in the same areas at deeper waters. There was a positive relationship between the mean CPUE of 2-year-old cod and the acoustic index of 3-year-old cod in the northern subarea (65ºN-68ºN). In the southern subarea (62ºN-65ºN), there was not a sufficient number of year classes to provide a comparison of the two surveys. Comparison of the year class abundance of saithe between the two surveys suggests that fyke nets might be an appropriate gear for catching saithe recruits, regardless of the irregular catches. There was a positive relationship between the mean CPUE of 2-year-old saithe and the acoustic index of 3-year old saithe in the northern subarea. In that case, it is recommended to assume a negative binomial distribution or using zero-inflated models. There were no time series of pollack in the study area that could be used for comparison recruitment abundance in this thesis. The time series from the shallow-water survey is still quite short, as there are three years of survey in the northern subarea (2013, 2016 and 2018) and two years in the southern subarea (2015 and 2017). Hence, the present study gives a preliminary assessment of the survey. It is recommended that the survey is continued with cod and saithe as target species, preferably with both subareas each year. As the trammel nets failed to provide sufficient catches of recruits, these could be excluded from the survey to save time and resources.

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1 INTRODUCTION

1.1 Background

The Institute of Marine Research (IMR) has been conducting annual surveys along the Norwegian coast since 1985. Initially, the main focus was on Northeast Arctic saithe, and in 1995 Norwegian coastal cod was included (Mehl et al. 2017). A challenge has been that neither this survey, nor data from the fisheries, provides information on fish abundance in shallow waters (the sublittoral; < 30 m depth). The shallows are important nursery areas for juveniles (recruits) of fish species, such as cod, saithe and pollack (Bakketeig, Hauge & Kvamme 2017). With an aim of quantifying the recruitment of these commercial species, an annual shallow-water survey was established in 2013 from 62°N to 68°N along the coast of Norway, and is still conducted today. The experimental fishing has been done by using small meshed trammel- and fyke nets, fishing from ~5-30 m depth. Choice of fishing method is based on experiences from IMR´s project KILO (Kunnskapsinnhenting Barentshavet – Lofoten - Vesterålen) in the Lofoten-area in 2011 and 2012 (Sundby et al. 2013). This thesis will analyse the time series of data collected from 62°N to 68°N. The aim is to evaluate whether this type of data can be used to establish recruitment indices for three stocks of gadoids: Norwegian coastal cod (*Gadus morhua* L.), Northeast Arctic saithe (*Pollachius virens* L.) and pollack (*Pollachius pollachius* L.).

1.2 Recruitment and its importance in stock management

Together with growth and mortality, the rate of recruitment is an important parameter that govern the biomass of fish populations (Jennings, Kaiser & Reynolds 2013). In fisheries science, recruitment is defined as “the number of individuals that reach a specified stage of the life cycle” (Jennings, Kaiser & Reynolds 2013). Here, recruitment is dealt with as the time when the individuals joins the commercial fishery, which is defined as age 3 years for Northeast Arctic cod and saithe by the International Council for Exploration of the Sea (ICES 2018b). ICES has not defined a recruitment-age for pollack to the fisheries, but is here assumed to be the same as for cod and saithe. At age 3 years, most cod and saithe (and pollack) have reached a size or migrated to depths or areas where they are susceptible to the gears utilized by their fisheries, hence this thesis aims at finding abundance indices for fish 0-2 years old.

In fisheries science, recruitment is a central theme. The idea originates from early studies by Hjort (1914) on Atlantic herring (*Clupea harengus* L.) and Atlantic cod, and postulate that by knowing the strength of recruitment, the future stock biomass can be predicted (Jennings, Kaiser & Reynolds 2013). Strong year classes will contribute to rich fisheries, some years later (Hjort 1914). This hypothesis has resulted in numerous studies on early life history of fish species. Yet, there have been no clear answers to what affects the fluctuations in year class strength (Jennings, Kaiser & Reynolds 2013). Considerable efforts have been put into estimating stock-recruitment models, aiming at finding the relationship between the spawning stock size and number of recruits. Hence, future stock sizes could be predicted by looking at the current stock. Historically, stock-recruitment models have been frequently used as a tool in the assessment of numerous fish stocks (Subbey et al. 2014). Still, there are great uncertainties linked to these models (Jennings, Kaiser & Reynolds 2013). Furthermore, early life mortality will affect the rate of recruitment, and considerable efforts have been put into estimating mortality of young fish. As the mortality of fish larvae is both great and highly varying, it is hard to predict. Most of the mortality (over 99%) in marine fishes occurs in the early life history, before settlement to the bottom (Jennings, Kaiser & Reynolds 2013). Though factors, such as food availability, will have an effect on the survival, predation is the main source of mortality on young fish (Hunter 1984).

The main objective of fisheries science is to know the stock biomass of fished species and predicting future biomass, in order to maintain a sustainable stock size (Jennings, Kaiser & Reynolds 2013). Even though the field of recruitment is still not fully understood, together with traditional surveys on the adult stocks and data from the fisheries, recruitment indices can contribute to a more comprehensive understanding of the stocks' abundance. Earlier attempts to estimate recruitment of e.g saithe in Norwegian waters have primarily focused on abundance of pelagic larvae before settling in inshore areas (Nedreaas 1994). In this study, fyke- and trammel nets are used to catch cod, saithe and pollack *after* they have settled at the sea bottom, before they are recruited to the fisheries, at 3 years of age.

1.3 Distribution, life history and ecological- and commercial importance of the studied species

1.3.1 Norwegian coastal cod (Gadus morhua)

In Norwegian waters, two main types of cod appear – the Northeast Arctic cod (NEAC) and the Norwegian coastal cod (NCC) (Bergstad, Jørgensen & Dragesund 1987). The two are separated by differences in growth zones in the otoliths, according to Rollefsen (1933). Furthermore, adult NEAC carries out long migrations from the Barents Sea to spawning areas along the Norwegian coast, while NCC lives more stationary in fjords and coastal areas of Norway (Bergstad, Jørgensen & Dragesund 1987). Traditionally, NCC is treated as two separate management units, split at 62º N. This thesis deals only with NCC north of this boundary. However, genetic differences have been revealed along the entire coast of Norway, suggesting several subpopulations of NCC (Dahle et al. 2018). Thus, there are local differences in time of maturation, growth, mortality, spawning areas, migration patterns etc. between local NCC along the coast (Yaragina, Aglen & Sokolov 2011). The abundance of NCC increases from south to north (Berg & Albert 2003).

Studies indicate that the NCC matures earlier than the NEAC, at about 4-6 years (Bakketeig, Hauge & Kvamme 2017). NCC spawns in fjords, separated from the NEAC, yet also in the same areas as NEAC at the outer nearshore banks. Lofoten, the Møre banks and shallow areas at Helgelandskysten are particularly important spawning areas, exploited by both NCC and NEAC (Bergstad, Jørgensen & Dragesund 1987; Jakobsen 1987). The spawning occurs during winter, from late January to ~mid April. Eggs drift in the open waters in the fjords and coastal areas, before the NCC fry settles in nursery areas at shallow waters (<20 m) during the following summer (Bastrikin et al. 2014; Olsen et al. 2010). 0-group of NCC have been found to prefer flat and soft-bottom habitats with some vegetation in the shore line, where it is somewhat aggregated (Sundby et al. 2013). Moreover, 0- and 1-year old cod have previously found to prefer habitats associated with macro algae, while 2-year olds and older individuals tend to be less dependent on the shelter of the algae (Keats, Steele & South 1987).

At around the age of 2 years, NCC start descending to deeper waters (Bakketeig, Hauge & Kvamme 2017). Cod is mainly viewed as a demersal fish, but can rise to more open waters to feed and spawn (Stensholt et al. 2002). Hence, adult cod can be found from the shoreline, and down to ~500 m depth (Bakketeig, Hauge & Kvamme 2017). Cod is an important species in the food web, eating a wide range of species and size groups; from planktonic crustacea, as juveniles, to fish and larger crustaceans etc., as adults (Link & Garrison 2002; Swalethorp et al. 2014).

According to the Arctic Fisheries Working Group (ICES 2018b), NCC is recruited to the commercial fishery by the age of 3. The cod fishery has been one of the most important Norwegian fisheries, with a history of both growth and depletion (Olsen et al. 2010). Today, NCC is mostly caught as bycatch in the NEAC fishery, mainly in the Lofoten area during the winter-months. In addition, recreational- and tourist fishing in near-city locations accounts for about 30 % of the total catch of NCC (Bakketeig, Hauge & Kvamme 2017). Historically, the NCC stock showed signs of decreasing abundance from 1997-2003, and has remained rather low (ICES 2018a).

For simplicity, NCC is, from here on, is referred to as “cod.”

1.3.2 Northeast Arctic Saithe (*Pollachius virens*)

Saithe is an endemic species of the North Atlantic, and is divided into 7 managing stocks, between USA/Canada, Scotland, Ireland, Iceland, the Faroe Islands, the North Sea and the Norwegian Sea north of 62º N. Still, there is an excessive migration and exchange between the stocks and the true structure is uncertain (Olsen et al. 2010). However, genetic studies have revealed 4 separate units; Barents Sea, Central Northeast Atlantic, Rockall and Canada (Saha et al. 2015). This thesis deals only with Northeast Arctic saithe (ICES 2018c), from here on referred to as “saithe.”

Spawning areas of saithe north of 62º N are somewhat similar to those of cod, with the most important areas being the shallow banks off Møre, Haltenbanken off Helgelandskysten and the Lofoten area (Nedreaas 1986). Spawning occurs during winter, from January to March, and the eggs drift with the northward currents (Bakketeig, Hauge & Kvamme 2017). 0-group of saithe migrate inshore, and settle in the shore line along the coast of Norway (Nedreaas 1986). Juvenile saithe feed on planktonic crustaceans (Bakketeig, Hauge & Kvamme 2017), living in schools at depths less than 60 meters (Olsen et al. 2010).

At the age of ~3 years, the saithe migrates to feeding grounds in the coastal areas off Norway. There, they prey on copepods, euphausids and different fish species, such as herring, sprat, small cod and haddock, Norway pout and blue whiting (Mehl 2005), occupying waters from 0-300 meters, both pelagic and demersal (Stensholt et al. 2002). In addition, adult saithe carries out long spawning- and feeding migrations, following Norwegian spring spawning herring (Runde 2005). Hence, adult saithe is an important predator in Norwegian waters.

The saithe is recruited to the commercial fishery at the age of 3 years (ICES 2018b). As with the cod fishery, the Norwegian saithe fishery has a history of both growth and decline. Today, the state of the stock has been evaluated to be viable (ICES 2018b). Still, there is a great uncertainty to the stock assessment, as there are no good measurements of the recruitment to the fishery, because juvenile saithe occupies very shallow areas inshore. In addition, schooling behaviour and comprehensive migrations limits the research surveys ability to obtain good estimates of adult saithe abundance (Mehl, Zuykova & Drevetnyak 2011). Several attempts has been made to obtain reliable recruitment estimates, by running surveys *before* the 0-group migrates inshore (Mehl 2007; Mehl et al. 1989; Nedreaas 1986). Moreover, Aglen (1994) attempted to estimate juvenile abundance in shallow waters by acoustic small-scale surveys. Still, these attempts were all terminated due to low correlation between the recruitment estimates and the abundance of recruited saithe, some years later (Bergstad, Jørgensen & Dragesund 1987).

1.3.3 Pollack (*Pollachius pollachius*)

Because of low commercial interest, few studies have been made on pollack. Hence, knowledge on stock size, biology, population structure etc. is very limited and the studies that has been conducted is mostly as a by-study from studies on commercial valuable species (Heino et al. 2012; Jakobsen 1985).

Pollack is found from the west coast of Portugal in the south, to the British Isles in the east and to the northernmost part of Norway (Bakketeig, Hauge & Kvamme 2017), although there seems to be little genetic variation between pollack distributed in the North Sea and the coast of France (Charrier et al. 2006). The data collected for this thesis is limited to 62ºN to 68ºN.

In Norway, the pollack spawns during spring and juveniles are found pelagic inshore, until they reach the age of 3. Adult pollack live benthopelagic at depths from 40-100 m (Cohen et al. 1990). They prey mostly on pelagic fish and mesopelagic nekton, such as Mueller's pearlside, shrimps and krill (Bakketeig, Hauge & Kvamme 2017).

As mentioned above, there is low commercial interest of pollack, and it is mostly caught as bycatch in other fisheries north of 62ºN. Therefore, the quotas are based on the total catch of pollack, 3 years at a time. These have shown a decrease in stock size since 2007, although there has been some increase the last years (Bakketeig, Hauge & Kvamme 2017). On the other hand, pollack is a popular species in the recreational fishery of Norway, particularly in the northern part (Volstad et al. 2011).

As very little is known about pollack in Norwegian waters, a successful estimation of the recruitment of pollack could be a valuable contribution to the total stock estimation.

1.4 Objectives

By analysing data obtained through the shallow-water survey using fyke nets and trammel nets in the sublittoral, there are two main objectives of this thesis:

1) Evaluate the use of fyke nets and trammel nets in shallow areas, as a method for catching recruits (0-2 years).
2) Describing fish communities in shallow waters in Norway between 62ºN and 68ºN by suggesting recruitment indices for Norwegian coastal cod (*Gadus morhua*), Northeast Arctic saithe (*Pollachius virens*) and pollack (*Pollachius pollachius*).

2 MATERIALS AND METHODS

The data analysed in this thesis have been collected during the annual shallow-water survey conducted by the Institute of Marine Research (Aglen, A., 2018, pers.comm.). To the extent possible, the survey has been standardized with respect to locations, gear set up, fishing time, time of year etc., between the years in order to maintain the quality of the time series. However, various factors, such as weather and time, cause some variation. Based on earlier experiences, the survey has been conducted in August/September each year, as this has proven to give better catches and easier working conditions, compared to that of the winter, due to more daylight and a calmer weather.

2.1 Study Area

The data have been collected along the Norwegian coast, between 62˚N and 68˚N (Figure 2.1.1 and 2.1.2). Consequently, the study area is large and stretches through a long gradient of varying climate and marine habitats, strongly affected by the seasonality of the north. Sea temperatures varies from ~5 ℃ in winter to ~14 ℃ in summer, when the cruise is conducted (Albretsen & Asplin 2017).

The seabed in shallow waters along the coast of Norway includes mostly rocky bottom with kelp forest and other algae, as well as sandy or muddy bottom with different kinds of vegetation (Svenning & Jonsson 2005).

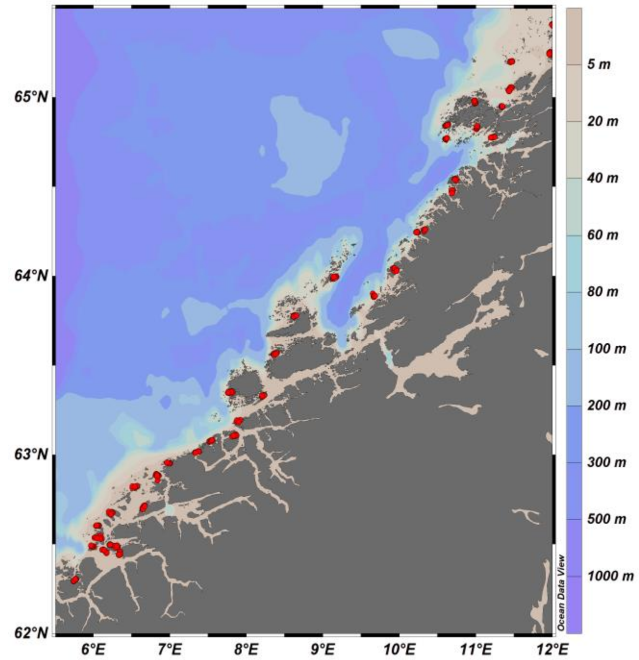

Figure 2.1.1 – Locations in the southernmost area (Stadt – Vikna), covered in 2015 and 2017.

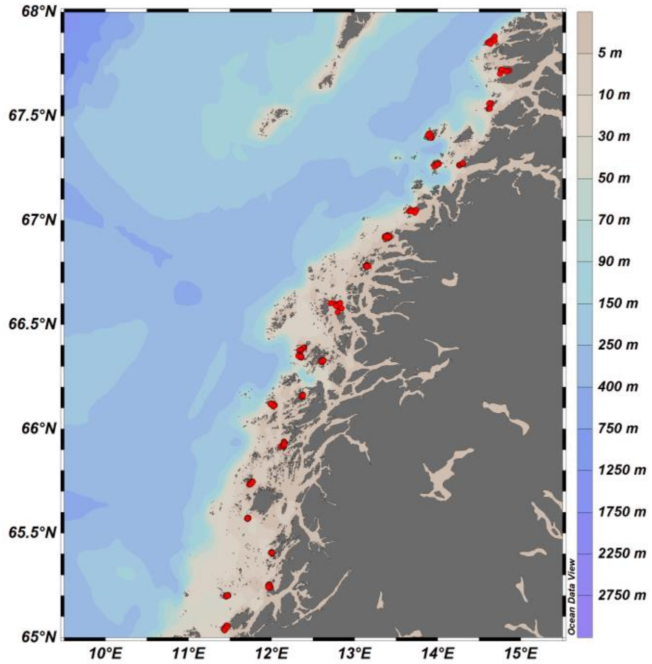

Figure 2.1.2 – Locations in the northernmost area (Vikna – Steigen), covered in 2013, 2016 and 2018.

2.2 Survey design

The study area was divided into two subareas; "South" from Stadt (62˚N) to Vikna (65˚N) and "North" from Vikna to Steigen (68˚N). Hence, the survey has been conducted every other year for the two subareas, with the exception of 2014, when the survey did not take place (Table 2.2.1). Within each subarea, locations were distributed to cover shallow areas (<30 m depth), the potential nursery areas of cod, saithe and pollack (Figure 2.1.1 and 2.1.2). Within each location, six fyke net settings and 2 trammel net settings were put out (Figure 2.2.1). The fyke nets were placed to cover the shallowest areas, typically 5-9 meters depth, while the trammel nets covered the deeper areas down to 30 meters depth. To the extent possible, the same positions have been selected every year, although factors, such as weather and time, cause some variation both in numbers and positions of trammel- and fyke net settings (Table 2.2.1).

Table 2.2.1 – Overview of subarea and number of stations each year.

