DTU Aqua
National Institute of Aquatic Resources

Investigating coastal fish stocks and fishery opportunities at the west coast of Denmark (Vesterhavsfisk)

Alexandros Kokkalis, Josianne G. Støttrup, Peter Munk, Grete E. Dinesen, and Elliot J. Brown

DTU Aqua Report no. 399-2022

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Preface

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Executive summary

Background: West coast of Denmark used to be an important fishing area in previous decades. Fishers in the area have reported declines in local fish populations and fishing vessels have been reduced in numbers. Fishing is taking place further North, in Skagerrak, or further off-shore. Such observations were also confirmed by previous scientific projects in the area. Nevertheless, stocks in the North Sea have been rebuilding and there is a question if the coastal areas will also see an increase in population sizes of important commercial species.

Aims of the project: Given the situation in the area, the Vesterhavsfisk project has as a main goal to investigate important species distribution changes and evaluate potential fishing opportunities in the area. The aims of the project are to i) collate existing knowledge from previous studies in the area, ii) gather new information from 2 scientific surveys along 3 transects off the Danish west coast and one transect in Skagerrak, iii) recruit commercial fishers to conduct experimental fishing using commercial style gillnets along the same transects, iv) collect stomach contents from plaice and benthic samples to investigate feeding preferences of the species along the different transects and, v) evaluate the potential of re-establishing the area as commercially and biologically sustainable fishing grounds.

Results: Commercial species were caught during the Havfisken survey, but the sizes indicate that the coastal area is mostly used by juvenile populations that are not interesting commercially. The number of fish caught during the gillnet experimental fishing were too low confirming that the area is not a viable fishing area. Stomach and benthic analyses for plaice showed differences in the feeding behaviour of the species and the faunal biodiversity from North to South. Changes in environmental conditions, like increasing temperatures closer to the shore have caused important commercial species like cod to stay away from these coastal areas during their adult stages, as they are outside their temperature tolerances.

Conclusion: The available information prior to this project, as well as the investigations carried out throughout its duration, confirmed previous observations of low commercial fishing opportunities in the area. The investigations give some first insights of the environmental conditions that lead to the decline of the populations, but the investigations should continue to be able to make sound scientific conclusions.

Background and project aims

For a number of years, commercial fishermen in Denmark have pointed out severe declines in abundance of several fish species in some historic coastal fishing grounds. A study was conducted in 2013 (Støttrup et al. 2014) to obtain an overview on the fishermen's observations and to evaluate whether existing survey data could substantiate these observations. These interviews showed that a fish stock decline was of a magnitude that forced the fishermen to change their fishing practices such as increasing fishing distance to harbour or shifting target species. The severe declines in fisheries output started in the 1980’s and effects became evident in the beginning of this century, where the number of smaller vessels in many of the coastal harbours were significantly reduced (Nielsen et al. 2013).

The species for which severe declines were most notable, were the commercially important Atlantic cod (*Gadus morhua*) and European plaice (*Pleuronectes platessa*) but declines of other species were also noted. For the two key species, cod and plaice, coastal fisheries have almost been given up along most of the Danish west coast of Jutland, from the southern border with Germany to around Hanstholm in the north. However, further north in Jammerbugt, the fisheries for both species are still active and profitable. The decline in coastal fisheries, which supported mostly smaller vessels, caused many of these fishers to either fish further offshore, change harbour, or give up fishing.

Declining trends in the abundance of coastal fish species, mainly focusing on cod and plaice have also been observed in neighbouring countries, such as the Netherlands and Sweden (Dutz et al. 2016) and attributed to changes in physical habitat attributes such as temperature and salinity, apart from fishing impacts. The displacement of plaice adults and juveniles away from the coastal North Sea area to deeper waters since the 1990’s has been attributed to temperature (Teal et al., 2012; Poos et al., 2013) possibly combined with changes in coastal nutrient loadings (Støttrup et al. 2017). In this project, we aimed to explore the present-day distribution of fish along the Danish west coast and potential fishing opportunities for commercial coastal fisheries in this area. An area, which due to its large extend, shallowness and hydrography, could be highly productive.

1. Introduction

1.1 The coastal areas off western Jutland, physics and fish

1.1.1 Bathymetry and sediment types

The area of investigation in the south-eastern North Sea is generally very shallow, the seabed declining steadily from zero at the coast to 50 m about 60 nautical miles offshore (Fig. 1.1). Extended areas of the shallowest depths 0-20 m are seen at Horns Reef, in the Wadden Sea south of Blåvandshuk, and in the Jammerbugt.

Most of the area has a flat sandy bottom, however, patches of gravel are found in specific areas (Fig. 1.2). Offshore, at bottom depths larger than 50 m, the sea floor becomes more muddy. Areas of mixed sediments of glacial origin, including larger stones are found at Jydske Rev, Lille Fisker Banke and into Skagerrak.

1.1.2 Basic hydrographic characteristics

The hydrography of the south-eastern North Sea is influenced by the general anti-clockwise circulation of water masses in the North Sea, water entering in the north-west from the Atlantic and in the south-west from the English Channel and leaving along the Norwegian Trench. In addition, freshwater enters in the south from the major rivers of the Netherlands and Germany and flows northward in the nearshore areas off Jutland. Thus, a wide area of the shallow Wadden Sea is of relatively low salinity, while the band of low saline water becomes narrower to the north (Fig. 1.3 ab). During the spring and into the late autumn, the solar energy leads to a strong temperature stratification in central areas of the North Sea, where the depth of the thermocline is basically determined by the surface mixing due to wind action. However, tidal movements also lead to mixing, which in this case, acts from the bottom waters up. The mixing in shallow areas leads to a relatively higher bottom temperature here compared to deeper areas (Fig. 1.3 cd).

The inflow of different water masses and the respective mixing processes produce water masses of different characteristics, which will be separated by so-called hydrographic fronts. In the area of investigation, off the coast of Jutland, we define three water masses separated by two fronts (Fig. 1.4). These are:

a) The nearshore waters, the Jutland Coastal Current (JCC), permanently influenced by the river freshwater outflow, and salinity generally below 32.5 ppt (PSU, practical salinity unit, ‰). The flow extends about 40 nautical miles offshore in the southernmost areas (e.g. off Fanø), when only 10 nautical miles off Thyborøn. In the summer/autumn the water of JCC is mostly above 16^{o}C).

b) The water of intermediate salinities which is periodically influenced by the runoff and the tidal mixing, called Region Of Freshwater Influence (ROFI), which has bottom salinities ranging 32.5-34.5 ppt.

c) The saline northern North Sea water of strong Atlantic influence and bottom salinities ranging 34.5-35.5 ppt. This is called Central North Sea water (CNS).

In-between these water masses we find two frontal zones: an inshore *saline front*, and more off-shore a *tidal mixing front* (Fig. 1.4). The JCC waters, inshore of the saline front, are of most relevance to the present study, however, in the northern part of the investigation area both fronts are positioned more inshore and our investigation covers a more complex zone of different water masses. The same is the case for our "area of comparison", further north still, in the Jammerbugt area. Here the described water masses, JCC, ROFI and CNS all run close to the coast. The nutrient load in the area is to a large extent linked to the waters from the large rivers, thus it is high in the JCC and as such related to salinity level (Støttrup et al 2017). We here use the described linkage between salinity and nutrient load to illustrate the distribution total nitrogen (TN) in the surface during wintertime across the present investigation area (Fig. 1.5).

1.1.3 Decadal changes in the coastal hydrography off Jutland

During the last 40 years the basic hydrography of the North Sea has changed. The overall temperature has increased when the salinity has declined. These major trends will be briefly described here, based on hydrographic CTD data from the ICES database.

Because the focus of the present investigation is primarily benthic fish, we focus on the potential changes in environmental characteristics near the bottom of the water column. As mentioned above, both bottom temperature and salinity would show some relation to water depth, thus we look into changes in these parameters within intervals of bottom depth. In Fig. 1.6 the overall averages of temperature and salinity are shown for 2 m bottom depth intervals in the range 10-50 m bottom depth. We compare averages for the two periods 1980-99 and 2000-17 (years inclusive), and because of the seasonal variability, analyses are separated into the 4 quarters (Q) of the year.

Temperature shows an increasing trend with bottom depth during the quarters Q1 and Q4, while the trend is reversed during Q2 and Q3 (Figs 1.6a-d). With few exceptions, waters at the bottom have, on average, become warmer during the latter of the two periods. The increase in temperature is most prominent in Q2, and less marked in Q4, and within a quarter it is generally of the same order irrespective of bottom depth. Figure 1.7 illustrates the trend and annual variability for the shallow area of 15-20 m bottom depth. During the period the temperature showed a general increase for the first three quarters of the year (approx. 1 °C per 30 years, 0.03 per year), while a temperature increase could not be distinguished in the Q4 data.

The magnitude and direction of the long-term changes in salinity depend on both quarter and bottom depth (Fig. 1.8a-d). For Q2-4, the data averaged for the shallow waters, at bottom depths <25 m, indicate a decline in salinity from the first 20 year period to the next, while an opposite trend of increasing salinity is seen for Q1. At depths >25m the salinities remained basically the same, with a slight tendency of decline in Q2 and Q4. In Fig. 1.9a the yearly variation in salinity is illustrated for the depth stratum 15-20 m. The measures are quite variable between years and in the overall magnitude shows a cyclic pattern during the period of investigation. This cyclic tendency is likely related to the long-term variability in the North Atlantic meteorology, as expressed by the NAO index (Fig. 1.9c). When this index is relatively high (blue bars in Fig. 1.9c), there is a tendency of larger precipitation in central/southern Europe, which increases the flow of the major rivers (Rhine, Mosel) entering the southern North Sea. This cyclic pattern influences the interpretation of long-term variability. Seen over the period 1980-2017 (Fig. 1.9a), the changes (interpreted by linear regression) are minor, seen as increasing (Q3) stagnant (Q1) or increasing (Q2 and Q4), but when seen for 1990-2017 (Fig. 1.9b) the decline is pronounced in all quarters, a decline of about 1 ppt for the three decades.

Nutrient load in the shallower areas off Jutland have changed during recent decades. The water quality regulations concerning the quality of the water that enters the North Sea from rivers, have led to a general decline in nutrient concentrations of the Jutland Coastal Current. There has for example been a reduction in total nitrogen (TN) to about 50% in water masses of same salinity during the period 1985-2015 (Støttrup et al 2017).

1.1.4 Decadal changes in fish abundances off Jutland

Description of the general trend in fish abundances are here based on the Q1 survey series of the "International Bottom Trawl Surveys". This internationally coordinated survey covers the entire Norths Sea during Q1 (mainly January-February). Here we use hauls performed in the area east of 6°E, and south of 57°30N, and calculate average catch per hour (CPUE) for hauls carried out with strata of certain bottom depths. Our interest is the shallowest areas and for our basic description of this area we use the stratum 15-25 m bottom depth, where between 10 and 20 hauls were carried out each year. Catches of nine species of commercial importance, and two non-commercial fish species were of sufficient magnitude to avail reasonable abundance estimation within this stratum (Fig. 1.10).

Five of the investigated species showed stable or slightly increasing abundances during the period. These were the two pelagic species, herring (*Clupea harengus*) and sprat (*Sprattus sprattus*), the lemon sole (*Microstomus kitt*) and the two non-commercial species, scorpionfish (*Myoxocephalus scorpius*) and hook-nose (*Agonus cataphractu*s). The abundances of the remaining species, cod, whiting (*Merlangius merlangus*), dab (*Limanda limanda*), sole (*Solea solea*), plaice and flounder (*Platichthys flesus*), declined during the period. The declines of these species' abundances led to persistently very low numbers in shallow areas, especially after the year 2000 (Fig. 1.10).

In order to inspect whether potential changes in abundances of given fish species are specific for the shallow areas, we compare the findings for the stratum 15-25 m with abundances estimated for the deeper stratum 35-45 mm (strata in Fig. 1.11). We illustrate this relationship on a log-scale which will express values above and below 1 (0 on the log-scale) by the same distances (Fig. 1.12). For a number of species, herring, sprat, flounder, whiting and lemon sole there appears no temporal change in the distributional patterns with respect to the two strata (Fig. 1.12a,c). For cod, plaice and dab the relationships decline during the period, from a generally higher abundance nearshore to a generally higher abundance offshore (Fig. 1.12b). The background for this tendency differs however between these species: 1) Dab had a relatively constant abundance offshore, while abundance inshore have been declining, 2) cod had declining abundance in both strata, the offshore decline was not as marked as for the inshore, and finally 3) plaice had increasing abundance offshore contrasting a decline inshore. The abundances of the scorpionfish are significantly higher inshore than offshore, however, during the period there have been increasing abundances offshore leading to some decline in the relationship (Fig. 1.12c).

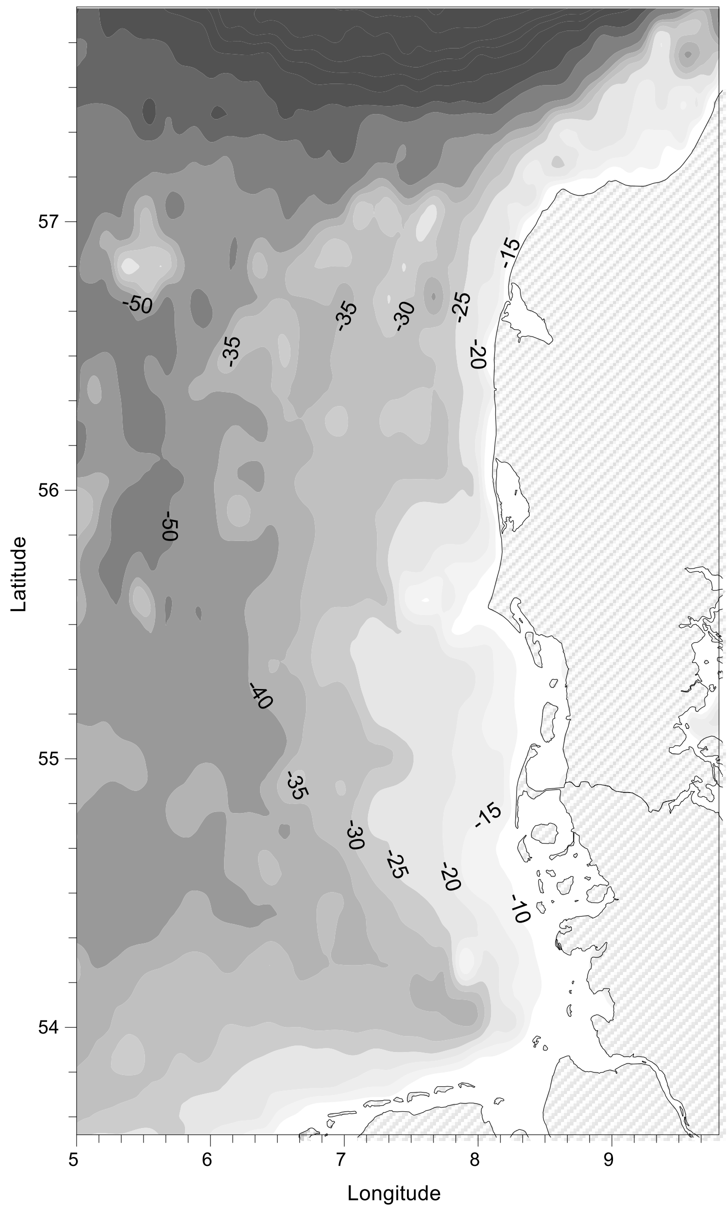

Figure 1.1. Bathymetry of the eastern North Sea. Depth interval of 5m illustrated by different shading.

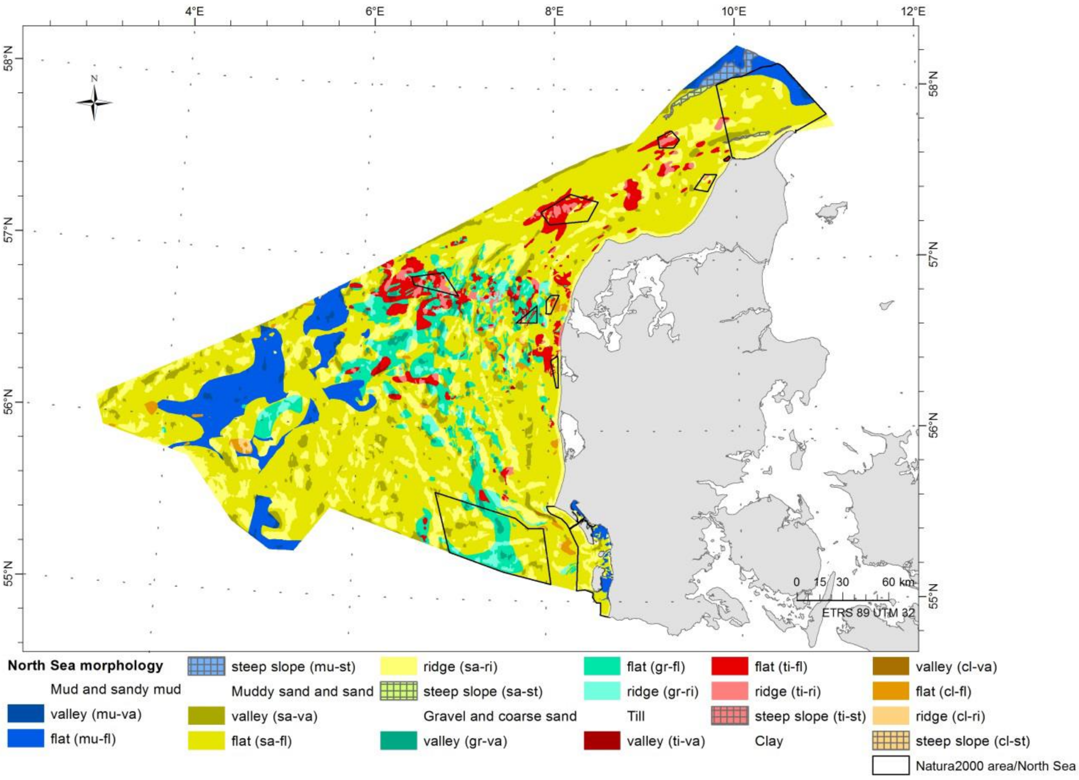

Figure 1.2. Seabed morphology map of the Danish part of the North Sea. Different characteristics of the seabed, i.e. constituents as sand and gravel as well as bottom steepness are illustrated by different colours and shadings as given by inserted legend.

