Spatial and temporal variations in bycatch of Cod (*Gadus morhua)* and Golden Redfish (*Sebastes norvegicus)* in the Norwegian saithe fishery

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ABSTRACT

Reducing bycatch is a crucial measure in avoiding overexploitation of vulnerable fish stocks. Challenges occur in mixed fisheries as vulnerable and depleted stocks function as a 'choke species', reducing potential yields from healthy stocks. Improving knowledge about spatial and temporal patterns to develop improved species, area and gear-specific management advice could serve a viable option in avoiding the catch of unwanted species. Norwegian Coastal cod (*Gadus morhua)* and golden redfish (*Sebastes norvégicus)* are two commercially exploited species experiencing considerable declines in the last decade and are caught as bycatch in the saithe fishery of Norway. Saithe is one of Norway's most commercially viable demersal fisheries, landing around 150-200 thousand tonnes annually. This thesis aims to investigate spatial and temporal variations in bycatch of cod and golden redfish across gear types, areas, years, seasons, and depths. Daily logbooks and sales notes provided by the Norwegian Directorate of Fisheries (NDF) are analyzed qualitatively to identify hotspots of increased bycatches in both large (>15m) and small vessels (<15m) in the Norwegian saithe fishery between 2015 and 2021. The results demonstrate that the northern regions, mainly north of 67° latitudes, experience intensified fishing efforts, leading to substantial bycatch of both target species. Bottom trawling emerges as the primary fishing method associated with bycatch of both species in large vessels, followed by Danish seine. Meanwhile, set nets contribute the most to bycatch amongst small vessels, having proportionally higher bycatch than large vessels. There was a quarterly effect on bycatch, for both cod and golden redfish. Furthermore, this study identified hotspots of bycatch, such as north of Sørøya, Malangsbanken, Fugløybanken, Arnøya, in the Barents and Norwegian Sea. Hotspots were observed in the North Sea on the edge of the Norwegian Trench, the northern Fladen Ground, and southwest of the Shetland Islands. The overlapping spawning areas and aggregations of the target and study species contribute to the elevated levels of bycatch. Based on these findings, future research should explore the depth and spatial segregation between Norwegian costal cod and Northeast arctic cod and the length distribution at golden redfish depths to gain insights into potential depth-specific habitat preferences. This knowledge will inform targeted management strategies for mitigating bycatch and promoting sustainable fishing practices in the saithe fishery and beyond.

1. INTRODUCTION

1.1 SAITHE FISHERY OF NORWAY

The saithe (*Pollachius virens*) fishery of Norway is part of the Norwegian mixed fishery and is one of the most commercially viable species caught in Norway (Mehl *et al.*, 2011). The average annual catch in the last five years in the Norwegian and Barents Sea saithe is approximately 170 000 tonnes, and in the North Sea, 77 000 tonnes (ICES, 2015, 2022c). Different types of bottom trawls are the dominating fishing gear used in the North Sea (86%) and the Norwegian and Barents Sea (43,4%). Gear types such as purse seine (16,4%), gill nets (15,7%), and other conventional gear (15%) (longlines, Danish seine and handline) is extensively used to land saithe in the Norwegian and Barents Seas (Mehl et al., 2011). The fishery is divided into a coastal fleet, mainly consisting of boats less than 15 meters, and a high-seas fleet consisting of boats larger than 15 meters. Saithe is a migratory demersal species belonging to the family *Gadidae*, and is known to occur pelagically (Mehl et al., 2011). During springtime, it draws closer to coastal waters and moves to deeper water in wintertime (Heino *et al.*, 2012; Olsen *et al.*, 2010). The population is divided into the Northeast arctic saithe (NEA saithe) and North Sea saithe (NS saithe) but mixing between populations is known to occur. Mature individuals from the coast of Northern Norway undertake spawning migrations to the western coast and northern North Sea (Jakobsen, 1985). NEA saithe is distributed along the Norwegian coast from Stadt to the Kola peninsula, and it spawns on the coastal banks from Lofoten to the North Sea from January to Mars. The NS saithe's distribution is in the northern North Sea and Skagerrak and spawns in February to marsh on Eggakanten, west of Shetland to Vikingbanken (ICES, 2015; Jakobsen *et al.*, 2011; Moen, 2014).

1.2 BYCATCH

Bycatch is a global issue due to wasteful use of protein resources. The increased demand of protein due to rapid growing in populations, requires improved utilization of unexploited resources. The issue of bycatch is complex, caused several factors including the use of low-selective fishing methods, limitations in accurately observing the catch until it surfaces, and the overlapping distribution of fish stocks (Boyce, 1996). Bycatch is defined as the unselective catch of non-target species (Davies *et al.*, 2009). Global estimates suggests that 40% of annual marine landings are bycatch (Davies et al., 2009). Typical cases of unwanted bycatch are birds, jellyfish, marine mammals, elasmobranchs and sea turtles (Komoroske *et al.*, 2015; Lewison *et al.*, 2004). Protected species are considered unwanted catch. The ban on targeting blue ling in Norway is an example of a protected and unwanted catch (Forskrift om blålangefisket, 2009). Sufficient management requires clearly defined measures intended to precisely ensure the sustainable capture of any species available to the fishery operation (Davies et al., 2009).

A downside of regulating vulnerable species is potential short-term economic consequences for the fishermen. Management advice that ensures avoiding the overexploitation of vulnerable and threatened species is necessary, without reducing the yield from fast-growing stocks (Dolder *et al.*, 2018). Reducing the catch of unwanted species through spatiotemporal actions necessitates a comprehensive understanding of the fishery's spatiotemporal dynamics (Dolder et al., 2018). Bycatch-maps can be used in quantifying spatial patterns, allowing to focus mitigation efforts at identified "bycatch hotspots," i.e., areas of persistent bycatch events for one or multiple overexploited stocks (Lewison et al., 2004; Yeh *et al.*, 2013).

Fisheries that typically suffer from significant bycatch are shrimp trawling and demersal finfish trawling (Kelleher, 2005). Shrimp trawling is a widespread fishery, with the highest bycatch rates out of any fishery (Davies et al., 2009; Mendo *et al.*, 2022). The total estimated discard rate of tropical shrimp trawling is 27% (Kelleher, 2005). High-selectivity gear types such as purse-seines, handlines, jigs, traps, and pot fisheries have lower discard rates (Pérez Roda, 2019). According to Clegg et al. (2020), gear types catching the highest numbers of fish species in coastal fisheries are bottom gillnets and longlines in the northern region, and bottom gillnets and shrimp trawl in the southern region. Equivalently for high-sea fisheries, bottom trawl land the most fish-species in north of 62°N, and industrial trawl and bottom trawl south of 62° N latitude.

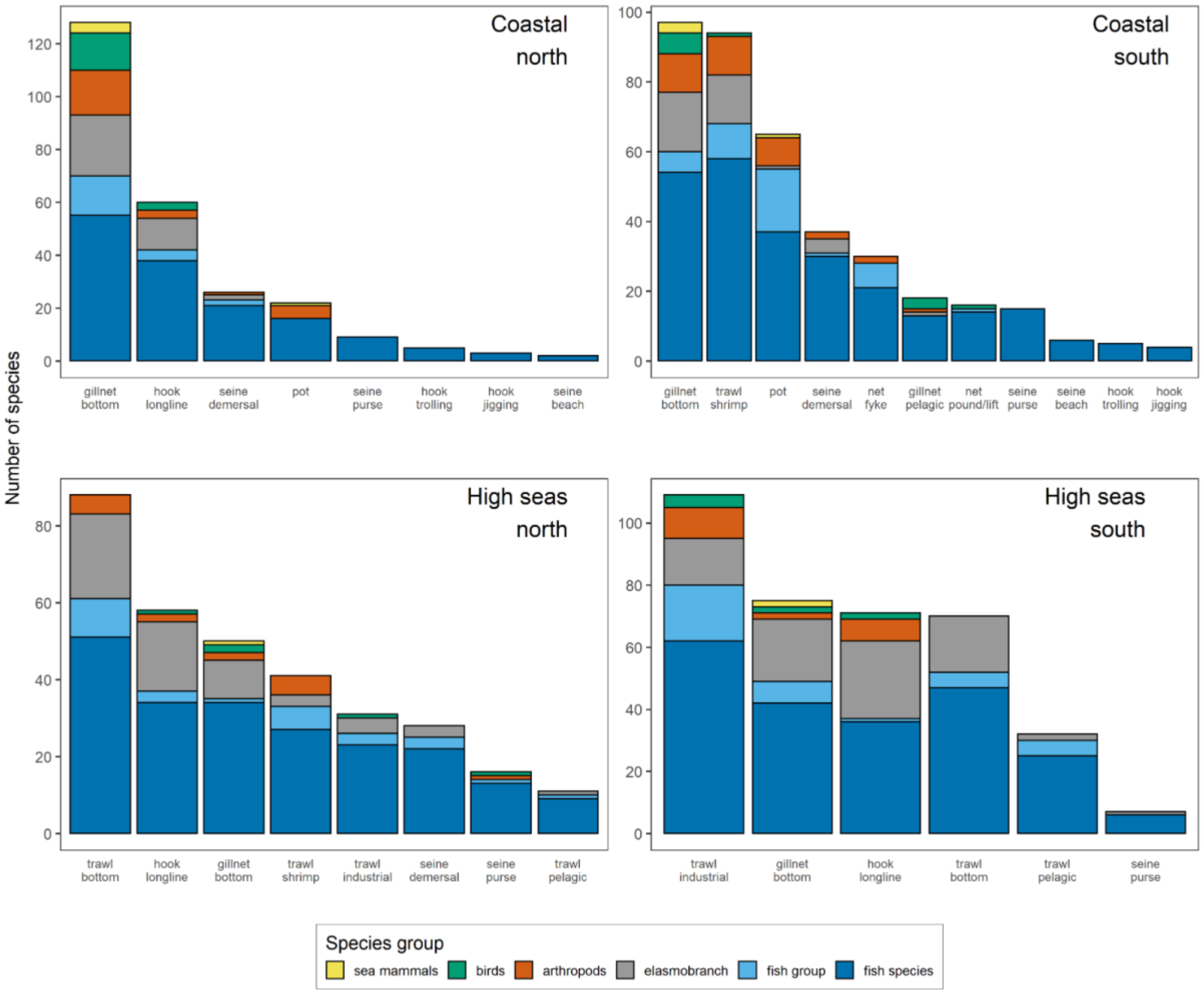

Figure 1*:* Summary of species caught and the composition per gear type, by the Norwegian Reference Fleet. North/South is relative to 62°N latitude (Clegg, 2020).

1.3 DISCARDING

Discards are the thrown-away or dumped portion of the total catch before landing. The reason can differ, such as the catch of unwanted species of low or no marketable value and threatened species.(Clegg, 2022; Davies et al., 2009). Discarding in Norwegian fisheries is illegal by law, known as the discard ban. Catches that violate regulations must be brought to shore by fishermen, in accordance with the landing obligation (Havressurslova, 2008,§15). The landing obligation was fully enforced in Norway in 2009 (Borges, 2015). Motives for discarding are many; catch being below legal minimum landing size (MLS), lack of quota, species of low/no value, or damaged catch. Discards are an issue in stock management because when not reported, the data is unavailable to statistics, introducing bias to fishing mortality estimates (f) and inaccurate conclusions in stock assessment (Casey,1996; (Cook, 2019). The Norwegian Reference Fleet is an effort implemented in Norway by the Institute of Marine Research (IMR) in collaboration with commercial fishing vessels (Williams, 2020). One of the goals with this implementation of the reference fleet is to improve precision of discard estimates.

1.4 MITIGATION PRACTICES

Recent bycatch research has led to increased efforts developing bycatch-reducing gear and devices, driven by a better understanding of the affected species, the scale of the issue, and its spatial distribution (Komoroske et al., 2015). Technological development has improved the efficiency and effort of commercial fisheries(Jenkins *et al.*, 2022). For instance, trawl cameras and sensors are used to observe the catch enter prior to- and during the fishing operation which may increase the precision of catch identification (Rosen *et al.*, 2013). Bycatch reduction devices (BRDs) are modifications designed and developed to make existing fishing gear more size- and/or species selective, altering the effort towards older/larger fish or specific species. Examples are sorting grids, excluder systems, and grid panels (Brinkhof *et al.*, 2022; Grimaldo *et al.*, 2023; Rose *et al.*, 2022). An equally important tool is the fishermen's knowledge about biotic and abiotic factors and gear knowledge, in addition to the transfer of such knowledge within and between communities. The adoption process is slow, and the yield of introducing the solutions has yet to prove significant change (Jenkins et al., 2022).

Fishing strategy is defined as the choice of a combination of fishing gear, area, target species and season (Salas *et al.*, 2004; Yletyinen *et al.*, 2018). Having various fishing strategies available gives the fishermen a better ability to face environmental, regulatory, and economic changes. Fishing strategy can be used to alter the fishing pressure on specific stocks. Utilization of fine-scale experience and knowledge about spatial and temporal aspects of fish stocks can be a valuable tool in mitigating unwanted catches and discards in mixed fisheries. Spatiotemporal solutions are recognized by fishermen (Calderwood *et al.*, 2021), despite lack of formal management advice concerning such measures.

1.5 MIXED FISHERIES

Mixed fisheries are the predominant type of fishery worldwide, where the catch of several fish species during the same fishing operation is known as a "technical interaction" (Biseau, 1998). The North Sea demersal fisheries are a representative example of mixed fisheries where many target and bycatch species are caught together (Kühn *et al.*, 2023). If a species is managed by individual quotas and catches do not match available stock quotas, a vessel must stop fishing when filling the first quota, described as a "choke" species (Baudron *et al.*, 2015). Alternatively, a weaker species' overexploitation occurs as fishers continue to catch healthier stocks. Therefore, scientific tools to simplify the complexities of mixed fisheries are needed to help achieve a compromise between under-harvesting healthy stocks and overharvesting vulnerable stocks (Hilborn *et al.*, 2019).

1.6 GEAR SELECTIVITY

Several gear parameters, that differ between gear, affect selectivity. Gear parameters, depending on the gear type, are tow speed, mesh size, soak time, mesh shape, net dimensions, and vertical slack. The main determinant of gillnet catchability is often considered to be the fish girth, as the species-selection ability is compromised when multiple species fall within the selection range (Reis *et al.*, 1999). Fish-related parameters include fish availability, shape (girth), size, bait type and behaviour. Typical low-selection gear types are different types of bottom trawls. Gear types considered to be more selective are purse seine, jigging and bottom gillnets. According to a report on monitoring bycatches in Norwegian fisheries from IMR, low selectivity gear types catching the highest number of species are gill nets and shrimp trawls by the coastal fishery and bottom and industrial trawls in the high-seas fishery (Clegg, 2020). Bottom trawls are the most significant annual contributor to seafood production on a global scale but produces the most bycatch discards. An assessment from FAO on global discards revealed that average discard rates (2010-2014) in bottom trawls was 21.8%, and 10.1% in gillnets, with the bulk coming from bottom gillnets (Pérez Roda, 2019).

1.7 QUOTA FLEXIBILITY

Quotas in Norway are determined based on advice from the marine research community, nationally (IMR) and internationally (ICES). The NDF distributes quotas to commercial vessel groups for every species available for the fishery. Catching a species without having a quota for it is considered bycatch. Bycatch-quotas are implemented as a bycatch-regulation, making the bycatch marketable for the fishermen holding a quota. A portion of the annual TAC (Total Allowable Catch) is reserved, species-wise, to be caught as bycatch in other fisheries. The bycatch-percentage of a species determines the portion of bycatch allowed in a total landing, and depends various factors, such as gear type, fishing area, target species and vessel size (Høstingsforskriften, 2021).

1.8 COD

Norwegian coastal Cod (NCC) is a commercially depleted fish stock suggestive of improvements in management (ICES, 2021b). The 62-degree latitudes separate the management of Norwegian cod: Northeast Arctic Cod and North Sea cod, respectively, and each includes a Coastal cod segment. While Northeast Arctic cod undertake an annual spawning migration from the Barents Sea to areas 00, 05, and 06 (Fig. 2) along the Norwegian coast from January to April, Norwegian coastal cod are known to inhabit fjords and coastal sea banks throughout their lifetime. In certain parts of southern Norway, North Sea cod are observed to make occasional migrations to the coastal areas. The distribution of the three cod stocks overlaps at spawning grounds during spawning season, at feeding grounds, and generally in fjords and coastal banks (Jakobsen, 1987; Jakobsen et al., 2011). Morphological similarities make them difficult to distinguish, but is possible based on otolith characters (Rollefsen, 1933). A theory presented by Marshall and Frank (1995) assumed to apply to gadoid stocks suggests that demersal species follow the 'ideal free distribution'; individuals avoid high densities to maximize their fitness. A large proportion of demersal fish species' diet consists of benthos, of which the availability and distribution are primarily affected by the nature of the sea bottom (Grey, 1974).

1.9 COD REGULATIONS

In Norwegian fisheries management, cod is treated as three separate stocks split into three regions: North of 67°N, between 62°N and 67°N, and south of 62°N. The Northern Shelf cod (NSC) stock is divided into three sub-areas, where the Viking sub-stock component is most accessible to the Norwegian fishery (ICES, 2023a). Current minimum legal catch lengths for cod are 44 cm and 40 cm north (both NEAC and NCC) and south (NSC and NCC) of 62° N, respectively, with allowance to have in total up to 15 % undersized individuals of cod, haddock, and saithe per catch (Høstingsforskriften, 2021). All regulations determined for NEAC also apply to NCC (ICES, 2021b). The annual cod quota set by the Ministry of Trade, Industry, and Fisheries is common for NEAC and NCC. The NEAC quota includes a proposed TAC (Total Allowable Catch) for Coastal Cod. Otolith shape analyses are used to estimate annual coastal cod catches post-fishing year (ICES, 2021a). To regulate the catch of undersized fish, the Norwegian Directorate of Fisheries (NDF) may ban fishing operations for up to 14 days in specific areas north of 62° N if the catch composition violates the allowance of undersized shrimp, cod, haddock, saithe, Greenland halibut or redfish (Høstingsforskriften, 2021). Additionally, particular fishing gear can get banned from certain areas south of 62° N if the undersized fish proportion exceeds 15 % of cod, saithe, haddock and whiting combined per haul.

1.10 GOLDEN REDFISH

Golden redfish is a bottom-dwelling cold-water oceanodromous fish that inhabit the North Atlantic Ocean. It lives at depths between 100 and 500 meters on the continental shelf, along the coastal and inside fjords. Juveniles are usually found in-shore and inside fjords. Spawning grounds stretch all the way from Shetland to Andøya, with hotspots around Storegga, Hatlebanken and Vesterålen (ICES, 2022b). Golden redfish have a high age of maturity (typically at ten years) and are a slow-growing species (Jakobsen et al., 2011), two traits vulnerable to overexploitation (Peres, 2010). Both are traits making such stocks particularly vulnerable to overfishing(Peres, 2010). Golden redfish is an ovoviviparous species, meaning fertilization of the eggs happens at a different time and place than spawning. Females carry the eggs until winter when they spawn. Golden redfish is known to be highly residential until reaching maturity. During summer males and females aggerate for mating around Bear Island and outside Norwegian coast east of Cape North (Drevetnyak *et al.*, 2011). Females are known to aggregate at the spawning-grounds in springtime, being vulnerable to bottom trawling and bottom set nets (ICES, 2018c).

Golden redfish (Sebastes norvegicus) is one of several commercial redfish stocks in the Norwegian fishery (ICES, 2018a, 2018b). There is no direct fishery for the species, given that the TAC advice from the IMR has been 0 since 2017. During the last 15 years, the spawning stock biomass (SSB) of *S. norvegicus* has been halved (ICES, 2018a, 2022b). Catches decreased consistently from 1986 until 2015 but since increased from 4 to 10 thousand tonnes (2021), annually. Golden redfish is caught as bycatch in other commercially prominent groundfish fisheries.

1.11 REDFISH REGULATIONS

The regulations for golden redfish is described in Høstingsforskriften, as with harvesting of all marine species Norwegian waters (Høstingsforskriften, 2021). As of March 1, 2022, fishing for redfish with trawl is prohibited (§15). Any direct fishery for redfish with conventional gear above 62° N is prohibited by §39, except for vessels below 15 meters using juksa (mechanized hooking device) between June 1 and August 31. The allowed bycatch-percentage of redfish cannot exceed 10% in landings with large-meshed trawls within 12 nautical miles from groundlines and 20% outside that zone (§41). This regulation also applies for vessels under 21 meters fishing with conventional gear, including purse seine. The current minimum legal catch size for redfish is 30 cm outside 12 nautical miles from baselines of the territorial sea and 32 cm inside, applicable to all fisheries. A maximum 10% of undersized individuals per haul is allowed (Høstingsforskriften, 2021). To avoid misidentification of the redfish species, regulations apply to all redfish species found in the area.

1.12 GOAL OF THE STUDY

Part of the annual NEA saithe management recommendations is to minimize bycatch of coastal cod and redfish. However, current knowledge regarding the extent of cod and redfish catches, as well as their distribution and the contribution of various fishing gears is a lack of understanding regarding the pattern of bycatch within saithe fishery. It is crucial to consider whether using accurate information on seasonal changes and variations in catch location, timing, and gear type to generate improvement recommendations for managing the saithe fishery. limited. The overall goal of this study is thus to describe these aspects of the saithe fishery. Management recommendations for saithe require knowledge of bycatch species, thus results from this study will:

a) Aid in improving management advice of NEA saithe and North Sea saithe.
b) Contribute to improved management recommendations for golden redfish, NEA, NS, and Norwegian coastal cod.

1.12.1 RESEARCH QUESTION

This thesis aims to analyse Norwegian catch and landings data from the period 2015 to 2021 in order to answer the following research questions:

1. What is the extent of cod / costal cod and redfish bycatch in the North Sea and Northeast Arctic saithe fishery?
2. Are there spatial and temporal patterns as well as gear effects in the catch of cod and redfish?
3. What is the estimated bycatch of coastal cod North of 62^{0}N?

2 MATERIALS AND METHODS

ERS (Electronic reporting system) logbook data and sales note data from all commercial fishing operations between 2015 and 2021, was provided by the Norwegian Directorate of Fisheries. Catches located outside the study area was considered outliers and was excluded from the analysis. Areas deemed less representative of the overall distribution was excluded from the analysis (n<400). Entries with missing statistical area or located outside the study area (222) was removed. Entries with missing *gear type* (48) were also removed.

2.1 DATA

2.1.1 - THE LOGBOOK DATA

In Norway, all fishing vessels above 15 meter and outside 4 nautical miles of the groundline of Skagerakk are obligated to report ERS–(ERS-forskriften, 2009). Catch data recorded in daily logbooks has been made available to IMR by the Fisheries Directorate. This offers a solid base for doing spatiotemporal analyses of fishing activity. The daily logbooks are based on each fishing operation which is given a unique entry, with total landings segregated by species. Each entry contains an estimated total live weight for each species, alongside the time and location of the fishing operation. Official catch statistics are reported as round weight (live weight when removed from the sea), but on factory vessels, all catch reporting is done post-production. Product weights are converted back to round weight using official conversion factors for each product (Norwegian Directorate of Fisheries, 2021). This weight conversion has a negligible impact on our study as factors are applied consistently across all vessels. Although reported weights are estimated at sea, various regulations ensure that weights match those officially declared in sales notes when weighed and sold on land (10% tolerance) to verify the accuracy of reported catches (Gullestad *et al.*, 2015). Whilst catches are weighed more accurately in sales notes, logbooks offer sufficient data resolution for our analysis. Some uncertainty in terms of which entries spans multiple statistical areas over a period of weeks is expected. Nevertheless, for the purposes of this study we assume the ERS data is representative of true reported catches in large vessels (15 meters <).