Year	Location	Subarea	No. of fishing days	No. of trammel settings (36 and 45 mm)	No. of fyke settings
2013	Vikna-Steigen (65˚N -68˚N)	North	12	48	72
2015	Stadt-Vikna (62˚N -65˚N)	South	23	92	138
2016	Vikna-Steigen (65˚N -68˚N)	North	21	84	126
2017	Stadt-Vikna (62˚N -65˚N)	South	21	80	132
2018	Vikna-Steigen (65˚N -68˚N)	North	20	72	120

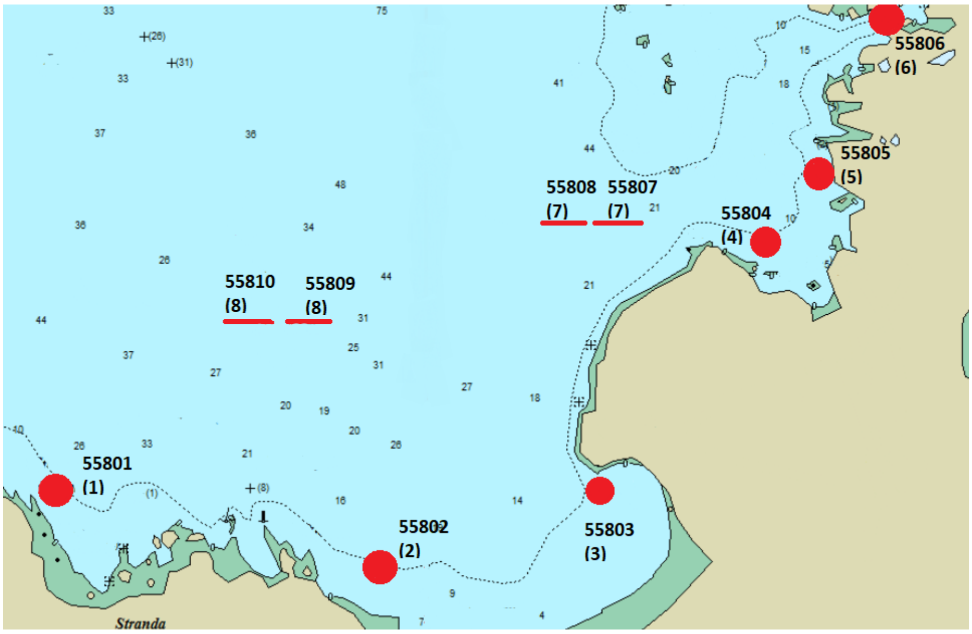

Figure 2.2.1 – Example of one location, containing 6 fyke net settings (red dots) and 2 trammel net settings (red lines). Station numbers in parenthesis and serial numbers above. Throughout this thesis, "station" refers to separate serial numbers. Here from Bøvika in Steigen.

2.3 Sampling gear

The research vessel "Fangst" (50 ft), with an additional small motor boat (17 ft) equipped with a Garmin echosounder and chart plotter, has been used throughout the survey. The acoustic data were solely used for recording bottom depth. The trammel nets were put out and hauled from R/V "Fangst", while the fyke nets were handled by hand from the small boat. This allowed an easier access to the shallowest areas.

A trammel net has an upper headrope with floats and a footrope with attached weights, and triple netting walls. The two outermost nets are large meshed, while the middle one has smaller meshes and is more loosely attached. Fish is caught by penetrating the outer net, and pursing and tangling in the inner slacked net (Figure 2.3.2; (Salvanes et al. 2018)). The trammel nets used for collecting data for this thesis where all 27 x 2 m. Each net setting consisted of two nets with 36 mm mesh size (bar length), and two nets with 45 mm mesh size (bar length), in total 4 nets per setting. The two mesh sizes were separated with a 10 m rope (Figure 2.3.1). In order to avoid damage by crabs on both nets and caught fish, the trammel nets were raised roughly 35 cm above the bottom, by extra attached ropes between the net and footrope. Soak time for trammel nets was 12 hours, put out on the evening and hauled the morning after.

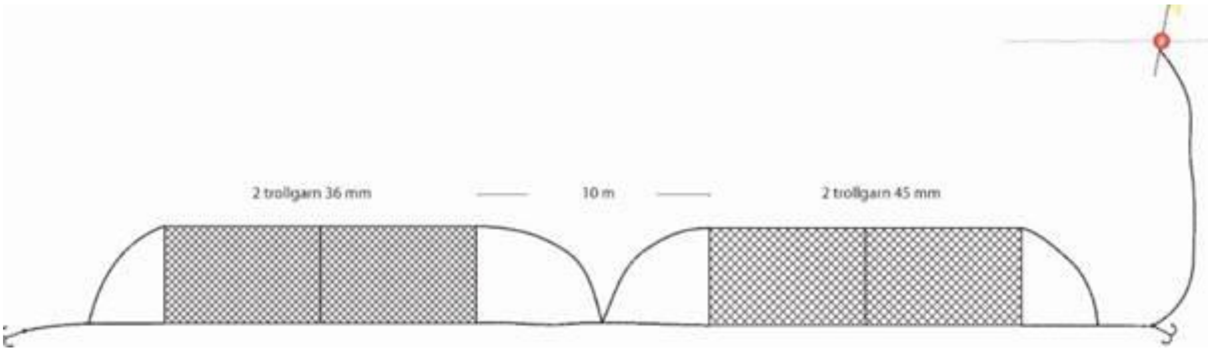

Figure 2.3.1 – One trammel net setting, consisting of two 45 mm meshed- and two 36 mm meshed nets (bar lengths).

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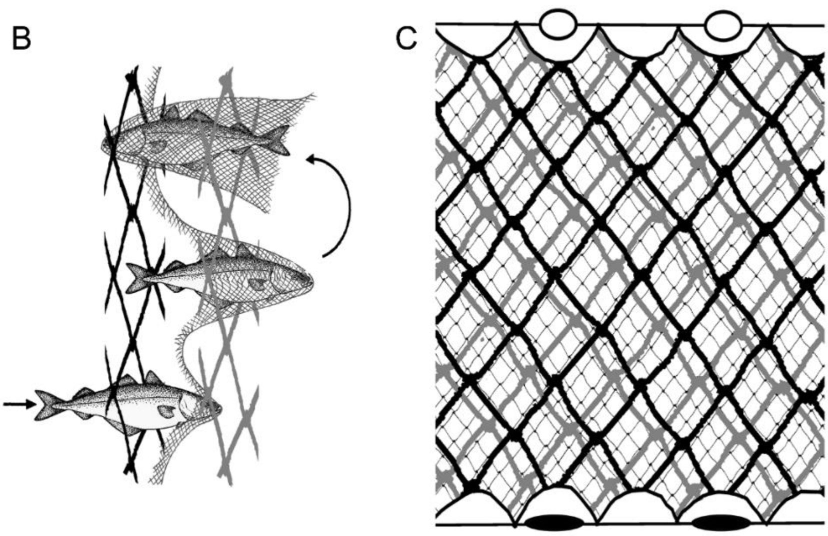

Figure 2.3.2 – (B) How a fish is caught in a trammel net and (C) the structure of the netting walls (Salvanes et al. 2018).

The fyke nets used in this study were 60 cm tall and consisted of a lead net in the middle and cylindrical net bag (cod end) on each side with funnels. The net colour was green for the whole fyke. When fish meets the lead net, it is guided towards one of the cod ends, where it easily can enter, but cannot escape because of the funnel-structure (Salvanes et al. 2018). The lead net had a stretched mesh size of 31 mm, while the netting of the cod end was 15 mm stretched. Weights attached in each end of the setting kept the fyke nets at the bottom. Each fyke net setting consisted of two doubled fyke nets, this gave in total 4 cod ends for one setting (Figure 2.3.3; (van der Meeren 2017)). Typical soak time was 22 hours for fyke nets, put out on the evening and hauled the following afternoon.

Figure 2.3.3 – One fyke net setting, consisting of two doubled fyke nets, where each has a 6 m lead net in the middle and two cod ends. In total 4 cod ends (van der Meeren 2017).

2.4 Data description

Once the gear was hauled, the catch was measured in accordance with "Håndbok for prøvetaking av fisk og krepsdyr" (Mjanger et al. 2010). The catch was treated equally for trammel- and fyke nets. All individuals of every species were counted and all fish were length measured [cm], from the snout to the end of the tail fin. With some exceptions, additional measurements were conducted for cod and pollack. This includes otolith sampling, sex and maturity stage.

These measurements, together with information on the station (position, soak time and depth), were then registered in IMR's software Sea2Data (Huse et al. 2012). Here, each net setting was assigned a running station number. Furthermore, a running serial number was assigned to each fyke net setting and each mesh size of the trammel net setting. Hence, each location had 8 station numbers and 10 serial numbers (Figure 2.2.1). In the preceding data analysis, the serial numbers have been the separator between observations, allowing separation between the two mesh sizes of trammel nets. Throughout this thesis, “station” refers to separate serial numbers, being either a fyke net station, a 36 mm (bar length) or a 45 mm (bar length) meshed trammel net station.

2.5 Data analysis

All data analyses have been conducted in RStudio version 3.5.1 (Rstudio 2016). The files were exported from Sea2Data and imported to RStudio. Here, the station file and individual file was merged to one data frame, by creating a unique variable for each observation from year and serial number. Next, cod, saithe and pollack where separated in three data frames.

2.5.1 Age determination

Due to lack of age readings from otoliths, to various degrees, different methods have been used to age the remaining individuals.

For cod, an age-length-key was used, aging individuals based on the age-length relationship of the aged individuals in the data file. This was carried out on data from each year separately, in accordance with the approach described in “Introductory Fisheries Analysis with R” (Ogle 2016). First, the data frame was separated to “aged” and “unaged” individuals. From the “aged” frame, the frequency of individuals in each length-age combination was found. Next, the age-length-key was constructed by calculating the conditional proportion the jth age group constituted in length i ($p_{i|j}$). Lastly, the unaged individuals where assigned an age by equation 2.1, where N_{ij} is the number of individuals at age j and length i and N_i is the number of unaged individuals.

$$N_{ij} = N_i p_{j|i} \tag{2.1}$$

The same approach was used for aging pollack, though available age readings from the sampling areas were not sufficient for using the established R-packages (Ogle 2016). The best available age-length-key for pollack originates from an earlier study in a Western Norwegian fjord, Masfjorden (Salvanes 1995), and this was used manually to calculate age compositions of pollack in this study area in Microsoft Excel. This was done for all years, both subareas, pooled. The age-length relationship between the Masfjord-data and this study’s data were compared, and an assumption was made that the two were equivalent. As the lacking age readings of pollack were mostly young individuals, the Masfjord-data was utilized for pollack under 35 cm. Above this length, data from the shallow-water survey were sufficient as a basis for age-length relationships.

For saithe, no otolith sampling was conducted in any of the years and an age-length-key could not be used for age determination. Instead, individuals were grouped “small”, “medium” and “large”, assuming these to represent 0-group and 1-year olds, 2-year olds and 3-year olds and older respectively (Table 2.5.1). This was done for all years, both subareas, pooled. Allocation of fish sizes among these groups is based on age-length-keys from the acoustic survey (Mehl et al. 2017; Mehl et al. 2016; Mehl et al. 2015; Mehl et al. 2014; Mehl et al. 2013), assuming that these age-length relationships are similar to those of the shallow-water survey.

Table 2.5.1- Grouping of saithe based on length. Grouping supported by age-length-keys from IMR’s acoustic coastal survey (Mehl et al. 2017; Mehl et al. 2016; Mehl et al. 2015; Mehl et al. 2014; Mehl et al. 2013).

Group	Assumed age [years]	Length interval [cm]
Small	0 + 1	< 20
Medium	2	20-29
Large	3 +	> 30

2.5.2 Modelling the probability of catch by species and gear

A binary variable was added to the data to describe presence of a species. Each serial number was assigned either “1”, meaning said species was present in the catch, or “0”, meaning the species was not present. A general linear mixed effect model (Bates et al. 2015) was applied to the dichotomized data to evaluate the probability of catching the three species by gear, as these models allows 0-values in the data. The variables “gear” and “year” were used as fixed factors, while “location” was assumed to be a random factor. No interaction term between the variables was applied and the error distribution was assumed to be binomial (Eq. 2.2). The model was tested against a null model (m0) (Eq 2.3), without “gear”, using a likelihood ratio test and χ^2 statistic (Appendix III b).

m1 $\leftarrow$ *glmer (Presence ~ gear + year + (1|location), family=binomial, Dataframe)* (2.2)

m0 $\leftarrow$ *glmer (Presence ~ + year + (1|location), family=binomial, Dataframe)* (2.3)

These models were applied to each age group for all three species. The mean fitted values from the model were calculated and expressed as the relative probability of catch for each gear; a value between 0 and 1 (Appendix III c).

2.5.3 Catch per unit effort calculations

As a measure of abundance of each age group, catch per unit effort (CPUE) was calculated. One unit of effort was assumed to be the fishing period of each gear put out, being ~12 hours for trammel nets and ~22 hours for fyke nets. Here, the variables "year" and "serial number" were used for identifying each single gear. Thus, aggregating the data frame by each gear resulted in 10 estimates of CPUE per location – 6 fyke nets and 4 trammel nets. Furthermore, the mean CPUE for each year and age group was calculated for all three species.

2.5.4 Modelling the effect of gear on CPUE

Another generalized linear mixed effect model (Bates et al. 2015) was applied to estimate the effect of different gears on the estimated CPUE for each age group. This model was only applied to cod, as the data on saithe and pollack were deemed too patchy to allow such analysis. "Gear" and "year" were used as fixed factors, while the effect of "location" was assumed to be a random factor. Poisson distribution was assumed and no interaction terms between variables were used (Eq. 2.4). The model was tested against a null model (m0) (Eq 2.5), without "gear", using a likelihood ratio test and χ^2 statistic (Appendix III b).

m1 $\leftarrow$ *glmer (CPUE ~ gear + year + (1|location), family=poisson, Dataframe)* (2.4)

m0 $\leftarrow$ *glmer (CPUE ~ year + (1|location), family=poisson, Dataframe)* (2.5)

A summary of the best fitted model was printed to evaluate the effect of gear on the CPUE (Appendix III b).

2.5.5 Modelling recruitment indices

For cod, the summary output from the generalized linear mixed effect model (Eq. 2.4) was used to suggest indices of recruitment for each year. The estimates were transformed by exponentiation. If an age group were solely caught by one gear, results from the null model (Eq. 2.5) were used as indices.

2.5.6 Comparing results with acoustic indices

In order to evaluate the CPUE estimates and indices from this study, a comparison of cod and saithe results with indices from the acoustic survey (Mehl et al. 2016; Mehl et al. 2015; Mehl et al. 2013; Mehl et al. 2014; Mehl et al. 2017) was made. This was done by identifying year classes, caught as 0-2-year olds by fyke nets in the shallow-water survey, that were detectable as 3-year olds in the acoustic survey, assuming they recruit to the acoustic survey at that age. Next, these year classes were plotted on a logarithmic scale with the mean CPUE from the shallow-water survey on the x-axis, and the acoustic indices of the same year class as 3-year olds on the y-axis. A comparison was also made between 3-year olds caught in the shallow-water survey and 4-year olds in the acoustic survey. Because 2013 was the reference year when conducting the model, indices of this year was set to “0” (exp(0) = 1). Plotting this with the acoustic indices would conceal differences between age groups. Therefore, the mean CPUE is used, as this is the fundamental data that is modelled (Eq. 2.4). If the CPUE estimates from this study are reliable, they should increase as the indices from the acoustic survey increases. There are no time series for pollack in this area that could be used in comparison with the recruitment indices from this study.

3 RESULTS

3.1 Length frequency of catch by gear

3.1.1 Cod

Out of the three gears, the fyke nets caught the highest number of cod in both the southern and the northern subareas. In addition, the fyke nets had the highest catches of small length groups of the three gears, giving catches from both the 5 cm (<10 cm) and 10 cm (10-15 cm) group. The highest catches of fyke nets were found in the 20 cm (20-25 cm) length group, both in the northern and southern area. The trammel nets did not catch cod smaller than 15 cm. The 36 mm trammel net caught the highest number of cod at about 30-35 cm, while the 45 mm trammel net caught the highest number at approximately 40-45 cm. The curves were somewhat skewed to the right for both trammel nets (Figure 3.1.1 and 3.1.2).

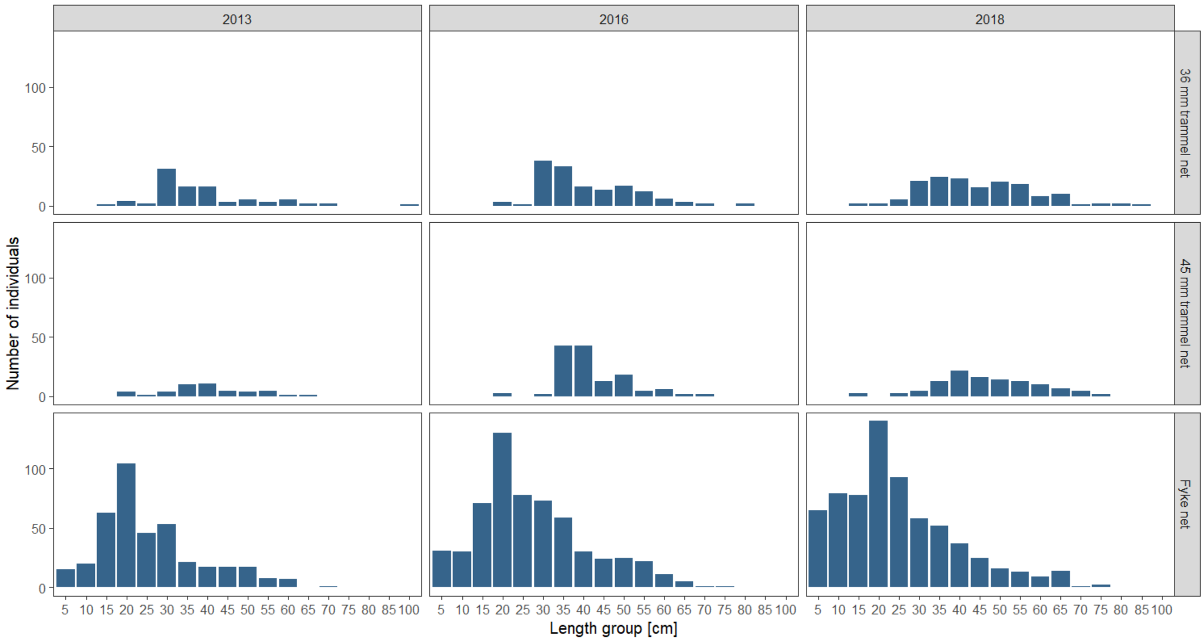

Figure 3.1.1 – COD_North: Total number of cod in each 5 cm length group caught with respective gears, for separate years in the northern subarea. X-axis showing 5 cm length groups, starting at 5 cm. Note that northern subarea was not sampled in 2014, 2015 or 2017.

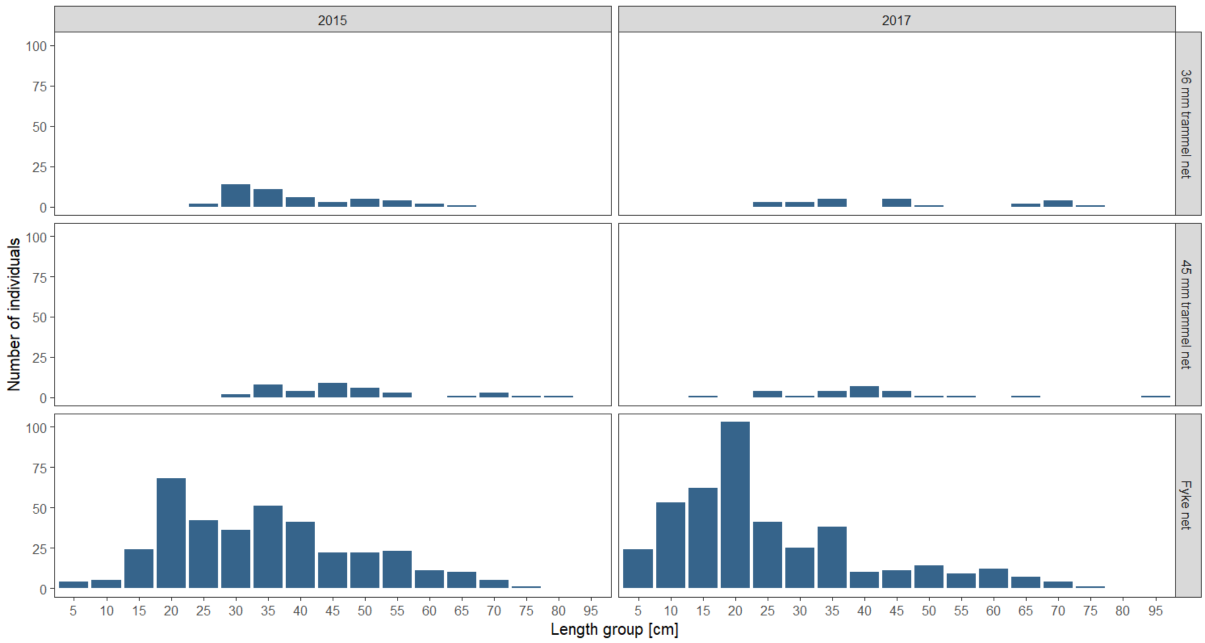

Figure 3.1.2 – COD_South: Total number of cod in each 5 cm length group caught with respective gears, for separate years in the southern subarea. X-axis showing 5 cm length groups, starting at 5 cm. Note that southern subarea was not sampled in 2016.