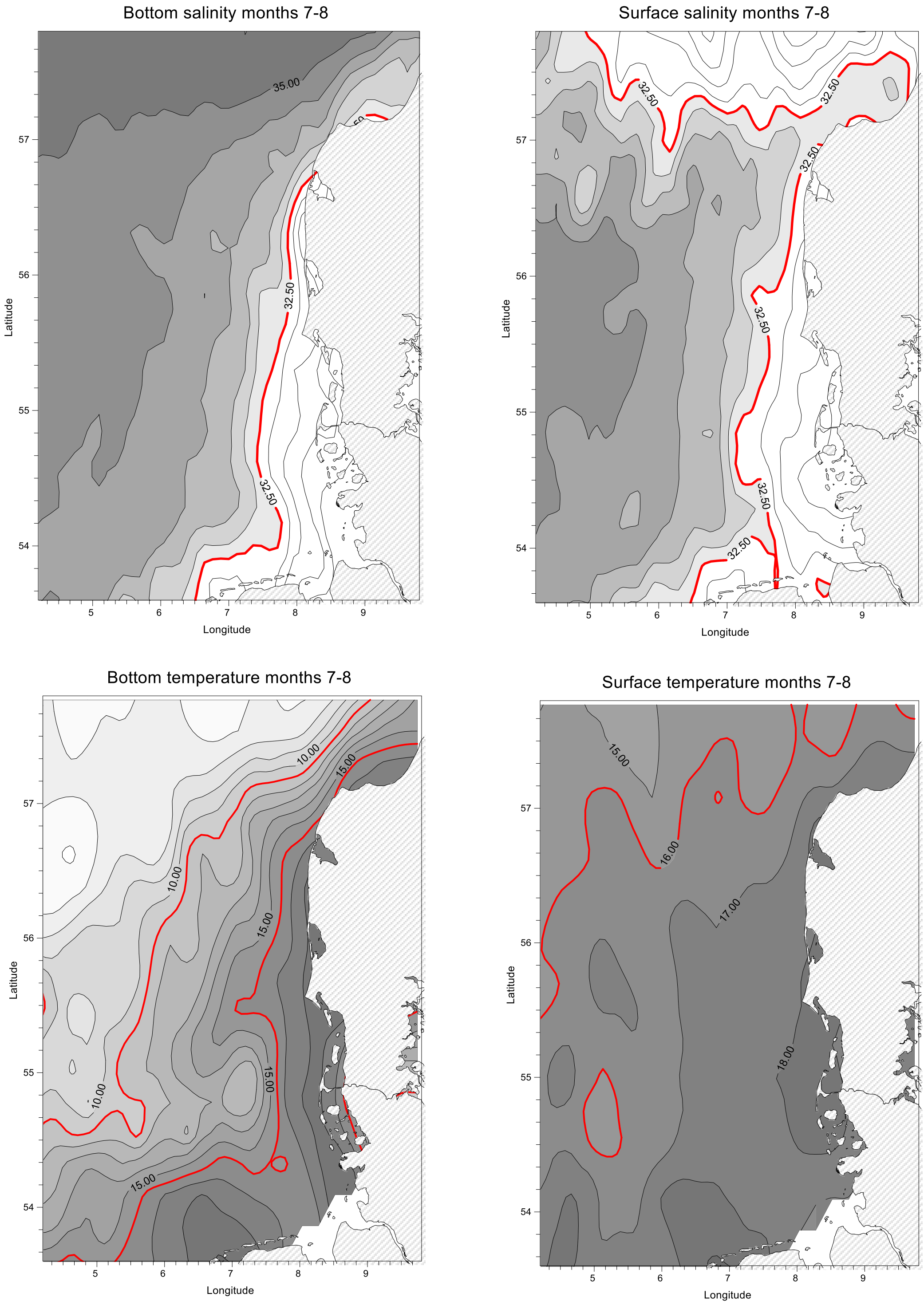

Figure 1.3. Salinity and temperature measured during July and August (months 7-8). a) Salinity at the bottom and b) at the surface, contour lines every 0.5 ppt. c) Temperature at the bottom and d) at the surface. Contour lines every 1°C.

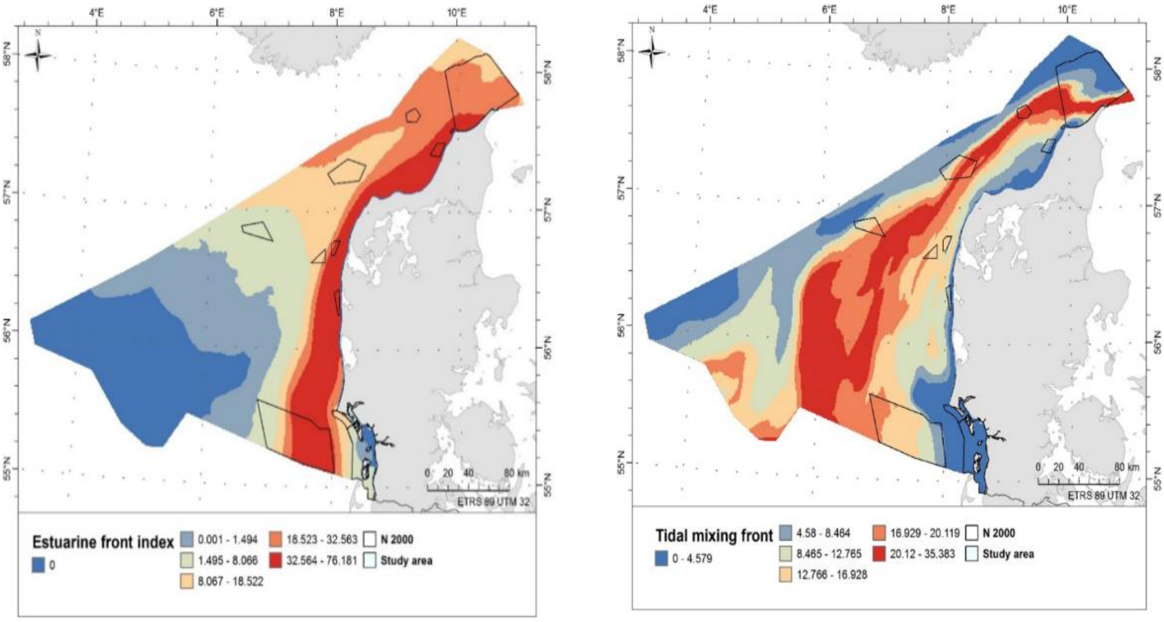

Figure 1.4. Front indices off the coast of Jutland. a) Estuarine (saline) front index, defined as the frequency of occurrence of salinity 32-33.5 during a year, in legend. b) Tidal mixing front, defined by the frequency of a surface temperature difference of 2-4°C.

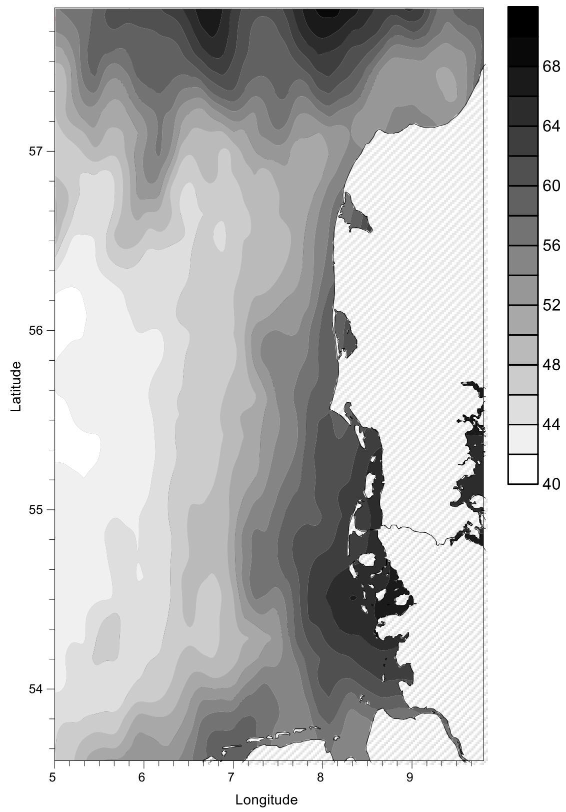

Figure 1.5. Nutrient load shown as total nitrogen in surface (µM N) estimated from salinity using coefficients for wintertime 2015 as shown in Støttrup et al. (2017).

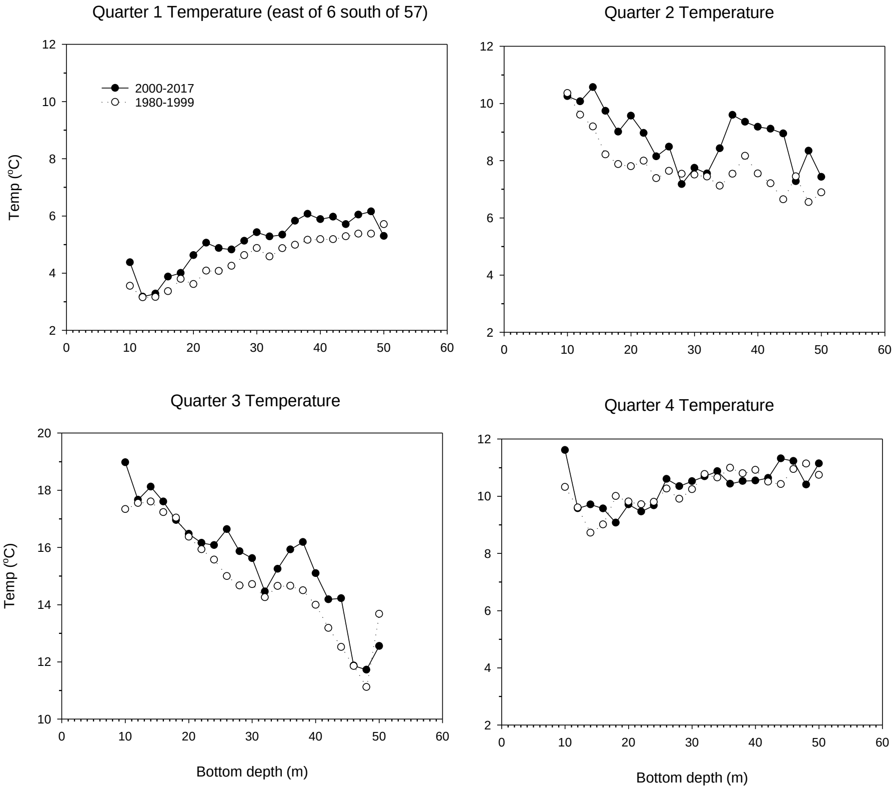

Figure 1.6. Temperature (°C) at the bottom, averages of measures within quarters of the year, and 2 m bottom intervals. Illustrated for two extended periods 1980-1999 (open symbols) and 200-2017 (closed symbols).

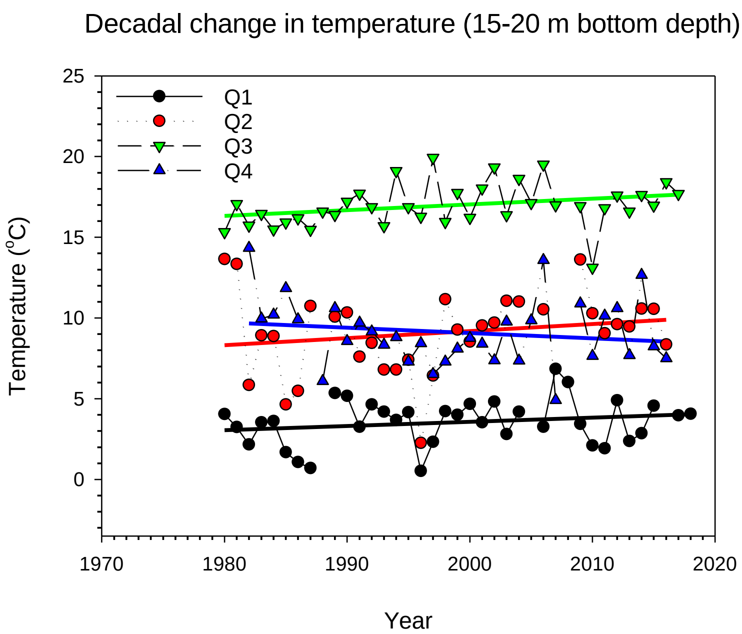

Figure 1.7. Changes in temperature (°C) at the bottom for the 15-20 m stratum. Averaged for quarters of the year, illustrated by different symbols, linear regressions inserted using colours comparable to symbols.

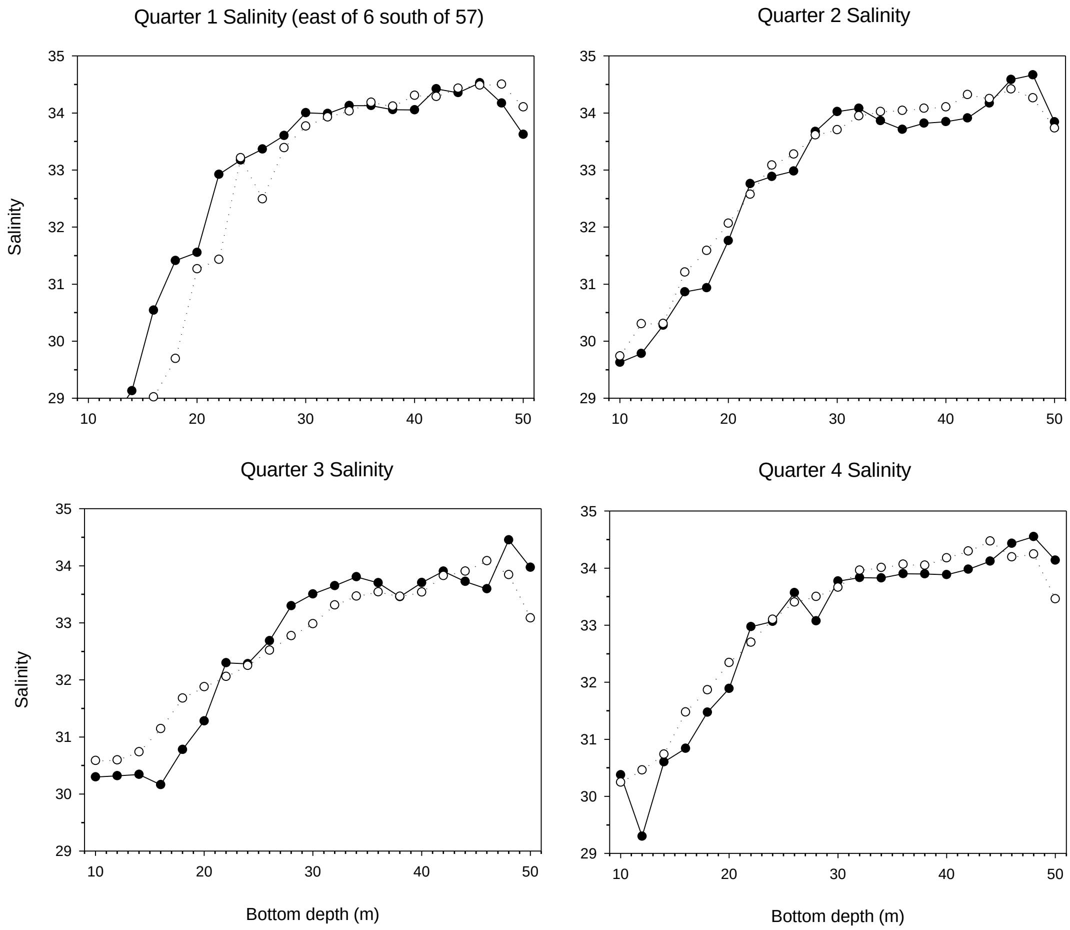

Figure 1.8. Salinity (ppt) at the bottom, averages of measures within quarters of the year, and 2 m bottom intervals. Illustrated for two extended periods 1980-1999 (open symbols) and 2000-2017 (closed symbols).