2.1.2 - SALES NOTE DATA

To capture the section of saithe-fishing activities contributed by vessels below 15 meters, investigation of sales notes data for such vessels was done. The reporting system in the sales note database centred around the landing and sale of catches (Landingsforskriften, 2014). In Norway, all catches are sold through registered sales organizations. Skippers are by law required to report the first-hand sale of catches, which must be signed by both the seller and buyer. Thus, the sales note database provides a record of all landed catches by species and weight in Norwegian waters. When a vessel returns to port to land catches, it must submit a landing note that includes the total catch weight of each species, the statistical area of the catch, and the date it was landed. For each fish sale, a sales note is generated that reports the quantity sold. However, since multiple sales notes

can be generated for one catch, sales notes are not a reliable measure of fishing effort, as for daily logbooks. To address this, sales notes must be traced back and aggregated to individual trips based on the landing date and vessel identity reported on the sales notes. Coastal vessels typically operate on day trips, so assuming reported landing date represent one day of fishing is reasonable. However, due to complex sales of catches from multiple trips, delayed reporting, or reporting errors, there may be some variability in this assumption.
The sales-note data was included to cover fishing vessels below 15 meters contributing to the saithe fishery. Sales note data was retrieved from NDF (Norwegian Directorate of Fisheries*)* and filtered to include only saithe targeted fishing operations in Norwegian fishing territories between 2015 and 2021, where cod and/or golden redfish was caught as bycatch.

2.1.3 - THE NORWEGIAN REFERENCE FLEET

The Norwegian Reference Fleet is a trust-based collaboration between fishers and scientists to improve data for input into stock assessments and provide yearly otolith data on cod in the catch. The purpose of using the reference fleet data was to use otolith data from Estimated Catch at Age (ECA) analyses to distinguish NCC from NEAC). This information was used to estimate the ratio of NCC within the total bycatch of cod north of 62°N latitude in both data sources. The reference fleet provides length measurements and random samples of otoliths from cod catch. Identification of the two types of cod found in the study areas is based on differences in growth structures in the otoliths (Rollefsen, 1933). Based on this sampling, cod catches per gear, area, and quarter are split into NCC and NEAC in the end of the year (ICES, 2021a).The ratio of NCC retrieved from otolith-data provided from area 06 and 07 (68 %) was sampled as one, and this value was used for both areas. Coastal cod proportions per quarter was missing for 2020 and 2021.The mean NCC-proportion from 2015-2019 was used for the missing years.

2.2 STUDY

2.2.1 - STUDY SPECIES

The investigated species for this study is Atlantic cod (*Gadus morhua)* and Golden redfish (*Sebastes norvegicus)*. In management, NEAC is divided into several genetically separate populations, which fully or partially does not breed with each other (ICES, 2021b). The segregated populations are Coastal cod (southern) and North Sea cod south of 62° N, and Coastal Cod (northern) and Northeast Arctic Cod north of 62° N. Splitting method for redfish is not relevant as *S. mantella* and *S. norvegicus* is separated in both the logbook- and sales note databases, and the identification is assumed to be correct.

2.2.2 - STUDY AREA

This study aims to cover saithe fishery in only Norwegian waters and Norwegian vessels. Only Norwegian fishing zones in the Norwegian Sea, North Sea, and Barents Sea are included (Fig.2). Catches registered without reported statistical area or outside the numbered areas was excluded from the analysis. Statistical areas included in logbook data was 12, 3, 4, 5, 0, 6, and 7 from north of 62° N, and 28, 8, and 42 from south of 62° N latitude (Fig. 2). The focused main areas in sales-notes were 3, 4, 5, 0, 6 and 7 from north of 62° N, and 8 and 28 from south of 62° N latitude. Areas excluded from the analysis and visualizations in each dataset, and the corresponding number of observations are available in Appendix B.

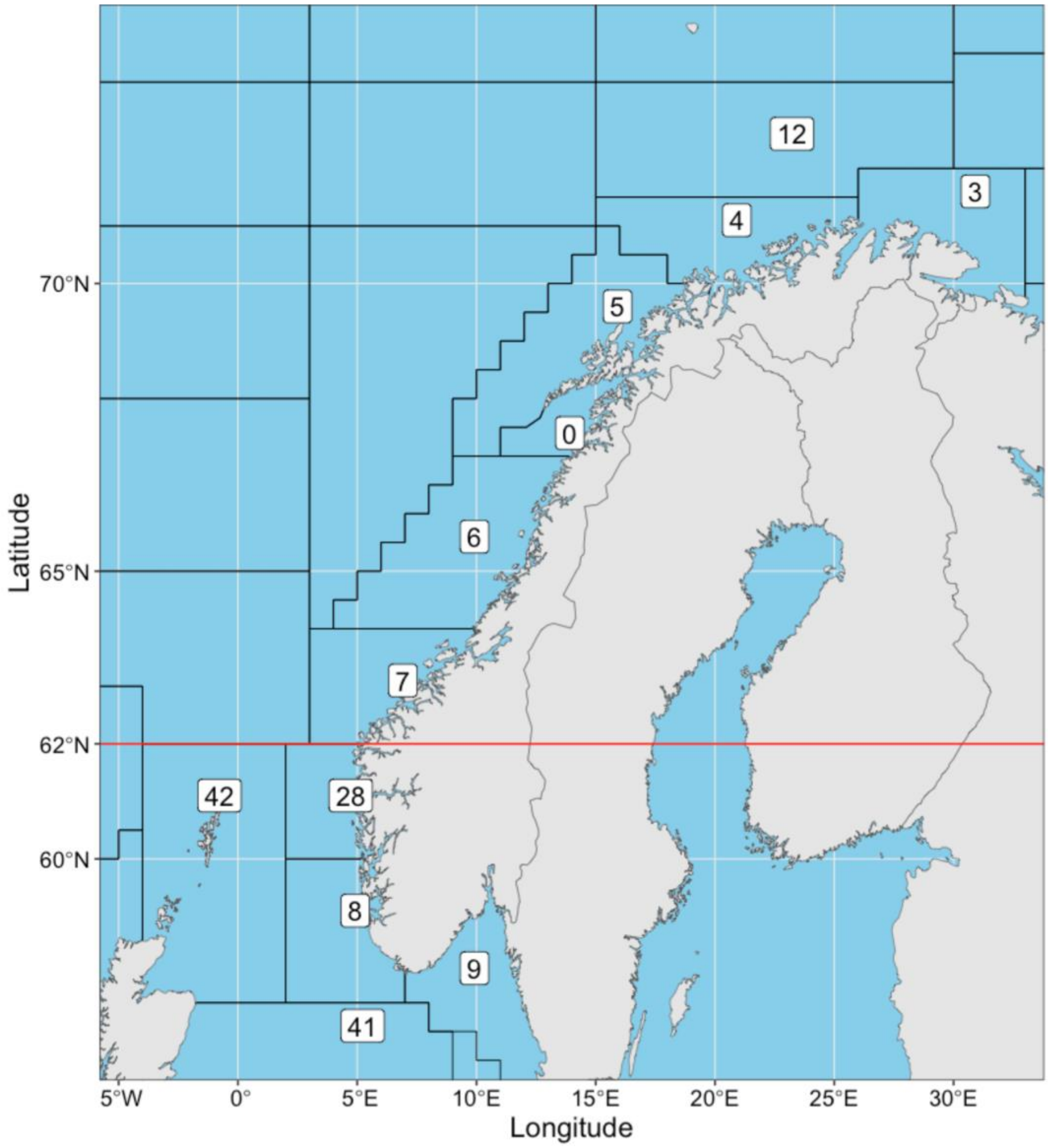

Figure 2: Map of the relevant statistical areas defined and provided by the Norwegian Directorate of Fisheries. The red horizontal line represents 62° N latitude and separates the northern and southern regions.

2.2.3 - Defining study fisheries in datasets

The logbook database report target species for every fishing operation, making it easy to filtrate for saithe. Saithe fishery in logbooks was defined as landings where saithe was given as the target species, and landings where saithe constituted the largest proportion out of cod, golden redfish, beaked redfish, and haddock.

Defining saithe fishery in the sales note database required a different approach as target species was not given. Target species of a fishing operation is defined from an analysis of the composition of the landings of each fishing trip (Biseau, 1998). This method assumes that every deliverance each day by an individual boat is considered a fishing operation, which is not necessarily the case. Entries was summarized and aggregated per date of landing and vessel name. For entries without vessel names, callsign was used to ensure a unique identity of each vessel. Only catches fulfilling this criterion was considered *saithe fishery*. Only vessels with a documented vessel length below 15 meters was included for the sales note data, meaning each database concerned two separate vessel size groups.

2.3 DATA ANALYSIS

Bycatch quantities of cod and golden redfish was summarized across statistical areas, seasons, gear type and depth, and then qualitative analysed. Data exploration was carried out following steps 1-4 according to the protocol described in Zuur *et al.* (2010).

Data preparation and statistical analysing was done in RStudio and the programming language (Version 2022.12.0.353;R Core Team, 2021). It was used to analyse the data and visualize bycatch quantities by location, season, and gear type. Secondly, the software was used to generate maps to describe a more detailed geographical distribution of the bycatch of the given species in saithe fishery.

The main packages used for data preparation and visualisations was: **tidyr** (Wickham & Girlich, 2022), **dplyr** (Wickham, François, et al., 2022), **ggplot2** (Wickham et al., 2016), **sf** (Pebesma, 2018), **ggspatial** (Dunnington, 2022) and **ggmap** (Kahle *et al.*, 2013). Full list of packages and usage is found in Appendix E.

2.3.1 - CHOICE OF VARIABLES

The main variables chosen for the analysis was bycatch of study species (continuous), year (factor), quarter (factor), fishing gear (categorical) and statistical area (factor). Additional important columns used for calculations was round-weight, total catch, location, fishing depth, date of landing and species. Full list of used and calculated columns can be found in Appendix F. *Quarter* was derived from landing dates, *total catch* was calculated by summarising round-weight of all registered species in each catch, and *proportion* was calculated by weight of bycatch (cod and golden redfish) divided by weight of saithe for each catch.

2.3.2 - STATISTICS

Despite the data not meeting the assumption of normal-distribution, equal variance, or equal sample-sizes, ANCOVA was performed to test for significant difference in mean of bycatches between area and gear type. A post-hock test was performed to investigate which gear types and areas differentiated. The output was interpreted with caution. One-way ANOVA was used to test significant difference in annual bycatch across quarters. One-way ANOVA was used to increase robustness against violation of unequal variance.

Linear mixed-effects models were fitted to annual bycatch of cod and golden redfish across quarters to describe the variation. Linear models with quadratic and cubic polynomial terms were applied to cod and golden redfish, respectively. Mean, standard deviation and confidence intervals was calculated for the bycatch of cod and golden redfish in logbooks and sales-notes, respectively.

2.4 DATA PREPARATION

2.4.1 – FILTRATION OF AREAS, GEAR TYPES AND VESSELS

Overall total catches of saithe were calculated from sales-notes for both large and small vessels, as sales-note is assumed to contain higher precision of weight estimates. The choice of excluding certain areas and gear types from the analysis was evaluated based on catch contribution to the Norwegian saithe fishery. The filtrated data has a coverage of 98.4 and 91.1% of the saithe fishery by large vessels and small vessels, respectively. The reasoning for excluding areas was offshore statistical main areas with marginal contribution two the catch of saithe. The exclusion is assumed to not affect the results in regards the research question of this study. Full list of number of observations per area and year pre-exclusion is found in (Appendix A). Maximum depth range was cut-off at 500 meters due to high ratio of incorrect depths above this limit.
The study aims to cover the Norwegian saithe fishery, which implies excluding foreign vessels. Additionally, vessels without registered length-group in both datasets was excluded.

2.4.2 - SPLITTING METHODS:

The method for population segregation (NCC and NEAC) differed between north/south of 62° because otolith data was only available for the northern region. To differentiate between the visually indistinguishable populations, otolith data from an additional data source was used (ICES, 2022a). Estimated proportions of NCC and NEAC is produced based on biological otolith data collected yearly for cod from areas north of 62°N latitude. Variables available for NCC proportions was year, quarter, statistical main area, and gear type, separately. The splitting-method way applied to cod-bycatches both from large vessels and small vessels.

Splitting cod catches south of 62°N latitude was done geographically. Different splitting-method was needed for large vessels and small vessels, respectively, because vessels below 15 meters is obligated to report ERS (ERS-forskriften, 2009). For logbooks, coordinates for stop-position were used to split catches according to the territorial seas of Norway. The zone is defined as waters within 12 NM from the closest shore line (Metych, 2023). Catch data located inside or outside this border was defined as Norwegian costal cod or North Sea cod, respectively. For sales-notes the column "Kyst.hav.kode" defines whether the landing was caught outside or inside the 12 NM zone. Catch of cod in landings with code '8' was defined as NCC and '0' was defined as NSC. The otolith-splitting method was used to estimate NCC-proportions in catches of cod, especially in logbook data as populations are not logged separated. As cod-landings are stock-segregated post fishing-year, they are not segregated in sales-notes. The ECA-index was applied to total cod bycatches.
Coastal cod proportions from the ECA-data sampled per area were limited to areas 03, 04, 05, 00, and areas 06 and 07 was sampled together. Gear types was limited to *trawl*, *gillnet*, and *other gears*. Due to missing data in ECA-index per quarter for years 2020 and 2021, mean values per quarter from 2015 to 2019 was used (ICES, 2021a).

2.4.3 - Gear type conversions

Gear types were categorized into groups of main fishing gear. Raw data includes specific gear type used for every fishing operation or sales note, as a wide variety of fishing gears is used in the saithe fishery. For visualization and analysis purposes gear types was categorized by seven groups of main gear: bottom trawl, Danish seine, purse seine, set nets, pelagic trawl, other gear and longlines. The category 'other gears' consists mainly of was 'juksa' (mechanised and manual), pots and other hooking gear. The full list of gear type conversions can be found in Appendix A.

Otolith-data with NCC-proportions for gear types was limited to gillnet, trawl, and others. The already defined main gear types were renamed accordingly, purse seine and Danish seine in logbooks was categorised as 'others'. In the sales-note data other gears and Danish seine was categorized as others.

2.4.4 - Geographic reference

Statistical main areas and locations defined and provided by the Norwegian Directorate of Fisheries was downloaded and used for geographical visualization and analysis. Statistical zones from ICES and the Norwegian Directorate of Fisheries are used for reporting catches. The first level is main areas, and the second is locations (Fiskeridirektoratet, n.d.). The electronic reporting system make sure entries in daily logbook data is geographically localized. Coordinates was used to convert positional data into statistical main area and location, with the external software *ArcMap*.

The geographic reference used in sales-notes was statistical area and location, reported per sales-note. As most catches in sales-notes is caught with passive fishing gear, the geographic precision is assumed to be high.

3 RESULTS

3.1 ANALYSIS OF BYCATCH QUANTITIES

A summary of catches and landings from logbook and sales notes data is presented in Table 1. Number of observations by data type (logbook and sales note) varied by statistical area and between years. Several statistical areas showed similar number of catches or landings throughout the time-series.

Table 1: Number of observations from each statistical main area included in the analysis per year in logbook- and sales-note data. Full list of areas is found in *Appendix A.* Most areas showed overlapping coverage in both data-sources. Areas 12 and 42 had few or no landings in sales-notes. Variations in number of landings from each data-source in the selected main areas and years was observed.

Main area	Year	Salesnote	Logbook	Total	Main area	Year	Salesnote	Logbook	Total
12	2015	0	16	16	**6**	2015	2943	2030	4973
12	2016	0	157	157	**6**	2016	3079	1079	4158
12	2017	1	195	196	**6**	2017	2818	764	3582
12	2018	0	88	88	**6**	2018	3279	1091	4370
12	2019	1	98	99	**6**	2019	3781	855	4636
12	2020	0	70	70	**6**	2020	4258	670	4928
12	2021	17	145	162	**6**	2021	3804	749	4553
3	2015	916	1605	2521	**7**	2015	3861	2688	6549
3	2016	1469	2671	4140	**7**	2016	3850	2011	5861
3	2017	1802	2494	4296	**7**	2017	3330	2029	5359
3	2018	1572	2736	4308	**7**	2018	4551	2345	6896
3	2019	1508	2067	3575	**7**	2019	3634	2229	5863
3	2020	1363	2352	3715	**7**	2020	3958	2134	6092
3	2021	1646	3912	5558	**7**	2021	3891	2654	6545
4	2015	2846	2030	4876	**28**	2015	791	1061	1852
4	2016	1717	2732	4449	**28**	2016	707	1054	1761
4	2017	2416	2541	4957	**28**	2017	641	1095	1736
4	2018	2670	3839	6509	**28**	2018	593	1413	2006
4	2019	3876	2863	6739	**28**	2019	722	2042	2764
4	2020	5126	4113	9239	**28**	2020	685	2008	2693
4	2021	4413	3803	8216	**28**	2021	686	2091	2777
5	2015	4825	2936	7761	**8**	2015	739	1050	1789
5	2016	6694	2852	9546	**8**	2016	1184	821	2005
5	2017	5057	2491	7548	**8**	2017	1159	557	1716
5	2018	3889	2710	6599	**8**	2018	1025	1521	2546
5	2019	4349	2974	7323	**8**	2019	1573	2311	3884
5	2020	4128	3250	7378	**8**	2020	1611	2745	4356
5	2021	5245	4346	9591	**8**	2021	1780	1821	3601
0	2015	2986	609	3595	**42**	2015	0	2306	2306
0	2016	3716	838	4554	**42**	2016	0	2425	2425
0	2017	3826	644	4470	**42**	2017	0	4014	4014
0	2018	4031	570	4601	**42**	2018	0	2641	2641
0	2019	4080	537	4617	**42**	2019	0	3033	3033
0	2020	3788	522	4310	**42**	2020	0	2116	2116
0	2021	4520	501	5021	**42**	2021	0	316	316

3.1.1 By Year

Saithe-landings from large vessels showed an overall increase in annual total weight during the time-period (2015 –2021), with a peak in 2018 (Fig. 3a). The difference between total annual saithe catches and saithe catches from records selected for this study was relatively small. The mean proportion of cod-bycatch in the logbook data showed a slightly increasing trend over time, with a peak of ~8.75% in 2016 (Fig.3c). The mean proportion of golden redfish-bycatch was visibly lower than for cod, and never exceeded 1.25%. Annual total saithe landings recorded on sales-notes were lower compared to the logbook (Fig. 3b). An increase in total annual catch was observed during the period (2015-2021). The proportion of cod and golden redfish in the saithe-landings was roughly constant both in large vessels and small vessels through the time-series. The proportion of cod in catches from small vessels ranged from 12.6% to 17.1%, and from 6- 8.5% in large vessels. The annual bycatch proportion of golden redfish ranged from 1.4-2.4% in small vessels, and 0.4-0.9% in large vessels (Fig. 3 c and d). Total annual bycatches of cod by large and small vessels ranged from 6.6-10.3 and 2.2-3.5 thousand tonnes, respectively. Total annual bycatches of golden redfish ranged from 450-1500 and 290-770 tonnes in large and small vessels, respectively.

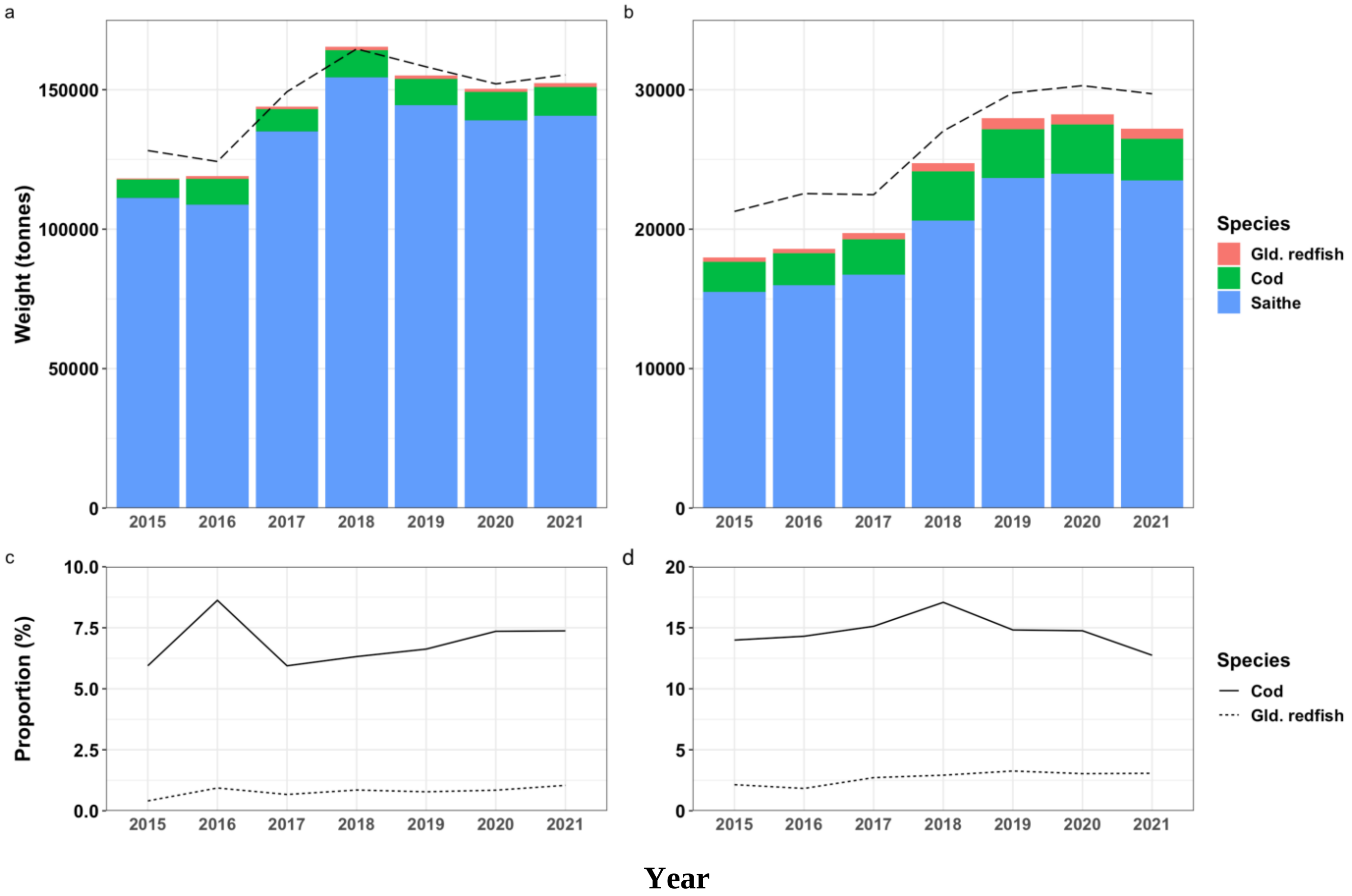

Figure 3. Total annual catch/landings of saithe and bycatch of cod and golden redfish in the ‘saithe’ fishery. a) total annual catches from logbook data. b) total annual catches in sales-note data. c) bycatch proportions of cod and golden redfish in logbook data and d) bycatch proportions of cod and golden redfish in sales-note data. The stippled line in a) and b) displays total annual catch /landings of saithe. Note that y-axes are different.

3.1.2 - BY GEAR TYPE

The largest quantity of bycatch of cod and golden redfish was taken with bottom trawl and set nets based on logbook and sales-note data respectively (Fig. 4). The latter two gear types also contributed the highest total saithe landings. Other gear types that contributed to the bycatch of cod were Danish seine and set nets in logbooks, and other gear (juksa, pots, fyke nets and undefined gear) and Danish seines in sales-notes. Bycatch by purse seine was marginal, despite considerable amounts of saithe caught by this gear. Bycatch proportions of cod showed variations by gear type in logbooks (Fig. 4c), with Danish seine (11.4 %), bottom trawl (8.1%) and set nets (6.5 %) having the highest total proportions. The bycatch of golden redfish was generally low or zero except for bottom trawl and set nets.

Landings recorded in the sales-note data were dominated by set nets (Fig. 4b). Small amounts of cod were caught with other gears and Danish seines, and total saithe landings were low for these gears. The overall saithe landings per gear type match well with the catch distribution in the selected data. The average bycatch proportion of cod in sales-notes records showed large variations between gears. The Highest cod proportions were observed for Danish seine (15.9%), followed by with set nets (11.6 %) and other gear (7.5%). Golden redfish total bycatch proportion was highest in set nets (2.6%), and marginal in Danish seines (0.11%) and other gear (0.8%).

