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Evaluation of the ecosystem effects of the Danish Norway pout fishery in relation to the Norway pout box management area in the northern North Sea

Par : Matthieu BIGNÉ

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Devant le jury composé de :

Président : Youen VERMARD

Maître de stage : J. Rasmus NIELSEN

Enseignant référent : Didier GASCUEL

Autres membres du jury :

Étienne RIVOT (Enseignant référent associé)

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1. Introduction

The Norway pout (*Trisopterus esmarkii*) fishery in the North Sea and Skagerrak plays a significant economic role for EU (Denmark) and Norway (ICES 2016b). This small-meshed industrial trawl fishery may have a certain influence on other fish stocks and commercial fisheries in the North Sea area because of the by-catch of other species in the fishery (e.g. juvenile stages of other gadoids, herring and/or larger saithe, Nielsen et al. 2016) and because Norway pout is a prey species for important predators including cod, saithe, haddock and whiting (Nielsen et al. 2012; Lambert et al. 2009; Nielsen 2016). Besides, the Norway pout fishery may have additional ecosystem effects in form of benthic habitat impacts from demersal trawling (e.g. Eigaard et al. 2016a) on different types of sensitive habitats on the fishing grounds covering among other the Fladen Ground in the northern North Sea. The present study investigates ecosystem effects and environmental impacts of the Norway pout fishery relative to the Norway pout box closure (Fig. 1) established as a technical management measure in the North Sea Norway pout fishery. This is done by first conducting comparative analyses of distribution and density patterns of Norway pout and important by-catch species inside and outside the Norway pout box, which is an extensive closed fishing area for small meshed fisheries in the northern North Sea east of Scotland (see Fig. 1) established in 1977. Secondly, it is assessed where the fishing for Norway pout affects different types of potential sensitive benthic habitats as well as the relative distribution of those habitats in the non-restricted fishing areas outside the Norway pout box compared to the relative distribution of similar habitats inside the restricted Norway pout box area. The question of whether the Norway pout fishery would significantly still have higher by-catch levels of other species including the juvenile gadoids inside than outside the Norway pout box is still under debate. The management question hereunder is to know whether the current measures to protect other species and especially the juveniles of gadoids such as the escapement grid and the by-catch regulations (fractions) are adequate and especially whether the closure areas are necessary or not. On this basis, the ecosystem effects and environmental impacts of the Norway pout fishery in relation to the effect of the Norway pout box management measure is evaluated and discussed.

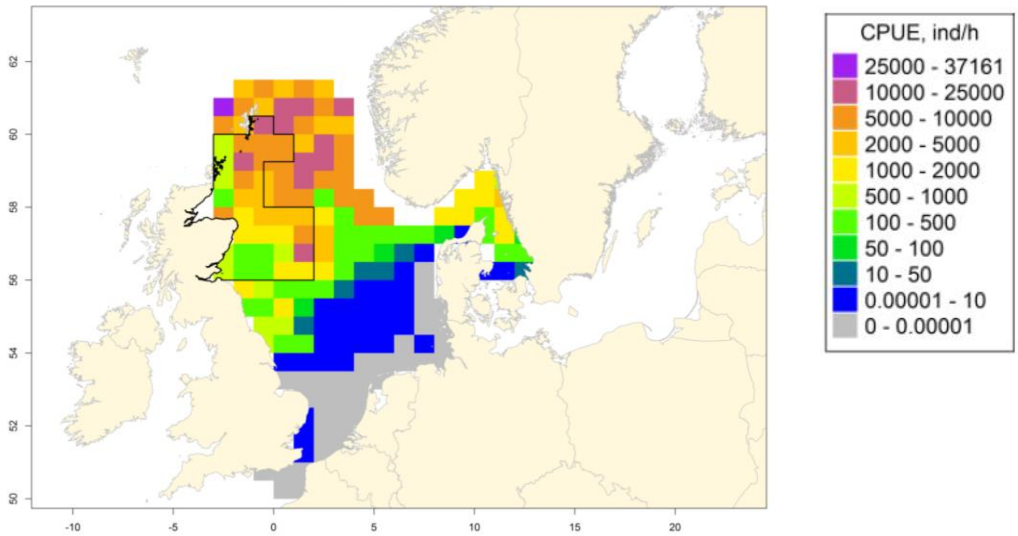


Figure 1 – Average distribution map of the Norway pout during first quarter survey in relation to the Norway pout box (area delineated by the black line) where the Norway pout fisheries are prohibited since 1977. This distribution map shows the number of individuals of all Norway pout age groups (1 to 6) averaged over the period 1985-2015 out of the NS-IBTS survey data. (From ICES, 2016b; Nielsen 2016)

Objectives

The present project aims to evaluate the environmental impacts and by-catch effects of the Norway pout fishery in relation to the closed Norway pout box technical management measure. This is done by evaluating the absolute and relative occurrence of target and by-catch species outside and inside the Norway pout box, as well as in relation to the bathymetry and the relative distribution of sensitive habitats to Norway pout fishery inside and outside the box. The Norway pout box was set up with the claimed goal to protect the populations of other fish species with focus on juvenile gadoids against the Norway pout fishery (Nielsen et al. 2016). Accordingly, it is relevant to conduct analyses on the spatial distribution of the different species according to their species and size composition. This is done by comparative analyses of distribution and density patterns of Norway pout and important by-catch species as well as of different benthic habitats inside and outside the box. Here are used partly fishery independent trawl survey information inside and outside the box for which both fish species and length information is available, partly Norway pout fishery species composition data outside the box, and EUNIS Level 4 habitat (benthic substrate) distribution.

The objectives of the present work are accordingly to:

- Evaluate on the basis of research survey information whether distribution and density of Norway pout, as well as of important by-catch fish species, in the Norway pout fishery are different inside and outside the Norway pout box in relation to different physical explanatory factors such as the bathymetry and the benthic EUNIS benthic habitat at level 4 influencing the fish occurrence;
- Evaluate on the basis of research survey information whether the absolute and relative fish species composition according to different fish size classes are different inside and outside the Norway pout box in relation to different physical explanatory factors;
- Evaluate fish species composition in the Norway pout fishery to evaluate relative by-catches of different species in the fishery to be compared with survey compositions;
- Evaluate current Norway pout fishing coverage and species composition in the Norway pout fishery according to the relative distribution of Norway pout fishery sensitive benthic habitats, respectively, inside and outside the Norway pout box.

1.1. The Norway pout stock in the North Sea

Norway pout is a small gadoid that rarely reaches more than five years of age (Lambert et al. 2009; Nielsen et al. 2012). Most individuals become mature at age 2 which is the age group mostly determining the spawning stock biomass (Nielsen et al. 2012) but Lambert et al. (2009) showed that almost 20 % of the individuals reach maturity at age 1. Therefore, the abundance is closely linked with the strength of the recruitment, which varies considerably over years (Nielsen, 2016). In the North Sea, the Norway pout is mainly distributed north of 57°N (Nielsen, 2016; Fig. 1) whereas it can also be found southerly in the Skagerrak-Kattegat area, even though it does not spawn here (Lambert et al. 2009). Norway pout in the North Sea and Skagerrak-Kattegat is considered to belong to the same stock. Lambert et al. (2009) but also Nash et al. (2012) and Huse et al. (2008) present results that indicate that there likely is only one main spawning area located along the eastern Scottish coasts and between the coasts of Shetland and Norway along the isocline of 120 m depth (Huse et al. 2008).

1.2. Ecology of Norway pout in the North Sea

Intra-specific relationships for Norway pout influencing stock distribution and density

Some density-dependence is noticeable in the population dynamics of the Norway pout stock. Lambert et al. (2009) showed that the Norway pout grow faster when the stock density is low, which induces a reduction of the age-at-50%-maturity and of the length-at-50%-maturity. Yet, these trends are considered to be weak, and Nielsen et al. (2012) could, based on their summary investigations, not reject the null hypothesis saying that there is no density dependence for Norway pout. Kempf et al. (2009) showed the absence of dependence between the Norway pout spawning stock biomass and the stock recruitment. Conversely, the stock recruitment was shown to be slightly correlated with the sea surface temperature during quarter 2 when the predation by the cod was taken into account. Nielsen et al. (2012) have also shown a significant mortality likely caused by spawning stress but it is still difficult to disentangle the effects of size-selective mortality from a possible density-dependent mortality. Thus, intraspecific relationships may influence size dependent density patterns of the North Sea stock.

Inter-specific relationships for Norway pout influencing stock distribution and density

Norway pout is a major prey species for many larger and commercial important predator species of the North Sea such as cod (*Gadus morhua*), whiting (*Merlangius merlangus*), saithe (*Pollachius virens*) and haddock (*Melanogrammus aeglefinus*) (Nielsen et al. 2016 and references herein). Lambert et al. (2009) have shown that the spawning stock biomass (SSB) of whiting is positively correlated with the mean weight-at-age (MWA) of Norway pout (at ages 0 and 1 respectively in Q3 and Q4) whereas cod SSB was shown to be negatively correlated with MWA of Norway pout (at ages 0 and 1 respectively in Q4 and Q2). Whiting SSB has also been shown to be positively correlated with the mean length-at-age of Norway pout (at age 1 in Q2), while the same correlation has been shown to be negative considering haddock SSB. These correlations suggest that cod and haddock feed on large individuals of Norway pout whereas the whiting feed on smaller individuals leading to an increase in growth of Norway pout owing to density-dependent effects but also to competition for food effects (Nielsen et al. 2016; Nielsen 2016). Early studies have shown that the diet of 0-group whiting and adult Norway pout were very similar (Raitt and Adams, 1965 in Nielsen, 2016).

Sparholt et al. (2002) have shown that the mortality of the age 1 and age 2 Norway pout had been decreasing over the period from 1970 to 2000. This decreasing trend could be attributed to the decrease alongside of the stock of the gadoids such as cod, whiting and saithe (Nielsen, 2016). However, even though this interaction likely is important for the age 1 individuals, it seems less important for the age 2 individuals whose mortality is likely mainly determined by the spawning activity (Lambert et al. 2009; Nielsen et al, 2012). Rindorf at al. (2010) found that most of the predation on Norway pouts by saithe, cod, whiting or haddock occurs in the second half of the year in different areas than the spawning areas. Cormon et al. (2016) also have shown a significant correlation between saithe growth and abundance of Norway pout (density dependence). The interspecific relationship between cod and Norway pout has also been shown to have a significant influence on the recruitment of both of these species in a certain range of temperatures (Kempf et al. 2009). Yet, according to Nielsen (2016) there are no strong correlations between the growth rate, the mean weight at age or the SSB of cod, haddock, whiting or saithe and the total stock biomass of Norway pout, except for slight positive correlations between SSB of cod and TSB of Norway pout and also mean weight at age for age 3-4 cohort of haddock and TSB of Norway pout. As for the larvae and age 0 individuals of Norway pout, their main predators are the small pelagic fish such as the herring (*Clupea harengus*) or the mackerel (*Scomber scombrus*) (ICES, 1996). Huse et al. (2008) have also shown a significant negative relationship between the herring biomass and the spawning stock biomass of Norway pout two years later, which indicates that the herring could be a major predator of planktonic larvae of Norway pout. Yet, further studies are needed to test this hypothesis (Huse et al. 2008). In this context, it should be considered that herring and Norway pout are spatially overlapping (Huse et al. 2008).

The assessment of the most important predator species of Norway pout per age group has been carried out from the ICES North Sea multi-species stock assessments conducted in the SMS (Stochastic Multi-Species) model run for 2013 (ICES, 2016b). The results show the average partial predation mortality of Norway pout and the share of it in the diet of many predator species of the North Sea. The Table 1 sums up the most important predators feeding on Norway pout by species and age in the North Sea. This table comes from the cross-checking of two tables summarizing the predation mortality (M2) by predator species and age on Norway pout age groups and the predation by predator species in total per Norway pout age group but also from graphs representing the Norway pout share in diet of main predators in the North Sea per size group. This avoids bias due to the higher or lower abundance of predators. Note that Norway pout plays a major role in the diet of many predators of the North Sea for relatively young stages (age 2) and older as well. In particular, larger gadoids are significantly dependent on Norway pout. Consequently, there is a documented strong influence of interspecific interactions on size dependent density patterns of the Norway pout stock in the North Sea.

Table 1 - Main predator age groups of Norway pout by species, i.e. age groups where Norway pout has high importance as prey, according to the latest (2013) multi-species SMS model baseline run for the North Sea (From ICES, 2016b)

Species	Main importance	Focus ages in analyses
Cod	Age 2 and older	Age 2-4
Whiting	Age 2 and older	Age 2-4
Haddock	Age 3 and older	Age 3-4
Saithe	Age 2 and older	Age 2-4
Pollack	Age 2 and older	Age 2-4
W. mackerel	Age 2 and older	Age 2-6
G. gurnard	Age 3 and older	Age 3-4

1.3. The importance, distribution and targeting of the Norway pout fishery in the North Sea

Relative importance and targeting of the Norway pout fishery in the North Sea

The North Sea is one of the world's most intensively fished areas (Gascuel et al. 2016). The landings in the North Sea have been decreasing since the 1960s. Currently the total catch levels are around 1400 thousands of tons per year (ICES 2016a; ICES 2016c). Many stocks are still overfished even though the situation is improving thanks to a better management of Norway and the European Union (Gascuel et al. 2016). The major fishing countries in this area are Norway, the United Kingdom and Denmark and to a lesser extent Belgium, Netherlands, Germany, Spain, France and Sweden (ICES, 2016a). The important fisheries in the area cover both pelagic and demersal resources. The pelagic fishery plays a major role in the North Sea thanks to the herring fishery, which landed in 2015 more than 480 000t (ICES, 2016c). Other important commercial pelagic species are the mackerel and the sprat (*Sprattus sprattus*) (ICES, 2016c). The demersal fishery includes the human consumption fishery e.g. gadoid fish, flatfish, Norway lobster (*Nephrops norvegicus*), and the small meshed industrial demersal fishery whose landings are mostly for reduction purposes covering Norway pout and sandeel (*Ammodytes spp.*) besides small meshed shrimp fishery for consume purposes (ICES, 2016a). In 2015, the landings of the demersal fishery reached in total 600 000t, with approximately 300 000t for the whole industrial fishery (ICES, 2016a). Since 2001, the landings of the Danish Norway pout fishery are below 100 000t but vary a lot over years because of the variations in the recruitment of the Norway pout (Nielsen et al. 2016; cf. section 1.1). Some by-catch of Norway pout can also occur because of other small-meshed fisheries.

Distribution and characteristics of the Norway pout fishery in the North Sea
Norway pout has been fished for reduction purposes for fifty years (Nielsen et al. 2016). Norway pout is caught as a targeted species in both the Danish and Norwegian fisheries, as well as a by-catch species in the Norwegian blue whiting fishery (ICES, 2016b). Figure 2 shows the distribution of the Danish fisheries targeting Norway pout. The Danish fishery is an offshore fishery mainly located on the Fladen Ground area between 0˚E and 2˚E and to a lesser extent in the Skagerrak-Kattegat area (Nielsen et al. 2016). The Norwegian fishery is mostly located along the Norwegian trench but is also significantly represented on the Fladen Ground in third and fourth quarters (Appendix A). Since 2000, there are almost no landings south of latitude 57˚N (Fig. 2). Figure 3 shows that the fishing activity of the Danish fishery mostly takes place during the third and the fourth quarters of the year but this pattern is not so strong for the Norwegian part of the Norway pout fishery (Nielsen et al. 2016). The main gear used in the fishery is the otter trawl with a mesh size of 16-31 mm (Nielsen et al. 2016). This small mesh size is often considered as inducing high by-catch rates of other species. The fishing vessels are mostly large trawlers (ICES, 2016b; Eigaard et al. 2012).

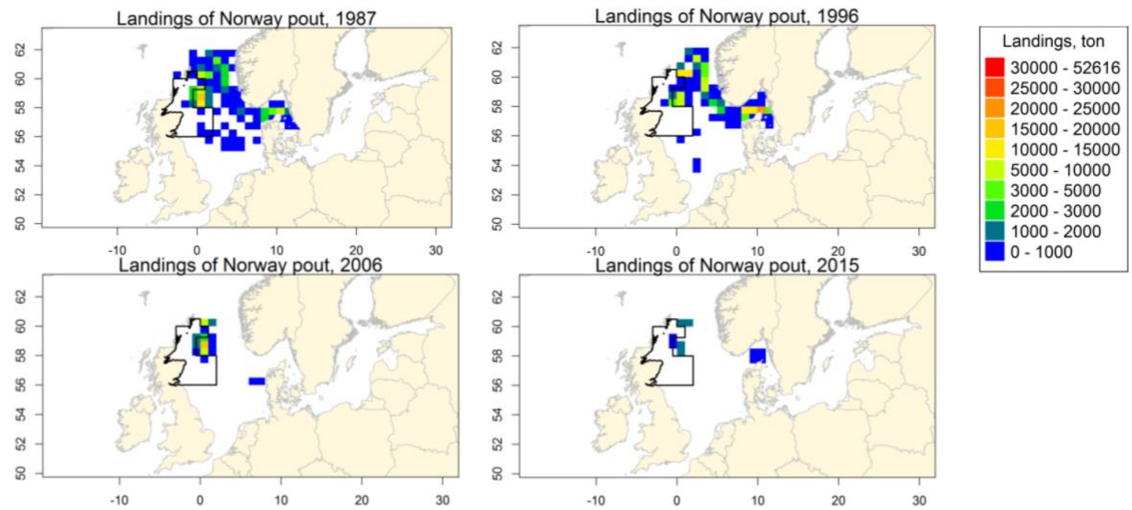


Figure 2 - Average landings of the Danish Norway pout fishery by ICES statistical rectangles for four years of the period 1987-2015. The black line is the boundary of the Norway pout box. (From Nielsen, et al. 2016)

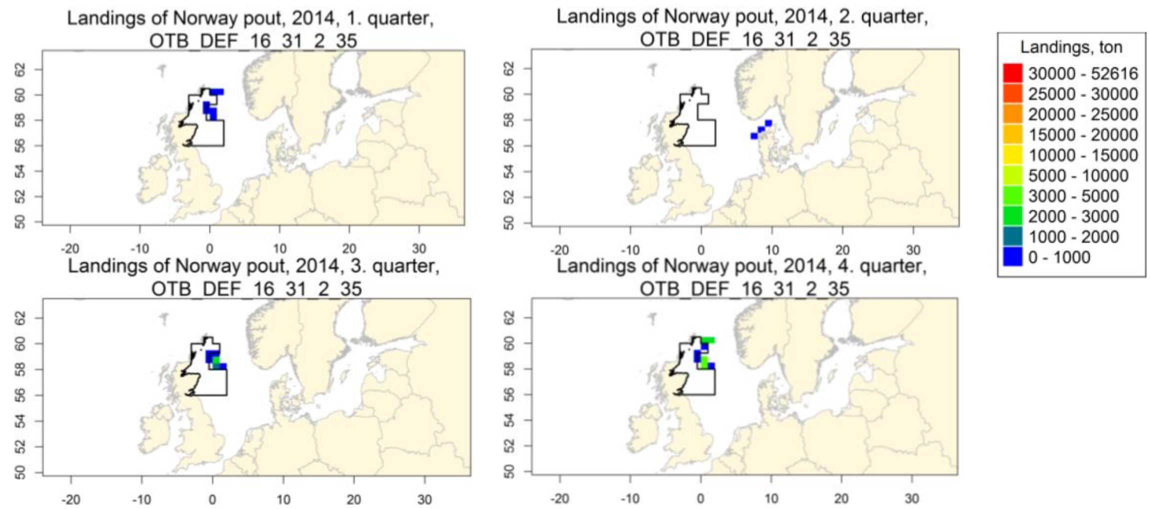


Figure 3 - Average landings of the Danish Norway pout fishery by ICES statistical rectangle for each quarter of 2014. The black line is the boundary of the Norway pout box. (From Nielsen, et al. 2016)

Management of the Norway pout fishery in the North Sea

TAC and landing obligation - Besides the general TAC and quota regulation of Norway pout in the North Sea, several management measures are in force to limit by-catches in the small meshed fishery covering by-catch fractions and use of special sorting grids or panels (Nielsen et al. 2016). In 1996, Denmark decided to implement a 10% limit of herring by-catch because of a very high fishing pressure on the North Sea herring stock. In 2000, this limit was set up to 20% in the whole North Sea as an adjustment to EU rules and the 10% limit only remained in the Skagerrak-Kattegat (Nielsen et al. 2016). In 1998, the European Union decided to implement by-catch quotas for other species: the catch on board had to consist of at least 90% of a mixture of two or more targeted species or of at least 60% of one targeted species. The by-catch of any mixture of cod, haddock, saithe was also limited to a maximum of 5% (15% for other species). According to the landing obligation implemented in 2015 (ICES 2016b) all catches must now be taken on board to be landed. It should in this context be noted, that there previously has been no discard from the targeting Norway pout and combined Norway pout – blue whiting reduction fisheries because all the catches are turned into fish oil and fishmeal (Nielsen et al. 2016). If a fishery catches unwillingly species in excess of the quota for these species or if the concerned member state has no quota for these species, these catches may be deducted from the quota of the target species if the catches do not reach more than 9% of the quota of the target species (Article 15, point 8, in the EU regulation EU/1380/2013). This limit is set at 5% concerning by-catches of whiting in the Danish Norway pout fishery according to the Danish national management of the Discard Plan under the EU (Danish) TAC-Quota Regulation for 2016 (Nielsen et al. 2016). A discard ban is also in force in the Norwegian fishery and some maximum relative by-catch fractions per area and type of fishing gear in use are applied in the Norwegian fishery (Nielsen et al. 2016).

Gear selectivity and sorting grids - Some technical measures to increase selectivity are also in force in the Norway pout fishery. Since 2012, a 35 mm grid is mandatory in the Danish fishery to enable larger gadoids, (e.g. cod, saithe) to escape (ICES, 2016b; Nielsen et al. 2016). Besides, the Norwegian fishery operates in many cases with selective panels of typically 40 mm bar width since 2010, but this device is not always mandatory (Nielsen et al. 2016). Eigaard et al. (2012) estimated that the introduction of the sorting grid reduced the catch rates by 5-10%. The reduction of the by-catch of gadoids in biomass is estimated to be around 50% but it still seems to be difficult to totally avoid the catch of small gadoids (Eigaard et al. 2012). When this small-meshed fishery appeared during the 1960s, the by-catches were important especially considering whiting and haddock, but also herring, cod and saithe. In particular, special attention has been paid to the by-catches of juveniles of haddock and cod (Nielsen et al. 2016). Yet, the by-catches of this fishery have decreased thanks to the selectivity measures and have been reported to have reached a low level of 5-10% (Nielsen et al. 2016).

Spatial Closure - In 1977, the United Kingdom government decided to establish a closure area to small-meshed trawl fishery along the eastern Scottish coast in the northern North Sea: the so-called "Norway pout box" (Figs. 1-3). In 1986, this closure area was included in the newly implemented European Common Fisheries Policy, EU-CFP (Nielsen et al. 2016). The Norway pout box covers an extensive area in the northern North Sea extending approximately from 56°N to 62°N and from the Scottish east coast to 2°E (Figs. 1-3). Small meshed trawl fishery is totally forbidden in this area with the declared aim of protecting the juveniles of larger gadoid species (i.e. cod, haddock and whiting). This has been a controversial topic since the first discussions and establishment of this closure. Indeed, the Norway pout box has restricted the Danish Norway pout fishery from the northwestern part of the North Sea. Furthermore, the effects of the Norway pout box, forty years after its settlement are still not evaluated (ICES, 2016b). Now that the United Kingdom is about to leave European Union then this will likely lead to a renegotiation of fishing agreements between UK and EU and reconsideration of the closure. The relevance of this box almost entirely lying into the UK waters is an important matter of concern for the management of Danish but also Norwegian and English demersal fisheries in the northern North Sea.

1.4. North Sea benthic habitats affected by the Norway pout demersal fishery

An issue in present context is whether the benthic impacts of the Norway pout fishery is at a level and relative order of magnitude compared to other fisheries where it will be relevant to adapt the spatial management measures such as the Norway pout box to the type of sediment according to the seabed footprint of the Norway pout fishery. The Norway pout fishery is conducted in areas with different types of marine benthic habitats. Three main types of habitats can be identified in the northern North Sea fishing area according to the EUNIS habitat classification at level 4 (EMODnet, in Eigaard et al. 2016a). The figure 4 shows that the most common type of seabed substrate in the northern North Sea and other North Sea areas is the sublittoral sand (A5.2) but on the Fladen ground, where the activity of the Danish Norway pout fishery is very concentrated, the sublittoral mud (A5.3) is also very common. The Norwegian trench has a very particular seabed, which mostly consists of deep-sea mud (A6.5). In addition to these three main different types of sediments, some local particularities exist such as sublittoral coarse sediment along the coasts of the Shetland Islands.

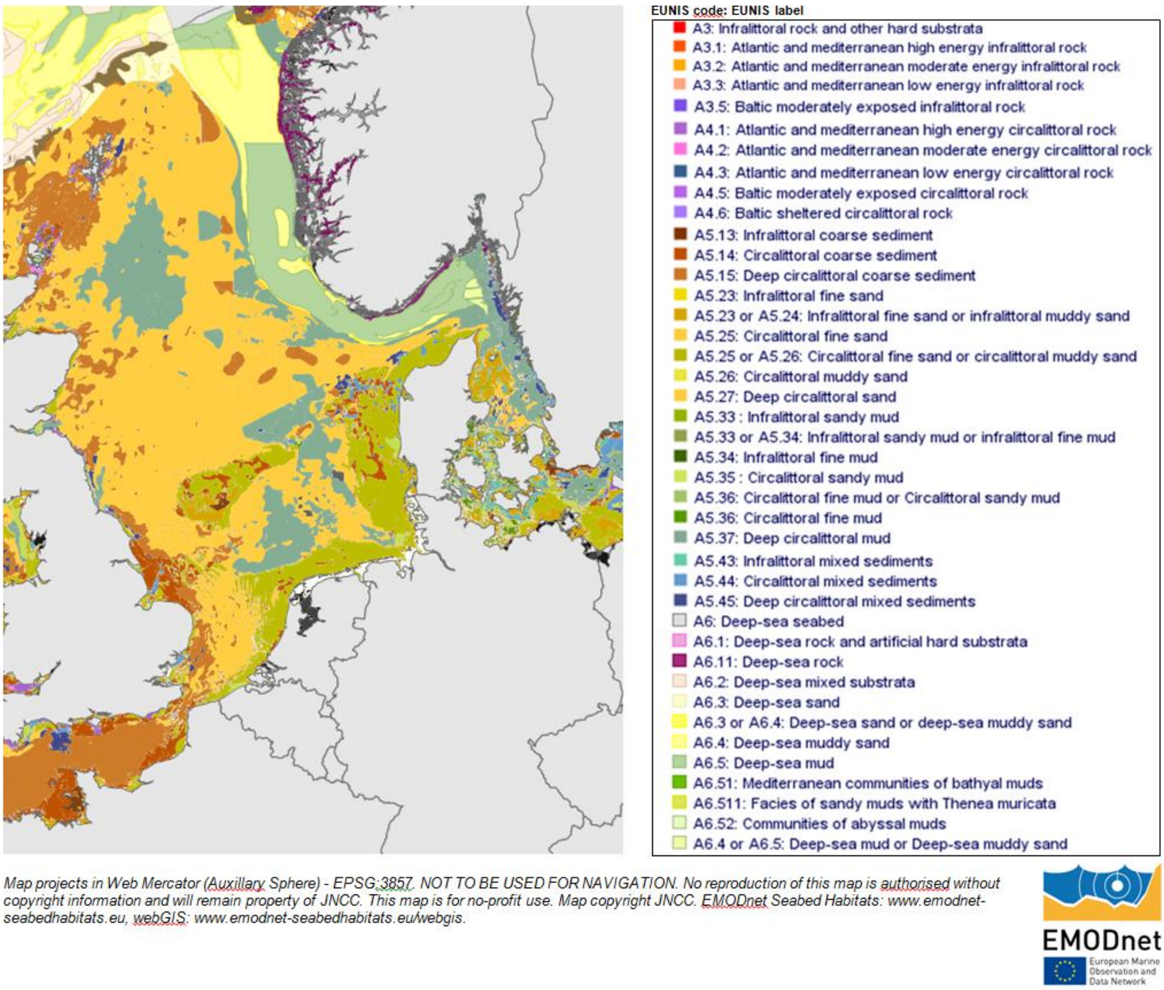


Figure 4 - Cartography of benthic EUNIS habitats at level 4 (From EMODnet Seabed Habitats)

The Danish Norway pout fishery mostly operates on grounds of sublittoral mud but also on grounds of sublittoral sand (Eigaard et al. 2016b). Eigaard et al. (2016a) have shown that this fishery does not affect these two areas in a similar way. Indeed, Eigaard et al. (2016a) report that the trawl doors as well as the tickler chains of the otter trawl gears are responsible for a deeper seabed footprint than beam trawls, seines or dredges, and especially on muddy grounds. It is also reported that the penetration on sandy ground is less important than on muddy ground but still significant (Ivanović et al. 2011). Yet, compared with métiers targeting crustaceans and some demersal species in the northern North Sea, the Norway pout fishery seems to have a relatively low impact deeply in the sediment (Eigaard et al. 2016b). The swept area is also estimated to be relatively low compared with other métiers fishing with demersal towed gears (Eigaard et al. 2016a) – see Figure 5.

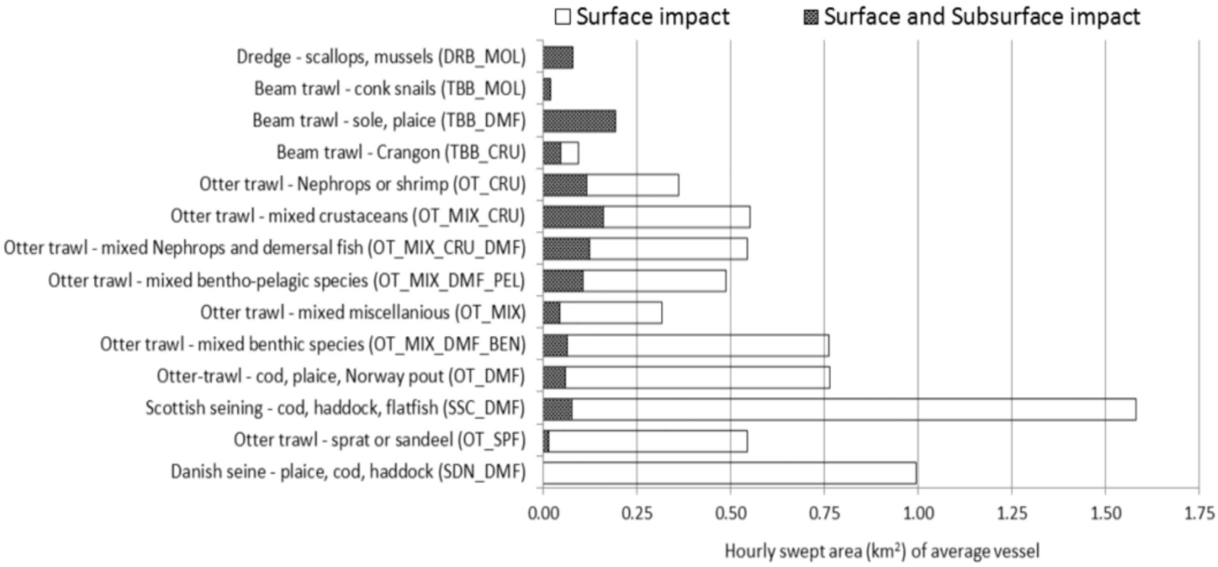


Figure 5 - Area of seabed swept in 1h of fishing with an average-sized vessel with impact at the surface level and at both the surface and the subsurface level for the 14 BENTHIS métiers (From Eigaard, 2016a)

Specific aims and zero-hypotheses tested

Consequently, the present study will combine fishery independent information and commercial fishery information in integrated analyses of species composition of the fish in the northern North Sea as indicated from the survey information and the species composition in the catches of the targeted Danish Norway pout fishery in relation to the Norway pout box management measure and area. Thus, the four following 0-hypotheses are tested:

- H01: "There is no difference in the **species composition** including distribution and density patterns of Norway pout and important Norway pout fishery by-catch species inside and outside the Norway pout box **as indicated from survey information**."
- H02: "There is no difference in the **fish length composition** inside and outside the Norway pout box **as indicated from survey information**."
- H03: "There will likely be no difference in the **species composition of the catches of the small meshed fishery** inside and outside the Norway pout box."
- H04: "The relative distribution according to relative area coverage of **sensitive benthic habitats to Norway pout fishery is not different between inside and outside the Norway pout box**."

This study will provide new knowledge on the ecosystem effects and environmental impacts of the Norway pout fishery in relation to effects of certain management measures and mitigations for the Norway pout fishery such as the Norway pout box with focus on by-catch levels of other species and their juvenile stages as well as with respect to relative impacts on different types of benthic habitats.

2. Material and methods

2.1. Distribution and density patterns of Norway pout and important by-catch species in relation to the Norway pout box using survey data

2.1.0. Description of the data from NS-IBTS surveys and definition of a spatial and time-related framework

Data extraction

Data from ICES IBTS survey in the North Sea have been used. These data are publicly available and can be easily downloaded from the DATRAS website of ICES (http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx). In the NS-IBTS surveys, all participating countries use the GOV trawl as their standard survey gear for all quarters (ICES, 2015). A standard haul duration is 30 minutes for all vessels and all quarters, except for a few hauls in third quarter in the period 2015 and onwards (third quarter in 2015-2016 in present context) (ICES, 2015).

Compilation, categorization and selection of data

Trawling is normally restricted to day hours (ICES, 2015). Therefore, all observations during the night have been removed. There are actually very few hauls conducted during the night (0.94% of the total dataset) and there is no major misbalance in the data in relation to this variable. Besides, all the hauls whose duration is not comprised between 10 and 40 minutes are removed from the study. This selection criterion must be taken with more care since there is a slight misbalance in the sampling plan because of the 15 min hauls during third quarter since 2015. Therefore, this selection is rather conservative: only some inane values (such as haul duration of 5 or 50 minutes) which can be considered as failures in the experiment protocol are removed. As the spectrum of haul duration still is quite extensive, it will be mandatory to take this variable into account in the statistical analysis.

Definition of spatial and time scales and frames

Data are analyzed for the period 2006 to 2016 in first quarter and third quarter of the year. This period is chosen because in the second part of the present study, commercial fishery data are used in comparative analyses to the fishery independent research vessel data, and the commercial fishery data are mainly available during this period with respect to catch data by fleet / métier. Besides, NS-IBTS surveys began in the sixties to map the distribution of juveniles of herring but the whole North Sea has been covered by the NS-IBTS surveys, only two years before the establishment of the Norway pout box, in 1974 (ICES, 2015). Accordingly, the time series before the establishment of the box are too short to base robust statistical analyses on time differences on them. Furthermore, during this period, the surveys were not fully standardized: different gears and haul duration were in use according to the nationality of the vessels. This is the reason why the present statistical analysis present a spatial comparison (inside/outside) instead of a temporal comparison (before/after) of the species composition in relation to the Norway pout box. Note that observations are only available for first quarter and third quarter because the NS-IBTS surveys are only conducted during these quarters during the period of interest.

The aim of this study is to focus on the effect of the Norway pout box. Therefore, the effect of the closure area must be isolated from other already well-known effects such as the depth or the nature of the bottom sediment, in order to avoid confounding effects which potentially influence the spatial distribution of the fish populations analyzed (see below). . Thus, it has been chosen to represent the Norway pout box effect with the distance to the boundary of the

Norway pout box as Goñi et al. (2006) or Stelzenmüller et al. (2007) have successively processed to test the spillover effect resulting from marine protected areas. Thus, the great circle distance to the closest boundary of the Norway pout box is calculated for each haul (negative values are used when these hauls are actually located inside the box). The boundary of the area outside has been set at a maximum of 200 kilometers outside the border of the box among other to balance the distance levels as well as the number of observations inside and outside the Norway pout box. Hence, the area inside and outside cover approximately the same surface and the same number of observations. It must also be noted that there is a strong north-south component in the spatial coverage of the Norway pout box. This strong north-south component can also be observed in the distribution of many species of interest (Appendix G). To avoid bias due to this, the only observations that will be taken into account are the one located north of 56˚N and south of 60.5˚N. These values are respectively the southern and northern boundaries of the Norway pout box. The aim is to reduce the bias coming from the distribution of the species of interest but still to study the Norway pout box in its entirety.

Definition in relation to depth and benthic habitat areas

Peculiarities may also be linked with coastal or very deep areas in the North Sea such as in the Norwegian trench, which becomes very deep. Therefore, a selection according to depth has also been used based on the depth distribution characterizing the Norway pout (Lambert et al. 2009; Nielsen et al. 2012) and the Norway pout box. Consequently, the study covers the depth range from 40m to 200m bottom depth. The benthic EUNIS habitats at level 4 have been spatially merged with these NS-IBTS survey data. In our selected area, six different types of habitats can be found but three of them represent only 26 hauls altogether, thus the corresponding hauls were removed because the sampling plan according to years and quarters was really misbalanced. The three major habitat types that can be described in this area are:

- A5.15: “deep circalittoral coarse sediment”, i.e. coarse sediment, gravels or shells.
- A5. 27: “deep circalittoral sand”, i.e. fine and muddy sediment.
- A5. 37: “deep circalittoral mud”, i.e. muddy sediment at depths below 50-70 m

Further documentation about the EUNIS habitats can be found in Davies et al. (2004) and at the web site: http://eunis.eea.europa.eu/habitats.jsp.

The figure 6 shows the coverage of the 2926 IBTS GOV trawl hauls contributing to this study.

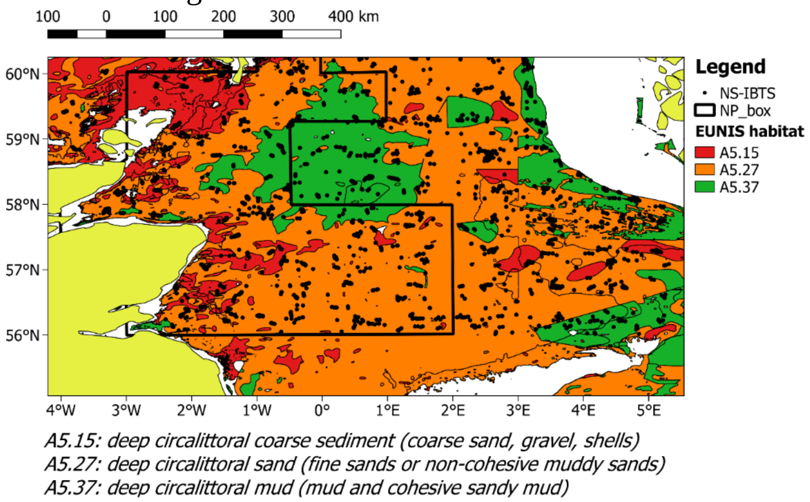


Figure 6 - Spatial coverage of the NS-IBTS data (haul location shown with black dots) for the period 2006-2016 after selection and analysis of underlying EUNIS benthic habitats shown by different colours.

The bathymetric homogeneity of the global study area explains the low correlation between depth and distance (r=0.14) shown on Figure 7. Yet, note that EUNIS A5.37 is associated with deeper grounds than both other habitat types. Given this data selection, the variable “distance to the boundary of the box” can, thus, be considered as a reliable indicator of the spatial coverage of the Norway pout box not confounded with other spatial influencing variables. This enables to analyse the effect of the distance to the box independently from other spatial effects.

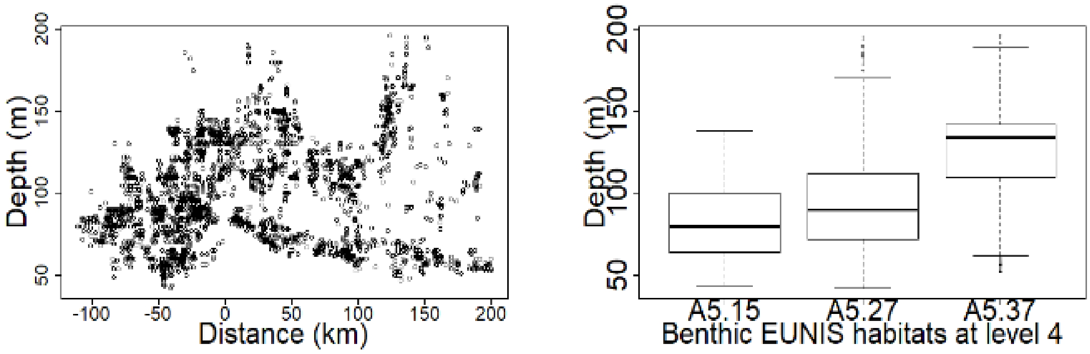


Figure 7 - Correlations between Depth, EUNIS benthic habitats and Distance to the boundary of the Norway pout box after selection of the survey data - the lower and upper limits of the boxes respectively are first and third quartiles - the lower and upper whiskers are respectively calculated as: *max(min(x), Q1 - 1.5 * IQR* and *min(max(x), Q3 + 1.5 * IQR)* where IQR is for Interquartile range.

For each haul, three variables are available: the fish species, the fish length class, and the number of individuals per species and length class.

Definition of fish species

The choice of the species of interest considered in this study has been motivated by the arguments given as justification of the Norway pout box (Nielsen et al. 2016). These species were selected because of fishery (technical) interactions (by-catches in the Norway pout fishery) and biological interspecific interactions with Norway pout (predators). Thus, only six species of commercial importance are included in the study: herring, cod, haddock, whiting, saithe and naturally Norway pout.

Definition of fish length classes

The length classes cover a range from 0-10 mm to 1390-1400 mm. No selection ogive has been applied: every length group of individuals by species is considered to represent the natural population and is accordingly relevant for the study. This should be seen in context of the small mesh sizes used in the surveys (and in the Norway pout commercial fishery).

Yet, the variables “length class” and “species” have been slightly transformed. Indeed, in the rough DATRAS tables, each modality of these variables is not defined for each haul. This issue is even more important for “length class” because, there is a special length class “0” defined by species in which no individuals are observed in a given haul but which have been used in general in the survey, i.e. is on the survey species list. This length class is meaningless since the reality is that no individual of the given species have been observed for any length class in these hauls. Accordingly, the table needed to be completed in order to have six species defined (in our case) for each haul and 140 length classes of 10 mm defined for each species of each haul. The values of CPUE for species and length classes which were not reported in a haul in the DATRAS rough table were set to 0 because they truly are null values (i.e. no observation of an individual of such a species and such a size in a given haul).

The main issue is to choose a variable giving a good representation of the length composition of a species. The variable “Length class” described above could not be a good indicator because of the strong time correlation between the different length classes, i.e. the “cohort effect”. To choose a rougher indicator of the length enables to aggregate different cohorts and to reduce this time correlation between different length groups. Therefore, we used a qualitative variable taking two modalities: “Small” and “Large” fish for each species. The “Small” group contains the individuals whose length is inferior or equal to the L50 of the species maturity ogive, i.e.

mainly juveniles, and the "Large" one contains all the fishes whose length is strictly superior to the L50, i.e. mainly mature fish. Accordingly, the variable "Length group" can be considered as an indicator of the maturity of the fishes.
The L50 values used to define the length groups for each species have been calculated from the ICES DATRAS SMALK data recorded during the NS-IBTS surveys. The temporal range of the data covers 2006 to 2016 (i.e. the temporal coverage of the study). The spatial coverage has been restricted to the ICES roundfish areas 1 to 3, which are the only ones overlapping with the study area. The spatial distribution of the roundfish areas is available on the ICES website: http://www.ices.dk/marine-data/Documents/DATRAS/Survey_Maps_Datras.pdf
As a seasonal pattern is noticeable for the species of interest, it has been chosen to use the observations during the season when the different fish species spawns. All the species of interest are spring-spawners, i.e. in first and second quarters, except for the herring, which has two spawning seasons in spring and in autumn (Dahle and Eriksen, 1990). For the herring, it has in present context been chosen to take the mean between the L50 in both the spring and in the autumn.
The Equation 1 shows the logistic model used to estimate the proportion of mature individuals in a given length class (Sokal and Rohlf, 1995 in Lambert et al. 2009):

$$\mathrm{logit(p)} = -\mathrm{b.L50} + \mathrm{b.Length} \qquad (1)$$

where p represents the proportion of mature fish in a given length class and b is a regression coefficient. Note that the models do not take into account any yearly effect whereas there is probably one as it has been demonstrated by Rochet et Munch (2002) for the cod in the North Sea during the period 1982-1995. Yet, considering that the results of these models are in accordance with the present biological knowledge, the values directly estimated from these models have been directly used to define the length groups. The figure 8 below shows the maturity ogive for Norway pout that has been estimated in the present work (other maturity ogives are plotted in Appendix B).

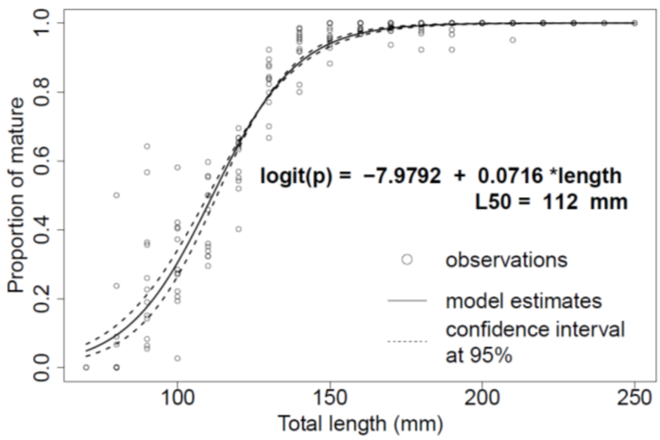


Figure 8 - Estimated maturity ogive for Norway pout in first quarter

2.1.1. *Initial analyses to determine dependencies in species composition*

The first part of the study consists of an overview of the variations of the species composition according to the depth, the distance to the Norway pout box and the benthic habitat type. The analyses are simply graphical. These analyses have been conducted on the CPUE in number of individuals and in kilograms as well. Theses initial analyses have two main goals. Firstly, they are necessary to parametrize the statistical models developed in the following. Indeed, making these initial analyses enable to get aware of which variable to include in the model, but also which kind of relationship between the explanatory variables and the response variable should be expected. Secondly, they enable to point out some general patterns that should absolutely be kept in mind when analysing the outputs of the models.

2.1.2. Initial analyses to determine dependencies in Norway pout and important by-catch species length composition

In a similar way, the length composition of the different species of interest has been investigated by plotting the number of individuals against distance and the "ground variables" (i.e. depth and EUNIS benthic habitats) to figure out whether there exist important dependencies. The link between the explaining variables and the logarithm of the number of individuals has been visualized with simple plots associated with simple linear regression model. It has been chosen to arbitrarily add 1 to the number of individuals values to be able to plot the null values when log-transforming. This is only done in these preliminary analyses, but not in the statistical in depth analyses conducted afterwards (see below). Considering the range of the number of individuals, this transformation will not lead to any major distortion.
These analyses lead also to the exploration of dependent variables tested in the statistical analyses. The variations in the length composition according to the type of sediment and the depth can be considered as significant. Consequently, both of these variables are included in the further statistical analysis. Then, there appears no important effect on the length composition of the species due to the distance to the Norway pout box but this is precisely what has to be tested here. This variable must also be considered as an explaining variable. Finally, it seems highly necessary to consider a seasonal effect.

2.1.3. Statistical analysis of the length composition of the Norway pout and the important by-catch species according to the NS-IBTS survey data.

In accordance with the preliminary analysis, a main model has been set up with the following variables:

- Number of individuals (response variable): integer variable giving the recorded number of individuals of one given length group belonging to one given species;
- EUNIS (explanatory effect): qualitative variable giving the nature of the benthic habitat according to the EUNIS habitat classification at level 4;
- Depth (explanatory effect): continuous variable giving the bottom depth at which the haul has been conducted in meters;
- Distance (explanatory effect): continuous variable giving the distance to the boundary of the Norway pout box in kilometers;
- HaulDur (explanatory effect): continuous variable giving the haul duration with the precision of a minute;
- Year (explanatory random effect): class variable giving the year when the haul has been conducted;
- Longitude, Latitude (explanatory effect): the geographical coordinates of the haul with the precision of a decimal degree (hundreds of a degree);

The analyses are conducted running one model per species, length group and quarter. Several models were fitted independently instead of including the length group and the quarter as explaining effects into the model in order to avoid implementing too complex models with interaction terms difficult to interpret. Yet, it was absolutely necessary to take the species, length and seasonal variability into account as it has been shown with the graphical analyses.

2.1.3.1. Model selection

Choice of the type of the model

It has been chosen to use generalized additive models (GAMs) partly because GAMs enable to take non-linearity and non-constant variance structures in the data into account (Guisan et al. 2002). Besides, GAMs enable to assess relatively complex relationships between the response variable and the explaining variable without defining precisely the functional form of these relationships (Goñi et al. 2006; Zuur, 2012). The explaining variables are added as smooth components (Guisan et al. 2002). Thus, GAMs are considered as data-driven processes rather than process-driven (Guisan et al. 2002). This choice is relevant for two main reasons:

Firstly, it enables to take the temporal and spatial correlation into account (Zuur, 2012). Indeed, including the year and the quarter enables to take into consideration the temporal variations of the number of individuals and to establish a more explaining model. Yet, the time variation of the fish density is not interesting in itself (not in this study at least), so using the time variable as a random effect in such a mixed effect model enables to save many degrees of freedom (Zuur, 2009). The same kind of argument justifies the use of spatial smoothers, whereas the method is a little more complicated because it involves taking the "spline on the sphere" applied to geographical coordinates. This spline is defined as a generalization of the Euclidean multidimensional classical thin plates and of periodic polynomial splines on the circle (Wahba, 1981; Wood, 2011). This spherical spline has been compared with the "Gaussian process" which can also be considered as a relevant alternative to define geoadditive models (Kamman and Wand 2003). The "Gaussian process" presents the advantage not to assume isotropy contrarily to the "Spline on the sphere". Yet, based on AIC comparison and likelihood ratio tests, the "Spline on the sphere" has always proved to be more adapted in this context.

Secondly, it makes more sense to expect a non-linear effect of the distance because of the boundary effect (Goñi et al. 2006). This expectation is supported by the first visualization of the variations of the number of individuals according to the distance to the Norway pout box boundary (see corresponding Results section). This expectation can also be relevant considering the bottom depth factor. Therefore, we compared models assuming a linear relationship between the explaining variables and the response variable to generalized additive models, which should enable better to take into account these non-linear effects (Zuur, 2012).

Six different models have been tested for each species and length group for the first quarter only. The first quarter alone has been preferred to carry out the choice of the model because the first quarter survey data are of better quality with higher number of stations in general than the data from the third quarter surveys. More scientific survey vessels take part in the sampling in first quarter than in the third quarter IBTS, which allows a better spatial coverage and more observations (ICES, 2015). Furthermore, the survey is better standardized during the first quarter than during the third quarter with respect to the haul duration. Indeed, fifteen minutes hauls instead of thirty minutes hauls have been conducted for several hauls/stations during the third quarter of NS-IBTS since 2015 (ICES, 2015). Besides, the selective issue of 0-groups is more important during the third quarter than during the first quarter, i.e. not all 0-group individuals are fully selected in the third quarter for all species.

Different criteria have been used to select the model giving the best answers to the stated hypotheses and problems addressed here. The AIC is preferred to the BIC because the aim is to define an explicative model and not a predictive one, so there is no point in over-penalizing by the number of parameters (Rigby and Stasinopoulos, 2005). The proportion of explained deviance and the R-squares have also been used. The models have also been compared according to the distribution of the residuals given by the classic analytic graphs (e.g residuals versus fitted values or versus explanatory variables, qq-plots) and to some plots enabling to test spatial or temporal correlation such as spatial bubble-plots and auto-correlograms (Zuur, 2009). The models have been selected according to their ability to answer the problems addressed here, i.e. the objectives and zero hypotheses in order to give a more clear answer to the problem. For example, models which do not take into consideration any interaction between depth and distance have been preferred to very complex models including this interaction when it was statistically reasonable to do so. The different models tested during this first step are summarized in the table 2 below.