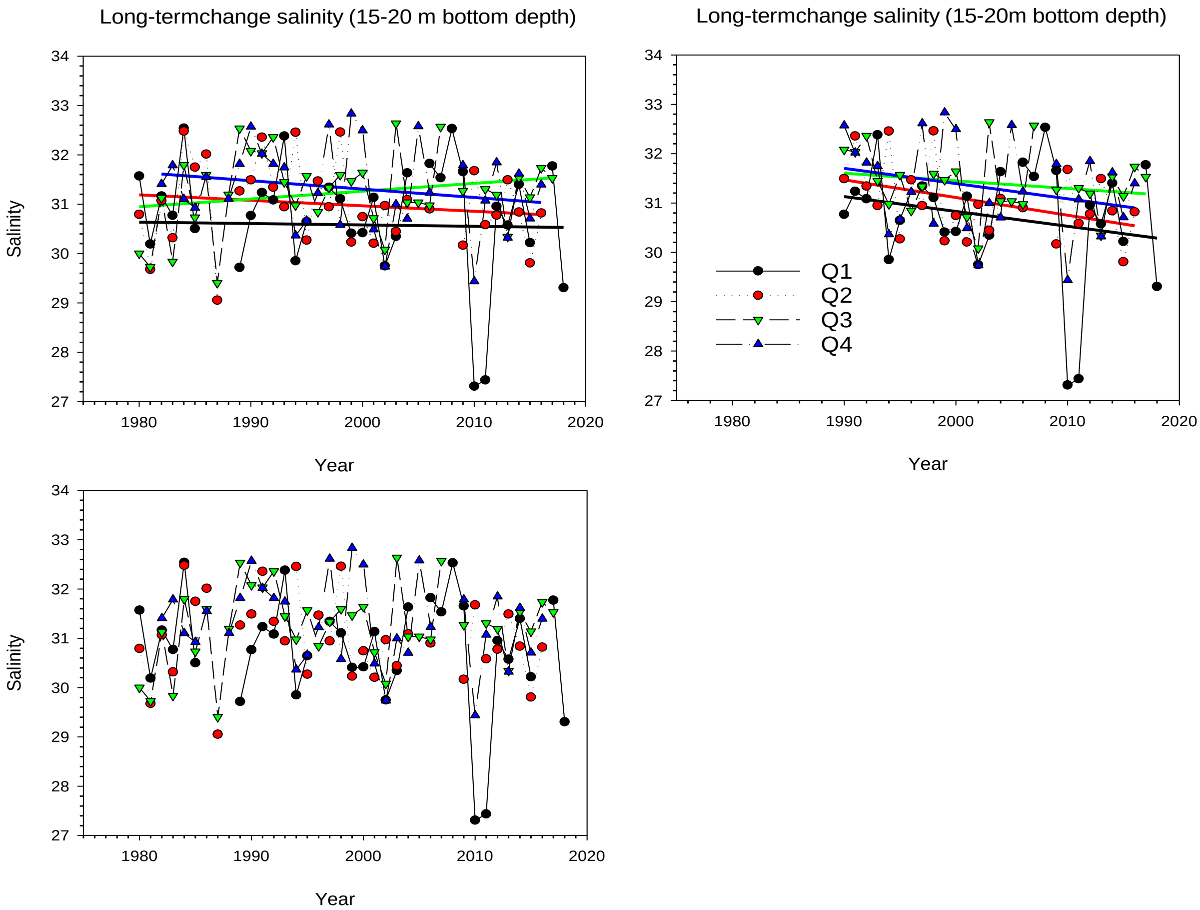

Figure 1.9. Changes in salinity (ppt) at the bottom for the 15-20 m stratum. a) Averaged for quarters of the year, illustrated by different symbols, linear regressions inserted using colors comparable to symbols, b) same as for a) but regression made for shorter time.

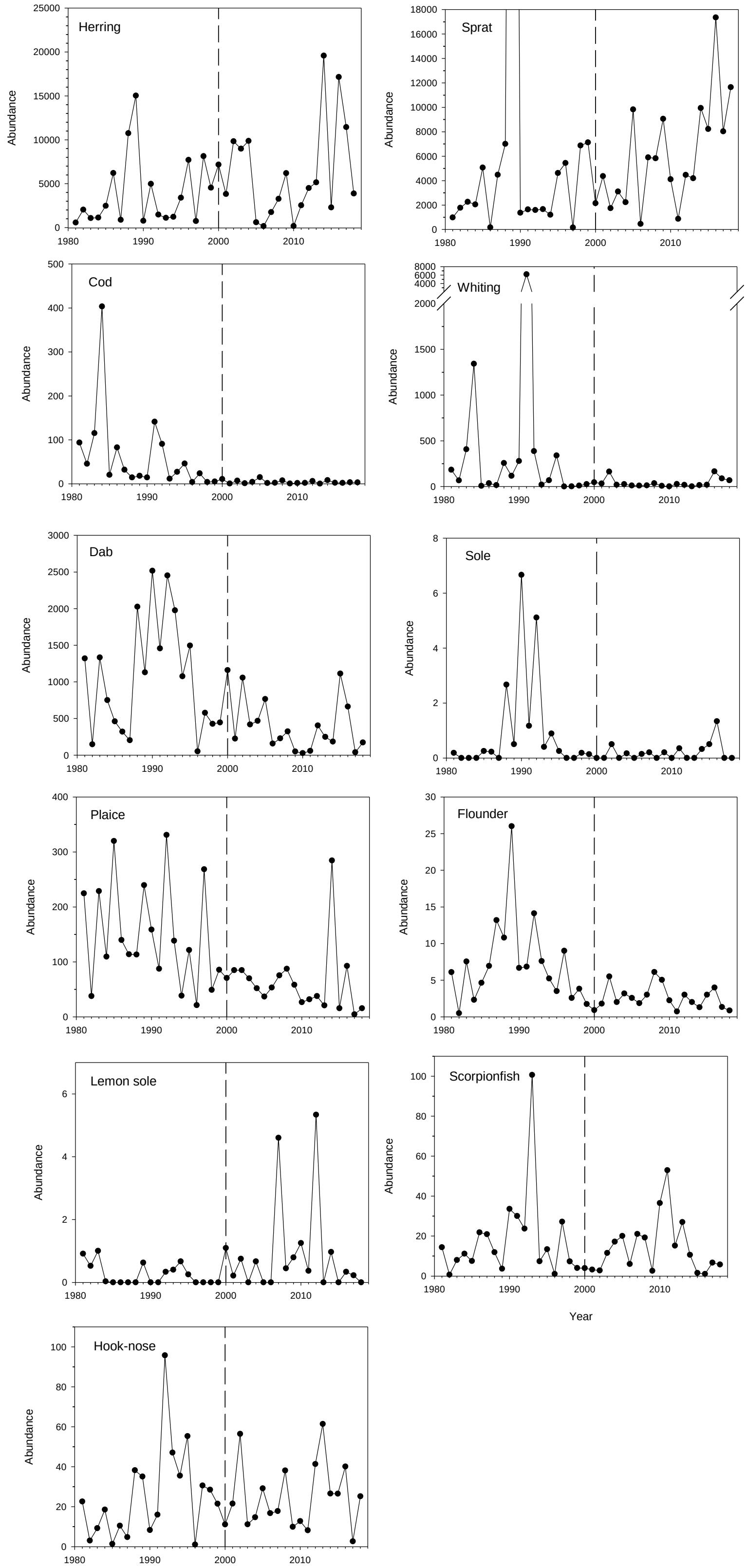

Figure 1.10. Abundance estimates of 11 relatively abundant species of fish caught during the IBTS 1 quarter surveys. Dots represent CPUE estimates in no h^{-1} averaged for the area east of 6°E and south of 57°30'N.

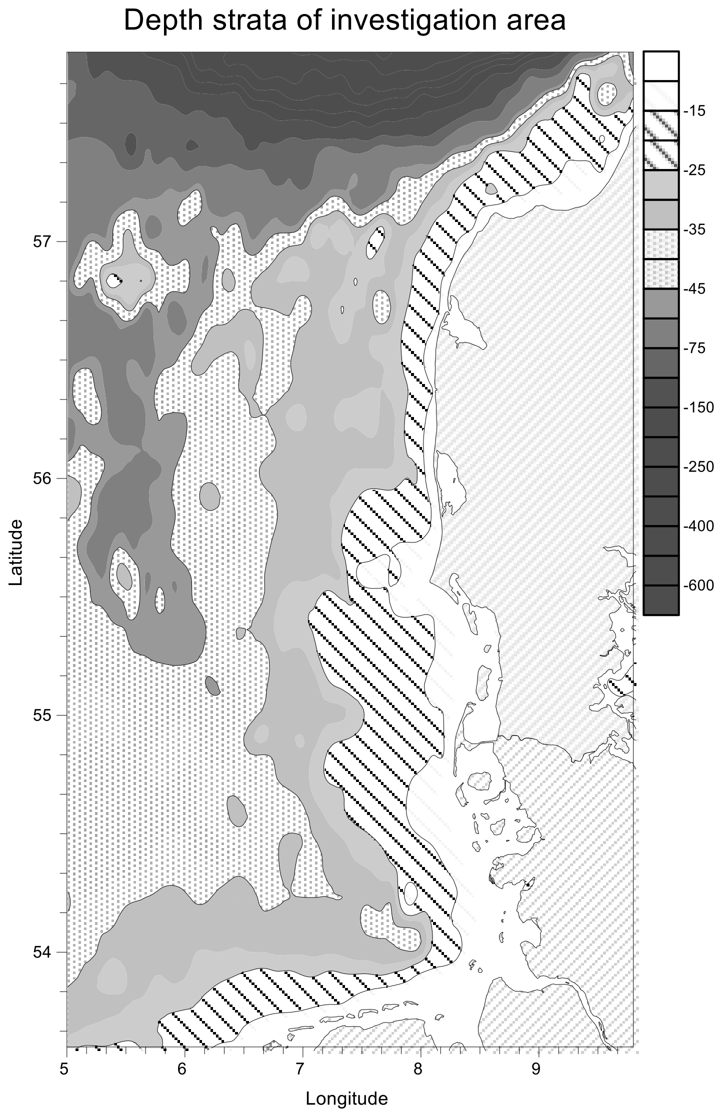

Figure 1.11. Illustration of the two depth-stratum areas used in the evaluation of change in relative abundances. Hatched area: 15-25 m, dotted area: 35-45 m.

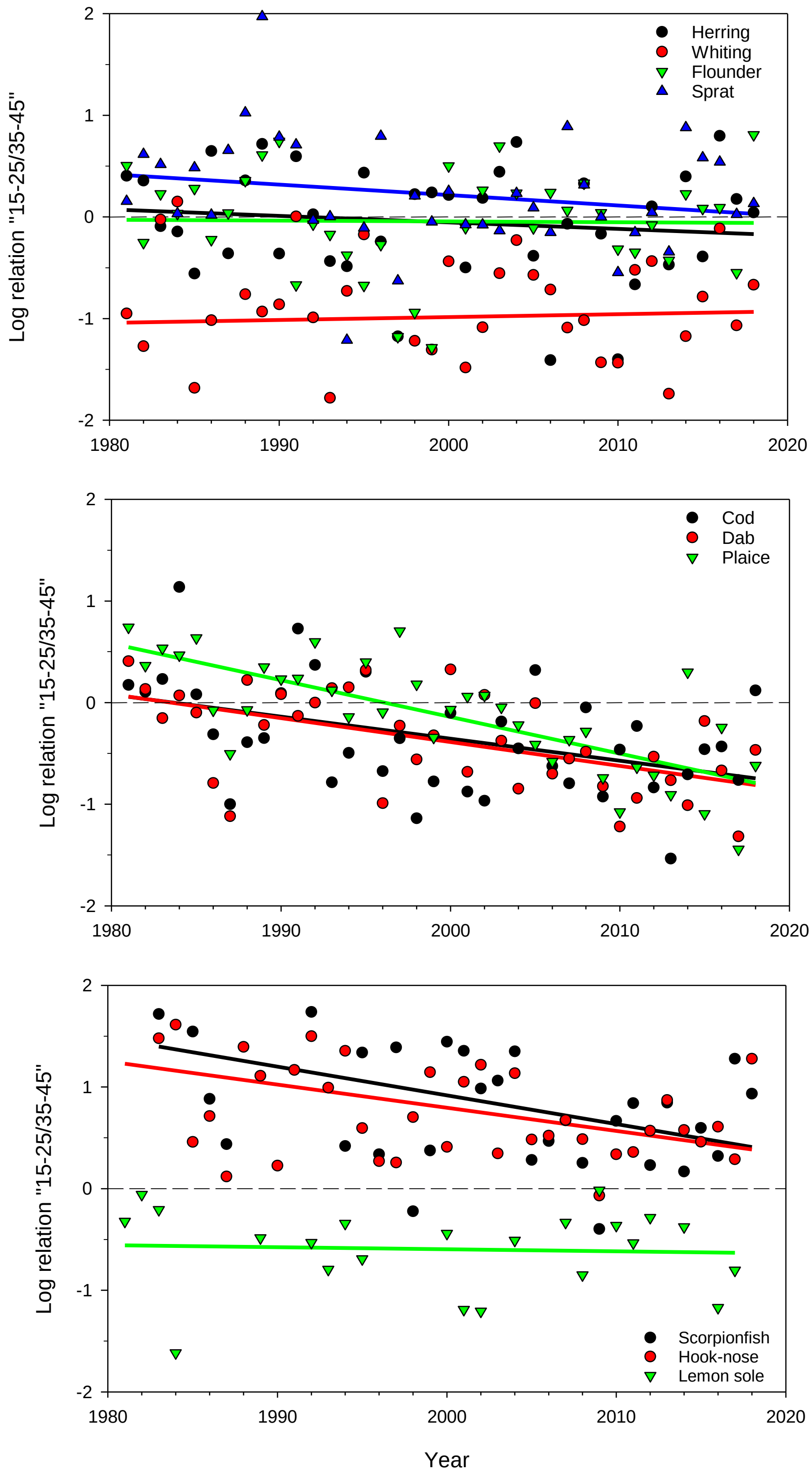

Figure 1.12. Relative importance of the nearshore area (15-25 m bottom depth) to the more offshore area (35-45 m bottom depth). Log-scaled relationship, e.g. when value is 1 the 15-25 m CPUE is 10 times the CPUE of the 35-45 m, when -1 the 35-45 m CPUE is 10 times the CPUE of the 15-25 m.

2. Scientific surveys and experimental fishing

2.1 Scientific surveys

The main aim of the project is to investigate potential fishing grounds near the coast off west of Jutland. There is a sparsity of data in the area, as the International Bottom Trawl surveys do not cover shallower areas and the commercial fishing has almost stopped. Therefore, data collection was carried out during the duration of the project using during two scientific surveys with the scientific vessel Havfisken. Here, we describe the design of the data collection along with a presentation of main findings and issues that were encountered.

2.1.1 August 2019

Methods: The first fishing survey in this project was conducted during August 2019, using the research vessel Havfisken. The aim was to conduct trawl-fishing using a standard trawl (TV3; 540#) on 5 stations in each of four transects. Each transect started 500 m from the coast and at intervals of around six nautical miles perpendicular to the shore. The transect positions were aligned with those transects that were to be covered by commercial gillnet fishers (see section 2.2. Experimental fishing). At each station, a CTD profile was be taken as well as a Bongo V-haul.

Results: The vessel sailed out from Hirtshals on August 26, 2019 and, due to generally favourable weather, covered the four transects, Thorup (Jammerbugt), Thyborøn, Hvide Sande and Esbjerg (Fig. 2.1).