3.1.2 Saithe

The fyke nets also had the highest total catch in numbers of saithe compared to the two other gears. Most of the fyke net catches were in the 10 cm (10-15 cm) length group, for each year in both subareas. In contrast, both the 45 mm and 36 mm meshed trammel nets caught a few or 0 individuals ≤ 20 cm. The 36 mm trammel net caught most saithe from the 30 cm length group in the northern subarea. Catches in the south showed that the 36 mm trammel nets caught most individuals in the 35 cm (35-40 cm) length group in 2015, while 2017 catches did not reveal a clear optimal length. Overall, catches from the 45 mm trammel net were quite low, and did not show a clear pattern in optimal catch length (Figure 3.1.3 and 3.1.4).

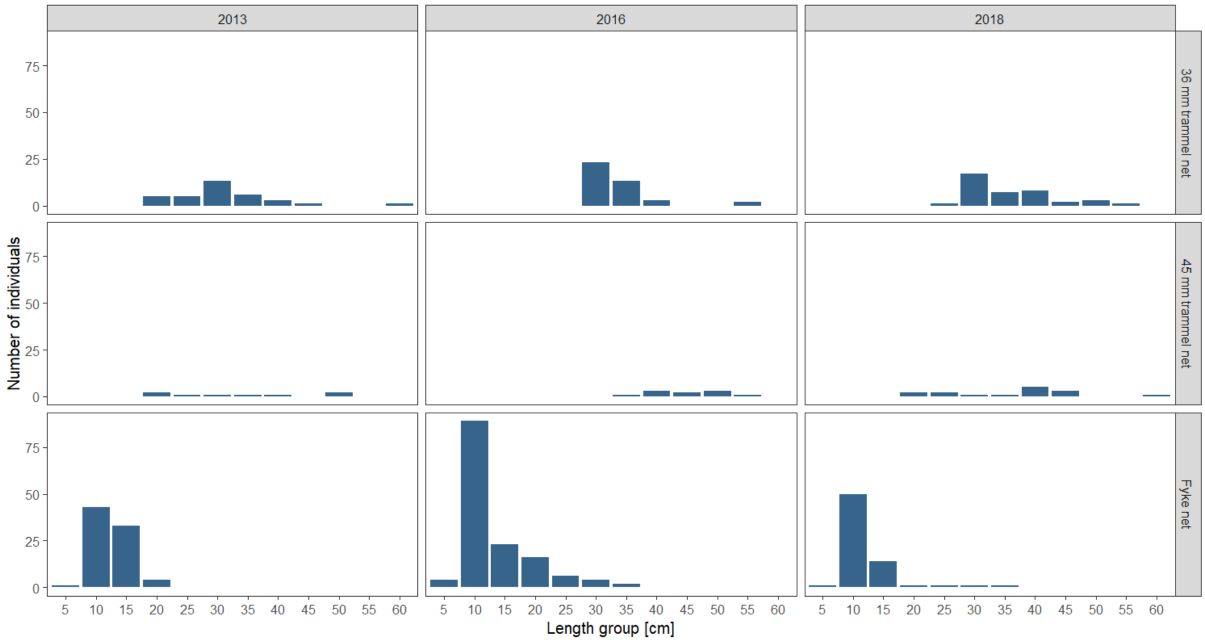

Figure 3.1.3 – SAIHTE_North: Total number of saithe in each 5 cm length group caught with respective gears, for separate years in the northern subarea. X-axis showing 5 cm length groups, starting at 5 cm. Note that the northern subarea was not sampled in 2014, 2015 or 2017.

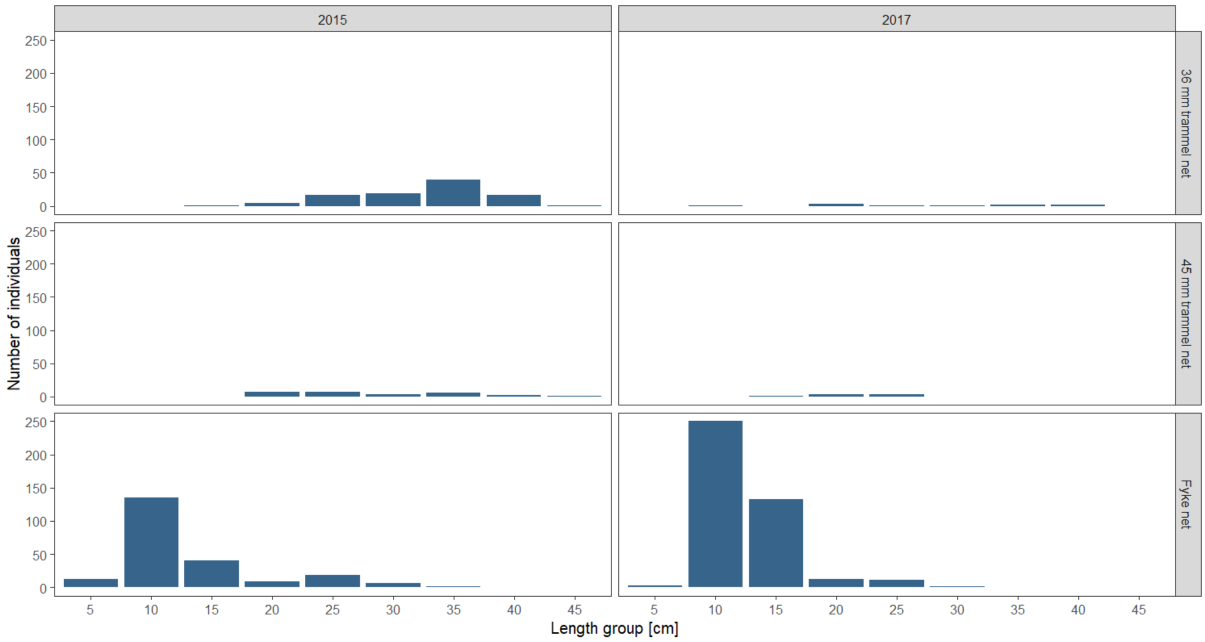

Figure 3.1.4 – SAITHE_South: Total number of saithe in each 5 cm length group caught with respective gears, for separate years in the southern subarea. X-axis showing 5 cm length groups, starting at 5 cm. Note that the southern subarea was not sampled in 2016.

3.1.3 Pollack

The 36 mm meshed trammel nets caught the highest numbers of pollack, each year in both subareas. The fyke nets caught the most of the smallest individuals out of the three gears, with most of the catch being under 25 cm. For both mesh sizes of trammel nets, the curves were skewed to the right, with a peak at around 40-45 cm for the 36 mm net and around 45-50 cm for the 45 mm net (Figure 3.1.5 and Figure 3.1.6).

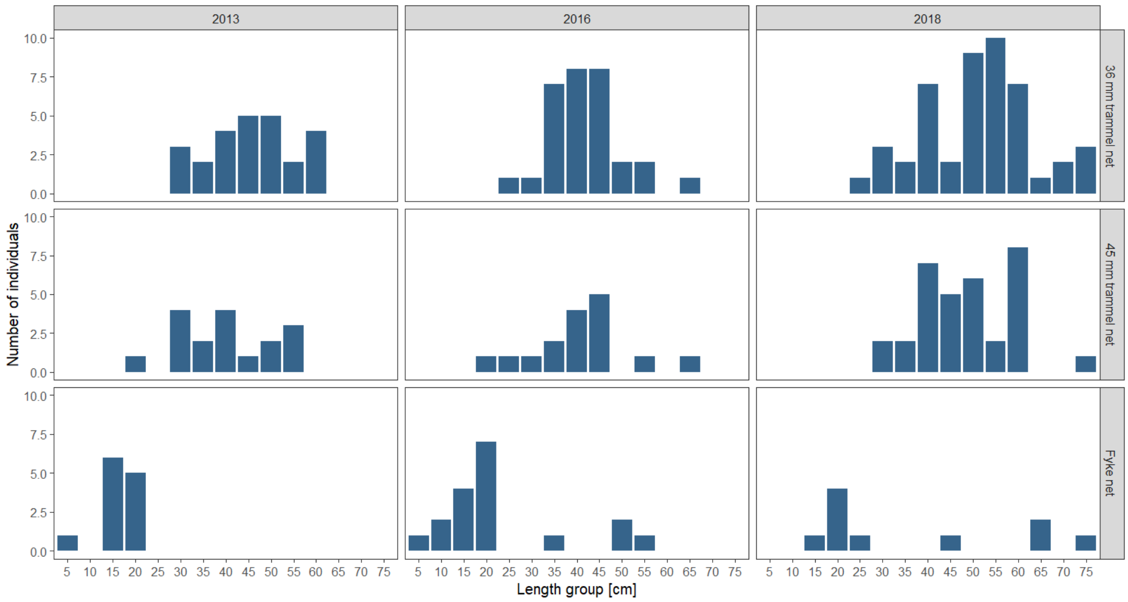

Figure 3.1.5 – POLLACK_ North: Total number of pollack in each 5 cm length group caught with respective gears, for separate years in the northern subarea. X-axis showing 5 cm length groups, starting at 5 cm. Note that the northern subarea was not sampled in 2014, 2015 or 2017.

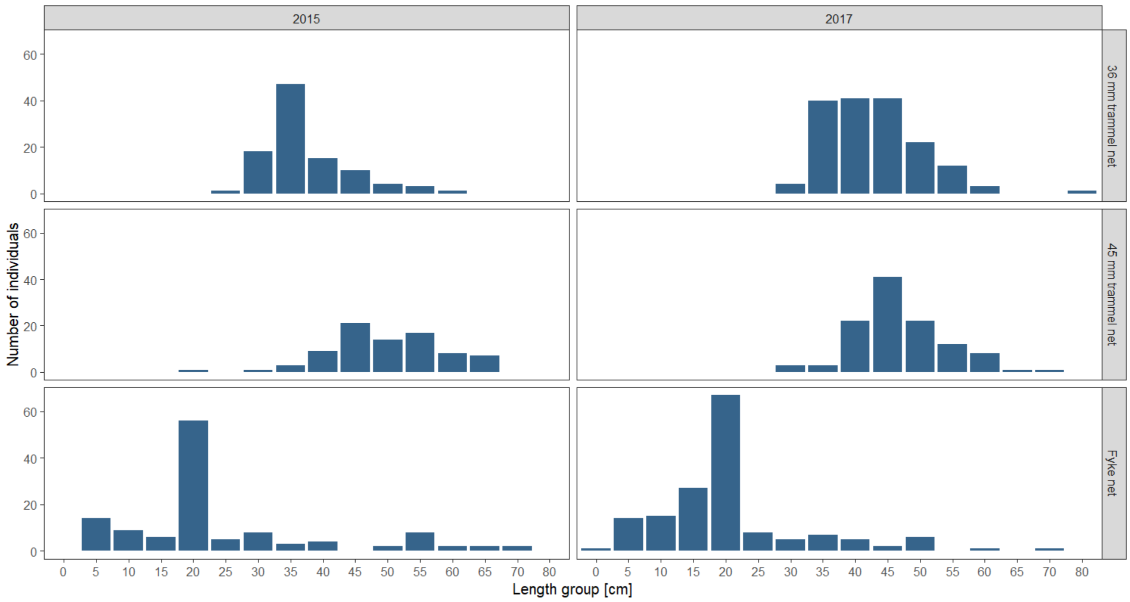

Figure 3.1.6 – POLLACK_South: Total number of pollack in each 5 cm length group caught with respective gears, for separate years in the southern subarea. X-axis showing 5 cm length groups, starting at 5 cm. Note that the southern subarea was not sampled in 2016.

3.2 Age composition of the total catch

3.2.1 Cod

The age groups defined as recruits in this thesis (0-2 year olds) accounted for 68 % of the total catch of cod in both subarea, with 1-year olds being the most numerous (Table 3.2.1). In the northern subarea, 2349 individuals were caught throughout the survey period. In the southern subarea, a total of 914 individuals were caught through the two years of survey (Table 3.2.1 and 3.2.2).

Table 3.2.1 – COD_North: Total number of caught cod, all gears pooled, by length and age in the northern subarea in 2013, 2016 and 2018. For individuals lacking age, this has been calculated using an age-length-key.

	Age										
Length [cm]	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Sum**
6-9	108	1	2								111
10-14	121	8									129
15-19	2	213	3								218
20-24		368	22								390
25-29		104	122	3							229
30-34		6	245	31	3						285
35-39		1	177	76	15	1	1				271
40-44		2	69	106	37	1					215
45-49			18	71	34	4	2	2			131
50-54			1	43	67	12	11	1		1	136
55-59				13	37	25	19	3	2		99
60-64				2	17	16	19	2	5	2	63
65-69				1	10	5	19	5	3	1	44
70-74					2	2	6	1	2	2	15
75-79						2	3			2	7
80-88						2	2		1		5
104										1	1
Sum	231	703	659	346	222	70	82	14	13	9	2349

Table 3.2.2 - COD_South: Total number of caught cod, all gears pooled, by length and age in the southern subarea in 2015 and 2017. For individuals lacking age, this has been calculated using an age-length-key.

	Age										
Length [cm]	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Sum**
5-9	28										28
10-14	54	4									58
15-19		87									87
20-24		171									171
25-29		74	18								92
30-34		2	64	15							81
35-39			83	31	3						117
40-44			20	35		9	4				68
45-49			17	17	13	3	4				54
50-54			5	19	17	4	4				49
55-59				26	6	6	2				40
60-64					9	11	5				25
65-69					6	8	3	5			22
70-74					7	1	2	2	4		16
75-79						2	1				3
80-84								1	1		2
98										1	1
Sum	82	338	207	143	61	44	25	8	5	1	914

3.2.2 Saithe

Saithe catches consisted of 68 % small, 12 % medium sized and 20 % large individuals. In total, 1216 saithe has been caught during the whole survey (Table 3.2.3).

Table 3.2.3 – SAITHE_ North + South: Total number of caught saithe, all gears pooled, by length and group in both the northern and the southern area, all years. Individuals have been grouped based on age-length-keys from the acoustic coastal survey (Mehl et al. 2016; Mehl et al. 2015; Mehl et al. 2013; Mehl et al. 2014; Mehl et al. 2017).

		Group		
Length [cm]	**Small**	**Medium**	**Large**	**Sum**
7-9	21			21
10-14	568			568
15-19	245			245
20-24		69		69
25-29		73		73
30-34			91	91
35-39			82	82
40-44			43	43
45-49			10	10
50-54			8	8
55-59			4	4
60-64			2	2
Sum	834	142	240	1216

3.2.3 Pollack

35 % of the total catch of pollack in both subareas was found to be recruits (0-2 years). The 3-year olds were the most numerous with a total catch of 197 individuals followed by a total number of 185 1-year olds (Table 3.2.4).

Table 3.2.4 – POLLACK_North + South: Total number of caught pollack, all gears pooled, by length and age in both the northern and the southern area, all years. For unaged individuals, this was calculated using an age-length-key from Masfjorden (Salvanes 1995) for individuals <35 cm.

	Age												
Length [cm]	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**11**	**12**	**Total**
2-4	1												1
5-9	30												30
10-14	26												26
15-19	24	20											44
20-24	2	140											142
25-29		13	5										18
30-34		11	38	4									53
35-39			21	92	8								121
40-44				76	42	10	2						130
45-49				23	67	44	8						142
50-54		1		2	44	40	5	3		1			96
55-59					7	39	18	9					73
60-64						23	12	4	2				41
65-69							5	4	6	1			16
70-74							2	3			1		6
75-80										4	1	1	6
Sum	83	185	64	197	168	156	52	23	8	6	2	1	945

3.3 Presence of the three species

3.3.1 Cod

Out of the total 964 stations through all years of survey, 769 of them gave catches of cod. In the northern subarea, cod was present in 88 % of all stations, while it was present in 70 % of all stations in the southern subarea. Of the 3 gears, fyke net was the most successful in catching cod, as 88% of the fyke net stations caught cod. The 36 mm and 45 mm trammel nets caught cod in 67% and 69 % of the stations, respectively (Figure 3.3.1 and 3.3.2).

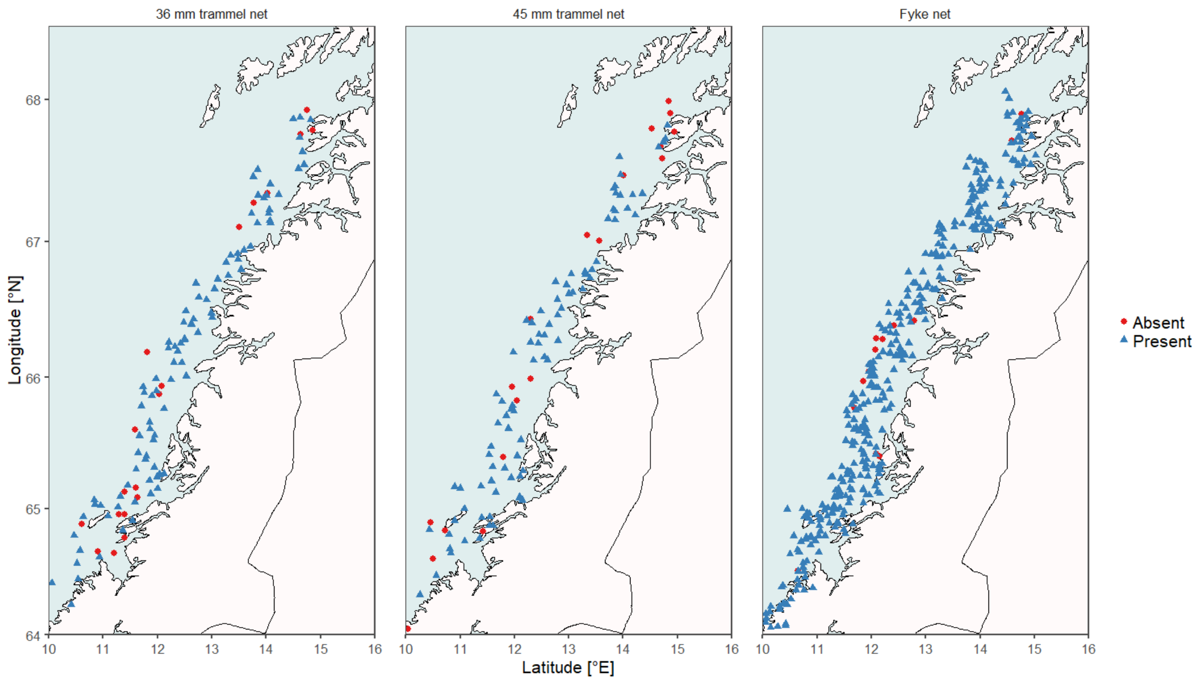

Figure 3.3.1- COD_North: Stations in the northern subarea, for all years pooled, where cod was present/absent in the catch. Note that the latitudinal positions of the stations are not fully accurate as these have been jittered in order to avoid overlap between points.