The highest mean proportion of cod in saithe-landings by large vessels was caught with Danish seine (24%), followed by set nets (20%), bottom trawl (15%) and purse seine (15%). For small vessels, the highest mean proportions of cod per saithe-catch was taken with Danish seines (32%) set nets (23%) and other gear (20%). The largest mean proportions of golden redfish of gear type were set nets (11%), bottom trawl (7%), purse seine (6%) and Danish seine (5%) for large vessels. Equivalently for the small vessels, set nets (10%) had the highest mean bycatch proportion, followed by other gear (7%) and Danish seines (3%). The largest means was not found in gear types producing the most total bycatch, but effort being higher in bottom trawl and set nets results in higher total contribution from those gear types.

Table 2: Summary of means, standard deviations, and confidence intervals for cod (red) and golden redfish (blue) bycatches (tonnes) per gear type in logbook data (vessels > 15m).

Species	*Gear type*	*Mea*	*SD*	*CI*
Cod	Bottom trawl	0.53	1.24	1.02
	Purse seine	0.11	0.80	0,66
	Danish seine	0.49	1.04	0,86
	Set nets	0.66	1.05	0,86
Redfish	Bottom trawl	0.09	0.33	0.27
	Purse seine	0.00	0.02	0.02
	Danish seine	0,01	0.07	0.06
	Set nets	0,10	0.3	0.24

Table 3: Summary of means, standard deviations, and confidence intervals for cod (red) and golden redfish (blue) bycatches (tonnes) per gear type in sales-note data (vessels < 15m).

Species	*Gear type*	*Mean*	*SD*	*CI*
Cod	Other gear	0.04	0.09	0.08
	Set nets	0.18	0.41	0.39
	Danish seine	1.14	1.65	1.57
Redfish	Other gear	0.005	0.02	0.02
	Set nets	0.04	0.13	0.12
	Danish seine	0.01	0.07	0.06

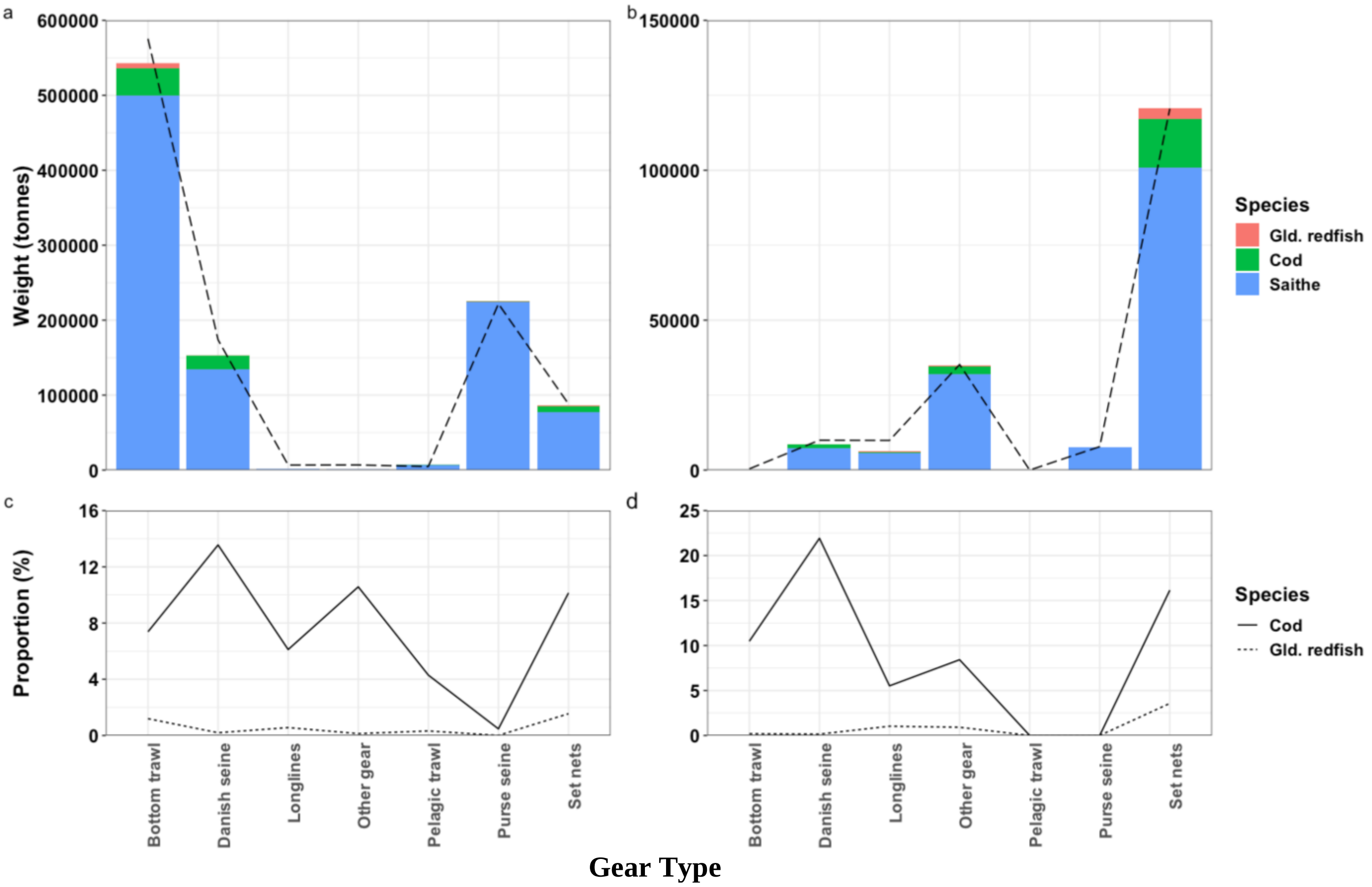

Figure 4. Total weight of saithe, cod and redfish catches /landings, by gear type. Stippled lines indicate total overall saithe catch in each data-source. a) total catches caught by large vessels, b) total catches caught by small vessels, c) bycatch proportions by large vessels and d) bycatch proportions by small vessels.

3.1.3 - By area

The geographic extent of catch data showed that total saithe-landings and bycatch proportion increased with latitude (Fig. 5a and c). Based on logbook data highest bycatch of cod were caught in statistical areas 03 (12.4 thousand tonnes, 8.0%), 04 (21.7 thousand tonnes, and 10.3%) and 05 (16.9 thousand tonnes and 14.0%). Golden redfish bycatch was 1350 (1%), 2380(1.1%) and 2520 (2.1%) tonnes in respective areas. Distinct decrease in bycatches was seen from area 06 and southwards, despite large saithe landings in area 42 (Fig. 5a.) In areas south of 62° N bycatch proportion of cod was low (2-4%) (Fig. 5c.). Large variations in bycatch proportions of cod were observed between areas north of 62° N latitude, with the highest proportions observed in area 12 (24.0%) and 00 (19.9%). Comparatively, saithe catches were low. The proportion of golden redfish caught by large vessels decreased with latitude, with large proportions observed in areas 12 and 05 (Fig. 5d.). Total saithe catches were minimal in area 12.

The geographic distribution of catch data in the sales-notes was dominated by areas north of 62° N latitude (Fig. 5b). The largest bycatch quantities of cod were found in statistical areas 04, 05 and 00, where also saithe landings were highest. Despite large saithe catches in area 07, bycatch of cod was low (4.3 %) comparative to other areas north of 62 N latitude (Fig. 5d). Golden redfish was caught between area 03 in the north and area 06, and bycatch proportions ranged from 2.2-4.2 % (largest in 04 and lowest in 00). South of area 06 of golden redfish was minimal or absent in catches. With exception to area 00 and 12, proportions of cod- bycatch north of 62° N latitude was notably higher in sales-notes (11-26%) compared to logbooks (1.2-14 %) (Fig. 5d.)

Table 4: Mean, standard deviation and confidence intervals for cod and golden redfish bycatches (tonnes) per main area from large vessels (> 15m).

Species	*Area*	*Mean*	*SD*	*CI (±)*
Cod	**12**	2,29	2,38	1,24
	03	0,64	1,18	0,61
	04	0,99	1,60	0,83
	05	0,77	1,50	0,78
	00	0,84	1,56	0,81
	06	0,18	0,39	0,20
	07	0,11	0,30	0,16
	08	0,13	0,21	0,11
	28	0,12	0,22	0,11
	42	0,19	0,51	0,27
Redfish	**12**	0,61	1,18	0,61
	03	0,08	0,32	0,17
	04	0,11	0,34	0,17
	05	0,11	0,34	0,18
	00	0,01	0,06	0,03
	06	0,08	0,26	0,14
	07	0,01	0,07	0,04
	08	0,00	0,00	0,00
	28	0,00	0,01	0,01
	42	0,00	0,01	0,00

Table 5: Mean, standard deviation and confidence intervals for cod and golden redfish bycatches (tonnes) per main area from small vessels (< 15m).

Species	*Area*	*Mean*	*SD*	*CI (±)*
Cod	**03**	0,21	0,41	0,24
	04	0,28	0,64	0,37
	05	0,15	0,35	0,21
	00	0,17	0,41	0,24
	06	0,07	0,15	0,09
	07	0,04	0,15	0,09
	08	0,01	0,03	0,02
	28	0,02	0,10	0,06
Redfish	**03**	0,05	0,16	0,09
	04	0,04	0,14	0,08
	05	0,04	0,13	0,07
	00	0,02	0,08	0,05
	06	0,02	0,07	0,04
	07	0,01	0,04	0,03
	08	0,00	0,00	0,00
	28	0,00	0,02	0,01

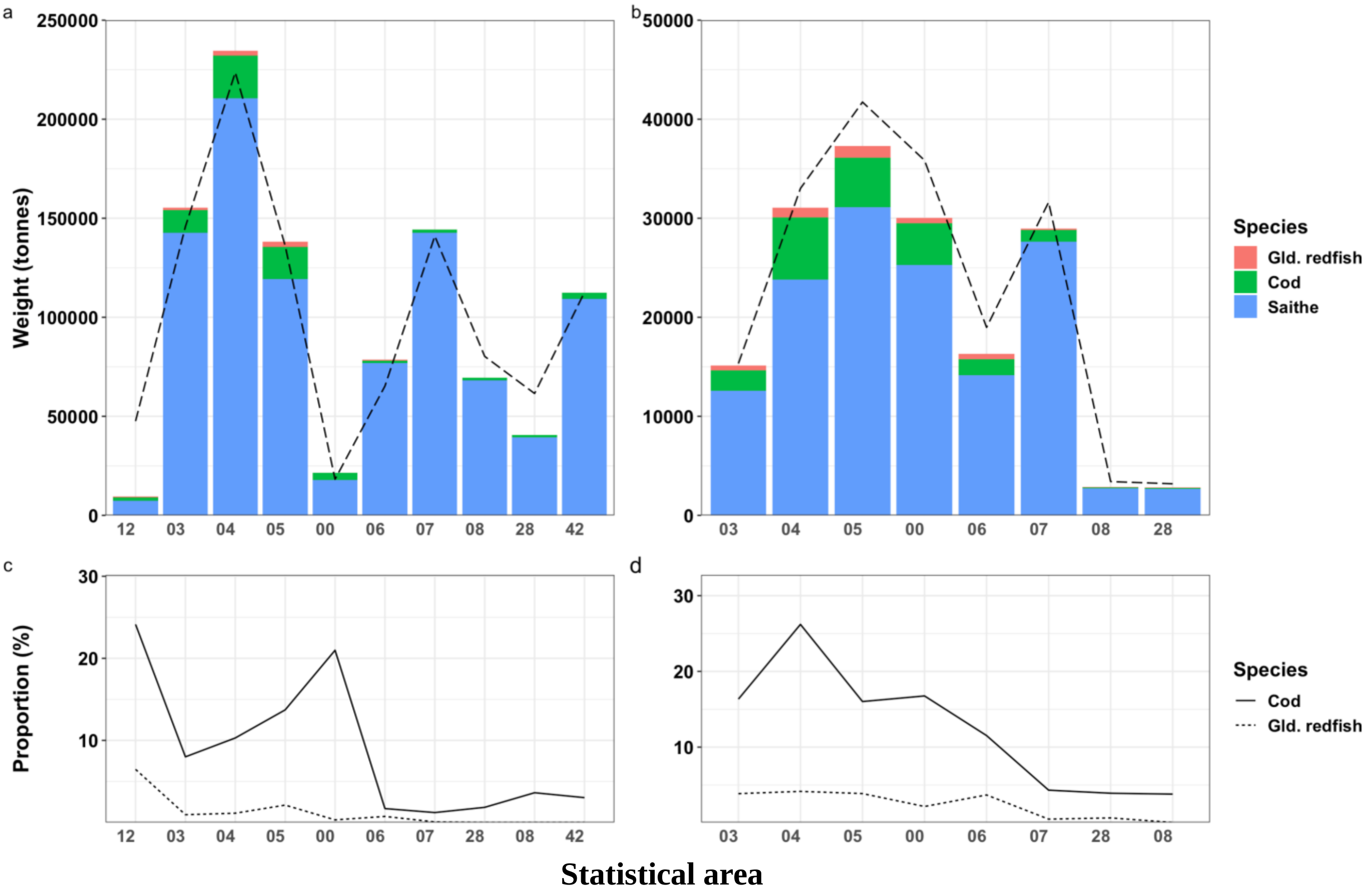

Figure 5. Total catch weight with bycatch of cod and golden redfish per statistical area from logbook- and sales-note data. Stippled lines in a) and b) show overall total catch of saithe. a) logbook data, b) sales-note data, c) bycatch proportions in logbook data, d) bycatch proportions in sales-note data.

3.2 Annual catches per gear type and statistical main area

Examining annual catches from large vessels show that distribution of saithe-landings and corresponding bycatch across gear types are area specific (Fig. 6). Bottom trawl is used across a wide geographic area to catch saithe, covering all areas except for areas 12 and 00. Purse seine catches are restricted to areas 03, 04 and 07, Danish seine to 03, 04, 05 and 00 and set nets to 03, 04, 05 and 00. Bottom trawl consistently caught large quantities of saithe and bycatch in all areas. Peaks in quantity of bycatch are observed in areas 04 and 05. High catches are taken in area 08, 28, and 42 but cod bycatch is limited. Purse seine caught almost no bycatch, still contributing to large saithe catches in areas 3, 4, and 7. Bycatch with Danish seine occurred in 03 and 04. Set nets were not widely used to catch saithe by large vessels (>15m) but bycatch did occur in 05, 06, 07 and 42 (Fig. 6).

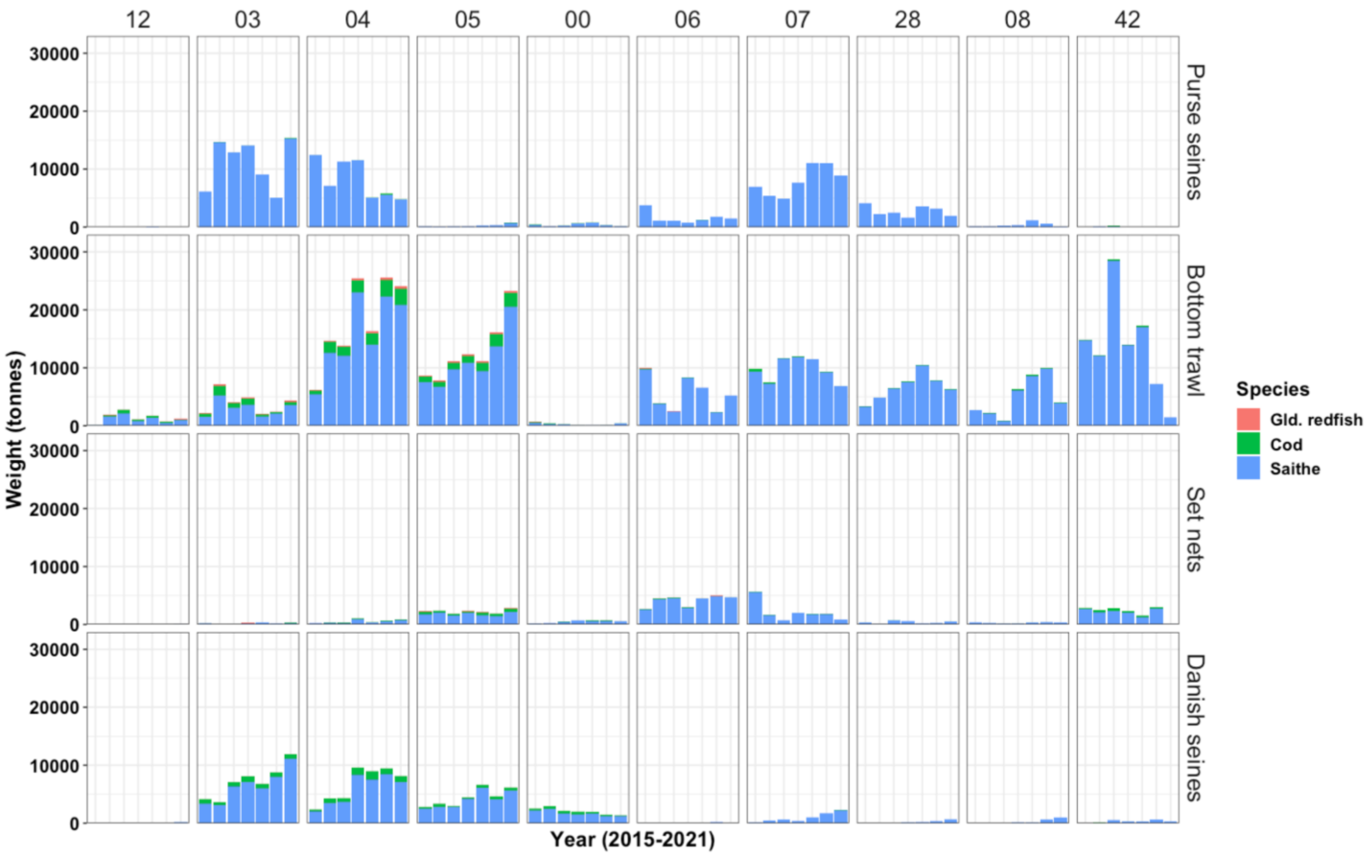

Figure 6. Annual saithe catches and bycatch of cod and golden redfish in weight from logbook data (vessels>15m), across the main gear types and areas during the study period.

The distribution of annual catches by small vessels across statistical areas and gear type showed that set nets dominated landings in all areas north of 62 °N (Fig. 7). Accordingly, most bycatch comes from set nets, predominantly form area 04, 05 and 00. Other gear produced consistently low catches of saithe in 03 to 07, with some bycatch in 04 and 05. Proportions of bycatch in set nets from small boats (<15m) in the northern areas are high (15.3-34.4 % from area 03-00) compared Danish seine (12.2 - 18.8 % in area 03-00) and bottom trawl (13.1-26.6% in area 03-05) by large vessels. However, the total quantity of bycatch in small vessels is lower due to lower total landings. In the middle region (area 06 and 07) bycatch proportion of cod with set nets was 14.0 and 4.8 % in small vessels. In large vessels bycatch proportion was 2.8 and 2.4% in set nets and 1.4 and 2.0% in bottom trawl. Only minor annual saithe-landings with set nets from small vessels were observed in 28 and 08. Proportions of cod-bycatch caught by large vessels was 1.2-3.4 % with bottom trawl and 10.0-15.6 % with set nets in area 08,28 and 42 (Fig. 7).

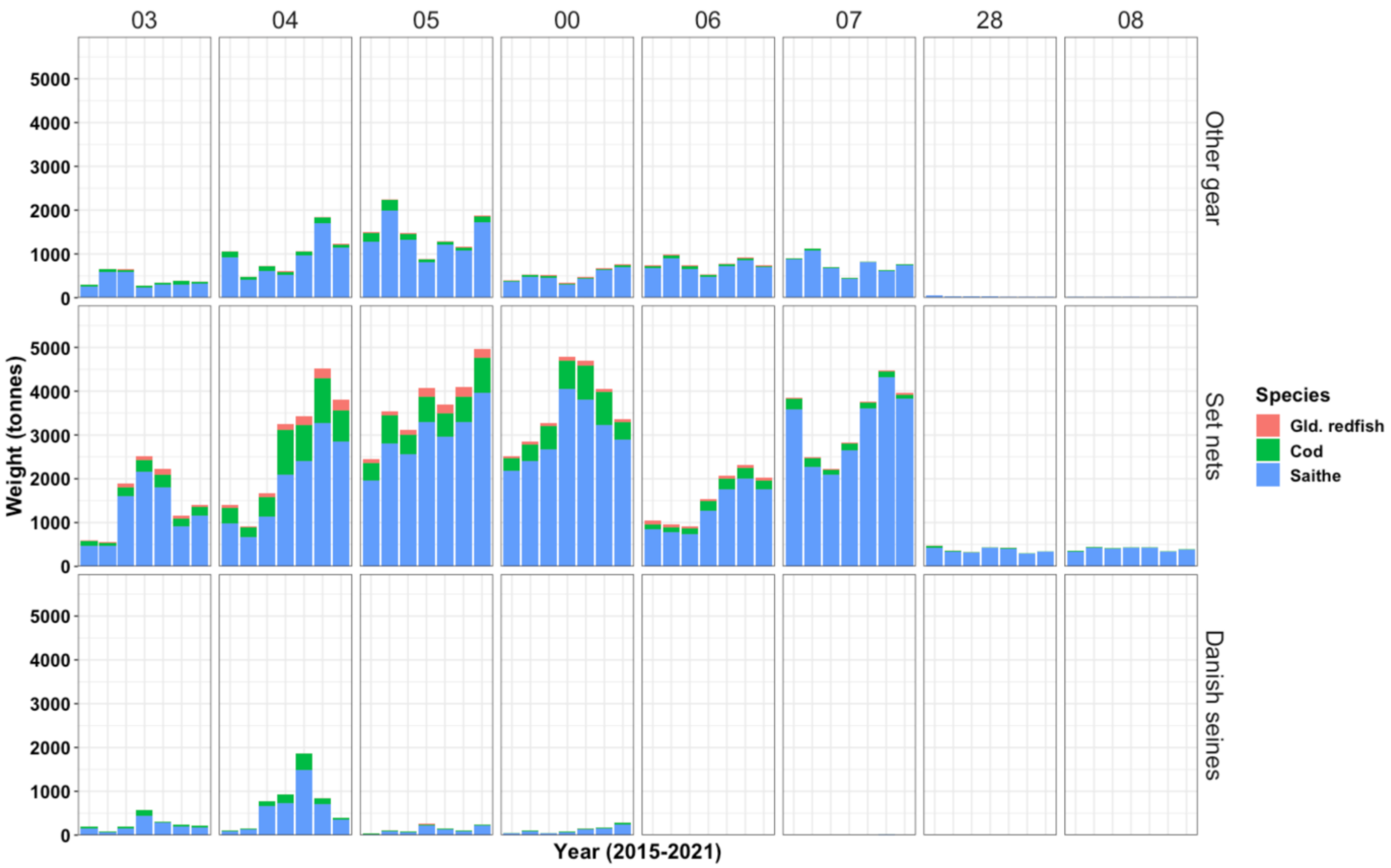

Figure 7: Annual saithe catches and bycatch of cod and golden redfish in weight from sales-note data, across the main gear types and areas during the study period (2015-2021).

Results from ANCOVA showed that bycatch of cod and golden redfish was significantly correlated to area, gear type and the interaction between variables (Table 6 and 7). The post-hock test indicated significant p-values in most interactions between gear types and areas, except 42-28, 6-28, 7-28, 6-42, 7-42, 7-6, 8-6 and 8-7 in large vessels. Insignificant p-values in bycatch of golden redfish caught by large vessels were found for interactions between Danish seine-purse and area 04-03, and between Danish seine and other gear by small vessels. Full list of post-hock output is found in Appendix D

Table 6: Summary output from the analysis of covariance (ANCOVA) examined the effects of main area, gear types, and their interaction on bycatch of cod and golden redfish, by vessels larger than 15m.