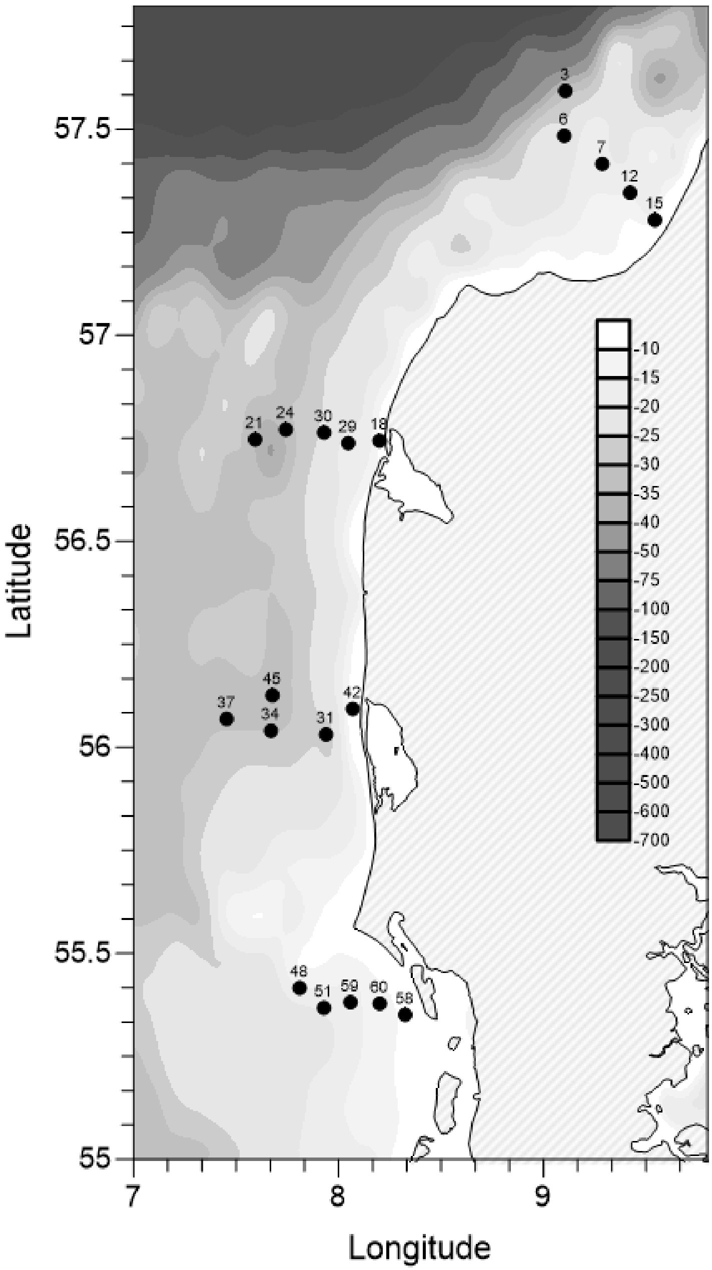

Figure 2.1. Map showing the stations sampled using TV3-trawl, CTD and Bongo during the August 2019 survey.

Around 50 fish species were sampled in the trawl. Cod were mostly caught off Thyborøn in the station closest to shore and consisted mostly of juvenile cod (Fig. 2.1). At this station 77% of all the cod caught were caught here, which meant that few cod were caught in the remaining stations and of these very few were adult cod. The paucity of cod (especially of adults) observed in this survey series, may be in part due to the sea water temperatures during the survey (Fig. 2.2), which were above the cod's tolerance (Dinesen et al. 2019).

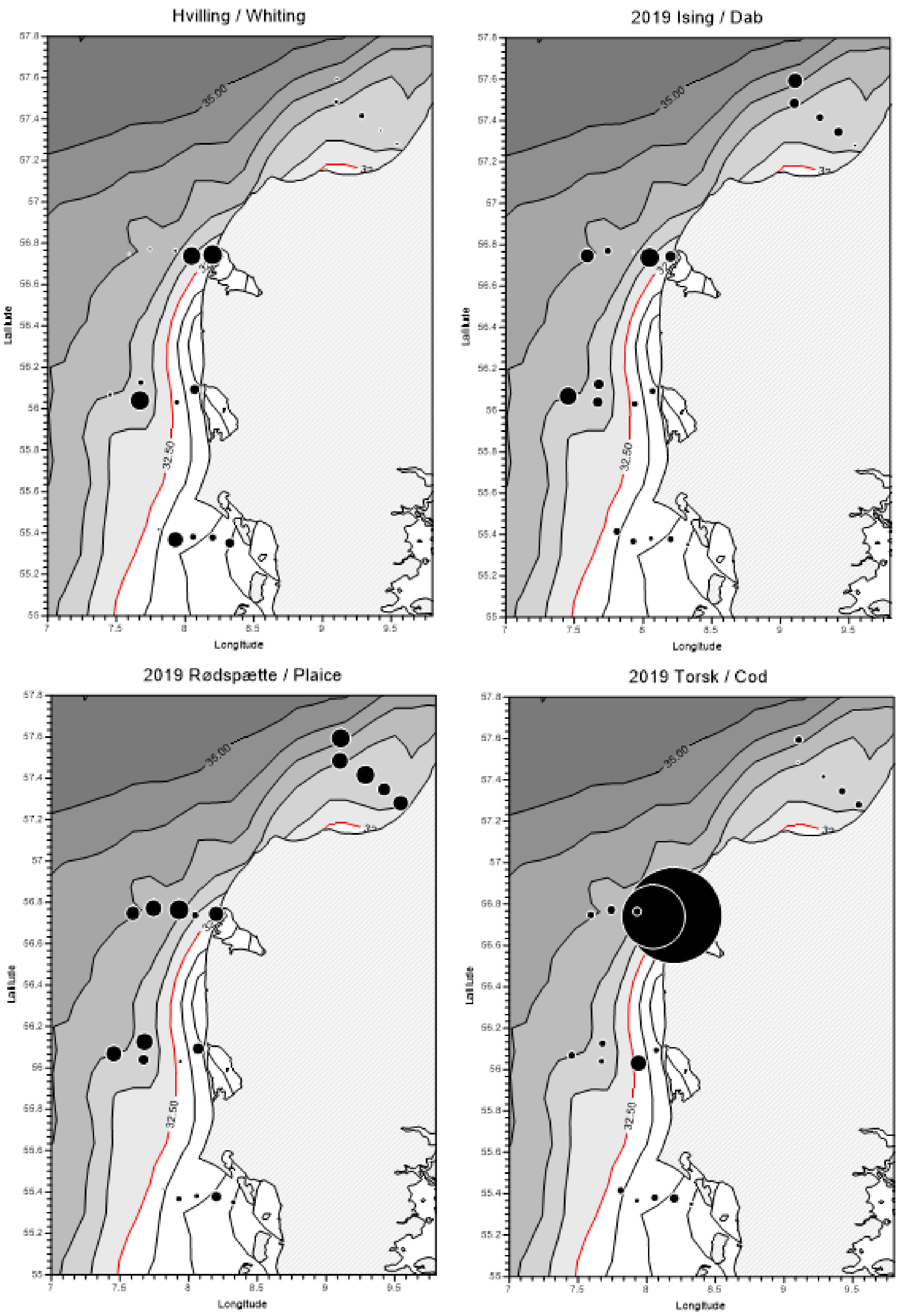

Figure 2.2. Total numbers (indicated by the size of filled circles) of whiting, dab, plaice and cod caught in each trawl station during the 2019 Havfisken survey. The shaded areas and contour lines show the measured salinity (in ppt) with darker greys indicating higher salinity.

Plaice were primarily caught in the Skagerrak transect (47%) with fewer in the Thyborøn transect (34%) and sporadic catches in the southern two transects, Hvide Sande and Esbjerg (Fig. 2.2).

Very few whiting were caught in Jammerbugt, but were caught in the more southern transects, close to shore in Thyborøn and further offshore in Hvide Sande and Esbjerg. Dab were caught in high numbers in all transects, lowest in Esbjerg.

Grey gurnard (*Eutrigla gurnardus*) were mostly caught in the offshore positions in the two northern transects, whereas tub gurnard (*Chelidonichthys lucerna*) were caught in all stations, highest numbers in the Esbjerg transect. Most of the sole (*Solea solea*) and solenette (*Buglossidium luteum*) were caught in the Hvide Sande transect.

The CTD data also showed less saline water closer to the shore and a north-south near-shore gradient with least saline water in the Esbjerg area indicative of the influence from the Jutland Coastal Current (Fig. 2.3).

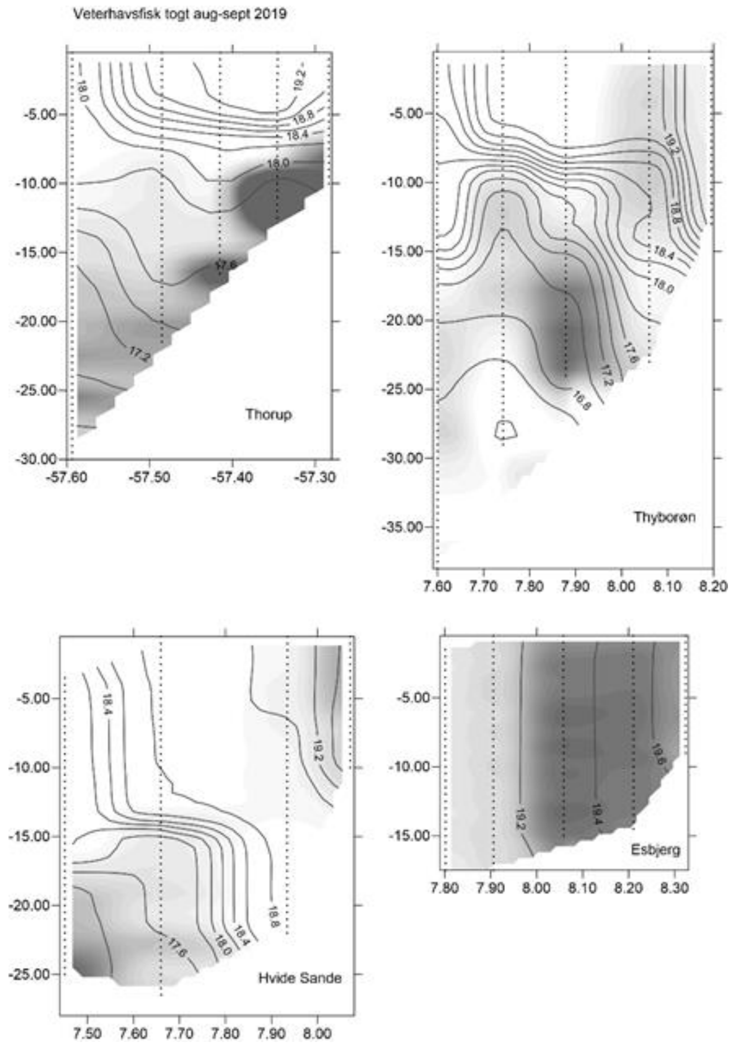

Figure 2.3 Temperature profiles at the four transects. Data acquired from the CTD. The y-axis shows the depth and the x-axis shows longitude (degrees east) except of the Thorup transect, where it is latitude (degrees north).

The Bongo data showed higher abundances of the invasive ctenophore *Mnemiopsis leidyi* in the southern transects.

2.1.2 May 2020

Methods: The fishing survey conducted in May 2020 should revisit the stations sampled in the previous survey (August 2019). However, as some of the stations in the 2019 survey either did not ensure a good depth coverage for a transect or lacked the sediment type aimed at for the bottom fauna analyses, a couple of stations were re-located. These were Station 29 (Thyborøn), which was moved to a sediment type which was sandy, Station 48 (Esbjerg) was moved to a deeper position. During this survey, five bottom fauna samples were taken on one particular station (chosen from a combination of depth and bottom type prior to the survey) and plaice stomachs were taken aiming for 20 stomachs per 10 cm size group <10, 10-20 and >20 cm size groups. If an insufficient number of plaice were sampled, plaice from neighbouring positions were also sampled. In addition, VP2 was used to sample the plankton in each station. There was an additional plan to fish with commercial style gillnets on the stations in the Esbjerg transect, since this transect was not covered by the experimental fishing (Section 3.2). Protocols for the benthic sampling, gillnet fishing and the stomach sampling were drawn up prior to the survey.

Results: The original plan of starting in Esbjerg, change participants half-way through and end in Hirtshals, was revised due to COVID-19 restrictions. The survey started from Hirtshals on May 5th 2020, with a crew, which lasted the duration of the survey. The weather was generally not so favourable and any work was abandoned on the first day due to very strong north-westerly winds. Despite the strong winds and high waves, all stations except one in the Skagerrak transect were sampled. The gillnet fishery in Esbjerg had to be abandoned as it was deemed too dangerous under the prevailing conditions. All bottom fauna samples were taken and 192 plaice stomachs were sampled. From Skagerrak 41 stomachs (2 stations), Thyborøn 52 stomachs (1 station), Hvide Sande 50 (1 station) and 48 from Esbjerg (2 stations). Most of the plaice were from the size group 20-30 cm. Further analysis on the stomach and bottom fauna is described in Chapter 3.

Sea water temperature during the survey ranged from 8 to 10℃, warmest closest to shore.

Very few cod were caught in this survey (Fig. 2.4), whereas plaice were caught in most stations and dab were more abundant in the two southern transects.

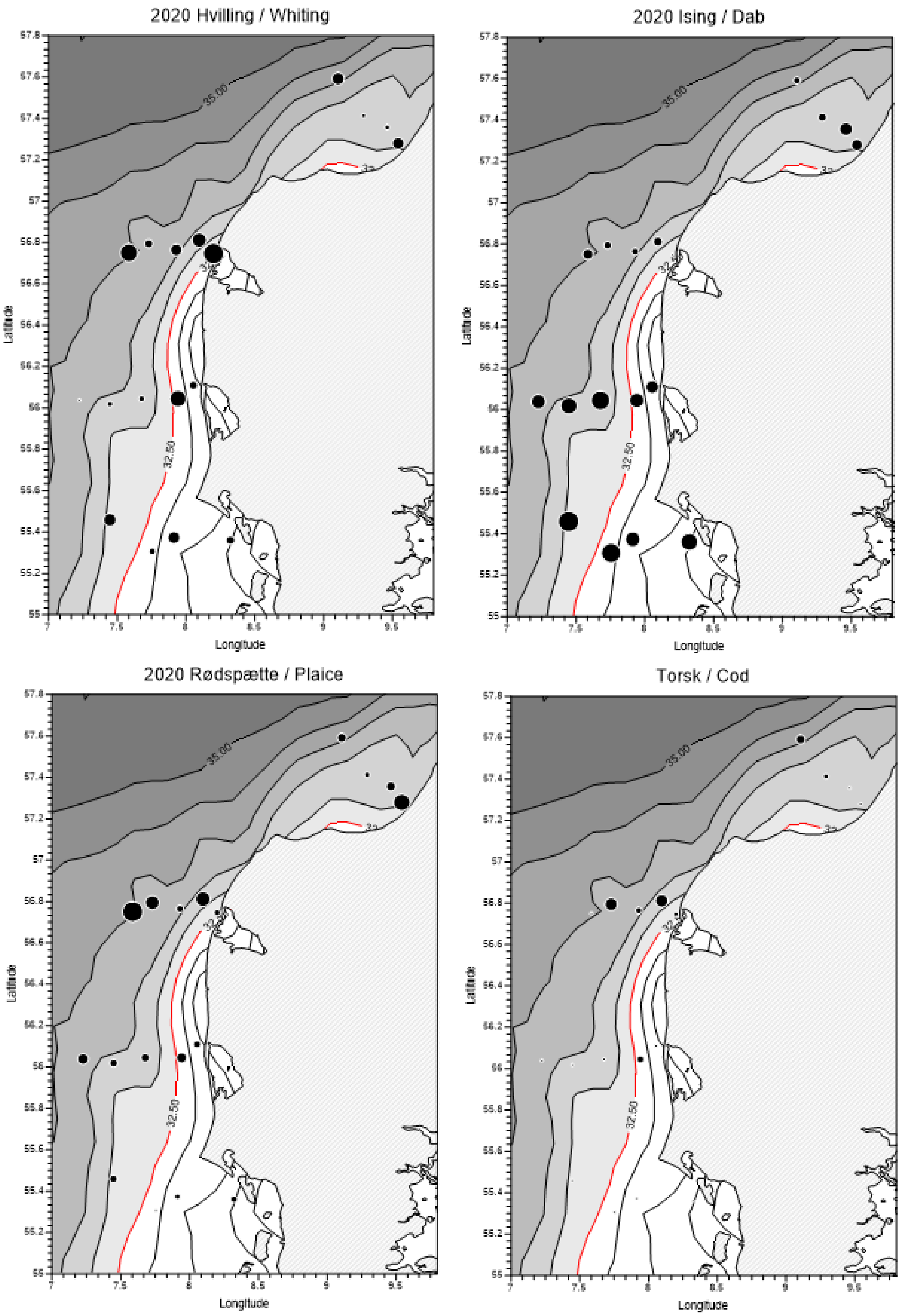

Figure 2.4 Total numbers of whiting, dab, plaice and cod caught in each trawl station during the 2020 Havfisken survey. The shaded areas and contour lines show the measured salinity (in ppt) with darker greys indicating higher salinity.

2.2 Experimental fishing

The plan for the experimental fishing was to conduct gillnet fishing with commercial vessels on the four transects and covering the four seasonal quarters of the year. This was carried out in collaboration with Henrik Lund (DFPO), who facilitated the contact with commercial fishermen. The transects were the same as those used for the scientific surveys described in Section 2.1 above. However, each transect consisted of a broad band within which the fishery could take place. At each transect four positions were sampled, each with 5 gillnets (each gillnet was: toggegarn 1,5 x 4,75 mm, 20,5 md, 2000k, 6x3x350mm 2,0 md, 334 k, mounted with 56 m float-line nr. 3 and 64 m bottom sinkline no 3). The gillnet was purchased new to ensure the same gear was used by all the fishermen in the project and a protocol was drawn up to ensure harmonised sampling. Catch per unit effort (CPUE) was calculated as numbers caught per 12 hour soak time.

Results. Several commercial fishermen were contacted to conduct the gillnet sampling. In the end, five conducted single or double transects. Only three of the planned four transects were sampled as it was not possible to engage commercial fishermen to sail to Esbjerg to sample that transect. The stations that were sampled are shown in Fig. 2.5. One fisher conducted a transect that was outside the specified transect sections, but the data was still valid and thus included in the results.