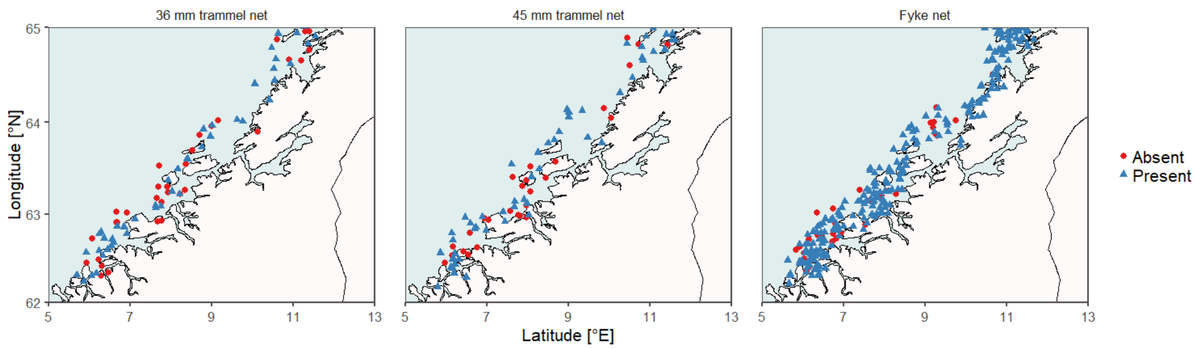

Figure 3.3.2 – COD_South: Stations in the southern subarea, for both years pooled, where cod was present/absent in the catch. Note that the latitudinal positions of the stations are not fully accurate as these have been jittered in order to avoid overlap between points.

3.3.2 Saithe

Saithe was present in the catch of 413 of 964 stations. This accounted for 39 % of the stations in the northern subarea and 48 % of stations in the southern subarea. Furthermore, 50% of fyke nets, 43 % of 36 mm trammel nets and 22 % of 45 mm trammel nets had saithe in the catch (Figure 3.3.3 and 3.3.4).

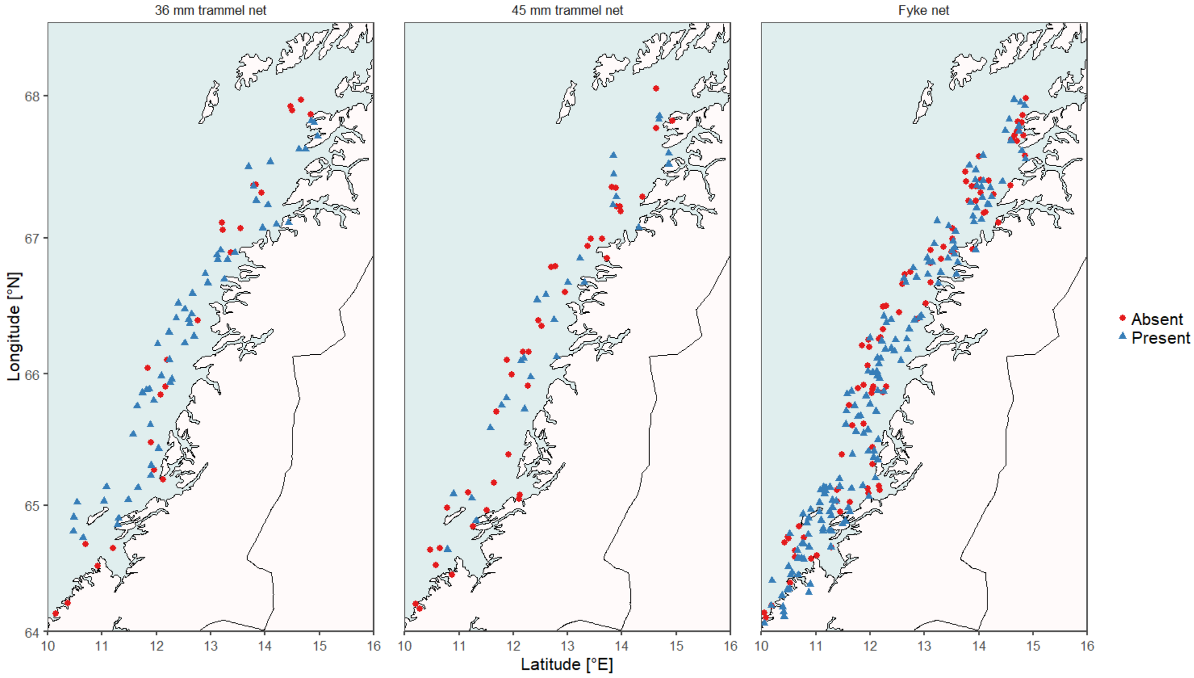

Figure 3.3.3 – SAITHE_North: Stations in the northern subarea, for all years pooled, where saithe was present/absent in the catch. Note that the latitudinal positions of the stations are not fully accurate as these have been jittered in order to avoid overlap between points.

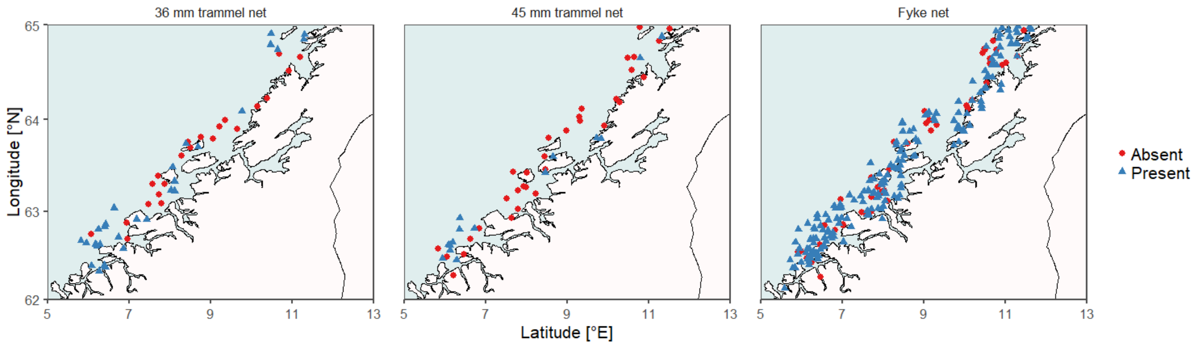

Figure 3.3.4 – SAITHE_South: Stations in the southern subarea, for both years pooled, where saithe was present/absent in the catch. Note that the latitudinal positions of the stations are not fully accurate as these have been jittered in order to avoid overlap between points.

3.3.3 Pollack

Through all years, pollack was present in the catch of 344 of 964 stations. In the northern subarea, 17 % of all stations had catches of pollack, while 58 % of stations in the southern subarea caught pollack. 50 % of all 36 mm trammel nets, 43 % of all 45 mm trammel nets and 29 % of all fyke nets caught pollack (Figure 3.3.5 and 3.3.6).

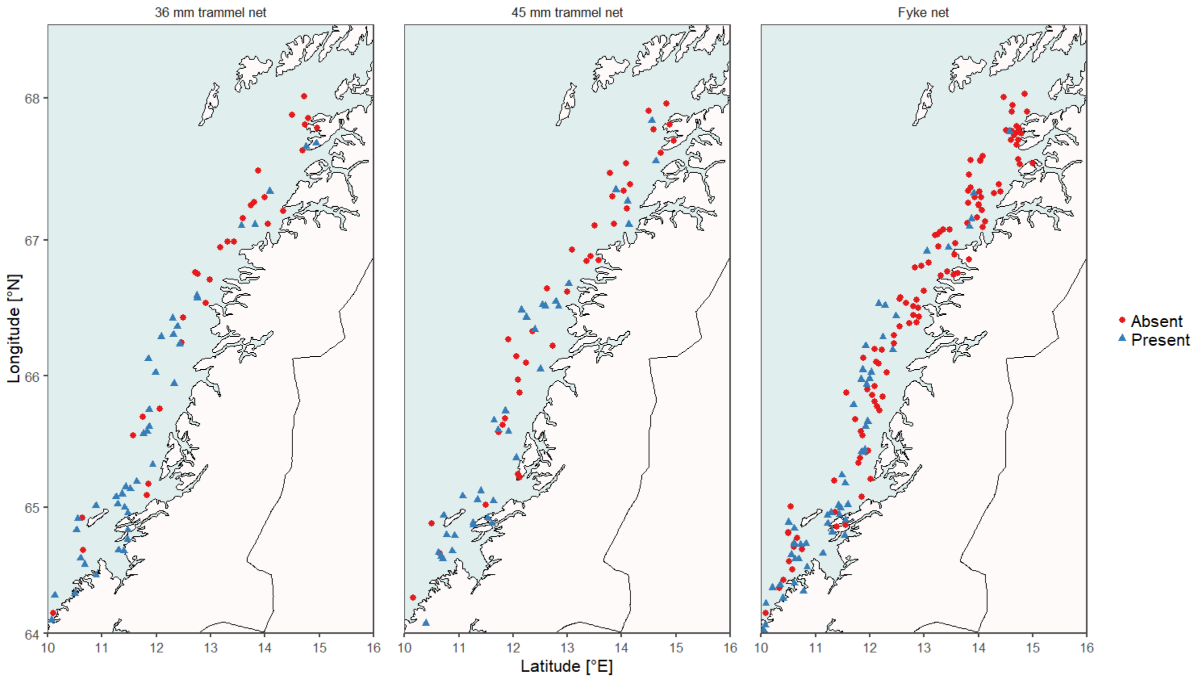

Figure 3.3.5 – POLLACK_North: Stations in the northern subarea, for all years pooled, where pollack was present/absent in the catch. Note that the latitudinal positions of the stations are not fully accurate as these have been jittered in order to avoid overlap between points.

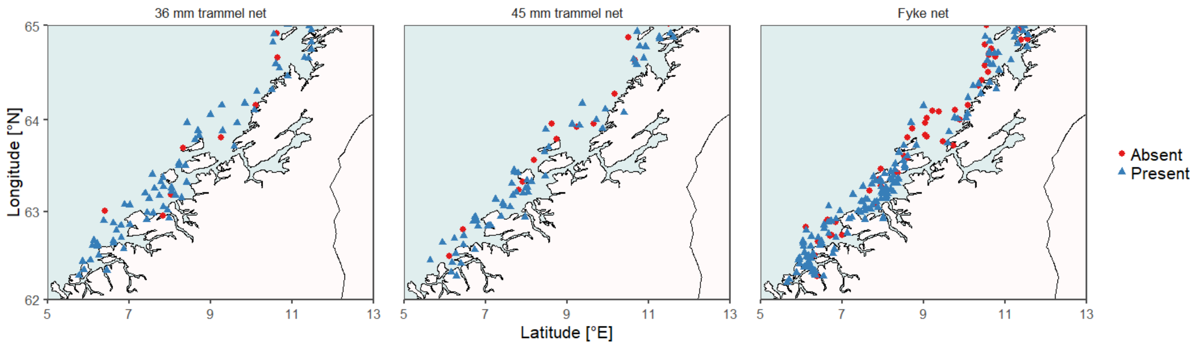

Figure 3.3.6 – POLLACK_South: Stations in the southern subarea, for both years pooled, where pollack was present/absent in the catch. Note that the latitudinal positions of the stations are not fully accurate as these have been jittered in order to avoid overlap between points.

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3.4 Relative probability of catch

None of these models (Eq. 2.2) were performed on 0-group of neither cod or pollack, as these were solely caught by fyke nets. The likelihood ratio test between the model (Eq. 2.2) and null model (Eq. 2.3) showed a significant effect of “gear” for all ages of all three species, except for the medium group of saithe.

3.4.1 Cod

The model results showed that fyke net had the highest probability of catching cod at any age, out of the three gears (P = <.001, Table 3.4.1). The effect of fyke net was strongest for 1-year-old cod and decreasing with age. The 36 mm trammel net had a higher probability of catching cod than the 45 mm, though there was no significant P-value. The mean fitted values also showed that the overall probability of catch was high for all ages for fyke nets, while there was an increase in probability with age for the trammel nets (Table 3.4.1 and Figure 3.4.1).

Table 3.4.1- COD_North + South: Results from the generalized linear mixed effect model; Presence ~ gear + year + (1|location), for cod. The estimates are transformed by exponentiation to give estimates of the relative probability of catch for the gears in comparison to the reference gear (45 mm trammel net). Fitted values from the model are presented as means of all years, giving the overall probability of catch. Significant P-values are marked ”*”.

Age [years]	Gear	Exp(Estimate)	Std. error	*P*-value	Mean fitted value
1	45 mm trammel net	1	-	-	0.13
	36 mm trammel net	1.87	0.54	.25	0.18
	Fyke net	119.43	0.52	<.001*	0.86
2	45 mm trammel net	1	-	-	0.42
	36 mm trammel net	1.68	0.31	.09	0.54
	Fyke net	7.29	0.28	<.001*	0.82
3+	45 mm trammel net	1	-	-	0.71
	36 mm trammel net	1.28	0.26	.36	0.73
	Fyke net	4.72	0.26	<.001*	0.86

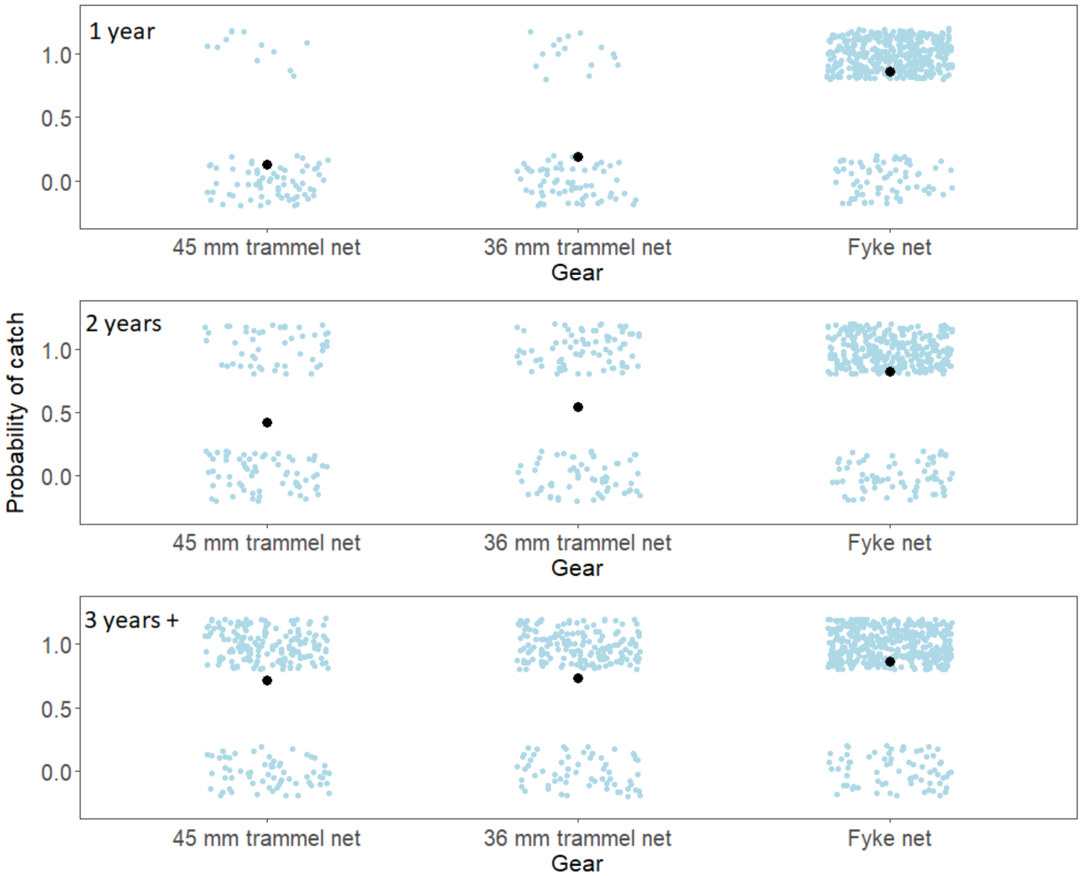

Figure 3.4.1 – COD_North + South: Raw data (blue points), representing either (1) catch or (0) no catch, together with the mean fitted values (black points) for cod. The position of the raw data have been jittered.

3.4.2 Saithe

The fyke nets had a significantly higher probability of catching small (*P* = <.001, Table 3.4.2) and medium sized (*P* = 0.4, Table 3.4.2) saithe, while it had a significantly lower probability of catching large saithe (*P* = <.001, Table 3.4.2) than the trammel nets. The 36 mm trammel net had the highest probability for catching large saithe (*P* = <.001, Table 3.4.2). Mean fitted values show a generally low probability of catching saithe. Largest probability of catch was found for fyke net catching small saithe (Table 3.4.2 and Figure 3.4.2).

Table 3.4.2 – SAITHE_North + South: Results from the generalized linear mixed effect model; Presence ~ gear + year + (1|location), for saithe. “Small” corresponds to ages 0 and 1, “medium” corresponds to age 2 and “large” corresponds to age 3 and older. The estimates are transformed by exponentiation to give estimates of the relative probability of catch for the gears in comparison to the reference gear (45 mm trammel net). Fitted values from the model are presented as means of all years, giving probability of catch. Significant *P*-values are marked ”*”.