Table 2 – Formulas of the six models tested. $\mathcal{I}$ indicates any distribution family of esperance $\mathbb{E}$ and variance $\mathbb{V}$. The smoother effects are indicated with s(…). The term written after "bs = " indicates which kind of spline was used.

Scenario number	Formula
1	CPUE ~ $\mathcal{I}$($\mathbb{E}$ = EUNIS + HaulDur + s(Year, bs = random) + s(Latitude, Longitude, bs = spline on the sphere), $\mathbb{V}$)
2	CPUE ~ $\mathcal{I}$ ($\mathbb{E}$ = EUNIS*Depth + HaulDur + s(Year, bs = random) + s(Latitude, Longitude, bs = spline on the sphere), $\mathbb{V}$)
3	CPUE ~ $\mathcal{I}$ ($\mathbb{E}$ = EUNIS*Distance + HaulDur + s(Year, bs =random) + s(Latitude, Longitude, bs = spline on the sphere), $\mathbb{V}$)
4	CPUE ~ $\mathcal{I}$ ($\mathbb{E}$ = EUNIS*Distance*Depth + HaulDur + s(Year, bs = random) + s(Latitude, Longitude, bs = spline on the sphere), $\mathbb{V}$)
5	CPUE ~ $\mathcal{I}$ ($\mathbb{E}$ = EUNIS + HaulDur + s(Depth, by = EUNIS) + s(Distance, by = EUNIS) + s(Year, bs = random) + s(Latitude, Longitude, bs = spline on the sphere), $\mathbb{V}$)
6	CPUE ~ $\mathcal{I}$ ($\mathbb{E}$ = EUNIS + HaulDur + s(Depth, Distance, by = EUNIS) + s(Year, bs = random) + s(Latitude, Longitude, bs = spline on the sphere), $\mathbb{V}$)

The haul duration was added as a simple additive covariate assuming a linear relationship with the fish density because there is no reason to expect a non-linear link between these two variables as long as the haul duration is comprised in a reasonable range (Godø et al. 1990).

Selection of the statistical distribution family

The negative binomial distribution with the canonical link function logarithm has been used for the initial comparative study. This choice among the other distribution has been motivated according to the initial analyses and the visualization of the dispersion of the data and according to the distribution of the residuals in the statistical modeling. Several statistical distributions have been tested in the modeling (see below and corresponding Results section).

As the response variable is an integer variable, the first family that has been tested is the Poisson family but this distribution assumes that the variance equals the mean, while it is not totally appropriate for the present dataset where over-dispersion is noticeable in some cases, especially for species like the herring or the Norway pout which can reach up locally really high density values. The negative binomial distribution allows for inclusion of the null observations and assumes a link mean-variance such as:

$$variance = mean + \frac{mean^2}{\theta} \qquad (2)$$

where θ is a positive real value describing the aggregation of the data. A small value for θ indicates that the over-dispersion is important, whereas the negative binomial behaves identically to the Poisson distribution when θ goes towards infinite (Nielsen, 2015).

Thus, this is better adapted to solve the problem of over-dispersion (Nielsen, 2015).

Some other distributions have also been tested and the outputs of the model built upon them have been compared with the outputs of the model built with the negative binomial distribution. Indeed, the negative binomial model did not fit well for the species showing the highest level of aggregation such as saithe and herring, but also not too well for Norway pout, cod and

whiting (see Appendix H2). Indeed, these species have more dense aggregated distribution, i.e. tend to have schooling behavior, which makes their spatial distribution contagious, i.e. very fragmented and increase the probability of occurrence of null values in survey data (Nielsen, 2015). It can be seen in appendix D that the saithe shows the highest level of aggregation, which is in accordance with the knowledge concerning this predator species forming multiple schools migrating in the whole North Sea (Pitcher and Partridge, 1979).
Zero-inflated distributions have been tried thanks to the GAMLSS R package (Rigby and Stasinopoulos, 2005). Yet, the zero-inflated Poisson model did not succeed in dealing with the over-dispersion as well as the negative binomial model does. A zero-inflated negative binomial model has also been tried but this model did not improve the fit and outputs compared to the simple negative binomial model.
The Tweedie distribution has also been considered. This distribution applies to continuous variables (summarized in Nielsen, 2015). The response variable, the number of individuals, is integer but according to the range of variation of the number of individuals, it seems reasonable to assume that the Tweedie distribution can be used here. This distribution is also relevant with respect to overdispersion as it assumes a mean-variance link such as:

$$variance = a\,.mean^{p} \text{ (Wood, 2011)} \quad (3)$$

Where a and p are positive constants.
Finally, the delta model was tested. This approach is particularly adapted to deal with the questions of fish schooling since it consists in applying two successive models (summarized in Nielsen, 2015): the first model explains the presence of an individual and the second one explains the number of individuals knowing that it is not null (i.e. individuals are present). A product between the first model and the second one aims to explain the number of individuals taking null values into account. The first model explaining presence can be considered as a way to predict the probability of occurrence of a school whereas the second model explaining the number of individuals knowing presence can be considered as a way to predict the size of a school when there is one. An analysis of the distribution family to use in the delta model has first been conducted. The best model was the one predicting the presence with a binomial and the number of individuals knowing presence with a log-Gaussian.
These three stochastic models (i.e. negative binomial, Tweedie and Delta) were compared. This comparison has been conducted in the same way than the one concerning the choice of the shape of the model except for the fact that the AIC could obviously not be used to compare the outputs of the delta model with the outputs of both of the other models.
Finally, in this testing procedure, a backwards selection of the type of the model had also to be conducted if the distribution family of the final model was not the one used for the choice of the type of the model.

2.2. Investigation of the species composition of the Norway pout and other important by-catch species combining Danish commercial fishery data and NS-IBTS survey data

2.2.0. Description and selection of the data from the Danish commercial fishery

In the commercial data from the Danish Norway pout fishery, landings in kilograms are recorded by species. The catches are recorded according to time and to position with the precision of the centre of the c-squares (squares of 0.05 degrees * 0.05 degrees). The depth at which the hauls were conducted is also recorded. Since the position is known, the distance to the Norway pout box boundary can easily be calculated in a similar way to what has been done for the analysis of the survey data. This commercial data has also been merged with the EUNIS benthic habitats at level 4 with 0.05*0.05 c-square spatial resolution. In addition, the fishing effort in time-units (minutes, hours and days) and the horse power class of the fishing vessel are also recorded.

Data extraction

The period covered by the commercial fishery data is the same as the one selected for the survey data, i.e. 2006-2016. The quarterly distribution is very different. Indeed, the Danish fishery has mostly been active during third and fourth quarter since 2002 as shown in figure 9. By nature, the main spatial coverage of the commercial data is different from the main spatial coverage of NS-IBTS data. The commercial fishery data covers mainly deeper grounds while, on purpose, the NS-IBTS data covers all depth strata more evenly, including inside the box. The box being a closure for fishing, almost all the catches are located outside the Norway pout box in a narrow strip comprised between the eastern box boundary and 70 kilometers far from it. More precisely, there are two fishing hotspots: the largest between 58˚N and 59.3˚N and the smallest between 60˚N and 60.5˚N as it appears from Figure 10. Some rare outliers due to a slight fishing activity in Skagerrak have been removed. Also, the Danish Norway pout fishery is concentrated on the muddy grounds as shown by fewer observations in the corresponding EUNIS benthic habitats. Indeed, the most represented EUNIS benthic habitat is the A5.37 (muddy ground). The sandy habitat (A5.27) is far less represented than in the survey data and the coarse sediment habitat (A5.15) is not represented at all.

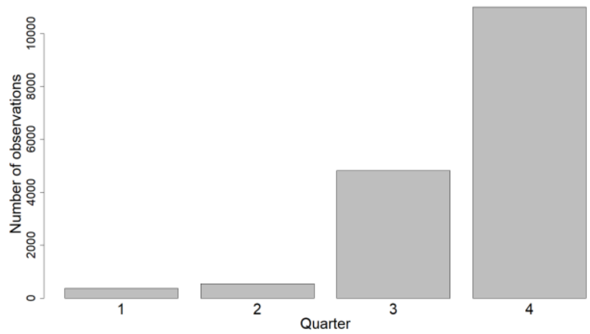
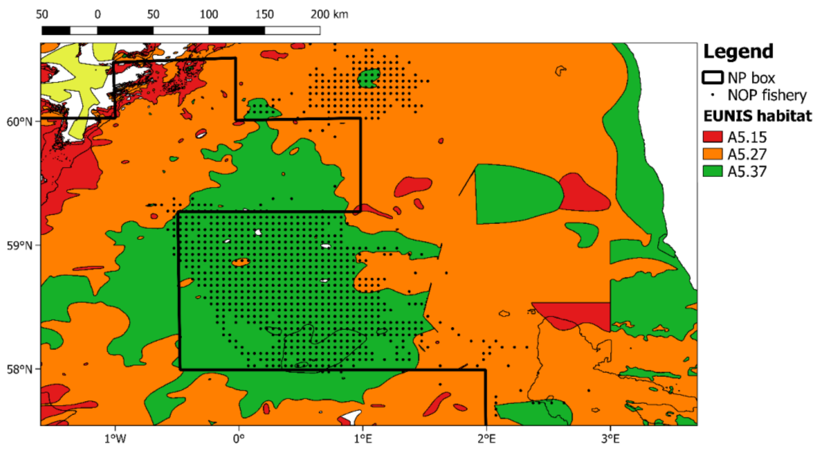


Figure 9 - Quarterly distribution of the observations of hauls from commercial fishery data



A5.15: deep circalittoral coarse sediment (coarse sand, gravel, shells)
A5.27: deep circalittoral sand (fine sands or non-cohesive muddy sands)
A5.37: deep circalittoral mud (mud and cohesive sandy mud)

Figure 10 - Spatial coverage of the Danish Norway pout fishery during the period 2006-2016 according to commercial data and analysis of underlying EUNIS benthic habitats

The main fishing vessel horse power classes in the Danish fleet fishing Norway pout are 500-1000, 1000-1500 and 1500-2000 HP with a majority of ships belonging to the 1000-1500 horse power class during the period 2006-2016 (Fig. 11). No significant differences in the range of fishing effort have been noticed according to horse power classes.
The Figure 11 shows also the variations of the effort according to year. There was no fishing activity in 2007 because the fishery was totally closed after a recruitment failure and decline in the Norway pout stock in this period (Nielsen et al. 2016). The relatively low level of the stock in the following years explains also probably why the ships in the 1500-2000 horse power class were inactive in 2008 and 2009. In the first half of the years 2006, 2011 and 2012 the fishery was also closed (Nielsen, 2016). This explains the inactivity of the ships belonging to the 500-1000 and 1500-2000 horse power classes in 2011. The fishing pressure tends to be more stable now at a lower level than in the beginning of the 2000 decade.

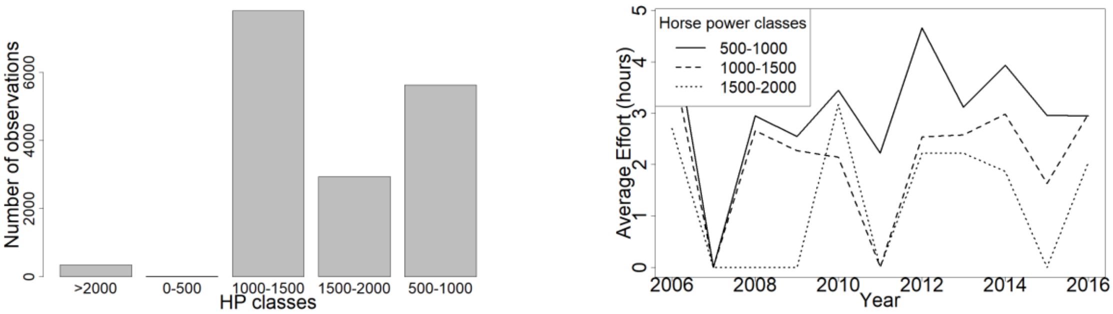


Figure 11 - Number of observations per horse power classes of the Danish Norway pout fishery (left) - Average effort versus year according to horse power classes (right)

2.2.1. Initial analyses concerning the likely species composition of the landings of the Danish Norway pout fishery inside the box

Assessment of likely species composition of the landings inside the Norway pout box
It is relevant to assess what would be the species composition of the landings of the Danish Norway pout fishery if the Norway pout box were open. To achieve this, the survey data and the commercial fishery data have been combined resulting in the estimation of the species composition of the catches of the Danish Norway pout fishery inside the box.
First, let:

$$\mathrm{CPUE}_{\mathrm{sp,\,y,\,EUNIS}} = q_{\mathrm{sp,\,y,\,EUNIS}} \,.\, B_{\mathrm{sp,\,y,\,EUNIS}} \quad (4)$$

where the CPUE is the catch per unit effort (in kilograms per hour) per species, B is the biomass of fish (in kilograms) and q is a factor linking CPUE to B (the so-called catchability). The subscripts "sp", "y" and "EUNIS" indicate that equation 4 is applied respectively per species, year and EUNIS benthic habitat. Applying this relationship to the CPUE recorded in the survey and to the landings recorded in the commercial data, the landings recorded in the commercial data can simply be expressed as in equation 5:

$$CPUE_{sp,y,EUNIS}^{commercial} = \frac{q_{sp,y,EUNIS}^{commercial}}{q_{sp,y,EUNIS}^{NS-IBTS}} \,.\, CPUE_{sp,y,EUNIS}^{NS-IBTS} \quad (5)$$

As only one fishery is considered in a homogenous spatial context, the ratio between the commercial catchability and the survey catchability may be assumed to be constant. Thus, first, the catchability ratio for each one of the three main horse power classes is calculated, per year and EUNIS benthic habitat in the area where both survey data and commercial fishery data are available and overlapping. In a second step, the species composition of the landings per year and EUNIS benthic habitat is assessed for the whole study area by simply multiplying the catchability ratio and the CPUE in weight units recorded in the survey data. Thus, we assessed the CPUE of each species per EUNIS benthic habitat, year and horse power class in the Danish Norway pout fishery for the whole study area. The catchability ratio has not been calculated by depth and distance to the Norway pout box because these two variables have very different range of variation in the commercial fishery data and in the survey data. It would then have been impossible to predict most of the observations in the whole study area. Note also that this has only been done for third quarter since the NS-IBTS surveys are only conducted in first and third quarters and the commercial data is very poor in first quarter during the period 2006-2016. Of course, the assessment can only be carried out on EUNIS benthic habitats that are well represented in the commercial data: A5.27 (sandy grounds) and A5.37 (muddy grounds). Some initial analyses have been conducted for the whole study area concerning EUNIS benthic habitat. The analyses regarding depth and distance to the Norway pout box boundary can only be carried out on the observations outside the Norway pout box (i.e. the true observations reported in the commercial fishery dataset).

Assessment of the biomass distribution of Norway pout and of important by-catch species

When using the survey data, it has always been preferred to conduct the statistical analysis with density instead of biomass since recruitment, growth, maturity and mortality influence the biomass whereas the fish density is influenced mainly by the mortality and recruitment only. Since the main question is about the recruitment and mortality of juveniles, it is more relevant to conduct analyses with fish density when it is possible. However, the landings obtained from the commercial fishery are only given in weight (biomass) and not in number of individuals. The NS-IBTS data should then be converted in biomass in order to combine them with the commercial fishery data as explained above. This is the reason why in the present work, a length-weight relationship has been assessed for each species of interest.

These length-weight relationships have been calculated for each species, by quarter and year. The SMALK data recorded during the NS-IBTS surveys have also been used. The temporal range of the data has been restricted to the period 2006 to 2016 and the spatial coverage has been restricted to the roundfish areas 1 to 3.

The equation 4 shows the model used to estimate the weight of a fish from its length (Froese et al. 2014). A decimal logarithm conversion has been used to avoid convergence issues as it is recommended in Froese et al. (2014):

$$\log10(\mathrm{W}) = \log 10(\mathrm{a}) + \mathrm{b}.\log10(\mathrm{L}) \tag{6}$$

where W represents the weight of a fish in grams and L its length (in cm). Two parameters must then be estimated: a and b. a characterizes the body-shape of the fish e.g. a = 0.001 characterizes eel-like fish whereas, a = 0.1 characterizes spherical fish (Froese et al. 2014). The parameter b is reported to be around 3 for species whose growth does not affect their body-shape (Froese, 2014).

The estimated values for both these parameters can be found in appendices C1 and C2. Some important quarterly differences can be observed in relation to the biology of species. For spring-spawners the values of the parameter a are often greater in third quarter indicating that the fishes in third quarter are more “spherical” than in first quarter. It is in accordance with the fact that the winter but also the spawning during first quarter induce a weight-loss. On the contrary, in third quarter fish are saving some energy to prepare for winter. For herring which is spring and fall spawner, this trend cannot be noticed and the values of a are rather homogenous. In a similar way, except for herring, it can be found that the values for b are greater in first quarter than in third quarter. In first quarter, b is often greater than the reference value of 3, whereas it is smaller in third quarter. It means that compared with individuals of third quarter, during first quarter the individuals tends to become fatter when their length increases. This typically denotes the fact that the juveniles represent an important part of the population during third quarter six months after spawning whereas they represent a lesser part of the population during first quarter of the next year because of mortality and growth.

2.2.2. *Statistical analysis of the species composition of the landings of the Danish Norway pout commercial fishery as assessed for the full area*

A statistical model has been formulated by species, for third quarter based on the data assessed for the whole study area (outside and inside the Norway pout box) with the following variables:

- Proportion of the species in the landings weight (dependent/response variable): continuous variable comprised between 0 and 1 calculated for each observation as the landings of one given species divided by the total landings;
- EUNIS (explanatory effect): qualitative variable giving the nature of the benthic habitat according to the EUNIS habitat classification at level 4;
- HPClass (explanatory effect): qualitative variable giving the horse power class;
- Year (explanatory effect): class variable giving the year when the landings have been recorded;

As the proportion in the landings for each species is the response variable, the Dirichlet distribution has been used. This distribution is the multidimensional generalization of the Beta-distribution (Maier, 2014) so that, for each species i:

$$E[X_i] = \frac{\alpha_i}{\sum_{i=1}^{K} \alpha_i} \tag{6}$$

$$Var[X_i] = \frac{\alpha_i.(\sum_{i=1}^{K} \alpha_i - \alpha_i)}{(\sum_{i=1}^{K} \alpha_i)^2.(\sum_{i=1}^{K} \alpha_i + 1)} \tag{7}$$

where X_i is the proportion the species i in the landings, K is the number of species and α_i is the concentration parameter corresponding to the species i. According to Equations 6 and 7, the concentration parameter vector $\alpha = (\alpha_1,\ldots,\alpha_K)$ directly represents the species composition as well as the variance of the estimation.

To achieve this, the R package "DirichletReg" developed by Maier (2014) has been used.

The explaining factors were selected by comparing ten different models according to the AIC and using also Likelihood ratio test.

3. Results

3.1. *Results on the investigation of the distribution and density patterns of Norway pout and important by-catch species in relation to the Norway pout box using survey data*

3.1.1. *Initial analyses to determine dependencies in species composition*

3.1.1.1. *Maps of species distribution*

The maps presented in appendix E give a global overview of the distribution of each species (cod, haddock, herring, Norway pout, saithe and whiting) by season in the study area. The species distribution is apparently not homogenous in the study area and some major trends can be noticed. Cod showed a rather homogenous distribution with a slight northwards pattern especially during first quarter based on these initial analyses. The cods were also rather densely located along Scottish coasts or along the Norwegian trench. During the third quarter especially, they seem to be mostly distributed outside the Norway pout box along the Norwegian trench. Note also, that the proportion of large individuals seem to be higher in the North than in the South. Saithe shows a strongly aggregated distribution pattern with a narrow location in the northeasterly area outside the Norway pout box along the Norwegian trench according to the initial analyses. It moved westwards during the first quarter. Haddock showed a continuous distribution mostly located in the South (especially during third quarter) and along the Scottish coasts: the great majority of haddocks were inside the Norway pout box. No pattern in the length composition of the species could really be noticed except that the proportion of large individuals was higher far from the coasts. Whiting's distribution showed a slightly southwards trend like haddock. This species was also mostly distributed along the Scottish coasts inside the box but expanded more Northwards and Eastwards during the first quarter with a higher proportion of large individuals within the northern and eastern limits of its distribution area. Herring appears to show a strongly aggregated distribution. This was mostly a southerly-located species with a higher proportion of large individuals in the northern limit of its distribution. Herring seemed to be equally distributed inside and outside the box. Norway pout had a slightly aggregated distribution. This species was mostly located in the northern part of the study area and moved eastwards during the first quarter for spawning, and was then mostly distributed outside the Norway pout box. During the third quarter, it tended to move slightly westwards and the density inside the box could reach a significant level. The impact of the Norway pout fishery could be suspected resulting in low density in the most intensively fished areas during the third quarter.

3.1.1.2. Species composition in relation to distance to the Norway pout box boundary

Here are only presented the results of the initial analyses considering the species composition in biomass because it enables better description of the role of each species in the ecosystem. The graphs for these initial analyses in density are shown in appendix F.

Figure 12 indicates some noticeable trends in the species composition from the survey data according to the distance to the Norway pout box boundary. The total biomass appears slightly higher outside the box than inside during the first quarter when some species such as Norway pout seems to move eastwards to spawn. Yet, during the third quarter, the total biomass appears much higher inside the box than outside. The proportion of Norway pout seems always to be lower in the two distance classes the furthest inside the box than in the other distance classes. It reaches its highest level (25 % of the total biomass) in the classes comprised between 30 meters inside and 100 meters outside of the box. The proportion of haddock, and to a lesser extent whiting, seem important in the box during the first quarter, but lower during the third quarter. Herring obviously reaches high levels of biomass in the whole study area during the third quarter. The contribution of cod and saithe to the total biomass seems weak except for the furthest distance classes according to the box boundary. As indicated on the distribution maps, saithe is mostly located outside the box far from its boundaries whereas the distribution of cod seems more homogenous.

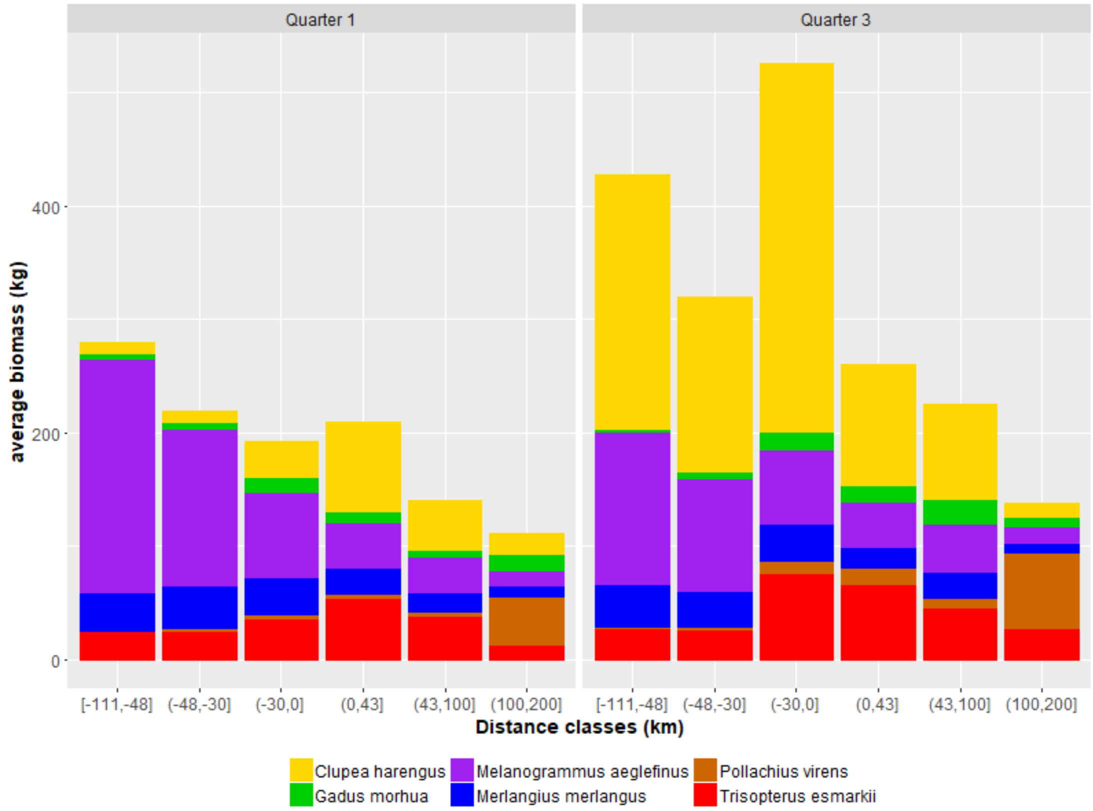


Figure 12 - 2006-2016 average species composition in biomass versus Distance classes according to quarter and position (inside or outside the Norway pout box). These six distance classes have been built with the main objective to have three classes wholly inside the Norway pout box (distance inferior or equal to 0) and three classes totally outside (distance superior to 0). These intervals have then been chosen to have approximately the same number of data in each distance class.

3.1.1.3. Species composition in biomass in relation to the depth and to the benthic EUNIS habitats

Figure 13 indicates some important distribution patterns according to bottom depth. Total biomass increases with the depth but some quarterly differences and some different patterns linked with the observed area (inside or outside) can also be noticed. In relatively shallow waters, haddock and whiting seem to contribute to a larger part of the fish populations inside the Norway pout box compared to outside. Herring seems more frequent in the shallow waters outside the box. On grounds deeper than 95 meters, Norway pout represents more than the half of the total biomass. This observation must be set in context of the important forage fish role of Norway pout on the local scale. The contribution of the largest species (i.e. cod and saithe) appears much smaller than the one of the other species. It can still be noticed that both of these species seem more frequent on relatively deep grounds.
Figure 14 indicates that the average total biomass appears to be higher on muddy seabeds (EUNIS A5.37) than on sandy grounds (EUNIS A5.27) except during the first quarter of year inside the box. Norway pout seems to show a preference for muddy grounds whatever the quarter is. Haddock and whiting seem to represent a high proportion of the fish population on coarse sediment grounds (EUNIS A5.15) which are mainly located inside the box. On the contrary, haddock represents a smaller part of the fish population on muddy seabeds. Herring seems to avoid coarse sediment but is distributed equally on sandy and muddy grounds. The distribution of the cod seems to be rather homogenous according to the benthic habitat type even if it represents a slightly higher part of fish population on coarse sediment. The observed saithe in the study area mostly aggregates on muddy grounds outside the box.

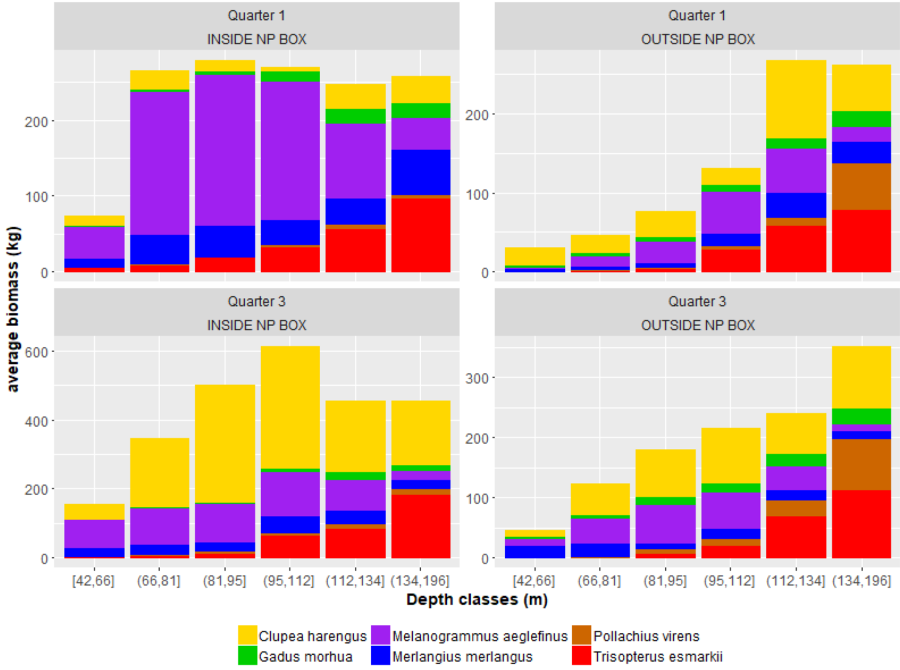


Figure 13 - Species composition in biomass versus depth classes according to quarter and position (inside or outside the Norway pout box). These six depth classes used here are taken according to the quantiles in order to have the same number of observations in each depth class.

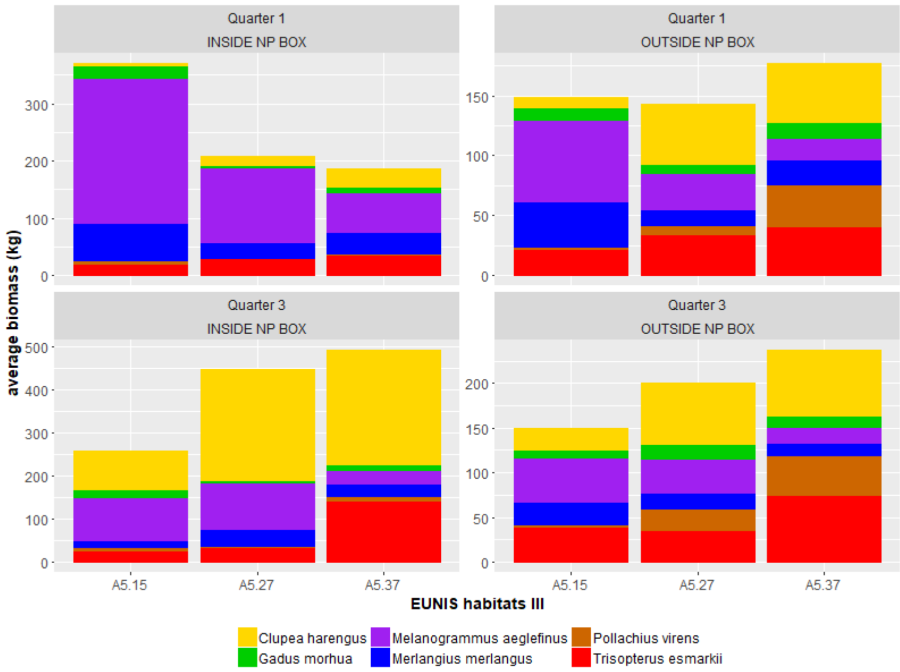


Figure 14 - Species composition in biomass versus benthic EUNIS habitats according to quarter of year and position (inside or outside the Norway pout box)

3.1.2. Initial analyses to determine dependencies in Norway pout and important by-catch species according to length composition

3.1.2.1. According to distance

The distance to the Norway pout box boundary always seems to explain poorly the density of the Norway pout as well as density of the important by-catch species (appendix G1). In particular, for the species reaching the largest sizes (i.e. cod and saithe) no trend can be observed except for a slight increase in the density of the small individuals of saithe when going further away outside of the Norway pout box. Yet, it must be noted that there is no species or length groups for which the density increases with the distance to the Norway pout box boundary except for the small saithe. Accordingly, it is relevant to test whether the decreasing trends observed for herring, haddock, whiting and Norway pout are significant in the statistical analyses. Note again the apparent strong seasonal influence, which is distinct in the herring, the whiting and the Norway pout distributions.

3.1.2.2. According to the depth and the benthic habitat type

The link between depth and the density of the species of interest seems often weak as indicated on the figures in appendix G1. Yet, this seems to be highly dependent on the species in question. For the Norway pout, depth explains rather well the distribution patterns of the large and small individuals. The correlation is higher between depth and density of large individuals than between depth and density of small individuals. An increase of the density of large individuals with the depth can be seen for all the species except haddock. For saithe and Norway pout, an increasing trend appears for both large and small individuals, and for Norway pout, the slope of the line is sharper for large individuals than for the small ones. Combining these observations from the initial analyses leads to the expected conclusion that the proportion of small individuals in a fish population is higher on shallow grounds. This could be regarded as a justification of the Norway pout box since the grounds are on average slightly shallower inside the Norway pout box than outside but still the statistical analyses have to confirm or reject such a statement. However, the value of the initial analysis is to point out that, if any depth effect is to be assumed in the further statistical analysis, then it will probably be relevant to assume a non-linear effect instead of a linear one in the models used. For example, the link between density and depth has a parabolic shape for haddock. Besides, the influence of the quarter is also well apparent. During the third quarter the proportion of large Norway pout individuals on deeper grounds is higher than during the first quarter. The seasonal effect is also very apparent in the depth distribution of whiting.

The spawning distribution (and possible migration effect) in relation to the length composition of the short-lived species is indicated on barplots in appendix G2 showing the length composition of each species versus the EUNIS benthic habitat according to the area and the season. For example, the proportion of juveniles is higher in third quarter (after spawning) than in first quarter (before spawning) for Norway pout and whiting. This pattern cannot be noticed at all for long-lived species such as cod, saithe or even haddock. Taking this into account, the length composition of the fish populations does not show important variations according to the substrate type. However, the proportion of saithe juveniles seems higher on coarse sediment grounds (EUNIS A5.15), and the proportion of large adult individuals seems to be higher on muddy grounds (EUNIS A5.37). For Norway pout, the proportion of small individuals was higher on muddy grounds than on sandy and coarse sediment grounds during the first quarters of period 2006-2016. Yet, this pattern is the opposite during the third quarter of the year, i.e. the proportion of small individuals is higher on coarse grounds. The effect of the area (inside or outside the Norway pout box) varies also according to the species and the quarter in question. For many species such as cod, Norway pout and saithe there seems not to be any significant difference between the length composition inside the Norway pout box and outside. Yet, this apparently also strongly depends on the season and the type of the substrate. For example, during the first quarter the proportion of herring juveniles seems to be higher on coarse and sandy sediments inside the box than outside, whereas there is an opposite trend on muddy grounds.

3.1.3. *Statistical analysis of the length composition of the Norway pout and of the important by-catch species according to the NS-IBTS survey data.*

3.1.3.1. *Model selection*

Choice of the type of the model

The results of this first selection step are summarized in the tables of appendix H1.

Whatever the length group and species are, the best models are the ones including the continuous variables depth and distance as non-linear factors (i.e. models 5 and 6, Table 2). The large cod for which the model 6 is not that good is the only exception. Considering these results, it has finally been decided to use the model 5 for the common analyses (equation 8). This model is often fitting a bit less well than the model 6 in terms of AIC but it has the great advantage to estimate an isolated distance effect while the model 6 assumes a 2-dimensional non-linear effect between depth and distance. The analysis of the results from the model 6 would be, consequently, more complex to interprete.

$$\begin{aligned} \textit{Number of individuals} \sim \textit{EUNIS} + s(\textit{Depth} \mid \textit{EUNIS}) + s(\textit{Distance} \mid \textit{EUNIS}) + \textit{Haul Duration} \\ + \textit{random}(\textit{Year}) + \textit{sos}(\textit{Latitude}, \textit{Longitude}) \end{aligned} \quad (8)$$

Selection of the family distribution

Considering the selection of the model 5, different stochastic model variations of this according to statistical distribution used are compared and summarized in table 3. The results of this second model selection step are summarized in the tables of appendix H2.

The only model that gives directly interpretable outputs for all the species, length groups and quarters is the delta model. Therefore, the delta model was finally the one used to explain the distribution of the different size groups and species in relation to the distance to the box and to the physical factors.

Indeed, the models run with the negative binomial distribution do not fit well for small Norway pout during the first and third quarters, for large Norway pout during third quarter, for small herring during the first and third quarters, for large herring during first quarter, for small cod during third quarter, for small whiting during first quarter, and for small saithe during first quarter. The models run with the Tweedie distribution are more reliable but still do not fit well for small Norway pout during the third quarter and herring during the first quarter. Therefore, it has been decided to keep the delta model in common for all the species, length groups and quarters. However, it should be noticed that the presence model often leads to spatial correlation issues and trends in the residuals of distance and depth can sometimes be observed. The interpretation of this is different according to the species. As for whiting and haddock, the relatively less well fit of the presence model is simply caused by the fact that the proportion of absence of fish is very low for these species which leads the model to build estimations based on very few observations. Because the proportion of presence observations is so high for these species, this issue is easily solved when taking into consideration directly the outputs of the density knowing presence model instead of combining these outputs with those of the presence model. Indeed, as the null observations are rare, their removal should not restrict the statistical validity of the density knowing presence model. For Norway pout, cod and herring, the observed patterns are not so important and should not lead to major misinterpretations of the model outputs. For saithe, the case is much more complex to handle and all the results concerning saithe must here be taken with great caution since there are strong spatial patterns

in the residuals. This is partly due to the very high proportion of null observations and partly to the current distribution of saithe, which is mostly located north-eastwards in the North Sea. It has been decided to analyse separately the outputs of each step of modeling because of the difference in the reliability of the outputs coming successively from the presence and the density knowing presence models (Cunningham and Lindenmayer, 2005). The impossibility of estimating the standard error of the product of both models is also an argument justifying this careful approach.
As the delta model was finally preferred to the other family distribution, a backwards selection was made again to define whether the model whose shape is given in equation 9 was the best to use with this kind of distribution. The results of this backwards selection are summarized in the tables of appendix H3. It finally comforted the choice of the model written in equation 8.

Table 3 - Formulas of the stochastic models tested. The smoother effects are indicated with s(…). The term written after "bs = " indicates which kind of spline was used. NB, Tw, B and N respectively refer to the negative binomial, the Tweedie, the binomial and the Gaussian distribution families. E refers to the esperance and V to the variance.

Scenario number	Formula
Model 5 with Negative binomial (NB)	CPUE ~ NB(E = EUNIS + HaulDur + s(Depth, by = EUNIS) + s(Distance, by = EUNIS) + s(Year, bs = "re") + s(Latitude, Longitude, bs = "sos", V)
Model 5 with Tweedie (Tw)	CPUE ~ Tw(E = EUNIS + HaulDur + s(Depth, by = EUNIS) + s(Distance, by = EUNIS) + s(Year, bs = "re") + s(Latitude, Longitude, bs = "sos", V)
Model 5 with Delta model	1. Presence ~ B(E = EUNIS + HaulDur + s(Depth, by = EUNIS) + s(Distance, by = EUNIS) + s(Year, bs = "re") + s(Latitude, Longitude, bs = "sos", V) 2. ln(CPUE) ~ N(E = EUNIS + HaulDur + s(Depth, by = EUNIS) + s(Distance, by = EUNIS) + s(Year, bs = "re") + s(Latitude, Longitude, bs = "sos", V)

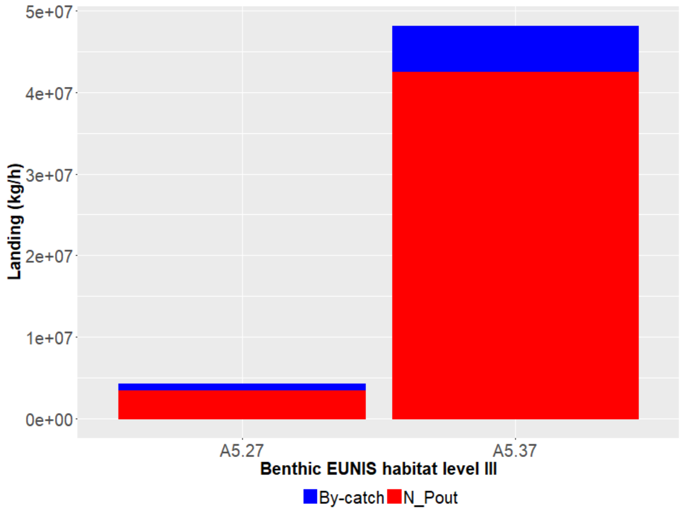
Model outputs
An example of the outputs is plotted in appendix I1 (large whiting during first quarter) and all the results are summarized in the tables of appendix I2 and appendix I3. As described above, the outputs of the models for saithe (small and large) are not reliable because of a very high proportion of null observations coupled with a strong spatial pattern. Accordingly, these outputs and results should be taken with great caution.
First, the outputs are analysed in relation to the distance effect. Considering large and small individuals of Norway pout and herring, the distance is almost never significant and when the distance effect is significant, it is very weak. The distance is also not significant with respect to explaining the density of small individuals of haddock and whiting and large individuals of cod. Yet, during the first quarter, the number of large individuals of haddock and whiting is higher far away from the Norway pout box boundary and decreases when getting closer to the open access area. Besides, a decreasing trend is also observed for small cod on the coarse substrate type (EUNIS A5.15) during the third quarter.
Secondly, the outputs are analysed in relation to the "ground effects" (i.e. the depth and the EUNIS benthic habitat). The EUNIS benthic habitat is never significant as main effect to explain the variations in the density of the species and sizes of interest except for large whiting during the first quarter. In this case, it indicates that the density of large individuals is higher on the coarse sediment type. The influence of the benthic habitat must then be deduced under consideration of the interaction with both other explaining variables as the smoothers for depth and distance are defined according to each type of benthic EUNIS habitat. The explanatory power of the depth in interaction with the EUNIS habitat type is higher for the density of the large individuals than for the density of the small ones. Especially the density of small individuals during first quarter is poorly explained by these two variables. This should be seen

in context of the higher variability in the density of young individuals than in the density of older ones. The density of all size groups of herring is also relatively poorly explained by these variables: herring is a pelagic species. The general pattern is that the density increases until a limit-depth and thereafter decreases. The value of this limit-depth varies according to the species. For haddock, it is around 110 meters but it is higher than 130 meters for whiting and reaches more than 150 meters for Norway pout. It is also found that the presence of large cod in first quarter and large Norway pout in third quarter increases with the depth without reaching any limit-depth: both of these species have a deeper distribution than the other species. The limit-depth values are also lower for small individuals than for large ones for whiting, herring and especially Norway pout. It is in accordance with the fact that juveniles prefer shallower waters. For a given species, length group and quarter of year, this density pattern according to depth shows only slight variations according to the habitat type. Haddock, both large and small, are found to be mostly distributed on the sandy grounds. Also, whiting juveniles are found to be more distributed on shallow sandy grounds than on muddy grounds and juveniles of Norway pout are slightly more distributed on coarse and sandy grounds than on muddy grounds. Depth is often observed as a non-significant factor on coarse sediment grounds. This is probably because the coarse sediment grounds are more spatially fragmented than the two others, which leads to the occurrence of many different communities and induces an increase of the variability, which cannot always well be captured in the models.

3.2. Results on the investigation of the distribution patterns of Norway pout and of other important by-catch species combining Danish commercial fishery data and NS-IBTS survey data

3.2.1. Initial analyses concerning the species composition of the landings of the Danish Norway pout fishery

On the figure 15 showing the assessed composition of the landings of the Danish Norway pout fishery for the whole study area as explained in section 2.2.1., it appears that there are no big variations according to the EUNIS benthic habitat. The by-catch composition hardly differs between habitats. However, the proportion of the by-catch seems to be higher on sandy grounds than on muddy grounds. Accordingly, it is relevant to test statistically the EUNIS habitat effect on the landing species composition in the Danish Norway pout fishery.



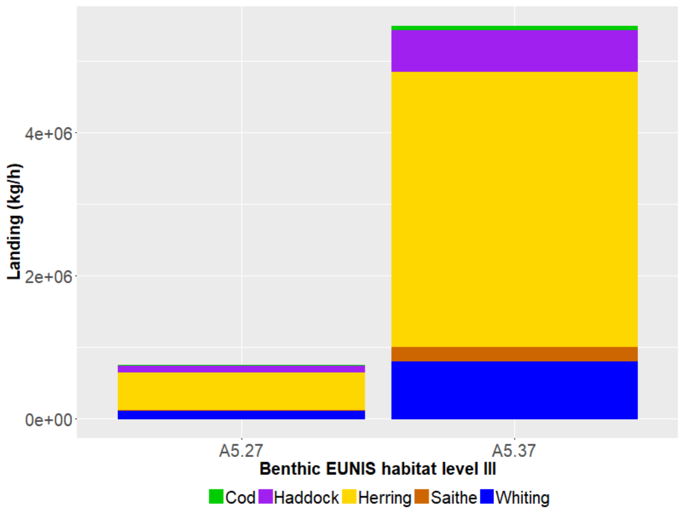


Figure 15 - Composition of the landings of the Danish Norway pout fishery re-assessed for the whole study area averaged for the period 2006 - 2016 according to EUNIS benthic habitat - left: total composition of the landings (target species + aggregated by-catch species) - right: composition of the by-catch only

3.2.2. *Statistical analysis of the species composition of the landings of the Danish Norway pout fishery*

Model selection

The final model includes both Year and EUNIS benthic habitat as explaining factors but excludes the horse power class shown as non-significant. Equation 9 gives the formula of the model used to analyse the species composition of the by-catches of the Norway pout fishery:

$$Proportion \sim Dir(EUNIS * Year) \tag{9}$$

Model outputs

The outputs of the model are summarized in table 4 below. For Norway pout, haddock and whiting, the variable “EUNIS benthic habitat” is significant as main effect as well as in interaction with the variable “Year”. The analysis of the outcomes for these three species must then be carried out by adding the different coefficients estimated for main and interaction factors. The proportion of Norway pout in the catches of the Danish Norway pout fishery is estimated to be significantly higher on the muddy grounds (EUNIS A5.37) than on the sandy grounds (EUNIS A5.27). This implies that the by-catch of the Danish Norway pout fishery are significantly higher on sandy grounds. It also appears that the proportion of haddock and whiting in the catches are significantly lower on muddy grounds, which reciprocally means that the proportion of haddock and whiting is significantly higher on sandy grounds. These results concerning the proportion of Norway pout, haddock and whiting in the catches of the Danish Norway pout fishery are valid for every year of the study period. For herring and saithe, the variable “EUNIS benthic habitat” is not significant as main effect but it is sometimes significant in interaction with the variable “Year”. The proportion of herring in the landings is significantly lower on muddy grounds than on sandy grounds in the years 2008 and 2015 whereas the by-catch of saithe are shown to be significantly higher on muddy grounds in the years 2014 and 2016. The variations of the proportion of cod in the landings is not significantly explained either by the type of the benthic EUNIS habitat, or by the year.

Table 4 - Summary of the model with the formula is: Proportion ~ Dir(EUNIS*Year) – Pr(>|z|) is the p-value resulting of the test whose null hypothesis is that the estimated coefficients are equal to 0. According to the central limit theorem, the Z- statistic can be used thanks to the relatively large amount of data (> 30) that enables to approximate the Student-test (assuming a Student distribution) by a Z-test (assuming a Gaussian distribution).

	COD		SAITHE		HERRING		HADDOCK		WHITING		NORWAY POUT	
	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)
EUNIS A5.37	0,08965	0,553	0,147	0,33	0,18554	0,21936	-0,46571	0,00212	-0,5417	0,00044	1,18457	2,35E-14
2008	0,22299	0,081	0,18946	0,138	0,53479	3,07E-05	0,21877	0,0912	-1,5609	2,00E-16	-0,27356	0,03351
2009	-0,09084	0,493	-0,09084	4,93E-01	0,10942	0,41164	-0,55784	3,08E-05	-1,5155	2,00E-16	-0,28242	3,56E-02
2010	0,10803	0,364	-0,03923	0,742	0,28118	0,01829	-0,11598	0,33364	-0,6933	1,56E-08	-0,2655	0,02666
2011	-0,08615	0,561	-0,08615	5,61E-01	0,81854	8,90E-08	-1,17902	2,30E-15	-1,9033	2,00E-16	-0,41311	5,94E-03
2013	-0,02504	0,843	-0,03085	8,07E-01	0,16168	0,2016	-1,10249	2,00E-16	-0,8485	7,06E-11	0,0074	9,54E-01
2014	-0,01335	0,926	0,16075	2,63E-01	0,4263	0,00305	-0,31835	2,74E-02	-0,3962	7,20E-03	0,17285	2,33E-01
2015	-0,04913	0,731	-0,04913	7,31E-01	0,76902	1,03E-07	-0,39807	5,65E-03	-1,1157	2,09E-14	-0,31178	3,03E-02
2016	0,09146	0,454	0,11869	3,31E-01	0,23498	0,05484	-0,77834	2,35E-10	-0,5653	7,35E-06	0,03093	8,02E-01
EUNIS A5.37:2008	0,10725	0,633	0,04105	8,55E-01	-0,48375	0,03178	-0,39125	8,30E-02	0,3103	1,71E-01	-0,55756	1,59E-02
EUNIS A5.37:2009	0,04393	0,855	-0,10922	6,49E-01	-0,19577	0,41694	0,29229	2,26E-01	1,0093	3,43E-05	-0,64098	9,78E-03
EUNIS A5.37:2010	0,03922	0,841	-0,11267	5,66E-01	-0,2729	0,16325	0,2989	1,28E-01	0,4268	3,16E-02	-0,19975	3,20E-01
EUNIS A5.37:2011	-0,01484	0,956	-0,07219	7,87E-01	-0,3854	0,15424	1,08288	5,10E-05	1,7423	1,07E-10	-0,2488	3,63E-01
EUNIS A5.37:2013	-0,02127	0,915	0,10074	6,13E-01	-0,16131	0,41911	0,56618	4,54E-03	0,11	5,87E-01	-0,33546	1,07E-01
EUNIS A5.37:2014	-0,09719	0,668	0,19665	3,86E-01	-0,33809	0,13657	0,07793	7,32E-01	-0,104	6,51E-01	-0,75931	1,13E-03
EUNIS A5.37:2015	-0,06174	0,782	-0,11909	5,94E-01	-0,67073	0,00286	0,08365	7,09E-01	0,5028	2,62E-02	-0,10719	0,64385
EUNIS A5.37:2016	-0,03708	0,847	0,15082	4,33E-01	-0,09522	0,62096	0,353	6,68E-02	-0,0579	7,67E-01	-0,52152	8,58E-03

4. Discussion

The results obtained in the preliminary and statistical analyses are below discussed on integrated basis addressing each of the null hypotheses.

4.1. Species composition in relation to the Norway pout box (H01).

Some important differences in the species composition inside and outside the box have been found. These differences are highly dependent on the season. The total biomass is higher in the third quarter than in the first. In the first quarter, the total biomass is higher outside the box than inside, but in third quarter, during the period of activity of the Norway pout fishery, the total biomass is much higher inside the Norway pout box than outside. The proportion of the Norway pout in the total biomass reaches its highest level in the very surroundings of the box boundary. The main predator species are unequally distributed. Saithe and to a lesser extent cod are mainly distributed with highest densities outside the box whereas haddock and whiting are mainly located inside the box where they represent a very high proportion of the fish communities especially during the first quarter. In particular, haddock represents more than half of the total biomass inside the box during the first quarter.
There is also found a current significant difference in species composition according to bottom depth where haddock and to a lesser extent whiting represents a relatively high proportion of the fish biomass on shallow grounds whereas Norway pout and to a lesser extent cod are mostly distributed on deep grounds. Saithe also has a deep distribution, while the distribution of the pelagic herring is only slightly influenced by the depth. The small individuals are found to have a more shallow distribution than the large ones for Norway pout and whiting. Furthermore, there is observed a significant difference in species composition on different benthic habitats with some main trends. Whiting is distributed mostly on coarse sediment and to a lesser extent on sandy grounds. Haddock is mostly located on sandy grounds, whereas Norway pout is mostly distributed on muddy grounds. The distribution of bathymetry and benthic habitat types both inside and outside the box can be assumed as having been constant over the period since establishment of the Norway pout box. If we similarly assume that the statistical bathymetry and habitat associated densities of the different fish species has not changed over time in this period, then there is a time consistent effect of the Norway pout box because the relative distribution of the different depth strata and benthic habitat types are different in the area inside and outside the box. The area inside the box is characterized by being shallower and having a higher proportion of sandy habitats where a relatively higher proportion of whiting and haddock are distributed, compared to Norway pout with a more deep and muddy sediment distribution.
However, these differences in the species composition inside and outside the box may also result from various other distinct phenomena, e.g. changes in more variable physical environmental factors such as the water temperature, which may affect the depth distribution, or changes in biological interactions. First, we cannot <u>prove</u> that there is no accumulated effects over time of the establishment of the Norway pout box where the absence of the Norway pout fishery over time changes the species and size composition in the box. That is, that there initially may not have been so great differences in the species composition between inside and outside the box when the box was established despite the above indicated strong dependency in species composition according to depth and habitats. The important differences observed on the period 2006 - 2016 may be a long-term effect of the box associated to more variable biological interactions. Consequently, what is mainly investigated here is what the current effects of the box are and what the consequences would be if the box were opened. Secondly,

some distribution and density patterns of some fish populations and assemblages in the North Sea has been reported to have changed since the establishment of the Norway pout box in 1977 (Perry et al. 2005; Dulvy et al. 2008). These modifications can be due to some environmental drivers. Considering long-term trends, the climate change seems to be a major cause of changes in the distribution of the species and assemblages of fish in the North Sea. Perry et al. (2005) have shown a significant shift of the centre of the distribution correlated with the increase of the temperature (+ 1.05°C from 1977 to 2001). This has been shown for 15 demersal species of the North Sea both commercially exploited or not. Here a significant move of Atlantic cod northwards was also observed in relation to the increase of the sea temperature. It was also shown that Norway pout surprisingly moved southwards. The authors explained this trend based on the fact that in the northern North Sea, the North Atlantic Drift warms up the whole northern North Sea waters during winter. Such opposed movements for these species are, thus, highly likely to question the efficiency of the Norway pout box whose boundaries have not been revised since its establishment forty years ago. In a similar way, Dulvy et al. (2008) showed a deeper distribution of demersal species of the North Sea over the twenty-five years period 1980-2004. Some of the commercial species considered in this study have been shown to have a deeper distribution at a significant rate of 8 m.decade^{-1} (cod and saithe). The whiting has also been shown to have significantly deeper distribution but at a slower rate than cod or saithe (3 m.decade^{-1}). A similar deepening was also observed for Norway pout and haddock but was only slightly significant. The human exploitation has also an impact on the fish distribution as it has been shown in Daan et al. (2005) on the basis of the analysis of the correlation between size spectra and maximum length with the fishing effort estimated in the North Sea over the period 1977-2000. Thus, it has been shown some important spatial differences in the short or long-term effect of the fisheries on the fish assemblages in the North Sea. The exploitation patterns in the North Sea have changed significantly since 1977 (Gascuel et al. 2016) and this is possible that the box boundaries should be revised in consequence.