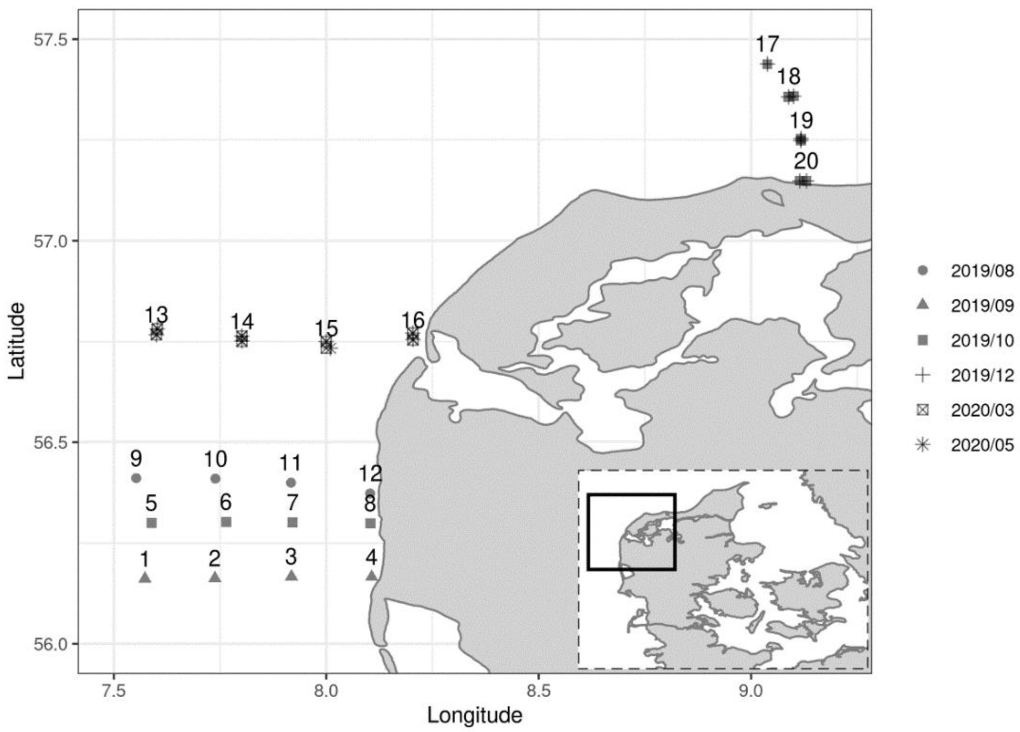

Figure 2.5. Stations sampled by the commercial fishers. Stations 17-20 are in the Skagerrak transect, 13-16 in the Thyborøn transect and the stations 1-12 are grouped into the Hvide Sande transect.

Dab was the most commonly caught species in the gillnet fishery, with lower numbers of plaice and cod and much fewer numbers of 12 other fish species (Fig 2.6).

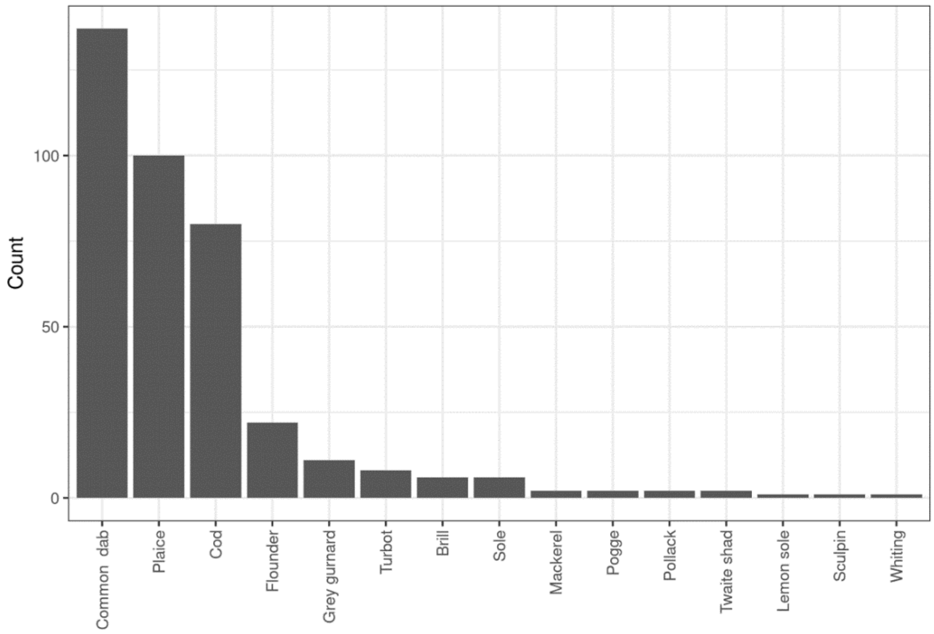

Figure 2.6. Total number of fish caught per species by the commercial gillnet fishers during 2019 and 2020 within this project.

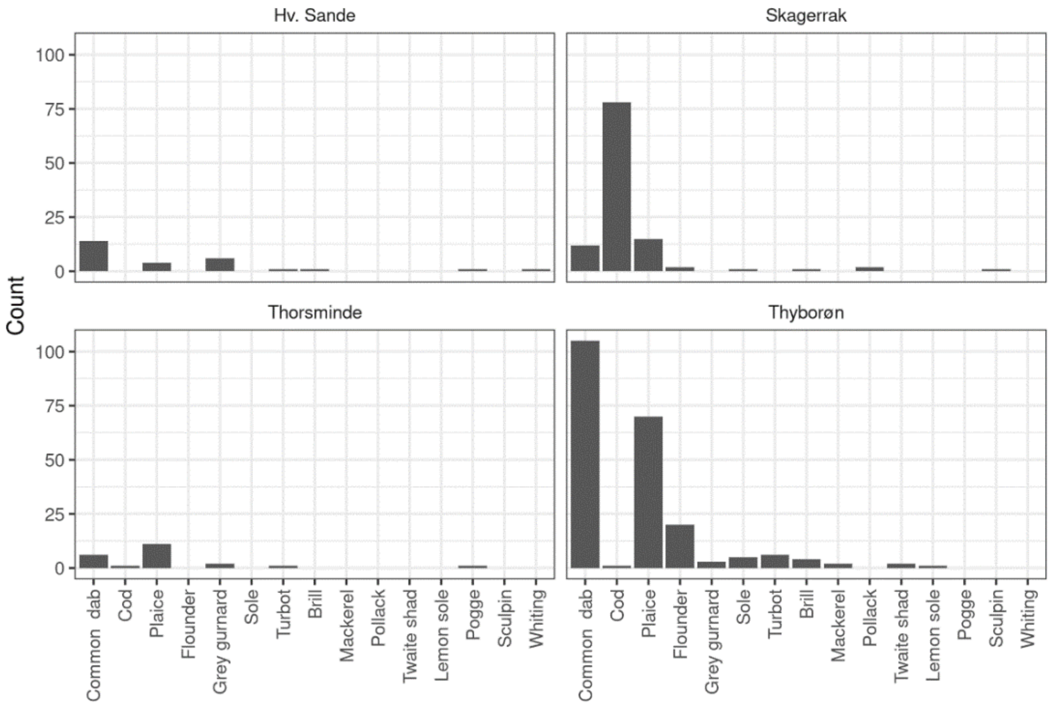

Figure 2.7. Numbers caught per species by commercial gillnet fishers in the four areas, Thorsminde is grouped together with the Hvide Sande transect in the following.

The three most commonly caught species were dab, plaice and cod (Fig. 2.6, Fig 2.7). In the following analyses of results, we focus in on these three species. Gillnet soak time varied from 2 to 20 hours and in order to harmonise data, catch of unit effort (CPUE) was calculated as numbers caught per 12 hours soak time. Dab were caught in all months, though highest numbers in Q3 (months 7-9, Figure 2.8) and in the more southern transect (Fig. 2.9). Cod was primarily caught in Q4 (months 10-12, Figure 2.8) and primarily in Skagerrak (Fig. 2.10). Plaice was primarily caught in Q3 (months 7-9, Figure 2.8) and caught in all the transects, though highest numbers in the Hvide Sande transect (Fig. 2.11).

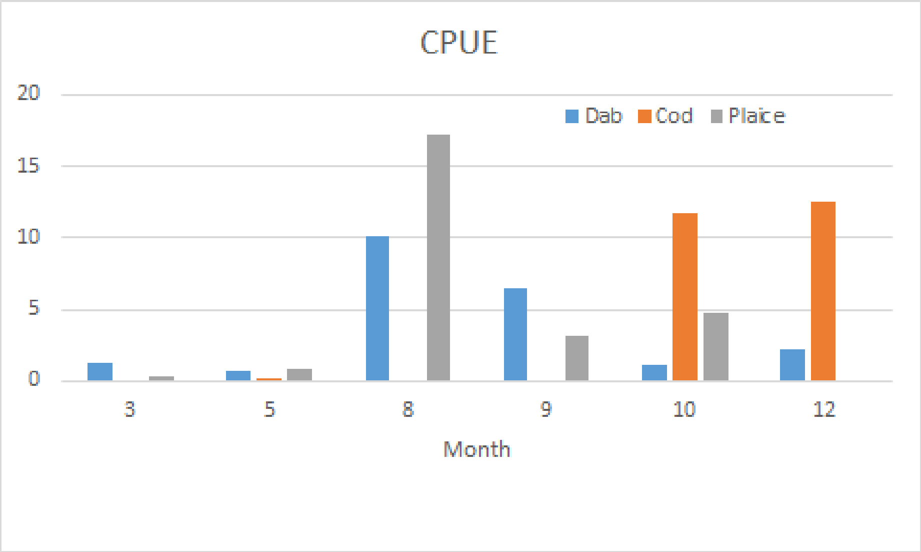

Figure 2.8. CPUE (#/12hr) of dab, cod and plaice caught in the gillnet experimental fishery by month.

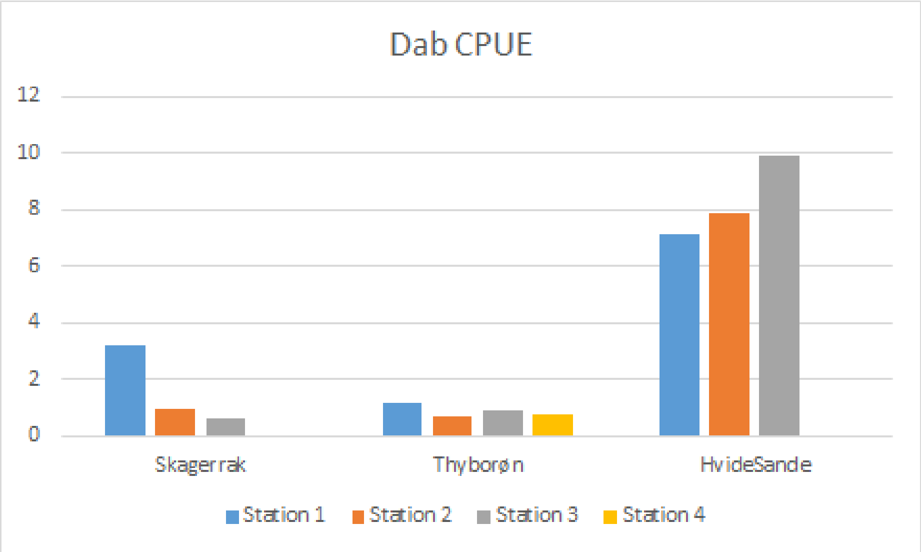

Figure 2.9. CPUE (#/12hr) of dab caught in the gillnet experimental fishery by transect and distance from land. Station 1 is closest to land about 0,5 nautical mile from the shore. Stations 2, 3 and 4 more offshore at an equidistance of around 5 nautical miles from each other.

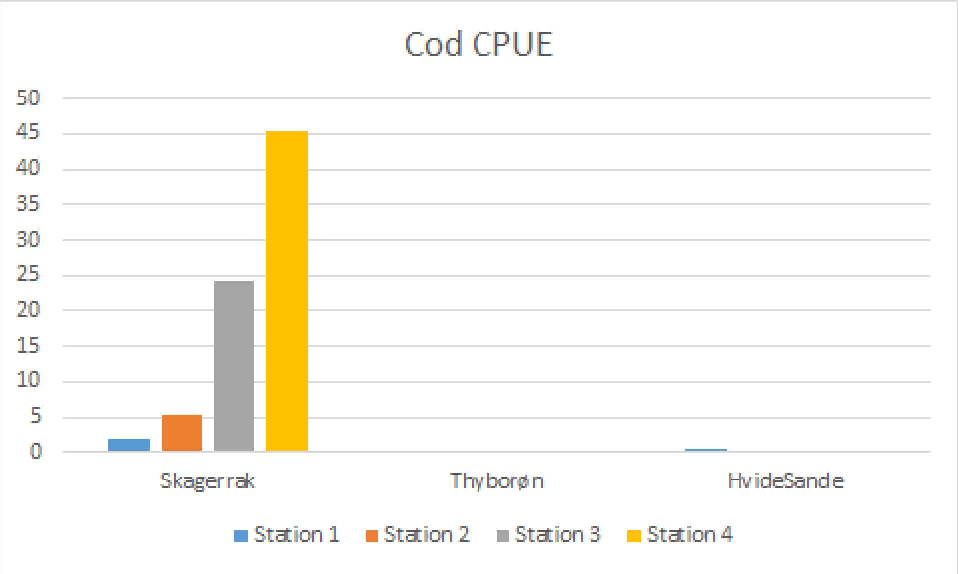

Figure 2.10. CPUE (#/12hr) of cod caught in the gillnet experimental fishery by transect and distance from land. Station 1 is closest to land about 0,5 nautical mile from the shore. Stations 2, 3 and 4 more offshore at an equidistance of around 5 nautical miles from each other.

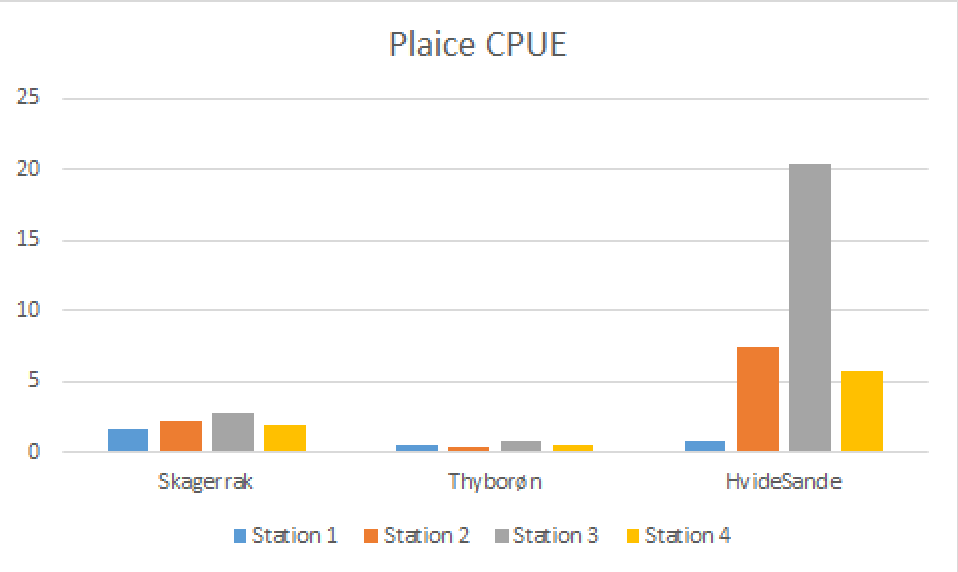

Figure 2.11. CPUE (#/12hr) of plaice caught in the gillnet experimental fishery by transect and distance from land. Station 1 is closest to land about 0.5 nautical miles from the shore. Stations 2, 3 and 4 more offshore at an equidistance of around 5 nautical miles from each other.

2.3 Species distribution in connection with environmental conditions

Aim: In this section, we use the collected information of the two Havfisken surveys, both fish numbers and CTD measurements to investigate major drivers of the distribution of different species. To meet that goal, we use statistical models that include correlate the numbers of individuals caught in each station with the measured environmental conditions, location and year as covariates.

Methods: During both Havfisken surveys, near each haul a CTD profile of the water column was taken to have direct observations of temperature and salinity where the fish were caught (Figure 2.12).