Specie	*Gear type*	*D*	*Sum*	*Mean*	*F*	*P-*
Cod	Gear type	3	1901	633.5	592.3	<0.001
	Area	9	22348	2483.1	2321.5	<0.001
	Gear&Area	26	7906	304.1	284.3	<0.001
	Residuals	12	137604	1.1		
Redfish	Gear type	3	203	67.69	1125.5	<0.001
	Area	9	856	95.15	1582.1	<0.001
	Gear&Area	26	349	13.41	222.9	<0.001
	Residuals	12	7738	0.06		

Table 7: Summary output from the analysis of covariance (ANCOVA) examined the effects of main area, gear types, and their interaction on bycatch of cod and golden redfish, by vessels smaller than 15m.

Species	***Variable***	***Df***	***Sum***	***Mean***	***F-***	***P-***
Cod	Gear type	2	2103	1051.6	9255	<0.001
	Area	7	1020	145.8	1283	<0.001
	Gear&Area	14	660	47.1	414.7	<0.001
	Residuals	153399	17430	0.1		
Redfish	Gear type	2	46.0	23.005	2424.8	<0.001
	Area	7	51.9	7.420	782.1	<0.001
	Gear&Area	14	37.3	2.662	280.6	<0.001
	Residuals	153399	1455.3	0.009		

3.3 BYCATCH AT DEPTH

The total weight of bycatch caught by large vessels across weight at depth in logbook data showed are difference in depth-distribution across gear types and between species (Fig. 8). The bycatch in saithe landings was generally observed at slightly deeper depths for golden redfish with bottom trawl, set nets and Danish seine (mean 225, 158 and 193m) than for cod (mean 193, 141, 163 m). Limited Golden redfish catches with Danish seine made a comparison across species difficult, with depths ranging from 0-350m for cod and 100-300m for golden redfish. The distribution of catch weight per depth-interval in bottom trawl is similar between cod and Golden redfish, with cod catches slightly more skewed towards shallower depths (Fig. 8).

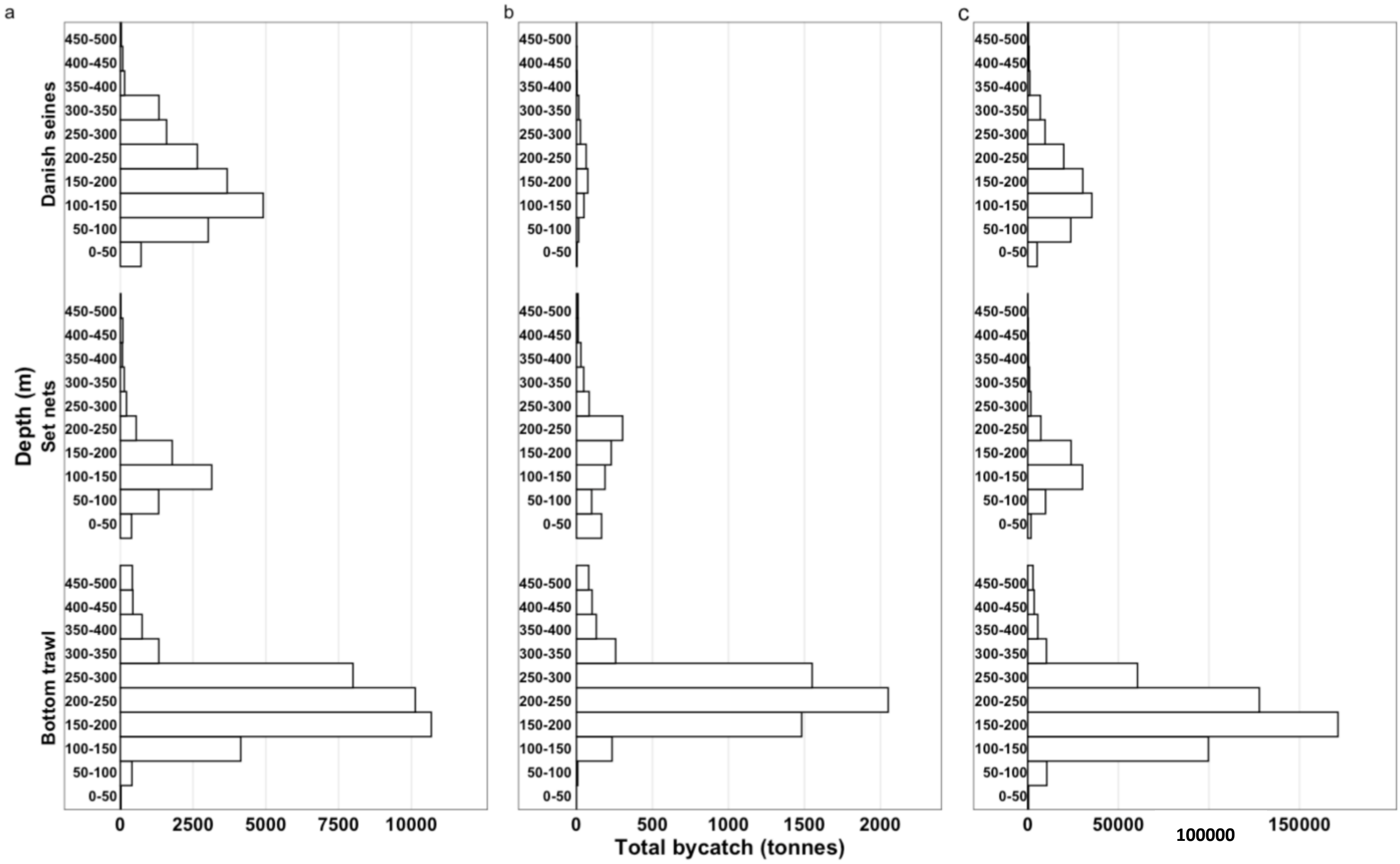

Figure 8: Distribution of total bycatch of cod (a), golden redfish (b) and saithe-catches (c) across depth-range caught with Danish seine, set nets and bottom trawl, as recorded in the logbook data.

3.4 Seasonal variation

3.4.1 - Cod

Seasonal variations in bycatch of cod from large vessels (>15m) could be described with a polynomial function with a quadratic term (Fig. 9). The pattern followed a concave curve that drops from a peak in Q1, continued to decrease in Q2 and Q3, before partially increasing in Q4. Annual bycatch of cod by from large vessels showed large quarterly variation, with only some years falling within the confidence intervals. The correlation coefficients of the fitted line were 0.58 and 0.72 for large vessels and small vessels, respectively.

The bycatch from small vessels (<15m) showed a similar concave trend for cod, with the minimum value reached between Q2 and Q3, and an increase in Q4 (Fig. 8). Variation between years in bycatch per quarter was low in small vessels (<15m), with fewer observations falling outside the confidence interval. The ANOVA applied to bycatch quantities of cod showed significant correlation in both large and small vessels ($P < 0.001$) (Table 8).

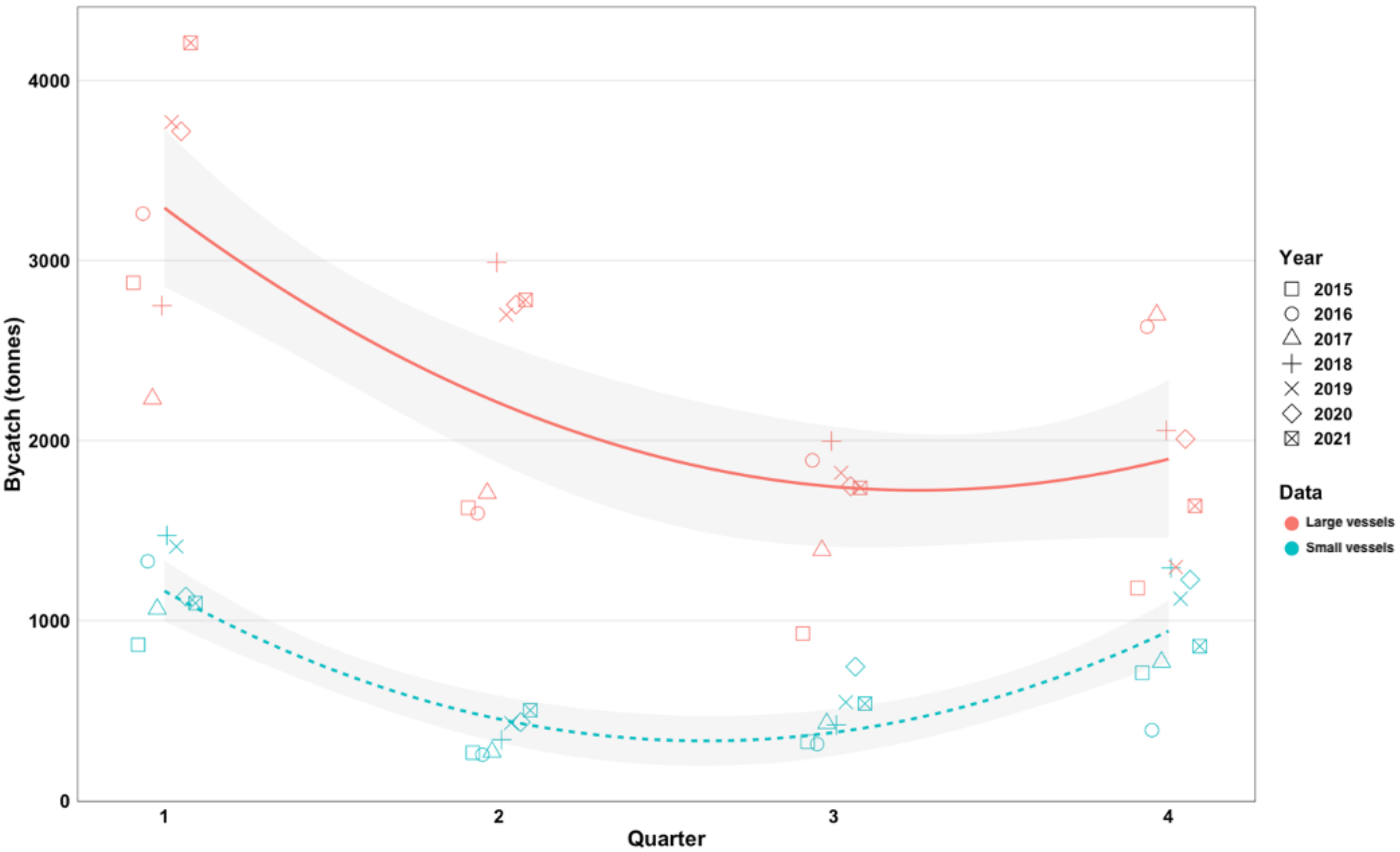

Figure 9. Quarterly variation in bycatch of cod based on logbook and sales-note data. The x-axis represents quarter and y-axis shows bycatch in tonnes summarised per year in the time-series. The stippled and solid curves represent fitted linear models with confidence intervals (grey areas).

Table 8: Summary statistics from ANOVA on bycatch (tonnes) across quarter in logbook data (vessels > 15m), for cod and golden redfish, respectively.

Species		*df*	*Sum Sq*	*Mean Sq*	*F*	*P-value*
Cod	Quarter	3	10407094	3469031	10.2	<0.001
	Residuals	24	8176310	340680		
Redfish	Quarter	3	206636	68879	5.68	<0.001
	Residuals	24	291229	12135		

Table 9: Summary statistics from ANOVA test on bycatch (tonnes) across quarter in the sales-note data (vessels > 15m) for cod and golden redfish, respectively.

Species		*df*	*Sum Sq*	*Mean Sq*	*F*	*P-value*
Cod	Quarter	3	3180607	1060202	23.2	<0.001
	Residuals	24	1098082	45753		
Redfish	Quarter	1	170829	56943	16.5	<0.001
	Residuals	26	82897	3454		

3.4.2 - Golden redfish

The quarterly variation in bycatch of golden redfish had the same trend for logbook and sales notes data (Fig. 10). Lowest bycatch was observed in Q1 and Q2, increasing to its peak in Q3, before dropping in Q4. The mean annual bycatch of golden redfish showed similar magnitude in large vessels and small vessels Q4. The 95% confidence intervals seem to cover some of the variation between years. The correlation coefficients of the fitted line were 0.42 and 0.68 for the logbook and sales notes data respectively. Mean proportion in annual total bycatch of golden redfish in large vessels was 2.4, 5.5, 6.1 and 4.1 % (Q1-Q4) and 1.8, 5.5, 7.1 and 5.7 % (Q1-Q4) in small vessels. The ANOVA applied to annual bycatch of golden redfish showed significant correlation in both large and small vessels (P < 0.001) (Table 8).

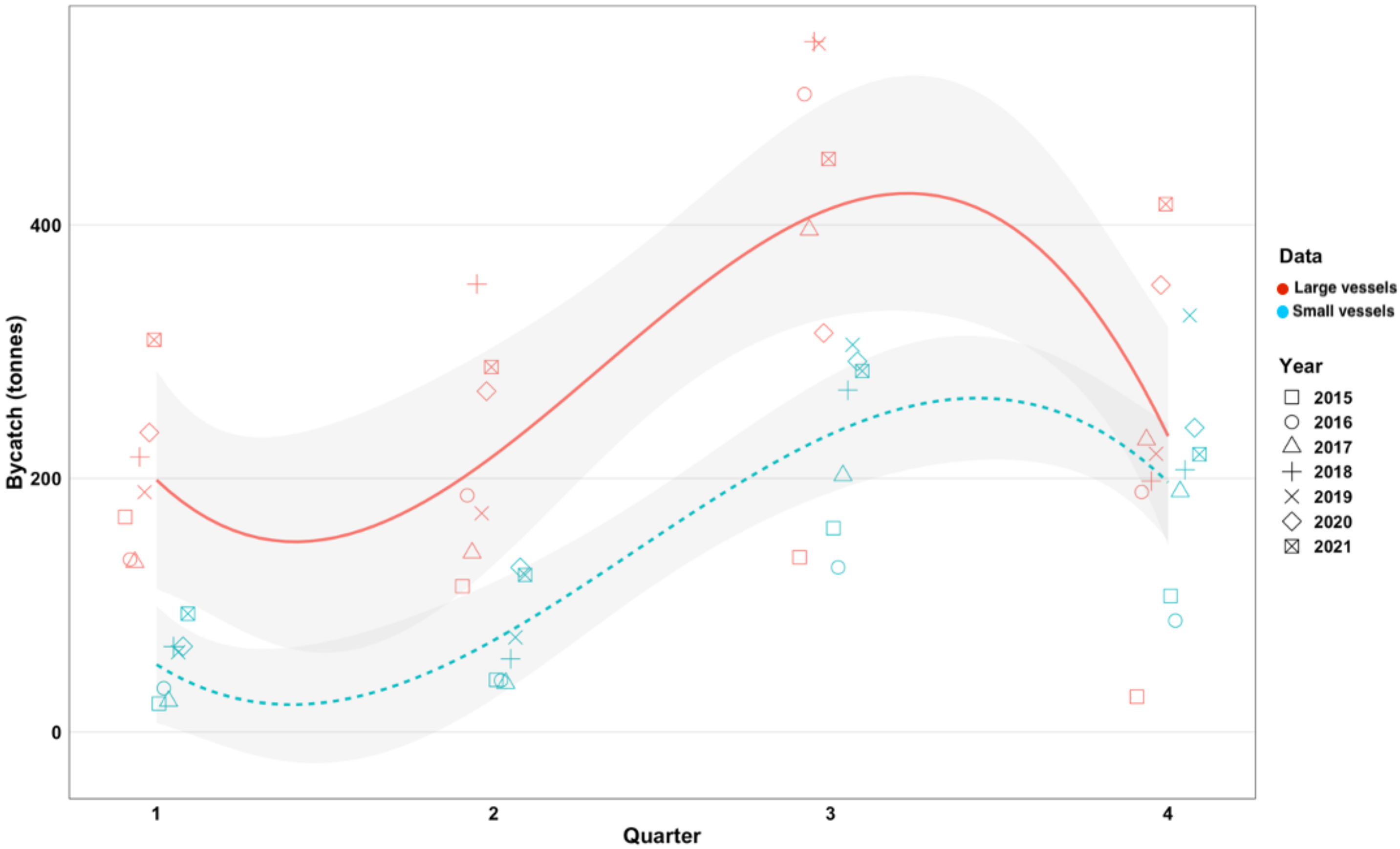

Figure 10. Quarterly variations in bycatch of golden redfish in the logbook (vessels >15m) and sales-note data (vessels <15m), respectively. The x-axis is quarter, y-axis is bycatch quantities (tonnes), and years has unique shapes. Fitted linear models with confidence intervals are represented by the stippled and solid line.

3.5 Splitting NEA cod and Coastal cod with ECA-data

3.2.1 - Quarter

Estimated ratios of northern coastal cod (NCC) and north-east arctic cod (NEAC) obtained from Estimated catch at age (ECA) runs applied to the bycatch of cod from areas north of 62° N latitude showed that the largest amounts of NEAC was across all years caught in Q1 and Q2 (Fig. 11). Q3 was the only quarter with proportionally larger amounts of NCC caught compared to NEAC. As the weight of NEAC in the catches decrease in Q3 and Q4, coastal cod proportions increased.

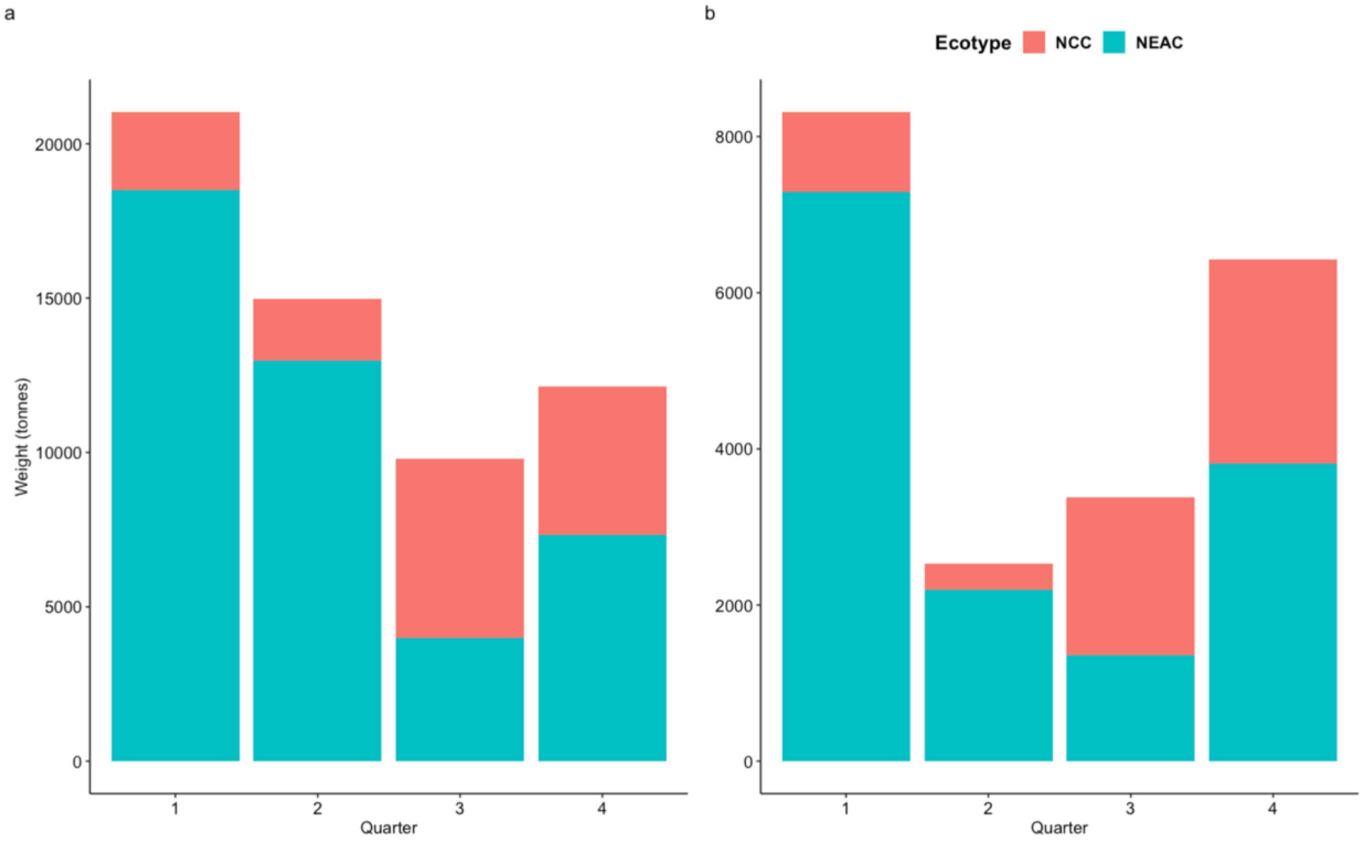

Figure 11. Total quarterly catches of Norwegian Coastal Cod and Northeast Arctic Cod in saithe fishery north of 62° N. a) Total bycatch of cod by large vessels (logbooks), b) total bycatch by small vessels (sales notes).

3.2.2 - By gear type

ECA ratios applied per gear type showed that the ratio between NCC and NEAC depend on the gear type used (Fig. 12). The highest proportions of NCC were observed for trawl and ‘others’ due to large total quantities of cod. Gillnets caught the highest amount of NCC based on sales-notes data. Sales-notes data showed that vessels < 15 meters caught large proportions of NCC (Fig 12).

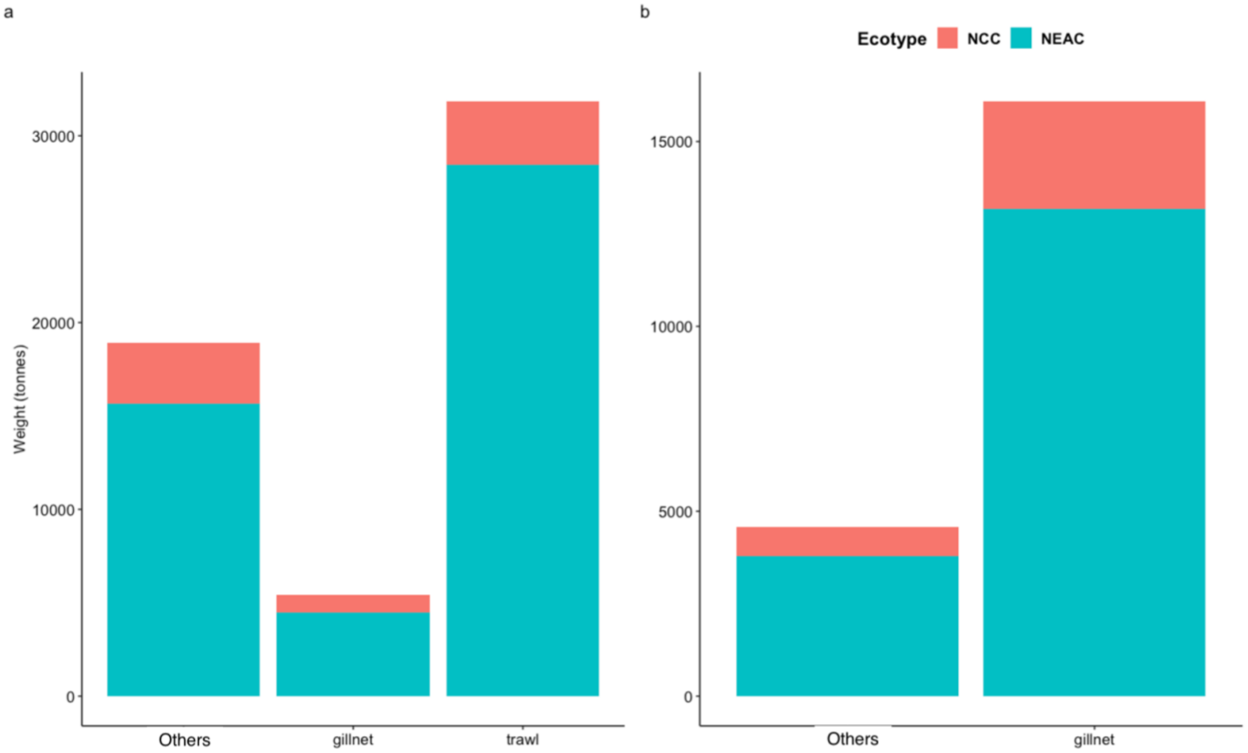

Figure 12. Summary of the total catch of cod across gear types in the saithe fishery split into NCC and NEAC, respectively. a) Total bycatch of cod by large vessels (logbooks), b) total bycatch by small vessels (sales notes).