Group	Gear	Exp(Estimate)	Std. error	*P*-value	Mean fitted value
Small	45 mm trammel net	1	-	-	0.005
	36 mm trammel net	2.45	1.24	.47	0.016
	Fyke net	222.30	1.02	<.001*	0.471
Medium	45 mm trammel net	1	-	-	0.092
	36 mm trammel net	1.62	0.39	.22	0.137
	Fyke net	1.92	0.32	.04*	0.152
Large	45 mm trammel net	1	-	-	0.120
	36 mm trammel net	6.07	0.33	<.001*	0.382
	Fyke net	0.23	0.38	<.001*	0.037

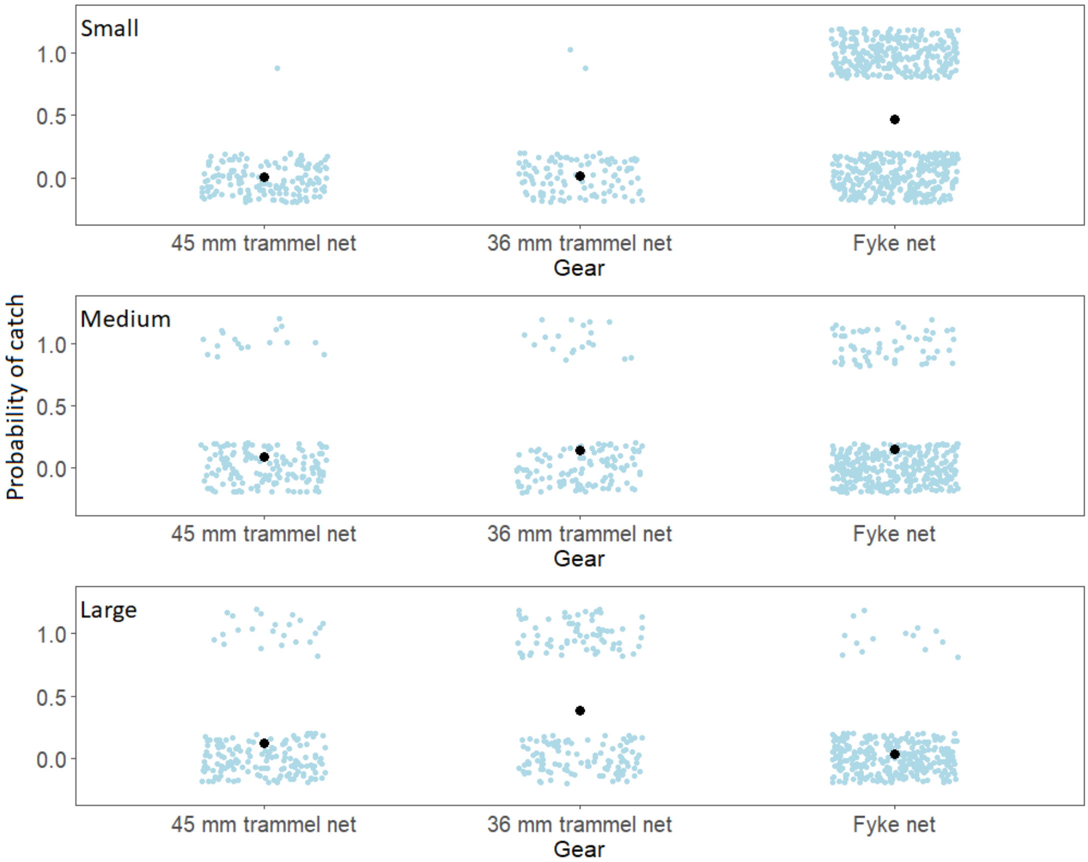

Figure 3.4.2 – SAITHE_North + South: Raw data (blue points), representing either (1) catch or (0) no catch, together with the mean fitted values (black points) for saithe. "Small" corresponds to ages 0 and 1, "medium" corresponds to age 2 and "large" corresponds to age 3 and older. The position of the raw data have been jittered.

3.4.3 Pollack

The model results showed that fyke net had the highest probability of catching 1-year old pollack (P = <.001, Table 3.4.3). The 36 mm trammel net had the highest probability of catching 2-year old (P = <.001, Table 3.4.2) and 3-year old and older (P = .03, Table 3.4.2) pollack. Mean fitted values show that there is a larger probability of catching 3-year-old pollack and older, than 1- and 2-year-old pollack (Table 3.4.3 and Figure 3.4.3).

Table 3.4.3 – POLLACK_North + South: Results from the generalized linear mixed effect model; Presence ~ gear + year + (1|location), for pollack. The estimates are transformed by exponentiation to give estimates of the relative probability of catch for the gears in comparison to the reference gear (45 mm trammel net). Fitted values from the model are presented as means of all years, giving probability of catch. Significant *P*-values are marked "*".

Age [years]	Gear	Exp(Estimate)	Std. error	*P*-value	Mean fitted values
	45 mm trammel net	1	-	-	0.038
1	36 mm trammel net	1.71	0.71	.45	0.043
	Fyke net	7.40	0.52	<.001*	0.206
	45 mm trammel net	1	-	-	0.035
2	36 mm trammel net	10.41	0.66	<.001*	0.214
	Fyke net	0.61	0.61	.42	0.022
	45 mm trammel net	1	-	-	0.584
3 +	36 mm trammel net	1.81	0.27	.03*	0.649
	Fyke net	0.06	0.28	<.001*	0.096

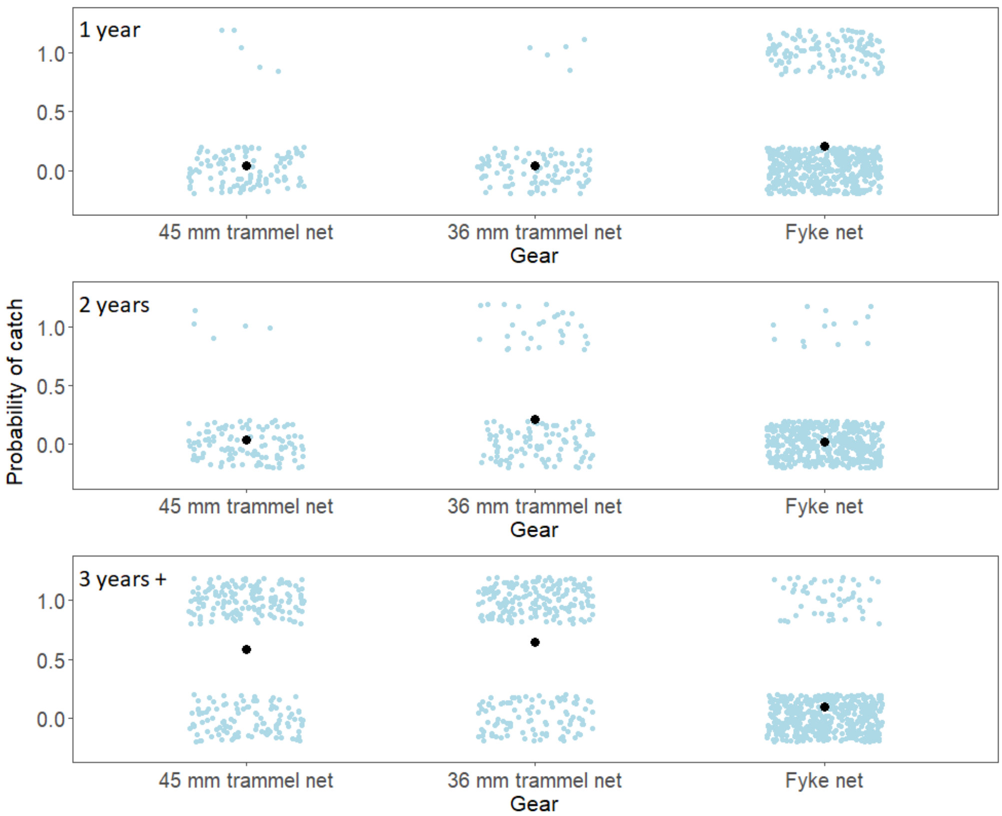

Figure 3.4.3 – POLLACK_North + South: Raw data (blue points), representing either (1) catch or (0) no catch, together with the mean fitted values (black points) for pollack. The position of the raw data have been randomized.

3.5 Catch efficiency of cod by gear

The generalized linear mixed effect model gave poor fits for saithe and pollack, and results are only represented for cod. The model was not performed for 0-group of cod, as fyke net was the only gear that caught this group. Model assumptions were satisfactory (Figure 7.A - 7.C, Appendix IV).

The fyke nets had a clearly higher catch efficiency for 1-year old (*P* = <.001, Table 3.5.1) and 2-year old cod (*P* = <.001, Table 3.5.1), compared to the 45 mm meshed trammel net. There was no significant difference between the two trammel nets in catch efficiency for 1-year old- or 3-year old and older cod. For 2-year old cod, the 36 mm meshed trammel net was more efficient (*P* = .01, Table 3.5.1) than the 45 mm meshed trammel net.

Table 3.5.1 – COD_North + South: Results from the generalized linear mixed effect model; CPUE ~ gear + year + (1|location), for cod. The estimates are transformed by exponentiation to give estimates of the relative efficiency of the gears in comparison to the reference gear (45 mm trammel net). Fitted values from the model are presented as means of all years, being estimated CPUE. Significant *P*-values are marked ”*”.

Age [years]	Gear	Exp(Estimate)	Std. error	*P*-value	Mean fitted values
1	45 mm trammel net	1	-	-	0.18
	36 mm trammel net	1.64	0.34	.15	0.26
	Fyke net	11.38	0.27	< .001*	2.20
2	45 mm trammel net	1	-	-	0.85
	36 mm trammel net	1.38	0.13	.01*	1.18
	Fyke net	1.62	0.11	<.001*	1.58
3 +	45 mm trammel net	1	-	-	1.07
	36 mm trammel net	1.14	0.09	.12	1.21
	Fyke net	1.06	0.08	.48	1.05

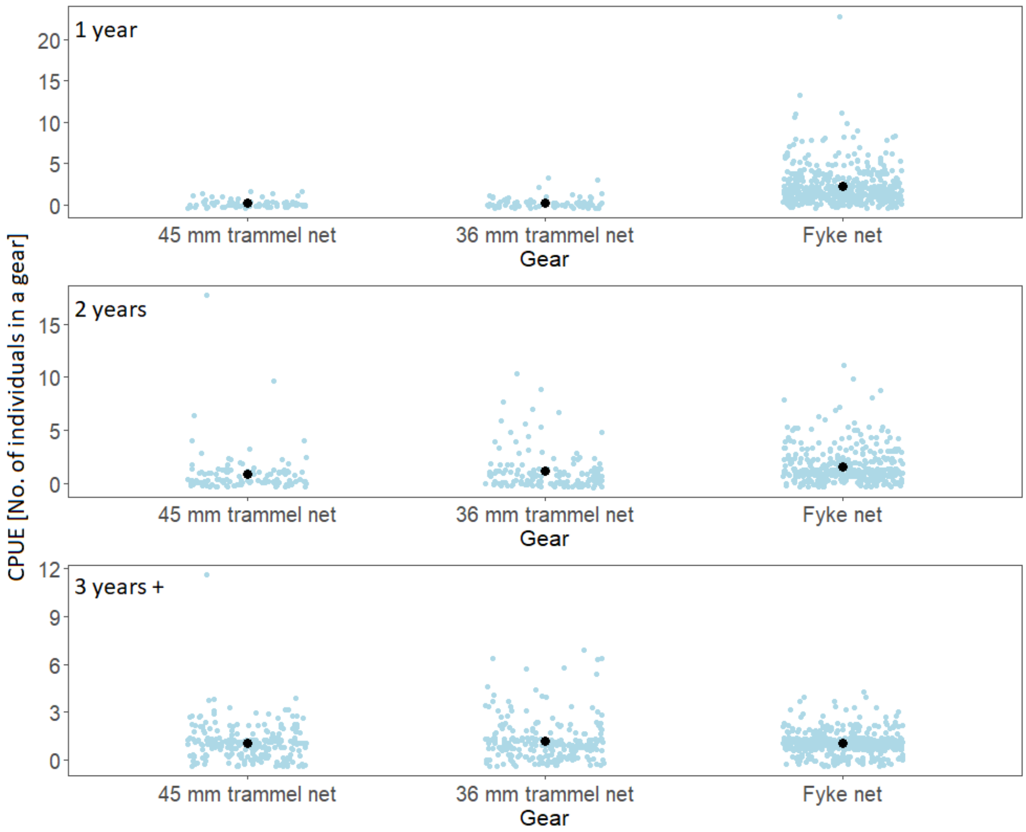

Figure 3.5.1 – COD_North + South: Raw data (blue points), representing CPUE [No. of individuals in a gear], together with the mean fitted values (black points) for cod. The horizontal positions of the raw data have been jittered.

3.6 Estimated recruitment indices for cod

The model output reveals a generally higher recruitment of cod for the years the survey was conducted in the northern subarea (2013, 2016 and 2018) than in the southern subarea (2015 and 2017). However, the difference is only significant for 0-group in 2015 (P = < .001, Table 3.6.1), 0-group in 2018 (P = .03, Table 3.6.1), 1-year olds in 2015 (P = < .001, Table 3.6.2), 2-year olds in 2015 (P = < .001, Table 3.6.2) and 2-year olds in 2017 (P = < .001, Table 3.6.2). There is a great annual variation in the youngest age groups, particularly for the 0-group, decreasing with age. For the 0- group and 1-year old cod, increasing trends were found in both subareas. The indices of 2-year olds showed a slight increase in the north, while they decreased in the south (Table 3.6.1 and Table 3.6.2).

Table 3.6.1 – COD_ North + South: Results from the generalized linear mixed effect model; CPUE ~ year + (1|location), for 0 group cod. The estimates are transformed by exponentiation to give estimates of the relative recruitment in comparison to the reference year (2013). Significant *P*-values are marked ”*”.

Age [years]	Year	Exp(Estimate)	Std. error	*P*-value
0	2013	1	-	-
	2015	0.12	0.49	<.001*
	2016	1.29	0.36	.48
	2017	0.91	0.35	.79
	2018	2.14	0.35	.03*

Table 3.6.2 – COD_ North + South: Results from the generalized linear mixed effect model; CPUE ~ gear + year + (1|location), for 1-year old and older cod. The estimates are transformed by exponentiation to give estimates of the relative recruitment in comparison to the reference year (2013). Significant *P*-values are marked ”*”.

Age [years]	Year	Exp(Estimate)	Std. error	*P*-value
1	2013	1	-	-
	2015	0.44	0.22	<.001*
	2016	0.86	0.22	.50
	2017	0.68	0.22	.08
	2018	0.97	0.22	.90
2	2013	1	-	-
	2015	0.44	0.22	<.001*
	2016	0.90	0.21	.63
	2017	0.37	0.23	<.001*
	2018	0.94	0.21	.79
3 +	2013	1	-	-
	2015	0.67	0.16	.01*
	2016	1.11	0.15	.50
	2017	0.53	0.17	<.001*
	2018	1.05	0.16	.73

3.7 Estimated mean catch per unit effort (CPUE) by age

3.7.1 Cod

The mean CPUE was generally higher in the northern than in the southern subarea. Fyke net catches revealed an increasing mean CPUE for 0-group in both subareas. There was a small decrease in 1-year olds in the northern subarea, and an increase in the southern subarea. For 2-year olds, there was an increasing trend in the northern subarea, while in the south, CPUE was the same in 2015 and 2017. (Table 3.7.1). Both the 2016 and the 2015 year class showed an increase in mean CPUE from 0-group to 2-year olds. The 2016 year class had a CPUE of 1.48 fish per fyke net as 0-group in 2016, and 2.16 fish per fyke net as 2-year olds in 2018. The 2015 year class had a CPUE of 0.19 fish per fyke net as 0-group in 2015, and 1.02 fish per fyke net as 2-year olds in 2017 (Table 3.7.1).

Table 3.7.1 – COD: Mean CPUE [No. of fish in a gear] with standard errors for cod over age groups for fyke net, each year.

	Age	**0**	**1**	**2**	**3+**	**Total**
Sub-area	**Year**	**Mean (Se)**	**Mean (Se)**	**Mean (Se)**	**Mean (Se)**	**Mean (Se)**
North	2013	1.36 (0.26)	2.92 (0.43)	1.94 (0.25)	1.20 (0.08)	7.42 (1.02)
	2016	1.48 (0.26)	2.65 (0.25)	1.82 (0.14)	1.14 (0.06)	7.08 (0.71)
	2018	2.56 (0.44)	2.58 (0.21)	2.16 (0.22)	1.09 (0.06)	8.38 (0.93)
South	2015	0.19 (0.06)	1.30 (0.15)	1.02 (0.14)	1.03 (0.07)	3.55 (0.42)
	2017	1.14 (0.14)	1.96 (0.18)	1.02 (0.11)	0.89 (0.06)	5.00 (0.49)

Note that trammel nets did not catch 0-groups. 1-year olds caught by trammel nets showed a decreasing trend in the north and increasing in the south, while 2-year olds showed the opposite pattern (Table 3.7.2).

Table 3.7.2 – COD: Mean CPUE [No. of fish in a gear] with standard errors for cod over age groups for 36- and 45 mm meshed trammel nets together, each year.

	Age	0	1	2	3+	Total
Sub-area	Year	Mean (Se)	Mean (Se)	Mean (Se)	Mean (Se)	Mean (Se)
North	2013	0 (-)	1.26 (1.78)	2.93 (3.98)	2.47 (2.27)	6.66 (8.04)
	2016	0 (-)	0.50 (1.07)	3.57 (6.50)	3.11 (3.16)	7.18 (10.73)
	2018	0 (-)	1.11 (1.14)	3.29 (3.79)	3.14 (2.17)	7.55 (7.10)
South	2015	0 (-)	0.05 (0.22)	1.18 (1.80)	1.08 (1.15)	2.32 (3.18)
	2017	0 (-)	0.16 (0.56)	0.51 (0.96)	0.83 (1.16)	1.51 (2.67)

3.7.2 Saithe

The overall mean CPUE of fyke nets were higher in the southern subarea. There was a decrease of small saithe (0-1 year olds) in the north, and an increase in the south. For the medium sized saithe (2-year olds), mean CPUE was stably low all years, though somewhat higher in the south. (Table 3.7.3).

Table 3.7.3 - SAITHE: Mean CPUE [No. of fish in a gear] with standard errors for saithe over size groups for fyke nets, each year.

	Group	Small	Medium	Large	Total
Sub-area	Year	Mean (Se)	Mean (Se)	Mean (Se)	Mean (Se)
North	2013	1.10 (0.35)	0.08 (0.04)	0 (-)	1.18 (0.39)
	2016	1.03 (0.15)	0.29 (0.07)	0.09 (0.04)	1.41 (0.26)
	2018	0.55 (0.10)	0.02 (0.02)	0.02 (0.02)	0.60 (0.14)
South	2015	1.46 (0.21)	0.35 (0.08)	0.14 (0.06)	1.95 (0.35)
	2017	2.97 (0.46)	0.40 (0.11)	0.02 (0.02)	3.40 (0.59)

Trammel nets caught no small saithe in the northern subarea, and showed a very small mean CPUE in the southern. There was a decrease in mean CPUE of medium saithe in both subareas. In 2016, mean CPUE of medium sized saithe was 0. Trammel nets were most efficient in catching the large group of saithe (Table 3.7.4).

Table 3.7.4 – SAITHE: Mean CPUE [No. of fish in a gear] with standard errors for saithe over size groups for 36- and 45 mm meshed trammel nets together, each year.

	Group	Small	Medium	Large	Total
Sub-area	**Year**	**Mean**	**Mean**	**Mean**	**Mean**
North	2013	0 (-)	0.82 (0.35)	1.33 (0.35)	2.15 (0.71)
	2016	0 (-)	0 (-)	1.24 (0.46)	1.24 (0.46)
	2018	0 (-)	0.19 (0.12)	1.40 (0.34)	1.59 (0.46)
South	2015	0.04 (0.04)	0.94 (0.39)	2.24 (1.21)	3.22 (1.64)
	2017	0.06 (0.06)	0.29 (0.22)	0.14 (0.08)	0.48 (0.35)

3.7.3 Pollack

The mean CPUE of pollack is generally quite low compared to saithe and cod, particularly for fyke nets. The mean CPUE of pollack was highest in the southern subarea, for all gears. In the northern subarea, fyke net catches are stably low for all age groups. In the south, mean CPUE showed increasing trends for both 0-group and 1-year olds (Table 3.7.5).

Table 3.7.5 – POLLACK: Mean CPUE [No. of fish in a gear] with standard errors for pollack over age groups for fyke nets, each year.