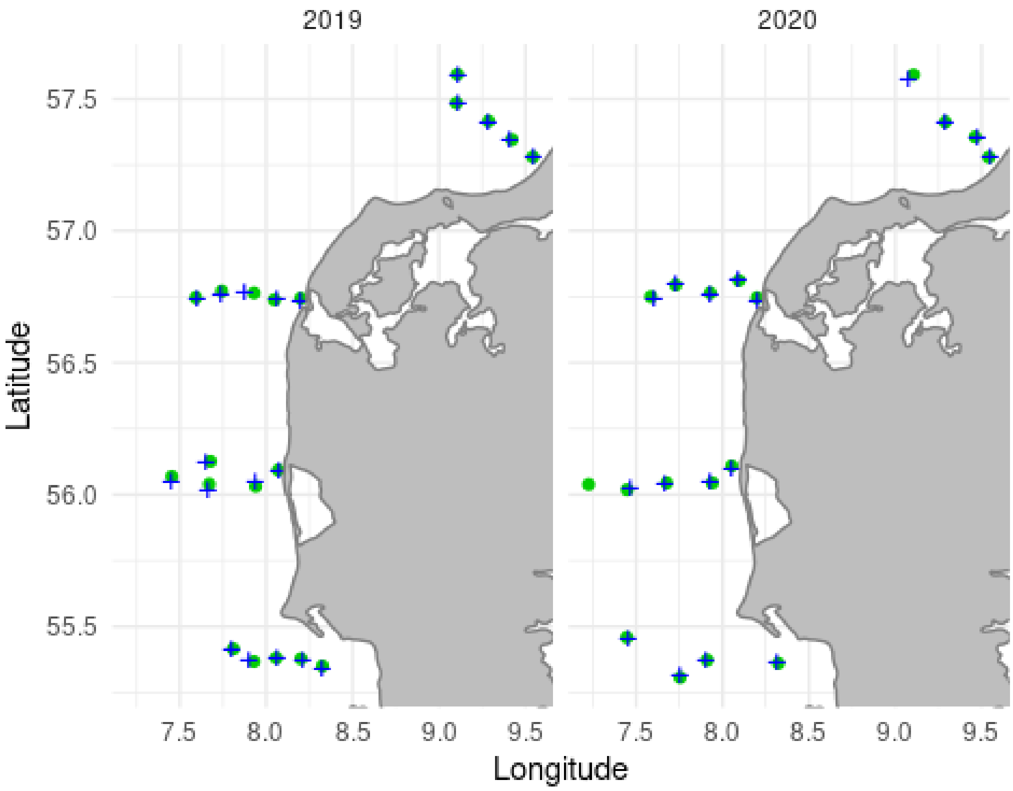

Figure 2.12. Trawl stations (green dots) and corresponding CTD stations (green crosses) during the August 2019 (left) and May 2020 (right) Havfisken surveys.

Using these observations and of total numbers of each species caught and the corresponding haul durations of each station, we build statistical Generalised Additive Models (GAMs, Wood 2006). The models have the general form

$$numbers \sim factor(year) + f_1(latitude) + f_2(depth) + f_3(bottom\ temperature) + f_4(bottom\ salinity) + offset(fishing\ duration)$$

where year is treated as a factor in the model to account for differences between years (and month of sampling), f are smooth functions in the model and fishing duration is used as an offset to account for differences in number of caught individuals due to difference in effort. The ten species with most observations were modelled (Table 2.1), as less observations were not leading to reasonable models.

There was no attempt to do model selection of statistically significant parameters as the aim of this exercise was to investigate how the combination of all environmental parameters affect the observed numbers of fish in the different stations.

Table 2.1 The ten species observed in most sampling stations during the 2019 and 2020 Havfisken scientific surveys.

Species	***Latin name***	**Stations**
Common dab	*Limanda limanda*	37
Plaice	*Pleuronectes platessa*	37
Whiting	*Merlangius merlangus*	37
Grey gurnard	*Eutrigla gurnardus*	30
Herring	*Clupea harengus*	30
Sprat	*Sprattus sprattus*	28
Common dragonet	*Callionymus lyra*	23
Mackerel	*Scomber scombrus*	23
Solenette	*Buglossidium luteum*	19
Cod	Gadus morhua	17

Results: The fitted model for each species are summarised in Tables 2.2 and 2.3. Shortly, the elements of the model fit and goodness of fit measures and statistics presented in the two tables are as follows (from top to bottom). The estimate and corresponding standard deviation in parentheses of the intercept and year effect. These values are similar to the ones typically presented for regression models. The degrees of freedom and effective degrees of freedom in parentheses of each smooth function. If the degrees of freedom are equal to one, the smooth function is penalised to a linear relationship, whereas higher degrees of freedom indicate nonlinear spline functions. The statistical significance of each model component is indicated with zero to three stars, showing no significance to high statistical significance. The interpretation of the number of stars in terms of p-values is shown below the tables.

Further, the Akaike information criterion (AIC) is a standard measure of the quantified information used for model selection and is based on the log likelihood, which is presented below. For GAMs deviance and deviance explained, are more appropriate measures of the amount of variation the model is able to explain (for Gaussian models it is equal to the unadjusted R^2, but for other model families the deviance explained is more appropriate measure of fit). The generalized cross validation score (GCV) is an estimate of the mean square prediction error based on exhaustive cross validation. The final two lines show the number of observations and number of smooth terms, which are the same for all models.

For all the presented species the location (modelled as latitude, lat) is a significant covariate that explains the distribution of each species. Depth seems to be significant only for cod and plaice. The bottom salinity and temperature do not appear to be significant for most species. This is not a big surprise as both are correlated with depth and therefore their effect is already covered. The deviance explained by the models is relatively high for some of the species (e.g. grey gurnard: 87%, cod 70%) but quite low for others (e.g. sprat: 46%). Especially for sprat, that result is not very surprising because they are utilising mostly the upper part of the water column and are closer to the bottom were the trawling takes place only for feeding. Bottom salinity seems to be a significant driver for the distribution of cod and grey gurnard.

Table 2.2. Model fit and of cod, plaice, sprat, herring and common dragonet.

	cod	plaice	sprat	herring	Common dragonet
(Intercept)	−15.45 (7.06)*	−11.57 (5.33)*	−17.46 (6.82)*	−21.42 (5.77)**	−11.42 (6.02)
factor(year)2020	−17.93 (18.58)	−9.16 (14.01)	10.07 (17.77)	13.20 (15.03)	−18.16 (15.80)
EDF: s(lat)	1.92 (1.99)**	1.25 (1.43)***	1.64 (1.87)**	1.75 (1.94)*	1.00 (1.00)***
EDF: s(depth)	1.00 (1.00)**	2.87 (2.98)**	1.08 (1.16)	2.65 (2.91)	1.00 (1.00)
EDF: s(tempbot)	1.00 (1.00)	1.76 (1.97)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)
EDF: s(salbot)	1.00 (1.00)***	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)
AIC	228.14	588.80	487.23	463.76	336.99
Log Likelihood	−105.07	−283.02	−234.58	−221.03	−160.49
Deviance	550.20	338.62	968.06	658.37	643.76
Deviance explained	0.70	0.61	0.46	0.60	0.48
Dispersion	30.01	9.38	29.68	20.64	19.71
GCV score	97.37	278.39	225.65	215.01	152.57
Num. obs.	29	29	29	29	29
Num. smooth terms	4	4	4	4	4

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

Table 2.3. Model fit of grey gurnard, whiting, dab, mackerel and solenette.

	grey gurnard	whiting	dab	mackerel	solenette
(Intercept)	−13.88 (6.15)*	−13.63 (4.77)**	−8.63 (4.84)	−23.00 (5.61)***	−27.85 (5.41)***
factor(year)2020	−16.54 (16.19)	−0.61 (12.51)	−13.23 (12.70)	8.83 (14.56)	16.84 (14.00)
EDF: s(lat)	1.88 (1.98)***	1.92 (1.99)***	1.77 (1.94)***	1.00 (1.00)***	1.94 (2.00)***
EDF: s(depth)	1.00 (1.00)	1.00 (1.00)*	1.01 (1.02)	1.00 (1.00)	1.00 (1.00)
EDF: s(tempbot)	1.99 (2.16)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)*
EDF: s(salbot)	2.90 (2.99)***	1.00 (1.00)	2.66 (2.91)	2.00 (2.41)	1.00 (1.00)
AIC	418.29	610.74	667.49	315.65	288.49
Log Likelihood	−197.01	−296.37	−322.88	−148.42	−135.25
Deviance	241.39	255.92	359.18	554.46	423.06
Deviance explained	0.87	0.63	0.63	0.62	0.72
Dispersion	8.22	6.77	9.88	18.34	13.86
GCV score	199.96	289.62	318.61	141.33	129.37
Num. obs.	29	29	29	29	29
Num. smooth terms	4	4	4	4	4

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

2.4 Discussion

The catches in the gillnet experimental (commercial) fishery were too low to potentially support a fishery. The results reflect the absence of two commercially important species, cod and plaice along the Jutland North Sea coast that historically supported commercial coastal fisheries. The results reflect the concerns put forward by the fishermen and reported earlier (Støttrup et al. 2014) and further indicate no improvement on the situation.

It was not possible to gain data from the southernmost transect as this was too far from the current commercial fishing harbours. However, the results from the scientific surveys indicate a similar situation as for the other transects.

The modelling of numbers caught in each trawling station correlated with the measured environmental parameters show that the location (modelled as latitude) and depth is important predictors of the species distribution. Environmental covariates were in most cases not statistically significant predictors, something that was also observed in previous studies.

3. Diet composition and food selectivity of European plaice (*Pleuronectes platessa* L.) along a tidal gradient of the Danish North Sea coast

3.1 Introduction

Sustainable management of resources relies on ecosystem-based management, which implies understanding the processes that regulated abundances of wild fish populations. Declining abundance of commercially important species such as European plaice, *Pleuronectes platessa* Linnaeus, 1758, and Atlantic cod, *Gadus morhua*, Linnaeus, 1758, in coastal areas have become a topic of increasing concern, with economic and social consequences (van keeken et al., 2007; Dutz et al., 2016; Støttrup et al., 2014; Dinesen et al., 2019). Potential causes for these declining trends proposed, differ geographically and include climate (temperature) (e.g. Simpson et al., 2011) and primary productivity or food availability (Tulp et al., 2008; Støttrup et al., 2017).

Dramatic long-term changes in benthic habitats and their community composition of flora and fauna have been observed (e.g. Tulp et al., 2008) attributed to cumulative human pressures, such as physical disturbance from bottom trawling, eutrophication from agricultural nutrient enrichment, and increased coastal water temperature. Changes in benthic habitats affect macrofaunal density of individuals and species, and biomass production and, thus, directly influence food availability and growth of benthivorous fish, such as plaice.

Feeding selectivity of predatory animals depends on food availability, that is the occurrence, density and nutrient value of prey in the natural environment, and as well as prey accessibility to the predator. Selective feeders may be differently affected than opportunistic species, the latter being adopted to cope with more changeable food resources.

Historically, adult plaice selected for bivalves and polychaetes but over a century this was observed to shift to predominantly polychaetes with bivalves as secondary prey in the Southern North Sea (Rijnsdorp and Vingerhoed, 2001). This was hypothesised to be due to long-term changes in the benthic macrofaunal communities. In the Baltic Sea, the availability of benthic prey organisms in the area was verified as a biotic driver for flatfish, especially for plaice (Rau et al., 2019). We therefore hypothesised that the decline in plaice density in coastal waters could be due to lack of preferred prey species rendering the habitats unsuitable for plaice. We therefore carried out a pilot study at four sites to investigate if there was a North-South trend in plaice diet composition and selectivity of prey available in their local habitat.

3.1.1 Aims

This study aims to compare adult plaice: i) macrofaunal diet composition along a tidal gradient, and ii) food selectivity relative to the local faunal prey availability. The comparison was based on analyses of plaice stomach contents and benthic sediment samples collected along the Danish North Sea coast.

3.2 Material and methods

3.2.1 Study area

In this study, we focused on effects of environmental gradients related to tidal regime. This study, thus, comprise four sites located along the Danish North Sea coast, from the North to South, offshore of the commercial fishing communities Thorupstrand (in Skagerrak), Hvide Sande, Thyborøn, and Esbjerg on the West coast of Jutland (Figure 3.1). The Danish North Sea coastal waters are characterised by a latitudinal gradient from the northern micro-tidal Skagerrak to the southern macro-tidal Wadden Sea, with a dominant north-ward current, and longitudinal by an eastern shallow coastal seabed sloping westwards into deeper waters (>50 m depth). These hydrographic gradients influence the environmental conditions, such as substrate composition, salinity, temperature, and primary production. All samples were, thus, collected at four subtidal stations (with mean depth of 20 m) to keep the benthic habitat substrate condition (habitat: circalittoral sand) as similar as possible across sites. All sampling of benthic invertebrate fauna and plaice stomachs were conducted on-board the DTU Aqua R/V Havfisken during a field cruise in May 2020.

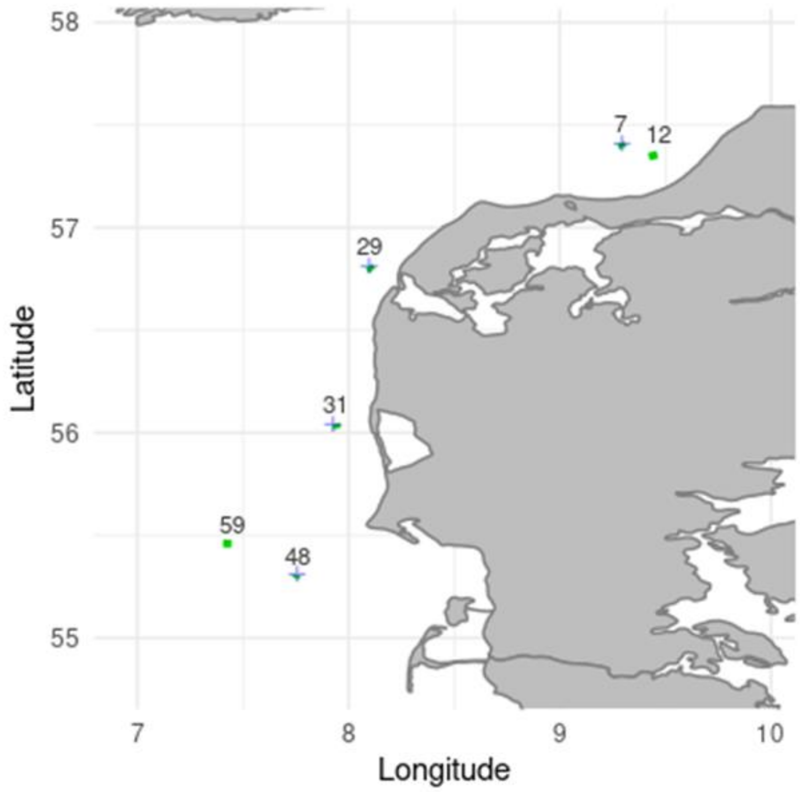

Figure 3.1. Location of the 20 Van Veen grab samples (blue crosses, station no. in bold below) and 6 TV3-trawl hauls (green segments) distributed at the four study sites along the Danish North Sea coast (from North to South): Skagerrak (S07, S12**), Hvide Sande (S29), Thyborøn (S31) and Esbjerg (S48,** S59**).**

3.2.2 Benthic sediment sampling

The macrobenthic invertebrate communities were collected using a 0.1 m^2 Van Veen grab by sampling 5 replicates distributed across the four sites (incl. four stations S07, S29, S31, S48). Each sediment sample were sieved through a 1 mm and 4 mm sieve and all retained material from each sample and fraction was preserved and stored in a 4% borax-saturated formaldehyde solution in ambient seawater.

3.2.3 Demersal trawling of plaice stomachs

Individuals of plaice were initially collected at a single station from each site (incl. four stations S07, S29, S31, S48). Each haul was conducted by deploying a TV3-trawl haul of 30 minutes duration, following the sampling protocol of the Danish fish survey and monitoring programme. Two additional hauls were conducted adjacent to (but not overlapping with) the initial stations due to low density of plaice at the most northern and southern sites (S12 adjacent to S07, and S59 adjacent to S48, respectively). From each haul, all plaice individuals were retrieved, length measured (to the nearest 0.5 cm) and wet weighted (to the nearest 0.1 g). The alimentary system was dissected to retrieve the stomach and gut, for which the wet weight was estimated (to the nearest 0.001 g). The combined stomach and gut were positioned in a pot, and first injected with and then submerged into 96% ethanol and stored until further analyses in the laboratory.

3.2.4 Faunal analyses

All biological material retrieved from the plaice stomachs was identified to the lowest taxonomic level (preferable to species) possible, depending on condition, ranging between five categories between one (very good) and five (dissolved and unidentifiable). All macrofaunal material from the grab samples were similarly identified to the lowest taxonomic level possible. For each identified taxon, all individuals were enumerated, and the total wet weight (to the nearest 0.001 g) was estimated for each stomach and sieve fraction of the grab replicates.

Prior to data analyses, all benthic macrofaunal taxa were subsequently grouped into higher taxonomic levels based on the resolution achieved for the macrofauna of the plaice stomachs. All macrofaunal taxa encountered in the benthic grab samples were considered potential prey regardless of individual size and weight.

3.2.5 Stomach content analysis

The analysis of stomach contents was done in two levels: i) for all collected stomachs, and ii) by sampling station to identify differences between areas. We calculated the vacuity index (VI), i.e.the percentage of empty stomachs, i.e. $VI = S_e/S_t * 100$, where S_e is the number of empty stomachs and S_t the total number of stomachs. Mean numerical, biomass and occurrence methods represented as percentages are used to describe the dietary composition (Hyslop, 1980). Specifically, the numerical abundance $\%N_p$ is calculated for each prey item p as

$$\%N_p = \frac{N_i}{N_t}100,$$

where N_i is the number of individuals of prey p and N_t is the total number of ingested individuals in all stomachs.