3.2.3 - Main area

NCC percentage per statistical main area based on ECA proportions showed that most of the bycatch was NEA cod in the northern areas (Fig. 13). The ECA data showed that the ratio of coastal cod is distinctly different north and south of 67° N latitude. Large vessels caught most coastal cod in areas 03, 04 and 05. Total landings by large vessels of coastal cod were low in areas 06 and 07. Area 00 had the lowest relative proportion of coastal cod. Small vessels caught relatively higher catches of cod in areas south of 67°, relative to north of that boarder. The average ratio of NCC caught was 17.6, 16.4, 13.3 and 16. 0% north of 62° (in areas 03, 04, 05, 00), and 71,8 % south of 62° (in areas 06 and 07).

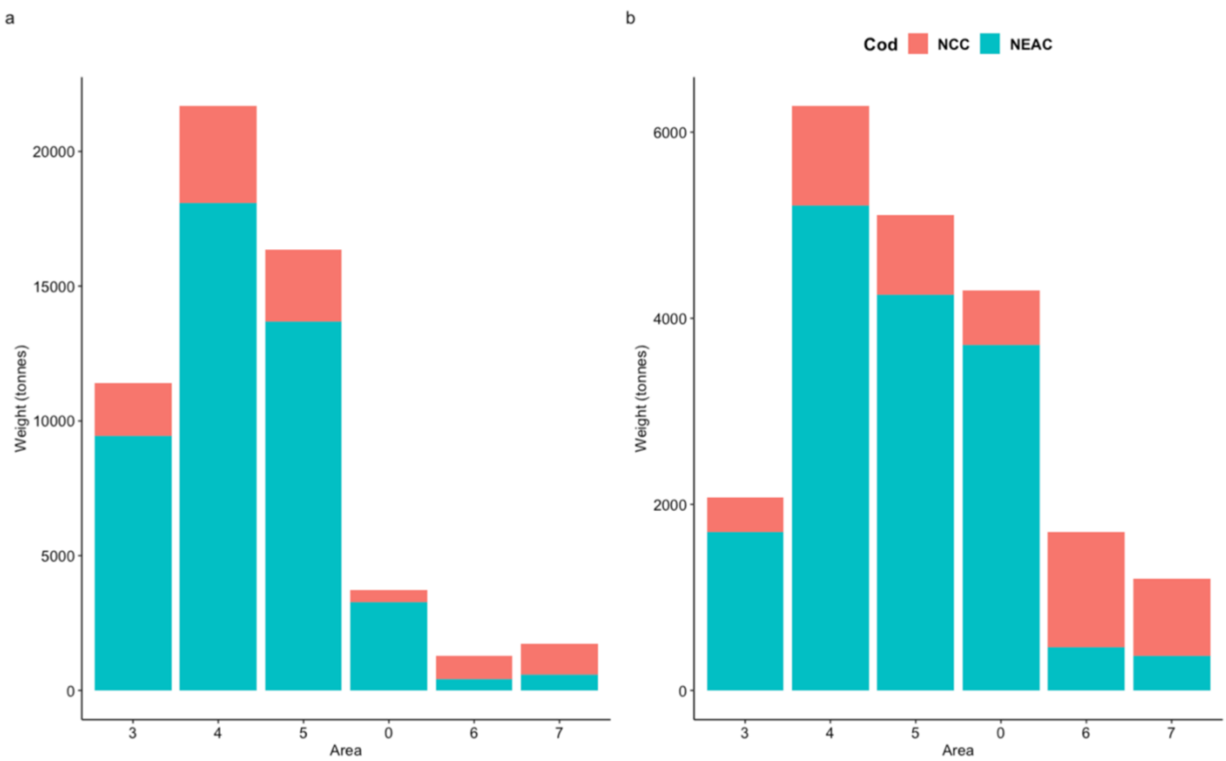

Figure 13. Summary of the total catch of cod across gear types in the saithe fishery split into NCC and NEAC, respectively. a) Total bycatch of cod by large vessels (logbooks), b) total bycatch by small vessels (sales notes).

3.2.4 - Splitting of cod south 62° N

Stock-segregation south of 62° N showed that 98 % of cod caught by large vessels was NSS, and 99 % of cod caught by small vessels was NCC, accordingly.

3.3 BYCATCH MAPS

3.3.1 - Cod North of 62 ° N

Mapping the distribution of bycatch per location makes it possible to identify patterns and hotspots of bycatch within statistical main areas. In bottom trawl catches bycatch of cod was concentrated along a narrow strip in area 03 to 05 (Fig 14). Hotspots of cod-bycatch were observed at Tromsoe-flaket (area 04 and 05) and north of Sørøya (area 05). In purse seine and set nets catches bycatch was scattered and hotspots were difficult to spot. Danish seine was mostly used in 03, 04, 05 and 00. Hotspot is seen outside the Varanger peninsula (area 03), northeast of Sørøya (area 04), north of Andøya (area 05) and around Røst (area 00). Bycatch of cod was caught in most stations in all statistical main areas except 12.

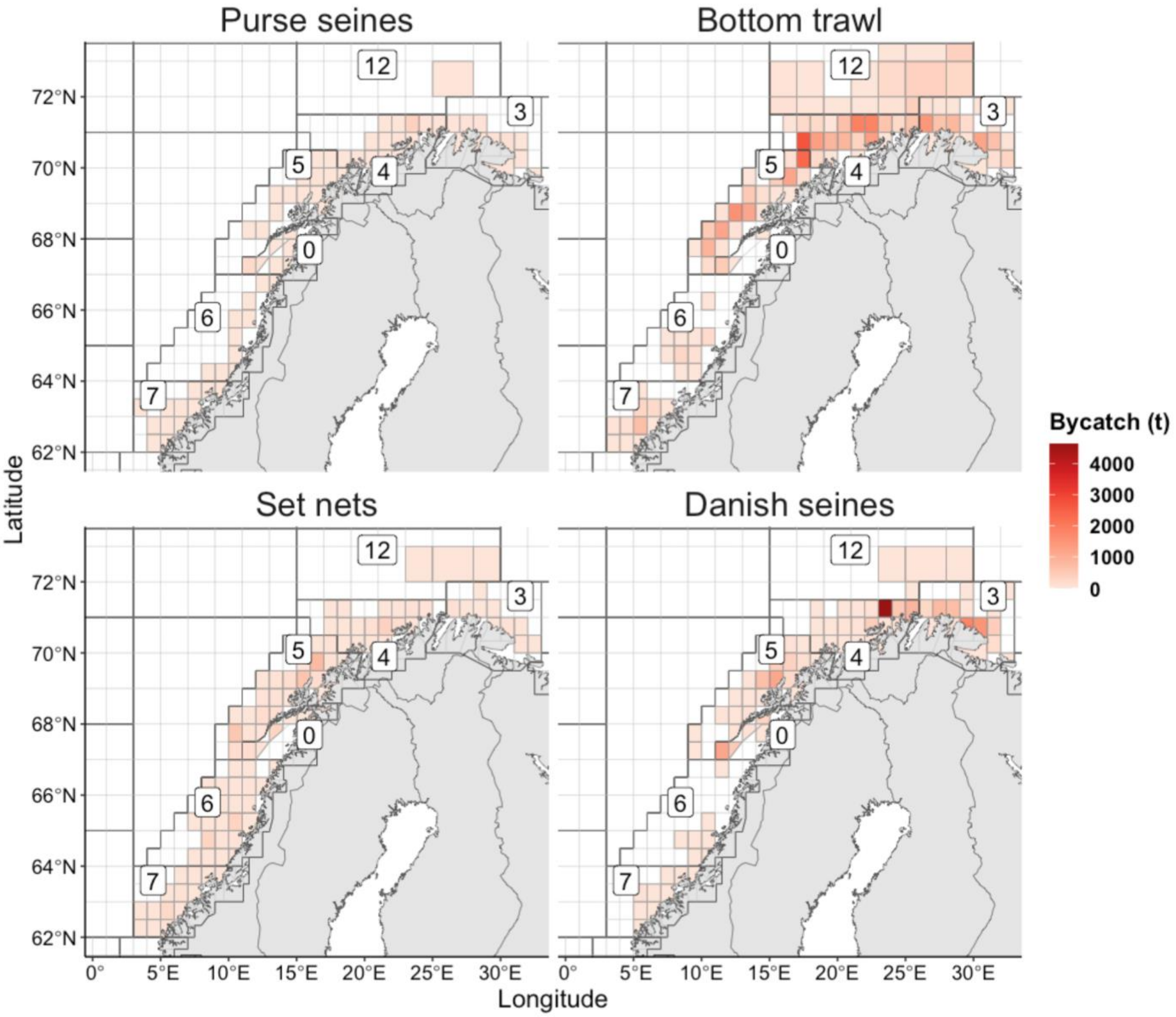

Figure 14. Distribution of bycatch of cod per statistical location rectangle for four main gear types north of 62° N, caught by large vessels >15m (logbook data). Labels indicate statistical area.

Bycatch in the sales-note was mostly concentrated in locations close to land. The highest concentrations were observed north of Andøya (05) and around Skjervøy (04). Other hotspots were observed north of Sørøya (area 04), north of Senja (area 05), and outside Svolvær and Røsthavet (area 00). In Danish seines, one is with high bycatch was northeast of Sørøya (Fig. 15).

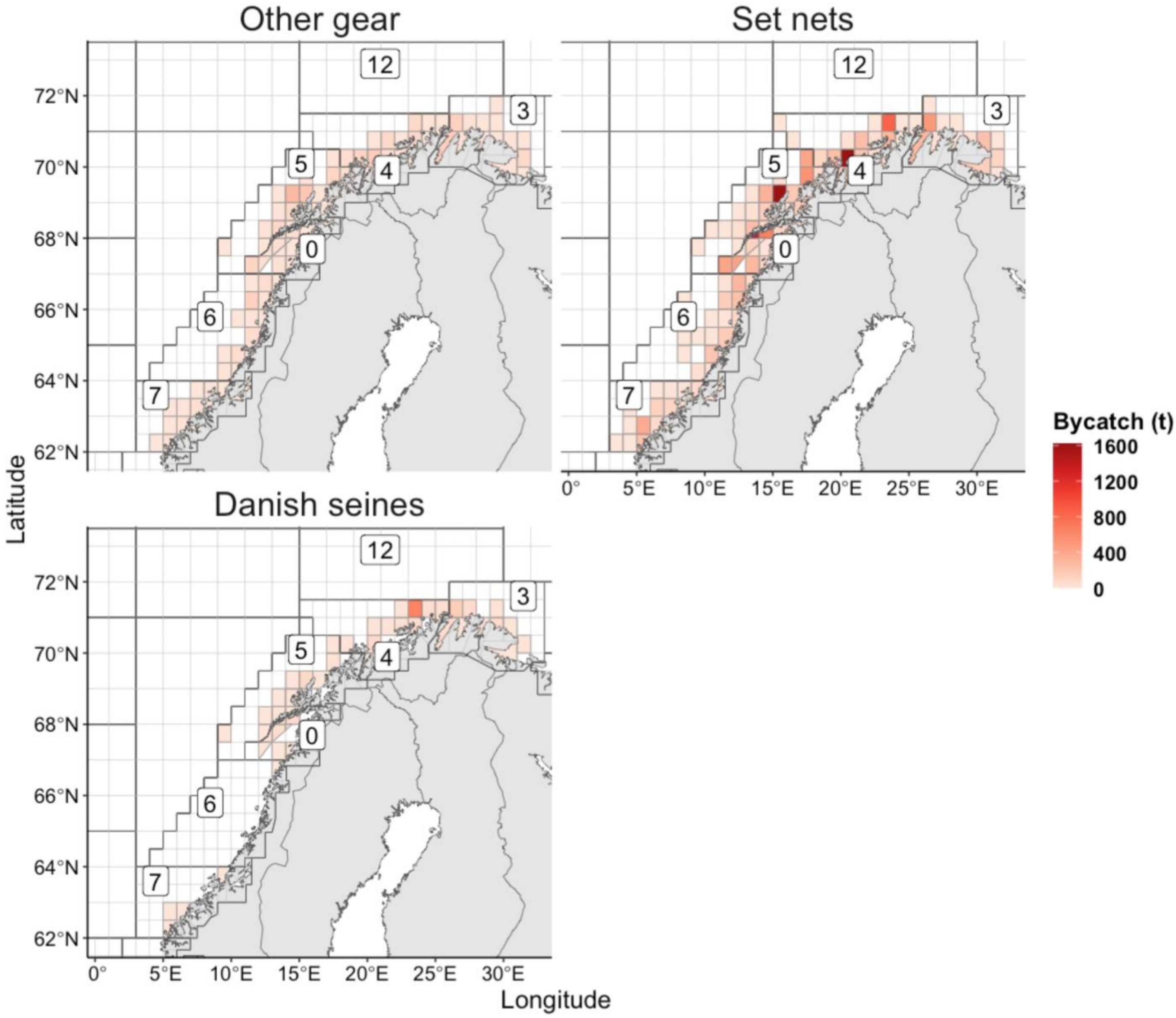

Figure 15. Distribution of bycatch of cod per statistical location rectangle for four main gear types north of 62° N, caught by small vessels < 15m (sales-notes data). Labels indicate statistical area.

3.3.2 Cod Bycatch by Quarter North of 62 ° N

Bycatch of cod from large vessels displayed seasonal difference of cod in areas 04, 05, 00, 06 and 07 (Fig 16). During Q1 high bycatch was observed along the Norwegian shelf in area 05, 00, 06 and 07. This contrasts with Q3 and Q4 where higher bycatch was observed in northern areas. Area 03, 04 and 12 appear relatively unchanged, except eastern parts of area 04 during Q3.

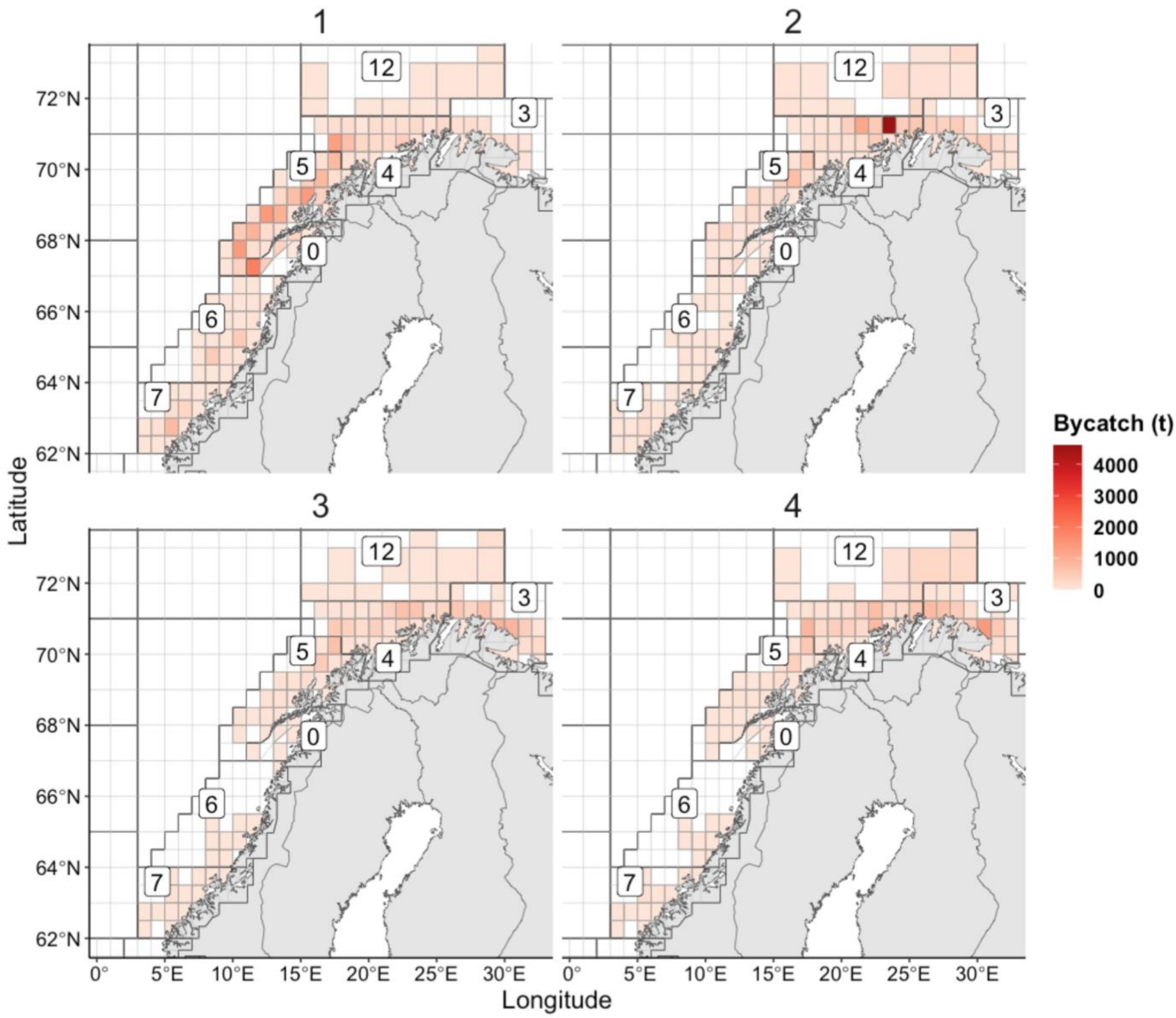

Figure 16. Quarterly distributions of bycatch of cod per statistical location rectangle for four main gear types north of 62° N, caught by large vessels >15m (logbook data). Labels indicate statistical area.

The geographical distribution of bycatch of cod from the sales-note data show increased bycatch in coastal locations in areas 04, 05 and 00 during the first quarter, and in 04 and 05 in the fourth quarter (Fig. 17). In addition, increased concentrations of cod were caught as bycatch along Helgelandskysten and Nord-møre during the first quarter. Overall, consistent catches are observed in the coastal fishery across the whole study area. High intensities were few in the second and third quarter. In areas 03, 04 and 12 bycatch quantities appear relatively unchanged, with exception to one spot east in area 04 during the third quarter.

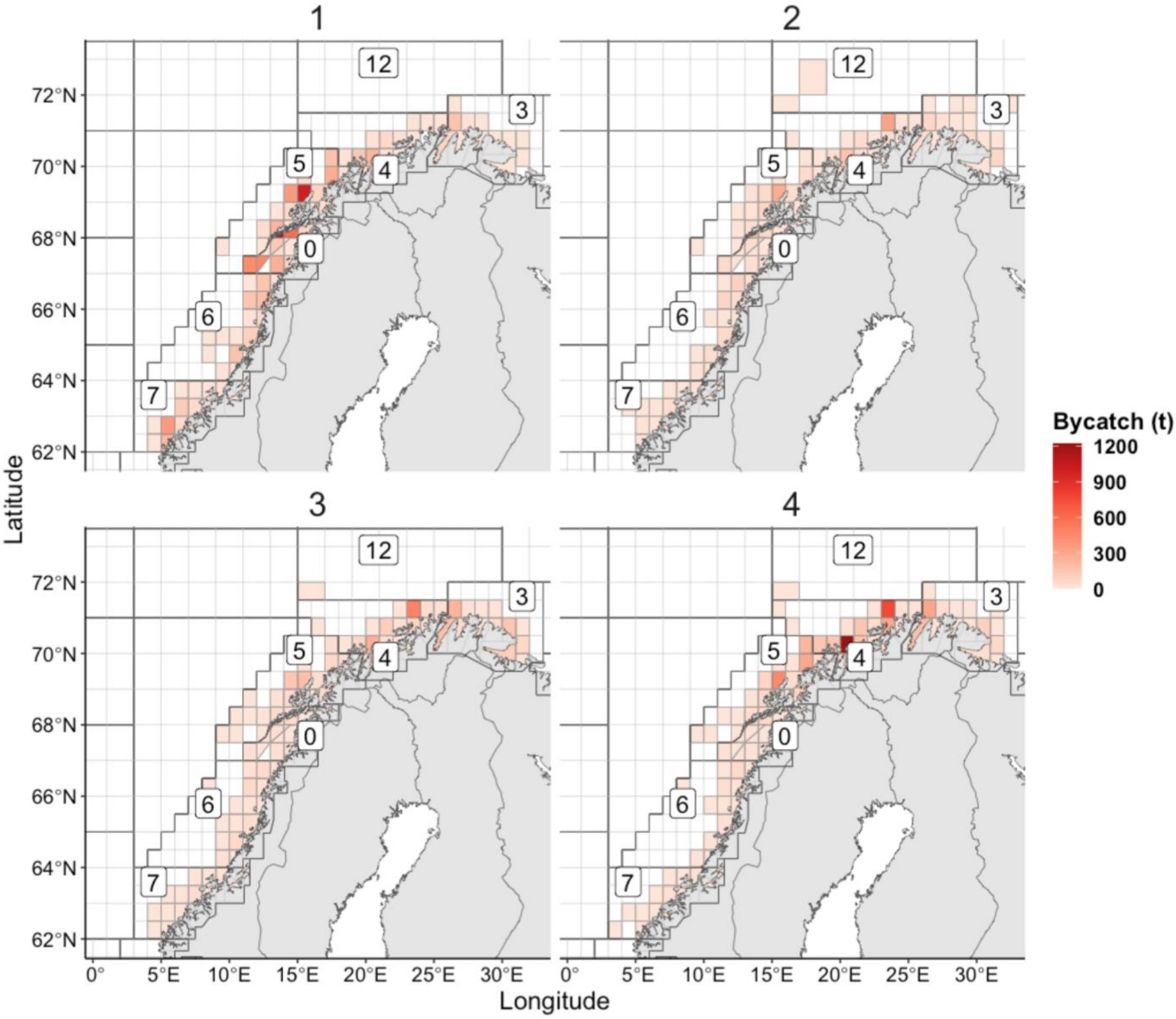

Figure 17. Quarterly distributions of bycatch of cod per statistical location rectangle for four main gear types north of 62° N, caught by small vessels < 15m (sales-note data). Labels indicate statistical area.

3.3.3 GOLDEN REDFISH

Bycatches of golden redfish by large vessels, displayed a similar distribution to NEA and coastal cod north of 62 ° N latitude (Fig. 18). A belt of increased bycatch concentration stretches from west of the Lofoten archipelago, pass outside Andøya and on the banks outside Troms and all the way to the Russian boarder. Catches offshore were observed with bottom trawl in area 12, primarily in the eastern parts. High bycatch rates were observed off the shorelines in areas 04 and 05. A clear boundary was observed at 67° N latitude, where mostly catches with set nets persist beyond this line. Bycatch of golden redfish in Danish seine and Purse seine were too low to detect any distinct pattern or hotspots. Set nets had a consistent coverage of bycatch across most statistical main areas, with hotspot observed north of Andøya.