4.2. Size composition and size-dependent by-catches such as juvenile gadoids in relation to the Norway pout box (H02)

The distance effect almost never explains significantly the variations of the density of the small individuals either in the preliminary plot analyses or in the following statistical analysis of the length compositions. Yet, during the first quarter, the density of the large individuals of both haddock and whiting decreases when the distance to the Norway pout box increases. This observed distance effect cannot come from the confusion of the effect of distance with another spatial variable (depth or EUNIS) because for both model explaining the number of large individuals of haddock and whiting in first quarter, depth is also significant. Furthermore, the interaction between depth and distance does not seem to be relevant since the models 5 (without interaction) and 6 (including non-linear interaction) are not significantly different according to the AIC. Yet, these trends cannot be observed either for large or small individuals during third quarter when the Norway pout box should have its main effect because the Danish Norway pout fishery has relatively high activity in this period. Therefore, even though the distance to the box significantly explains the number of large individuals of whiting and haddock in the first quarter, this effect should not be linked with the efficiency of the Norway pout box but rather with some particular migration patterns. Whiting and haddock are spring-spawners, which may explain the aggregation of the large individuals in a particular area during the first quarter. A decreasing trend was also noticed for small cod on coarse substrate (EUNIS A5.15) during the third quarter. However, such a trend is not comforted by the observations on the other types of grounds, and the Danish Norway pout fishery does not fish on coarse sediment. This trend can accordingly not be explained by the presence of the closure area. If there had been any effect of the Norway pout box, it should have been possible to observe a certain spill-over of juveniles as it could be observed when testing the effect of a marine protected area in Goñi et al. (2006) and Stelzenmüller et al. (2007). This is definitely not what was observed here. Thus, contrary to the justification given when it was set up, the Norway pout box does not seem to have any significant role in the protection of populations of juveniles nowadays. However, it must be noted that some spatial correlation was remarkable in the residuals of the models run for Norway pout and especially saithe. This can lead to a lack of precision in the outputs of these models. It could be possible to implement better correlation structures such as the one defined in the Log-Gaussian Cox process model to take into account the spatial autocorrelation (Nielsen, 2015). Using universal kriging with external trends combining GIS analyses and statistical analyses would also certainly be a relevant solution to improve this point (Stelzenmüller et al. 2007).

However, the distribution of juveniles have been shown to depend on the bathymetry for at least three species: Norway pout, whiting and to a lesser extent herring. For these three species, juveniles are more often represented on shallow grounds. The nature of the sediment has also been proved to influence significantly the distribution of the juveniles of whiting, Norway pout and especially haddock. Indeed, whiting and haddock juveniles are mostly distributed on the sandy grounds, while juveniles of Norway pout have a slight preference for coarse and sandy grounds. If the distribution of bathymetry and benthic habitat types both inside and outside the box are again assumed constant over the period since establishment of the Norway pout box as well as the statistical bathymetry and habitat associated densities of the different fish species and size groups, there is an effect of the box on the protection of juveniles.

Besides, it could be stated that the changes in fish distribution as well as the factors influencing this, that have been evoked in the discussion above, as well as long term effects of the box, have progressively made the Norway pout box less efficient than it used to be. Again climate and environmental driven variability may have a strong influences as discussed in relation to H01. It must be kept in mind that the Norway pout box was established just after the very peak of abundance of the gadoids due to the gadoid outburst, a period that showed particular stock structures with respect to species and size compositions (Hislop, 1996). Hislop (1996) raises the idea that the food may have been in short supply for juvenile population of some gadoids such as the haddock because of some strong recruitments whereas it was not the case for the adults. It seems then possible that the gadoid juveniles were much more widespread during the gadoid outburst than since the 1990s. This is even more likely considering that the gadoids considered in this study have no specific nursery grounds (haddock, whiting and Norway pout) or very extensive ones (cod and saithe) (Hislop, 1996).

Even though only indicative because of only few observations before the establishment of the Norway pout box, a rough time series analysis of survey data has been conducted to investigate whether some overall changes and trends in relative size composition for the different species considered can be observed (Fig. 16). It appears from those indicative analyses that for the different species there are no relative changes in size composition over time in relation to the Norway pout box. Juveniles of haddock, herring and especially whiting are mostly located inside the box while juveniles of cod, saithe and, to a lesser extent, Norway pout are mostly located outside the box, and these trends does not appear to change over time from before to after establishment of the box all the way up today. Accordingly, these indicative analyses do not indicate cumulative effects of the box with respect to size composition for the different species investigated. These differences of repartition can probably be explained by main variables such as depth and EUNIS benthic habitat type. In absence of any noticeable trend in the repartition of juveniles in relation to the Norway pout box since the seventies, the assumptions of any change in species and length composition due to the gadoid outburst should probably be excluded. Therefore, the distance to the boundaries of the box would certainly not have been significant to explain the distribution of the juveniles since the establishment of the Norway pout box. It seems highly possible that the Norway pout box boundaries were already not well defined to protect the gadoid juveniles in the late 1970s and in the 1980s.

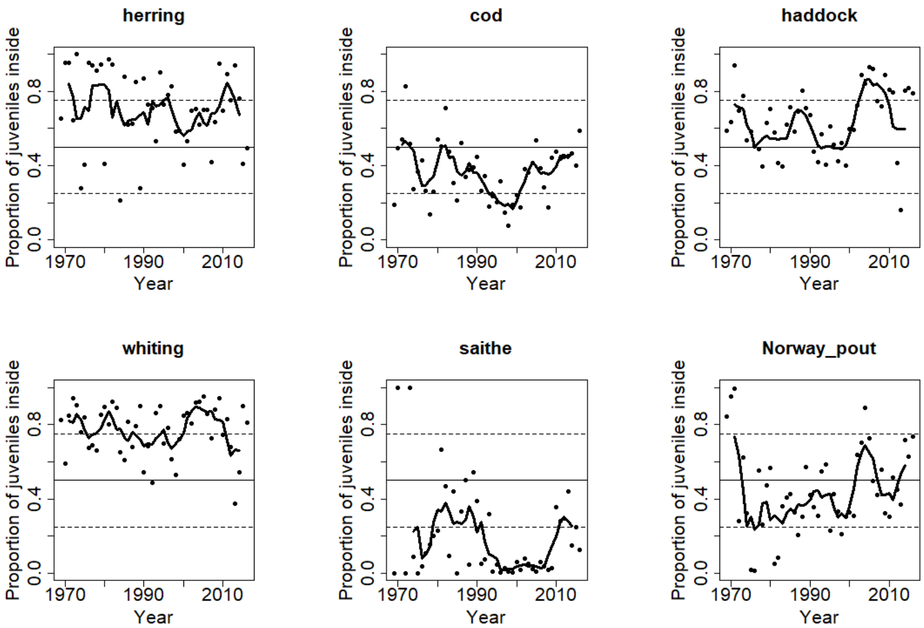


Figure 16 - Temporal variations of the proportion of juveniles inside the box. For each species, the proportion of juveniles inside is defined as the sum of all the small individuals inside the box divided by the total of all the small individuals of the study area. The dots are observations for each year while the solid line is a five-years-both-sided-moving average. As the areas inside and outside the box have approximately the same surface, the proportion would be expected to neighbour 0.5 (solid horizontal line) if there were as many juveniles inside and outside the box. The dashed horizontal lines are set at 0.25 and 0.75.

4.3. Catch composition on different habitat types in relation to the Norway pout box (H03 and H04)

The Norway pout box covers mostly sandy grounds whereas the Danish Norway pout fishery is mostly active on muddy grounds in the recent years. The muddy grounds have finer sediment than the sandy ones and are, thus, more sensitive to deteriorations by trawling because of the penetration of the gears (Ivanović et al. 2011). This could be considered as a first argument in favor of the Norway pout box. Besides, when assessing the species composition of the by-catches for the whole study area, the proportion of Norway pout in the catches has been shown to be lower on sandy grounds. This is mostly due to higher by-catches of haddock and whiting on sandy grounds. The average by-catch ratio of the Norway pout fishery during the study period in case of an opening of the Norway pout box reaches 11.4% on muddy grounds. The WKPout records a value slightly below 10% over 2006 – 2014 (Nielsen et al. 2016) but it concerns only the area where the Danish Norway pout fishery is currently active and include by-catches of Norway pout by other small-meshed fisheries not targeting Norway pout. This by-catch ratio is close to the by-catch ratio of other demersal fisheries operating in the North Sea such as the whiting fishery (9.2% during the period 2006 to 2011) (ICES, 2013). Yet, on sandy grounds, the by-catch ratio of the Danish Norway pout fishery in case of an opening of the box would be significantly higher (17.8%). The Norway pout box covers a much higher proportion of sandy grounds than the area where the Danish Norway pout fishery is usually active in the recent years. Therefore, under the hypothesis of a uniform distribution of the Danish Norway pout fishery in the northern North Sea, this indicates that an opening of the box would certainly lead to an increase in the by-catches. This conclusion is valid for all fishing vessel horse power classes existing in the fishery. Besides, Norway pout has been shown to represent a higher proportion of the total biomass on deeper than on shallow grounds. This is coherent with the distribution according to the benthic habitat considering that muddy grounds are associated with bottom depths below 50-70 meters (Fig.7 ; Davies et al. 2004). On the contrary, haddock and whiting are mostly distributed on shallow grounds. Therefore, the hypothesis H04 is rejected. As the grounds are on average shallower inside the box than outside, to exclude the small-meshed fishery from shallower sandy grounds where Norway pout is less frequent and where, consequently, the by-catches would certainly be higher is relevant. It enables a significant reduction of the by-catches of the Norway pout fishery with the same order of magnitude (around 50%) as what Eigaard et al. (2012) have assessed for use and implementation of the selectivity device introduced in the Danish Norway pout fishery in 2012. This is a very remarkable and important result.

However, it is more difficult to give an unequivocal answer to H03. These results tend obviously to reject it and to conclude that the by-catches would be higher inside than outside the box. Yet, these results are only based on the distribution of the EUNIS benthic habitats. The different ranges of variation of depth and distance in the NS-IBTS survey dataset and in the commercial fishery dataset did not allow to assess what would be the composition of the by-catches of the Norway pout fishery according to depth and distance inside the box. This is the limit of this evaluation based on spatial comparison (in/out) instead of temporal comparison (before/after). Yet, a complementary temporal analysis seems difficult to carry out because of the limitations in data with respect to length of time series. Only few data are available/reliable before the establishment of the box. If a robust temporal analysis should have been conducted, it is necessary to robustly evaluate which data are most valid for the period before the implementation of the box and how to make them fit with the data used here for the period 2006–2016. Only indications like those presented in figure 16 can be obtained from the available data. Another limit of this study is that the fish length composition of the catches was not available in the commercial dataset, which prevented from analysing the length composition of the by-catch of the Norway pout fishery. Accessing some data from observers on board would enable to complete the second part of the study with a statistical analysis of the length composition of the by-catches.

4.4. Conclusion

The species composition is very different inside and outside the box. Yet, the distribution of the juveniles is not significantly influenced by the distance to the Norway pout box boundaries. Indeed, the box itself does appear not to be the major factor causing the differences in species or size composition. Depth and benthic habitat type are more significant factors to explain the distribution of the juveniles. Juveniles are more abundant on shallow grounds, which are relative more important inside the box. Haddock and whiting are very abundant on the sandy grounds, which occur, in higher proportion inside the box. Therefore, the by-catches of the Danish Norway pout fishery would be higher inside the Norway pout boxe because of the higher proportion of the sandy grounds compared to the muddy grounds here (when compared to where the fishery is currently mainly operating outside the box. As the objective of box is to reduce the by-catches in the Danish Norway pout fishery, its boundaries should certainly be revised paying more attention to the depth and the type of sediment. There does not seem to be any relevant ecologic reason for excluding the Norway pout fishery from the deep muddy grounds located inside the box. These muddy grounds represent a small proportion of the enclosed area but their surface is still more than half as big as the surface of the grounds where the Danish Norway pout fishery is currently operating. An access to these enclosed muddy grounds may lead to a significant increase of the landings of the Norway pout fishery. Yet, such a modification of the boundaries should be carried out with great care and paying attention to the quotas of Norway pout and to the by-catch quotas and of the selective measures currently in force in the fishery.

Beare et al. (2013) analysing the effects of the plaice box in the southern North Sea raised the necessity of defining some accurate indicators in relation to the objectives of the box. This would certainly also have been highly relevant in the case of the Norway pout box in order to evaluate the consequences of this spatial closure in relation to precise objectives.

The present study covers only ecological aspects of the fishery impacts. Future studies should also pay attention to the economic and social consequences of the Norway pout box as well. The case of the Norway pout box is highly politicized (Nielsen and Mathiesen, 2006). Many different actors are competing for this area including fisher and industry organizations but also management authorities, research institutions and NGO environmental organisations from United Kingdom and the European Union (i.e. Denmark) and even, to a lesser extent, from Norway. It would be relevant to consider the questioning about the Norway pout box as a conflict of interests between industrial and human consumption fisheries (Nielsen and Mathiesen, 2006) rather than as a pure environmental issue. Further studies should analyse the interactions between ecosystemic, economic and social effects of diverse scenarios of effort re-allocation by the Danish Norway pout fishery in case of an opening of the box.

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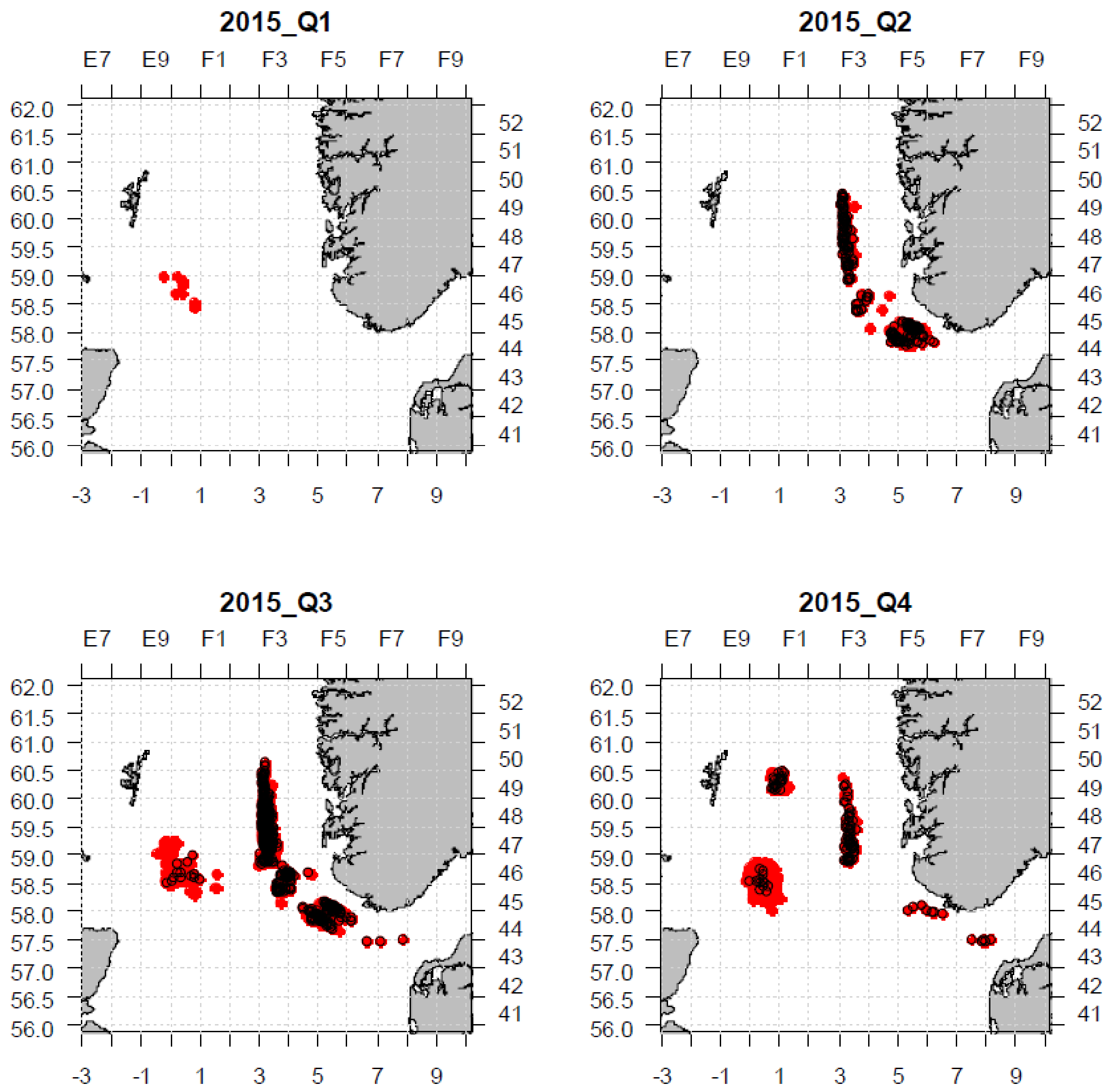
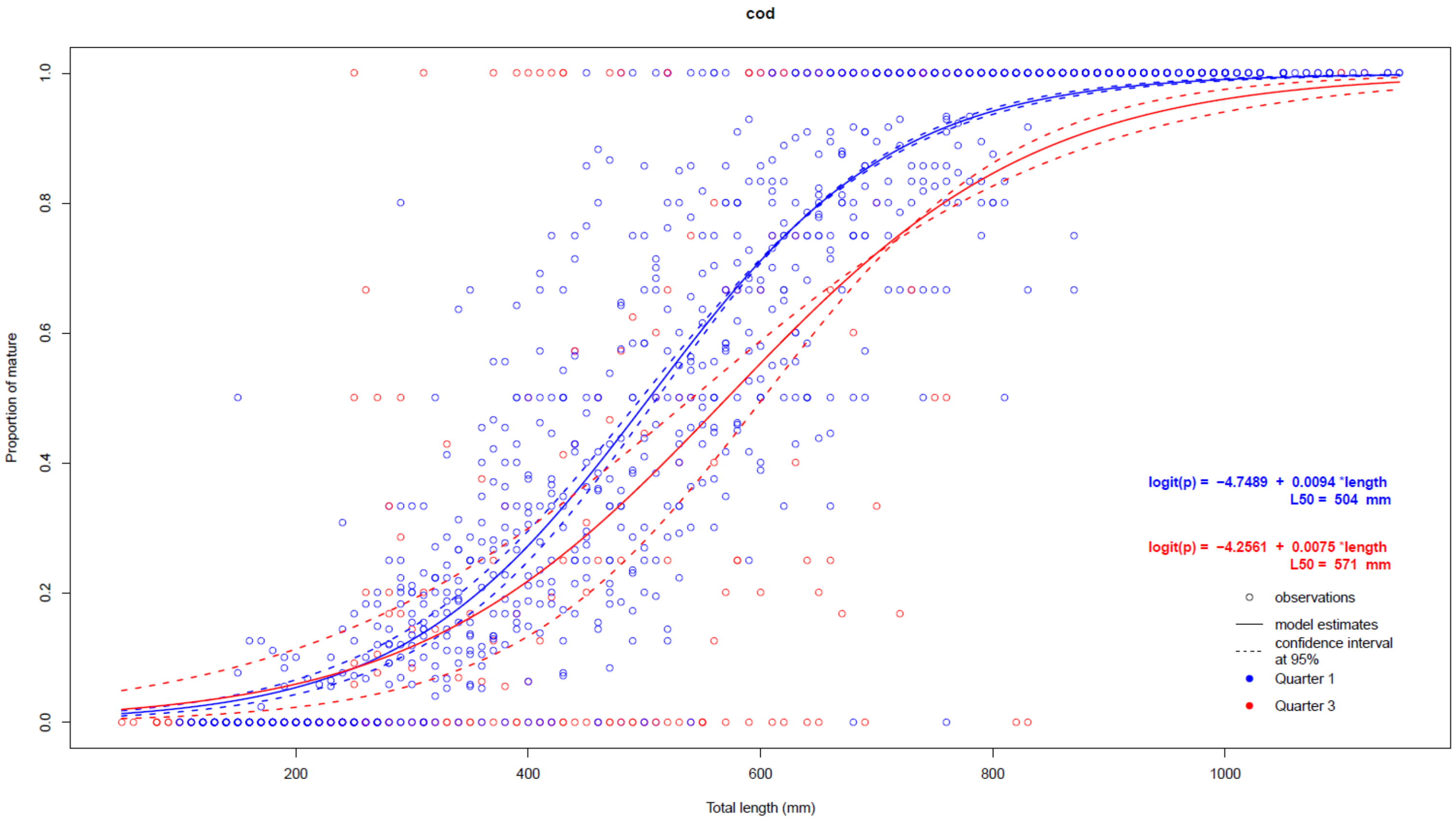
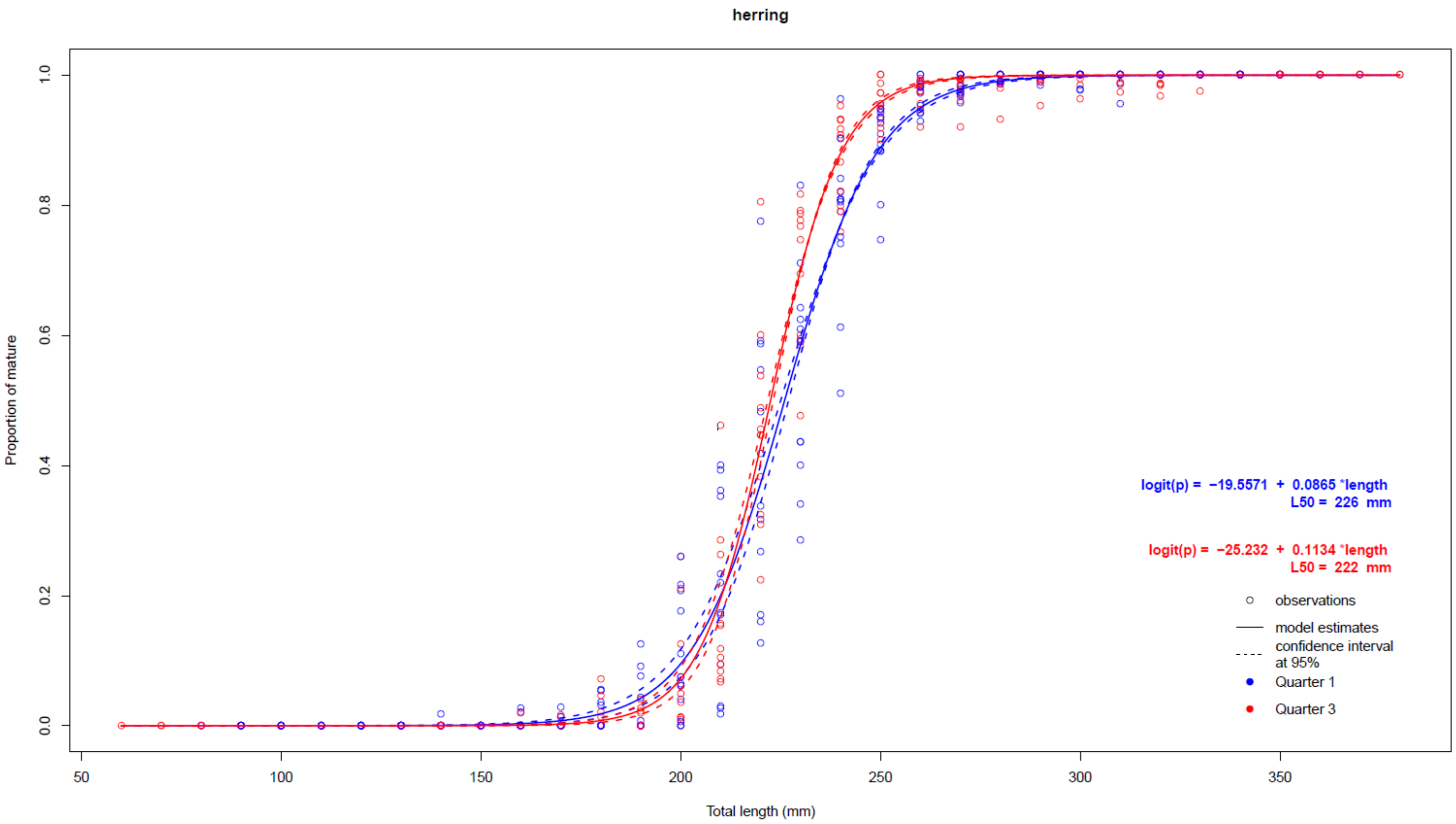
Appendix A: Distribution of the Norwegian Norway pout fishery

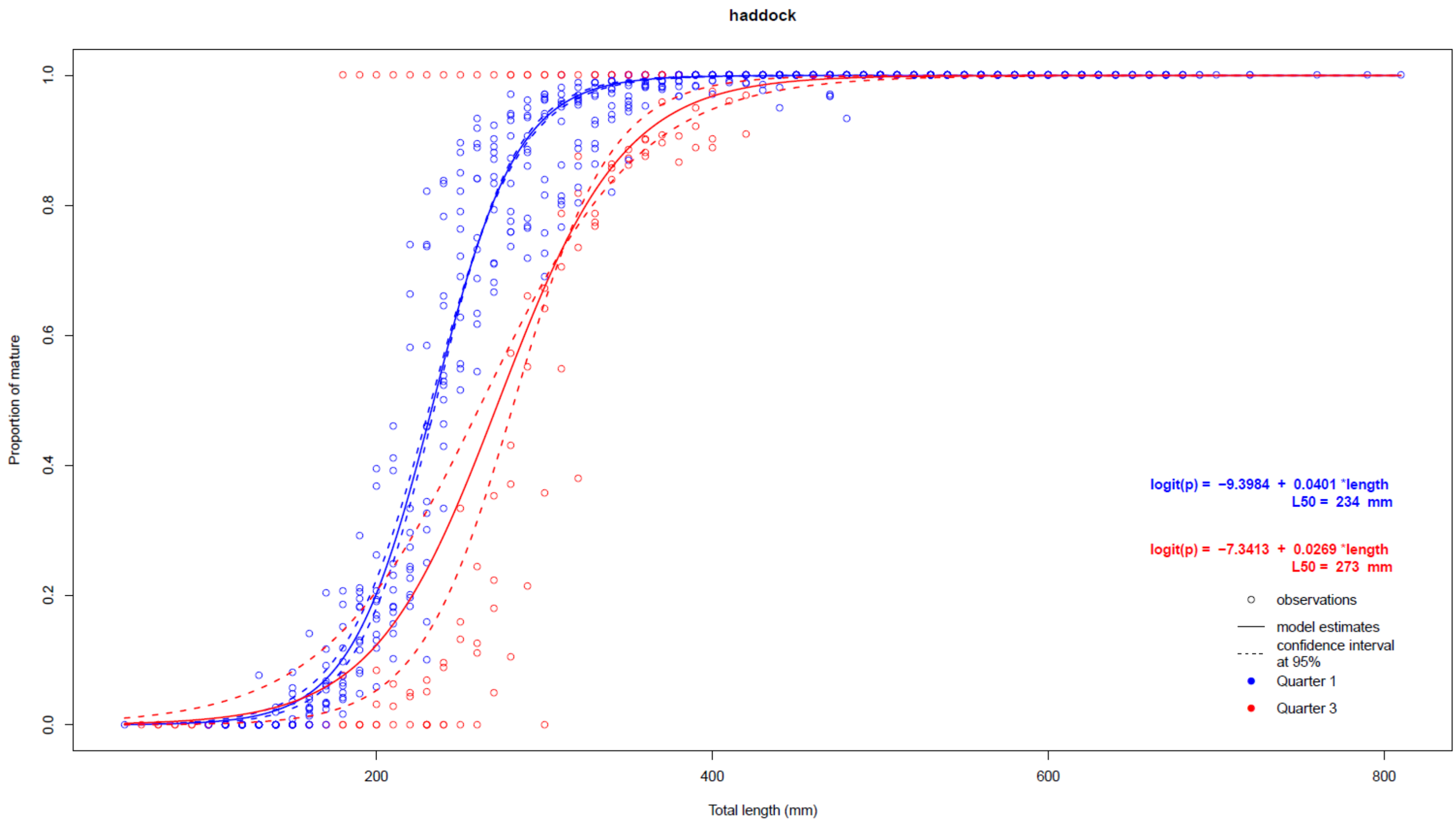


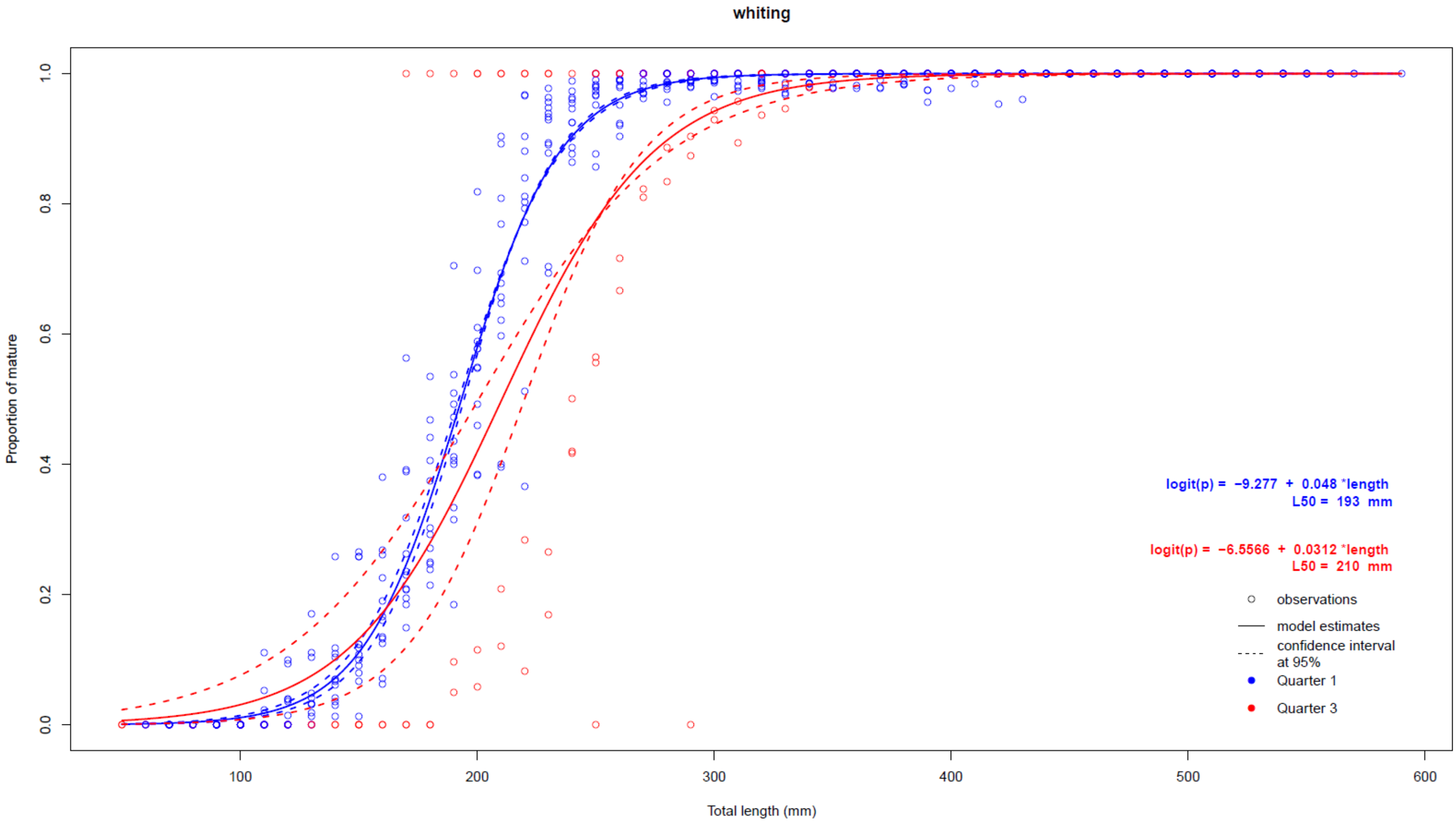
Geographical distribution of trawl hauls where Norway pout is the target species. Information is collected from the Norwegian logsheet database. Red dots represent vessels using selection grid, and black circles are vessels that are allowed to trawl without selection grid. (From ICES, 2016b)

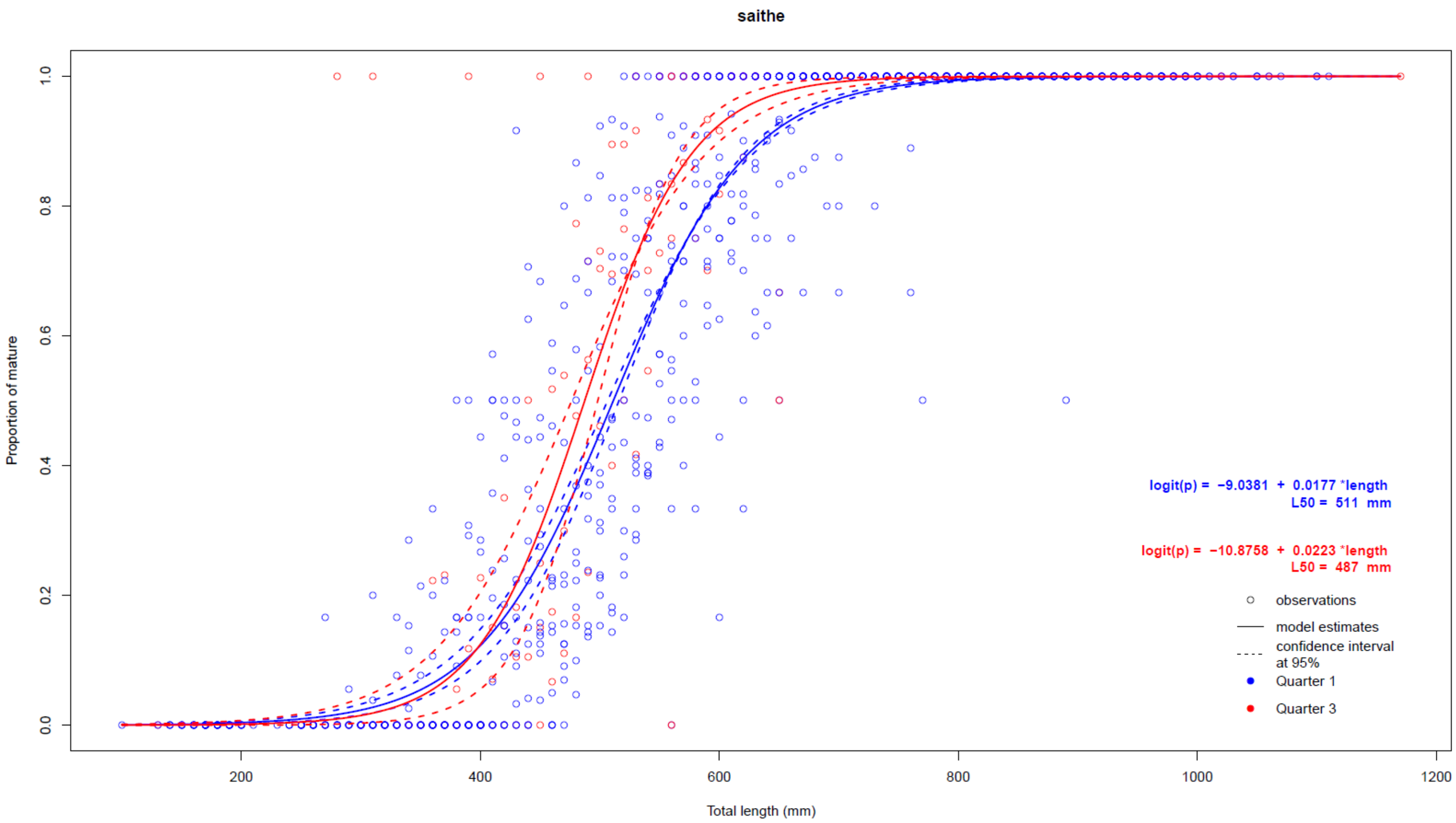
Appendix B: Estimation of the maturity ogive for each species of interest and each quarter of the year

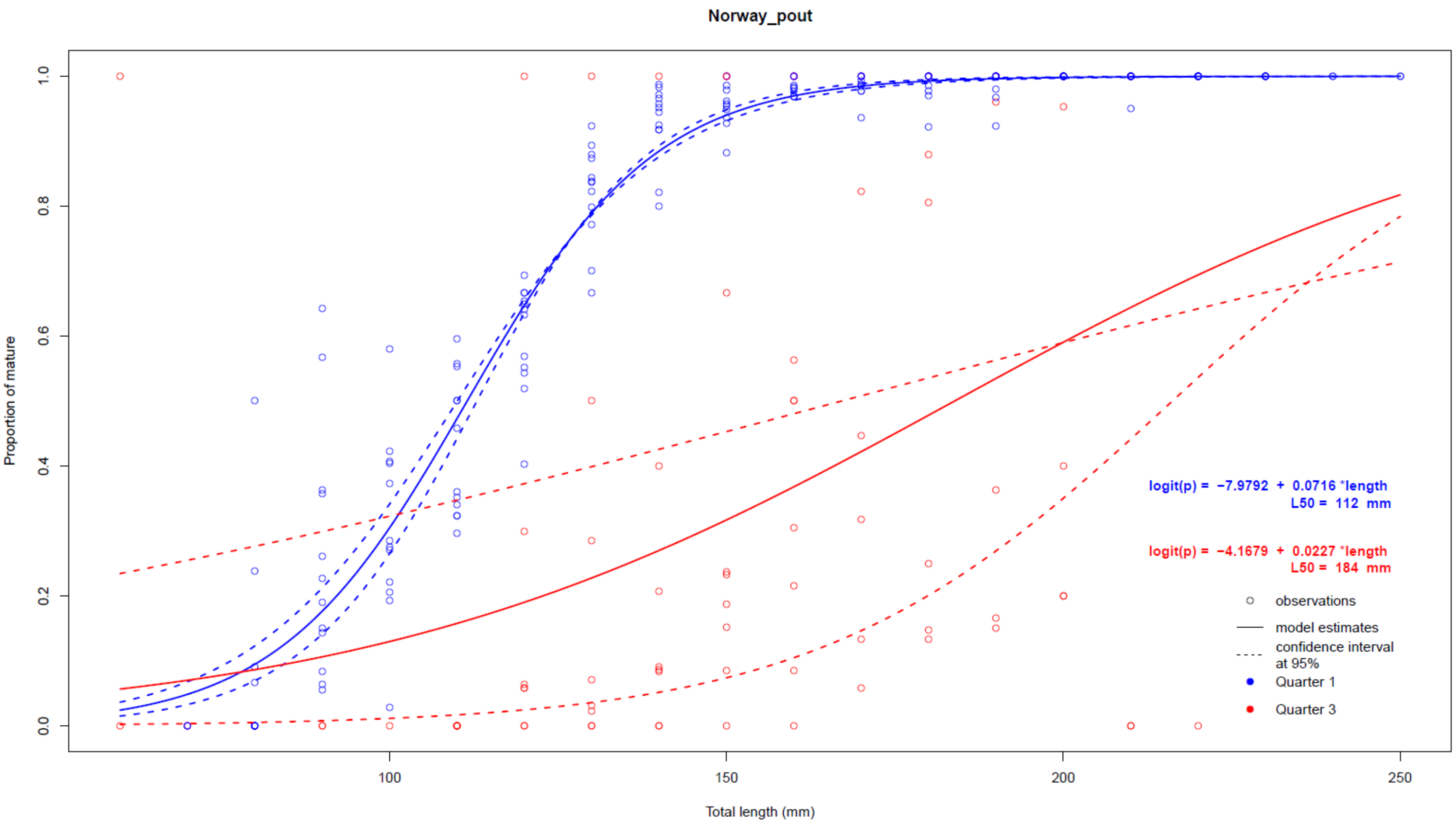





haddock
Proportion of mature
Total length (mm)
logit(p) = −9.3984 + 0.0401 *length
L50 = 234 mm
logit(p) = −7.3413 + 0.0269 *length
L50 = 273 mm
observations
model estimates
confidence interval at 95%
Quarter 1
Quarter 3


whiting
Proportion of mature
Total length (mm)
logit(p) = −9.277 + 0.048 *length
L50 = 193 mm
logit(p) = −6.5566 + 0.0312 *length
L50 = 210 mm
observations
model estimates
confidence interval at 95%
Quarter 1
Quarter 3


saithe
Proportion of mature
Total length (mm)
logit(p) = −9.0381 + 0.0177 *length
L50 = 511 mm
logit(p) = −10.8758 + 0.0223 *length
L50 = 487 mm
observations
model estimates
confidence interval at 95%
Quarter 1
Quarter 3


Norway_pout
Proportion of mature
Total length (mm)
logit(p) = −7.9792 + 0.0716 *length
L50 = 112 mm
logit(p) = −4.1679 + 0.0227 *length
L50 = 184 mm
observations
model estimates
confidence interval at 95%
Quarter 1
Quarter 3

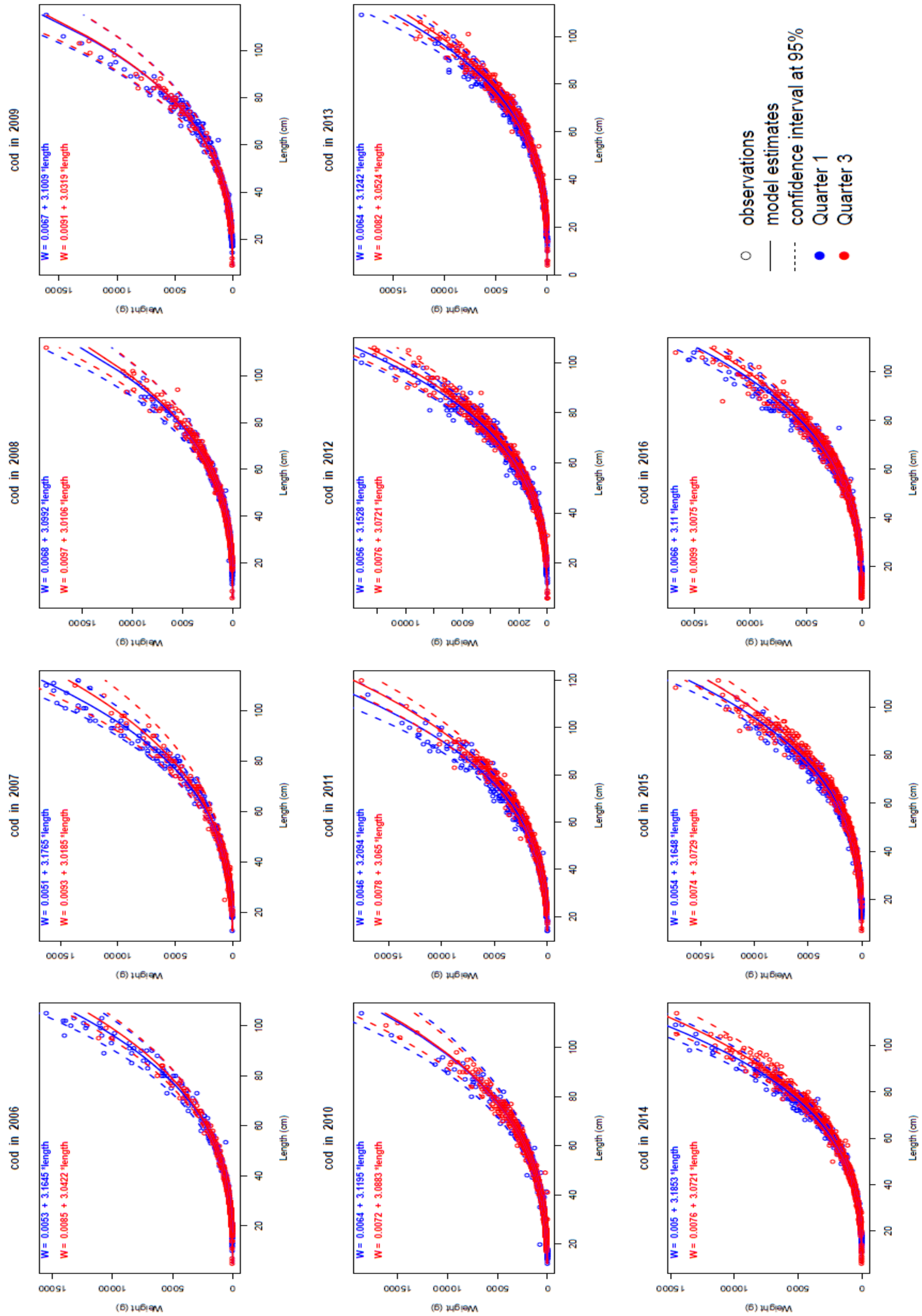
Appendix C1: Outputs of the estimation of the length-weight relationships from the SMALK data recorded during the NS-IBTS surveys by year and quarter of year

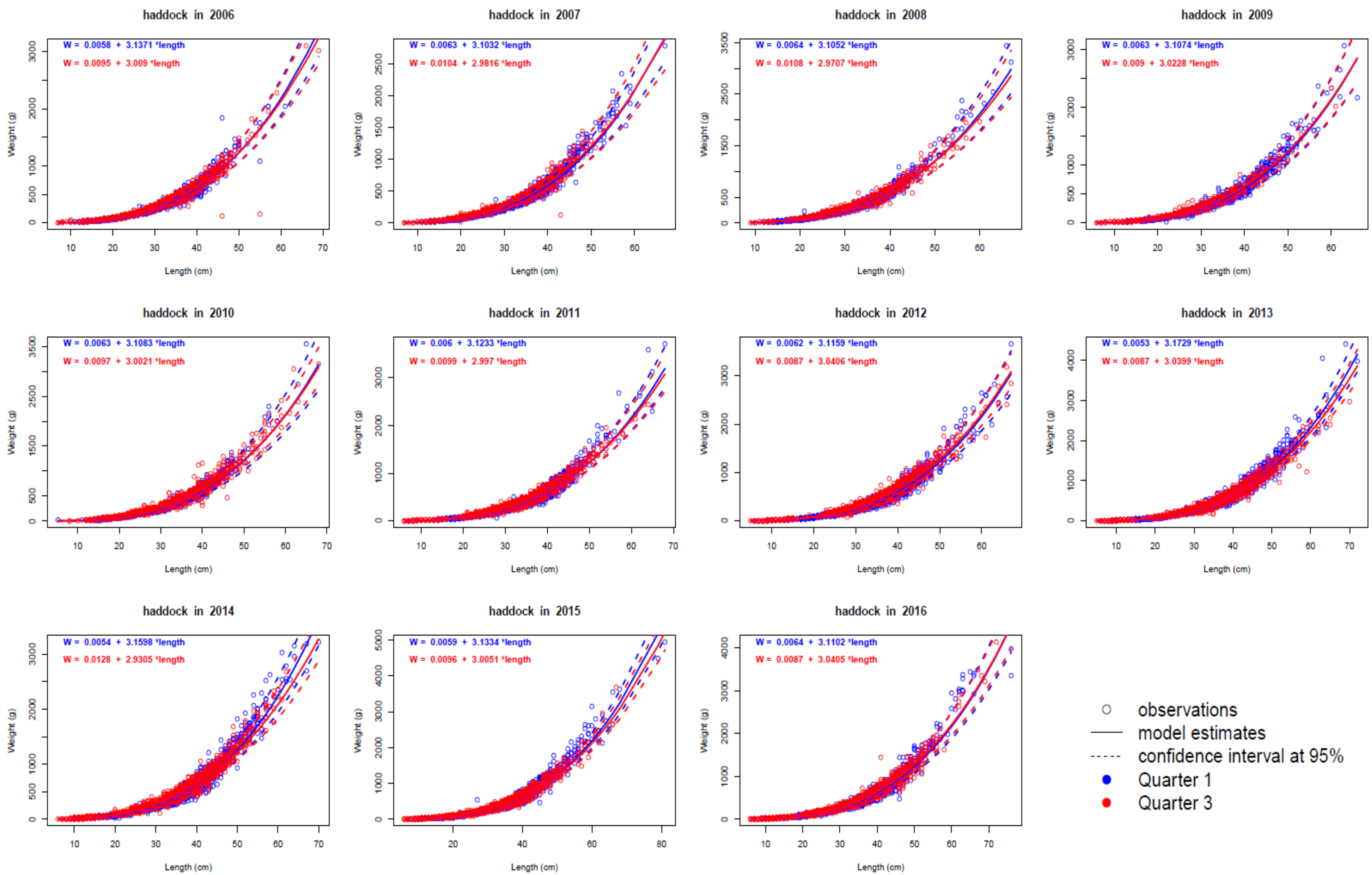
Species	Quarter	Year	a			b		
			Fitted value	Confidence interval 2,50%	Confidence interval 97,50%	Fitted value	Confidence interval 2,50%	Confidence interval 97,50%
COD	1	2006	0,0053	0,0048	0,0058	3,1645	3,1401	3,1890
		2007	0,0051	0,0047	0,0056	3,1765	3,1533	3,1998
		2008	0,0068	0,0061	0,0075	3,0992	3,0722	3,1261
		2009	0,0067	0,0060	0,0075	3,1009	3,0721	3,1297
		2010	0,0064	0,0057	0,0071	3,1195	3,0884	3,1506
		2011	0,0046	0,0043	0,0049	3,2094	3,1897	3,2291
		2012	0,0056	0,0052	0,0060	3,1528	3,1355	3,1701
		2013	0,0064	0,0060	0,0068	3,1242	3,1068	3,1416
		2014	0,0050	0,0047	0,0054	3,1853	3,1681	3,2025
		2015	0,0054	0,0052	0,0057	3,1648	3,1509	3,1787
		2016	0,0066	0,0062	0,0071	3,1100	3,0941	3,1260
	3	2006	0,0085	0,0080	0,0091	3,0422	3,0245	3,0599
		2007	0,0093	0,0084	0,0104	3,0185	2,9884	3,0486
		2008	0,0097	0,0090	0,0106	3,0106	2,9888	3,0325
		2009	0,0091	0,0082	0,0101	3,0319	3,0049	3,0589
		2010	0,0072	0,0066	0,0079	3,0883	3,0647	3,1118
		2011	0,0078	0,0073	0,0083	3,0650	3,0488	3,0811
		2012	0,0076	0,0070	0,0082	3,0721	3,0518	3,0923
		2013	0,0082	0,0078	0,0087	3,0524	3,0378	3,0671
		2014	0,0076	0,0071	0,0082	3,0721	3,0531	3,0912
		2015	0,0074	0,0070	0,0079	3,0729	3,0569	3,0890
		2016	0,0099	0,0094	0,0104	3,0075	2,9952	3,0198
HADDOCK	1	2006	0,0058	0,0054	0,0061	3,1371	3,1177	3,1565
		2007	0,0063	0,0059	0,0067	3,1032	3,0849	3,1215
		2008	0,0064	0,0059	0,0069	3,1052	3,0829	3,1276
		2009	0,0063	0,0059	0,0068	3,1074	3,0856	3,1292
		2010	0,0063	0,0058	0,0068	3,1083	3,0846	3,1321
		2011	0,0060	0,0057	0,0064	3,1233	3,1058	3,1408
		2012	0,0062	0,0058	0,0066	3,1159	3,0969	3,1349
		2013	0,0053	0,0050	0,0056	3,1729	3,1586	3,1872
		2014	0,0054	0,0050	0,0057	3,1598	3,1413	3,1784
		2015	0,0059	0,0056	0,0061	3,1334	3,1205	3,1463
		2016	0,0064	0,0060	0,0068	3,1102	3,0914	3,1291
	3	2006	0,0095	0,0089	0,0102	3,0090	2,9889	3,0291
		2007	0,0104	0,0096	0,0113	2,9816	2,9573	3,0058
		2008	0,0108	0,0100	0,0116	2,9707	2,9498	2,9915
		2009	0,0090	0,0084	0,0097	3,0228	3,0012	3,0444
		2010	0,0097	0,0092	0,0103	3,0021	2,9860	3,0182
		2011	0,0099	0,0094	0,0105	2,9970	2,9806	3,0134
		2012	0,0087	0,0082	0,0091	3,0406	3,0259	3,0553
		2013	0,0087	0,0083	0,0091	3,0399	3,0270	3,0529
		2014	0,0128	0,0121	0,0136	2,9305	2,9138	2,9473
		2015	0,0096	0,0092	0,0100	3,0051	2,9922	3,0179
		2016	0,0087	0,0082	0,0091	3,0405	3,0244	3,0567