Similarly, the percent weight ($\%W$) was calculated as

$$\%W_p = \frac{W_i}{W_t} 100,$$

where W_i is the weight (in g) of individuals of prey p and W_t is the total weight of ingested individuals in all stomachs.

The occurrence ($\%O$) is calculated as

$$\%O_p = \frac{O_i}{S_t} 100,$$

where O_i is the number of stomachs that contain prey p and S_t is the total number of stomachs.

The importance of each prey item is quantified using the index of relative importance ($\%IRI$) defined as

$$IRI = \%O(\%N + \%W)$$

$$\%IRI = 100\ IRI/\sum_i I\,RI_i.$$

The Shannon-Wiener diversity index H' is calculated for each sampling station to quantify the diet diversity in each area

$$H' = -\sum_{i=1}^{n} P_i \ln(P_i),$$

where P_i is the proportion of prey item i. Pielou's pooled quadrat method is used to evaluate the sample sizes for each sampling station (Pielou, 1966).

The Electivity index E_i derived from the Chesson index for each prey i is given as

$$E_i = \frac{w_i - 1/n}{w_i + 1/n},$$

$$w_i = \frac{r_i/P_i}{\sum r_i/P_i},$$

where r_i is the proportion of prey item i in the diet and P_i is the proportion in the benthos (Selleslagh and Amara, 2015). The Electivity index takes values from -1 (indicating avoidance) to 1 (indicating preference). A threshold of >0.1% occurrence of a taxon in the diet and the environment was included in the calculation of the Electivity index, to avoid the sensitivity of the index to very rare taxa.

3.3 Results

3.3.1 Diet composition and diversity

Individual body length of the 189 sampled plaice individuals ranged between 10 and 40 cm (mean $\pm$ SE = 20.5 $\pm$ 0.45 cm) and from 0.012 to 0.626 kg (mean $\pm$ SE = 0.12 $\pm$ 0.01 cm). Individual fish length, weight and condition factor ($k = 100w/l^3$) are presented per station along with the overall weight-length distribution (Figure 3.2).

The dietary stomach contents were examined for 189 individuals of plaice. Only 6 stomachs were found empty, total vacuity index, VI = 3.17% (Table 3.1). The majority of the stomach contents were in in good condition (1-3) thus allowing for identification of prey items to a detailed taxonomic level. This was regarded a result of injecting 96% ethanol directly into the stomachs, by which the food items were better preserved and post-mortal mucus secretion was much reduced.

A total of 51 different macrofaunal prey taxa were identified. For each haul, the numerical and weight percentages, as well as the diversity measured by the Shannon-Wiener diversity index (H'), of all macrofaunal prey recorded in the plaice stomachs was summarised (Table 4.2).

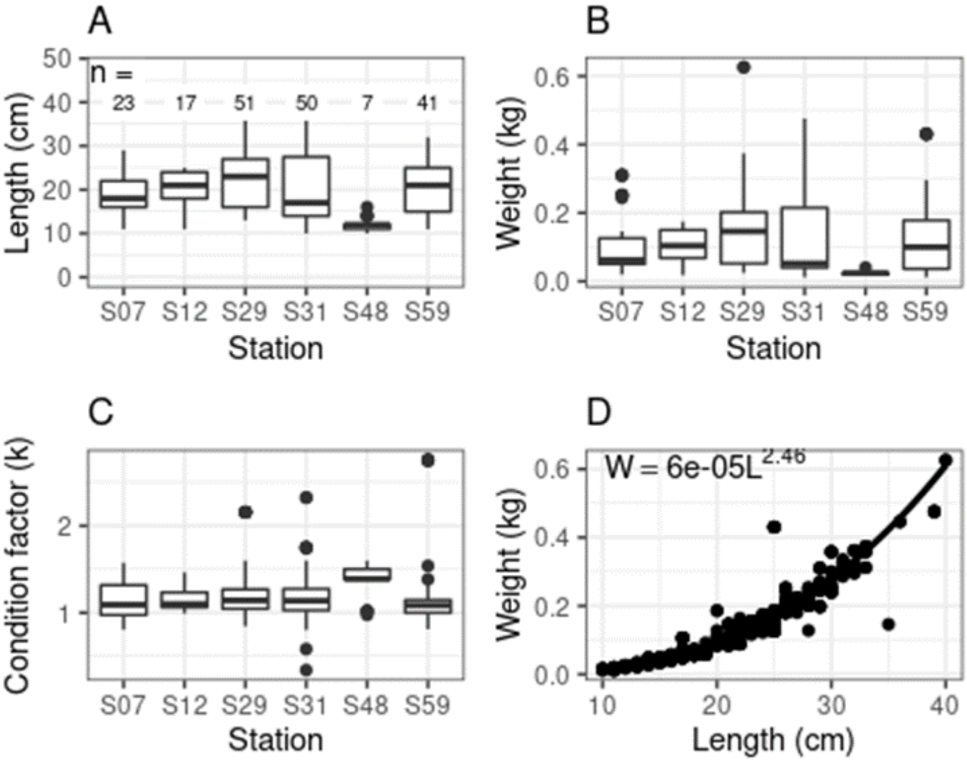

Figure 3.2. Individual body length (A), weight (B) and condition factor k (C) of plaice examined per station. The overall weight-length relationship (D, fit: solid line). The number of individuals per station is shown above the boxplots in panel A.

Table 3.1. Number of individuals with full and empty stomachs per station, percent vacuity index (VI) and Shannon-Wiener diversity index (H').

Station ID	Number of fish	Full stomachs	Empty stomachs	VI (%)	H
S07	23	22	1	4.35	0.748
S12	17	17	0	0	1.01
S29	51	48	3	5.88	1.25
S31	50	50	0	0	1.04
S48	7	6	1	14.3	0.227
S59	41	40	1	2.44	1.4
All stations	189	183	6	3.17	2.34

Table 3.2. Proportion in numbers (%N) and wet weight (%W), occurrence (%O) and percent relevant importance (%IRI) for all stomachs collected in each station and total index of relative importance (All).

	S07				S12				S29				S31				S48				S59				All
Taxon	**%N**	**%W**	**%O**	**%IRI**	**%N**	**%W**	**%O**	**%IRI**	**%N**	**%W**	**%O**	**%IRI**	**%N**	**%W**	**%O**	**%IRI**	**%N**	**%W**	**%O**	**%IRI**	**%N**	**%W**	**%O**	**%IRI**	**%IRI**
Amphipoda									0.24	0.01	2.13	0.00													**0.08**
Anthozoa					1.53	0.16	5.88	0.06																	**0.15**
Bivalvia	15.7	18.72	90.91	17.52	17.56	15.28	94.12	17.48	11.4	21.90	72.34	17.99	56.3	84.49	86.00	82.55	1.18	2.76	40	0.86	31.86	45.14	75.00	54.22	**23.8**
Chordata									0.12	0.17	2.13	0.00	6.53	6.46	2.00	0.18					17.70	20.80	10.00	3.61	**3.60**
Crustacea	4.27	2.24	45.45	1.66	3.05	3.22	35.29	1.25	3.21	0.53	34.04	0.95	1.68	0.25	12.00	0.16	1.18	0.59	40	0.39	0.88	0.18	7.50	0.07	**2.67**
Echinoidea	1.94	6.01	22.73	1.01	4.58	1.07	41.18	1.32	46.2	38.47	55.32	34.97	0.56	0.18	2.00	0.01	0.59	1.38	20	0.22	5.31	3.21	10.00	0.80	**16.3**
Gastropoda									0.83	1.47	6.38	0.11	0.37	0.24	4.00	0.02					0.59	0.13	5.00	0.03	**0.41**
Nematoda									0.36	0.02	2.13	0.01													**0.11**
Nemertea					1.53	0.85	23.53	0.32	0.71	0.23	8.51	0.06	0.19	0.05	2.00	0.00					0.59	1.36	5.00	0.09	**0.49**
Ophiuroidea	0.97	1.24	22.73	0.28	1.91	0.44	23.53	0.31	1.19	1.24	19.15	0.35	0.93	0.10	10.00	0.07	1.18	18.93	40	4.40	2.95	0.55	25.00	0.82	**1.39**
Polychaeta	77.1	71.80	95.45	79.53	69.85	78.99	94.12	79.26	35.8	35.96	85.11	45.57	33.4	8.22	60.00	17.02	95.88	76.33	100	94.14	40.12	28.63	62.50	40.34	**51.0**

The highest plaice diet diversity and evenness was observed in the northern stations (S07, S12, S29), and the lowest in the southern stations (S31, S48, S59) (Figure 3.3). The cumulative diversity curves (Figure 3.4) show that sufficient numbers of plaice stomachs were sampled when combining the stations at each of the four sites.

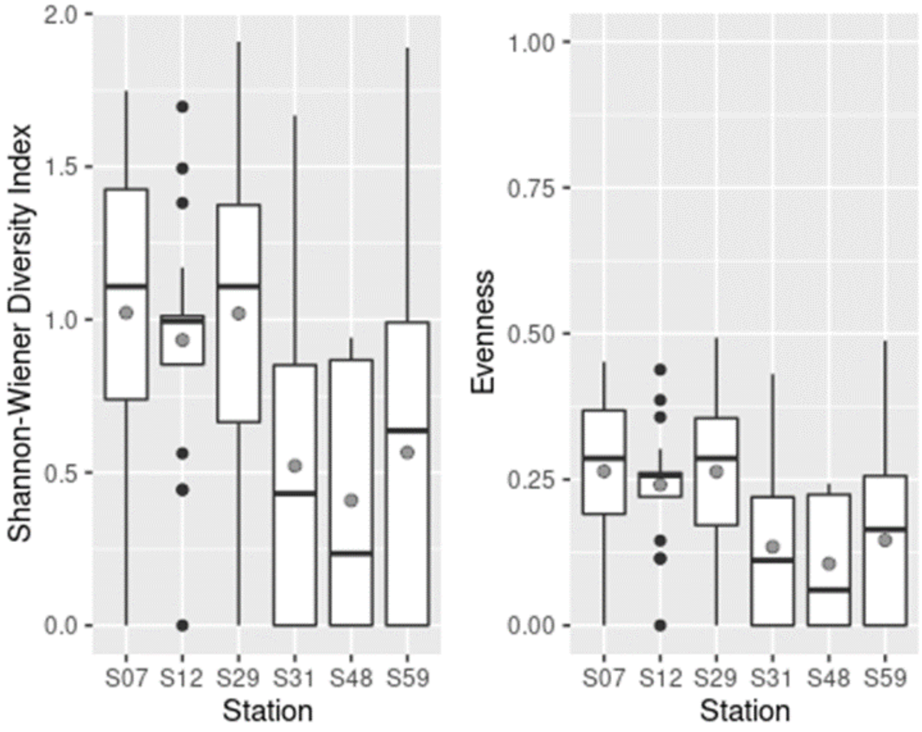

Figure 3.3. Shannon-Wiener diversity index (left) and evenness (right). The boxes span from the 25th to the 75th quantile and the whiskers span from the smallest observation ≥ 25th quantile - 1.5 IQR (interquartile range) to the largest observation ≤ 75th quantile + 1.5 IQR.

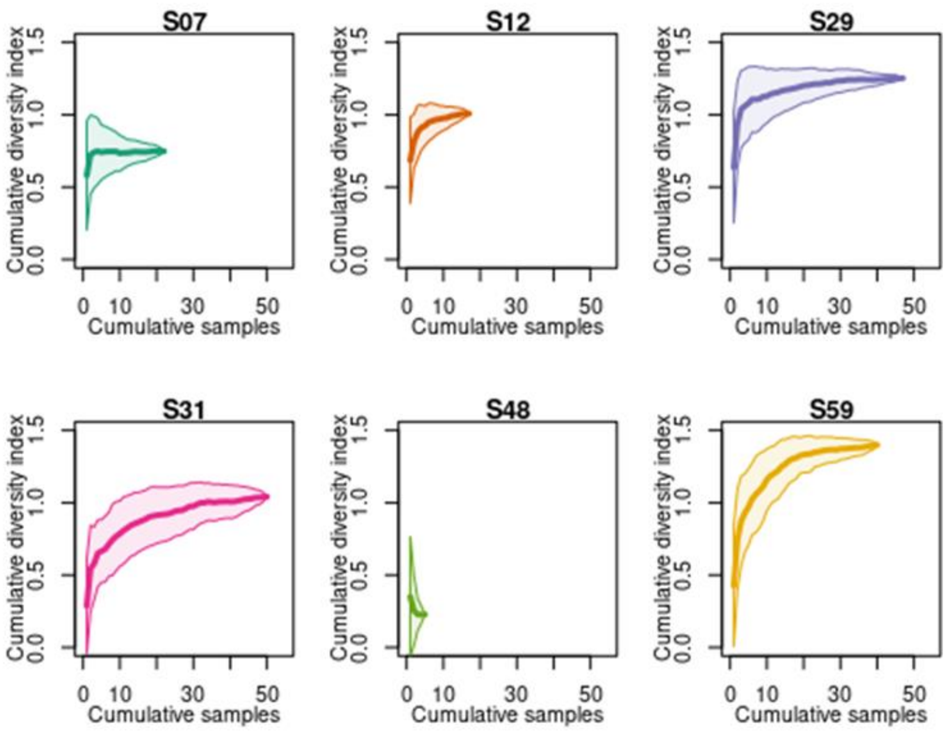

Figure 3.4. Cumulative diversity against the number of cumulative samples for each station; mean (solid thick lines) and ± 1 standard deviation (thin lines).

3.3.2 Diet diversity - environment/diet overlap

Polychaete and bivalve biomass dominated in the plaice stomachs at respectively the northern and southern stations, despite their lower proportion in the benthic macrofaunal communities at the respective sites (Figure 3.5). Small bodied sea urchins were also important in the diet at one station (S29). The biomass of the macrofaunal sediment samples was domitated by large bodied sea urchins, which are not considered suitable prey items for plaice.

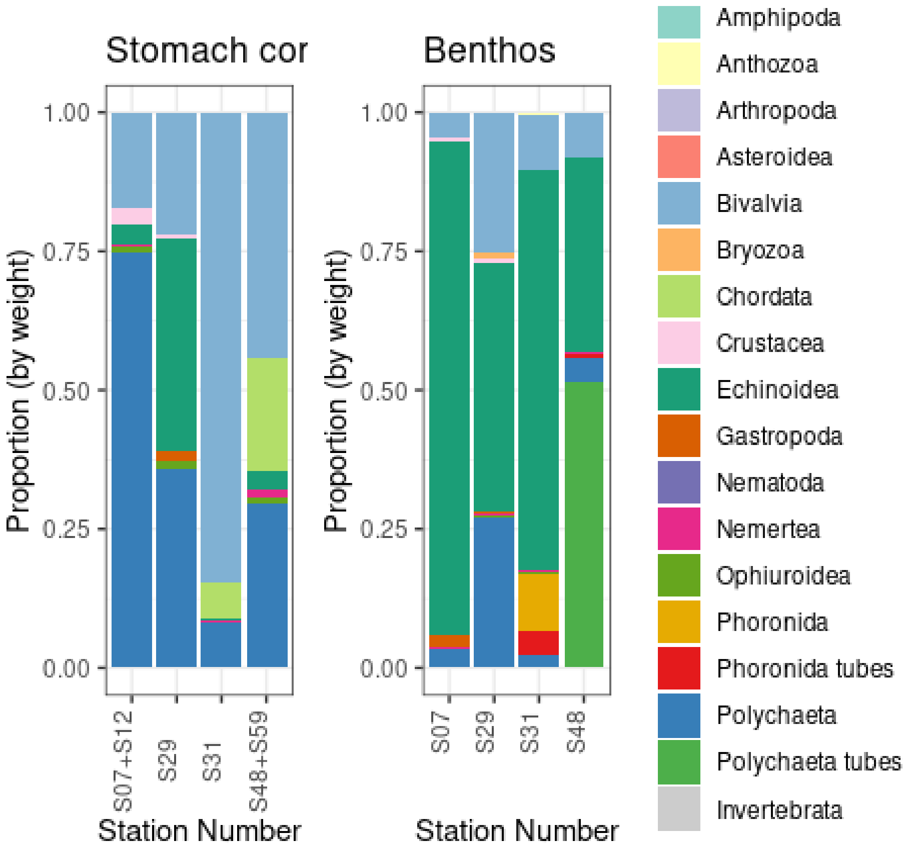

Figure 3.5. Proportion (by wet weight) of macrofaunal groups recorded from the A. Plaice stomachs, and B. Van Veen grab samples (1 mm and 4 mm fractions combined) for each station.

The macrobenthos associated with circalittoral sandy habitats along the Danish North Sea coast shows a higher species density in the North compared to the South. The smaller sized macrobenthos (1mm fraction) were more diverse compared to the larger bodied component (4 mm fraction) of the community. While the biomass of the small fraction was dominated by polychates and other tube building macrofauna, the large fraction was dominated by seaurchins (Figure 3.6). A similar trend was observed when comparing the individual grab sample biomass, although some variation was found between the 5 replicates of each station (Figure 3.7).