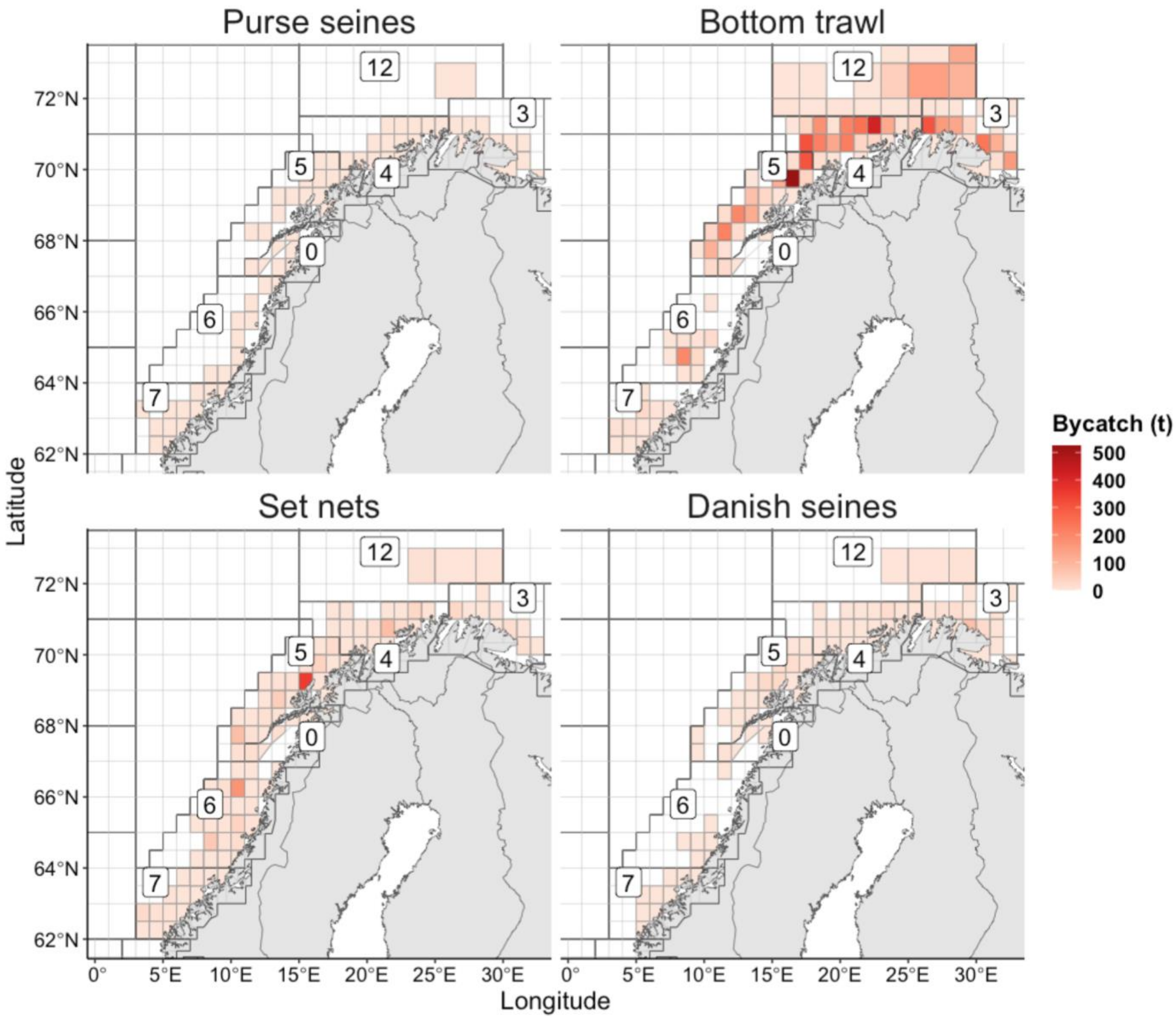

Figure 18. Distribution of bycatch of golden redfish per statistical location rectangle for four main gear types north of 62° N, caught by large vessels >15m (logbook data). Labels indicate statistical area.

Bycatch of golden redfish based on sales-note data (vessels < 15 m), were dominated by set nets (Fig. 19). Identifiable hotspots for golden redfish bycatch were located north of Andøya and around Arnøya southwest of Lopphavet. The highest concentrations of golden redfish were found on the coastal shelf in areas 03, 04, 05 and 00. A clear boundary is observed at 67° N latitude, where set nets were the most persistent gear beyond this line. Danish seines constitute negligible amounts of golden redfish, with low summarised catch distributed in 03, 04 and 05.

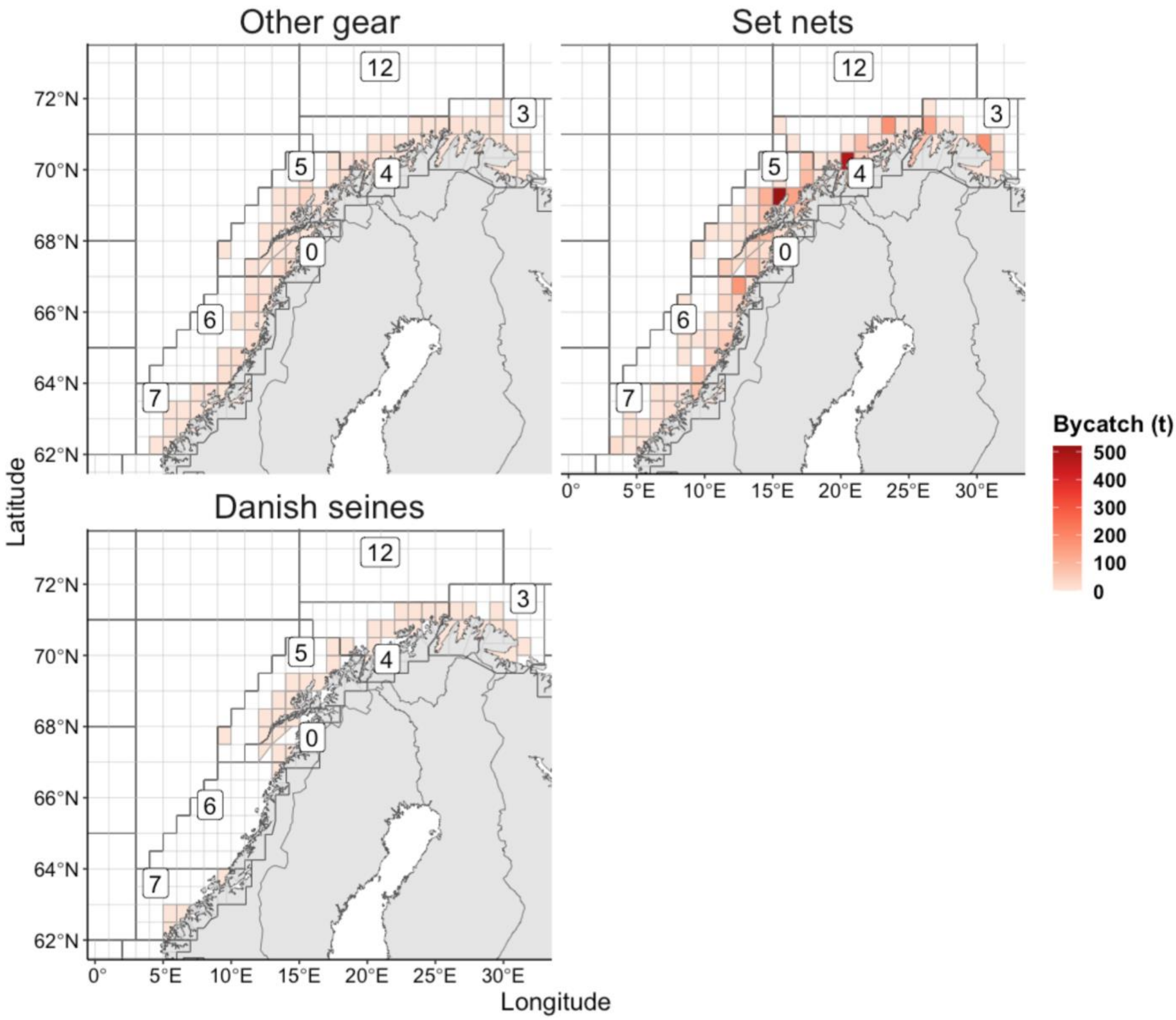

Figure 19. Distribution of bycatch of golden redfish per statistical location rectangle for four main gear types north of 62° N, caught by small vessels < 15m (logbook data). Labels indicate statistical area.

3.3.2 Cod bycatch South of 62 ° N

North Sea (NS) and NCC made up around 7.4% of cod bycatch compared to north of 62 ° N latitude. Bottom trawls stand out as the largest contributor to bycatch of cod by large vessels. All catches west of the 12 NM zone was assumed to be NS cod (Fig. 20). Stock segregation of cod-catches south 62 ° N latitude showed that only a minor proportion (~1%) of landings by large vessels would be considered coastal cod. A belt of large bycatch concentrations is seen in bottom trawl on the banks just west of the Norwegian trench. The belt extends to off-shore Lindesnes. Additional hotspot appears in 42, northeast of Shetland. The set net saithe-fishery had landings with high concentrations of cod around the Shetland fishing grounds, and east of 42 from north to south.

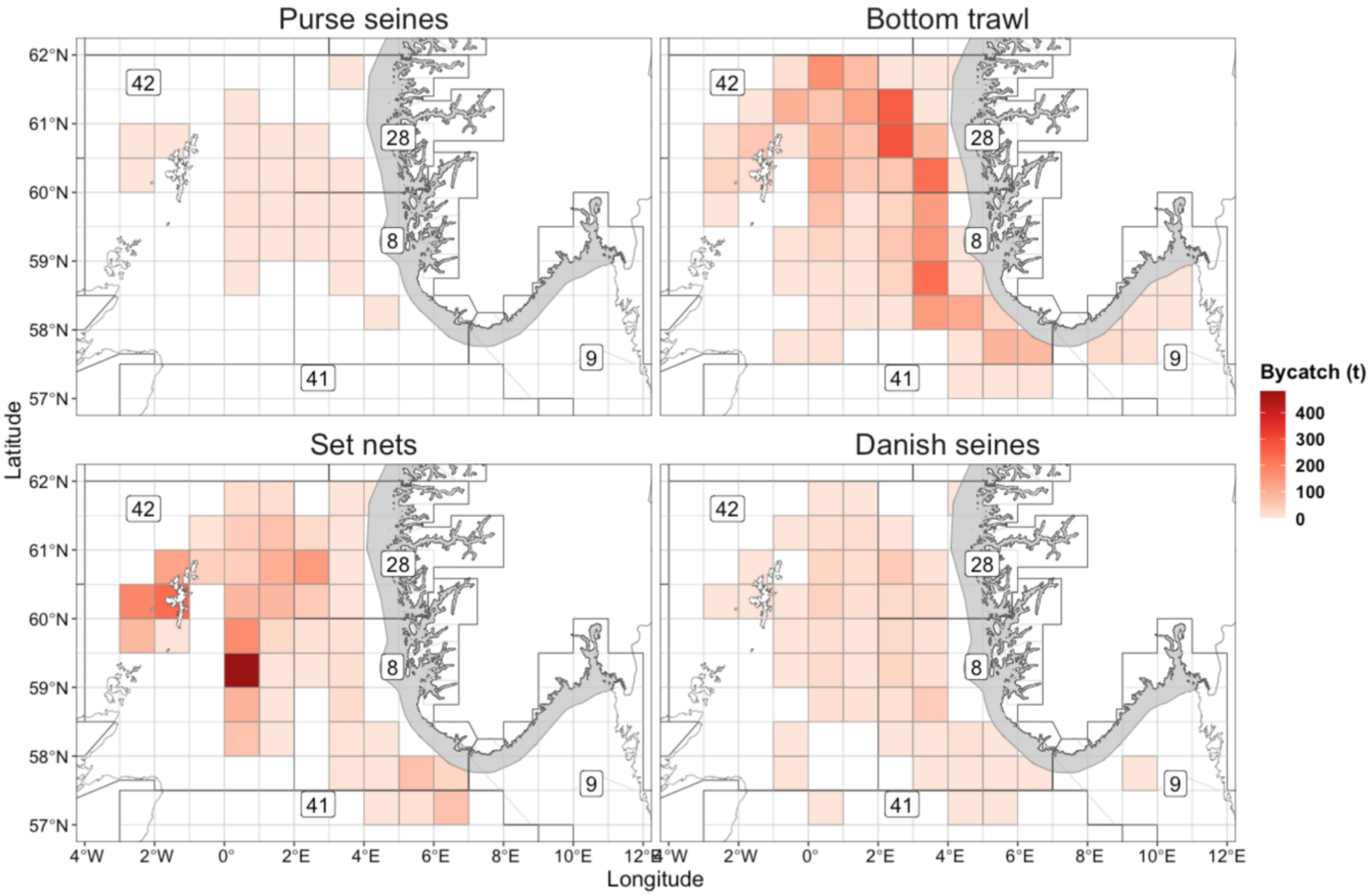

Figure 20. Distribution of bycatch of golden redfish per statistical location rectangle for four main gear types south of 62° N, caught by large vessels >15m (logbook data). Labels indicate statistical area.

Results from stock segregation showed that 98 % of cod bycatch from south of 62° N latitude in the sales note database was NCC. The distribution of bycatch varied depending on the gear type, with the highest catches observed for set nets, followed by other gears (Fig. 21). Set nets were evidently the only gear with visible areas of high catches. West of Stadt, around the Bergen peninsula, Austevoll and in the Hardanger fjord was hotspots of costal cod bycatch in the sales-notes from southern areas. Other gear types used were longlines and other gear, having minimal quantities with no hotspots visible.

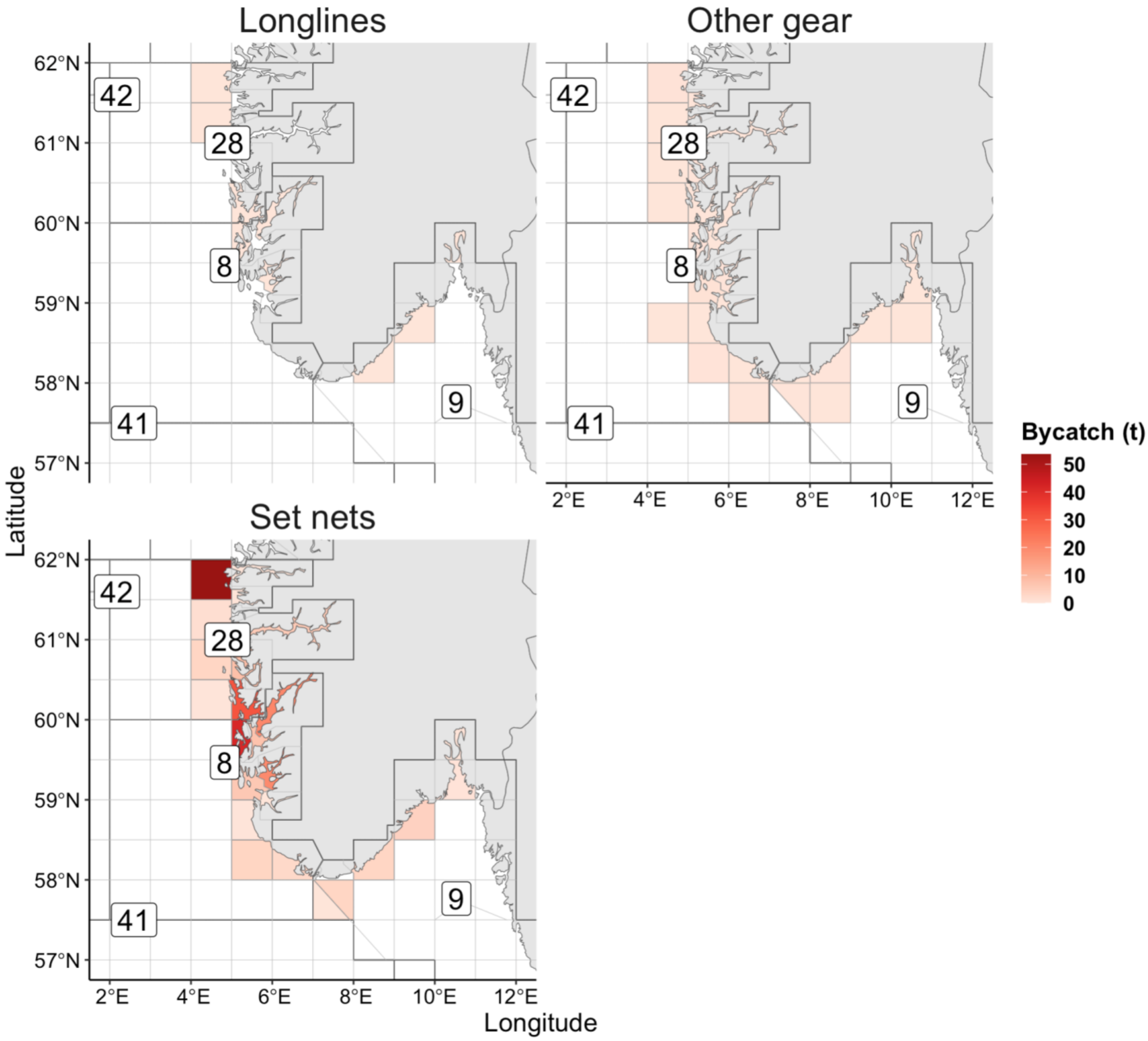

Figure 21. Distribution of bycatch of golden redfish per statistical location rectangle for four main gear types south of 62° N, based on the sales-note data (vessels < 15m). Labels indicate statistical area.

4. DISCUSSION

4.1. MAIN FINDINGS

The primary objective of the study was to investigate whether the amount of bycatch of cod (NEA, NS, Northern coastal and Southern coastal) and Golden Redfish in the saithe-target fishery of Norway vary with gear type, area, and seasonality and address which gear types, areas and season can explain patterns observed in bycatch.

I found that saithe landings from large vessels (>15m) and small vessels (<15m) were dominated by bottom trawling and set nets, respectively. Large vessels accounted for 85.4% of saithe catches. Additionally, the heaviest fished areas and, consequently, the largest bycatch quantities are predominantly landed by large vessels in the northern areas (statistical areas 03, 04, 05). The hardest fished areas for small vessels were 04, 05, 00 and 07, and bycatch proportions of cod per area, from largest to smallest, was 04 (26%), 00 (17%), 03 (16.5%) and 05 (16%). Among large vessels, Danish seine (13.6%), set nets (10.2%), bottom trawl (7.4%), and purse seine (0.5%) exhibited the highest proportions of cod by total weight. Similarly, for small vessels, Danish seines (21.9%), set nets (16.2%), and other gear (8.4%) demonstrated comparable patterns. In large vessels, the most extensive contributing gear types to bycatch of golden redfish by total weight were set nets (4.7%) and bottom trawl (1.9%). Whereas, for small vessels, set nets contributed (3.3%) and other gear (0.8%). Bycatch of cod from small vessels had a more prominent rebound than large vessels. Liner models fit annual bycatches of cod per quarter gave the best fit with a quadratic term, with coefficients of correlation of 0.58 and 0.72. Cubic terms for golden redfish gave the best fit, with coefficients of correlation of 0.42 and 0.68.

4.2. ANNUAL VARIATION OF TOTAL CATCHES

The analysis revealed that the total landings of saithe and bycatch of both cod and golden redfish increased from 2015 to 2021. The agreed TAC for saithe in subarea 1 and 2 increased by 62% from 2015 to 2021 (ICES, 2022c). Due to increased quotas, increased effort in the saithe-fishery is expected to produce more bycatch across the years. An increase in landings during the period was observed in some areas (04 and 00). Proportions of bycatch in total annual saithe-landings were roughly constant across years in both databases. Hall (2015) presents a general approach to managing the bycatch problem. The bycatch estimation formula (Eq. 1) suggests that bycatch is directly correlated to fishing effort, meaning that increased effort will result in increased bycatch. Two ways of reducing bycatch could be derived from the formula; either reduce fishing effort (quota) or reduce the bycatch-per-effort term. With increasing saithe-quotas, total annual bycatch is expected to rise unless the bycatch rate is reduced.

(Eq.1): $Bycatch = Effort\ x\ Bycatch\ per\ unit\ effort = Effort\ x\ BPUE$

4.3. Gear type variations

This analysis revealed that the amount /extent of bycatch of cod and golden redfish in the landings of saithe was related to gear type. The ANCOVA suggested a significant correlation between gear type and bycatch, taking to account the violation the assumptions. However, the gear types exhibiting the highest overall bycatch (bottom trawl and set nets) did not have the highest proportions of bycatch. The selectivity of gear types could explain the observed differences in bycatch proportions between gears. Primarily, the most frequently used gear types exhibited the highest total quantities of bycatch. During the past decade, bottom trawl accounted for approximately 40% of Norwegian saithe-catches, while purse seine and gill net contributed 25% and 20%, respectively. Conventional gear (longlines, set nets and hooks and Danish seine (Halaas, 1952) only consists of 15% of saithe landed. Danish seine has many shared features with bottom trawl but is lighter and sweeps a smaller area (Suuronen *et al.*, 2012). The catch of non-target species and undersized individuals related to Danish seine may be substantial (Walsh, 2011).

The calculations of bycatch proportions showed that purse seine is a highly selective gear type in the saithe fishery, with 220 thousand tonnes of saithe landings during the period. The age distribution in saithe landed by purse seine mainly constitutes young fish. The saithe fishery by large vessels is restricted to mainly offshore banks (Haltenbanken, Frøya banken, Langgrunna, Buagrunna, Sletta), where the purse seine fishery targets young (3- and 4-year-old) fish (Jakobsen et al., 2011). The young saithe have pelagic behaviour and therefore are not as accessible to bottom trawl as to purse seine, anticipating bycatch of cod and golden redfish to low or zero. The difference in species-specific ontogenetic behaviour, with golden redfish and cod having a bottom-related habitat preference regardless of age, resulting in limited bycatch (Drevetnyak et al., 2011; Mehl et al., 2011; Yaragina *et al.*, 2011).

4.4. SPATIAL VARIATIONS COD

The bycatch of cod showed variations across statistical areas. The bulk of cod bycatch was mainly in areas 03, 04, 05, and 00. This suggests that the distribution of cod abundance is not homogenous throughout the study area. Considerable cod-bycatch from the northern areas is expected as NEAC is highly abundant in this area. The general feeding- and nursing area of NEAC is in the Barents Sea and Svalbard waters. Mature NEAC undertakes large spawning migrations to Lofoten (areas 05 and 00) in Feb-March (Nakken *et al.*, 2008; Sundby *et al.*, 1994). Coastal cod abundance is thus higher north of 67°N, but the cod fisheries are dominated by NEAC (ICES, 2023b; Jakobsen, 1987). Coastal cod is less migratory and probably consists of separate populations inhabiting fjords and shelves along the coast (Berg *et al.*, 2003; Jakobsen, 1987). Young cod (3-5 years) pursue capelin-migrations to the coast of Finnmark and Murmansk in April-May (area 03) would also contribute to the increased distribution and bycatch here (Nakken et al., 2008).

We found that the cod bycatch was distinctly lower south of 67° N latitude, although large saithe-landings taken by bottom trawl persist as in areas south of 67° N latitude. Few migrations of NEAC to areas south of

67° N latitude give decreased cod bycatches and proportionally more coastal cod in the bycatch. Decreased presence of NEAC may result in fewer cod accessible to bottom trawling and more accessible to coastal vessels, given that coastal cod inhabit coastal- and fjord habitats. However, bottom trawling within 12 NM of the shoreline is not allowed(Høstingsforskriften, 2021). Cod-bycatch proportions in small vessels were higher in areas 06 and 07 (12 and 5%) than for bottom trawling (~2%), suggesting a low abundance of cod on the banks outside Helgelandskysten, Trønderlag and Møre.