	Age	0	1	2	3+	Total
Sub-area	**Year**	**Mean (Se)**	**Mean (Se)**	**Mean (Se)**	**Mean (Se)**	**Mean (Se)**
North	2013	0.05 (0.03)	0.13 (0.04)	0 (-)	0 (-)	0.17 (0.07)
	2016	0.04 (0.02)	0.08 (0.03)	0.01 (0.01)	0.03 (0.02)	0.15 (0.07)
	2018	0 (-)	0.04 (0.02)	0.01 (0.01)	0.03 (0.02)	0.09 (0.04)
South	2015	0.30 (0.08)	0.57 (0.08)	0.08 (0.03)	0.25 (0.05)	1.20 (0.23)
	2017	0.52 (0.09)	0.75 (0.12)	0.07 (0.03)	0.26 (0.05)	1.60 (0.29)

The trammel net catches showed a decreasing trend for 1-year olds in both subareas, both being 0 in 2018. Mean CPUE of 2-year olds showed an increasing trend in both subareas, being higher in the south. The trammel nets had highest CPUE for the oldest age groups (age 3+) all years. (Table 3.7.6).

Table 3.7.6 – POLLACK: Mean CPUE [No. of fish in a gear] with standard errors for pollack over age groups for 36 – and 45 mm meshed trammel nets, each year.

	Age	**0**	**1**	**2**	**3+**	**Total**
Sub-area	**Year**	**Mean (Se)**	**Mean (Se)**	**Mean (Se)**	**Mean (Se)**	**Mean (Se)**
North	2013	0 (-)	0.29 (0.25)	0.20 (0.13)	1.24 (0.53)	1.73 (0.91)
	2016	0 (-)	0.06 (0.06)	0.09 (0.09)	0.92 (0.30)	1.07 (0.45)
	2018	0 (-)	0 (-)	0.32 (0.25)	1.50 (0.29)	1.82 (0.54)
South	2015	0 (-)	0.23 (0.14)	0.76 (0.18)	2.44 (0.35)	3.43 (0.68)
	2017	0 (-)	0 (-)	1.00 (0.51)	3.22 (0.27)	4.22 (0.77)

3.8 Comparison with acoustic indices

3.8.1 Cod

In the northern subarea, four year classes of cod were detectable in the acoustic survey as 3-year olds; the 2011-, 2012-, 2013- and 2014 year class. 2-year olds were the only age group caught twice in the shallow-water survey, that were detectable in the acoustic survey. Remaining age groups could not be linked to a second measure. There was a positive relationship between mean CPUE of 2-year olds caught by fyke nets in the shallow water survey and the indices of the same year class as 3-year olds in the acoustic survey (Figure 3.8.1).

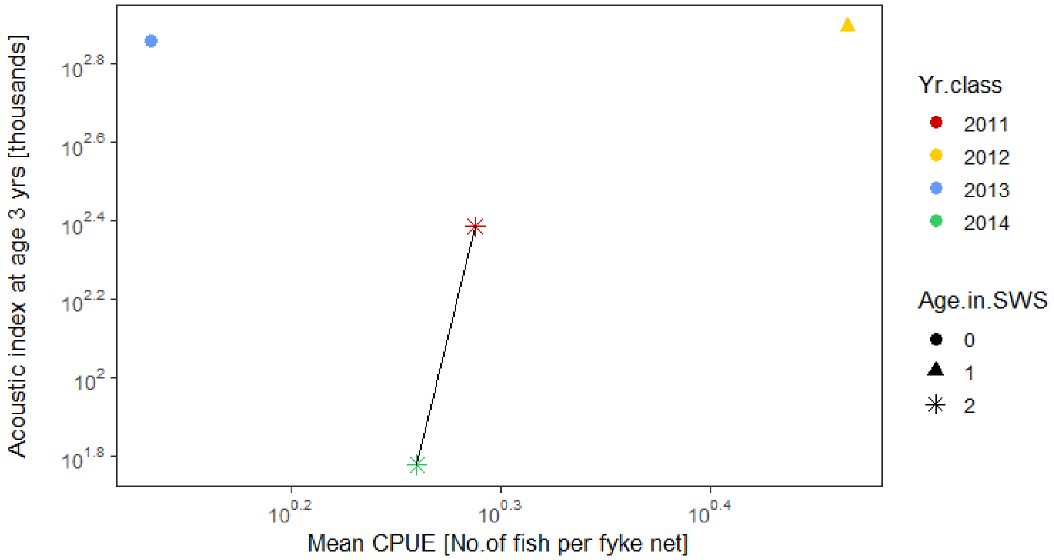

Figure 3.8.1 - COD_North: Comparison between mean CPUE of fyke nets from this study with indices of the same year classes as 3-year olds from the acoustic survey in the north. Both axis are logarithmic.

In the southern subarea, two year classes of cod were detectable in the acoustic survey: the 2013- and the 2014 year class. No age groups, that have recruited to the acoustic survey, were caught twice in the shallow-water survey. Hence, it is not possible to draw any conclusion on the relationship between the two surveys in the southern subarea (Figure 3.8.2).

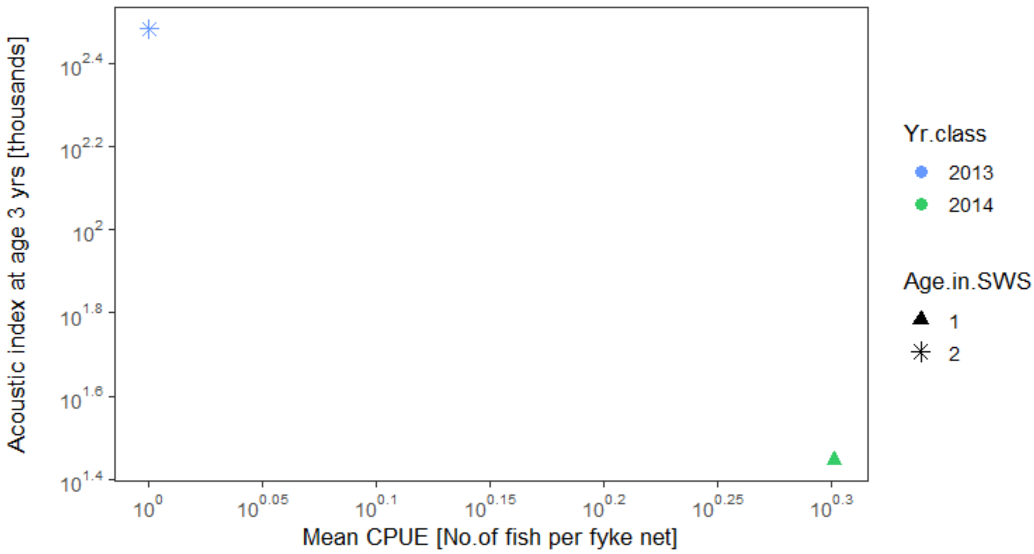

Figure 3.8.2 – COD_South: Comparison between mean CPUE of fyke nets from this study with indices of the same year classes as 3-year olds from the acoustic survey in the south. Both axis are logarithmic.

3.8.2 Saithe

In the northern subarea, four year classes of saithe were found in the acoustic surveys; the 2011-, 2012-, 2013 and 2014 year class. Because the 0-group and 1-year old saithe were grouped together in the “small sized” group, the acoustic indices of year class 2012 and 2013 were added together. There was a positive relationship between mean CPUE of 2-year olds and the acoustic indices for the same year classes as 3-year olds (Figure 3.8.3).

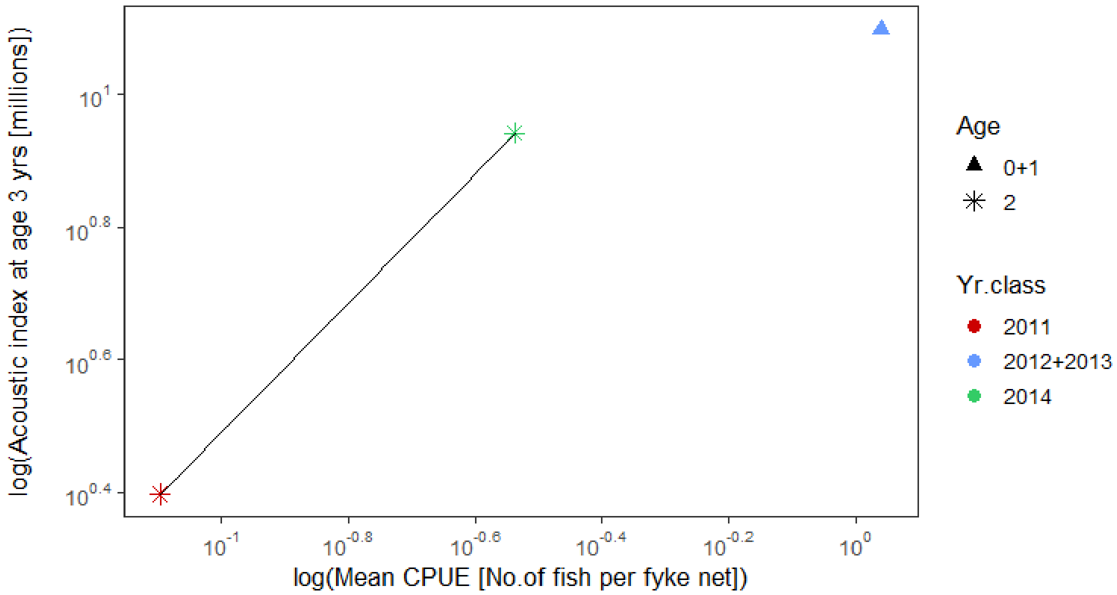

Figure 3.8.3 – SAITHE_North: Comparison between mean CPUE of fyke nets from this study with indices of the same year classes as 3-year olds from the acoustic survey in the north. The acoustic indices for year class 2012 and 2013 have been added together, as these have been merged together as "small" in this study. Both axis are logarithmic.

In the southern subarea, three year classes were detected as 3-year olds in the acoustic survey; 2013,- 2014- and 2015 year class. Note that the 2015 year class recruited to the acoustic survey in 2018, data that has not yet been published. Hence, the acoustic indices of year class 2014+2015 is not representable. No age groups of saithe, that were detectable in the acoustic survey, were caught several times in the southern subarea. Hence, no evaluation of the mean CPUE could be given in this area (Figure 3.8.4).

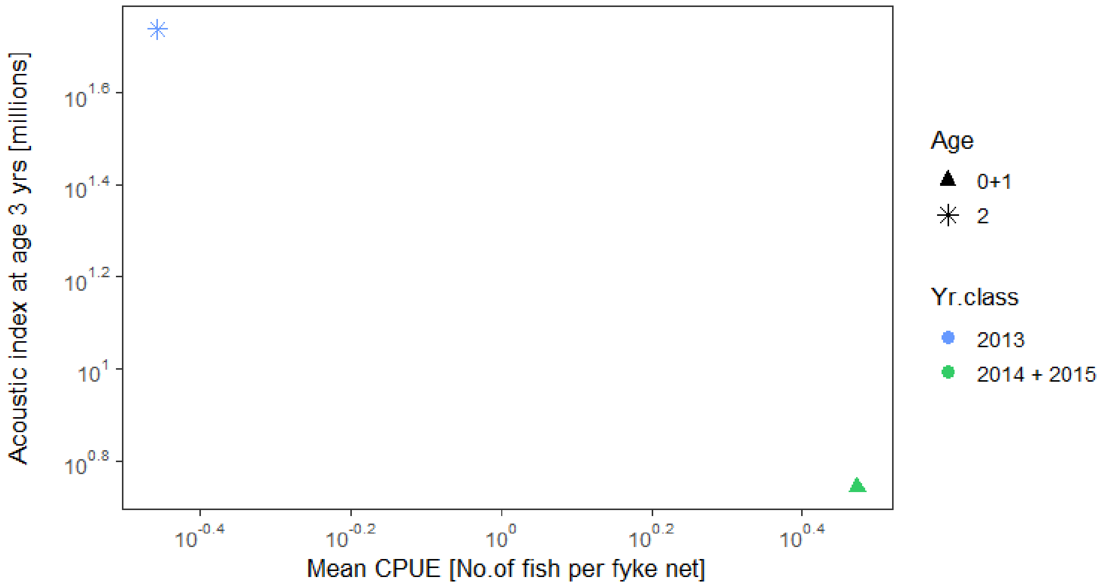

Figure 3.8.4 – SAITHE_South: Comparison between mean CPUE of fyke nets from this study with indices of the same year classes as 3 year olds from the acoustic survey in the south. The acoustic indices for year class 2014 and 2015 have been added together, as these were merged together as “small” in the shallow-water survey. Both axis are logarithmic.

4 DISCUSSION

The results showed that fyke nets were most successful in catching both 0-group, 1- and 2-year olds of all three species, while the trammel nets mostly caught individuals older than this. The data were sufficient for suggesting recruitment indices for cod, as 68 % of the total cod catch were recruits (0-2 years). There was a positive relationship between mean CPUE of 2-year old cod in the shallow-water survey and the acoustic index of the same year classes as 3-year olds in the northern subarea. Because of lacking age data and irregular catches of saithe and pollack recruitment indices could not be suggested for these species. Still, comparison with acoustic indices revealed a positive relationship between mean CPUE of 2-year old ("medium" sized) saithe in the shallow-water survey and the 3-year old index of the same year classes in the acoustic survey in the northern subarea.

4.1 Which gears catch the most recruits?

The fyke nets were able to catch the very smallest individuals of all three species, most of the catch being <25 cm. This is similar to what has been found in previous studies with fyke nets on cod (Nostvik & Pedersen 1999; van der Meeren 2017). The length composition of the trammel net catches were quite different from those of the fyke nets, mostly catching fish >20 cm. Salvanes (1991) found that 70 mm stretched meshed trammel nets, approximately equivalent to the 36 mm bar length net, had an optimal relative selectivity for cod of ~35 cm, with the curves skewed to the right. This is similar to the length frequencies of cod found for the 36 mm trammel net. Furthermore, the length distribution of the catches for the different mesh sizes of trammel nets were quite similar, though the highest number of catches of 45 mm net were somewhat higher. No previous studies have been made on fyke- and trammel nets' ability to catch saithe or pollack.

There are several factors possibly explaining the different length compositions of fyke- and trammel nets. Including the mesh size, the fishing method of the gears, vertical height of the nets and fishing depth. Firstly, and probably the most important, the mesh size of the net controls the minimum size of caught fish. If the girth of the fish is smaller than the meshes, it will escape through the net (Salvanes et al. 2018). The meshes of the fyke nets were smaller than the trammel nets, allowing smaller fish to be retained in the net. Furthermore, the way fish are caught in the gears are quite different, resulting in different size selective properties. Fish larger than the meshes of the trammel nets will try to escape by swimming in another direction.

As the trammel nets are loosely constructed, the fish will get pursed or entangled in the net when trying to escape by swimming to either sides, up- or downwards. In contrast, fish can still escape a fyke net once it has encountered it, by swimming over the lead net. This might not happen as frequently for the small fish, as these tend to swim slower than larger fish (Rudstam, Magnuson & Tonn 2011). Hence, they could enter the fyke before they are able to swim over the lead net, possibly explaining why the fyke nets catch small fish more frequently than large fish. Next, the fyke nets (60 cm tall) are vertically lower than the trammel nets (2 m tall), allowing fish, swimming above the sea floor, to pass over the net. In contrast, the trammel nets are higher in the water column, allowing fewer fish to swim over the net. In addition, the trammel nets were set about 35 cm above the sea floor, while the lower line of fyke nets were placed directly at the bottom. As smaller fish tend to stay closer to the seabed, where kelps and rocks provides shelter from predators (Gotceitas, Fraser & Brown 1995), the fyke nets might be more efficient in catching these, while trammel nets catch larger fish swimming above the seabed. Lastly, as the trammel nets are systematically located deeper than the fyke nets, there might be an indication that most juveniles occupy waters shallower than 10 meters depth, where most fyke nets were located. This is consistent with Heincke's law, postulating that size of fish increase with depth (Macpherson & Duarte 1991). Hence, trammel nets could be placed too deep to catch the smallest individuals. Clark and Green (1990) found that juvenile cod performs diurnal vertical migrations during summer, being inactive in the deep (30 meters) and actively swimming in the shallows (<15 meters) to feed. As both gears are passive and dependent on the fish to encounter the gear, this behavioural pattern might induce a higher efficiency of the fyke nets, for cod at least, as more active fish will have a higher probability of encountering the gear (Holst et al. 2005). This might also explain the overall higher catches in fyke nets.

Furthermore, the results revealed irregular catches of saithe and pollack, with few stations contributing to the majority of the catch. This is probably due to a more patchy distribution of individuals than of cod, leading to less frequent encounters with the gear. Juvenile saithe show schooling behaviour (Olsen et al. 2010), resulting in great catches in some stations and no catch for the rest. Hence, the results could be underestimating the abundance of young saithe in some areas, while overestimating it in others. This could be the case for pollack as well, though such schooling has not been documented.

4.2 Potential of the data to provide recruitment indices to the fishery

Results showed that fyke net catches from the shallow-water survey could potentially provide recruitment indices for cod. Saithe and pollack catches were too irregular for the statistical analysis conducted in this study, and data from the trammel nets did not provide sufficient information on 0-group and 1-year olds.

The indices of cod shows an overall higher abundance in the northern subarea. This is equivalent with previous studies on coastal cod (Berg & Albert 2003). Furthermore, there is a considerable annual variation in index level, particularly for the 0-group. Annual variation in year class strength has been a challenge in the management of the Northeast Arctic cod fishery (Ottersen 1996). Great variation has previously been found in 0-group abundance of cod in a beach seine time series from 1919 in Flødevigen, southern Norway (Espeland & Knutsen 2019). Gjøsæter and Danielssen (1990) revealed that two good year classes never followed each other in the beach seine series, possibly reflecting competition between 0-group and 1-year-old cod, as they share the same habitat and that 1-year-olds prey on 0-group (Gjøsæter 1988). Results from this study did not show contradicting fluctuations between 0-group and 1-year olds. In fact, they seem to covary. Therefore, predation might be exerted from older cod (Puvanendran, Laurel & Brown 2008). In the southern subarea, the indices of both 0-group and 1-year-olds are lower in 2015 than in 2017, while the opposite pattern is found in 2-year-olds and older, implying high mortality in 0-group and 1-year-olds in the years of high abundance of cannibalistic predators. This pattern is not as conspicuous in the northern subarea, indicating that other factors affect the level of recruitment there. Varying mortality in the recruits might rise from variation in abundance of other species (predators) or environmental factors, such as temperature, food availability, currents etc. (Grabowski & Grabowski 2019). Furthermore, the great annual variation in 0-group of cod might be a result of differences in timing of settlement to the shallow waters. The transition between the pelagic larvae stage to demersal settlement occurs during the summer after hatching (Lough et al. 1989). It is not yet fully understood what triggers the settlement of juveniles (Grabowski & Grabowski 2019). If settlement is not completed before the shallow-water survey occurs, this might contribute to an underestimation of the year class strength of the 0-group some years. Results showed that the mean CPUE of cod of the same year class was higher, when caught as 2-year olds, than as 0-group. This indicates an underestimation of 0-group of cod, as the abundance of a year class can only decline over time.