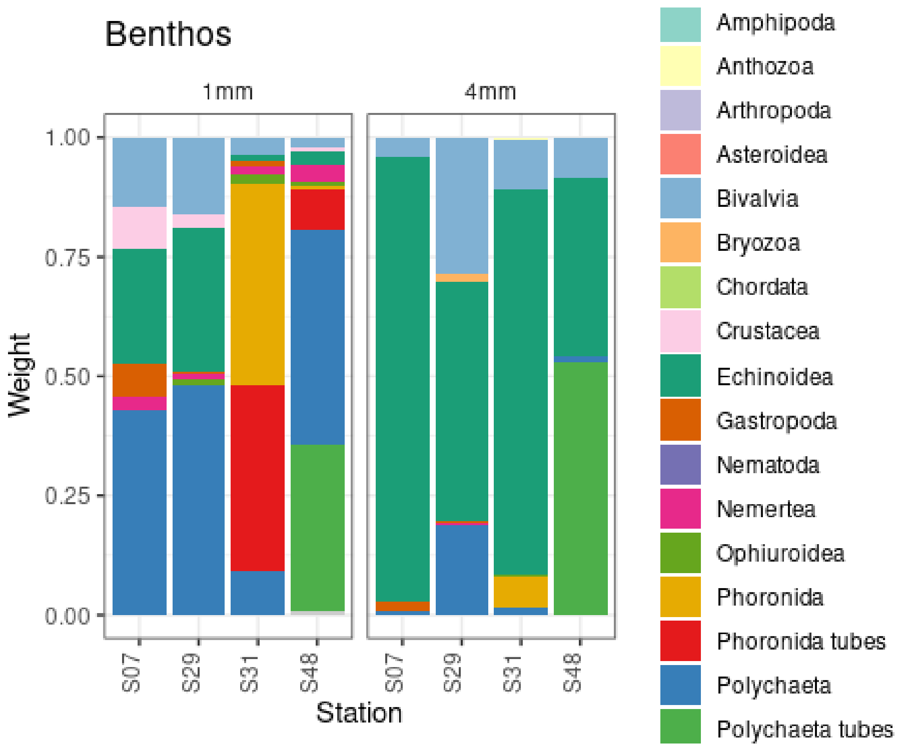

Figure 3.6. Proportion (biomass by wet weight) of macrofaunal groups recorded from the Van Veen grab samples for the A. 1 mm, and B. 4 mm fraction, respectively.

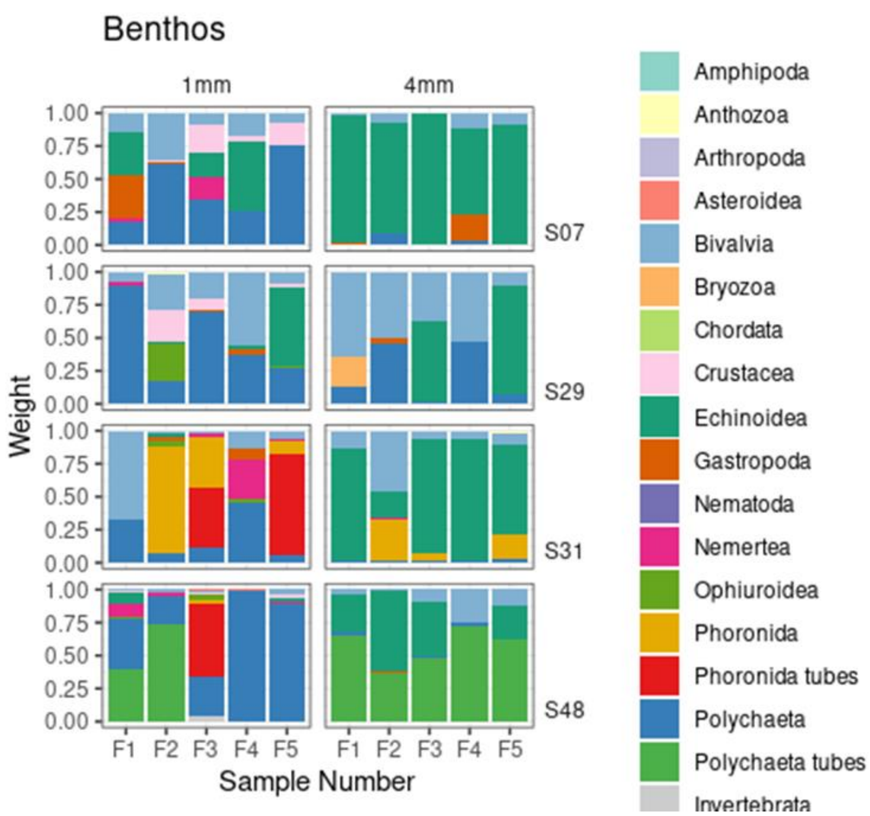

Figure 3.7. Proportion (by wet weight) of macrofaunal groups recorded from each Van Veen grab sample per A. 1 mm fraction, and B. 4 mm fraction for each station.

The Electivity index provides valuable information on the relative food selectivity of specific prey items compared with their relative density in the habitat. It does, however, not measure scales well. For example, at the northern-most site (stations S07+S12), only Ophiuroidea came out positive. The data showed that the proportion in the plaice stomachs was 600 times the proportion in the environment. In comparison, Polychaeta was only 20 times more abundant in the stomachs than in the environment. Therefore the electivity of the former is much higher than the latter (that the one is negative and the other positive comes from the transformation to the range [-1, 1]). The index provides a generalised overview of food preferences.

The Electivity indices based on density of prey individuals (Figure 3.8) showed that plaice in the northern site (S07, S12) besides Ophiuroidea and Polychaeta also selected for Anthozoa. At station S29 plaice only selected for Echinoidea, which was represented by one species, the small bodied *Echinocyamus pusillus* (O.F. Müller, 1776). At the southern station S31 plaice selected for Crustacea represented by Amphipoda, Bivalvia represented by *Macoma calcarea* (Gmelin, 1791) and *Ensis* spp., and Polychaeta. At the southern-most site (S48, S59) plaice selected for Echinoidae represented by *E. pusillus* and Bivalvia represented by *Ensis* spp.

The Electivity indices based on prey biomass (Figure 3.9) showed different food preferences. In the northern-most site (S07, S12) plaice preferred Polychaeta. At the station S29 plaice selected for Ophiuroidea and Gastropoda. At the southern station S31 plaice selected for Bivalvia and Polychaeta, while at the southernmost site (S48, S59) they selected for Ophiuroidea, Polychaeta, Bivalvia represented by *M. calcarea*, and Nemertea.

The results of the Shannon-Wiener diversity index, H', and the Electivity, E_i, index suggest that the higher diversity of the benthic macrofauna as witnessed from the stomach could better be utilized by plaice at the northern sites. This allowed the plaice to select for primarily for Polychaeta biomass at the northern-most site. In comparison, at the southern-most site, plaice appeared more opportunistic in their feeding mode and biomass preferences.

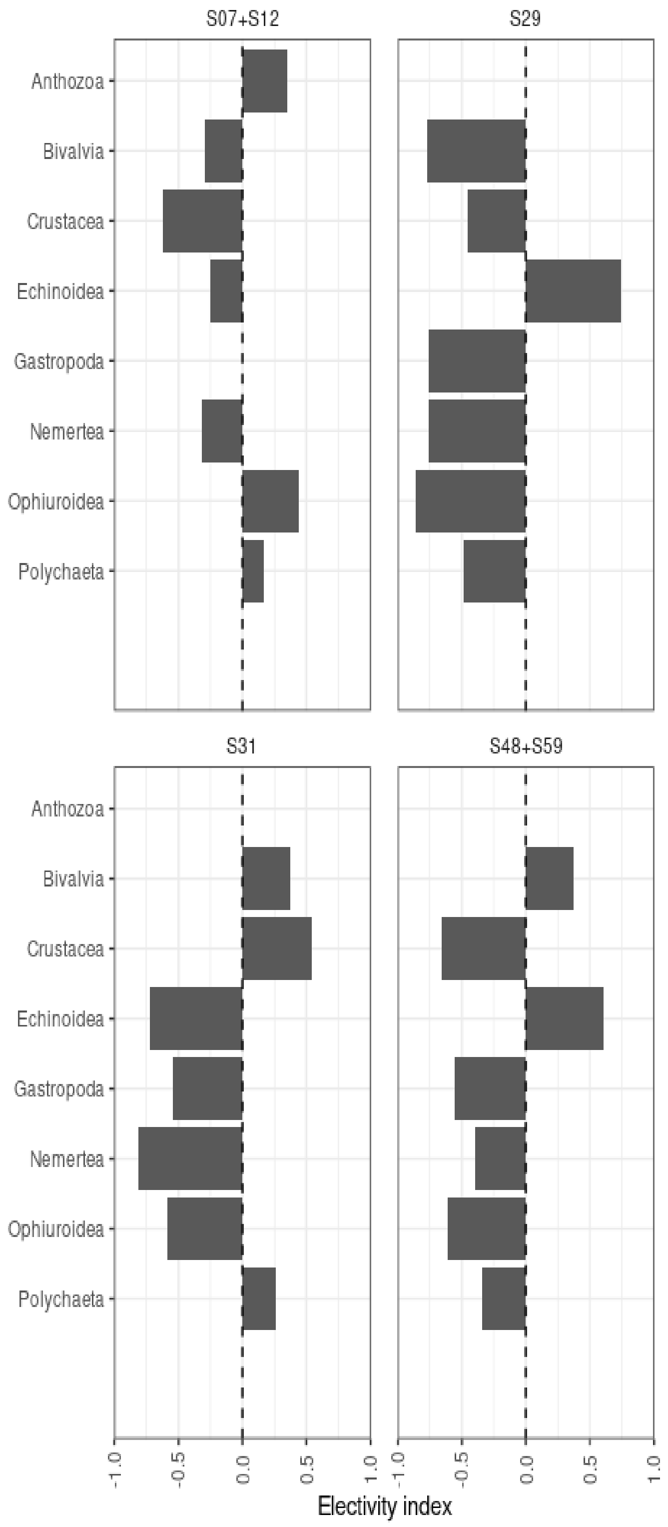

Figure 3.8. Electivity of plaice towards different macrofaunal groups in the different sampling stations calculated based on numerical density (%N). Positive values above 0.2 indicated a relative preference towards the prey.

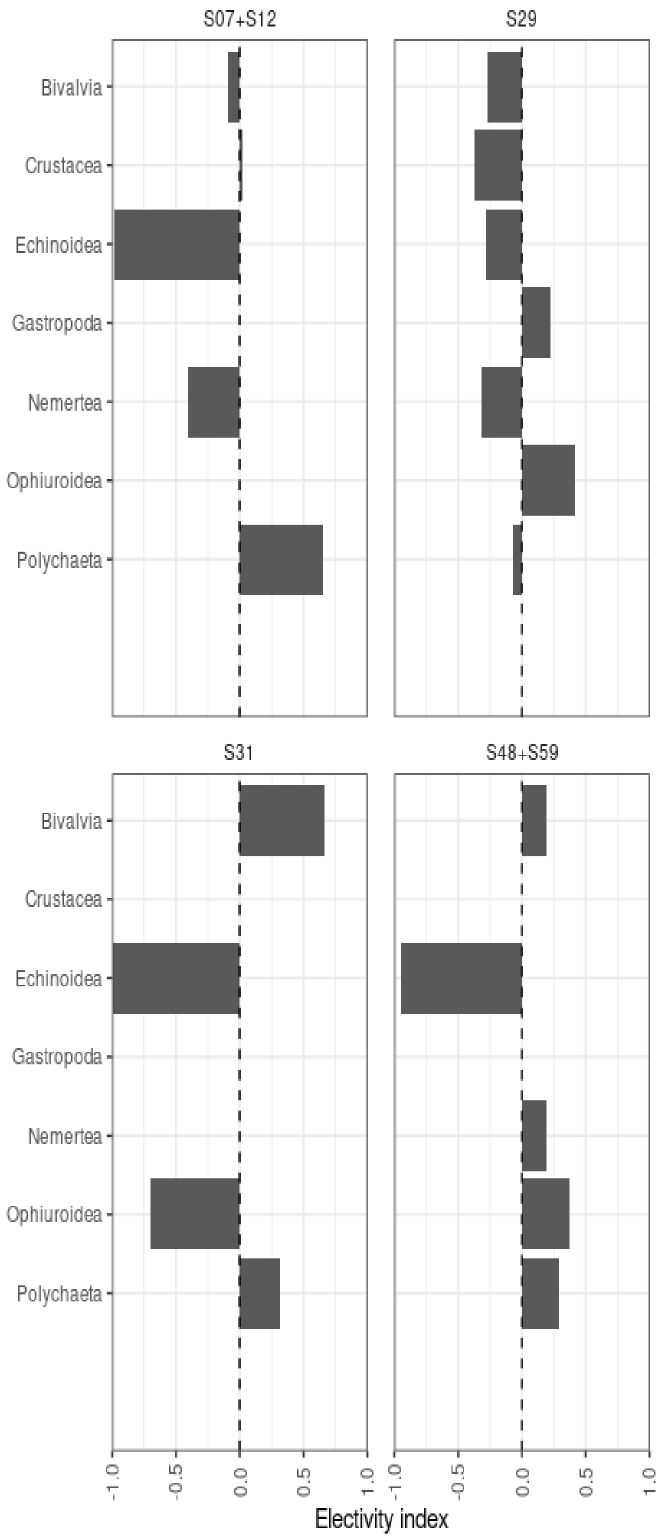

Figure 3.9. Electivity of plaice towards different macrofaunal groups in the different sampling stations calculated based on biomass (wet weight) ($\%W$). Positive values above 0.2 indicated a relative preference towards the prey.

3.4 Discussion

This pilot study showed differences in the both the macrofauna biomass available to plaice and differences in plaice selection depending on prey availability in the local habitat. Despite the restricted number of sites and replicates the results showed a longitudinal trend in circalittoral sandy habitats along the Danish North Sea coast.

A shift in plaice diet from predominantly bivalves to polychaetes observed Rijnsdorp and Vingerhoed (2001) between the start of the 20th and 21st century. A similar plaice diet composition was observed in the northern-most site (in 2020) where the plaice diet diversity was also high. In the two southern sites bivalve biomass dominated followed by polychaetes, although the species composition may have altered. This is in contrast to the findings in the same area by Rijnsdorp and Vingerhoed (2001) and suggests that changes in the benthic macrofaunal communities continue to happen.

In the two northern sites, although the higher species density of available prey was reflected in the plaice diet, they exhibited selectivity for specific prey items and their selection changed with prey availability. The selectivity in plaice indicated a preference for small sea urchins over specific bivalve species, which were then again preferred over polychaetes. It is unclear how the change in prey availability affects their selectivity and their growth and survival.

These results suggest that the northern site in Skagerrak still was an ideal foraging habitat for plaice reflecting historical conditions and supported by the fact that plaice fishery is still viable in this area. On the other hand, the conditions in the southern site, of the coast of Esbjerg, have drastically changed resulting in the absence of plaice and its fishery in the coastal areas.

Although a pilot study, some trends were detected, but more detailed work is required to disentangle the influence of the key pressures, responses of the benthic macrofaunal communities and the changes in tropic interactions. The results of the pilot study highlight the importance for fisheries management to ensure benthic habitat integrity to support viable commercial coastal fisheries.

4. Conclusion

One of the main motivations and aims of the Vesterhavsfisk project, from its inception, was to investigate observations of fishers that fish populations near the west coast of Denmark have been dramatically declined. Areas that could previously sustain fisheries are now abandoned and fishing takes place further offshore or further North. The information collected during the project through experimental commercial fishing and scientific surveys, supports the claims by the commercial fishers. The numbers caught during the gillnet fishing were quite low and not near enough to sustain a fishery on traditionally exploited species, like cod and plaice. Dab was the most caught species and is potentially the only species that could sustain a fishery based on numbers. Questions on available market for the species and on sustainable management limits and other precautionary approach measures of such a fishery were not investigated during this project and need further investigation. Establishing new fishing grounds should take into account all available knowledge so that it has the greatest potential of being sustainable, both for the sake of conservation of species diversity in the area but also for a sustainable community of fishers that can rely of the new collected resource.

The monitoring of the coastal areas is practically non-existent as it is not part of the annual international bottom trawl surveys that are gathering essential information that is used for stock assessments and management. These areas are crucial for many fish species as they are utilised in different life stages, e.g. as nursery grounds for juveniles. Therefore, monitoring of coastal areas in a consistent way can inform the assessment of important commercial stocks and lead to more appropriate management and sustainable exploitation.

Analyses of stomach contents in combination with benthic sampling, like the plaice case study presented here give invaluable insights of how the species utilises resources in its environment. The data collected during the Vesterhavsfisk project, provide indications of the species distributions in the coastal area, but it is only a glimpse into the state of the ecosystem as it is mostly a snapshot at a specific time point. Constant monitoring would provide better insights that would transform in better informed management decisions for commercially and biologically important species.

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