4.5. HOTSPOTS COD

The second goal of this study was to identify hotspots of high bycatch concerning gear type and or season. Hotspots were seen at the Varanger peninsula in area 03, Arnøya, the Tromsø plateau, north of Sørøya and Fugløybanken in area 04, Malangsgrunnen, North of Andøya, the banks west of Lofoten in area 05, South of Vestvågøya and southwest of Røst in area 00. Many of these areas are well-known spawning- and feeding grounds for most commercially viable species in Norway (Heath, 1994; Jakobsen et al., 2011; Mehl et al., 2011; Saville, 1959; Yaragina et al., 2011). Spawning distribution maps provided by Olsen et al. (2010) show that cod and saithe spawning overlap spatially and temporally, leading to the catch of NEAC and NCC when saithe is targeted. Research suggests that besides water quality parameters, physical traits at the spawning ground play a vital role as well (Grabowski *et al.*, 2012). Favourable physical traits are a mixture of coastal and offshore habitats, encompassing varying depths and diverse substrate types such as rocky shores, sandy bottoms, and submerged reefs. Interestingly, the hotspots in areas 05 and 00 are favoured by spawning NEAC, as Atlantic cod aggregates at specific grounds (González-Irusta *et al.*, 2016). The location and timing of spawning is adjusted with the North Atlantic current and the spring bloom of Calanus as prey (Vikebø *et al.*, 2021), to provide beneficial conditions for increasing the fitness of offspring (Höffle *et al.*, 2014). Additionally, collision of the cold and warm currents outside the Norwegian coast provides up-dwelling at the Polar Front zone, supporting the nutritional foundation (Yaragina et al., 2011).
The preferred spawning temperature by cod is 5-7°C, and high-salinity water (González-Irusta et al., 2016; Sandø *et al.*, 2020). Surprisingly few bycatch hotspots were observed in Vestfjorden (00), and with increasing sea temperatures spawning aggregation is expected to shift northwards.

4.6. North-Sea

Bycatch hotspots of North Sea cod appeared preliminary in bottom trawl, concentrated in a belt west of the Norwegian trench in areas 28 and 08. Furthermore, bycatch with set nets was observed west and southwest of Shetland and northern Fladen ground. (Hotspots outside Måløy and Sunnhordaland). As in the Barents Sea, North Sea cod and saithe have overlapping distribution in deeper water offshore (Heino et al., 2012; Jakobsen, 1985). Habitat choice is a complex aspect and is amongst other things, affected by bottom substrate, temperature, prey availability and presence of predators (Swain *et al.*, 1994). A study by Blanchard *et al.* (2005) found that the spatial extent of the optimal habitat of young cod in the North Sea had decreased from

1977 to 2002, suggesting increased temperatures is causing aggregation (Blanchard *et al.*, 2005). The distribution of fish is also known to be density-dependent; as density decreases, fish seek their optimal habitat preference (Swain et al., 1994). Distribution of older and larger cod is known to be temperature- and depth-dependent, as they have a lower optimal temperature for growth (Bjornsson *et al.*, 2002; Ottersen *et al.*, 1998). The observed belt of cod-bycatch caught with bottom trawl along the Norwegian trench is suggested to match their preferred habitat preferences, and with the stock's decline, this area is crucial for the North Sea cod stock. The Atlantic cod in the North Sea constitute several populations (Northeast, North West and Southern North Sea) that differ in spatial extent, timing and size at spawning and depth (Heath *et al.*, 2013). Bycatch in the northern part of Fladen and coastal waters south and West of Scotland was mainly caught with set nets, which matches the shallower distribution of these stocks (Righton *et al.*, 2010).

4.7. SPATIAL VARIATIONS AND HOTSPOTS IN GOLDEN REDFISH

As with cod, the bycatch of golden redfish was not distributed homogenously across the study area. The bulk of bycatch was caught in areas 03, 04 and 05 and moderately in area 12. Vital fishing grounds are west of Møre area (area 07), Haltenbank (area 06), the banks outside Lofoten and Vesterålen (area 05), and Sleppen east of Nordkapp (area 03) (ICES, 2018c).
Golden redfish is a benthic species well adapted to deep waters, preferring 300 meters depth or more. Across the geographic range of the bycatch of golden redfish, bottom depth was roughly consistent (250-350 meters). Increased bycatch was observed at the Halten bank (area 06), and banks west of Lofoten (area 05) match well with this. In addition, large aggregations were observed at the outer edge of Malangsbanken (area 05) and Fugløybanken (area (04), across Tromsøflaket (area 04) and at Ingøydjupet (area 04). Additionally, in set-net by small vessels, hotspots were found around Arnøya (area 04) and north of Andøya (area 05), where slopes and basins down towards ~300 m are found.

As females move towards the larval extrusion areas, males remain on the Murman rise (area 03) and Tromsøflaket (Drevetnyak et al., 2011). Such aggregations are likely to be caught with bottom trawling and gillnet-fishery for saithe. Moderate bycatches were caught with bottom trawl at the Nordkapp bank (area 12). The range of saithe trawling has extended further north in the Barens Sea as saithe-distributions are expected to extend to higher latitudes as a response to temperature rise (Dulvy *et al.*, 2008).

4.8. Bycatch at depth

The distribution of bycatch by the depth of large vessels indicated that golden redfish is deeper distributed than saithe and cod. The mean depth of saithe landings with golden redfish in bottom trawl was 226 m, whereas cod and saithe were nearly identical (193m and 192m). The general distribution of saithe is between 0-300 m. In shallow water, they aggerate at the bottom, and further offshore, they are distributed higher up the water column (Stensholt *et al.*, 2002). Cod is mainly found between 100-300 meters (Jakobsen et al., 2011). The

IMR has since 1994 performed continental slope surveys along Eggakanten North and South to determine the distribution of commercial deep-water species. Trawling at various depth strata from 300-1500 meters depth produces CPUE as a function of fishing depth and latitude. Due to a few catches, CPUE for golden redfish was not presented. Survey-based CPUE for beaked redfish and Norway redfish (*Sebastes viviparus*) showed that redfish are mainly distributed at 400-500 meters (IMR report 2019 & 2018). This suggests that restricting bottom trawling to shallower depth would reduce bycatch. Areas such as Storegga and Haltenbanken outside Møre and banks outside Lofoten and Vesterålen are crucial as females gather for larval extrusion (Jakobsen et al., 2011). Observing the difference in mean-catch depth between gear types is expected as the optimal fishing depth and method are gear-specific (Halaas, 1952; Karlsen, 1997). The generally shared depth distribution of cod and saithe is observed by the overlapping bycatch at depth for cod and saithe catches.

4.8. SEASONAL VARIATIONS COD

The seasonal variation in overall bycatch quantity of cod across all years followed a concave curve with maximum bycatch in the first quarter, dropping in the second and third quarters, then partially increasing again in the last quarter. The results correspond with the annual migration of Northeast Arctic cod from the Barents Sea to the Norwegian coast, mainly to areas 00, 05, and 06 (Jakobsen, 1987). Additionally, the otolith data from ECA showed that most cod caught in the first and second quarters were NEA cod (ECA). The Norwegian coastal cod spends its whole life along the coast, in fjords and coastal sea banks. In southern Norway, North Sea cod occasionally migrate to coastal areas. The three stocks overlap to varying degrees between both seasons and areas (ICES, 2021b).

Fresh-fish regulation

The fresh-fish program for cod is a regulation implemented to maintain the cod fishery outside the NEAC season during the first and second quarters (Lovdata, 2022). The arrangement implies that vessels landing catch (fresh) after the 26th of June, with 70% consisting of other species than cod on a weekly basis (Monday-Sunday) may have up to 30% cod as bycatch, exceeding the ordinary cod quota. The tax pressure shifts the from NEAC to NCC as the abundance of NEA-cod strongly decreases in the second half-year. Additionally, it promotes sustained deliverance of fresh fish throughout the year. On the other hand, it increase the bycatch percentage for golden redfish (30%) between August and December (Høstingsforskriften, 2021) §41.

4.9 SEASONAL VARIATIONS OF GOLDEN REDFISH

The bycatch of golden redfish varies seasonally, with the lowest bycatch in the first and second quarters, reaching a maximum in the third quarter and declining in the fourth quarter. Current and recent regulations on golden redfish prohibit bottom-trawl fishery during the spawning period from the 1st of March until the 9th of May. Additionally, a bycatch percentage of up to 10 % is allowed when fishing with conventional gear, except between the 1st of August and the 31st of December, when up to 30% is allowed (Høstingsforskriften, 2021). Increased bycatch percentage of golden redfish was observed in both vessel groups in the second and third quarters, but the decline in the 4th quarter was not as prominent in large vessels. The primary spawning grounds are located beyond Vesterålen, specifically in the Halten Bank area and the banks outside Møre during April and May (ICES, 2014). Our results suggest that the seasonal fluctuations in golden redfish bycatch may be a consequence of the regulations in place for the species. Despite copulation taking place during fall, which results in aggregations, the results do not align with the timing of spawning aggregations occurring in the spring (Bakketeig *et al.*, 2015, p. 206).

4.10 NEA COD VS. COASTAL COD

The otolith data (used in the ECA analysis) showed a high proportion of NEAC during the first and second quarters, with high cod landings especially in the main spawning areas of NEAC (05 and 00). After the spawning season, cod catches comprised 60% of NCC. Our results match the seasonal and spatial variations in NEA cod related to spawning migration. It may be hard to tell the level of mixing between the two stocks at the spawning grounds, as Coastal cod is considered more stationary than the NEA cod (Kirubakaran *et al.*, 2016; Sodeland *et al.*, 2016). A study by Nordeide (1998) revealed stock segregation, but with overlapping distribution of NCC and NEAC at the spawning sites. NEAC and NCC were found to overlap vertically, with NEAC being more abundant in deeper water. Further investigation of such segregation would offer a potential tool in altering the fishing pressure to NEAC, as it is more abundant during spawning.

Uncertainty and assumptions

4.11 GEOGRAPHIC PRECISION

Stop position and time was chosen as the representative position for fishing operations in the logbooks. ArcMap was used to link the fishing coordinates to main statistical areas and locations, which was used for plotting bycatch distribution maps. The choice was due to the study including both active and passive gear for analysis. Consequently, the choice includes assumptions about the geographic precision of catches in gear types covering large areas. The bottom trawl is a gear that may cover multiple locations and main areas in one fishing operation. Therefore, using geographic point references for spatial analyses would introduce bias/uncertainty. Using start- and stop coordinates for active fishing gear, and the size and number of set nets to calculate CPUE of bycatch would allow increased precision of mapping bycatch.

4.12 Landings assumption

The reporting system of landings in the sales notes (small vessels) differs from the logbooks (large vessels), as entries are registered for each sales note received at the fish factories. Multiple entries per landing may be produced as the catch before being handed over sorted. Multiple catches across multiple days and areas may be delivered simultaneously. Using entry as an identifier of catch-observations may introduce bias. One landing was assumed to equal unique landing dates and vessel IDs. A study by Clegg et al. 2018 on assessing bias in a fisheries self-sampling program assessed whether a landing date is a suitable identifier of trips. Daily observations from vessels in the Norwegian Reference Fleet were linked to the most recent landing date following each observation. They found that 75% of trips comprised one fishing day, while 98% of trips comprised three fishing days or less. The study concluded that landing dates are an appropriate identifier of fishing trips in the sales note database (Clegg *et al.*, 2018).

4.13 Challenges

Managing bycatch is challenging when desired protected species overlap with target species in a fishery. Both are delivered and sold at the fish factories with regular or bycatch quotas. A direct fishery for golden redfish is prohibited, and it entered the red-listed in 2006 (Artsdatabanken, 2021). This considered the type of conservation status for golden redfish is worse than for cod. Cod is not unwanted by the fishermen, as TAC exists for both NEA cod, NS cod and Coastal cod. The aim is to minimize the bycatch of non-target species whenever feasible. Considering the high degree of habitat overlap between cod and saithe makes bycatch mitigation even more difficult. The deeper distribution of Golden redfish offers potential in spatial- and depth restrictions.

4.14 Suggestions for improved management

Large vessels (15m<) accounted for 85.4% of total saithe catches. This suggests that regulation implementation application to large vessels, bottom trawling, would have most decisive impact on reducing bycatch quantities. As Hall et al. (2015) suggested, reducing the effort from such gear, primarily at the highly productive areas, would also mean reducing total landings of saithe.

I found that gear type, area, and calendar quarter are critical drivers for increased bycatches of cod. Even this approach did not include modelling bycatch concerning these variables; it could be used to predict where, when, where and with what gear we expect to catch the most bycatch. A study by Yuan Yan et al. (2022) used spatiotemporal modelling to predict the bycatch weight of the Greenland shark (*Somniosus microcephalus*) in the Canadian Arctic fishery. They identified spatiotemporal hotspots, and results indicated that calendar month and gear type were crucial drivers of high bycatch (Yan *et al.*, 2022). Using CPUE models would increase the species-specific precision of spatiotemporal patterns in the bycatch (Dolder et al., 2018). Applying such findings to conservation strategies and management decisions, such as limiting access to spatial hotspots, seasonal closures, and gear restrictions, could alter the fishing effort toward healthier, fast-growing stocks.

A paper by Little *et al.* (2015) examined real-time spatial management approaches in the U.S. and Europe to reduce bycatch and discards. Real-time closures (RTC) are practised in the Barents- and Norwegian Sea to reduce the catch of juvenile and protected species. This includes on site sampling, and if the catch is not satisfactory to regulations, an RTC is implicated immediately (Gullestad, 2013). The method is adopted by the Scottish demersal fisheries to reduce the discards of over-quota cod. The strategy aims to direct fishing away from cod aggregations based on catch compositions from vessel monitoring systems. Another example is rolling hotspots introduced in the Eastern Bering Sea pollock fishery to reduce the bycatch of chinook and chum salmon. Real-time zones are temporarily implemented based on reported bycatch information from the fishing fleet itself and rely on the correctness of the daily reporting system (Stram *et al.*, 2014). Combining real-time spatial incentives and retrospective spatiotemporal analyses of fisheries data could help keeping fisheries open and prevent the occurrence of 'choke species', limiting other commercial fisheries (Baudron et al., 2015; Little et al., 2015).

4.15 FURTHER RESEARCH

Investigation of bycatch of NCC and golden redfish in the haddock fishery would provide valuable knowledge in mitigating bycatch. The Haddock fishery is one of the most important commercial species in the Barens Sea, with annual landings between 150-200 thousand tonnes (ICES, 2020; Jakobsen et al., 2011; Russkikh *et al.*, 2011). Haddock is a more deep-dwelling fish compared to saithe. The fishery for haddock uses much of the same gear and methods as in saithe fishery, anticipating high bycatch of golden redfish. Investigating the bycatch of cod and golden redfish in the Haddock fishery of Norway would further aid and improve the stock management advice on cod and golden redfish.

Exploring the depth-related length composition in redfish species would be useful information to improve management regulations on golden redfish. Sampling several depth strata separately at different locations with a MultiSampler could reveal the level of mixing of size groups at depth (Engås *et al.*, 1997). Multi-meshed gillnets would be more applicable for sampling coastal and fjord habitats (Vašek *et al.*, 2009). Sampling with bottom set nets at stations with varying bottom depths or sampling a depth gradient along a slope would reveal any depth stratification in fish length. Identifying the depth distribution of smaller fish could be used to develop trawl- and gillnet-specific depth and mesh-size restrictions to avoid the capture of smaller and younger fish (Sampson, 2014).

4.16 Conclusion

Based on findings from this study, some management on Norwegian Coastal Cod and Golden redfish that could be considered includes:

I) Avoiding bottom gillnets and depth restriction for bottom trawl, Danish seine and set nets on golden redfish hotspots.

II) The expansion of bottom trawling for saithe in northern offshore areas would require monitoring, considering large catches of golden redfish on the North Cape bank.

III) To reduce the bycatch of Coastal cod in the saithe fishery North of 62° N, fishing effort from bottom trawl and Danish seine should be reduced at hotspots in areas 03, 04 and 05, and set nets should be avoided in area 06 and 07 during the third and fourth quarter.

IV) Avoid using bottom trawl south of 62° N along the Norwegian trench in areas 28 and 08 and set nets at northern Fladen and West/south of Shetland (area 42).

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APENDIX A: LIST OF GEAR-TYPE CONVERSIONS

Table 9: Full list of gear type conversions from both logbook and sales note databases.

	Logbooks	Salesnote
Bottom trawl	Bunntrål, otter Bunntrål (uspes) Otter dobbeltrål Bunntrål, bom Otter dobbeltrål, reke Bunntrål, kreps	Bomtrål Bunntrål Bunntrål par Reketrål Krepsetrål Sputniktrål
Purse seine	Surrounding nets -without purse lines Snurpenot/ringnot, et fartøy Snurpenot/ringnot	Snurpenot Snurpenot/ringnot
Danish seine	Snurrevad, skotsk Snurrevad, dansk Snurrevad Snurpenot/ringnot, to fartøy	Snurrevad
Pelagic trawl	Flytetrål, uspesifisert Flytetrål, par Partrål, uspesifisert Flytetrål, otter Annen trål (udefinert) Udefinert trål Flytetrål, otter	Flytetrål Dobbeltrål
Longlines	Setteline Flyteline Andre liner	Autoliner Flyteline Andre liner
Set nets	Combines gillnets-trammel net Udefinert garn Settegarn Encircling gillnets Gillnets and entangling nets (unspec) Drivgarn	Drivgarn Settegarn Udefinert garn
Other gear	Landnot, Dorg/harp/snik, Teiner, Udefinert not, Harvesting machines – pumps, Boat /vessel seines -Pair seines, Uspesifisert/uoppgitt redskap, Udefinert krokredskap, Juksa/pilk- manuell, Juksa/pilk- mekanisert, Skrape-mekanisert, Harpun,div.	Taretrål, Udefinert trål Brugde kanon/harpun, Rifle Havteiner, Juksa/pilk Oppdrett, Ruser, Teiner Tangkutter, Landnot, Kilenot Udef. Krokredskap Udef. Not og trål Håndplukking

APPENDIX B: ALL OBSERVATIONS IN LOGBOOKS AND SALES NOTES

Table 10: Full list of observations from each main area and year from both logbook and sales note databases.

Stat. area	Year	Salesnote	Logbook	Total	Stat. area	Year	Salesnote	Llogbook	Total
0	2015	2986	316	3302	**22**	2018	3	0	3
0	2016	3716	350	4066	**22**	2021	3	0	3
0	2017	3826	377	4203	**28**	2015	791	452	1243
0	2018	4031	304	4335	**28**	2016	707	510	1217
0	2019	4080	327	4407	**28**	2017	641	502	1143
0	2020	3788	239	4027	**28**	2018	593	763	1356
0	2021	4520	225	4745	**28**	2019	722	1358	2080
3	2015	916	664	1580	**28**	2020	685	1341	2026
3	2016	1469	1004	2473	**28**	2021	686	1486	2172
3	2017	1802	880	2682	**41**	2015	12	59	71
3	2018	1572	1003	2575	**41**	2016	10	54	64
3	2019	1508	1015	2523	**41**	2017	6	27	33
3	2020	1363	1220	2583	**41**	2018	30	51	81
3	2021	1646	2068	3714	**41**	2019	5	68	73
4	2015	2846	898	3744	**41**	2020	7	41	48
4	2016	1717	1630	3347	**41**	2021	2	28	30
4	2017	2416	1361	3777	**10**	2021	0	10	10
4	2018	2670	1864	4534	**12**	2015	0	7	7
4	2019	3876	1640	5516	**12**	2016	0	133	133
4	2020	5126	2296	7422	**12**	2018	0	30	30
4	2021	4413	2380	6793	**12**	2020	0	42	42
5	2015	4825	1158	5983	**13**	2016	0	17	17
5	2016	6694	1317	8011	**13**	2020	0	2	2
5	2017	5057	1136	6193	**20**	2015	0	1	1
5	2018	3889	1409	5298	**20**	2016	0	1	1
5	2019	4349	1556	5905	**20**	2017	0	4	4
5	2020	4128	1623	5751	**20**	2018	0	1	1
5	2021	5245	2625	7870	**20**	2020	0	1	1
6	2015	2943	759	3702	**20**	2021	0	3	3
6	2016	3079	459	3538	**23**	2018	0	4	4
6	2017	2818	322	3140	**30**	2018	0	1	1
6	2018	3279	401	3680	**30**	2019	0	6	6
6	2019	3781	412	4193	**30**	2020	0	9	9
6	2020	4258	309	4567	**31**	2015	0	5	5
6	2021	3804	390	4194	**37**	2015	0	19	19
7	2015	3861	776	4637	**37**	2016	0	6	6
7	2016	3850	637	4487	**37**	2017	0	4	4
7	2017	3330	856	4186	**37**	2018	0	2	2
7	2018	4551	901	5452	**37**	2019	0	6	6
7	2019	3634	798	4432	**37**	2020	0	4	4
7	2020	3958	1095	5053	**37**	2021	0	2	2
7	2021	3891	1370	5261	**38**	2018	0	1	1

8	2015	739	488	1227	**42**	2015	0	1180	1180
8	2016	1184	492	1676	**42**	2016	0	1395	1395
8	2017	1159	466	1625	**42**	2017	0	1973	1973
8	2018	1025	1125	2150	**42**	2018	0	1491	1491
8	2019	1573	1426	2999	**42**	2019	0	1875	1875
8	2020	1611	2055	3666	**42**	2020	0	1302	1302
8	2021	1780	1330	3110	**42**	2021	0	212	212
9	2015	759	121	880	**43**	2015	0	39	39
9	2016	593	69	662	**43**	2016	0	10	10
9	2017	849	52	901	**43**	2017	0	36	36
9	2018	99	62	161	**43**	2019	0	31	31
9	2019	116	104	220	**62**	2017	0	1	1
9	2020	1277	43	1320	**NA**	2015	0	41	41
9	2021	1476	46	1522	**NA**	2016	0	55	55
12	2017	1	88	89	**NA**	2017	0	46	46
12	2019	1	61	62	**NA**	2018	0	123	123
12	2021	17	80	97	**NA**	2019	0	224	224
13	2021	1	5	6	**NA**	2020	0	216	216
					NA	2021	0	294	294

Appendix C: Additional maps

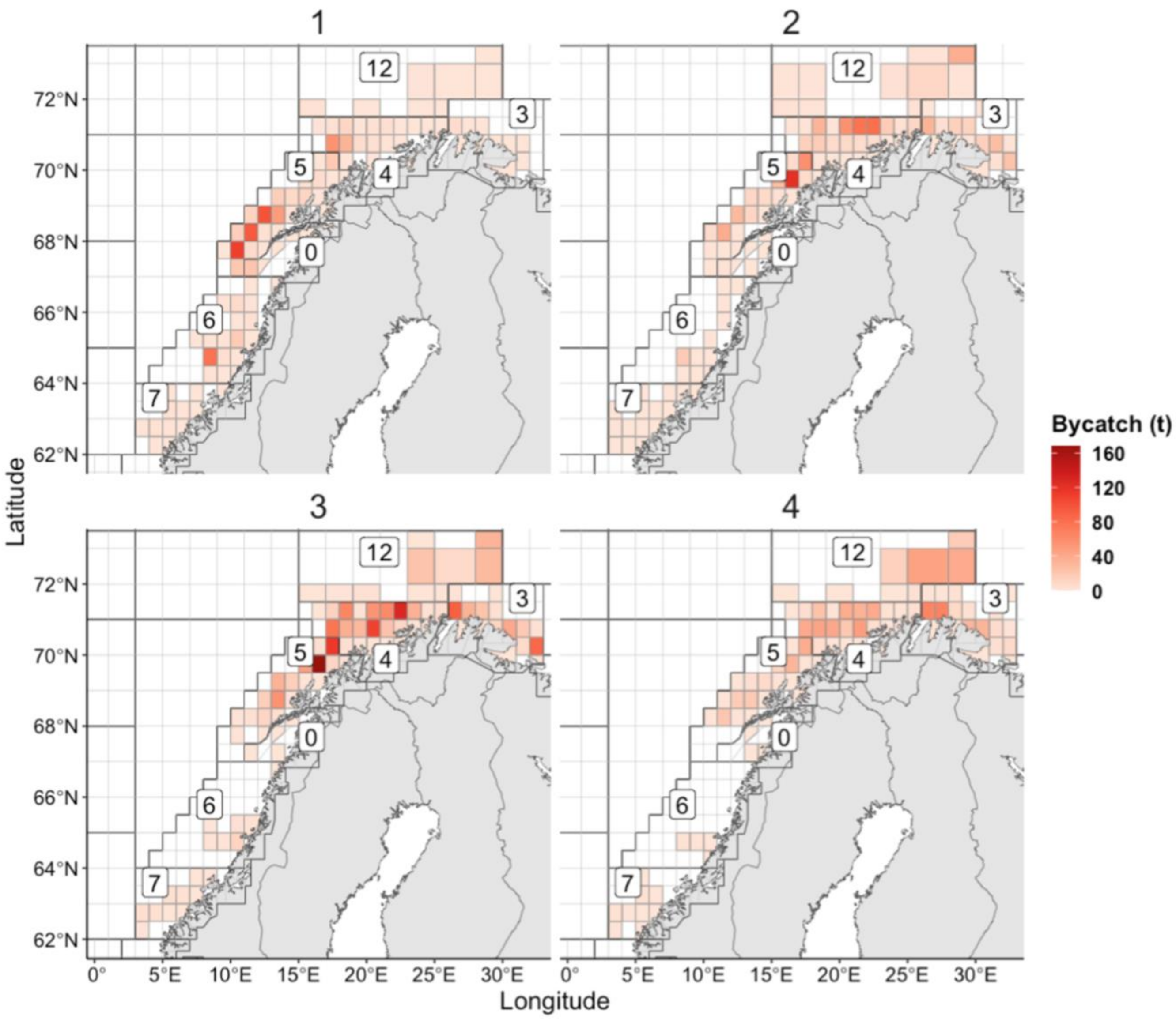

Figure 21. Quarterly bycatch of Golden redfish by large vessels north of 62°N latitude (>15m), between 2015 and 2021, only landings outside the 12 NM boarder.