The time series from the shallow-water survey is still too short to provide a sufficient number of year classes to be compared with year class strength of the acoustic survey (Mehl et al. 2016; Mehl et al. 2015; Mehl et al. 2013; Mehl et al. 2014; Mehl et al. 2017). Furthermore, the exchange between subareas every other year limits the number of ages during which one year class is caught in the survey. Therefore, a continuation of the survey is recommended in order to give a more accurate evaluation of the recruitment indices for cod. The preliminary results suggests that the mean CPUE of 2-year-old cod provides good estimates of recruitment, as there is a positive relationship between the two year classes caught as 2-year-olds in the shallow-water survey and as 3-year-olds in the acoustic survey in the northern subarea (Figure 3.8.1). However, a different relationship might appear when more year classes are added to the comparison. Because of the restricted number of comparable year classes, mean CPUE of 3-year-old cod in the shallow-water survey was also compared with 4-year-olds in the acoustic survey (Appendix V, Figure 7.D and 7.E). This also revealed a positive relationship between the two surveys in the northern subarea, suggesting that some individuals might recruit later. Hence, it could be useful to give abundance estimates for 3-year-olds as well. In the southern subarea, only one year class could be traced as 4-year-olds in the acoustic survey. An evaluation of recruitment indices of Northeast Arctic cod suggested that an index of early juvenile abundance gave the best early estimates of year class strength (Helle et al. 2000). Thus, the indices suggested in this study might be valuable for the management of coastal cod.

Considering saithe and pollack, the current generalized linear mixed effect model was not successful in producing recruitment indices. For saithe, recruits were well represented in the fyke net catches and the total number of caught individuals were sufficient. However, the catch was too patchy for the statistical analyses, as the model performed on cod in this study does not handle such patchy distribution well. Alternatively, one could have assumed negative binomial error distribution or used zero-inflated models, possibly giving a better result. As adult saithe in Norway migrates and operates as one mixed stock (Saha et al. 2015), the irregular catches might not be a problem in itself. Mean CPUE of fyke nets could be suggested as a measure of recruit abundance. In the northern subarea, the year class strength of 2-year-olds in the shallow-water survey and 3-year-olds in the acoustic survey displays a positive relationship (Figure 3.8.3). Earlier attempts to estimate recruitment of saithe has revealed low correlation between the estimated index and abundance of adult stock (Nedreaas 1994). However, the comparison between the acoustic- and the shallow-water survey still provides too few year classes to give a proper evaluation. Furthermore, increased effort should be put into age readings of saithe, as lack of aging makes the comparison between the two surveys less reliable. For pollack, recruits were not as well represented in the catches. This, together with the patchy distribution of catches and lack of age readings, constraints the ability of this study to provide an index for 0-2-year old pollack.

4.3 Limitations to the method

The gear selectivity was not accounted for in the preceding analysis. Though both fyke nets and trammel nets have a fairly low selectivity compared to e.g gill nets, non-selective fishing gears do not exist (Salvanes 1991). In addition to the population structure, there are numerous parameters that affects lengths of fish and species to be caught by the nets, including fish behavioural patterns, the net construction, environmental conditions etc. (Holst et al. 2005). As this limits the degree of random sampling, the selectivity of the gears should be accounted for. Still, similar catch frequencies of both fyke nets and trammel nets have been found in previous studies (van der Meeren 2017; Salvanes 1991). This, in addition to the standardization of the survey design between location and year, makes it reasonable to assume the catch length frequencies are representable for the populations.

The inadequate age readings for saithe and young pollack caused serious uncertainty related to the allocation of age to unaged fish. However, there has not been put too much emphasis on this, as there are several factors limiting the possibilities of obtaining indices for these species with the method used. Nevertheless, if the survey is proceeded with saithe as target species, a higher effort should be invested in sampling otoliths.

Possible limitations to the conducted generalized linear mixed effect models (GLMM) should be considered when evaluating the results. Year and gear, in addition to the random effect of location, were the only factors governing the resulting CPUE in these models. One should not dismiss the possibility of additional factors affecting the recruitment, as these could be numerous. Depth of gears was available in the data set. This was included in the models at an early stage of the data analysis, but did not seem to provide more explanation to the variability and was thereby excluded from further analysis.

Finally, it must be emphasised that the time series is still quite short, due to the exchange between subareas every second year. This limits the evaluation of the indices, as there are still few year classes to be traced in the adult stocks. Moreover, this made it not possible to compare the actual estimated indices of cod, only the mean CPUE of fyke nets. Still, the mean CPUE constitutes the basis of the indices, giving a good indication of the level of recruitment. Trammel nets were excluded from this comparison because of poor catches of recruits. The survey should continue with both subareas covered each year, in order to give a more thorough evaluation.

4.4 Future implications of the results

As Norwegian coastal cod north of 62º is mostly caught as by-catch in the Northeast Arctic cod fishery, less emphasis is put into estimating the coastal cod stock (Bakketeig, Hauge & Kvamme 2017). Coastal cod is included in the acoustic coastal survey, but with serious limitations (Mehl et al. 2017). Management advices are based on the current rebuilding plan. However, a new rebuilding plan is strongly recommended by ICES (ICES 2018a). Indices from the present study could provide valuable information to the stock estimation. Today, coastal cod north of 62º N is managed as one unit (Bakketeig, Hauge & Kvamme 2017). However, the population seems to consist of several local subpopulations. Each fjord system along the coast might house a self-recruiting stock that cannot rebuild itself if completely depleted (Dahle et al. 2018; Myksvoll 2008). Recruitment indices from the shallow-water survey might be a step towards more local management of the stocks, as one could predict the recruitment in the northern and southern subarea separately. Here, the time series has been divided at 65ºN, but as the time series gets longer, more data will be available and recruitment indices might be suggested at an even more local level.

Reliable estimates of recruitment is one of the biggest challenges in Norwegian saithe fishery today (ICES 2018c). Though the method used in this study failed to provide indices for saithe, results could still provide information on trends in CPUE of the recruits, providing useful information to the fishery.

5 CONCLUSION AND IMPROVING SUGGESTIONS

Overall, the data suggests that fyke net is a suitable gear for catching recruits of cod, while the trammel nets mostly caught larger individuals. Nearly 70% of the cod and saithe catches were recruits, while 35% of pollack catches were recruits. However, the distribution of both saithe and pollack catches were too patchy for estimating recruitment indices with the current statistical analyses. Therefore, indices could only be suggested for coastal cod. There are still too few year classes from the shallow-water survey to be traced as 3-year-olds in the acoustic coastal survey for a proper evaluation of the indices. However, preliminary results suggest that the estimated index of 2-year-old cod gives a good indication of year class strength, as there was a positive relationship between mean CPUE of 2-year-olds in the shallow-water survey and the acoustic index of the same year classes as 3-year-olds in the northern subarea. The same relationship was found for mean CPUE of saithe in the northern subarea, indicating that the data could also provide estimates of recruitment for the Northeast Arctic saithe fishery. In that case, more effort should be put into age readings of saithe. There are no time series for pollack in this area that could be used in comparison with the recruitment indices from this study. Nevertheless, because of few recruits in the pollack catches, combined with the irregularity of the catches, the current methods are evaluated as unsuitable for obtaining recruitment indices of pollack. It is recommended that the shallow-water survey should continue with cod and saithe as target species in order to give a proper evaluation of the indices, preferably in both subareas each year. As a resource-saving measure, the trammel nets could be excluded from the survey, as the fyke nets both caught more recruits, and an overall higher number of individuals.

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7 APPENDICES

Appendix I: Age data

a) Cod in the northern subarea

Total number of cod caught in the northern subarea in 2013, 2016 and 2018 all together, by age and length. NA`s are lacking age and have been assigned an age by using an ALK.

	Age											
Length [cm]	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**NA**	**Total**
6	3											3
7	5	1									1	7
8	13		1								16	30
9	29										42	71
10	25										30	55
11	25	1									18	44
12	16										3	19
13	2	3										5
14	2	4										6
15	1	9										10
16		14	1								2	17
17		36	2								3	41
18		63									8	71
19	1	73									5	79
20		75									12	87
21		72									11	83
22		73	6								10	89
23		66	8								6	80
24		35	8								8	51
25		29	10	1							7	47
26		23	17	1							8	49
27		22	11	1							3	37
28		9	31								6	46
29		6	29								15	50
30			31	2							6	39
31		2	48	3	1						9	63
32			48	9	1						4	62
33		2	45	3	1						6	57
34		2	46	10							6	64
35			53	5	2						5	65
36			37	12							4	53
37			34	17	1		1				4	57

38		1	18	17	4	1					4	45
39			19	16	6						10	51
40			18	16	5	1					5	45
41			17	17	4						2	40
42		1	16	25	10						3	55
43		1	13	17	9						1	41
44			3	20	8						3	34
45			10	19	8	1	1				1	40
46			5	14	5	1						25
47				10	5		1				2	18
48			1	13	5	1		1			2	23
49			2	11	7	1		1			3	25
50				15	20	1					3	39
51				8	13	2	2				2	27
52				6	7	6	2				1	22
53				7	16		2			1		26
54			1	4	8	3	5	1				22
55				5	8	8	8					29
56				3	6	2	4	2			1	18
57				2	14	4	2				3	25
58				2	6	4			1		1	14
59				1	1	5	5	1				13
60				1	6	8	2	1		1	3	22
61				1	4	1	6		1		1	14
62					4	4	2		1	1		12
63					1	1	5		1			8
64					1	1	3		1		1	7
65					5	1	8		2	1	1	18
66					1	2	5	1	1			10
67				1	2	2	2	1				8
68					1		1	3				5
69					1		2					3
70						1	4					5
71					1							1
72						1	1	1				3
74					1		1		2	2		6
75						1				1	1	3
76						1	2					3
77										1		1
80						1						1
81									1			1
83						1	1					2
88							1					1
104										1		1
Totalt	**122**	**623**	**589**	**315**	**209**	**67**	**79**	**13**	**11**	**9**	**312**	**2349**

b) Cod in the southern subarea

Total number of cod caught in the southern subarea in 2015 and 2017 all together, by age and length. NA`s are lacking age and have been assigned an age by using an ALK.

	Age										
Length [cm]	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Totalt**
5	1										1
7	3										3
8	8										8
9	16										16
10	22										22
11	14										14
12	9										9
13	9										9
14		4									4
15		9									9
16		7									7
17		23									23
18		25									25
19		23									23
20		37									37
21		41									41
22		40									40
23		25									25
24		28									28
25		26									26
26		18									18
27		12									12
28		13	8								21
29		5	10								15
30			14	3							17
31			18								18
32		2	16	2							20
33			8	6							14
34			8	4							12
35			16	9							25
36			26								26
37			9	10							19
38			20	6	3						29
39			12	6							18
40			3	8		6					17
41				13			4				17
42			9	5		3					17
43			3	4							7

44			5	5							10
45			8		6	3	2				19
46				8	5						13
47			7								7
48			2	7			2				11
49				2	2						4
50			5	4		1	4				14
51				8	4						12
52					4	3					7
53				3	4						7
54				4	5						9
55				8							8
56				8							8
57				7							7
58					6	6					12
59				3			2				5
60					4	4					8
61						1					1
62						4	3				7
63						2	2				4
64					5						5
65					2	4	2				8
66					4	2					6
67							1				1
68								5			5
69						2					2
70					7						7
71									4		4
72								2			2
73						1					1
74							2				2
75						2	1				3
77									1		1
82								1			1
98										1	1
Totalt	**82**	**338**	**207**	**143**	**61**	**44**	**25**	**8**	**5**	**1**	**914**

c) Saithe

Total number of saithe caught for all years together. No age readings were available, and individuals were grouped with ALK`s from the acoustic survey along the Norwegian coast (Mehl et al. 2016; Mehl et al. 2015; Mehl et al. 2013; Mehl et al. 2014; Mehl et al. 2017).

Length [cm]	**Age** **NA**	**Totalt**
7	1	1
8	6	6
9	14	14
10	36	36
11	41	41
12	97	97
13	175	175
14	219	219
15	179	179
16	56	56
17	7	7
18	1	1
19	2	2
20	3	3
21	6	6
22	11	11
23	22	22
24	27	27
25	45	45
26	13	13
27	3	3
28	4	4
29	8	8
30	5	5
31	7	7
32	11	11
33	36	36
34	32	32
35	30	30
36	25	25
37	7	7
38	11	11
39	9	9
40	14	14
41	10	10
42	6	6
43	10	10
44	3	3
45	2	2
46	3	3
47	1	1

48	1	1
49	3	3
50	2	2
51	1	1
52	2	2
53	1	1
54	2	2
55	1	1
56	1	1
57	2	2
60	1	1
63	1	1
Totalt	**1216**	**1216**

d) Pollack

Total number of pollack caught through all years of survey. NA`s are lacking age and are assigned an age based on ALK`s from this data and from the Masfjord-data for individuals <35 cm.

	Age													
Length [cm]	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**11**	**12**	**NA**	**Totalt**
2													1	1
5													1	1
7													2	2
8													9	9
9													18	18
10													7	7
11													7	7
12													6	6
13													5	5
14	1													1
15		1											3	4
16													4	4
17													3	3
18													7	7
19		6											20	26
20		8											30	38
21		4											27	31
22		3											31	34
23		5											24	29
24		2											8	10
25		1											6	7
26			1										1	2
27			1										1	2
28			1										1	2

29			2										3	5
30			3	1									1	5
31				1									3	4
32			3										9	12
33			2										9	11
34			2	2									17	21
35			4	8									21	33
36			2	4	1								10	17
37			1	12	1								12	26
38			1	8									14	23
39				10	2								10	22
40				20	4	1							21	46
41				5	5	1							10	21
42				7	6		1						7	21
43				10	6								6	22
44				4	5	3	1						7	20
45				9	13	8	1						15	46
46				2	12	6							11	31
47				3	10	8	1						8	30
48				1	8	5							4	18
49				1	2	2	2						10	17
50				1	9	7	1						9	27
51					6	2				1			3	12
52					4	2	1	1					10	18
53					6	9	1	1					7	24
54		1		1	3	5							5	15
55						7	7	3					11	28
56					1	4	2						3	10
57					2	3	1						6	12
58					1	4	1	1					7	14
59						5		1					3	9
60						8	3						3	14
61						2	3		1				2	8
62						1							4	5
63						4	1	1	1				2	9
64							1	2		1			2	6
65							3	1					1	5
66									1				2	3
67								1					2	3
68							1		2				1	4
70								1					2	3
71							1							1
74							1				1			2
77										1	1			2
78										2				2
79												1		1
80										1				1
Totalt	**1**	**31**	**23**	**110**	**107**	**97**	**34**	**13**	**5**	**6**	**2**	**1**	**515**	**945**

Appendix II: Age data for pollack from Salvanes (1995)

Raw data from Salvanes (1995) showing length at age for pollack in Masfjorden. These were used to calculate age length relationships for pollack under 35 cm. For pollack above this length, data from the SW survey was sufficient for calculating the relationship.

Length [cm]	Age											
	0	1	2	3	4	5	6	7	8	9	(blank)	Grand Total
2				2								2
12	12										12	24
14	28										14	42
15	180	30										210
16	368	16										384
17	391										17	408
18	108	18									18	144
19	57	76										133
20	20	240										260
21		357										357
22		682										682
23		1311									46	1357
24		2040	24								24	2088
25		3575									75	3650
26		4602									78	4680
27		4509									135	4644
28		3108	84								84	3276
29		2523	174								145	2842
30		1590	480								60	2130
31	62	930	806	31							155	1984
32		416	576								64	1056
33		330	1056	66							66	1518
34		136	1394	68							136	1734
35			980	175							70	1225
36		36	1260	540							72	1908
37			851	481							74	1406
38			988	532							76	1596
39			702	819	117						39	1677
40			480	640	40						40	1200
41			123	533	82	82					41	861
42				714	126	168						1008
43		43		774	129	86					43	1075
44				880	220	220	44				44	1408
45				315	180	135					45	675
46				506	276	46					46	874
47			47	188	235	94	94	47				705
48				288	384							672
49				245	490	98						833
50				100	300	100	50	50			50	650
51				51	561		102		51			765
52					260	260						520
53					106	159	53					318
54					54	216		54				324

55					55	165	55					275
56						112	168	56				336
57					57	57						114
58						58	116		58			232
59						118						118
61					61		122	61				244
65							65					65
66								132				132
73										73		73
Grand Total	1226	26568	10025	7948	3733	2174	869	400	109	73	1769	54894

Appendix III: R scripts

a) ALK for Cod.

Following procedure was conducted for each year separately (Ogle 2016).

```
#Place all individuals in a length interval of 10 cm:

TORSK2018 %<>% mutate(lCat10=lencat(length.cm, w=1,as.fact = TRUE,
drop.levels = FALSE))

# Separate the original data frame to “aged” and “unaged”:

TORSK.unaged <- filter(TORSK2018, is.na(age))
TORSK.aged <- filter(TORSK2018, !is.na(age))

# Calculating frequency of fish in each length interval by age:

alk.freq <- xtabs(~lCat10+age,data = TORSK.aged)

# Create the ALK with conditional proportions of each length interval
instead of frequency:

alk <- prop.table(alk.freq, margin = 1)

# Plot ALK

alkPlot(alk, type="area", pal="rainbow", showLegend = TRUE,
```

```
        leg.cex = 0.7, xlab = "Total Length (cm)")

alkPlot (alk, type = "bubble", xlab="Total Length (cm)")      #Bubble plot

#Assigning age to unaged individuals:

TORSK.unaged.mod<-alkIndivAge(alk,age~length.cm, data = TORSK.unaged)

#Binding the “unaged” and “aged” dataframes back together

TORSK2018.all.aged <- rbind(TORSK.aged, TORSK.unaged.mod)

#Control that there are no individuals without an age:
any(is.na(TORSK2018.all.aged$age))

# Binding years of the same subarea back together:

TORSK.nord.aged  <-  rbind(TORSK2013.all.aged,  TORSK2016.all.aged, TORSK2018.all.aged)
```

b) Statistical analyses

Following statistical analysis was conducted for each age group of each specie to model the likelihood of catch. Here Examplified by one-year old cod:

```
torsk.1 <- subset(CPUE.torsk, CPUE.torsk$age == "1" |  CPUE.torsk$age == "NA")

m1  <-  glmer(dic.species~gear.x+year.y+(1|location),family=binomial, torsk.1)
m0    <-     glmer(dic.species~+year.y+(1|location),family=binomial, torsk.1)

anova(m1,m0,test="Chi")
summary(m1)
```