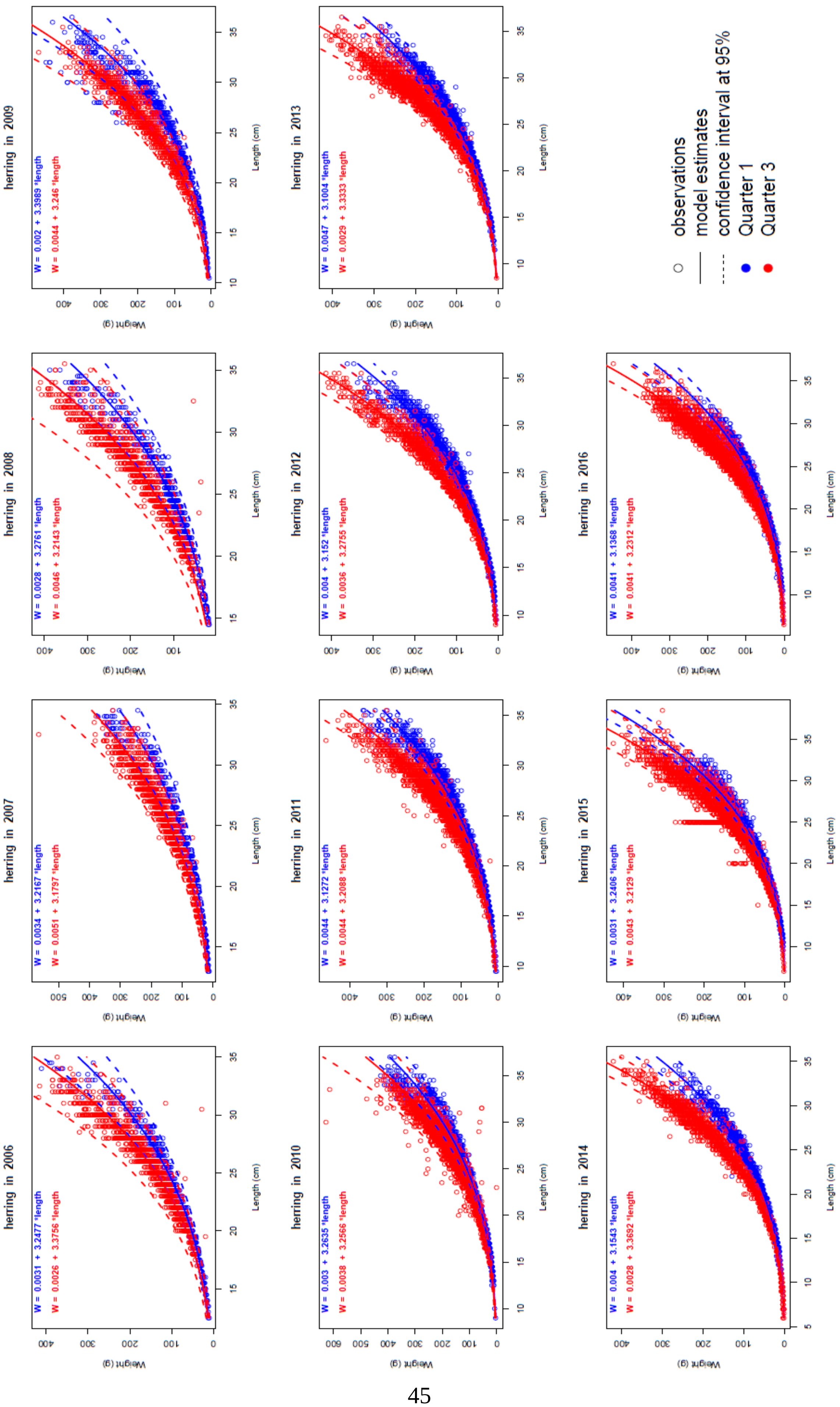
Species	Quarter	Year	a			b		
			Fitted value	Confidence interval 2,50%	97,50%	Fitted value	Confidence interval 2,50%	97,50%
HERRING	1	2006	0,0031	0,0028	0,0035	3,2477	3,2125	3,2828
		2007	0,0034	0,0030	0,0038	3,2167	3,1797	3,2538
		2008	0,0028	0,0025	0,0032	3,2761	3,2364	3,3158
		2009	0,0020	0,0017	0,0023	3,3989	3,3493	3,4484
		2010	0,0030	0,0028	0,0033	3,2635	3,2386	3,2885
		2011	0,0044	0,0042	0,0047	3,1272	3,1083	3,1461
		2012	0,0040	0,0038	0,0042	3,1520	3,1339	3,1700
		2013	0,0047	0,0044	0,0050	3,1004	3,0804	3,1204
		2014	0,0040	0,0038	0,0043	3,1543	3,1324	3,1763
		2015	0,0031	0,0029	0,0033	3,2406	3,2206	3,2605
		2016	0,0041	0,0038	0,0044	3,1368	3,1131	3,1605
	3	2006	0,0026	0,0022	0,0031	3,3756	3,3244	3,4267
		2007	0,0051	0,0045	0,0058	3,1797	3,1404	3,2190
		2008	0,0046	0,0038	0,0056	3,2143	3,1558	3,2727
		2009	0,0044	0,0038	0,0052	3,2460	3,1998	3,2923
		2010	0,0038	0,0033	0,0043	3,2566	3,2156	3,2976
		2011	0,0044	0,0040	0,0049	3,2088	3,1778	3,2397
		2012	0,0036	0,0032	0,0039	3,2755	3,2464	3,3045
		2013	0,0029	0,0026	0,0033	3,3333	3,2994	3,3671
		2014	0,0028	0,0026	0,0030	3,3692	3,3484	3,3899
		2015	0,0043	0,0039	0,0048	3,2129	3,1816	3,2441
		2016	0,0041	0,0038	0,0044	3,2312	3,2096	3,2527
NORWAY POUT	1	2006	0,0047	0,0040	0,0056	3,1528	3,0902	3,2154
		2007	0,0097	0,0078	0,0121	2,8859	2,8022	2,9696
		2008	0,0048	0,0038	0,0060	3,1326	3,0495	3,2156
		2009	0,0058	0,0049	0,0069	3,0743	3,0088	3,1397
		2010	0,0043	0,0037	0,0050	3,1860	3,1286	3,2433
		2011	0,0059	0,0051	0,0068	3,0640	3,0097	3,1184
		2012	0,0057	0,0049	0,0066	3,0783	3,0256	3,1310
		2013	0,0062	0,0055	0,0070	3,0479	3,0004	3,0954
		2014	0,0083	0,0071	0,0098	2,9505	2,8908	3,0101
		2015	0,0059	0,0052	0,0067	3,0583	3,0098	3,1068
		2016	0,0076	0,0064	0,0090	2,9733	2,9079	3,0386
	3	2006	0,0162	0,0112	0,0236	2,7520	2,6164	2,8876
		2007	0,0081	0,0062	0,0105	3,0092	2,9127	3,1058
		2008	0,0091	0,0070	0,0117	2,9682	2,8756	3,0608
		2009	0,0066	0,0052	0,0083	3,0886	3,0032	3,1740
		2010	0,0098	0,0082	0,0118	2,9200	2,8531	2,9869
		2011	0,0130	0,0107	0,0158	2,8248	2,7533	2,8963
		2012	0,0060	0,0051	0,0070	3,1107	3,0532	3,1682
		2013	0,0072	0,0063	0,0082	3,0277	2,9771	3,0783
		2014	0,0112	0,0094	0,0132	2,8829	2,8206	2,9452
		2015	0,0119	0,0100	0,0143	2,8357	2,7679	2,9035
		2016	0,0122	0,0102	0,0146	2,8330	2,7649	2,9010

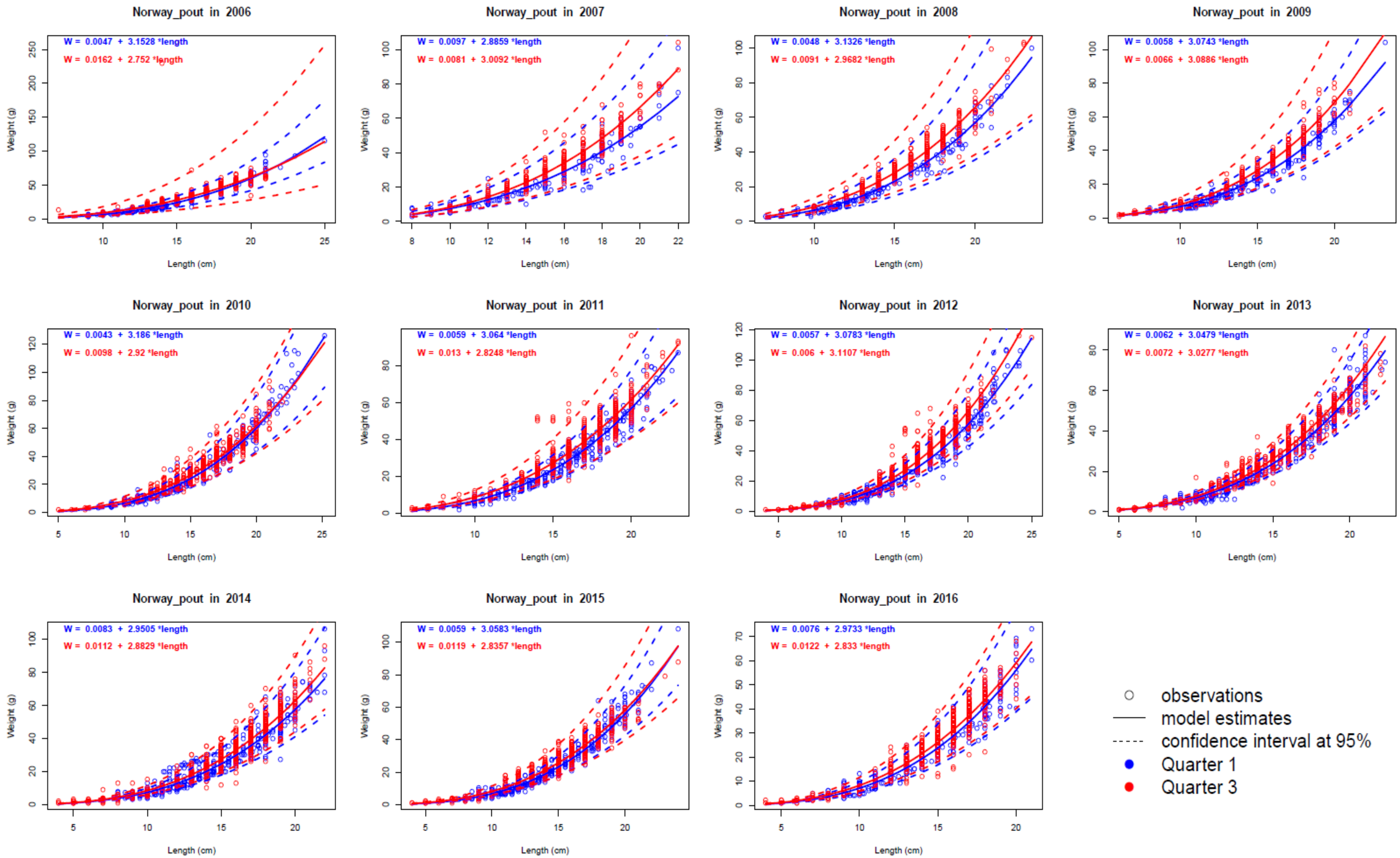
Species	Quarter	Year	a			b		
			Fitted value	Confidence interval 2,50%	Confidence interval 97,50%	Fitted value	Confidence interval 2,50%	Confidence interval 97,50%
SAITHE	1	2006	0,0060	0,0045	0,0081	3,0948	3,0195	3,1700
		2007	0,0026	0,0021	0,0033	3,2977	3,2402	3,3552
		2008	0,0036	0,0030	0,0042	3,2336	3,1906	3,2767
		2009	0,0041	0,0035	0,0049	3,2011	3,1604	3,2417
		2010	0,0052	0,0045	0,0060	3,1649	3,1302	3,1995
		2011	0,0043	0,0040	0,0046	3,1986	3,1803	3,2169
		2012	0,0037	0,0034	0,0041	3,2147	3,1921	3,2372
		2013	0,0048	0,0044	0,0053	3,1585	3,1343	3,1826
		2014	0,0036	0,0032	0,0041	3,2204	3,1915	3,2493
		2015	0,0040	0,0036	0,0045	3,2124	3,1846	3,2402
		2016	0,0033	0,0028	0,0039	3,2405	3,1999	3,2811
	3	2006	0,0072	0,0056	0,0093	3,0528	2,9878	3,1178
		2007	0,0106	0,0089	0,0126	2,9679	2,9224	3,0134
		2008	0,0086	0,0074	0,0099	3,0152	2,9792	3,0512
		2009	0,0133	0,0105	0,0167	2,9321	2,8746	2,9895
		2010	0,0065	0,0058	0,0072	3,1074	3,0810	3,1338
		2011	0,0117	0,0108	0,0127	2,9347	2,9131	2,9562
		2012	0,0085	0,0076	0,0095	3,0148	2,9869	3,0427
		2013	0,0067	0,0061	0,0074	3,0825	3,0566	3,1084
		2014	0,0126	0,0116	0,0137	2,9263	2,9054	2,9473
		2015	0,0094	0,0085	0,0105	2,9833	2,9563	3,0103
		2016	0,0086	0,0079	0,0095	3,0170	2,9942	3,0399
WHITING	1	2006	0,0045	0,0042	0,0048	3,1764	3,1533	3,1996
		2007	0,0046	0,0043	0,0049	3,1593	3,1380	3,1807
		2008	0,0052	0,0049	0,0055	3,1319	3,1126	3,1512
		2009	0,0056	0,0052	0,0060	3,1145	3,0925	3,1366
		2010	0,0036	0,0034	0,0038	3,2510	3,2313	3,2708
		2011	0,0039	0,0037	0,0041	3,2220	3,2066	3,2374
		2012	0,0044	0,0042	0,0046	3,1799	3,1653	3,1944
		2013	0,0043	0,0041	0,0046	3,1970	3,1819	3,2121
		2014	0,0046	0,0044	0,0049	3,1729	3,1576	3,1881
		2015	0,0039	0,0037	0,0041	3,2297	3,2147	3,2448
		2016	0,0048	0,0045	0,0050	3,1638	3,1467	3,1809
	3	2006	0,0097	0,0089	0,0106	2,9510	2,9255	2,9765
		2007	0,0129	0,0115	0,0145	2,8648	2,8296	2,9000
		2008	0,0096	0,0086	0,0107	2,9605	2,9293	2,9917
		2009	0,0077	0,0070	0,0085	3,0414	3,0122	3,0707
		2010	0,0086	0,0080	0,0092	2,9891	2,9693	3,0088
		2011	0,0112	0,0104	0,0120	2,9002	2,8797	2,9207
		2012	0,0091	0,0086	0,0096	2,9687	2,9530	2,9843
		2013	0,0094	0,0090	0,0099	2,9559	2,9411	2,9707
		2014	0,0113	0,0107	0,0119	2,9184	2,9024	2,9344
		2015	0,0098	0,0094	0,0103	2,9458	2,9313	2,9604
		2016	0,0119	0,0114	0,0125	2,8929	2,8791	2,9068

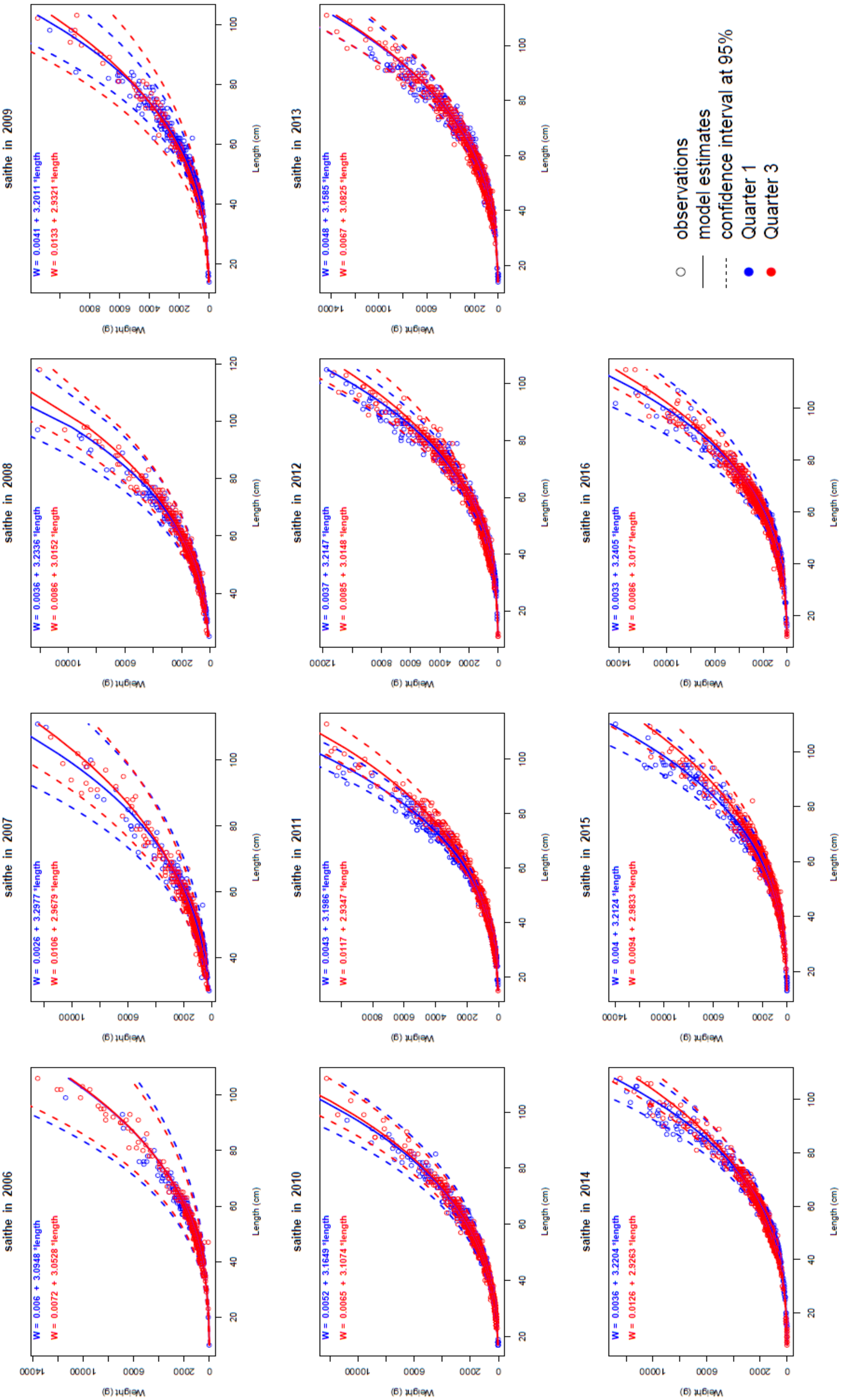
Appendix C2: Estimated length-weight relationship per species, year and quarter of year



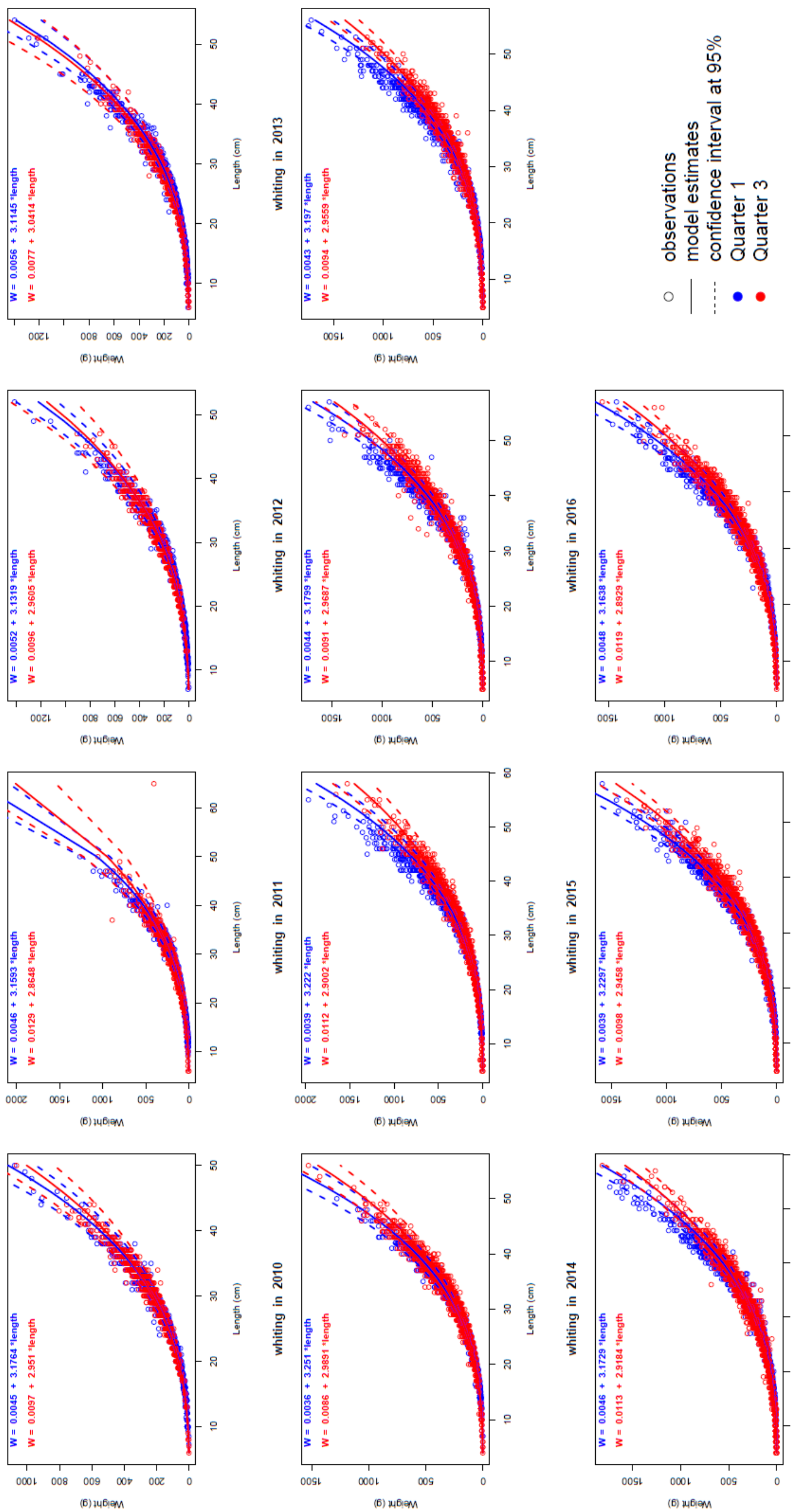

haddock in 2006
W = 0.0058 + 3.1371 *length
W = 0.0095 + 3.009 *length
haddock in 2007
W = 0.0063 + 3.1032 *length
W = 0.0104 + 2.9816 *length
haddock in 2008
W = 0.0064 + 3.1052 *length
W = 0.0108 + 2.9707 *length
haddock in 2009
W = 0.0063 + 3.1074 *length
W = 0.009 + 3.0228 *length
haddock in 2010
W = 0.0063 + 3.1083 *length
W = 0.0097 + 3.0021 *length
haddock in 2011
W = 0.006 + 3.1233 *length
W = 0.0099 + 2.997 *length
haddock in 2012
W = 0.0062 + 3.1159 *length
W = 0.0087 + 3.0406 *length
haddock in 2013
W = 0.0053 + 3.1729 *length
W = 0.0087 + 3.0399 *length
haddock in 2014
W = 0.0054 + 3.1598 *length
W = 0.0128 + 2.9305 *length
haddock in 2015
W = 0.0059 + 3.1334 *length
W = 0.0096 + 3.0051 *length
haddock in 2016
W = 0.0064 + 3.1102 *length
W = 0.0087 + 3.0405 *length
Weight (g)
Length (cm)
observations
model estimates
confidence interval at 95%
Quarter 1
Quarter 3


herring in 2006
W = 0.0031 + 3.2477 *length
W = 0.0026 + 3.3756 *length
herring in 2007
W = 0.0034 + 3.2167 *length
W = 0.0051 + 3.1797 *length
herring in 2008
W = 0.0028 + 3.2761 *length
W = 0.0046 + 3.2143 *length
herring in 2009
W = 0.002 + 3.3989 *length
W = 0.0044 + 3.246 *length
herring in 2010
W = 0.003 + 3.2635 *length
W = 0.0038 + 3.2566 *length
herring in 2011
W = 0.0044 + 3.1272 *length
W = 0.0044 + 3.2088 *length
herring in 2012
W = 0.004 + 3.152 *length
W = 0.0036 + 3.2755 *length
herring in 2013
W = 0.0047 + 3.1004 *length
W = 0.0029 + 3.3333 *length
herring in 2014
W = 0.004 + 3.1543 *length
W = 0.0028 + 3.3692 *length
herring in 2015
W = 0.0031 + 3.2406 *length
W = 0.0043 + 3.2129 *length
herring in 2016
W = 0.0041 + 3.1368 *length
W = 0.0041 + 3.2312 *length
Weight (g)
Length (cm)
observations
model estimates
confidence interval at 95%
Quarter 1
Quarter 3

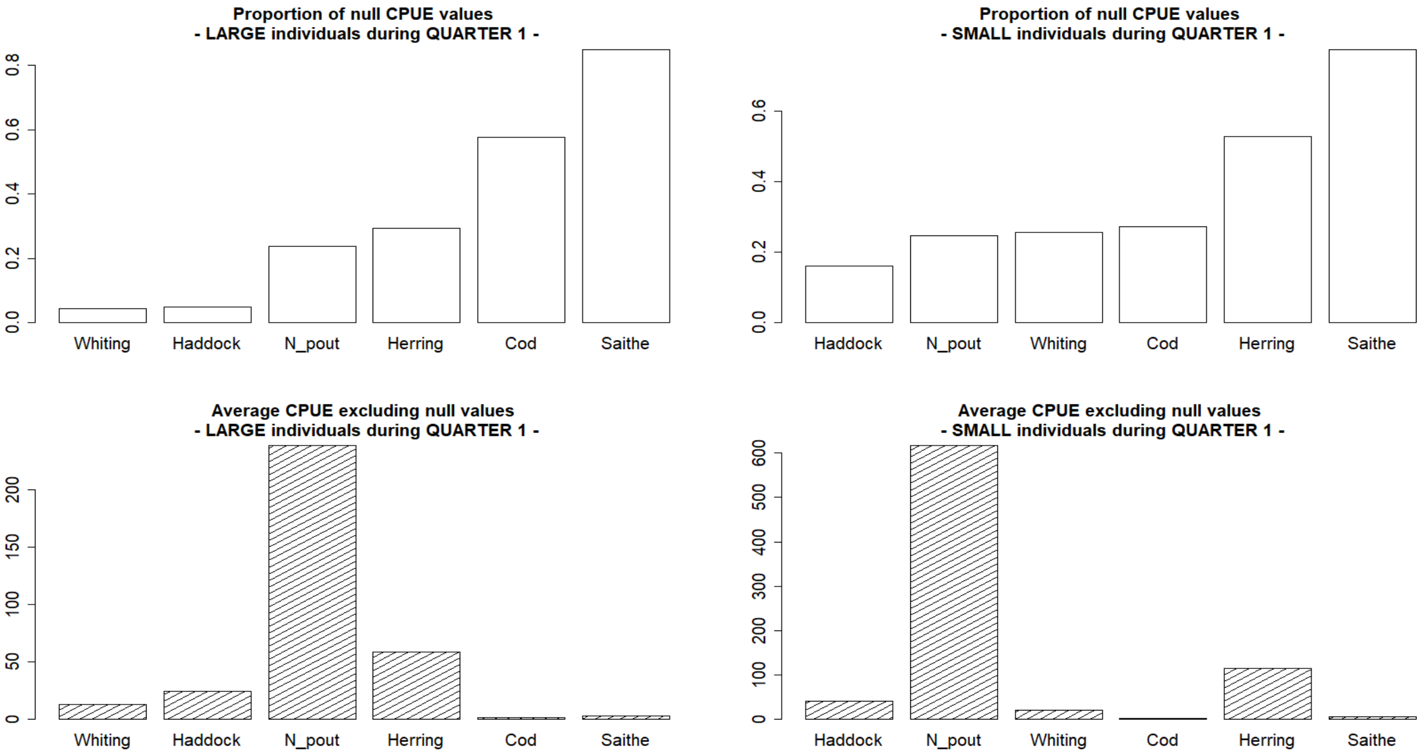

Norway_pout in 2006
W = 0.0047 + 3.1528 *length
W = 0.0162 + 2.752 *length
Norway_pout in 2007
W = 0.0097 + 2.8859 *length
W = 0.0081 + 3.0092 *length
Norway_pout in 2008
W = 0.0048 + 3.1326 *length
W = 0.0091 + 2.9682 *length
Norway_pout in 2009
W = 0.0058 + 3.0743 *length
W = 0.0066 + 3.0886 *length
Norway_pout in 2010
W = 0.0043 + 3.186 *length
W = 0.0098 + 2.92 *length
Norway_pout in 2011
W = 0.0059 + 3.064 *length
W = 0.013 + 2.8248 *length
Norway_pout in 2012
W = 0.0057 + 3.0783 *length
W = 0.006 + 3.1107 *length
Norway_pout in 2013
W = 0.0062 + 3.0479 *length
W = 0.0072 + 3.0277 *length
Norway_pout in 2014
W = 0.0083 + 2.9505 *length
W = 0.0112 + 2.8829 *length
Norway_pout in 2015
W = 0.0059 + 3.0583 *length
W = 0.0119 + 2.8357 *length
Norway_pout in 2016
W = 0.0076 + 2.9733 *length
W = 0.0122 + 2.833 *length
Weight (g)
Length (cm)
observations
model estimates
confidence interval at 95%
Quarter 1
Quarter 3



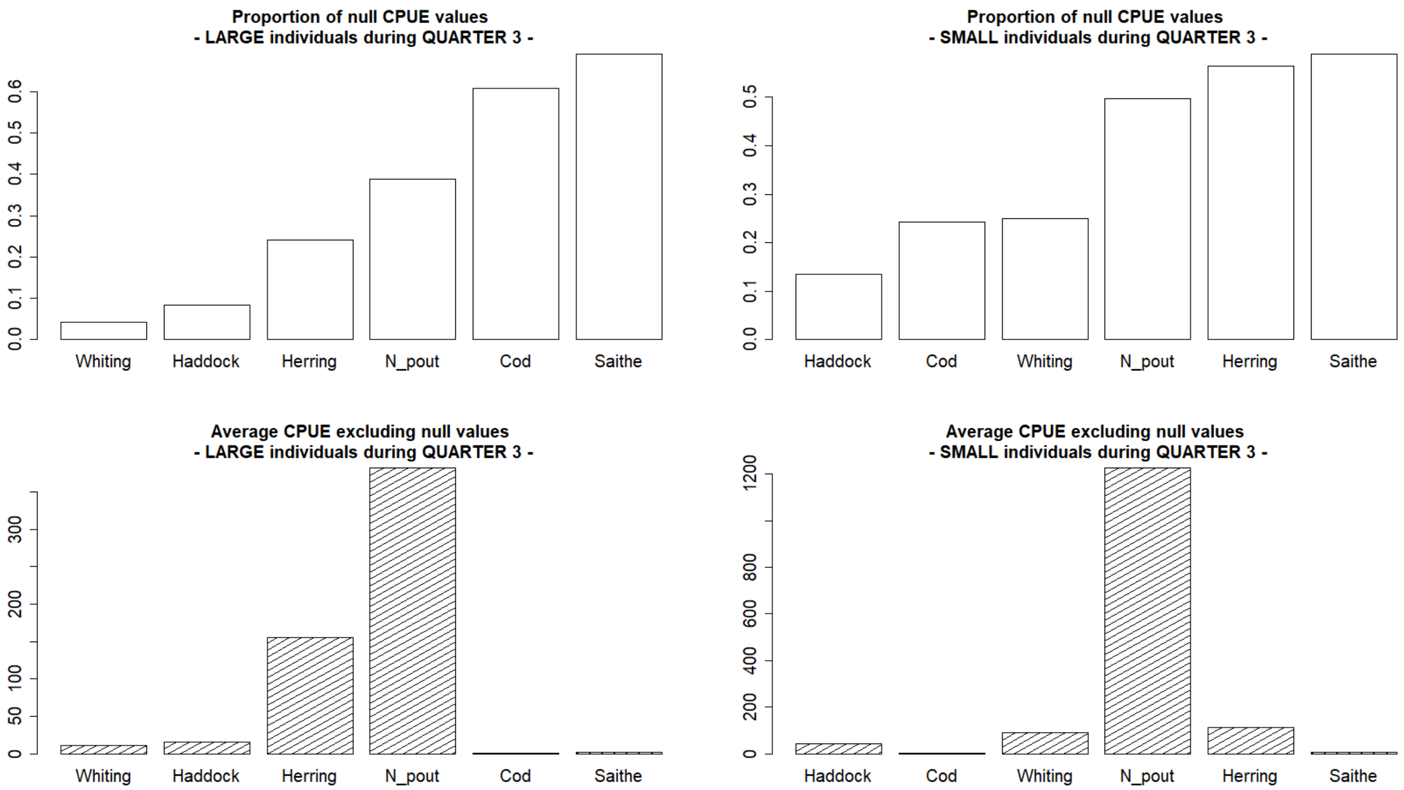
saithe in 2006
W = 0.006 + 3.0948 *length
W = 0.0072 + 3.0528 *length
saithe in 2007
W = 0.0026 + 3.2977 *length
W = 0.0106 + 2.9679 *length
saithe in 2008
W = 0.0036 + 3.2336 *length
W = 0.0086 + 3.0152 *length
saithe in 2009
W = 0.0041 + 3.2011 *length
W = 0.0133 + 2.9321 *length
saithe in 2010
W = 0.0052 + 3.1649 *length
W = 0.0065 + 3.1074 *length
saithe in 2011
W = 0.0043 + 3.1986 *length
W = 0.0117 + 2.9347 *length
saithe in 2012
W = 0.0037 + 3.2147 *length
W = 0.0085 + 3.0148 *length
saithe in 2013
W = 0.0048 + 3.1585 *length
W = 0.0067 + 3.0825 *length
saithe in 2014
W = 0.0036 + 3.2204 *length
W = 0.0126 + 2.9263 *length
saithe in 2015
W = 0.004 + 3.2124 *length
W = 0.0094 + 2.9833 *length
saithe in 2016
W = 0.0033 + 3.2405 *length
W = 0.0086 + 3.017 *length
Weight (g)
Length (cm)
observations
model estimates
confidence interval at 95%
Quarter 1
Quarter 3


whiting in 2009
W = 0.0056 + 3.1145 *length
W = 0.0077 + 3.0414 *length
whiting in 2008
W = 0.0052 + 3.1319 *length
W = 0.0096 + 2.9605 *length
whiting in 2007
W = 0.0046 + 3.1593 *length
W = 0.0129 + 2.8648 *length
whiting in 2006
W = 0.0045 + 3.1764 *length
W = 0.0097 + 2.951 *length
whiting in 2013
W = 0.0043 + 3.197 *length
W = 0.0094 + 2.9559 *length
whiting in 2012
W = 0.0044 + 3.1799 *length
W = 0.0091 + 2.9687 *length
whiting in 2011
W = 0.0039 + 3.222 *length
W = 0.0112 + 2.9902 *length
whiting in 2010
W = 0.0036 + 3.251 *length
W = 0.0086 + 2.9891 *length
whiting in 2016
W = 0.0048 + 3.1638 *length
W = 0.0119 + 2.8929 *length
whiting in 2015
W = 0.0039 + 3.2297 *length
W = 0.0098 + 2.9458 *length
whiting in 2014
W = 0.0046 + 3.1729 *length
W = 0.0113 + 2.9184 *length
Length (cm)
Weight (g)
observations
model estimates
confidence interval at 95%
Quarter 1
Quarter 3

Appendix D: Frequency of null observations and average fish density per species, length group and quarter

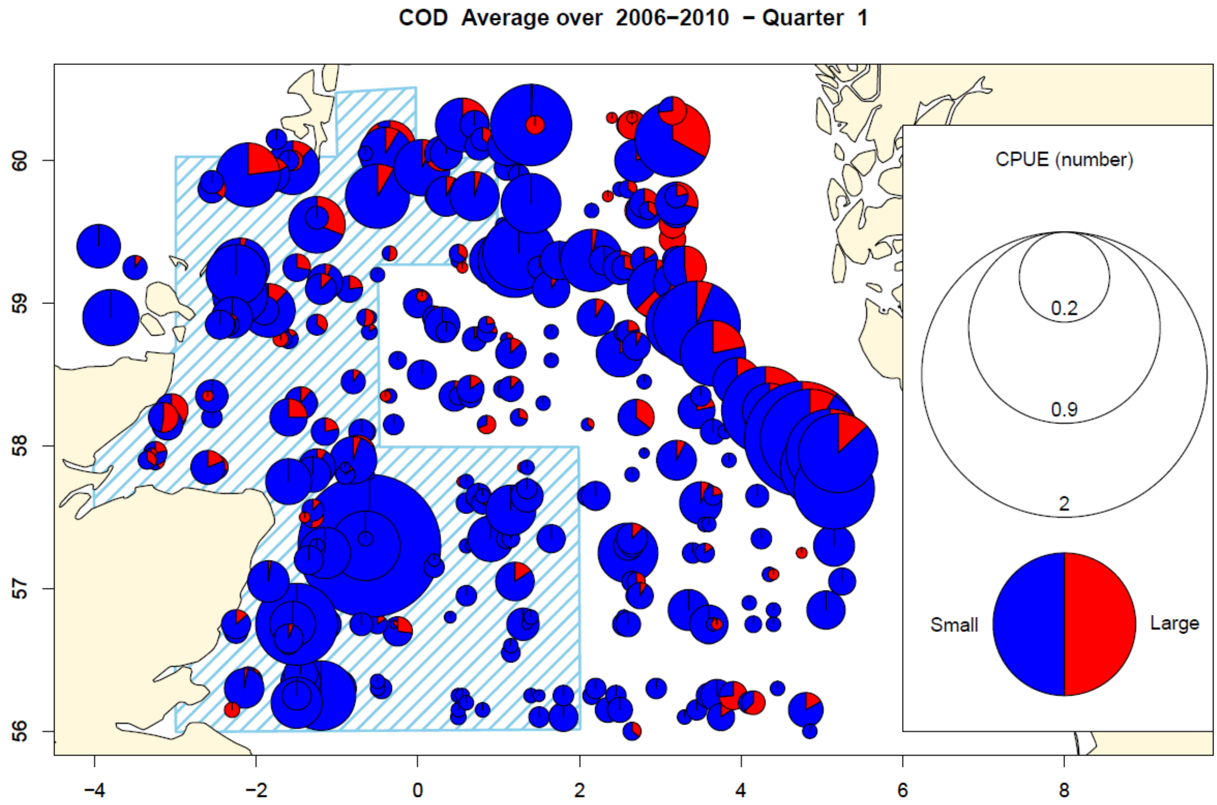


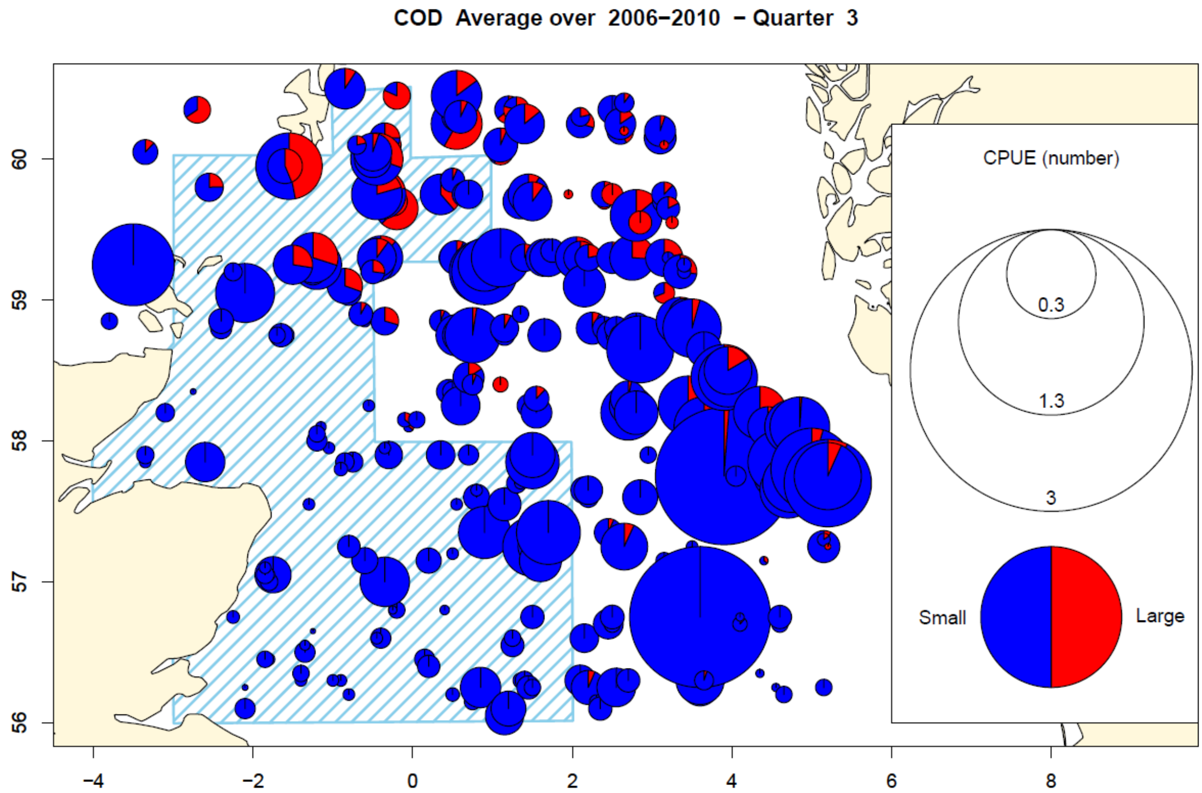
Summary of the distribution of the NS-IBTS data concerning fish density according to the Species and the length group in first quarter

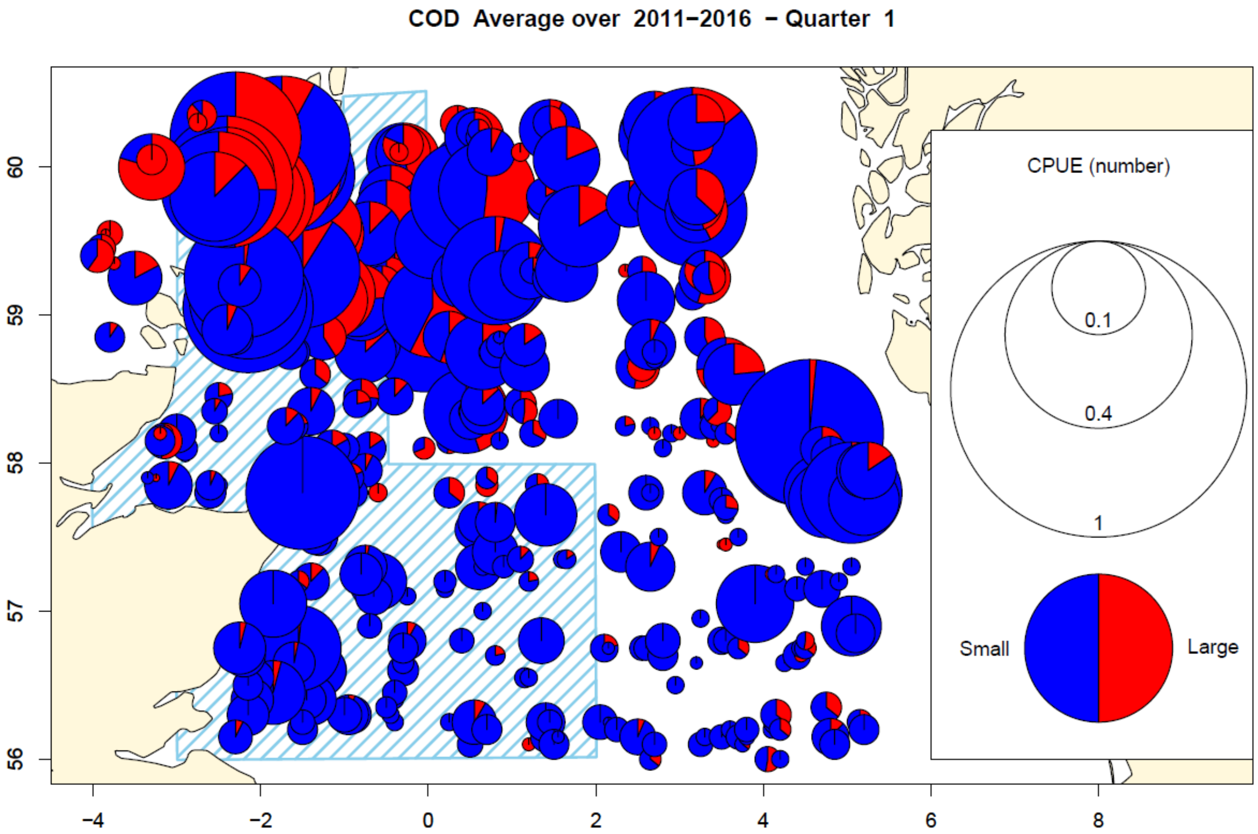


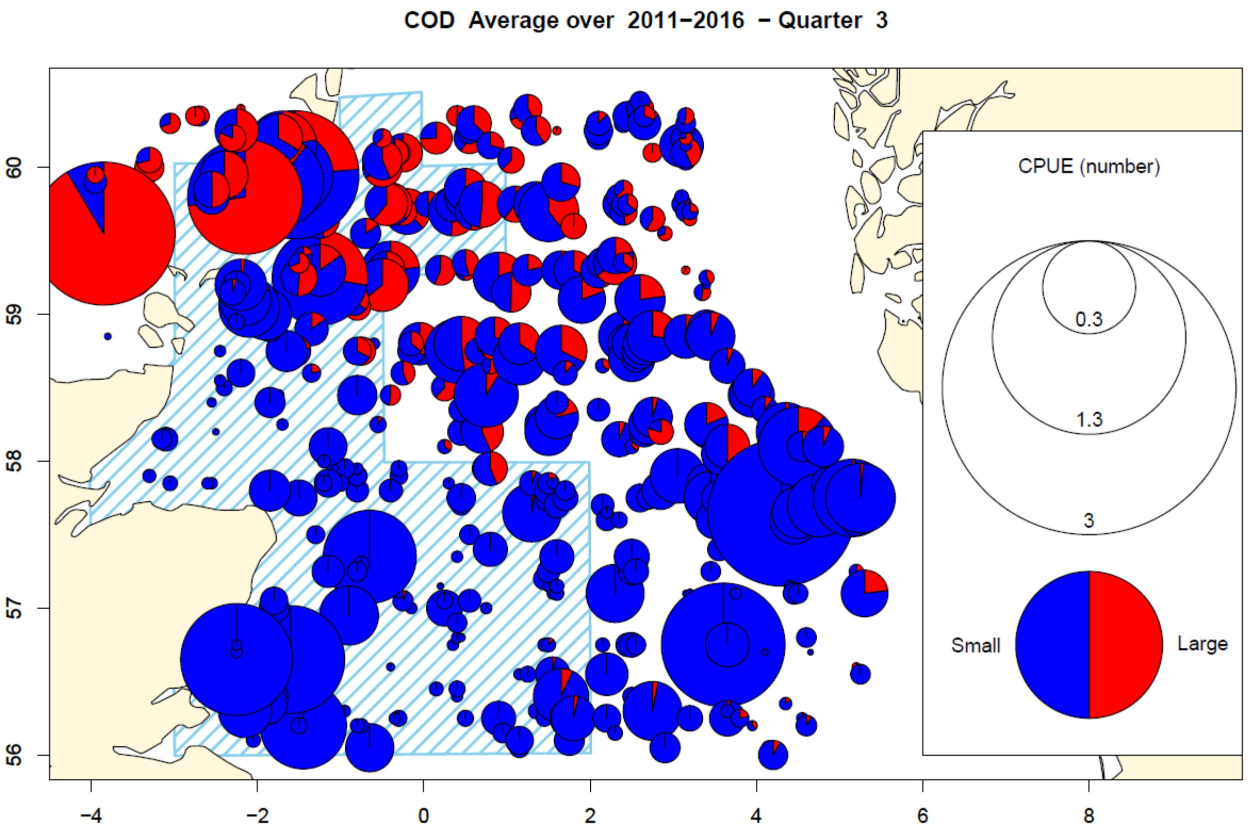
Summary of the distribution of the NS-IBTS data concerning fish density according to the Species and the length group in third quarter

Appendix E: Distribution of the species and life stage (juvenile, adult) of interest in the North Sea according to Time Period and Season of Year from the IBTS Survey Data