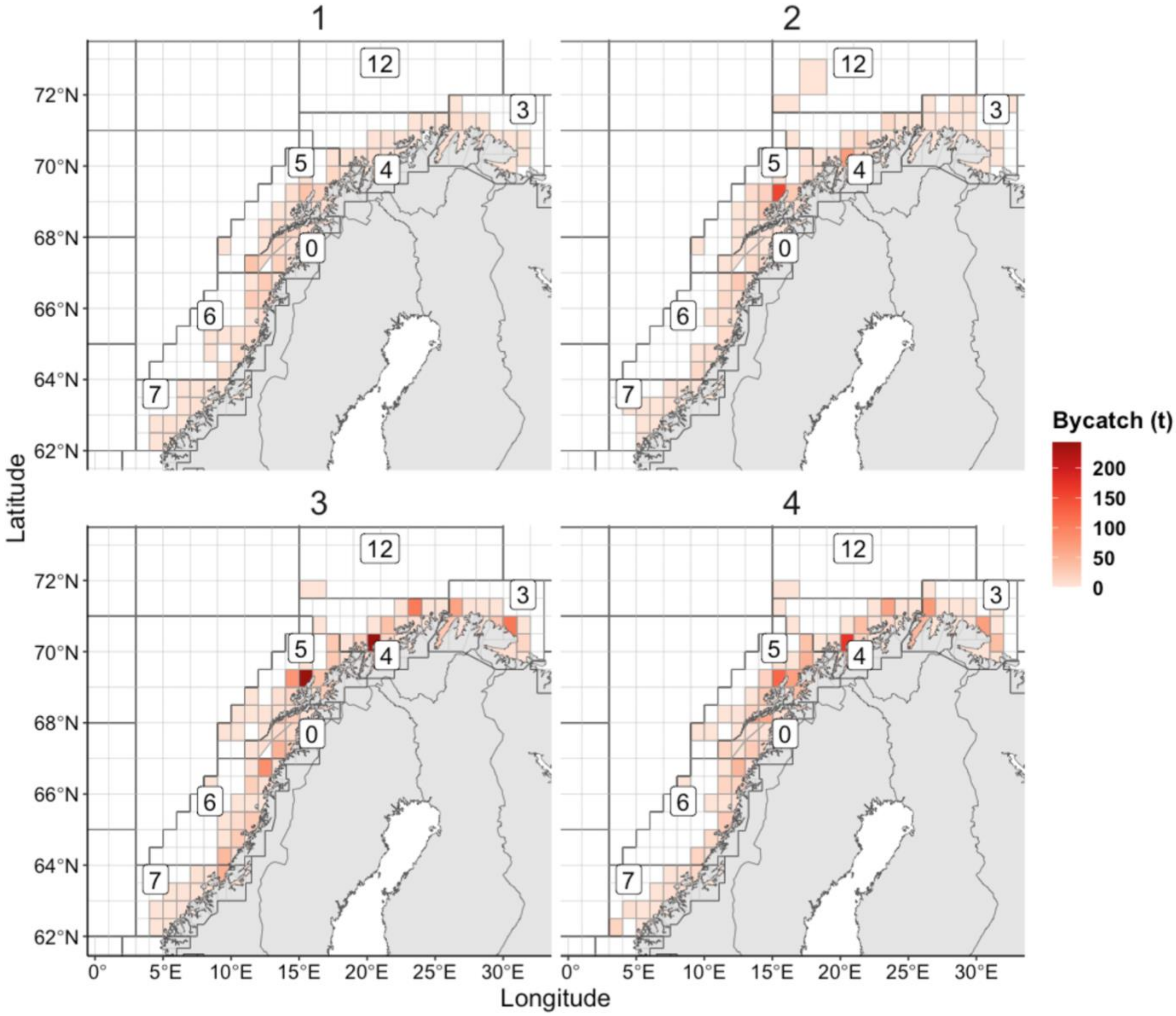

Figure 22. Quarterly bycatch of Golden redfish north of 62°N latitude by small vessels (15m>), between 2015 and 2021, only landings outside the 12 NM boarder.

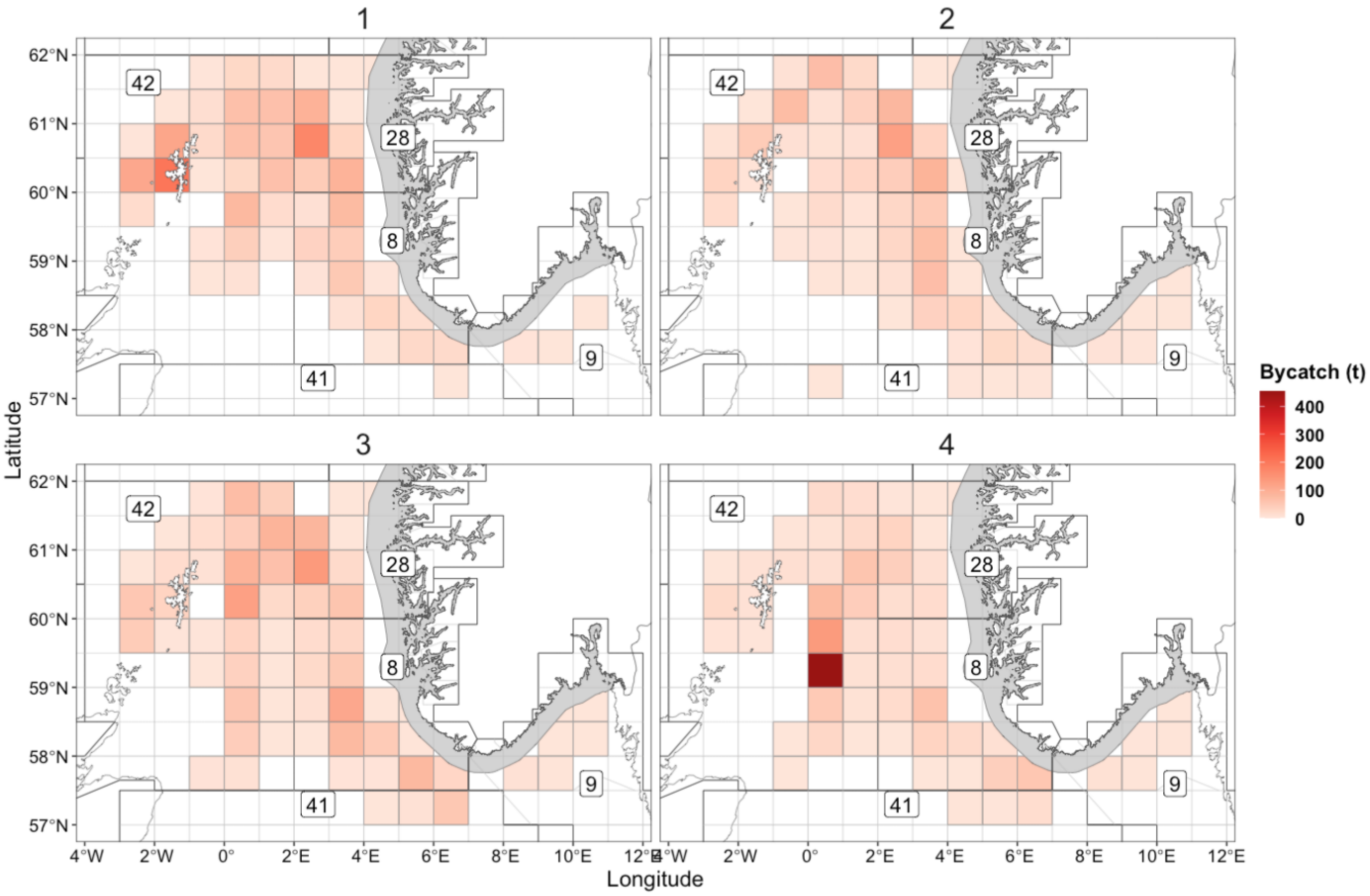

Figure 23. Quarterly bycatch of North Sea cod south of 62° N latitude by large vessels (15 m <) between 2015 and 2021, only landings outside the 12 NM boarder.

.

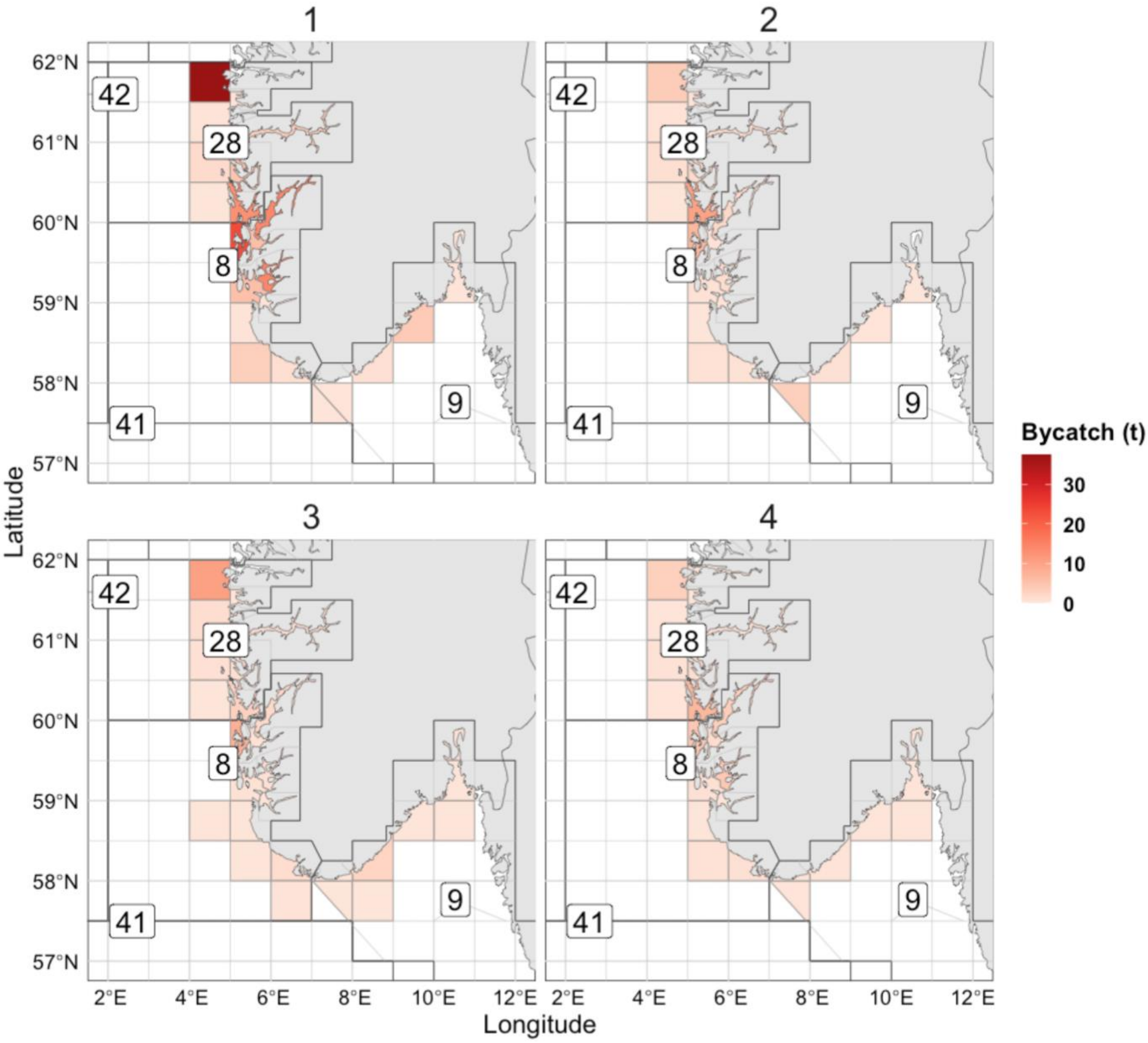

Figure 24. Quarterly bycatch of Norwegian coastal cod south of 62° N latitude by small vessels (<15 m), only landings within the 12 NM boarder.

APPENDIX D: SUMMARY OUTPUT POST-HOCK TEST

Table 11: Output from Post-Hock test on ANCOVA: bycatch of cod ~ gear type+area, logbook data (vessels >15m). Significant p-values are marked green.

Interaction	diff	lwr	upr	P adj
Set nets-Bottom trawl	0,135	0,109	0,162	0,000
Purse seine-Bottom	-0,421	-0,450	-0,392	0,000
Danish seine-Bottom	-0,034	-0,051	-0,017	0,000
Purse seine-Set nets	-0,556	-0,593	-0,520	0,000
Danish seine-Set nets	-0,170	-0,198	-0,142	0,000
Danish seine-Purse	0,387	0,357	0,417	0,000
12-00	1,440	1,311	1,570	0,000
28-00	-0,688	-0,750	-0,626	0,000
3-00	-0,121	-0,179	-0,062	0,000
4-00	0,189	0,131	0,247	0,000
42-00	-0,665	-0,724	-0,606	0,000
5-00	-0,072	-0,130	-0,014	0,003
6-00	-0,674	-0,740	-0,609	0,000
7-00	-0,683	-0,742	-0,624	0,000
8-00	-0,709	-0,770	-0,647	0,000
28-12	-2,128	-2,250	-2,006	0,000
3-12	-1,561	-1,681	-1,441	0,000
4-12	-1,251	-1,371	-1,132	0,000
42-12	-2,105	-2,226	-1,985	0,000
5-12	-1,512	-1,632	-1,392	0,000
6-12	-2,115	-2,239	-1,991	0,000
7-12	-2,123	-2,244	-2,002	0,000
8-12	-2,149	-2,271	-2,027	0,000
3-28	0,567	0,527	0,607	0,000
4-28	0,877	0,839	0,915	0,000
42-28	0,023	-0,017	0,063	0,735
5-28	0,616	0,578	0,654	0,000
6-28	0,014	-0,036	0,063	0,997
7-28	0,005	-0,035	0,045	1,000
8-28	-0,021	-0,065	0,023	0,898
4-3	0,310	0,277	0,343	0,000
42-3	-0,544	-0,579	-0,509	0,000
5-3	0,049	0,016	0,082	0,000
6-3	-0,554	-0,599	-0,508	0,000
7-3	-0,562	-0,598	-0,526	0,000
8-3	-0,588	-0,628	-0,548	0,000
42-4	-0,854	-0,887	-0,821	0,000
5-4	-0,261	-0,292	-0,230	0,000
6-4	-0,863	-0,908	-0,819	0,000
7-4	-0,872	-0,906	-0,838	0,000
8-4	-0,897	-0,936	-0,859	0,000
5-42	0,593	0,560	0,627	0,000
6-42	-0,009	-0,055	0,037	1,000
7-42	-0,018	-0,054	0,018	0,868
8-42	-0,043	-0,083	-0,003	0,021

6-5	-0,602	-0,647	-0,558	0,000
7-5	-0,611	-0,645	-0,577	0,000
8-5	-0,637	-0,675	-0,598	0,000
7-6	-0,009	-0,055	0,038	1,000
8-6	-0,034	-0,084	0,015	0,465
8-7	-0,026	-0,066	0,015	0,593

Table 12: Output from Post-Hock test on ANOVA, bycatch of cod ~ gear type+area, in sales-note data (vessels <15m). Significant p-values are marked green.

Interaction	diff	lwr	upr	p adj
Set nets-Other gear	0,137	0,133	0,141	0,000
Danish seines-Other gear	1,100	1,078	1,122	0,000
Danish seines-Set nets	0,963	0,941	0,984	0,000
3-0	0,044	0,032	0,057	0,000
4-0	0,114	0,104	0,123	0,000
5-0	0,018	0,009	0,026	0,000
6-0	-0,077	-0,086	-0,067	0,000
7-0	-0,110	-0,119	-0,101	0,000
8-0	-0,129	-0,141	-0,116	0,000
28-0	-0,168	-0,184	-0,152	0,000
4-3	0,069	0,057	0,081	0,000
5-3	-0,027	-0,038	-0,015	0,000
6-3	-0,121	-0,134	-0,109	0,000
7-3	-0,154	-0,166	-0,142	0,000
8-3	-0,173	-0,188	-0,158	0,000
28-3	-0,213	-0,231	-0,195	0,000
5-4	-0,096	-0,105	-0,087	0,000
6-4	-0,190	-0,200	-0,181	0,000
7-4	-0,223	-0,233	-0,214	0,000
8-4	-0,242	-0,255	-0,230	0,000
28-4	-0,282	-0,298	-0,266	0,000
6-5	-0,095	-0,103	-0,086	0,000
7-5	-0,128	-0,136	-0,119	0,000
8-5	-0,147	-0,159	-0,134	0,000
28-5	-0,186	-0,202	-0,170	0,000
7-6	-0,033	-0,042	-0,024	0,000
8-6	-0,052	-0,065	-0,039	0,000
28-6	-0,091	-0,108	-0,075	0,000
8-7	-0,019	-0,032	-0,007	0,000
28-7	-0,058	-0,074	-0,042	0,000
28-8	-0,039	-0,058	-0,021	0,000

Table 13: Output from Post-Hock test on ANOVA, bycatch of golden redfish ~ gear type+area, logbook data (vessels >15m). Significant p-values are marked green.

Interaction	diff	lwr	upr	p adj
Set nets-Bottom trawl	0,016	0,009	0,022	0,000
Purse seine-Bottom trawl	-0,084	-0,091	-0,078	0,000
Danish seine-Bottom trawl	-0,078	-0,082	-0,074	0,000
Purse seine-Set nets	-0,100	-0,109	-0,091	0,000
Danish seine-Set nets	-0,094	-0,101	-0,087	0,000
Danish seine-Purse seine	0,006	-0,001	0,013	0,136
12-00	0,552	0,521	0,582	0,000
28-00	-0,050	-0,065	-0,036	0,000
3-00	0,077	0,063	0,091	0,000
4-00	0,079	0,066	0,093	0,000
42-00	-0,061	-0,075	-0,047	0,000
5-00	0,087	0,073	0,100	0,000
6-00	0,016	0,000	0,032	0,039
7-00	-0,039	-0,054	-0,025	0,000
8-00	-0,054	-0,069	-0,039	0,000
28-12	-0,602	-0,631	-0,573	0,000
3-12	-0,474	-0,503	-0,446	0,000
4-12	-0,472	-0,501	-0,444	0,000
42-12	-0,613	-0,641	-0,584	0,000
5-12	-0,465	-0,493	-0,436	0,000
6-12	-0,536	-0,565	-0,506	0,000
7-12	-0,591	-0,620	-0,563	0,000
8-12	-0,606	-0,635	-0,577	0,000
3-28	0,128	0,118	0,137	0,000
4-28	0,130	0,120	0,139	0,000
42-28	-0,011	-0,020	-0,001	0,013
5-28	0,137	0,128	0,146	0,000
6-28	0,066	0,054	0,078	0,000
7-28	0,011	0,001	0,020	0,014
8-28	-0,004	-0,014	0,007	0,982
4-3	0,002	-0,006	0,010	0,998
42-3	-0,138	-0,147	-0,130	0,000
5-3	0,009	0,002	0,017	0,006
6-3	-0,061	-0,072	-0,050	0,000
7-3	-0,117	-0,125	-0,108	0,000
8-3	-0,131	-0,141	-0,122	0,000
42-4	-0,140	-0,148	-0,132	0,000
5-4	0,007	0,000	0,015	0,050
6-4	-0,063	-0,074	-0,053	0,000
7-4	-0,119	-0,127	-0,111	0,000
8-4	-0,133	-0,142	-0,124	0,000
5-42	0,148	0,140	0,156	0,000
6-42	0,077	0,066	0,088	0,000
7-42	0,021	0,013	0,030	0,000
8-42	0,007	-0,003	0,016	0,371
6-5	-0,071	-0,081	-0,060	0,000
7-5	-0,126	-0,134	-0,118	0,000

8-5	-0,141	-0,150	-0,132	0,000
7-6	-0,055	-0,066	-0,044	0,000
8-6	-0,070	-0,082	-0,058	0,000
8-7	-0,014	-0,024	-0,005	0,000

Table 14: Output from Post-Hock test on ANOVA, bycatch of golden redfish ~ gear type+area, in sales-notes (vessels <15m). Significant p-values are marked green.

Interaction	**diff**	**lwr**	**upr**	**p adj**
Set nets-Other gear	0,035	0,034	0,036	0,000
Danish seines-Other gear	0,003	-0,003	0,009	0,469
Danish seines-Set nets	-0,032	-0,038	-0,026	0,000
3-0	0,035	0,031	0,038	0,000
4-0	0,028	0,025	0,030	0,000
5-0	0,023	0,021	0,026	0,000
6-0	0,004	0,001	0,006	0,001
7-0	-0,015	-0,018	-0,013	0,000
8-0	-0,016	-0,020	-0,013	0,000
28-0	-0,026	-0,031	-0,021	0,000
4-3	-0,007	-0,011	-0,003	0,000
5-3	-0,012	-0,015	-0,008	0,000
6-3	-0,031	-0,034	-0,027	0,000
7-3	-0,050	-0,053	-0,046	0,000
8-3	-0,051	-0,055	-0,046	0,000
28-3	-0,061	-0,066	-0,056	0,000
5-4	-0,005	-0,007	-0,002	0,000
6-4	-0,024	-0,027	-0,021	0,000
7-4	-0,043	-0,046	-0,040	0,000
8-4	-0,044	-0,048	-0,040	0,000
28-4	-0,054	-0,058	-0,049	0,000
6-5	-0,019	-0,022	-0,017	0,000
7-5	-0,038	-0,041	-0,036	0,000
8-5	-0,039	-0,043	-0,036	0,000
28-5	-0,049	-0,054	-0,045	0,000
7-6	-0,019	-0,022	-0,016	0,000
8-6	-0,020	-0,024	-0,016	0,000
28-6	-0,030	-0,035	-0,025	0,000
8-7	-0,001	-0,005	0,003	0,992
28-7	-0,011	-0,016	-0,006	0,000
28-8	-0,010	-0,015	-0,005	0,000

APPENDIX E: LIST OF R-PACKAGES USED

Table 15: Full list of packages used for data preparation, analyzation, and visualization.

Purpose	Package
Data manipulation	ggpubr, devtools, tidyr, dplyr,lubridate,anytime,knitr
Linear modelling	lme4
Visualization	tidyverse, patchwork, ggplot, RColorBrewer, ggrepel
Maps	ggspatial, ggplot2, ggmap, sf, rgdal
Geographical splitting	RstoxData, dplyr,tidyr, knitr, sf,ggplot2

APPENDIX F: INCLUDED AND CALCULATED COLUMNS

Table 16: Full list of columns used for data preparation, analyzation, and visualization.

Logbook data	Sales note data
Date of landing, Latitude stop, longitude stop, gear type, fishing depth, Round-weight, Species, ICES areas, length-group vessel.	Date of landing, gear type, “Kyst.Hav”, statistical area, location, vessel name, callsign, length-group vessel, ICES areas.