Following statistical analyses was performed for cod, to model CPUE. Here exemplified for 1 year olds:

```
TORSK.1 <- subset(CPUE.torsk, CPUE.torsk$age == "1" |  CPUE.torsk$age
== "NA")


m1  <-  glmer(species~gear  +  year  +(1|location),family=poisson,
TORSK.1)
m0 <- glmer(species~+year +(1|location),family=poisson, TORSK.1)


anova(m1,m0)
summary(m1)
```

c) Plotting mean fitted values together with raw data

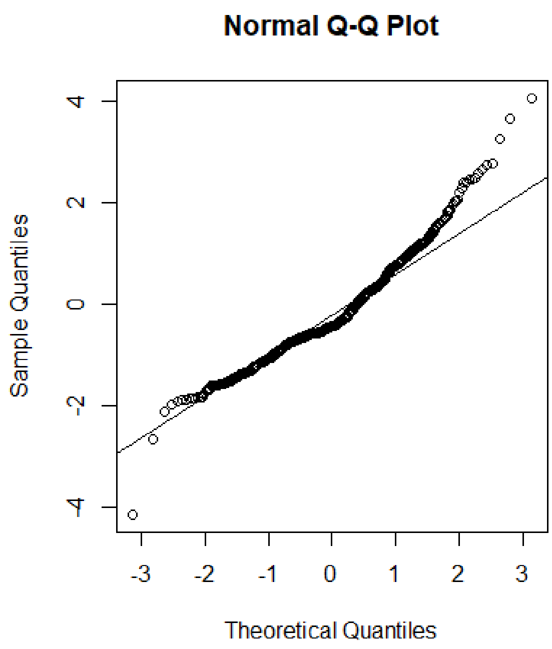
Basic R-script for plotting figure 3.4.1-3.5.1. Here exemplified by one-year old cod:

```
#Adding the fitted values to the dataframe:
TORSK.1$fit <- predict(m1, type="response")


#Calculating mean fitted values for each gear
mean.df <- aggregate(TORSK.1$fit,
                     by= list(gear = TORSK.1$gear),
                     FUN= function(x) c(mean= mean(x), sd= sd(x), n=
length(x)))
mean.df <- do.call(data.frame, mean.df) # To return vectors instead
of matrices


# Plot raw data together with mean fitted values from the model
p <- ggplot() +
  geom_jitter(data= TORSK.1, aes(gear,species),width = 0.2,colour=
"lightblue")+
  geom_point(data= mean.df, aes(gear,mean.fit),shape= 16, size=3)+
  theme_few()+
  xlab("Gear")+
  ylab("")+
  theme(axis.text=element_text(size=15),
        axis.title=element_text(size=16))
```

d) Plotting comparing plots

```
p <- ggplot(Torsk.ruse, aes(x = Indices, y=Ac..Indices)) +
  geom_point(aes(color = Yr.class, shape=Age.in.SWS), size = 3) +
  xlab("Mean CPUE [No.of fish per fyke net]") +  ylab("Acoustic index
at age 3 yrs [thousands]") +
  scale_color_manual(values=c("#FF0000", "#6699FF"))+
  scale_shape_manual(values = c(3))+
  theme_bw(base_size = 13) +
  theme(panel.grid.major   =   element_blank(),   panel.grid.minor   =
element_blank())+
  scale_y_log10(breaks = trans_breaks("log10", function(x) 10^x),
                labels = trans_format("log10", math_format(10^.x))) +
  scale_x_log10(breaks = trans_breaks("log10", function(x) 10^x),
                labels = trans_format("log10", math_format(10^.x)))
p
```

Appendix IV: Diagnostic plots from the generalized linear mixed effect models



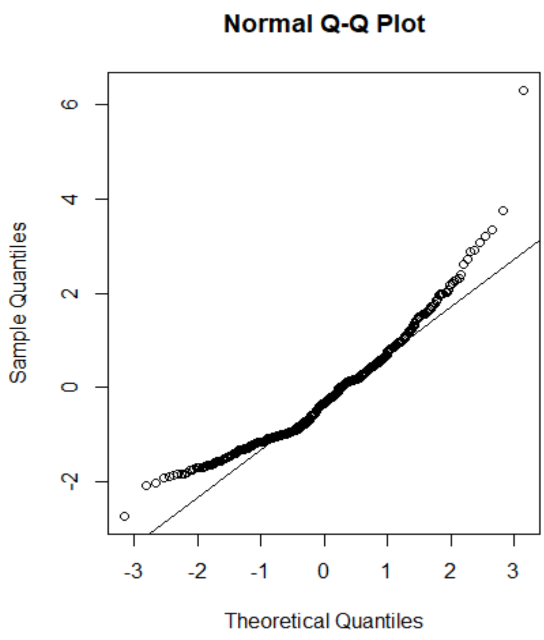


Figure 7.A – Normal distribution of the generalized linear mixed effect model on CPUE performed on 1-year old cod.

Figure 7.B – Normal distribution of the generalized linear mixed effect model on CPUE performed on 2-year old cod.

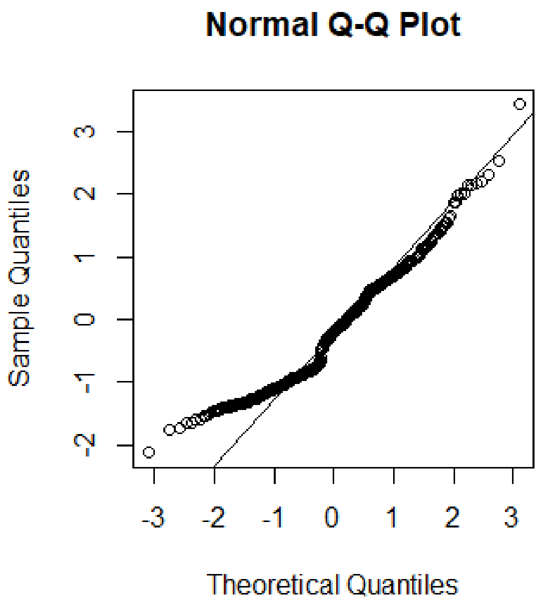


Figure 7.C – Normal distribution of the generalized linear mixed effect model on CPUE performed on 3-year old cod and older.

Appendix V: Comparison of mean CPUE of three-year old cod with acoustic index of four-year old cod.

Two year classes of cod were caught as 3-year olds in the shallow-water survey, that were detectable as 4-year olds in the acoustic survey in the northern subarea; 2010- and 2013 year class. These showed a positive relationship between mean CPUE as 3-year olds and acoustic index as 4-year olds (Figure 8.A).

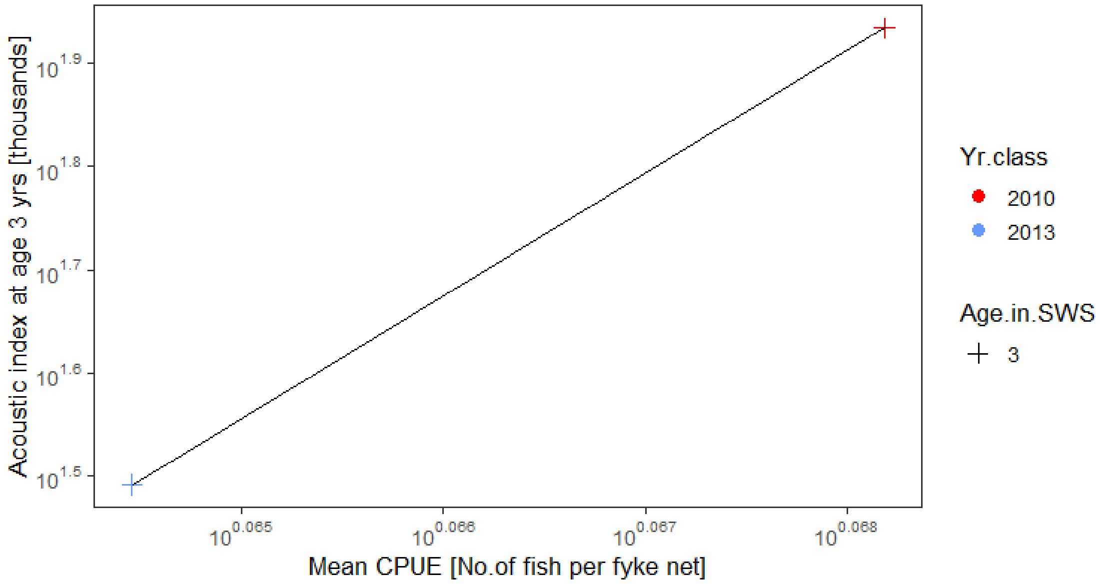


Figure 7.D – COD_North: Comparison between mean CPUE of 3-year olds caught by fyke nets from this study with indices of the same year classes as four-year olds from the acoustic survey in the north. Both axis are logarithmic.

The 2012 year class was the only year class caught as three-year old in the southern subarea, that were detectable in the acoustic survey as four-year olds. Hence, it is not possible to draw any conclusion on the relationship between mean CPUE and acoustic indices of cod in the south (8.B).

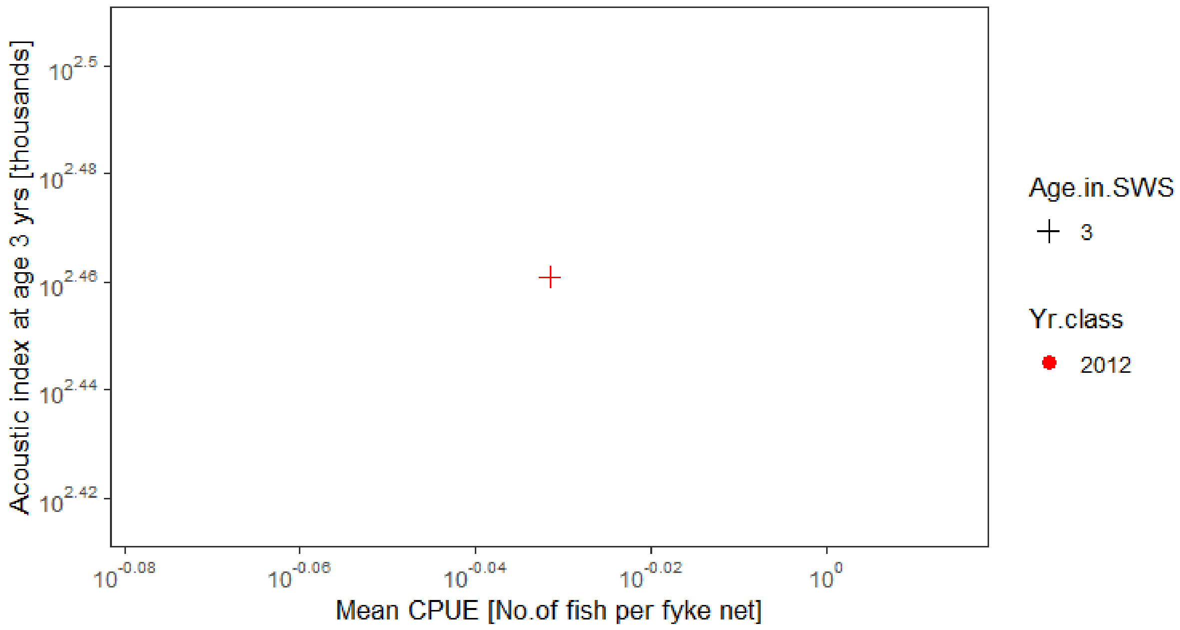


Figure 7.E – COD_South: Comparison between mean CPUE of three-year olds caught by fyke nets from this study with indices of the same year classes as four-year olds from the acoustic survey in the south. Both axis are logarithmic.

Appendix VI: Indices from the acoustic survey

a) Cod

Acoustic indices of coastal cod abundance along the Norwegian coast from 2013-2017, directly copied from the reports (Mehl et al. 2016; Mehl et al. 2015; Mehl et al. 2013; Mehl et al. 2014; Mehl et al. 2017). Areas comparable with subareas in this thesis are 06 (northern subarea) and 07 (southern subarea).

Tabell 11 Kysttorsk. Akustiske mengdeindeksar (i tusen) i kvart underområde og totalt i 2013.
Coastal cod. Acoustic abundance indices (in thousands) by sub areas and in total in 2013.

	Alder (Årsklasse) / *Age (Year class)*										
Område	1	2	3	4	5	6	7	8	9	10+	
Area	(12)	(11)	(10)	(09)	(08)	(07)	(06)	(05)	(04)	(03+)	Sum
03	2232	888	862	878	477	248	266	96	77	76	7538
04	2956	1663	998	1602	1267	1129	614	509	205	267	14242
05	569	133	99	254	245	144	119	81	5	47	2511
00	1498	154	202	186	328	338	84	86	160	29	6954
06	3223	388	620	623	425	209	59	197		12	7711
07[1]						4	23	4			30
Total	10478	3222	2780	3545	2742	2072	1164	971	449	431	27854

[1] Fjordane i område 07 ikkje dekka i 2013

Tabell 11 Kysttorsk. Akustiske mengdeindeksar (i tusen) i kvart underområde og totalt i 2014.
Coastal cod. Acoustic abundance indices (in thousands) by sub areas and in total in 2014.

	Alder (Årsklasse) / *Age (Year class)*										
Område	1	2	3	4	5	6	7	8	9	10+	
Area	(13)	(12)	(11)	(10)	(09)	(08)	(07)	(06)	(05)	(04+)	Sum
03	1175	1739	1065	908	914	411	387	131	91	81	6902
04	2886	2685	1403	782	1769	1202	645	276	300	102	12050
05	725	348	410	565	986	649	692	535	557	469	5936
00	67	209	193	204	213	238	247	76		18	1465
06	162	505	243	86	387	14	46	35			1478
07	89	30	111	114	246	146	36	136	32	6	946
Total	5104	5516	3425	2659	4514	2660	2053	1189	980	676	28776

Tabell 11 Kysttorsk. Akustiske mengdeindeksar (i tusen) i kvart underområde og totalt i 2015.
Coastal cod. Acoustic abundance indices (in thousands) by sub areas and in total in 2015.

	Alder (Årsklasse) / *Age (Year class)*										
Område	1	2	3	4	5	6	7	8	9	10+	
Area	(14)	(13)	(12)	(11)	(10)	(09)	(08)	(07)	(06)	(05+)	Sum
03	919	1163	1430	831	483	440	244	170	206	90	5977
04	3100	2113	798	636	563	442	206	88	109	64	8120
05	479	307	394	449	246	419	264	222	103	179	3063
00	1112	198	240	486	107	212	245	39	23	68	2730
06	1328	1298	785	865	613	415	52	20	28		5405
07[1]		5	48	174	42	55	17	61	60	3	465
Total	6939	5084	3695	3441	2053	1984	1029	601	529	404	25759

[1] Sørlege fjordar i område 07 ikkje dekka i 2015

Tabell 11 Kysttorsk. Akustiske mengdeindeksar (i tusen) i kvart underområde og totalt i 2016.
Coastal cod. Acoustic abundance indices (in thousands) by sub areas and in total in 2016.

Område *Area*	Alder (Årsklasse) / *Age (Year class)* 1 (15)	2 (14)	3 (13)	4 (12)	5 (11)	6 (10)	7 (09)	8 (08)	9 (07)	10+ (06+)	Sum
03	2360	1967	1309	967	556	179	175	91	58	106	7767
04	1806	1677	1955	946	689	350	325	268	69	122	8208
05	459	136	520	1022	699	550	174	471	15	121	4167
00	49		41	475	783	203	241	33	6	3	1834
06	177	434	722	62	162	138	86	41	22	10	1855
07	6		303	289	220	36	21	51	15	111	1050
Total	4857	4214	4850	3760	3108	1455	1022	955	187	474	24881

Tabell 5.3.2 Kysttorsk. Akustiske mengdeindeksar (i tusen) i kvart underområde og totalt i 2017.
Coastal cod. Acoustic abundance indices (in thousands) by sub areas and in total in 2017.

Område *Area*	Alder (Årsklasse) / *Age (Year class)* 1 (16)	2 (15)	3 (14)	4 (13)	5 (12)	6 (11)	7 (10)	8 (09)	9 (08)	10+ (07+)	Sum
03	202	1011	1301	637	470	283	95	73	83	45	4200
04	1088	1989	1903	1510	697	434	190	155	68	147	8179
05	309	669	724	521	917	587	301	166	79	41	4314
00	98	198	387	69	47	11	0	11	7	0	828
06	15	41	60	31	27	22	12	15	10	0	234
07	0	41	28	142	61	75	65	15	1	1	430
Total	1712	3950	4402	2910	2220	1412	664	436	248	234	18186

b) Saithe

Acoustic indices of abundance along the Norwegian coast from 2013-2017, directly copied from the reports (Mehl et al. 2016; Mehl et al. 2015; Mehl et al. 2013; Mehl et al. 2014; Mehl et al. 2017). Areas comparable with this thesis are C (northern subarea) and D (southern subarea).

Tabell 4 SEI. Akustiske mengdeindeksar (i millionar) i kvart underområde og totalt i 2013.
SAITHE. Acoustic abundance indices (in millions) by sub area and in total in 2013.

Område *Area*	Alder (Årsklasse) / *Age (Year class)* 1 (12)	2 (11)	3 (10)	4 (09)	5 (08)	6 (07)	7+ (06+)	Sum
A	2.8	2.9	45.0	6.8	7.0	5.9	2.6	73.0
B	0.0	3.7	36.3	6.3	1.9	1.9	1.3	51.4
C	0.0	0.0	2.2	2.3	1.6	1.4	0.7	8.2
D	0.0	6.3	29.8	4.4	0.4	1.9	1.1	43.9
Total	2.8	12.8	113.4	19.8	10.9	11.1	5.6	176.5

Tabell 4 SEI. Akustiske mengdeindeksar (i millionar) i kvart underområde og totalt i 2014.
SAITHE. Acoustic abundance indices (in millions) by sub area and in total in 2014.

Område *Area*	Alder (Årsklasse) / *Age (Year class)* 1 (13)	2 (12)	3 (11)	4 (10)	5 (09)	6 (08)	7+ (07+)	Sum
A	3.3	4.2	2.9	25.6	7.8	4.0	5.7	53.4
B	0.1	6.2	12.3	36.0	1.7	2.2	3.6	62.2
C	0.0	2.7	2.5	5.3	3.1	0.4	2.0	16.0
D	0.0	12.1	22.3	20.9	2.3	2.1	1.8	61.5
Total	3.4	25.2	40.1	87.8	14.9	8.7	13.2	193.1

Tabell 4 SEI. Akustiske mengdeindeksar (i millionar) i kvart underområde og totalt i 2015.
SAITHE. Acoustic abundance indices (in millions) by sub area and in total in 2015.

Område *Area*	Alder (Årsklasse) / *Age (Year class)* 1 (14)	2 (13)	3 (12)	4 (11)	5 (10)	6 (09)	7+ (08+)	Sum
A	0.1	8.8	12.7	14.4	18.4	2.5	5.2	62.0
B	0.0	25.1	48.2	5.7	9.7	3.7	3.2	95.6
C	0.0	0.1	5.0	3.9	1.5	0.5	0.9	11.9
D	0.0	45.3	6.3	5.0	4.7	0.8	0.3	62.5
Total	0.1	79.2	72.3	29.0	34.2	7.5	9.7	232.1

Tabell 4 SEI. Akustiske mengdeindeksar (i millionar) i kvart underområde og totalt i 2016.
SAITHE. Acoustic abundance indices (in millions) by sub area and in total in 2016.

	Alder (Årsklasse) / *Age (Year class)*							
Område *Area*	1 (15)	2 (14)	3 (13)	4 (12)	5 (11)	6 (10)	7+ (09+)	Sum
A	1.1	10.4	31.9	25.0	11.1	9.0	8.1	96.8
B	0.1	32.4	40.9	11.3	3.2	5.6	3.2	96.9
C	0	0.4	7.5	3.6	0.7	0.9	1.2	14.2
D	0	10.3	54.9	2.7	0.5	0.5	1.3	70.2
Total	1.2	53.6	135.3	42.7	15.4	16.1	13.8	278.1

Tabell 5.2.2 SEI. Akustiske indeksar (i millionar) i kvart underområde i 2017 estimert med StoX.
SAITHE. Acoustic indices (in millions) by subarea in total in 2017 estimated by StoX.

	Alder (Årsklasse) / *Age (Year class)*							
Underområde *Subarea*	1 (16)	2 (15)	3 (14)	4 (13)	5 (12)	6 (11)	7+ (10+)	Sum
A	32.7	17.0	35.7	36.1	7.49	1.13	5.78	136.0
B	2.68	4.25	41.1	15.0	2.54	0.86	1.55	67.9
C	0.00	0.20	8.74	6.83	1.67	0.09	0.27	17.8
D	0.00	2.10	5.54	6.01	1.63	0.69	1.14	17.1
Total	35.4	23.6	91.1	63.9	13.3	2.77	8.74	238.8