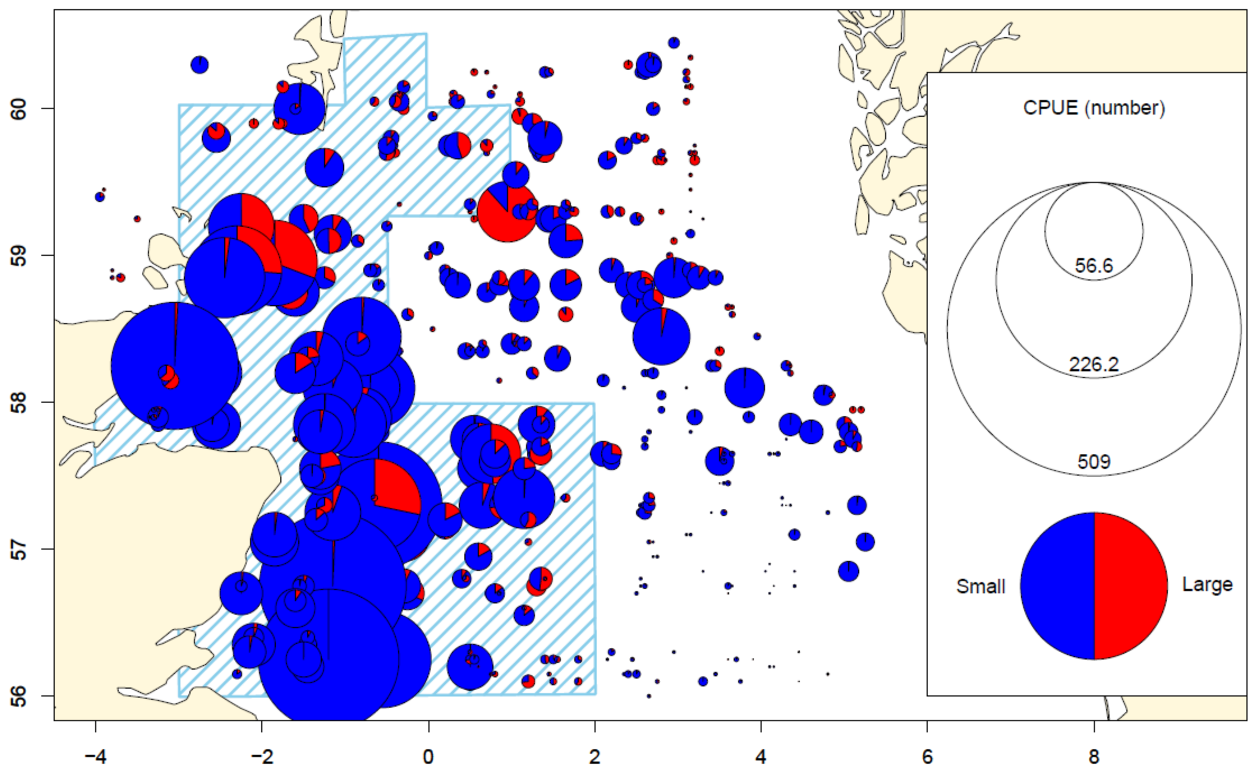




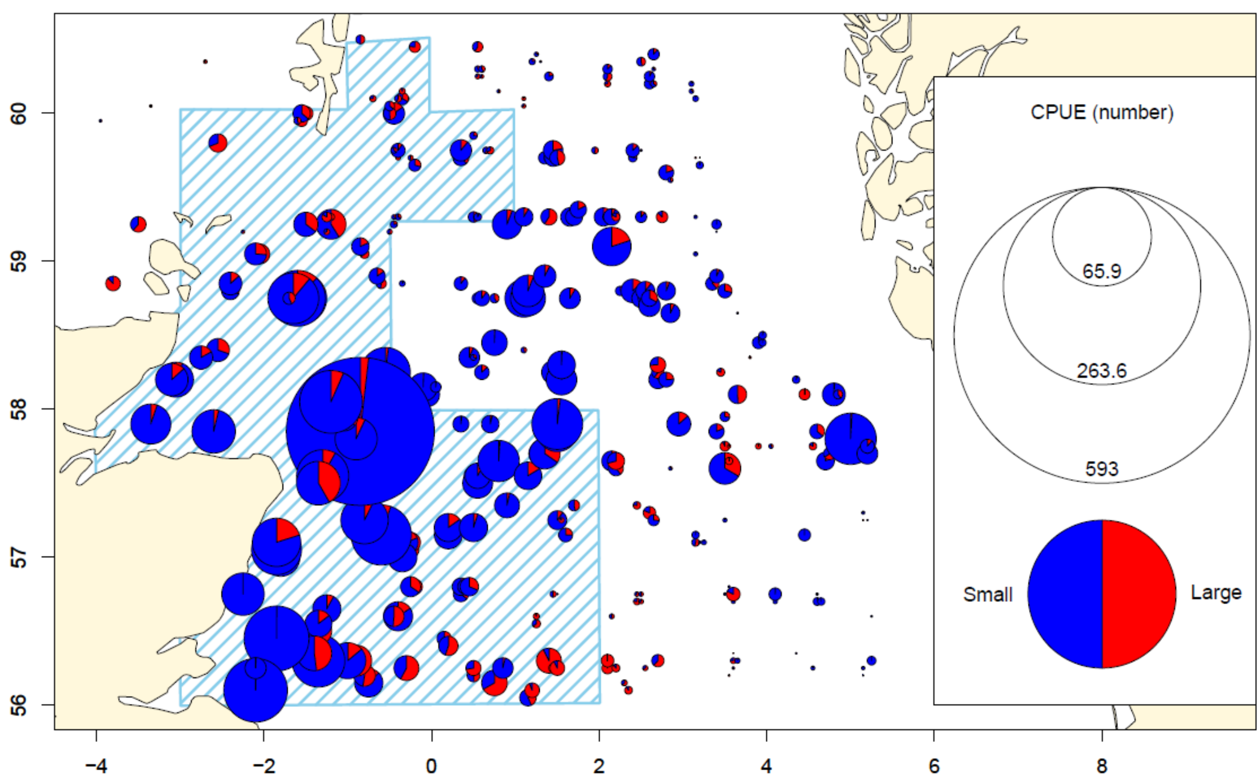

COD Average over 2011−2016 − Quarter 1
CPUE (number)
0.1
0.4
1
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

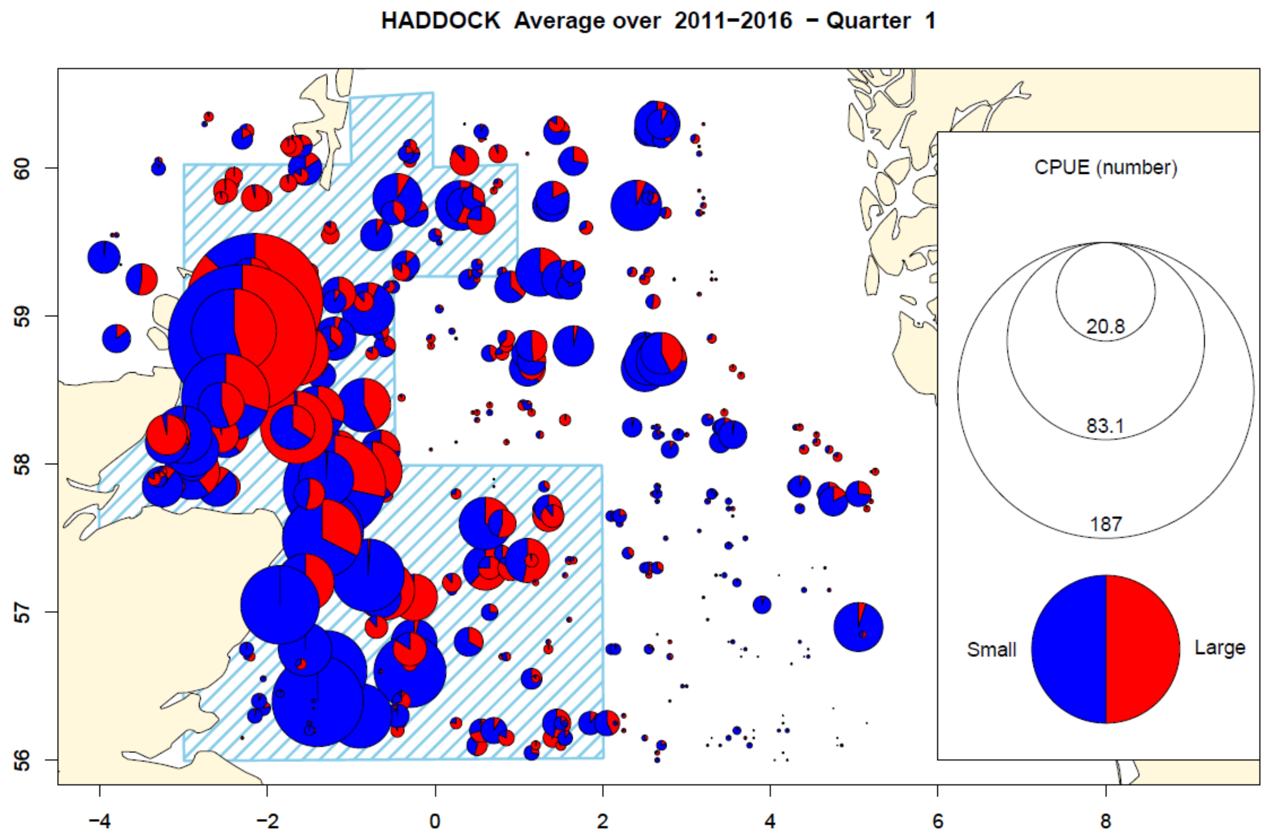

COD Average over 2011−2016 − Quarter 3
CPUE (number)
0.3
1.3
3
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

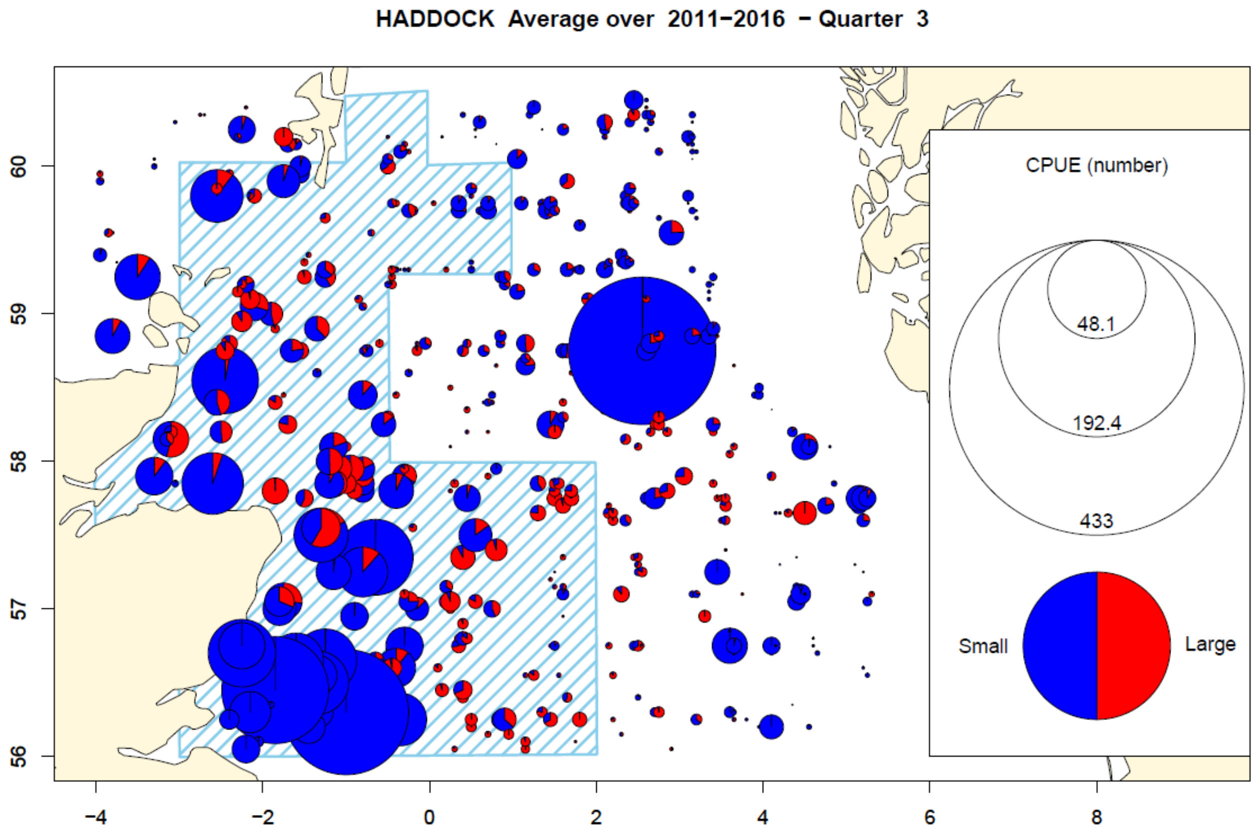
HADDOCK Average over 2006−2010 − Quarter 1



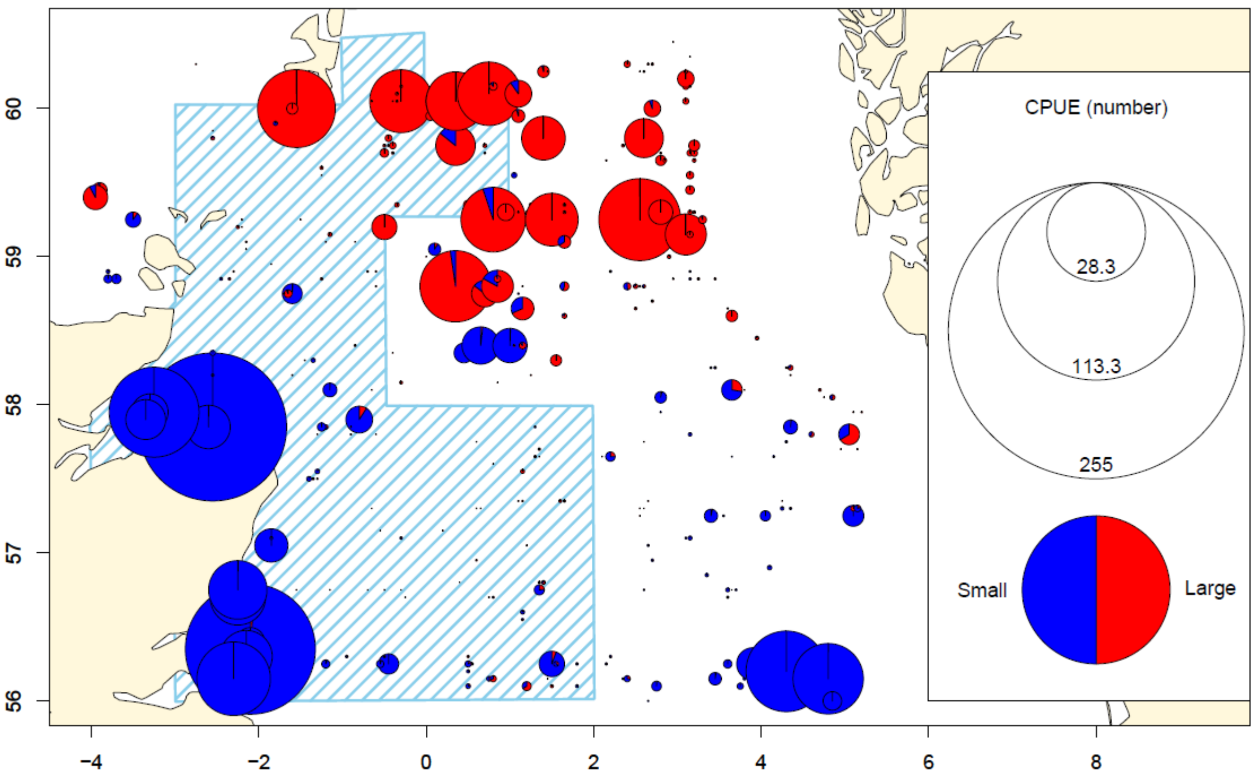
HADDOCK Average over 2006−2010 − Quarter 3



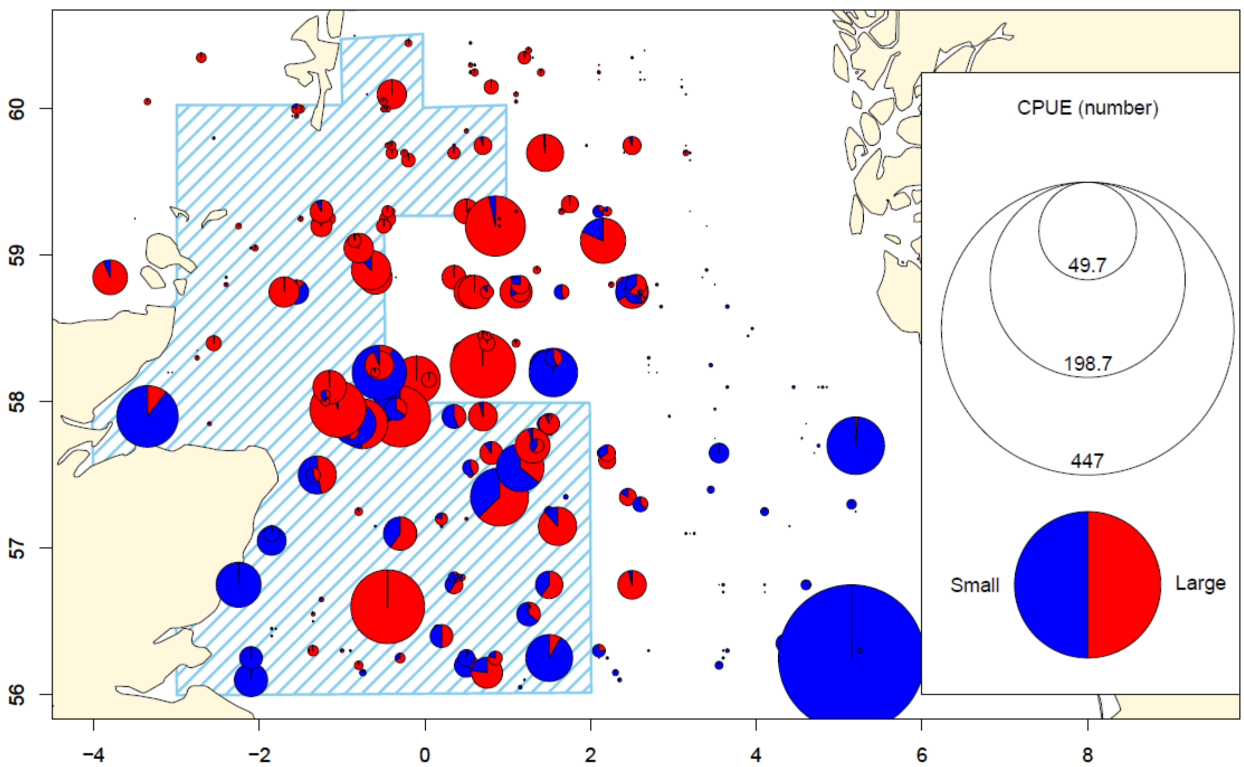

HADDOCK Average over 2011−2016 − Quarter 1
CPUE (number)
20.8
83.1
187
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

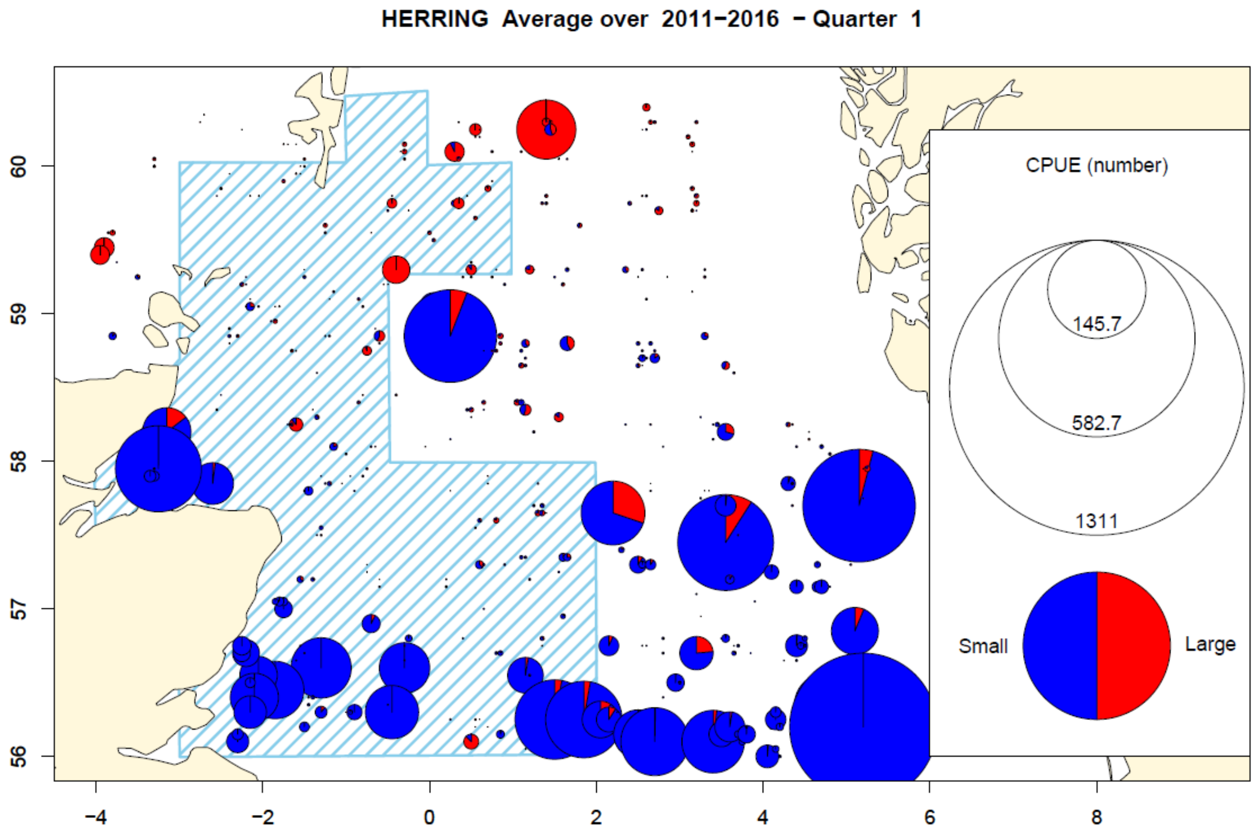

HADDOCK Average over 2011−2016 − Quarter 3
CPUE (number)
48.1
192.4
433
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

HERRING Average over 2006−2010 − Quarter 1

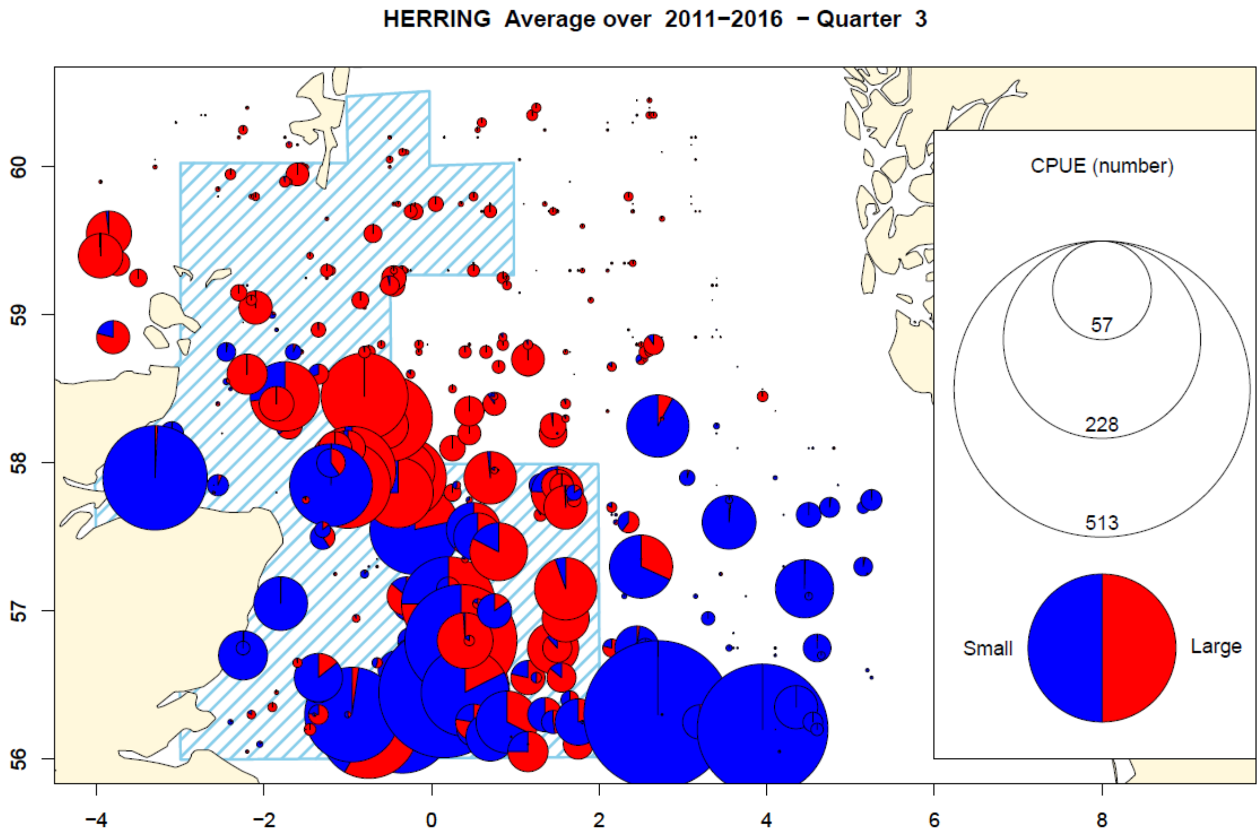


HERRING Average over 2006−2010 − Quarter 3

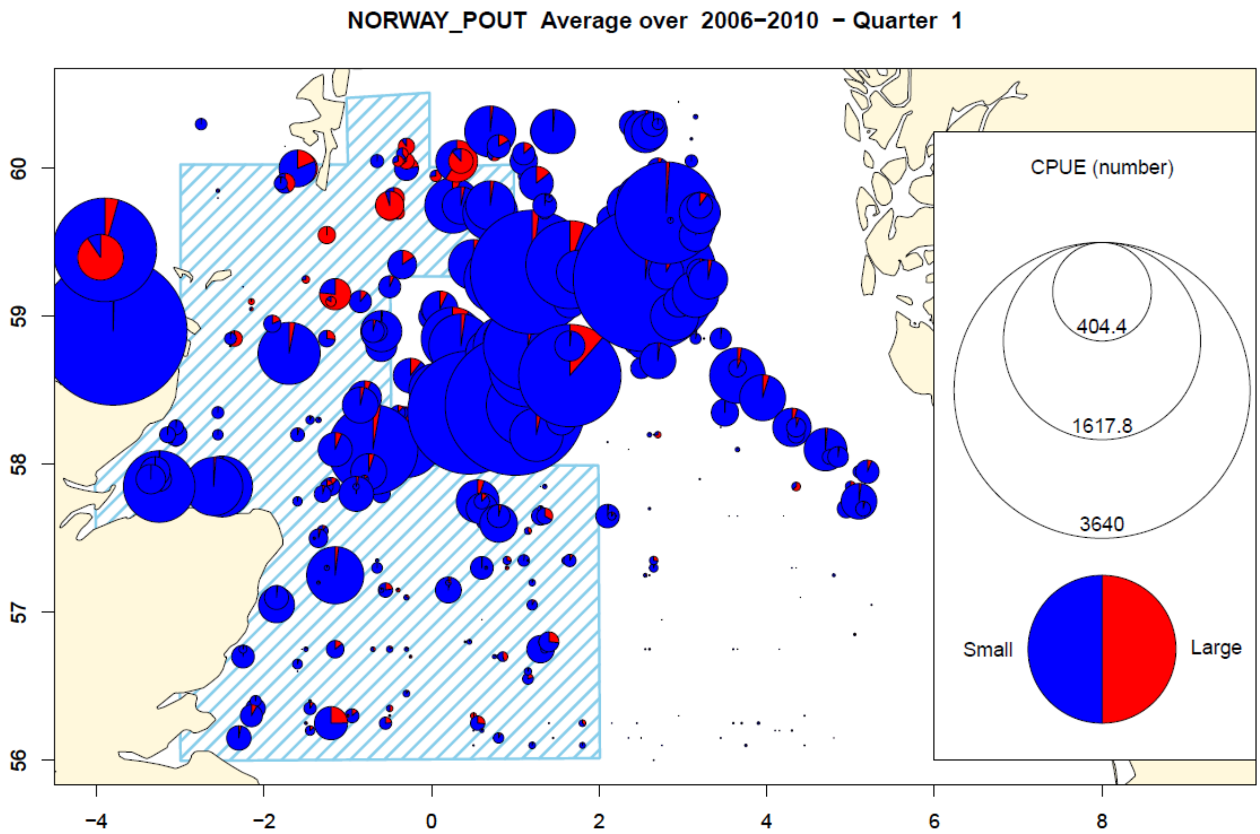


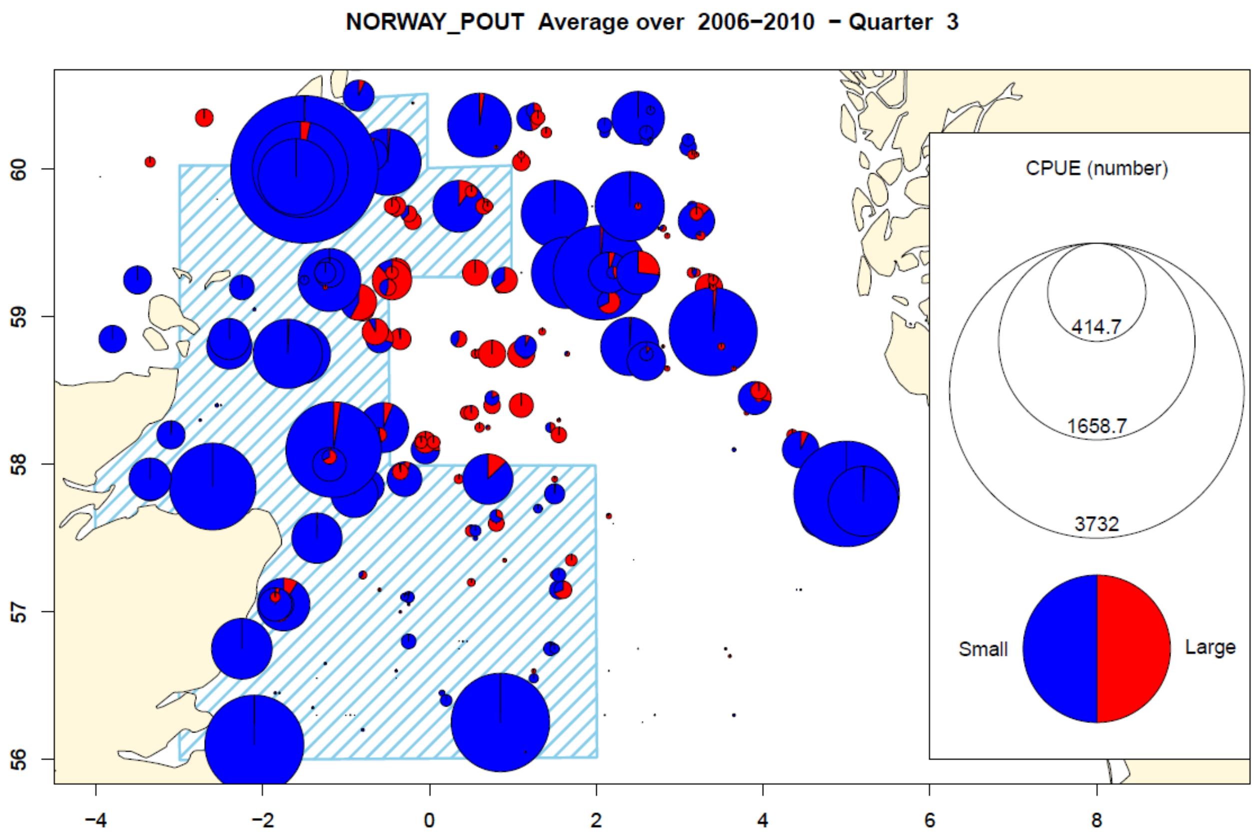


HERRING Average over 2011−2016 − Quarter 1
CPUE (number)
145.7
582.7
1311
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

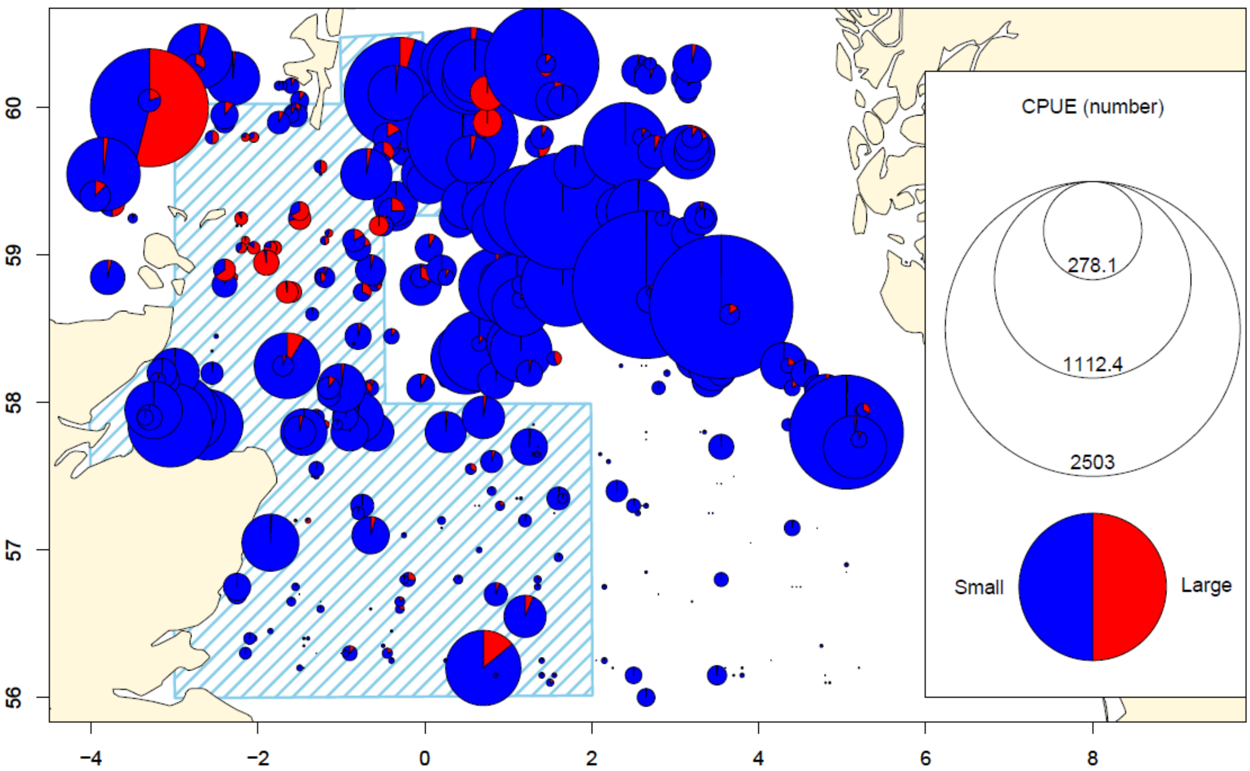


HERRING Average over 2011−2016 − Quarter 3
CPUE (number)
57
228
513
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

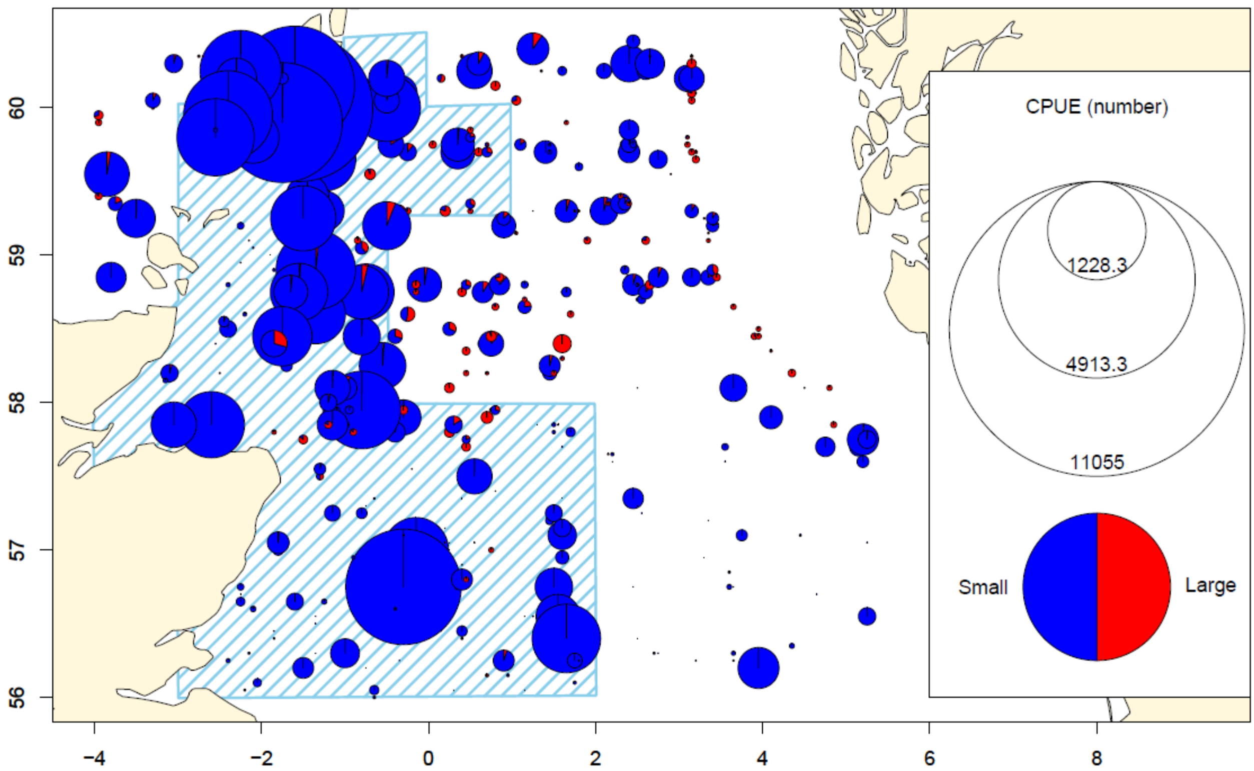

NORWAY_POUT Average over 2006−2010 − Quarter 1
CPUE (number)
404.4
1617.8
3640
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

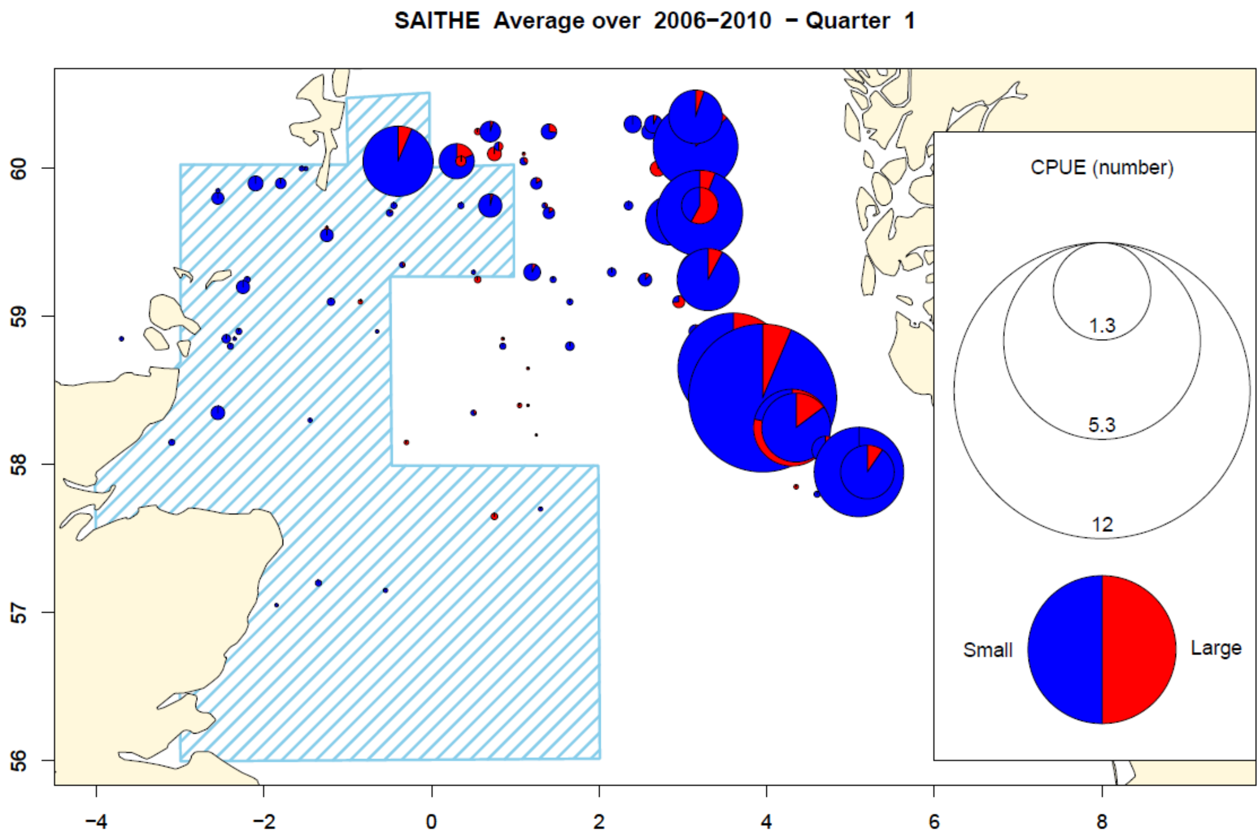

NORWAY_POUT Average over 2006−2010 − Quarter 3
CPUE (number)
414.7
1658.7
3732
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

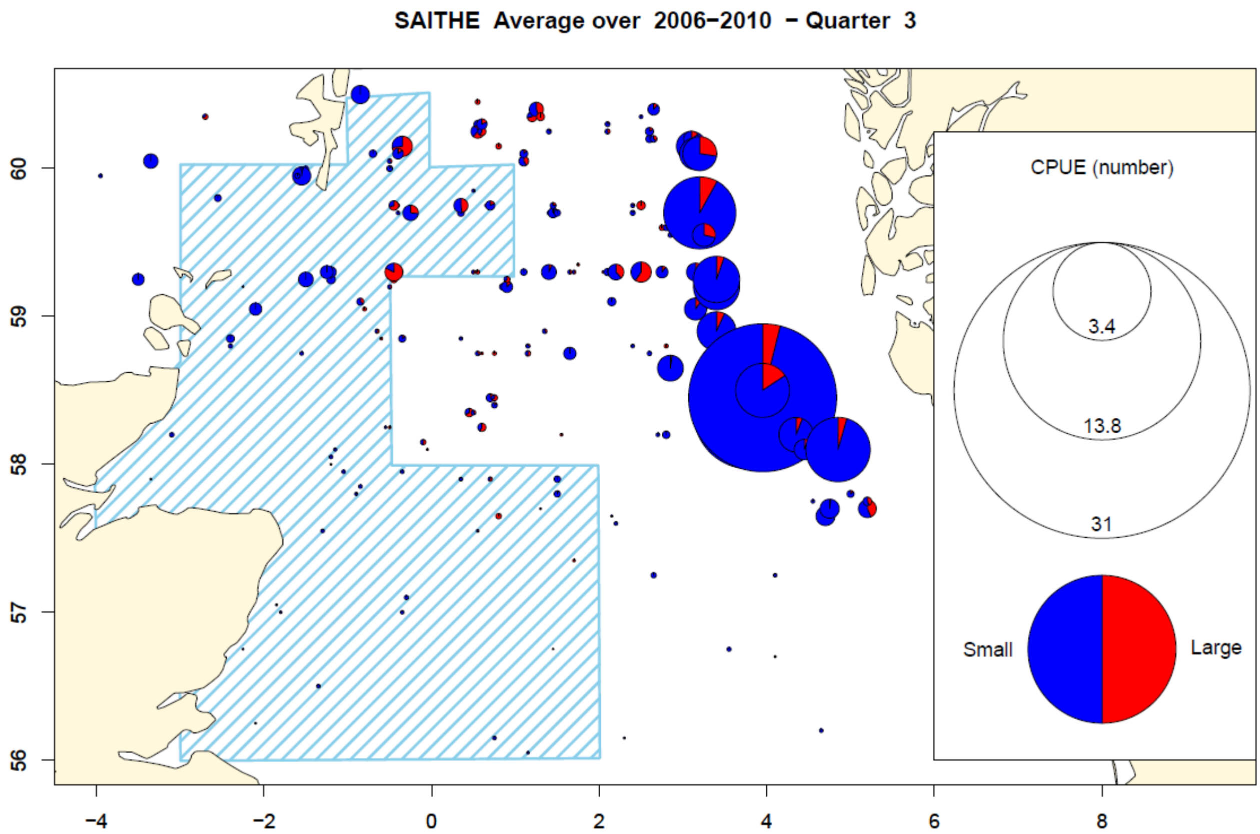
NORWAY_POUT Average over 2011−2016 − Quarter 1

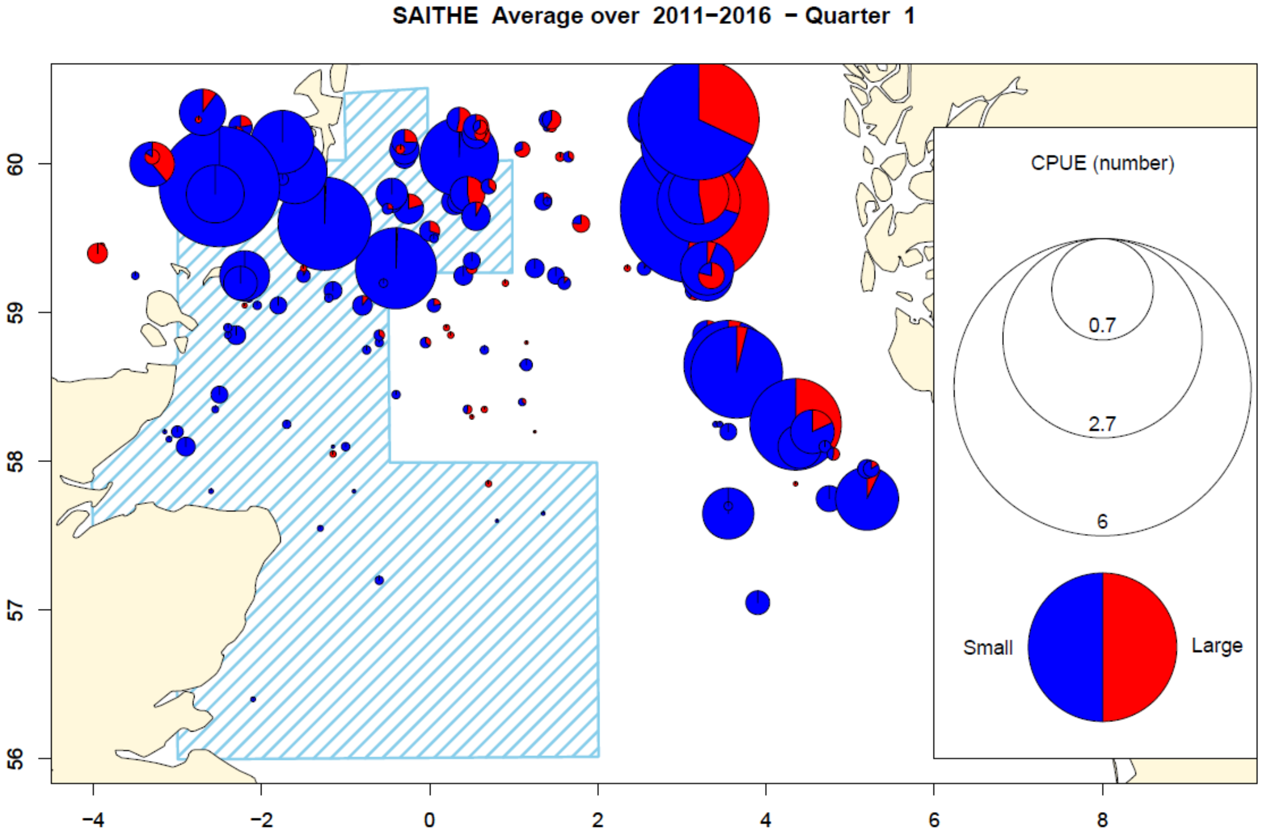


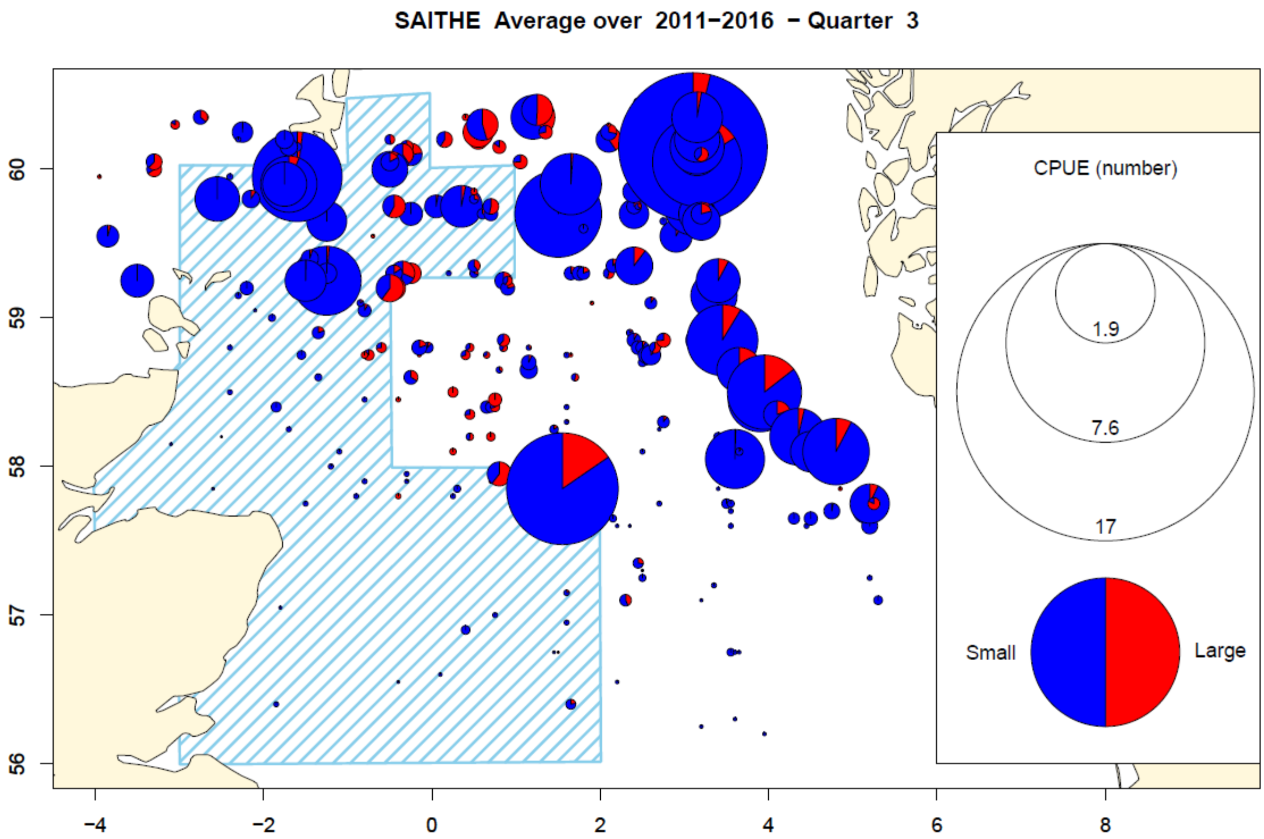
NORWAY_POUT Average over 2011−2016 − Quarter 3

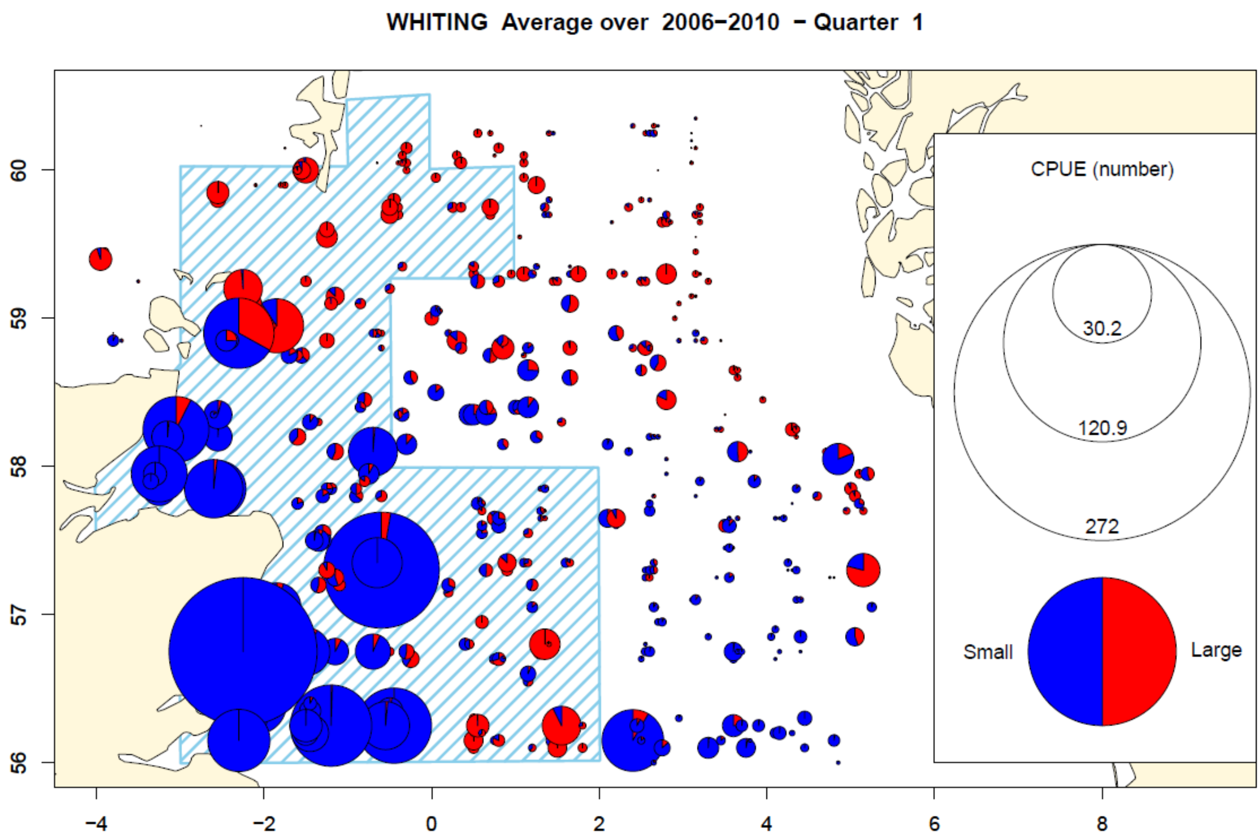


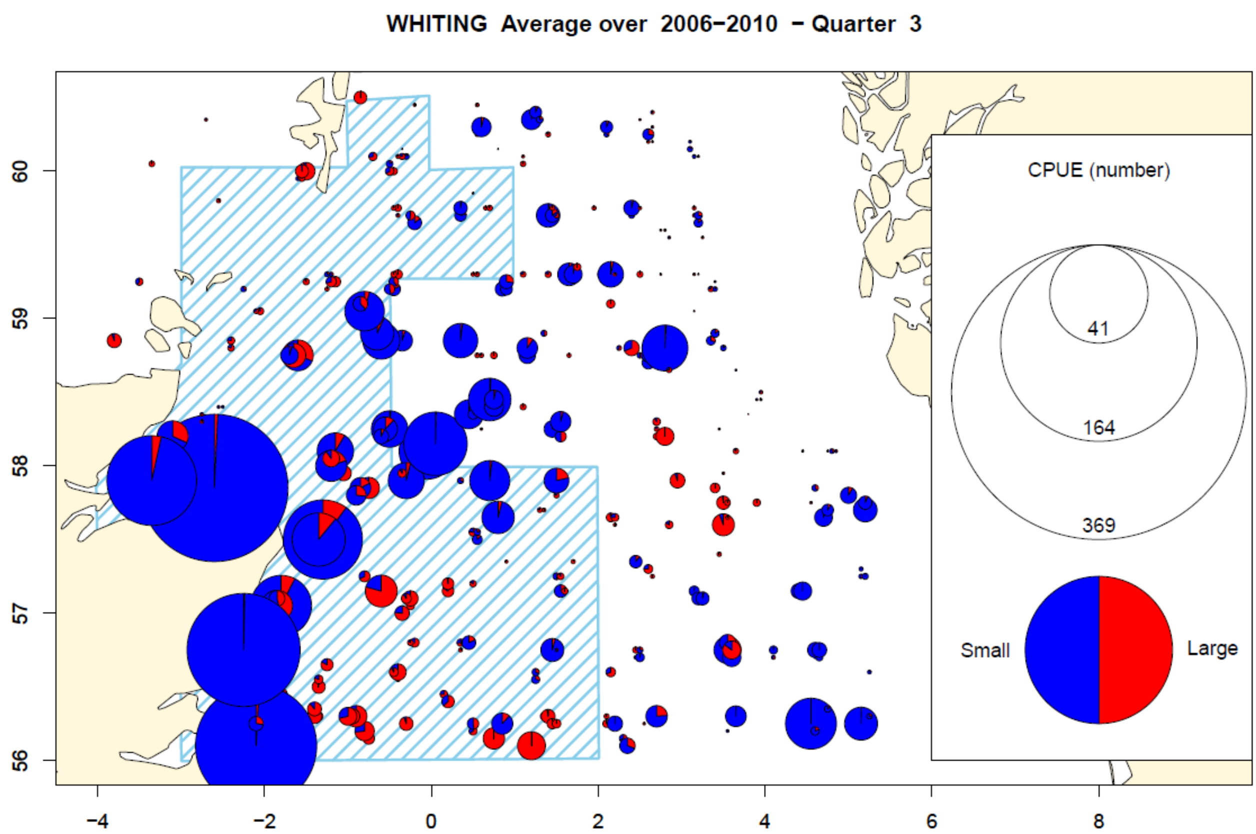

SAITHE Average over 2006−2010 − Quarter 1
CPUE (number)
1.3
5.3
12
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

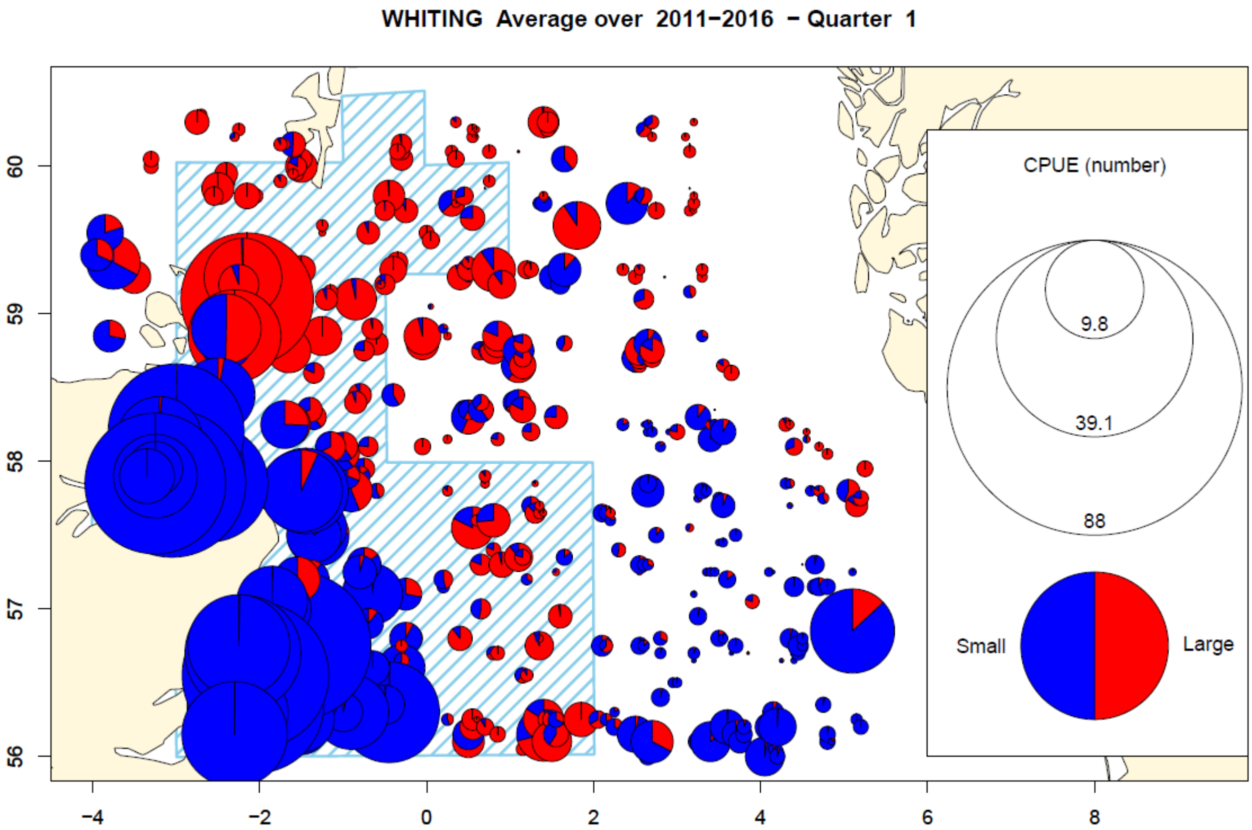

SAITHE Average over 2006−2010 − Quarter 3
CPUE (number)
3.4
13.8
31
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

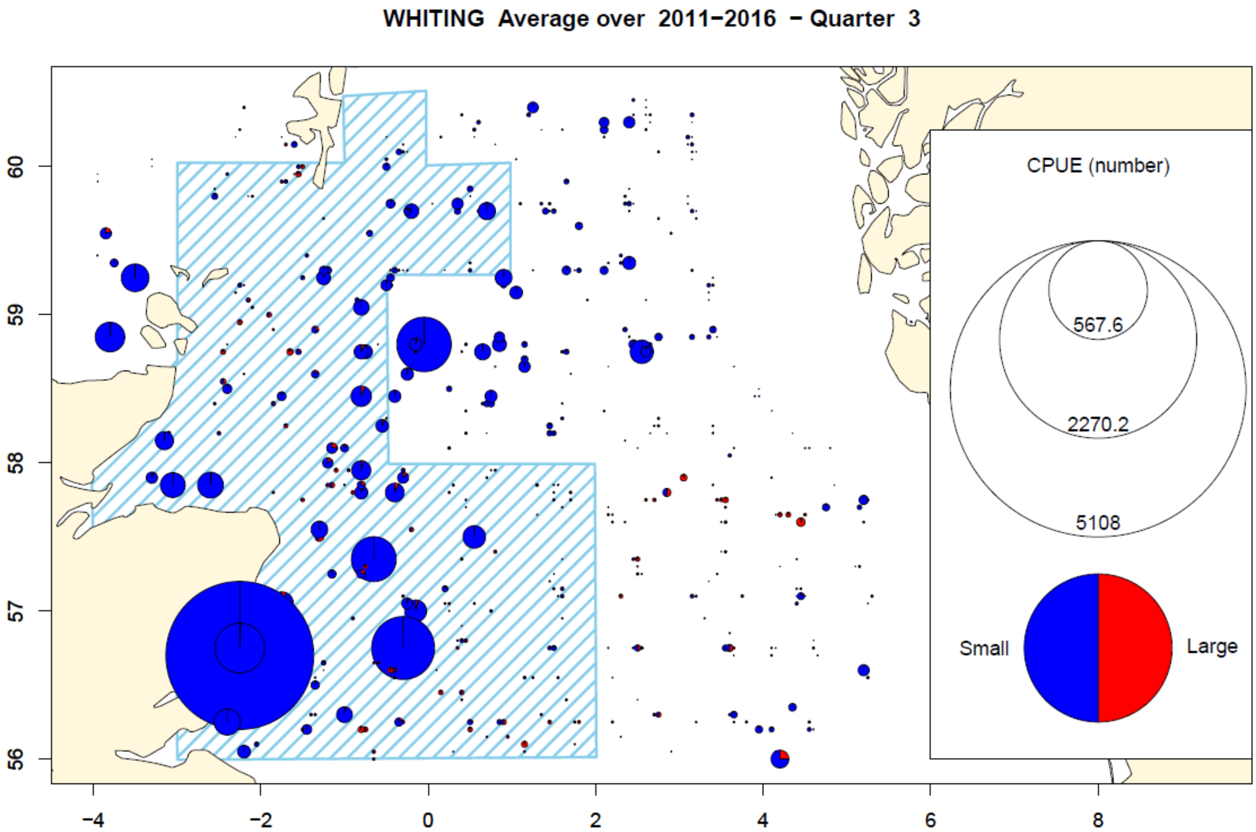

SAITHE Average over 2011−2016 − Quarter 1
CPUE (number)
0.7
2.7
6
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8


SAITHE Average over 2011−2016 − Quarter 3
CPUE (number)
1.9
7.6
17
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

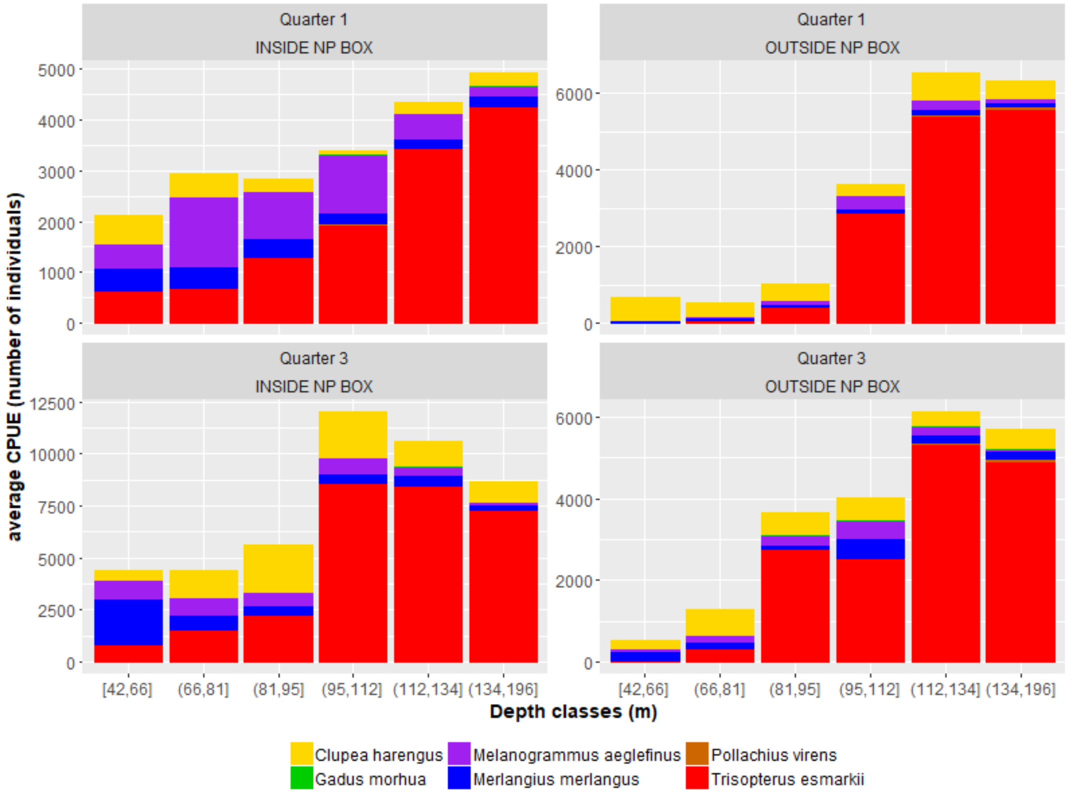

WHITING Average over 2006−2010 − Quarter 1
CPUE (number)
30.2
120.9
272
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

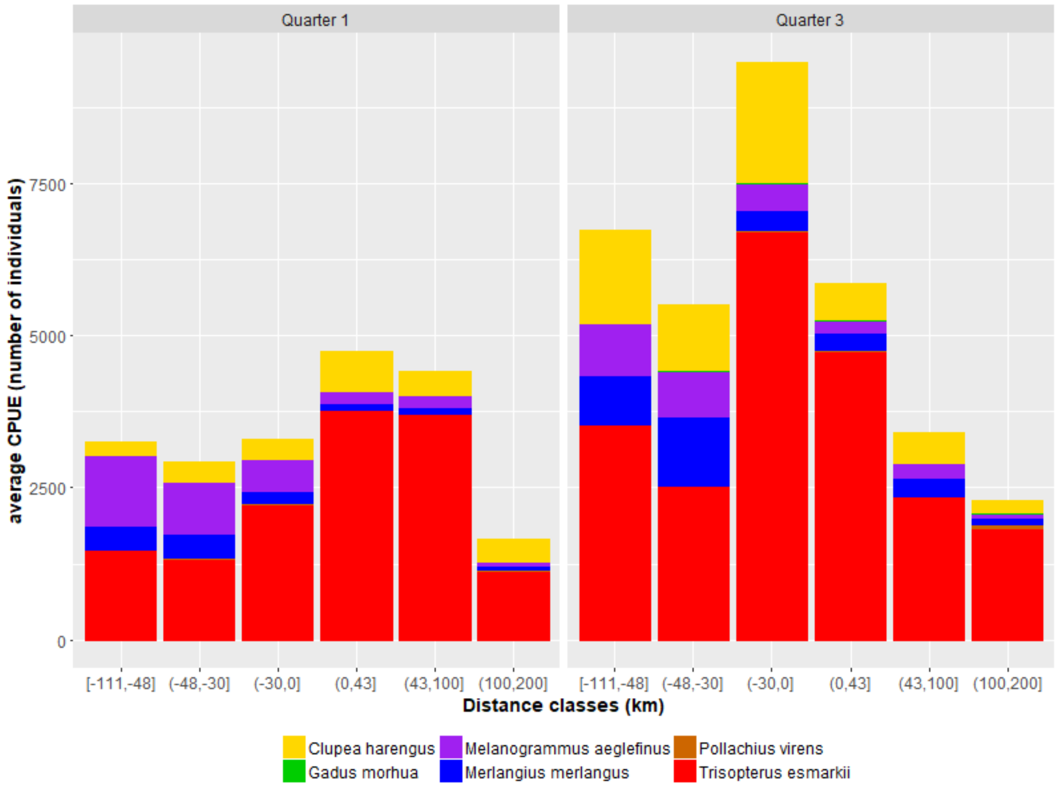

WHITING Average over 2006−2010 − Quarter 3
CPUE (number)
41
164
369
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

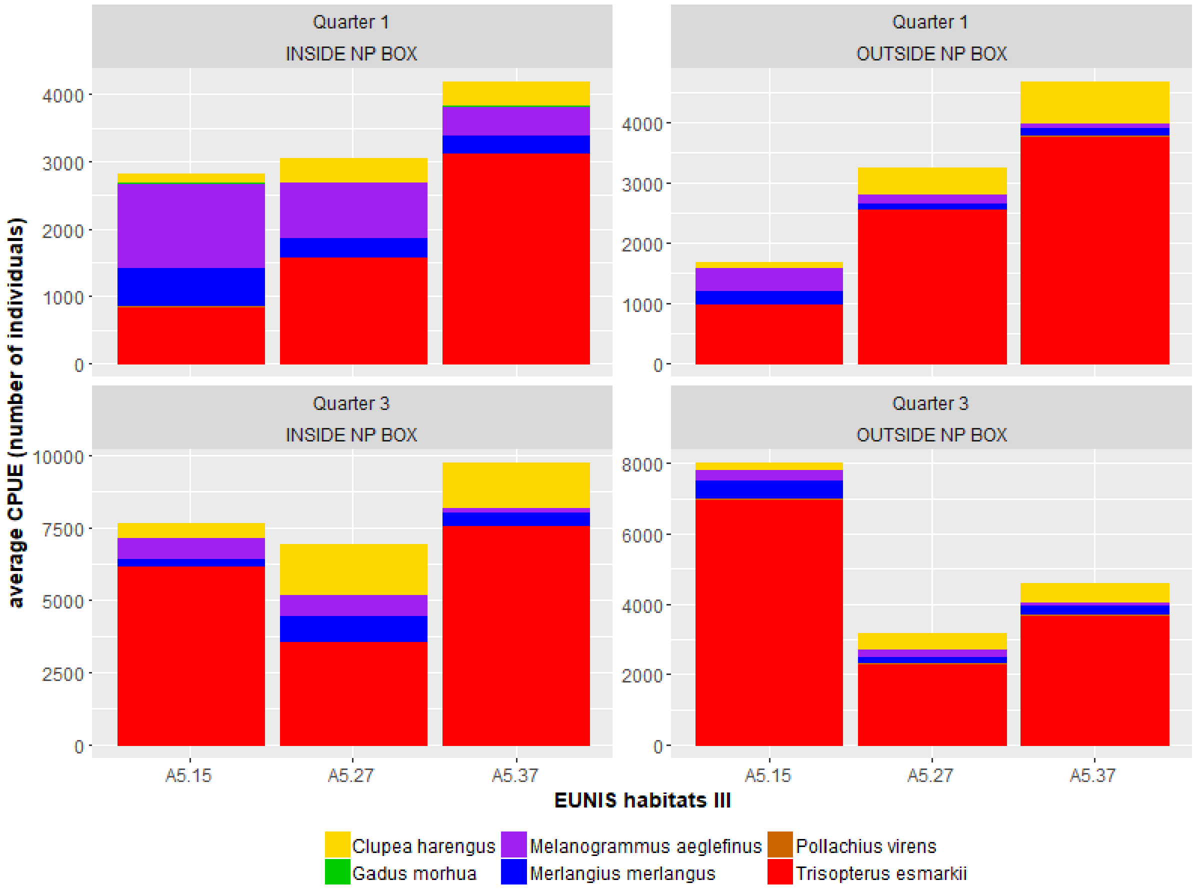

WHITING Average over 2011−2016 − Quarter 1
CPUE (number)
9.8
39.1
88
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8


WHITING Average over 2011−2016 − Quarter 3
CPUE (number)
567.6
2270.2
5108
Small
Large
60
59
58
57
56
−4
−2
0
2
4
6
8

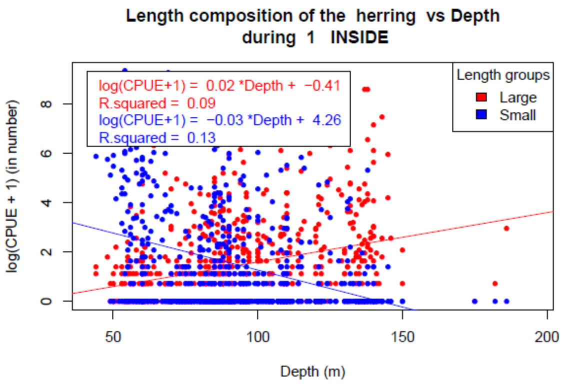
Appendix F: Initial analyses to determine dependencies in species composition (number of individuals) according the Norway pout box and season of year from survey data

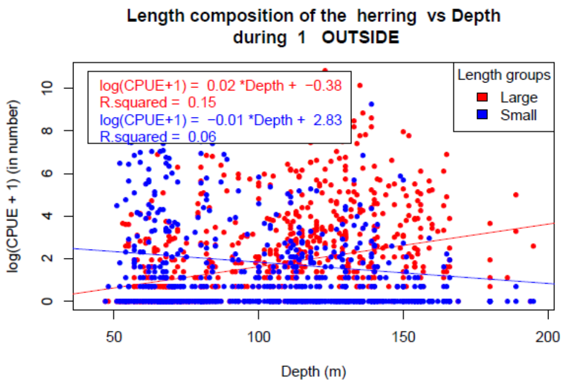


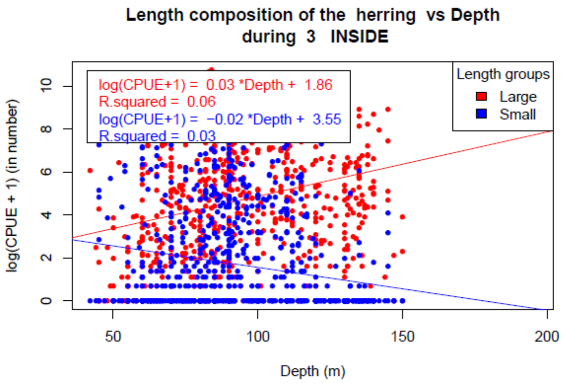


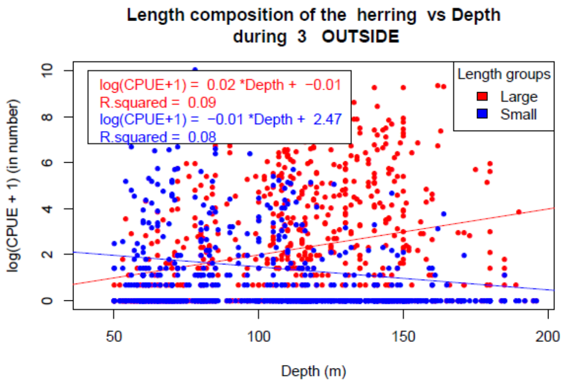

Quarter 1
INSIDE NP BOX
Quarter 1
OUTSIDE NP BOX
Quarter 3
INSIDE NP BOX
Quarter 3
OUTSIDE NP BOX
average CPUE (number of individuals)
0
1000
2000
3000
4000
2500
5000
7500
10000
6000
8000
A5.15
A5.27
A5.37
EUNIS habitats III
Clupea harengus
Gadus morhua
Melanogrammus aeglefinus
Merlangius merlangus
Pollachius virens
Trisopterus esmarkii

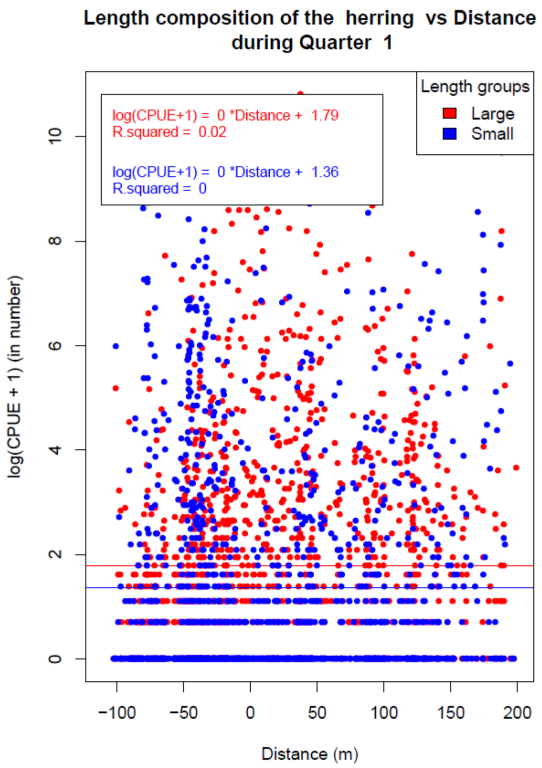
Appendix G1: Initial analyses to determine dependencies in length composition of Norway pout and important by-catch species according to the Norway pout box, depth and distance to the border of the box, based on NS-IBTS data

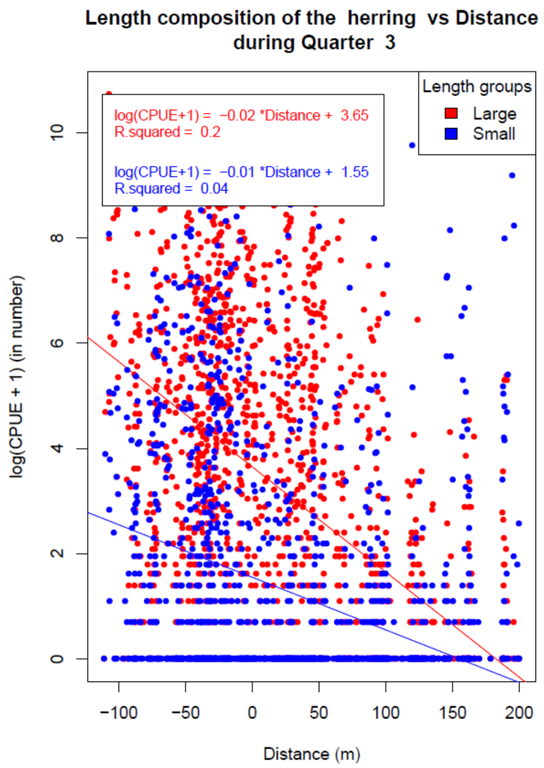


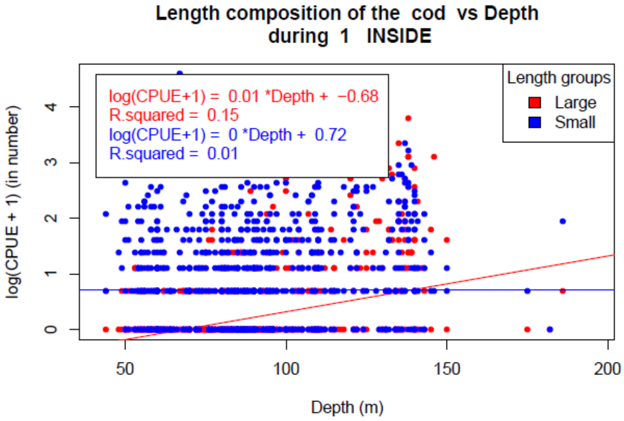


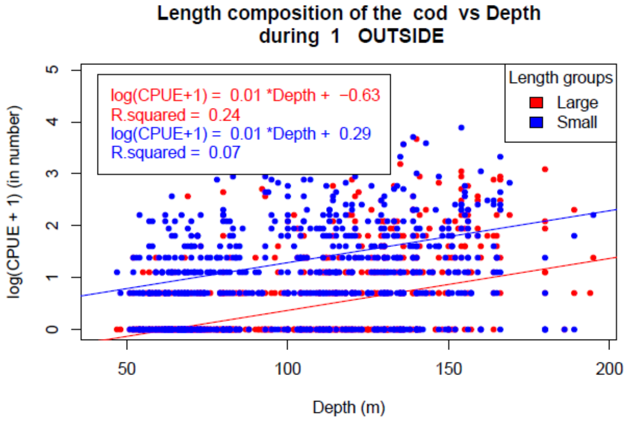


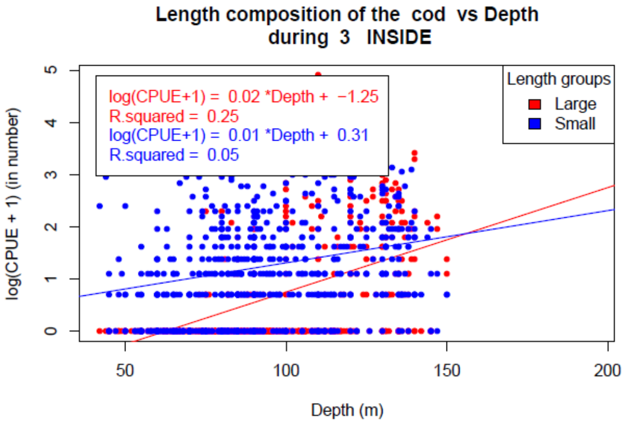


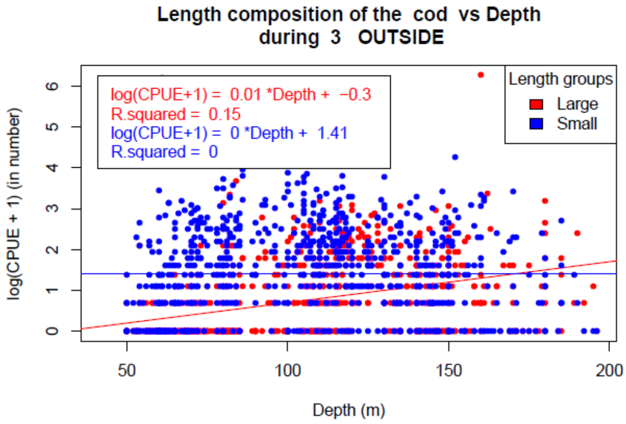


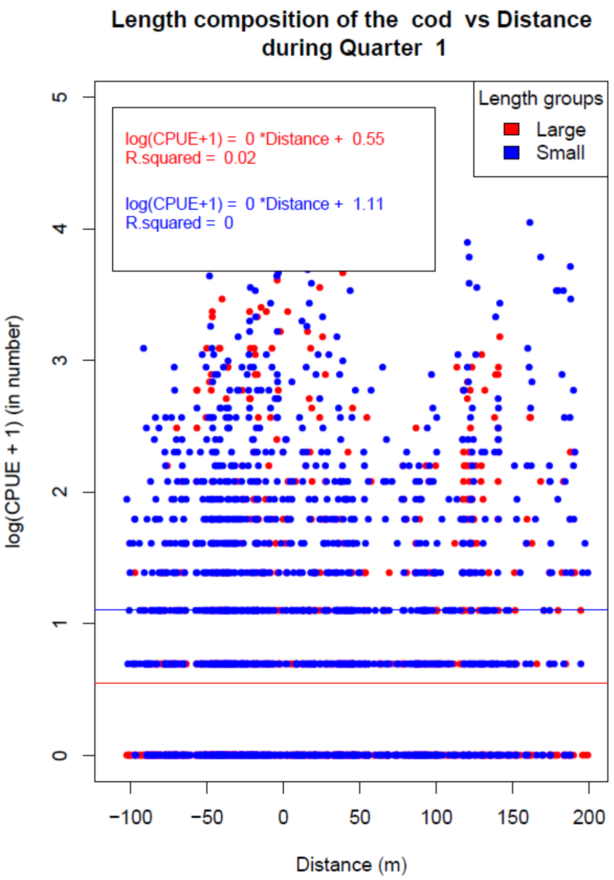


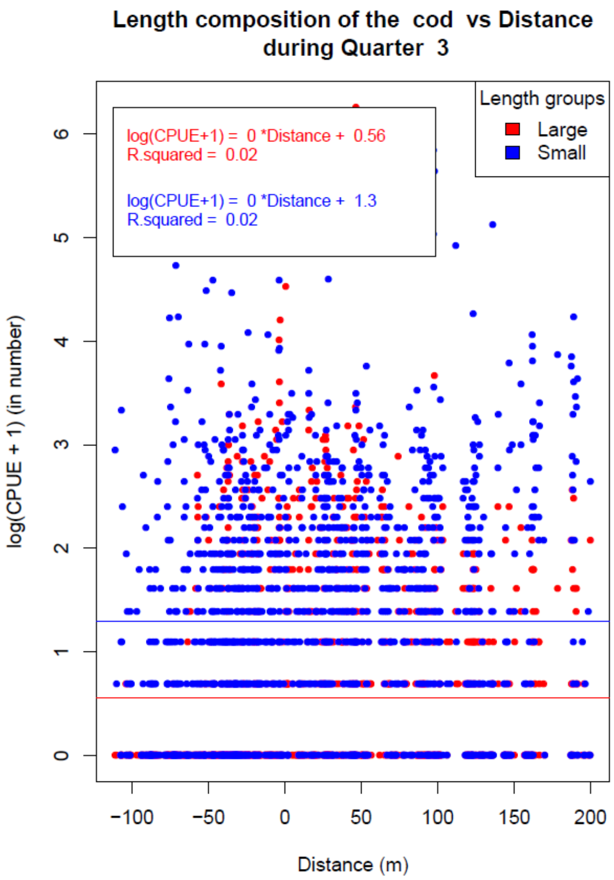

Length composition of the cod vs Depth during 1 INSIDE
Length groups
Large
Small
log(CPUE+1) = 0.01 *Depth + −0.68
R.squared = 0.15
log(CPUE+1) = 0 *Depth + 0.72
R.squared = 0.01
log(CPUE + 1) (in number)
Depth (m)

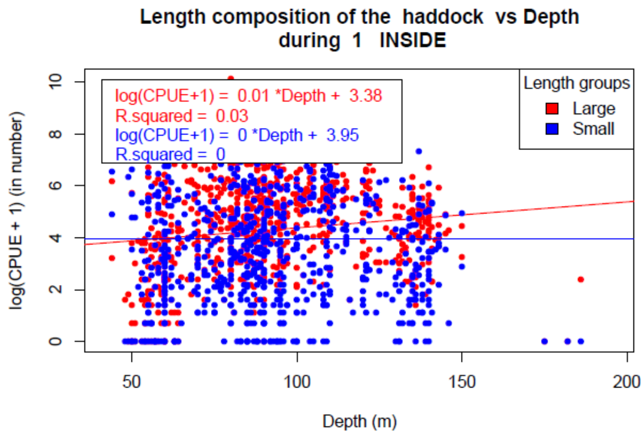

Length composition of the cod vs Depth during 1 OUTSIDE
Length groups
Large
Small
log(CPUE+1) = 0.01 *Depth + −0.63
R.squared = 0.24
log(CPUE+1) = 0.01 *Depth + 0.29
R.squared = 0.07
log(CPUE + 1) (in number)
Depth (m)

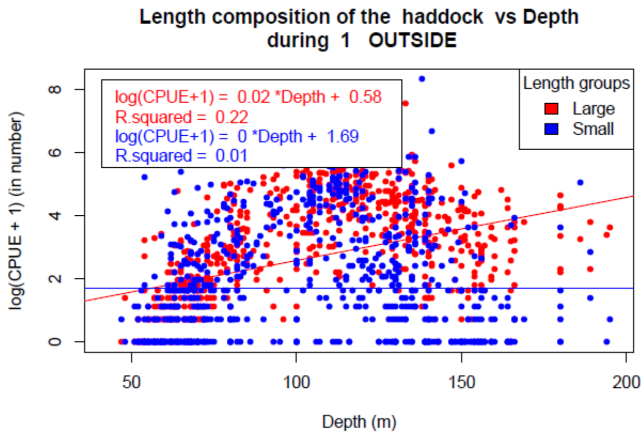

Length composition of the cod vs Depth during 3 INSIDE
Length groups
Large
Small
log(CPUE+1) = 0.02 *Depth + −1.25
R.squared = 0.25
log(CPUE+1) = 0.01 *Depth + 0.31
R.squared = 0.05
log(CPUE + 1) (in number)
Depth (m)

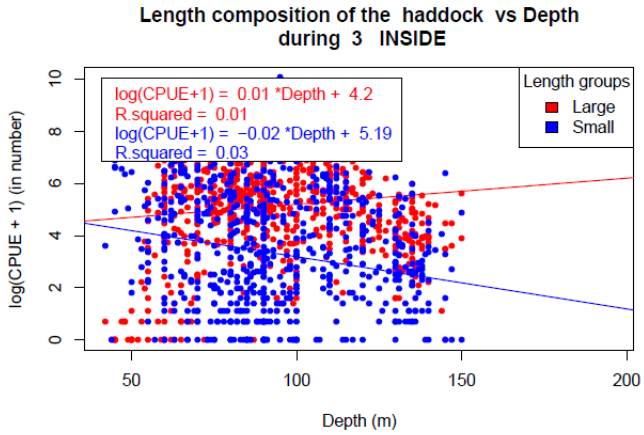

Length composition of the cod vs Depth during 3 OUTSIDE
Length groups
Large
Small
log(CPUE+1) = 0.01 *Depth + −0.3
R.squared = 0.15
log(CPUE+1) = 0 *Depth + 1.41
R.squared = 0
log(CPUE + 1) (in number)
Depth (m)

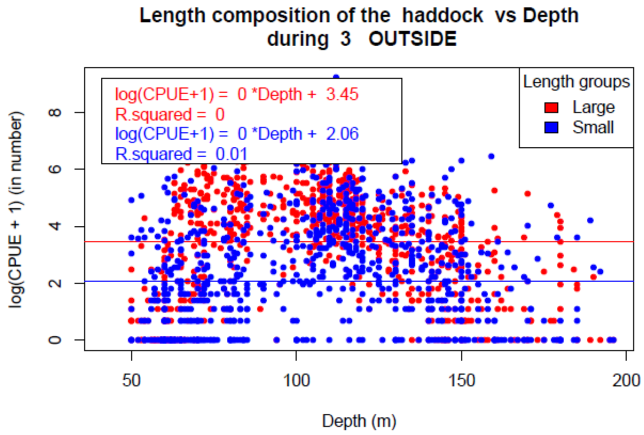

Length composition of the cod vs Distance during Quarter 1
Length groups
Large
Small
log(CPUE+1) = 0 *Distance + 0.55
R.squared = 0.02
log(CPUE+1) = 0 *Distance + 1.11
R.squared = 0
log(CPUE + 1) (in number)
Distance (m)

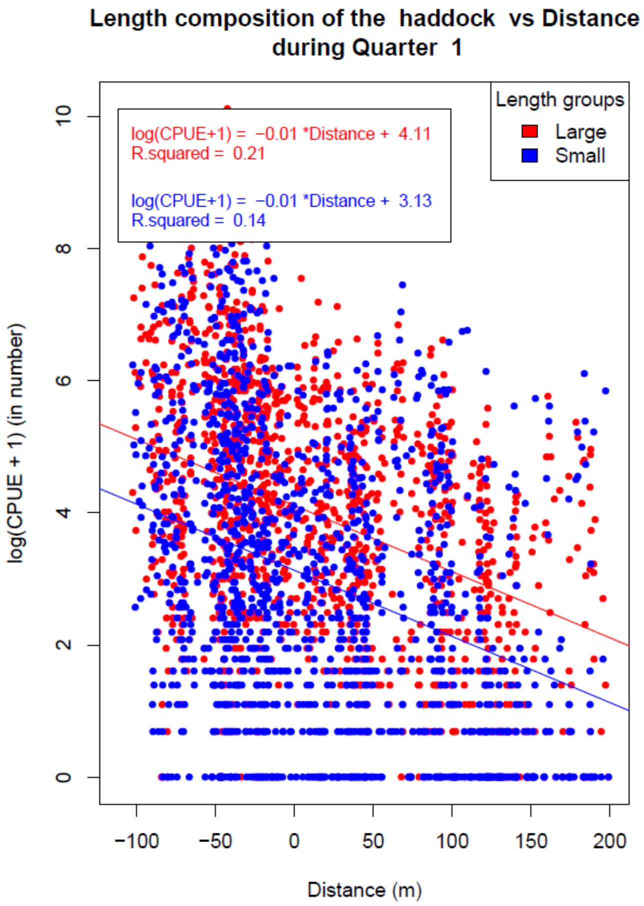

Length composition of the cod vs Distance during Quarter 3
Length groups
Large
Small
log(CPUE+1) = 0 *Distance + 0.56
R.squared = 0.02
log(CPUE+1) = 0 *Distance + 1.3
R.squared = 0.02
log(CPUE + 1) (in number)
Distance (m)

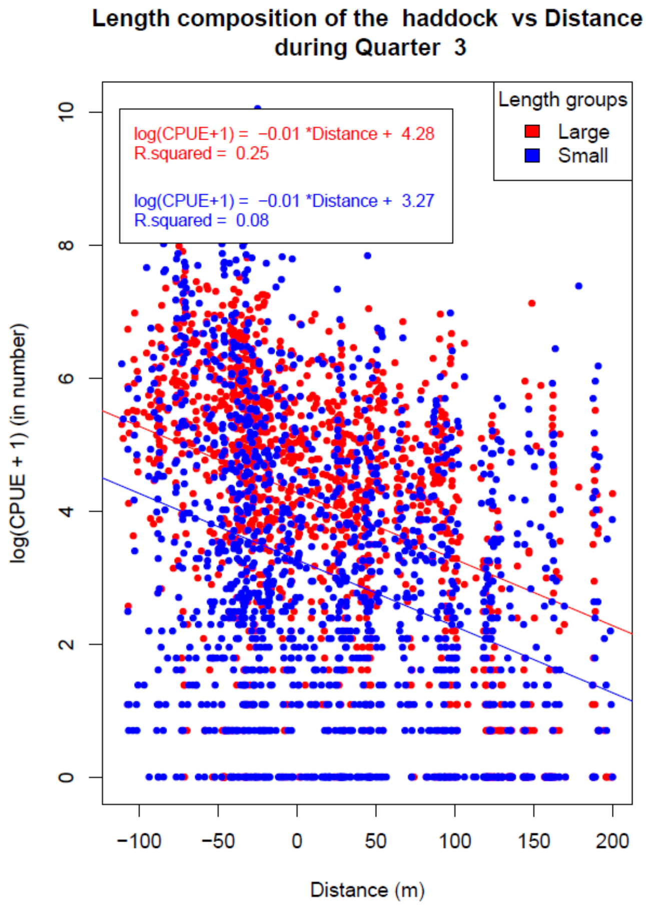

Length composition of the haddock vs Depth
during 1 INSIDE
log(CPUE+1) = 0.01 *Depth + 3.38
R.squared = 0.03
log(CPUE+1) = 0 *Depth + 3.95
R.squared = 0
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

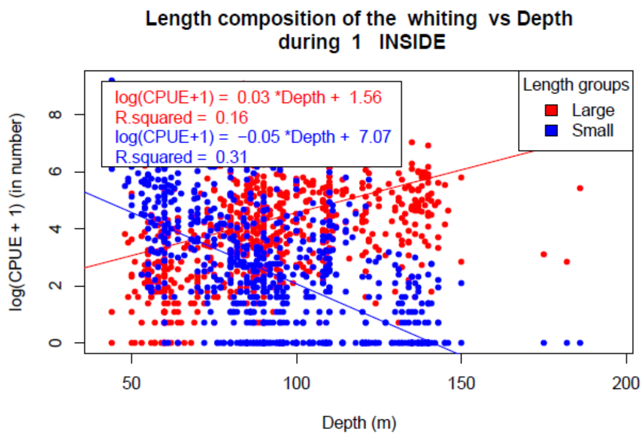

Length composition of the haddock vs Depth
during 1 OUTSIDE
log(CPUE+1) = 0.02 *Depth + 0.58
R.squared = 0.22
log(CPUE+1) = 0 *Depth + 1.69
R.squared = 0.01
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

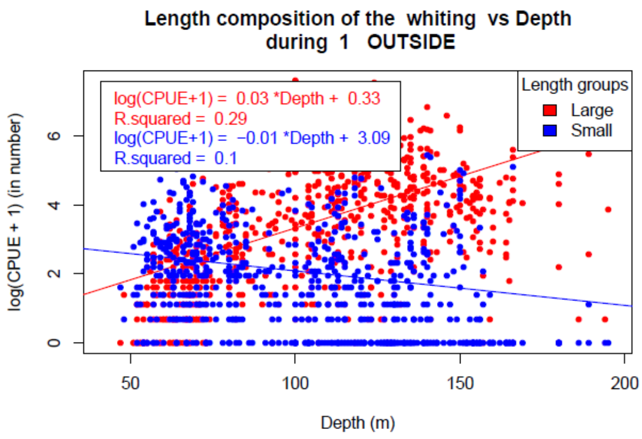

Length composition of the haddock vs Depth
during 3 INSIDE
log(CPUE+1) = 0.01 *Depth + 4.2
R.squared = 0.01
log(CPUE+1) = −0.02 *Depth + 5.19
R.squared = 0.03
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

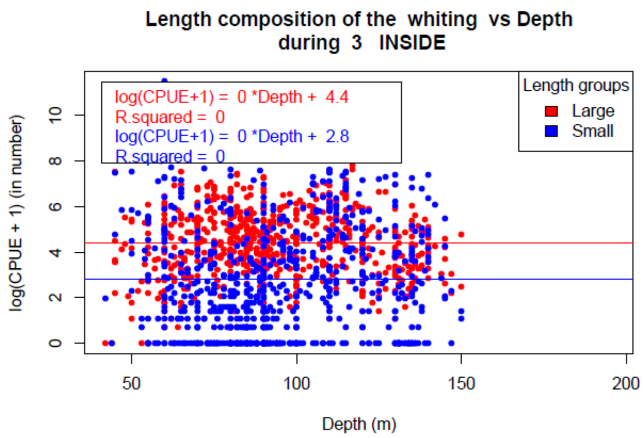

Length composition of the haddock vs Depth
during 3 OUTSIDE
log(CPUE+1) = 0 *Depth + 3.45
R.squared = 0
log(CPUE+1) = 0 *Depth + 2.06
R.squared = 0.01
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

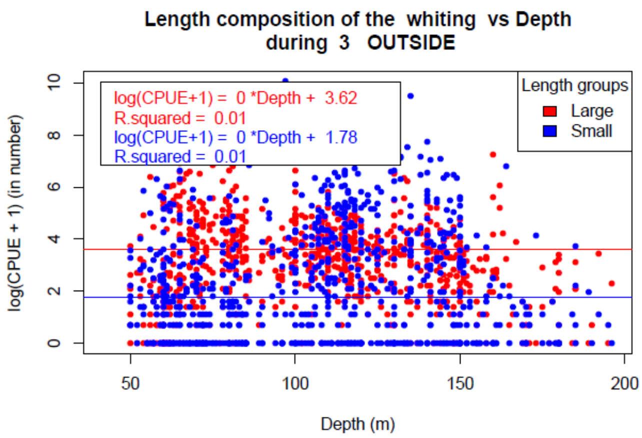

Length composition of the haddock vs Distance
during Quarter 1
log(CPUE+1) = −0.01 *Distance + 4.11
R.squared = 0.21
log(CPUE+1) = −0.01 *Distance + 3.13
R.squared = 0.14
Length groups
Large
Small
log(CPUE + 1) (in number)
Distance (m)

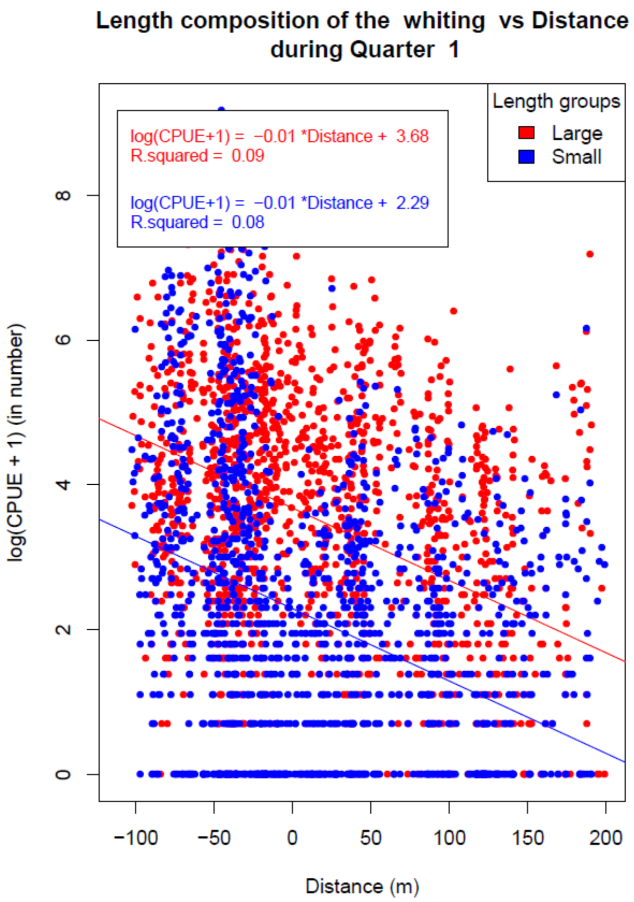

Length composition of the haddock vs Distance
during Quarter 3
log(CPUE+1) = −0.01 *Distance + 4.28
R.squared = 0.25
log(CPUE+1) = −0.01 *Distance + 3.27
R.squared = 0.08
Length groups
Large
Small
log(CPUE + 1) (in number)
Distance (m)

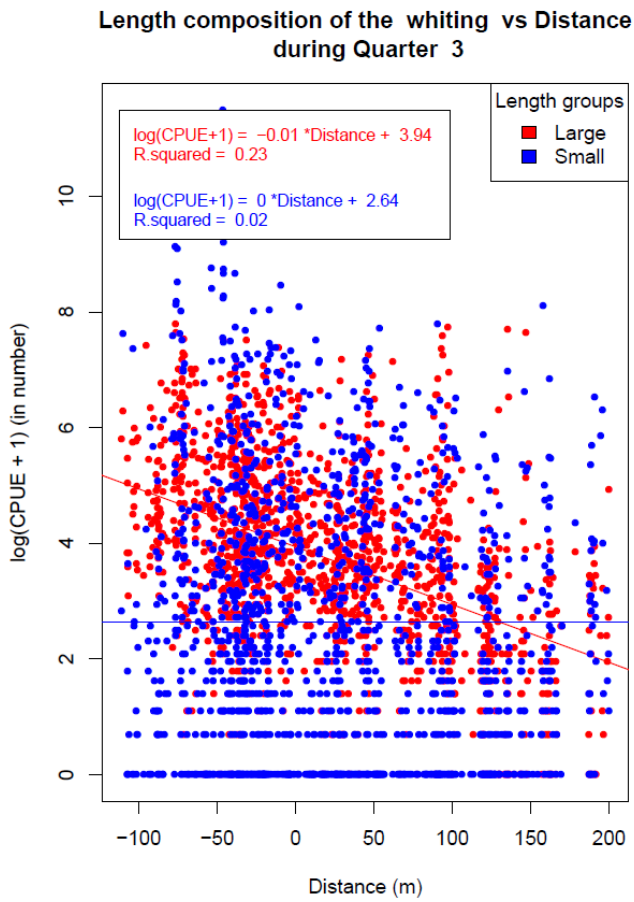

Length composition of the whiting vs Depth
during 1 INSIDE
log(CPUE+1) = 0.03 *Depth + 1.56
R.squared = 0.16
log(CPUE+1) = −0.05 *Depth + 7.07
R.squared = 0.31
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

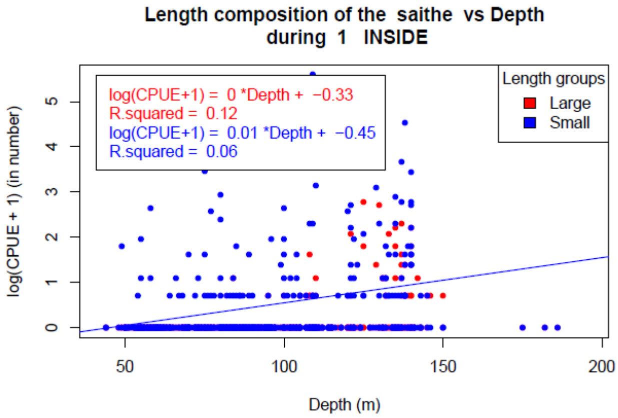

Length composition of the whiting vs Depth
during 1 OUTSIDE
log(CPUE+1) = 0.03 *Depth + 0.33
R.squared = 0.29
log(CPUE+1) = −0.01 *Depth + 3.09
R.squared = 0.1
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

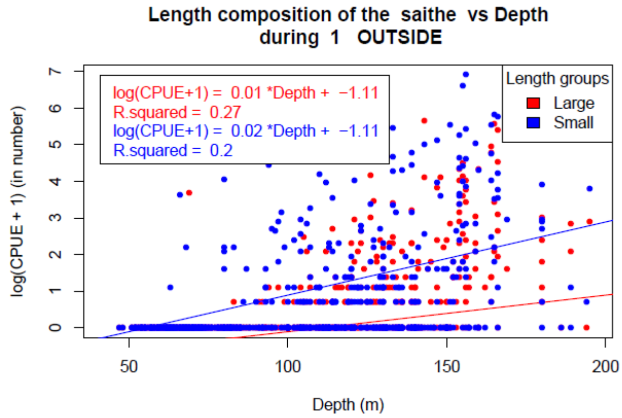

Length composition of the whiting vs Depth
during 3 INSIDE
log(CPUE+1) = 0 *Depth + 4.4
R.squared = 0
log(CPUE+1) = 0 *Depth + 2.8
R.squared = 0
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

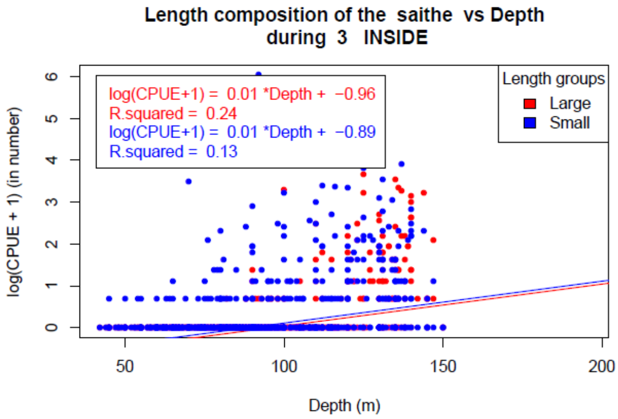

Length composition of the whiting vs Depth
during 3 OUTSIDE
log(CPUE+1) = 0 *Depth + 3.62
R.squared = 0.01
log(CPUE+1) = 0 *Depth + 1.78
R.squared = 0.01
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

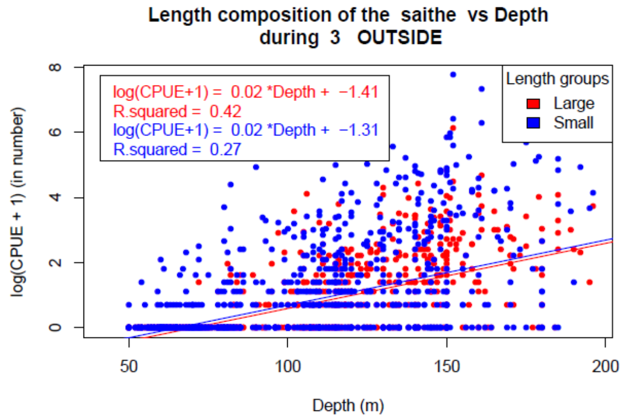

Length composition of the whiting vs Distance
during Quarter 1
log(CPUE+1) = −0.01 *Distance + 3.68
R.squared = 0.09
log(CPUE+1) = −0.01 *Distance + 2.29
R.squared = 0.08
Length groups
Large
Small
log(CPUE + 1) (in number)
Distance (m)

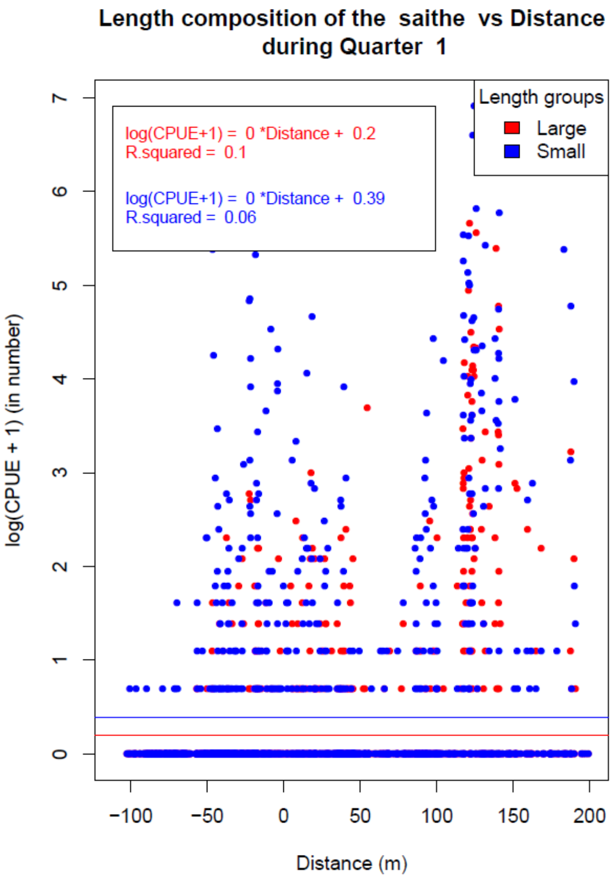

Length composition of the whiting vs Distance
during Quarter 3
log(CPUE+1) = −0.01 *Distance + 3.94
R.squared = 0.23
log(CPUE+1) = 0 *Distance + 2.64
R.squared = 0.02
Length groups
Large
Small
log(CPUE + 1) (in number)
Distance (m)

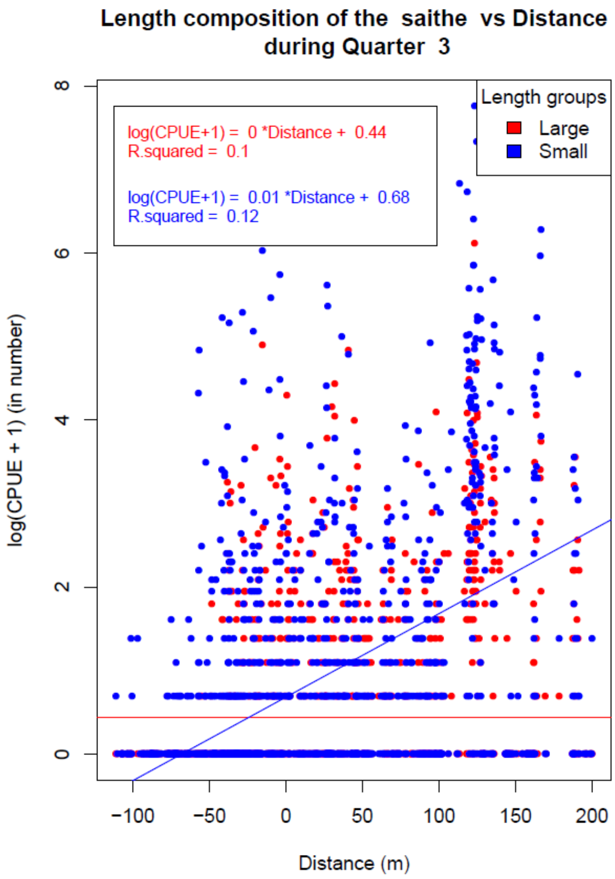

Length composition of the saithe vs Depth
during 1 INSIDE
log(CPUE+1) = 0 *Depth + −0.33
R.squared = 0.12
log(CPUE+1) = 0.01 *Depth + −0.45
R.squared = 0.06
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

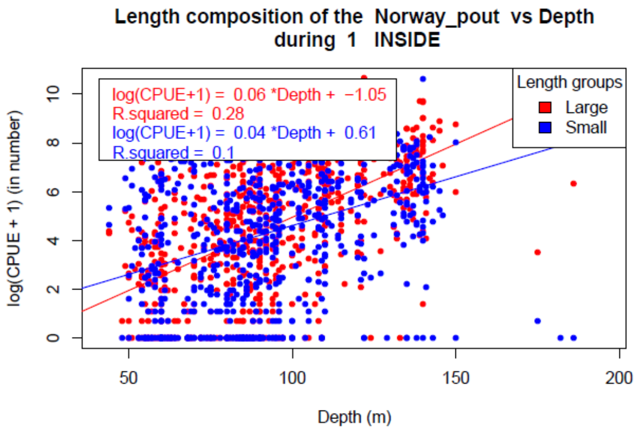

Length composition of the saithe vs Depth
during 1 OUTSIDE
log(CPUE+1) = 0.01 *Depth + −1.11
R.squared = 0.27
log(CPUE+1) = 0.02 *Depth + −1.11
R.squared = 0.2
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

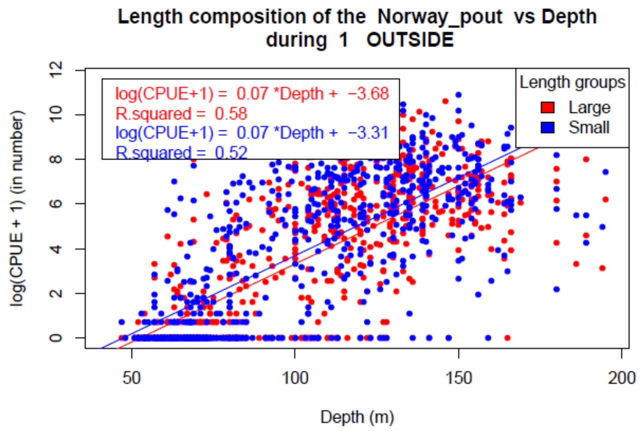

Length composition of the saithe vs Depth
during 3 INSIDE
log(CPUE+1) = 0.01 *Depth + −0.96
R.squared = 0.24
log(CPUE+1) = 0.01 *Depth + −0.89
R.squared = 0.13
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

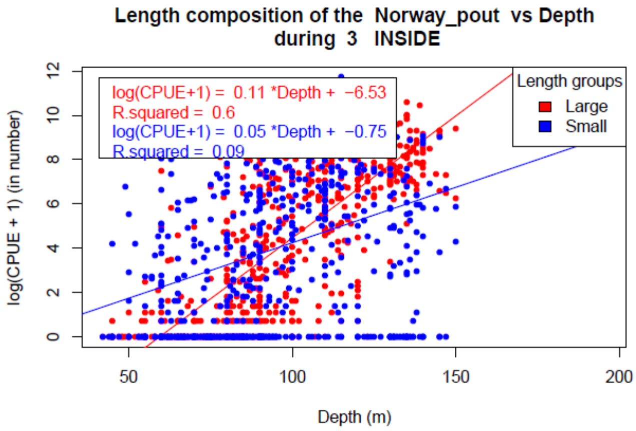

Length composition of the saithe vs Depth
during 3 OUTSIDE
log(CPUE+1) = 0.02 *Depth + −1.41
R.squared = 0.42
log(CPUE+1) = 0.02 *Depth + −1.31
R.squared = 0.27
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

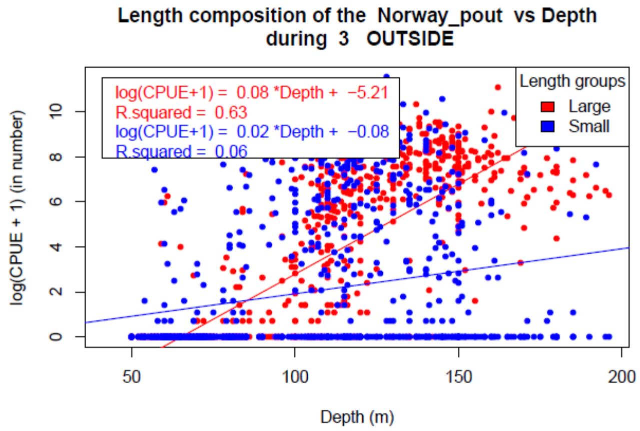

Length composition of the saithe vs Distance
during Quarter 1
log(CPUE+1) = 0 *Distance + 0.2
R.squared = 0.1
log(CPUE+1) = 0 *Distance + 0.39
R.squared = 0.06
Length groups
Large
Small
log(CPUE + 1) (in number)
Distance (m)

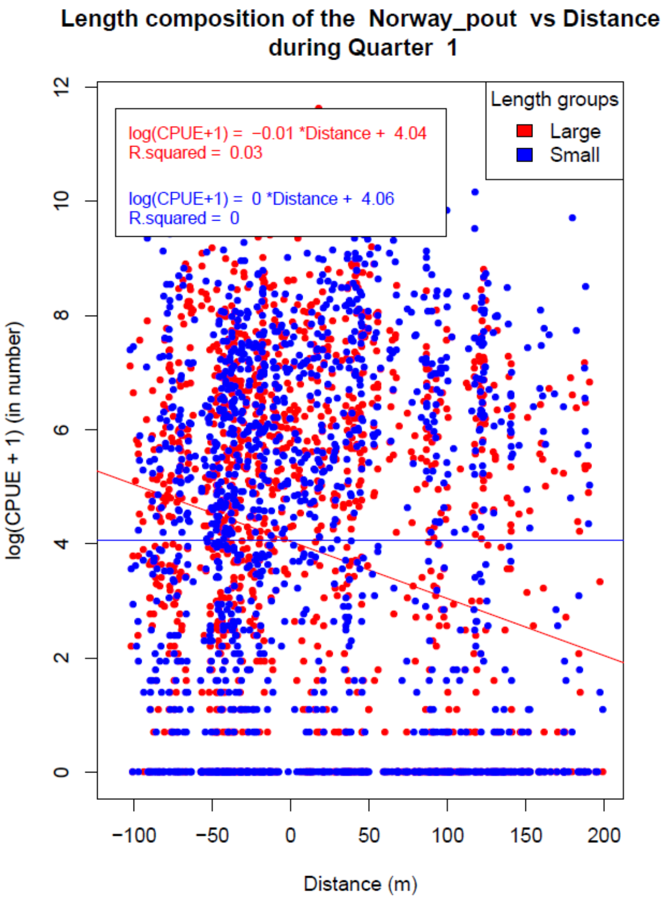

Length composition of the saithe vs Distance
during Quarter 3
log(CPUE+1) = 0 *Distance + 0.44
R.squared = 0.1
log(CPUE+1) = 0.01 *Distance + 0.68
R.squared = 0.12
Length groups
Large
Small
log(CPUE + 1) (in number)
Distance (m)

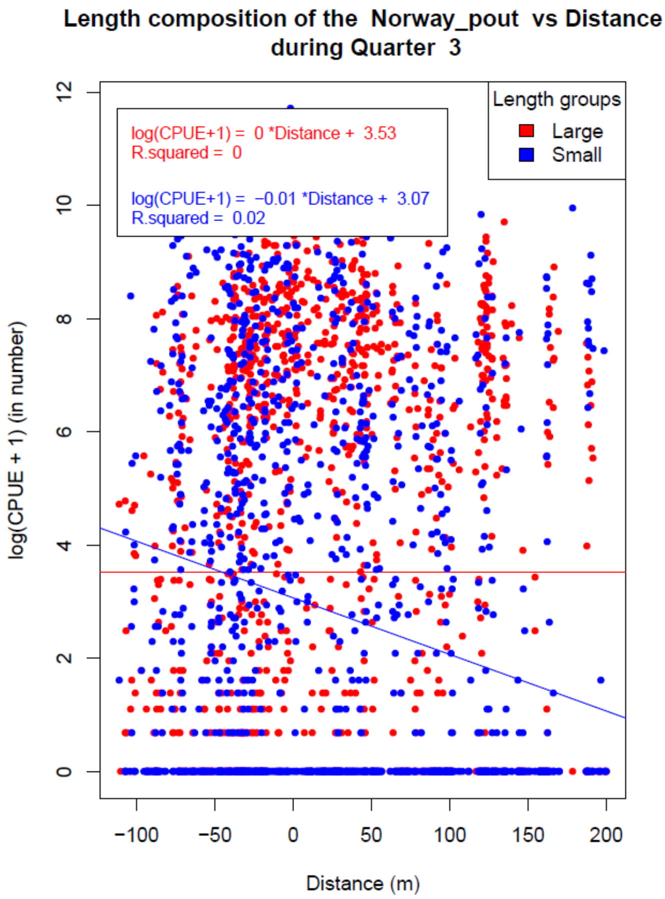

Length composition of the Norway_pout vs Depth
during 1 INSIDE
log(CPUE+1) = 0.06 *Depth + −1.05
R.squared = 0.28
log(CPUE+1) = 0.04 *Depth + 0.61
R.squared = 0.1
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)


Length composition of the Norway_pout vs Depth
during 1 OUTSIDE
log(CPUE+1) = 0.07 *Depth + −3.68
R.squared = 0.58
log(CPUE+1) = 0.07 *Depth + −3.31
R.squared = 0.52
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

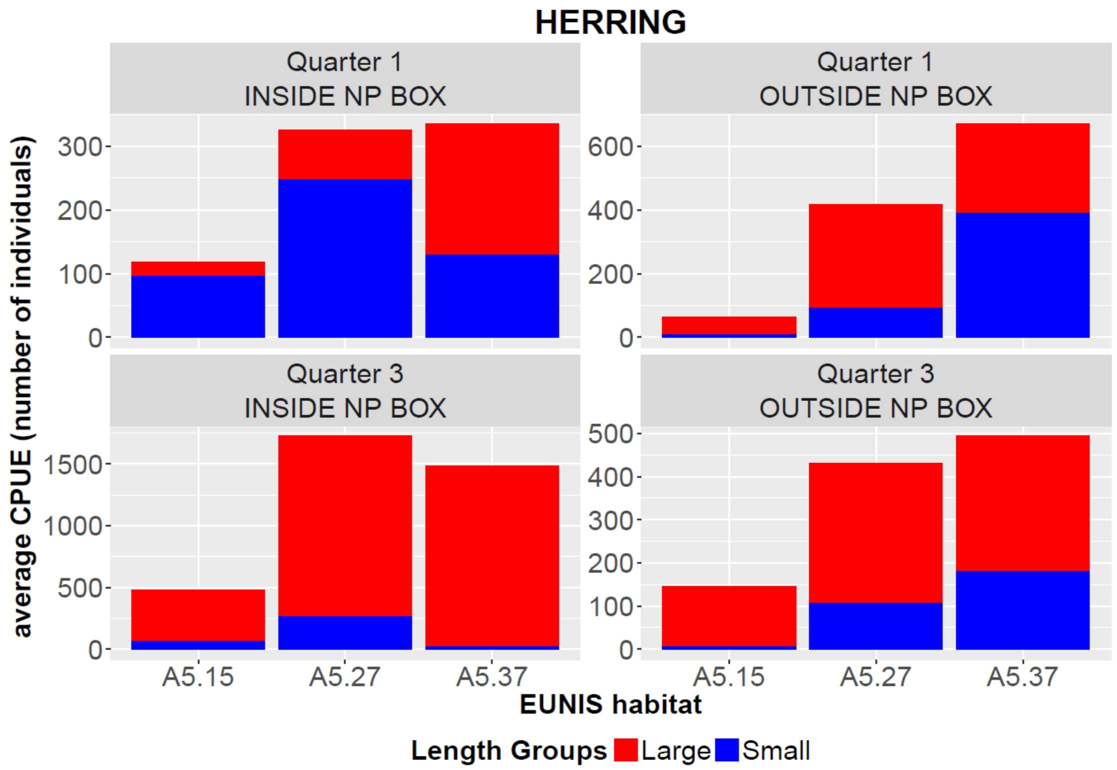

Length composition of the Norway_pout vs Depth
during 3 INSIDE
log(CPUE+1) = 0.11 *Depth + −6.53
R.squared = 0.6
log(CPUE+1) = 0.05 *Depth + −0.75
R.squared = 0.09
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

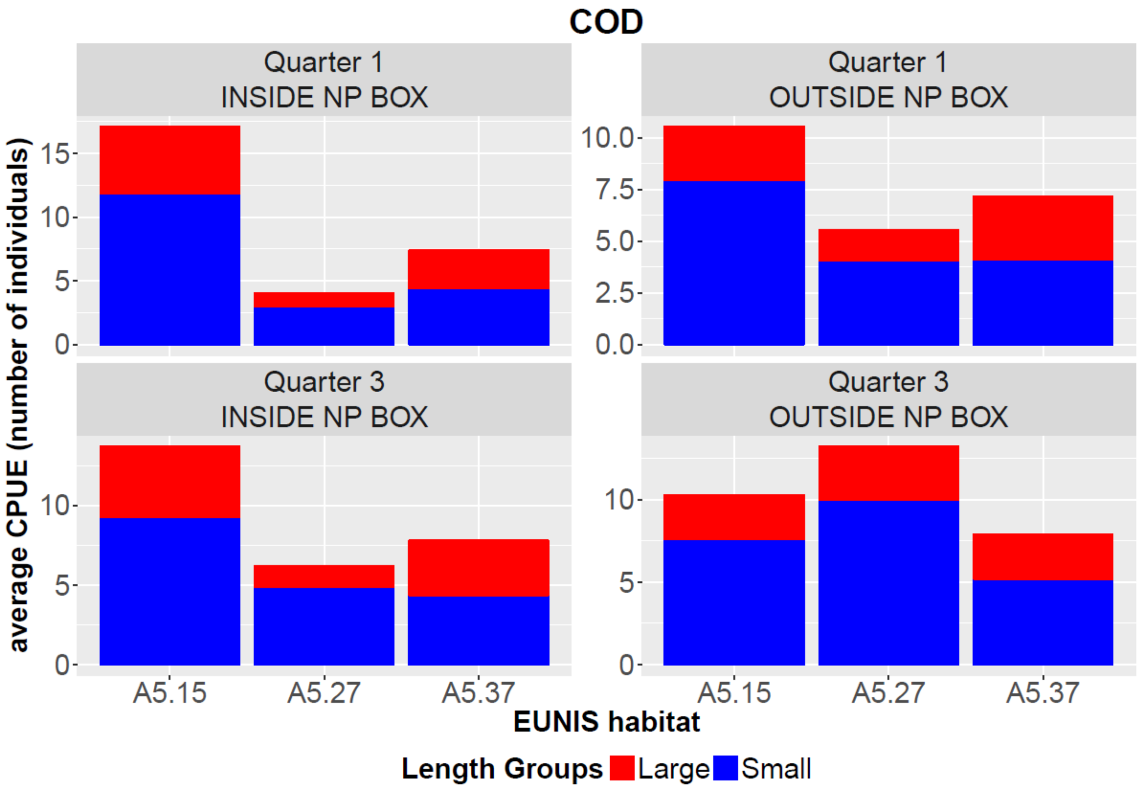

Length composition of the Norway_pout vs Depth
during 3 OUTSIDE
log(CPUE+1) = 0.08 *Depth + −5.21
R.squared = 0.63
log(CPUE+1) = 0.02 *Depth + −0.08
R.squared = 0.06
Length groups
Large
Small
log(CPUE + 1) (in number)
Depth (m)

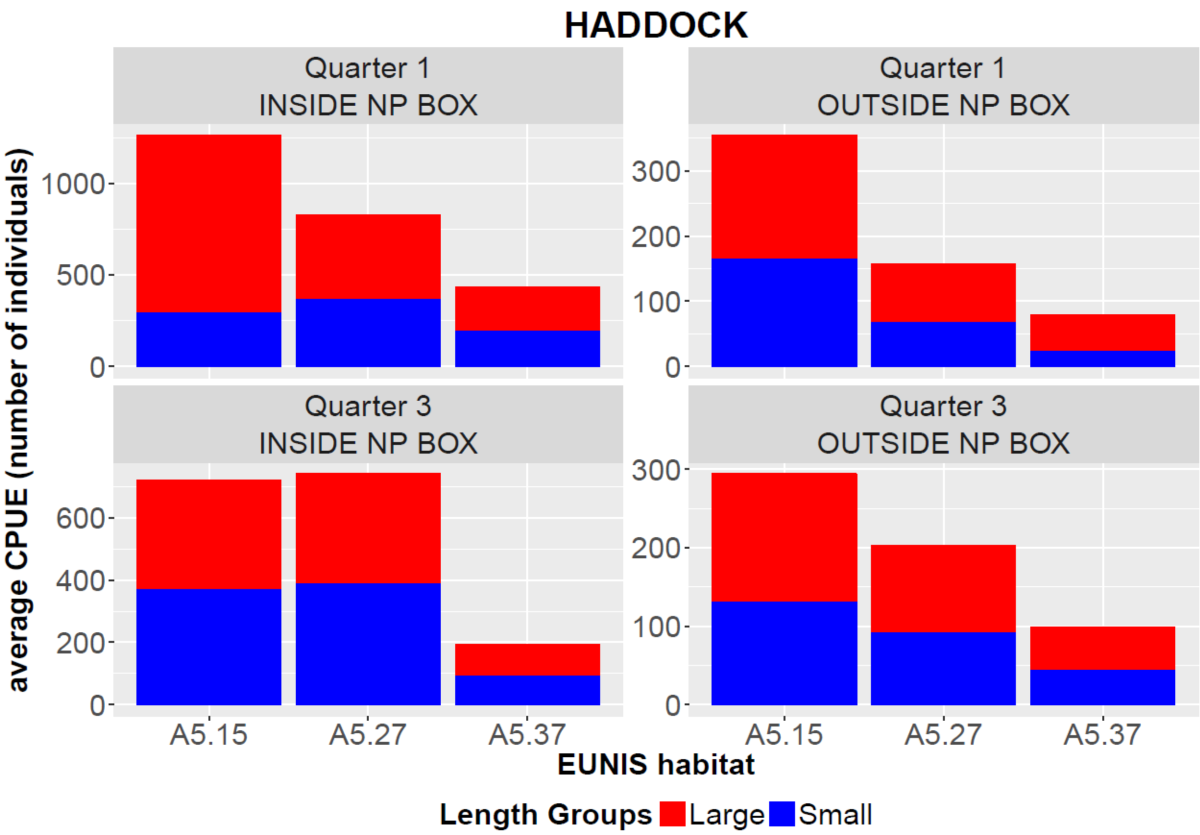

Length composition of the Norway_pout vs Distance
during Quarter 1
log(CPUE+1) = −0.01 *Distance + 4.04
R.squared = 0.03
log(CPUE+1) = 0 *Distance + 4.06
R.squared = 0
Length groups
Large
Small
log(CPUE + 1) (in number)
Distance (m)

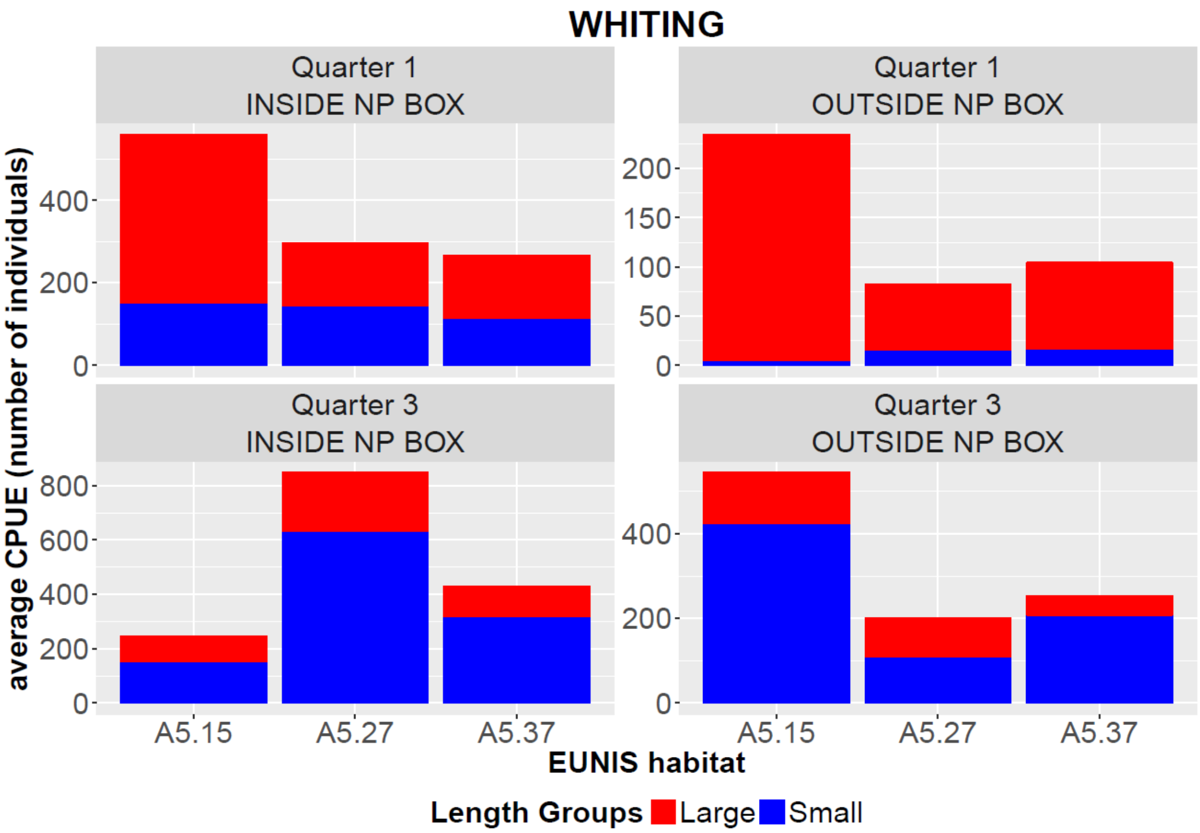

Length composition of the Norway_pout vs Distance
during Quarter 3
log(CPUE+1) = 0 *Distance + 3.53
R.squared = 0
log(CPUE+1) = −0.01 *Distance + 3.07
R.squared = 0.02
Length groups
Large
Small
log(CPUE + 1) (in number)
Distance (m)

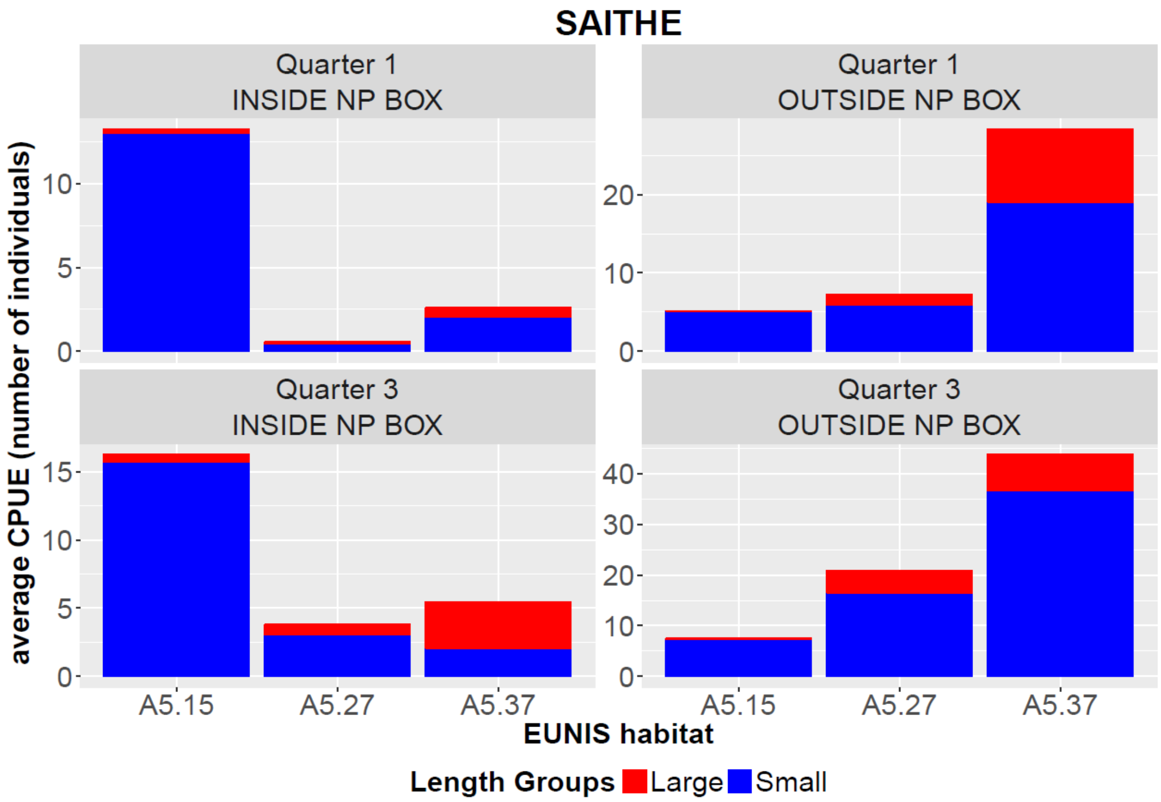
Appendix G2: Initial analyses to determine dependencies in length composition of Norway pout and important by-catch species according to EUNIS benthic habitat and season of year in relation to the Norway pout box based on NS-IBTS data

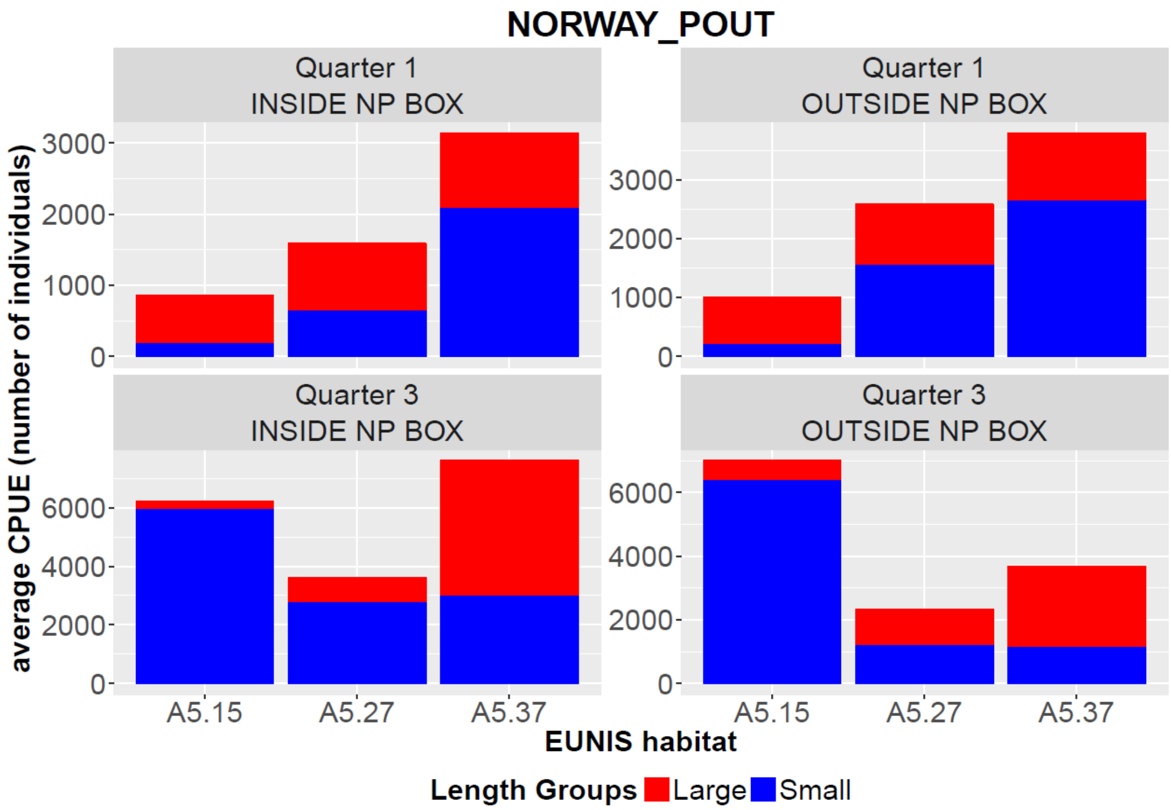





HADDOCK
Quarter 1
INSIDE NP BOX
Quarter 1
OUTSIDE NP BOX
Quarter 3
INSIDE NP BOX
Quarter 3
OUTSIDE NP BOX
average CPUE (number of individuals)
1000
500
0
300
200
100
600
400
A5.15
A5.27
A5.37
EUNIS habitat
Length Groups
Large
Small


WHITING
Quarter 1
INSIDE NP BOX
Quarter 1
OUTSIDE NP BOX
Quarter 3
INSIDE NP BOX
Quarter 3
OUTSIDE NP BOX
average CPUE (number of individuals)
400
200
0
150
100
50
800
600
A5.15
A5.27
A5.37
EUNIS habitat
Length Groups
Large
Small


SAITHE
Quarter 1
INSIDE NP BOX
Quarter 1
OUTSIDE NP BOX
Quarter 3
INSIDE NP BOX
Quarter 3
OUTSIDE NP BOX
average CPUE (number of individuals)
A5.15
A5.27
A5.37
EUNIS habitat
Length Groups
Large
Small


NORWAY_POUT
Quarter 1
INSIDE NP BOX
Quarter 1
OUTSIDE NP BOX
Quarter 3
INSIDE NP BOX
Quarter 3
OUTSIDE NP BOX
average CPUE (number of individuals)
A5.15
A5.27
A5.37
EUNIS habitat
Length Groups
Large
Small

Appendix H1: Investigation of the linear or non-linear effect of the explaining variables based on models using a negative binomial distribution or a Tweedie distribution for survey data during first quarter

Species	Length group	Distribution family	Scenario Number	Coefficients: EUNIS benthic habitats level 3	Coefficients: Haul Duration	Coefficients: Depth	Coefficients: Distance	R.squared	Explained deviance	AIC	Comments
MELANOGRAMMUS AEGLEFINUS	SMALL	negbin	1	S	S			0,338	51,70%	13671	residuals look fine
			2	S	S	S in interaction with EUNIS only		0,344	53,10%	13628	
			3	S	S		S in interaction with EUNIS only	0,339	52,30%	13658	
			4	S	S	S in interaction with EUNIS and EUNIS:Distance only	S in interaction with EUNIS and EUNIS:Depth only	0,351	54%	13607	
			5	S in interaction with Depth and Distance only	S	S	S	0,341	56,90%	13551	
			6	S	S	S	S	0,344	58,10%	13523	
	LARGE	negbin	1	NS	NS			0,325	63,10%	15960	residuals look fine
			2	S	NS	S		0,315	64,30%	15913	
			3	NS	NS		S	0,34	63,30%	15956	
			4	S	NS	S	S	0,334	65,10%	15888	
			5	S in interaction with Depth and Distance only	NS	S	S	0,35	68,20%	15784	
			6	S in interaction with Depth and Distance only	NS	S	S	0,333	68,70%	157781	
MERLANGIUS MERLANGUS	SMALL	tweedie	1	NS	S			0,461	66,20%	10937	very slight spatial autocorrelation and residuals with higher values than the one for the negbin (but no noticeable pattern)
			2	NS	S	NS		0,432	66,60%	10926	
			3	S in interaction with Distance only	S		S in interaction with A5.27 only	0,467	66,80%	10915	
			4	S in interaction with Distance and with Distance:Depth only	S	S in interaction with Distance and A5.37 only	S in interaction with A5.27, A5.37 and Depth:A5.37	0,464	67,30%	10897	
			5	S in interaction with Depth and Distance only	S	S in interaction with A5.27 and A5.37	S in interaction with A5.27 only	0,47	68,00%	10890	
			6	NS	S	S in interaction with Depth and A5.27 only	S in interaction with Depth and A5.27 only	0,482	69,00%	10877	
	LARGE	negbin	1	S	S			0,195	41,70%	15379	very slight spatial autocorrelation
			2	NS	S	S		0,149	43%	15346	
			3	S	S		NS	0,199	41,90%	153778	
			4	NS	S	S	NS	0,141	43,40%	15344	
			5	S	S	S	S	0,174	48,60%	15242	
			6	S	S	S	S	0,198	49,90%	15215	

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the meaning of scenario numbers, see the table 2 in section 2.1.3.1.

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Species	Length group	Distribution family	Scenario Number	Coefficients				R.squared	Explained deviance	AIC	Comments
				EUNIS benthic habitats level 3	Haul Duratio	Depth	Distance				
TRISOPTERUS ESMARKII	SMALL	tweedie	1	S	S			0,305	47%	17184	slight spatial correlation between residuals and residuals of higher amplitude than the one from the negbin
			2	S	S	S		0,291	47%	17169	
			3	S	S		S in interaction with A5.27 only	0,305	47%	17179	
			4	S as main effect and in interaction with Depth	S	S as main effect and in interaction with EUNIS	NS	0,289	48%	17164	
			5	S	S	S in interaction with A5.15 and A5.27 only	S in interaction with A5.27	0,288	50%	17122	
			6	S	S	S in interaction with Distance:A5.15 and	S in interaction with Depth:A5.15 and Depth:A5.27 only	0,332	51%	17103	
	LARGE	negbin	1	S	NS			0,07	37,8%	17143	slight spatial correlation between residuals
			2	S as main effect and in interaction with Depth	NS	S and the interaction with EUNIS as well		0,04	39,4%	17096	
			3	S	NS		S in interaction with A5.37 only	0,04	38,4%	17133	
			4	S as main effect and with simple inetraction terms	NS	S and interaction with EUNIS as well	S and interaction with EUNIS as well	0,23	40,7%	17071	
			5	S	NS	S	S in interaction with A5.15 only	0,09	41,0%	17075	
			6	S	NS	S	S	0,08	41,2%	17073	
GADUS MORHUA	SMALL	negbin	1	S	S			0,27	30,8%	6719	residuals look fine
			2	S as main effect and in interaction with Depth	S	S and the interaction with EUNIS as well		0,27	30,7%	6724	
			3	S as main effect and in interaction with Distance	S		S and the interaction with EUNIS as well	0,28	31,8%	6702	
			4	NS	S	S as main effect only	NS	0,26	31,7%	6710	
			5	S as main effect and in interaction with Depth	S	S in interaction with A5.15 and A5.27 only	NS	0,28	32,6%	6701	
			6	NS	S	S in interaction with A5.15 only	S in interaction with A5.15 only	0,30	34,1%	6697	
	LARGE	negbin	1	NS	NS			0,39	53,5%	4047	slight pattern in Depth and Distance residuals
			2	S as main effect and in interaction with Depth	NS	S and the interaction with EUNIS as well		0,23	53,4%	4042	
			3	NS	NS		NS	0,39	53,4%	4052	
			4	S as main effect and in interaction with Depth	NS	S as main effect and in interaction with EUNIS	NS	0,22	53,3%	4050	
			5	S as main effect and in interaction with Depth	NS	S	NS	0,44	54,6%	4037	
			6	NS	NS	S	S	0,30	54,1%	4052	

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the meaning of scenario numbers, see the table 2 in section 2.1.3.1.

Species	Length group	Distribution family	Scenario Number	Coefficients				R.squared	Explained deviance	AIC	Comments
				EUNIS benthic habitats level 3	Haul Duration	Depth	Distance				
POLLACHIUS VIRENS	SMALL	tweedie	1	S	NS			0,296	71,2%	3498	strong pattern in Distance, Depth residuals and strong correlation between spatial residuals
			2	S	NS	NS		0,284	71,7%	3494	
			3	S	NS		S in interaction with EUNIS only	0,304	71,5%	3498	
			4	NS	NS	NS	NS	0,303	72,0%	3497	
			5	NS	NS	NS	NS	0,328	72,6%	3494	
			6	S in interaction Depth:Distance only	NS	S in interaction with A5.37:Distance only	S in interaction with A5.37:Depth only	0,32	73,1%	3509	
	LARGE	negbin	1	NS	NS			0,347	80,9%	1694	strong pattern in Distance, Depth residuals and strong correlation between spatial residuals
			2	NS	S	NS		0,356	81,0%	1696	
			3	NS	S		S in interaction with EUNIS only	0,352	81,3%	1689	
			4	NS	S	S in interaction with EUNIS:Distance only	S in interaction with EUNIS:Depth only	0.357	81,5%	1694	
			5	NS	S	NS	NS	0.386	82,1%	1696	
			6	NS	S	S	S	0,392	83,3%	1680	
CLUPEA HARENGUS	SMALL	All the tested models give negative Rsquared									
	LARGE										

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the meaning of scenario numbers, see the table 2 in section 2.1.3.1.

Appendix H2: Investigation of the distribution to be used based on models for survey data during first quarter and third quarter

Species	Length group	Quarter	Scenario Number	Family	Coefficients: EUNIS benthic habitats level 3	Coefficients: HaulDur	Coefficients: Depth	Coefficients: Distance	R.squared	Explained deviance	AIC	Comments
NORWAY POUT	Small	Q1	5	negbin	S except in interaction with Distance	NS	S in interaction with A5.15 and A5.27	NS	-0,188	42,10%	17358	slight spatial correlation
			5	tweedie	S	NS	S in interaction with A5.15 and A5.27	S in interaction with A5.27	0,254	51,20%	17379	slight spatial correlation and dispersion relatively important
			Delta with 5	Binomial	S in interaction with Depth only	NS	S	NS	0,449	44,90%		spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S in interaction with Depth and Distance	NS	S in interaction with A5.15 and A5.27	S in interaction with A5.27	0,484	51%		residuals look fine
		Q3	5	negbin	S as main effect and in interaction with Depth	NS	S	S in interaction with A5.15 and A5.27	-89,6	40,40%	13592	spatial correlation and overfit
			5	tweedie	S	S	S	S in interaction with A5.15 only	-0,568	42,20%	13603	overfit
			Delta with 5	Binomial	S in interaction with Depth only	NS	S	NS	0,369	34,20%		slight spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S in interaction with Depth only	NS	S	NS	0,336	38,20%		residuals look fine
	Large	Q1	5	negbin	S	NS	S	S in interaction with A5.15 only	0,0928	40,90%	17053	slight spatial correlation
			5	tweedie	S	NS	S	S in interaction with A5.15 only	0,198	47,30%	17164	slight spatial correlation and larger dispersion
			Delta with 5	Binomial	S in interaction with Depth only	NS	S	NS	0,41	41%		spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S in interaction with Depth only	NS	S	NS	0,445	47,20%		residuals look fine
		Q3	5	negbin	S	S	S in interaction with A5.15 and A5.27	S in interaction with A5.15 and A5.37	-2,65	64,50%	14790	spatial correlation and overfit
			5	tweedie	S	S	S in interaction with A5.15 and A5.27	S in interaction with A5.15 only	0,38	67,30%	14623	slight trend in Depth residuals, slight overfit and larger dispersion of residuals
			Delta with 5	Binomial	S in interaction only	NS	S	S in interaction with A5.37 only	0,649	62,10%		spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S in interaction only	S	S	NS	0,62	65,20%		residuals look fine

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the precise formulas, see the table 3 in the section 3.1.3.

Species	Length group	Quarter	Scenario Number	Family	Coefficients				R.squared	Explained deviance	AIC	Comments
					EUNIS benthic habitats level 3	HaulDur	Depth	Distance				
COD	Small	Q1	5	negbin	S in interaction with Depth only	S	S in interaction with A5.15 and A5.27	NS	0,281	32,60%	6695	residuals look fine
			5	tweedie	S in interaction with Depth only	S	S in interaction with A5.15 and A5.27	NS	0,311	35,80%	6977	slightly larger dispersion of the residuals
			Delta with 5	Binomial	S in interaction with Depth only	NS	S in interaction with A5.27	NS	0,125	13,90%		slight trend in Depth residuals,
				Log-N	NS	NS	NS	NS	0,273	30,90%		residuals look fine
		Q3	5	negbin	S	S	S in interaction with A5.15 and A5.27	S in interaction with A5.15 only	-0,297	35,70%	7609	slight spatial correlation
			5	tweedie	S	S	S	S in interaction with A5.15 only	0,239	37%	7880	slight spatial correlation and larger dispersion of the residuals
			Delta with 5	Binomial	S in interaction only	NS	S in interaction with A5.37 only	S in interaction with A5.15 only	0,25	26,30%		spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S	S	S in interaction with A5.15 and A5.37	S in interaction with A5.15 only	0,3	34,20%		residuals look fine
	Large	Q1	5	negbin	S	NS	S	NS	0,419	53,30%	4024	slight trend in Distance and Depth residuals
			5	tweedie	S	S	S	NS	0,487	55,70%	4149	larger dipersion of the residuals and trend in Distance and Depth residuals
			Delta with 5	Binomial	S in interaction with Depth only	NS	S	NS	0,268	23%		trend in Depth residuals
				Log-N	S in interaction with Depth only	NS	S	NS	0,436	47,80%		spatial correlation
		Q3	5	negbin	S	S	S	NS	0,473	69,50%	3670	spatial correlation and trends in the residuals of Distance and Depth
			5	tweedie	S	S	S	NS	0,506	67%	3823	spatial correlation, trends in the residuals of Distance and Depth and larger dispersion of the residuals
			Delta with 5	Binomial	S in interaction with Depth only	S	S in interaction with A5.27 and A5.37	NS	0,6	55,70%		spatial correlation
				Log-N	S in interaction only	S	S in interaction with A5.15 and A5.37	S in interaction with A5.15	0,331	38,30%		spatial correlation

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the precise formulas, see the table 3 in the section 3.1.3.

Species	Length group	Quarter	Scenario Number	Family	Coefficients				R.squared	Explained deviance	AIC	Comments
					EUNIS benthic habitats level 3	HaulDur	Depth	Distance				
HADDOCK	Small	Q1	5	negbin	S	S	S in interaction with A5.27 and A5.37	S in interaction with A5.15 and A5.27	0,415	55,70%	13379	residuals look fine
			5	tweedie	S	S	S in interaction with A5.27 and A5.37	S in interaction with A5.15 and A5.27	0,475	59,20%	13795	residuals look fine but larger dispersion than with the negbin
			Delta with 5	Binomial	NS	S	NS	NS	0,375	40,30%		spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S	S	S	NS	0,534	56,10%		residuals look fine
		Q3	5	negbin	S in interaction only	S	S in interaction with A5.27 and A5.37	S in interaction with A5.15 only	0,271	44,50%	14295	residuals look fine
			5	tweedie	S in interaction only	S	S in interaction with A5.27 and A5.37	S in interaction with A5.15	0,317	50,20%	14685	residuals look fine but larger dispersion than with the negbin
			Delta with 5	Binomial	S in interaction only	S	S in interaction with A5.15 and A5.27	S in interaction with A5.27	0,237	30,60%		spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S in interaction only	NS	S in interaction with A5.27 and A5.37	S in interaction with A5.15	0,453	47,50%		residuals look fine
	Large	Q1	5	negbin	S in interaction only	NS	S	S	0,387	67,60%	15717	residuals look fine
			5	tweedie	S in interaction only	NS	S	S	0,443	69%	15993	residuals look fine but larger dispersion than with the negbin
			Delta with 5	Binomial	NS	NS	NS	NS	0,339	50%		spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S in interaction only	S	S	S	0,682	70,30%		residuals look fine
		Q3	5	negbin	S	S	S in interaction with A5.27 and A5.37	S in interaction with A5.27	0,272	56,90%	16016	slight spatial correlation
			5	tweedie	S	S	S in interaction with A5.27 and A5.37	NS	0,385	58,80%	16075	larger dipersion of the residuals
			Delta with 5	Binomial	S	S	S in interaction with A5.15 only	NS	0,54	61,30%		spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S	S	S in interaction with A5.27 and A5.37	NS	0,613	63,40%		residuals look fine

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the precise formulas, see the table 3 in the section 3.1.3.

Species	Length group	Quarter	Scenario Number	Family	Coefficients				R.squared	Explained deviance	AIC	Comments
					EUNIS benthic habitats level 3	HaulDur	Depth	Distance				
WHITING	Small	Q1	5	negbin	S	S	S in interaction with A5.27 and A5.37	S in interaction with A5.27	-5,18	63,60%	10557	overfit
			5	tweedie	S in interaction only	S	S in interaction with A5.27 and A5.37	S in interaction with A5.27	0,47	68%	10890	residuals look fine but relatively large dispersion
			Delta with 5	Binomial	S in interaction only	NS	NS	S in interaction with A5.27	0,435	41,60%		spatial correlation and slight trend in the residuals of Depth
				Log-N	S in interaction only	NS	S in interaction with A5.27	NS	0,551	57,30%		residuals look fine
		Q3	5	negbin	S	S	S	NS	-0,176	37,90%	12668	residuals look fine
			5	tweedie	S in interaction only	S	S	NS	0,164	44,20%	13124	residuals look fine but relatively large dispersion
			Delta with 5	Binomial	S in interaction only	NS	S in interaction with A5.27 only	NS	0,17	18,40%		slight trend in Depth and Distance residuals
				Log-N	S in interaction only	S	S in interaction with A5.27 and A5.37	NS	0,374	40,70%		residuals look fine
	Large	Q1	5	negbin	S	S	S	S in interaction with A5.15 and A5.27	0,147	46,80%	15194	residuals look fine
			5	tweedie	S	S	S	S	0,192	46%	15513	residuals look fine but relatively large dispersion
			Delta with 5	Binomial	S in interaction only	NS	S in interaction with A5.27	S in interaction with A5.37 only	0,198	36,60%		spatial correlation and trends in the residuals of Depth and Distance
				Log-N	S	S	S	S	0,477	50,20%		residuals look fine
		Q3	5	negbin	S	S	S	S in interaction with A5.15 and A5.37	0,245	47,30%	15633	residuals look fine
			5	tweedie	S	S	S	S in interaction with A5.15 only	0,269	48,50%	15923	slight trend in Depth residuals and relatively large dispersion
			Delta with 5	Binomial	NS	NS	NS	NS	0,443	60,20%		problems of convergence
				Log-N	S in interaction only	S	S in interaction with A5.15 and A5.37	S in interaction with A5.15 and A5.27	0,461	49,30%		residuals look fine

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the precise formulas, see the table 3 in the section 3.1.3.

Species	Length group	Quarter	Scenario Number	Family	Coefficients: EUNIS benthic habitats level 3	Coefficients: HaulDur	Coefficients: Depth	Coefficients: Distance	R.squared	Explained deviance	AIC	Comments
HERRING	Small	Q1	5	negbin	S in interaction only	S	S in interaction with A5.15 and A5.27	S in interaction with A5.37 only	-3,54	53,40%	8042	overfit
			5	tweedie	S in interaction only	S	S in interaction with A5.15 and A5.27	S in interaction with A5.37 only	-0,35	55,10%	8557	large dispersion and slight overfit
			Delta with 5	Binomial	S in interaction only	S	S in interaction with A5.27	NS	0,316	28,50%		residuals look fine
				Log-N	NS	S	NS	NS	0,377	42,30%		slight spatial correlation
		Q3	5	negbin	S in interaction only	NS	S in interaction with A5.15 and A5.27	S in interaction with A5.37 only	-0,18	45,90%	7950	trend in Depth residuals
			5	tweedie	S in interaction only	NS	S in interaction with A5.15 and A5.27	S in interaction with A5.37 only	0,0637	45,20%	8384	slight trend in Depth residuals and relatively large dispersion
			Delta with 5	Binomial	S in interaction only	NS	S in interaction with A5.27 and A5.37	S in interaction with A5.15	0,352	31,70%		trend in Depth residuals
				Log-N	S in interaction only	NS	S in interaction with A5.37 only	NS	0,209	27,10%		residuals look fine
	Large	Q1	5	negbin	S in interaction only	S	S in interaction with A5.15 and A5.37	S in interaction with A5.27	-0,675	40,30%	10493	slight overfit
			5	tweedie	S in interaction only	S	S	S in interaction with A5.27	-0,155	37,20%	11302	residuals look fine
			Delta with 5	Binomial	S in interaction with Depth only	NS	S in interaction with A5.27 and A5.37	NS	0,224	22%		slight spatial correlation and trend in Depth residuals
				Log-N	NS	NS	NS	NS	0,234	26,80%		residuals look fine
		Q3	5	negbin	S in interaction only	S	S in interaction with A5.15 and A5.27	S in interaction with A5.15	0,138	40,80%	15320	residuals look fine
			5	tweedie	S in interaction only	S	S	S in interaction with A5.15	0,233	44,30%	15813	larger dispersion of the residuals but fine
			Delta with 5	Binomial	S in interaction only	S	S in interaction with A5.27 only	NS	0,359	35%		spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S in interaction only	S	S in interaction with A5.15 and A5.27	S in interaction with A5.27	0,357	38,50%		residuals look fine

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the precise formulas, see the table 3 in the section 3.1.3.

Species	Length group	Quarter	Scenario Number	Family	Coefficients				R.squared	Explained deviance	AIC	Comments
					EUNIS benthic habitats level 3	HaulDur	Depth	Distance				
SAITHE	Small	Q1	5	negbin	NS	NS	NS	NS	-0,0632	75,10%	2982	spatial correlation, trends in the residuals of Distance and Depth and slight overfit
			5	tweedie	NS	NS	NS	NS	0,328	72,60%	3494	spatial correlation, trends in the residuals of Distance and Depth and large dispersion
			Delta with 5	Binomial	NS	NS	NS	NS	0,526	50,80%		spatial correlation and trends in residuals of Distance and Depth
				Log-N	S in interaction with Depth only	NS	S in interaction with A5.37	NS	0,349	40,40%		spatial correlation and very few observations remain
		Q3	5	negbin	S in interaction only	S	S	S in interaction with A5.15	0,182	65,20%	5130	slight trend in Distance and Depth residuals
			5	tweedie	S in interaction only	S	S in interaction with A5.15	NS	0,348	64,40%	5540	slight trend in Distance and Depth residuals and larger dispersion
			Delta with 5	Binomial	S in interaction only	S	S in interaction with A5.27	NS	0,427	37,30%		slight spatial correlation and trends in the residuals of Distance and Depth
				Log-N	S in interaction only	S	S	NS	0,492	53,10%		residuals look fine
	Large	Q1	5	negbin	NS	S	NS	NS	0,413	82,60%	1711	spatial correlation and trend in the residuals of Distance and Depth
			5	tweedie	S in interaction with Depth only	S	S in interaction with A5.27 and A5.37	NS	0,551	80%	2390	spatial correlation, trend in the residuals of Distance and Depth and larger dispersion
			Delta with 5	Binomial	S in interaction with Depth only	NS	S in interaction with A5.37	NS	0,553	57,40%		spatial correlation and trend in the residuals of Distance and Depth
				Log-N	S in interaction with Depth only	NS	S in interaction with A5.27 and A5.37	NS	0,397	47,10%		spatial correlation and very few observations remain
		Q3	5	negbin	S in interaction only	S	S in interaction with A5.27 and A5.37	S in interaction with A5.37 only	0,339	75,80%	3272	spatial correlation and trend in the residuals of Distance and Depth
			5	tweedie	S in interaction only	S	S in interaction with A5.27 and A5.37	S in interaction with A5.37 only	0,487	72,60%	3605	spatial correlation, trend in the residuals of Distance and Depth and larger dispersion
			Delta with 5	Binomial	S in interaction with Depth only	S	S in interaction with A5.27 and A5.37	NS	0,631	60,70%		spatial correlation and trend in the residuals of Distance and Depth
				Log-N	S in interaction with Depth only	S	S in interaction with A5.27 and A5.37	NS	0,378	42%		residuals look fine but few observations remain

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the precise formulas, see the table in the section 3.1.3.

Appendix H3: Investigation of the linear or non-linear effect of the explaining variables based on delta models for survey data during first quarter

Species	Length group	Distribution family	Scenario Number	Coefficients: EUNIS benthic habitats level 3	Coefficients: Haul Duration	Coefficients: Depth	Coefficients: Distance	R.squared	Explained deviance	AIC	Comments
GADUS MORHUA	SMALL	Binomial	1	NS	NS			0,103	11,10%	1603	residuals look fine
			2	NS	NS	S in interaction		0,104	11,20%	1603	residuals look fine
			3	S in interaction with Distance	NS		S	0,111	11,80%	1592	slight trend in depth residuals
			4	NS	NS	NS	S in interaction	0,114	12,40%	1587	residuals look fine
			5	S in interaction with Depth	NS	S in interaction with EUNIS A5.27	NS	0,125	13,90%	1580	residuals look fine
			6	NS	NS	NS	NS	0,138	16,60%	1573	residuals look fine
		Log-Gaussian	1	S	NS			0,265	29,6%	2713	residuals look fine
			2	NS	NS	NS		0,263	29,6%	2718	
			3	S as main effect	NS		S in interaction with A5.37	0,27	30,2%	2710	
			4	NS	NS	NS	NS	0,266	30,2%	2720	
			5	NS	NS	NS	NS	0,273	30,9%	2710	
			6	NS	NS	NS	NS	0,276	31,6%	2711	
	LARGE	Binomial	1	S	NS			0,265	23,3%	1605	slight trend in depth residuals
			2	NS	NS	S in interaction		0,268	22,8%	1589	
			3	S as main effect	NS		NS	0,265	23,5%	1609	
			4	NS	NS	S in interaction	NS	0,269	23,2%	1593	
			5	S in interaction with Depth	NS	S	NS	0,268	23,0%	1592	
			6	S in interaction	NS	S	S	0,267	22,9%	1593	
		Log-Gaussian	1	S	NS			0,416	45,6%	1436	residuals look fine
			2	S	NS	S		0,416	45,7%	1437	
			3	NS	NS		NS	0,414	45,5%	1440	
			4	NS	NS	NS	NS	0,421	46,9%	1440	
			5	S in interaction with Depth	NS	S	NS	0,436	47,8%	1419	
			6	S in interaction	NS	S in interaction with Distance:EUNISA5.37	S in interaction with Depth:EUNISA5.37	0,432	48,3%	1432	

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the meaning of scenario numbers, see the table 2 in section 2.1.3.1.

Species	Length group	Distribution family	Scenario Number	Coefficients				R.squared	Explained deviance	AIC	Comments
				EUNIS benthic habitats level 3	Haul Duration	Depth	Distance				
TRISOPTERUS ESMARKII	SMALL	Binomial	1	S	NS			0,409	39,80%	1086	trends in Depth and Distance residuals and spatial correlation
			2	NS	NS	S in interaction		0,414	40,20%	1074	
			3	S as main effect	NS		NS	0,409	39,80%	1088	
			4	NS	NS	S in interaction	NS	0,413	40,20%	1079	
			5	S in interaction with Depth	NS	S	NS	0,449	44,90%	1037	
			6	S in interaction with Distance:Depth	NS	S in interaction with Distance:EUNISA5.15 and Distance:EUNISA5.27	S in interaction with Depth:EUNISA5.15 and Depth:EUNISA5.27	0,464	47,30%	1037	
		Log-Gaussian	1	S	NS			0,475	49,9%	4449	residuals look fine
			2	S	S	S		0,479	50,3%	4440	
			3	S	NS		NS	0,474	49,9%	4452	
			4	S as main effect and in interaction with Depth	S	S as main effect and in interaction with EUNIS	NS	0,477	50,2%	4448	
			5	S in interaction	NS	S in interaction with A5.15 and A5.27	S in interaction with A5.27	0,484	51,0%	4434	
			6	S in interaction	NS	S in interaction with Distance:EUNISA5.15 and Distance:EUNISA5.27	S in interaction with Depth:EUNISA5.15 and Depth:EUNISA5.27	0,489	52,0%	4431	
	LARGE	Binomial	1	NS	NS			0,375	38,0%	1108	trends in Depth and Distance residuals and spatial correlation
			2	NS	NS	S in interaction		0,386	37,2%	1067	
			3	S in interaction with	NS		S in interaction with EUNIS only	0,382	39,1%	1098	
			4	NS	NS	S in interaction	NS	0,401	40,3%	1065	
			5	S in interaction with Depth	NS	S	NS	0,41	41,0%	1046	
			6	S in interaction	NS	S	S	0,42	42,8%	1052	
		Log-Gaussian	1	S	NS			0,409	43,4%	4550	residuals look fine
			2	S	NS	S		0,43	45,1%	4503	
			3	S in interaction	NS		NS	0,408	43,4%	4550	
			4	S in interaction with Depth	NS	S in interaction with EUNIS only	NS	0,433	45,7%	4503	
			5	S in interaction with Depth	NS	S	NS	0,445	47,2%	4486	
			6	S in interaction	NS	S	S	0,454	48,7%	4482	

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the meaning of scenario numbers, see the table 2 in section 2.1.3.1.

Species	Length group	Distribution family	Scenario Number	Coefficients				R.squared	Explained deviance	AIC	Comments
				EUNIS benthic habitats level 3	Haul Duration	Depth	Distance				
MELANOGRAMMUS ÆGLEFINUS	SMALL	Binomial	1	NS	S			0,35	37,90%	909	spatial correlation
			2	NS	S	NS		0,354	38%	906	
			3	NS	S		NS	0,349	37,90%	913	
			4	NS	S	NS	NS	0,363	38,90%	906	
			5	NS	S	NS	NS	0,375	40,30%	895	
			6	NS	S	NS	NS	0,432	46,30%	877	
		Log-Gaussian	1	S	NS			0,497	52,1%	4457	residuals look fine
			2	S	NS	S in interaction with EUNIS		0,508	53,1%	4433	
			3	S in interaction	NS		NS	0,498	52,3%	4458	
			4	S as main effect and in interaction with Depth	NS	S in interaction with EUNIS	NS	0,51	53,5%	4431	
			5	S as main effect and in interaction with Depth	NS	S in interaction with EUNIS A5.27 and EUNIS A5.37	NS	0,534	56,1%	4379	
			6	S in interaction	NS	S	S	0,54	57,4%	4378	
	LARGE	Binomial	1	NS	NS			0,263	42,6%	385	spatial correlation
			2	NS	NS	NS		0,273	44,1%	383	
			3	NS	NS		NS	0,285	44,5%	382	
			4	NS	NS	NS	NS	0,323	48,2%	377	
			5	NS	NS	NS	NS	0,339	50,0%	351	
			6	NS	NS	NS	NS	0,344	49,6%	360	
		Log-Gaussian	1	NS	S			0,637	65,2%	4356	residuals look fine
			2	S	S	S in interaction with EUNIS		0,645	66,0%	4329	
			3	NS	S		S in interaction	0,64	65,5%	4349	
			4	S as main effect and in interaction with Depth	S	S as main effect and in interaction with EUNIS	S in interaction	0,647	66,4%	4326	
			5	S in interaction	S	S	S	0,682	70,3%	4202	
			6	S in interaction	S	S	S	0,686	71,1%	4206	

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the meaning of scenario numbers, see the table 2 in section 2.1.3.1.

Species	Length group	Distribution family	Scenario Number	Coefficients: EUNIS benthic habitats level 3	Coefficients: Haul Duration	Coefficients: Depth	Coefficients: Distance	R.squared	Explained deviance	AIC	Comments
MERLANGIUS MERLANGUS	SMALL	Binomial	1	NS	S			0,421	40,20%	1112	spatial correlation and trends in Depth residuals
			2	NS	S	NS		0,423	40,40%	1113	
			3	S in interaction with Distance	S		S in interaction with EUNIS only	0,431	40,80%	1098	
			4	NS	S	NS	NS	0,431	41,00%	1105	
			5	S in interaction with Distance	S	NS	S in interaction with EUNIS A5.27 only	0,435	41,60%	1099	
			6	S in interaction	S	S in interaction with Distance:EUNISA5.27	S in interaction with Depth:EUNISA5.27	0,431	41%	1101	
		Log-Gaussian	1	NS	NS			0,543	56,2%	3510	residuals look fine
			2	S in interaction with Depth	NS	S in interaction with EUNIS only		0,548	56,9%	3502	
			3	NS	NS		NS	0,543	56,3%	3511	
			4	NS	NS	NS	NS	0,547	57,0%	3508	
			5	S in interaction with Depth	NS	S in interaction with EUNIS A5.27	NS	0,551	57,3%	3496	
			6	NS	NS	NS	NS	0,557	58,4%	3493	
	LARGE	Binomial	1	NS	NS			0,174	36,5%	397	spatial correlation
			2	NS	NS	NS		0,191	35,5%	391	
			3	NS	NS		NS	0,177	37,5%	400	
			4	NS	NS	NS	S in interaction	0,319	51,8%	374	
			5	S in interaction	NS	S in interaction with EUNIS	S in interaction with EUNIS	0,198	36,6%	383	
			6	NS	NS	NS	NS	0,213	39,5%	388	
		Log-Gaussian	1	NS	S			0,445	46,6%	4676	residuals look fine
			2	NS	S	S in interaction		0,45	47,1%	4666	
			3	NS	S		S in interaction	0,445	46,7%	4676	
			4	S in interaction with Distance	S	S in interaction	S as main effect and in interaction with EUNIS A5.37	0,453	47,6%	4663	
			5	S	S	S	S	0,477	50,2%	4610	
			6	S	S	S	S	0,482	51,2%	4608	

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the meaning of scenario numbers, see the table 2 in section 2.1.3.1.

Species	Length group	Distribution family	Scenario Number	Coefficients				R.squared	Explained deviance	AIC	Comments
				EUNIS benthic habitats level 3	Haul Duration	Depth	Distance				
CLUPEA HARENGUS	SMALL	Binomial	1	NS	S			0,308	27,60%	1555	residuals look fine
			2	NS	S	NS		0,308	27,80%	1556	
			3	NS	S		NS	0,307	27,60%	1558	
			4	NS	S	NS	NS	0,307	27,90%	1561	
			5	S in interaction with Depth	S	S in interaction with EUNIS A5.27	NS	0,316	28,50%	1541	
			6	NS	S	NS	NS	0,319	29%	1547	
		Log-Gaussian	1	NS	S			0,364	39,9%	2873	residuals look fine
			2	NS	S	NS		0,365	40,2%	2874	
			3	NS	S		NS	0,364	40,2%	2876	
			4	NS	S	NS	NS	0,363	40,6%	2882	
			5	NS	S	NS	NS	0,377	42,3%	2872	
			6	NS	S	NS	NS	0,364	40,4%	2877	
	LARGE	Binomial	1	S	NS			0,214	21,1%	1475	spatial correlation and trends in Depth residuals
			2	NS	NS	S in interaction		0,218	21,0%	1472	
			3	S	NS		NS	0,213	21,2%	1479	
			4	NS	NS	S in interaction	NS	0,218	21,1%	1477	
			5	S in interaction with Depth	NS	S	NS	0,224	22,0%	1460	
			6	S in interaction	NS	S in interaction with Distance:EUNIS A5.15 and Distance:EUNIS A5.27	S in interaction with Depth:EUNIS A5.15 and Depth:EUNIS A5.27	0,236	25,0%	1466	
		Log-Gaussian	1	NS	NS			0,235	26,5%	4109	residuals look fine
			2	NS	NS	NS		0,234	26,7%	4113	
			3	NS	NS		NS	0,234	26,5%	4112	
			4	NS	NS	NS	NS	0,232	26,8%	4120	
			5	NS	NS	NS	NS	0,234	26,8%	4115	
			6	NS	NS	NS	NS	0,235	27,0%	4114	

S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

For the meaning of scenario numbers, see the table table 2 in section 2.1.3.1.

Species	Length group	Distribution family	Scenario Number	Coefficients				R.squared	Explained deviance	AIC	Comments
				EUNIS benthic habitats level 3	Haul Duration	Depth	Distance				
POLLACHIUS VIRENS	SMALL	Binomial	1	NS	NS			0,517	49,20%	867	spatial correlation
			2	NS	NS	NS		0,514	49,10%	872	
			3	NS	NS		NS	0,517	49,40%	868	
			4	NS	NS	NS	NS	0,514	49,10%	878	
			5	NS	NS	NS	NS	0,526	50,80%	865	
			6	NS	NS	NS	NS	0,536	51,80%	865	
		Log-Gaussian	1	S	NS			0,335	39,9%	1110	residuals look fine but very few observations remain (323)
			2	S	NS	S in interaction with EUNIS A5.37		0,337	38,6%	1102	
			3	S in interaction	NS		NS	0,321	38,3%	1115	
			4	S in interaction	NS	S in interaction with EUNIS:Distance	S in interaction with EUNIS:Depth	0,345	40,1%	1102	
			5	S in interaction with Depth	NS	S in interaction with EUNIS A5.37	NS	0,349	40,4%	1100	
			6	S in interaction	NS	S in interaction with Distance:EUNIS A5.37	S in interaction with Depth:EUNIS A5.37	0,361	42,0%	1096	
	LARGE	Binomial	1	NS	NS			0,544	56,9%	600	spatial correlation and trends in Depth residuals
			2	NS	NS	NS		0,543	56,9%	605	
			3	S in interaction with	NS		S in interaction with EUNIS only	0,549	57,2%	598	
			4	S in interaction with Distance:Depth	NS	S in interaction with Distance and Distance:EUNIS	S in interaction with Depth and Depth:EUNIS	0,548	56,9%	605	
			5	S in interaction with	NS	S in interaction with EUNIS A5.37	NS	0,553	57,4%	601	
			6	S in interaction	NS	S in interaction with Distance:EUNIS A5.27 and Distance:EUNIS A5.37	S in interaction with Depth:EUNIS A5.27 and Depth:EUNIS A5.37	0,556	57,3%	596	
		Log-Gaussian	1	NS	NS			0,388	47,7%	625	residuals look fine but very few observations remain (214)
			2	NS	NS	NS		0,377	44,8%	623	
			3	NS	NS		NS	0,392	48,9%	626	
			4	NS	NS	NS	NS	0,391	47,5%	623	
			5	S in interaction with Depth	NS	S in interaction with EUNIS A5.27 and EUNIS A5.37	NS	0,397	47,1%	618	
			6	S in interaction with Depth:Distance	NS	S in interaction with Distance:EUNIS A5.27 and Distance:EUNIS A5.37	S in interaction with Depth:EUNIS A5.27 and Depth:EUNIS A5.37	0,407	49,5%	618	

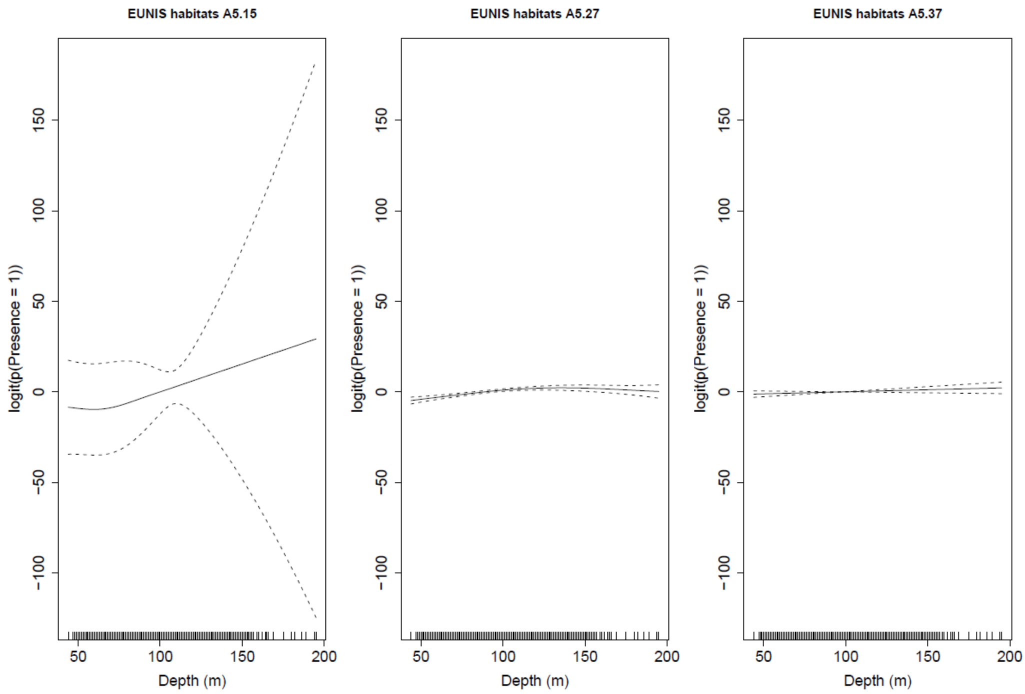
S means "significant", when it is used without other comments it just means that this factor is significant as main effect and all the interaction terms where it appears as well.

NS means "unsignificant".

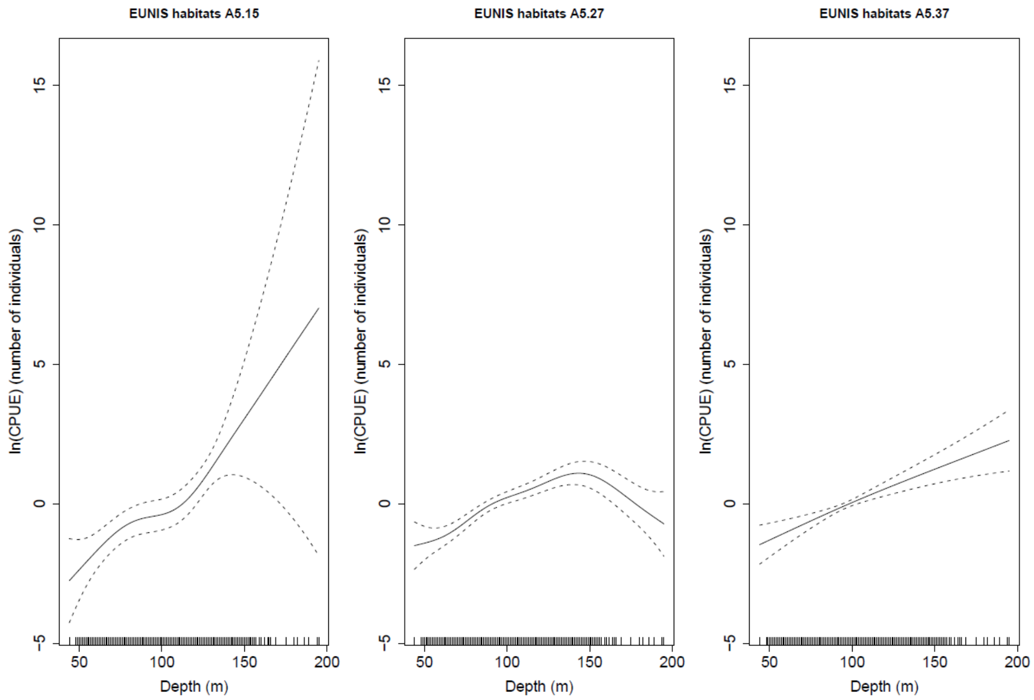
For the meaning of scenario numbers, see the table 2 in section 2.1.3.1.

Appendix I1: Outputs of the statistical analysis of the length-composition concerning large whiting during first quarter

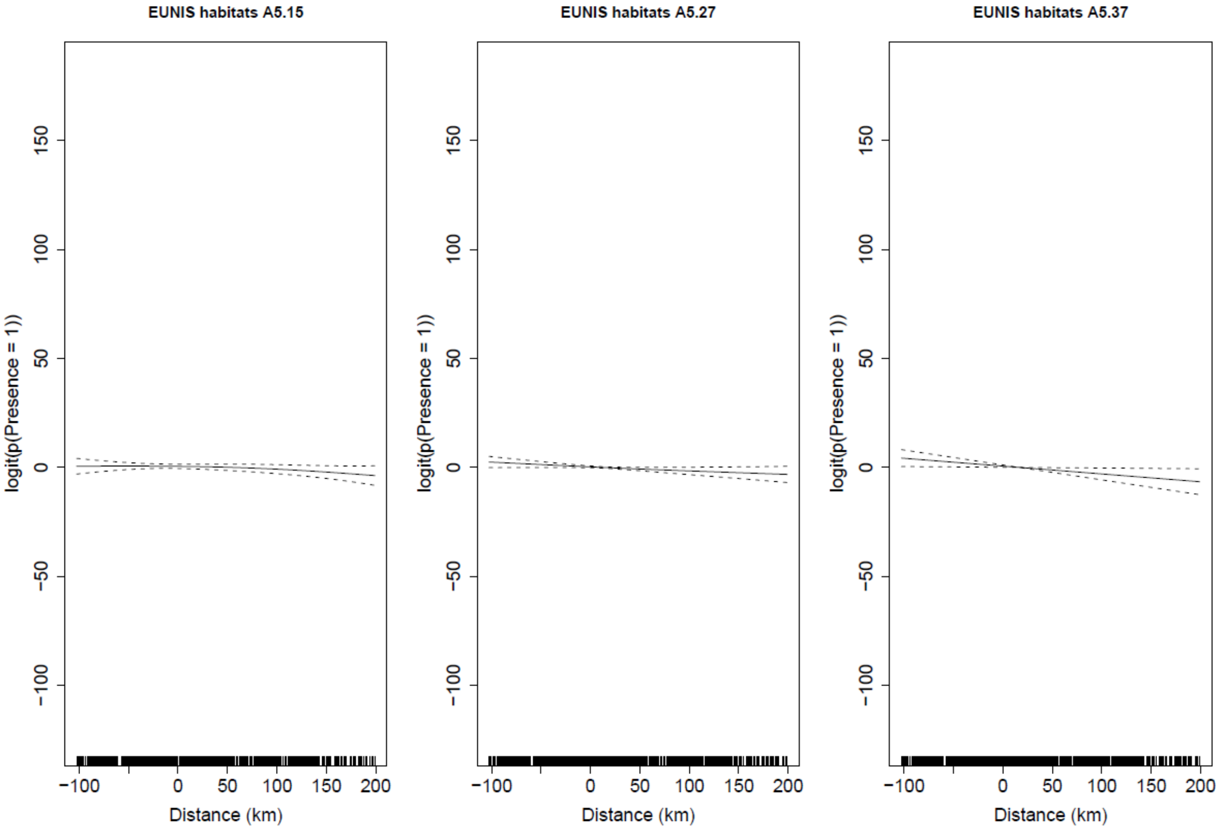
The following outputs are only given as examples. The other outputs are not included here because of space constraints but are available on request in electronic form. All the results are summarized in the tables of appendices K2 and K3.



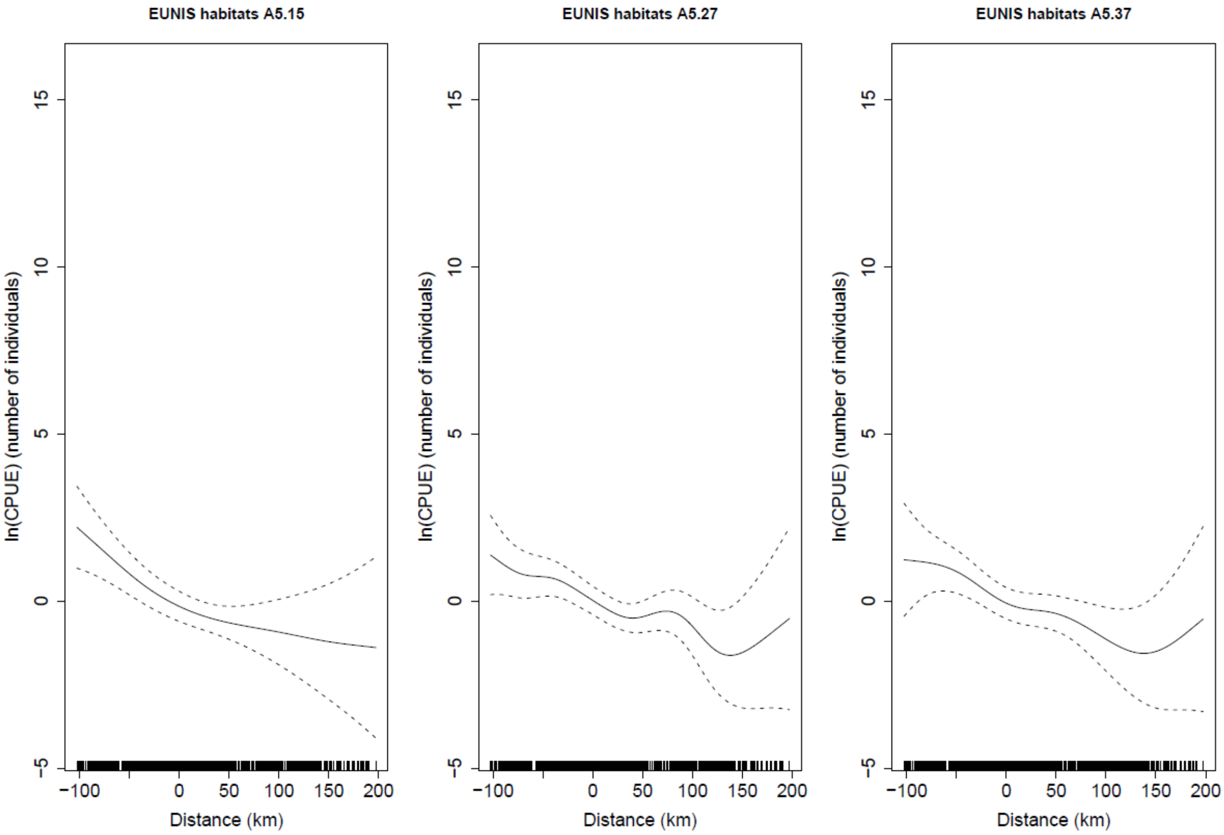
Smooth effect of Depth in the Presence model for large whiting during first quarter



Smooth effect of Depth in the Density knowing Presence model for large whiting during first quarter



Smooth effect of Distance in the Presence model for large whiting during first quarter



Smooth effect of Distance in the Density knowing Presence model for large whiting during first quarter

Appendix I2: Summary of the outputs of the statistical analysis of the length-composition of the Norway pout and the different important by-catch species concerning the distance effect

Species	Length group	Quarter	Presence model			CPUE knowing Presence model		
			EUNIS A5.15	EUNIS A5.27	EUNIS A5.37	EUNIS A5.15	EUNIS A5.27	EUNIS A5.37
COD	SMALL	1	NS	NS	NS	NS	NS	NS
		3	decreasing trend	NS	NS	slightly decreasing trend	NS	NS
	LARGE	1	NS	NS	NS	NS	NS	NS
		3	NS	NS	NS	slightly increasing trend	NS	NS
NORWAY POUT	SMALL	1	NS	NS	NS	NS	slightly increasing trend	NS
		3	NS	NS	NS	NS	NS	NS
	LARGE	1	NS	NS	NS	NS	NS	NS
		3	NS	NS	slightly increasing trend which levels off around 0 km	NS	NS	NS
HADDOCK	SMALL	1	NS	NS	NS	NS	NS	NS
		3	NS	almost flat trend	NS	convex parabolic trend (minimum around 0 - 50 km)	NS	NS
	LARGE	1	NS	NS	NS	decreasing trend which levels off around 0 km	decreasing trend leveling off around 0 km	decreasing trend leveling off around 0 km
		3	NS	NS	NS	NS	NS	NS
WHITING	SMALL	1	NS	slightly increasing trend	NS	NS	NS	NS
		3	NS	NS	NS	NS	NS	NS
	LARGE	1	NS	NS	slightly decreasing trend	decreasing trend	decreasing trend	decreasing trend
		3	NS	NS	NS	slight concave parabolic trend (maximum around 0	flat	NS
HERRING	SMALL	1	NS	NS	NS	NS	NS	NS
		3	slightly increasing trend	NS	NS	NS	NS	NS
	LARGE	1	NS	NS	NS	NS	NS	NS
		3	NS	NS	NS	NS	slightly increasing trend	NS
SAITHE	SMALL	1	NS	NS	NS	NS	NS	NS
		3	NS	NS	NS	NS	NS	NS
	LARGE	1	NS	NS	NS	NS	NS	NS
		3	NS	NS	NS	NS	NS	NS

NS means "non-significant".

Appendix I3: Summary of the outputs of the statistical analysis of the length-composition of the Norway pout and the different important by-catch species concerning the depth effect

Species	Length group	Quarter	Presence model			CPUE knowing Presence model		
			EUNIS A5.15	EUNIS A5.27	EUNIS A5.37	EUNIS A5.15	EUNIS A5.27	EUNIS A5.37
HERRING	SMALL	1	NS	increasing trend until 110 m then decreasing	NS	NS	NS	NS
		3	NS	increasing trend until 110 m then decreasing	increasing trend until 110 m then decreasing	NS	NS	decreasing trend until 80 m then increasing until 100 m then decreasing
	LARGE	1	NS	very slightly increasing trend until 130 m	very slightly increasing trend until 130 m	NS	NS	NS
		3	NS	very slightly increasing trend until 110 m	very slightly increasing trend until 110 m	increasing trend	increasing trend until 120 m	NS
WHITING	SMALL	1	NS	NS	NS	NS	very slightly increasing trend	NS
		3	NS	increasing trend until 130 m	NS	NS	increasing trend until 130 m	decreasing trend from 130 m
	LARGE	1	NS	very slightly increasing trend	NS	increasing trend until 150 m	increasing trend until 150 m then decreasing	increasing trend
		3	NS	NS	NS	decreasing trend until 120 m then increasing trend	NS	decreasing trend
HADDOCK	SMALL	1	NS	NS	NS	NS	increasing trend until 100 m then decreasing	decreasing trend
		3	slightly increasing trend	flat	NS	NS	decreasing trend from 110 m	decreasing trend from 110 m
	LARGE	1	NS	NS	NS	increasing trend until 110 m then decreasing	increasing trend until 120 m then decreasing	decreasing trend
		3	increasing trend	NS	NS	NS	increasing trend until 80 m then decreasing	decreasing trend

NS means "non-significant".

Species	Length group	Quarter	Presence model			CPUE knowing Presence model		
			EUNIS A5.15	EUNIS A5.27	EUNIS A5.37	EUNIS A5.15	EUNIS A5.27	EUNIS A5.37
SAITHE	SMALL	1	NS	NS	NS	NS	NS	slightly increasing trend
		3	NS	slightly increasing trend	NS	increasing trend until 120 m then decreasing	increasing trend	increasing trend
	LARGE	1	NS	NS	very slightly increasing trend	NS	decreasing trend until 100 m then increasing	increasing trend
		3	NS	increasing trend	increasing trend	NS	increasing trend	increasing trend
COD	SMALL	1	NS	Very slightly increasing trend	NS	NS	NS	NS
		3	NS	NS	decreasing trend from 110 m	decreasing trend	NS	slightly decreasing trend
	LARGE	1	increasing trend	increasing trend	increasing trend	slightly increasing trend until 120 m then slightly decreasing	flat	very slightly increasing trend
		3	NS	slightly increasing trend until 120 m then slightly decreasing	increasing trend until 120 m then decreasing	increasing trend until 110 m then decreasing	NS	decreasing trend from 110 m
NORWAY POUT	SMALL	1	flat	flat	very slightly increasing trend	increasing trend	increasing trend	NS
		3	slightly increasing trend	increasing trend until 100 m	increasing trend until 100 m then slightly decreasing	slightly increasing trend until 100 m	increasing trend until 110 m then decreasing	decreasing trend from 110 m
	LARGE	1	increasing trend	increasing trend	increasing trend	increasing trend	increasing trend until 150 m	increasing trend
		3	increasing trend	increasing trend	increasing trend	increasing trend	increasing trend until 150 m	increasing trend until 150 m

NS means "non-significant".

Vue d’ensemble

Le tacaud norvégien (*Trisopterus esmarkii,* en anglais « Norway pout ») est une espèce de poisson de petite taille atteignant sa maturité dès un ou deux ans et étant une proie relativement importante pour un certain nombres d’espèces démersales de la Mer du Nord. Depuis les années soixante, le tacaud ciblé par une pêcherie industrielle constituée de navires danois et norvégiens pour alimenter entre autres l’industrie aquacole en farine ou en huile de poisson. La zone de cantonnement du tacaud norvégien (« Norway pout box ») est une zone de restriction s’étendant au large des côtes écossaises et où l’activité des pêcheries ciblant le tacaud norvégien est strictement interdite de manière permanente. Cette zone de restriction fut mise en place par le gouvernement britannique en 1977afin de protéger les juvéniles présents sur les hauts fonds sableux écossais d’une pêcherie industrielle utilisant des engins à petite maille (16-35 mm) et de ce fait réputée peu sélective. Compte tenu de la distribution des pêcheries de tacaud norvégien danoises et norvégiennes, la boîte de tacaud norvégien est restrictive à l’égard de la pêcherie danoise, la pêcherie norvégienne étant plus concentrée au large des côtes norvégiennes du fait de la présence de la fosse norvégienne propice à la capture de ce petit Gadidé affectionnant les profondeurs importantes.

Dans la présente étude e, nous évaluons les effets écologiques présumés du cantonnement du tacaud norvégien sur les communautés de poissons du Nord de la Mer du Nord. Faute de données fiables antérieures à l’établissement de la boîte de tacaud norvégien, nous menons principalement une analyse spatiale (à l’intérieur ou à l’extérieur de la boîte de tacaud norvégien), l’analyse temporelle (avant/après l’établissement de la boîte de tacaud norvégien) se restreignant à un graphe indicatif. L’étude s’est concentrée uniquement sur le tacaud norvégien ainsi que sur les espèces présentant un intérêt commercial majeur dans la région et souvent citées pour être des prises accessoires importantes de la pêcherie de tacaud norvégien, à savoir : la morue de l’Atlantique (*Gadus morhua*), le hareng (*Clupea harengus*), l’églefin (*Melanogrammus æglefinus*), le lieu noir *(Pollachius virens*) et le merlan (*Merlangius merlangus*).
Dans un premier temps la composition des assemblages composés de ces six espèces est étudiée en fonction de la distance par rapport à la limite de la boîte de tacaud norvégien ainsi que de variables physiques comme la profondeur et le type d’habitat benthique (classification EUNIS,, Système d’Information Européen sur la Nature) au niveau 4. Les données relatives à cette analyse sont issues des campagnes scientifiques menées par de nombreux états en Mer du Nord et coordonnées par le CIEM (Conseil International pour l’Exploitation de la Mer) indépendantes des pêcheries commerciales présentes dans cette zone. La définition de la zone d’étude a constitué une première étape importante de ce travail. Une zone comprenant la boîte de tacaud norvégien dans sa totalité tout en étant relativement homogène sur le plan des variables spatiales devait être définie. Avoir un certain équilibre dans l’extension spatiale des zones interne ou externe à la boîte de tacaud norvégien est aussi un critère important ayant motivé la sélection spatiale des données. La composition spécifique ainsi que la répartition en taille des individus ont été analysées combinant simple étude graphique et analyse statistique. L’analyse statistique fait appel à des modèles de type GAMs (Modèles Additifs Généralisés) permettant de supposer un effet non linéaire des différentes variables explicatives, ainsi que de tenir compte des phénomènes d’autocorrélation spatiale et temporelle. Du fait de la forte agrégation de certaines espèces en bancs de taille et de dispersion variables, ont été employés des modèles delta estimant séparément la présence des individus et leur densité sachant la présence selon deux modèles stochastiques différents (binomiale et log-normale).
Dans un deuxième temps, les données du CIEM ont été combinées à des données commerciales de la pêcherie danoise de tacaud norvégien afin d’analyser quelle serait la composition des

prises accessoires de la pêcherie danoise de tacaud norvégien à l'intérieur de la boîte de tacaud norvégien si la restriction spatiale était levée. Cette combinaison des données d'une pêcherie commerciale et des données de campagne scientifique passe par le calcul d'un ratio de capturabilité propre à ces deux flottilles ainsi qu'à la zone d'étude. Ce ratio de capturabilité est estimé pour l'étroite zone de répartition de la pêcherie danoise de tacaud norvégien à l'extérieur de la boîte de tacaud norvégien. En effectuant le produit de ce ratio de capturabilité et des données issues de campagnes scientifiques disponibles pour la totalité de la zone d'étude, il est possible d'estimer quelle serait la composition des prises accessoires de la pêcherie danoise de tacaud norvégien à l'intérieur de la zone de restriction. Cependant, du fait de la grande différence de distribution des variables spatiales entre les données de campagne scientifique et les données commerciales, cette projection n'a pu tenir compte que des variations annuelles et dépendantes du type d'habitat benthique. En effet, dans la mesure où la pêcherie de tacaud norvégien est exclue de la boîte de tacaud norvégien, il n'existe presque pas de données commerciales pour des positions à l'intérieur de la boîte de tacaud norvégien et il est donc impossible d'estimer un prétendu effet de la distance par rapport aux limites de la zone. L'analyse est principalement statistique et permet par l'utilisation d'un modèle stochastique impliquant la loi de Dirichlet pour relier la composition des captures dans les débarquements de la pêcherie danoise de tacaud norvégien au type d'habitat. L'absence de données de pêcherie commerciale renseignant la taille des individus capturés empêche cependant d'étendre l'analyse de la composition en taille des espèces à une analyse de la composition en taille des prises accessoires de la pêcherie danoise de tacaud norvégien.

Les résultats démontrent que les espèces se distribuent différemment par rapport à la zone de cantonnement du tacaud. L'églefin et le merlan sont en effet présents de manière plus importante à l'intérieur de la zone de restriction (Nord-Ouest de la Mer du Nord). À l'inverse, la morue et surtout le lieu noir sont principalement distribués à l'extérieur de la zone de restriction (Nord-Est de la Mer du Nord) tandis que le hareng et le tacaud norvégien se distribuent. Malgré ces différences, la distance par rapport aux limites de la boîte de tacaud norvégien n'est que très rarement significative pour expliquer la distribution de grands ou de petits individus, exception faite des grands individus d'églefin et de merlan pendant le premier trimestre et des petits individus de morue sur substrat grossier pendant le troisième trimestre. Dans ce travail nous avançons que les effets constatés seraient davantage dus à des mouvements de population liés à la reproduction de ces espèces plutôt qu'à l'effet de la boîte de tacaud norvégien parce que depuis 2002, la pêcherie danoise de tacaud norvégien n'est quasiment active que pendant la deuxième moitié de l'année (troisième et quatrième trimestres) et est totalement absente des zones à substrat grossier.
En revanche, il est démontré que la composition des prises accessoires de la pêcherie danoise de tacaud norvégien devrait changer significativement si la boîte de tacaud norvégien était ouverte. En effet, la présence importante d'églefin et de merlan sur les hauts fonds sableux (ainsi que de hareng lors de certaines années particulières) engendrerait une augmentation significative des prises accessoires sur ces zones principalement situées à l'intérieur de la boîte de tacaud norvégien. Au contraire, les prises accessoires sont d'une ampleur relativement faible sur les substrats profonds et vaseux où la pêcherie danoise de tacaud norvégien est majoritairement active.

Le rôle de la boîte de tacaud norvégien apparaît donc comme étant ambigu. D'une part, cette zone de restriction ne semble pas être efficace quant à la protection des populations de juvéniles ce qui va à l'encontre de la justification invoquée par le gouvernement britannique pour sa mise en place. Néanmoins, elle permet indirectement de diminuer les prises accessoires de la pêcherie danoise de tacaud norvégien en excluant cette pêcherie de zones peu profondes et sableuses où les assemblages spécifiques sont moins favorables à la bonne sélectivité de cette activité. Cependant, dans la mesure où les sols profonds et vaseux compris à l'intérieur de la boîte de tacaud norvégien représentent une surface de l'ordre de la moitié de celle sur laquelle est aujourd'hui active la pêcherie danoise de tacaud norvégien, il serait envisageable de rediscuter les frontières de cette zone de restriction en tenant davantage compte pour leur mise en place de la nature du sédiment et des conditions bathymétriques. Une étude socio-économique apparaît aussi comme étant indispensable pour le diagnostic de cette zone de restriction tant est politisé le conflit entre le Royaume-Uni et l'Union Européenne (Danemark) et entre pêcherie pour la consommation humaine et pêcherie industrielle.

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Auteur(s) : **Matthieu Bigné** Date de naissance* : **15/10/1995**	Organisme d'accueil : **DTU Aqua** Adresse : **Kemitorvet** **Building 202** **2800 Kongens Lyngby** **Denmark** Maître de stage : **J. Rasmus Nielsen**
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English title : **Evaluation of ecosystem impacts of the Danish Norway pout fishery in relation to the Norway pout box management area in the northern North Sea**

Résumé :

Dans les années soixante, s'est développée en Mer du Nord une pêcherie ciblant le tacaud norvégien dont les captures sont destinées à être transformé en farine et en huile. En 1976, le gouvernement britannique mit en place une zone de gestion le long des côtes écossaises pour protéger les juvéniles de la pêcherie de tacaud norvégien réputée peu sélective. Depuis, cette pêcherie est exclue de cette « Norway pout box ». Les conséquences de cette restriction spatiale sur la composition spécifique sont étudiées ici, l´incidence sur la composition en taille de populations d'espèces commerciales également. Cette première étape repose sur des analyses graphiques ainsi que sur des analyses statistiques impliquant des modèles delta et GAM. Nous avons ensuite étudié les effets de la Norway pout box sur la composition spécifique des prises accessoires de la pêcherie danoise de tacaud norvégien en estimant la composition des captures de la pêcherie dans la Norway pout box si celle-ci était ouverte grâce à un modèle impliquant la loi de Dirichlet. Aucun effet significatif de la box concernant la protection des juvéniles n'est mis en évidence, mais cette zone de gestion semble pertinente pour protéger les fonds peu profonds et sableux où les prises accessoires d'églefin et de merlan parla pêcherie danoise de tacaud norvégien seraient significativement plus importantes.

Abstract:

In the 1960s, a small-meshed fishery for industrial purposes targeting Norway pout intensified in the northern North Sea in UK waters. The by-catch in this fishery came into debate and lead in 1977 to establishment of a closed management area along the Scottish coasts to protect other species with focus on juvenile gadoids: the so-called "Norway pout box". This study investigates ecosystem effects and environmental impacts of the Danish Norway pout fishery relative to this closure. First are conducted comparative analyses of distribution and density patterns of Norway pout and important by-catch species inside and outside the box involving initial graphical analyses of density patterns to guide and structure statistical analyses using mainly GAM and delta models. Secondly, it is assessed where the fishery affects different potential sensitive benthic habitats in relation to their relative distribution inside and outside the box. The Dirichlet distribution has been used to assess what would be the species composition of the landings inside the box. No strong patterns in size composition could be observed in relation to the box for the different species but it appears that the relative shallower and sandy grounds inside the box host relatively more haddock and whiting. A re-opening of the box would then certainly be associated with an increase of the by-catch of the Danish Norway pout fishery.

Mots-clés : analyses de données de campagne - analyses de captures de pêcherie – mer du Nord – mesures techniques de gestion - restriction spatiale – Tacaud norvégien - zone de gestion

Key Words: fishery analyses – North Sea – Norway pout - spatial fishery closure – survey analyses – statistical modeling - technical management measures

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