



Department of Arctic and Marine Biology

Interactions between 0-group Saithe (*Pollachius virens*) and 0-group Cod (*Gadhus morhua*) in shallow nursery areas

Diet differences and overlap of 0-group saithe and cod in the Porsangerfjord

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Abstract

In this study diet width and overlap between 0-group saithe (*Pollachius virens*) and 0-group cod (*Gadhus morhua*) was studied. Along with studying if habitat characteristics, length of the fish (cod and saithe), fjord distance, predator specie (cod or saithe) had an impact on the diet composition of the sampled fishes. A diet comparison between my diet findings and findings in earlier studies. The samples were obtained from Porsangerfjord (70-71 °N and 25-26 °E) in August 2023. The 0-groups were sampled using a beach seine in the intertidal. A total of 93 0-group saithe and 63 0-group cod were analysed in the laboratory. Diet width of the 0-group cod and saithe were similar, and there was a clear overlap in the diets of the two species, with important common prey groups ssuch as Harpacticoida, bivalves and shrimp. This overlap was found to be the largest in the outer and middle parts of the fjord. Station and species (0-group cod and saithe) was found to have the most impact on the diet composition, with fjord distance and predator length not having as much of an impact. Comparison of my diet data with earlier studies revealed a similar diet composition in my samples as in previous ones. Key differences between my diet data and previous diet data were the heavily reduced number of pelagic copepods in my data, but an increase in benthic copepods.

Key words: 0-group cod, 0-group saithe, diet composition, NMDS, CCA, habitat characteristics

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Introduction:

Saithe (*Pollachius virens*) and cod (*Gadus morhua*) are important species within Norwegian fishery as well as playing a vital role as prey and predators within their ecosystem (Olsen et al., 2010). Both species can be found co-occurring along the Norwegian coast.

The Norwegian coastal cod (NCC) spawn in fjords along the Norwegian coast and some outer coastal areas. They spawn in the deeper water masses to prevent the compensatory currents of the fjord washing the eggs out into the open ocean. The eggs in the deeper water masses are then retained in the fjord, and subsequently hatching within (Fevolden et al., 2012; Olsen et al., 2010). Saithe spawns at several areas along the Norwegian coasts, at a greater depth than the cod (Bromley et al., 1997; Jakobsen, 1987; Olsen et al., 2010). Saithe spawns at 150-200m depth, their eggs floating upwards in the water column, the current taking them north (Olsen et al., 2010)

Both 0-group NCC and 0-group saithe settle from the pelagic to the bottom in shallow waters and the littoral zone within the fjords and along the Norwegian coast. (Olsen et al., 2010).

The NCC spend their lives reasonably stationary within the fjords, with exceptions for the cod found in the northernmost fjords. These cod that exist in these large open fjords in Finnmark have been observed migrating to other coastal areas in close proximity during the autumn months, but returning during the winter to spawn (Fevolden et al., 2012; Olsen et al., 2010). Saithe spend the early part of their lifecycle in the littoral zone. Once they become juvenile, they have been observed to school together along the coast at a depth of 60m and above. Saithe and cod become juveniles after transitioning from the larvae stage to the juvenile stage in a process called metamorphosis. This happens at ca 1.5 cm of length and ca 40 days after hatching (Barrett, 1991; Olsen et al., 2010; Pedersen & Falk-Petersen, 1992). Saithe of age 2-4 years migrate to coastal banks found outside of Finnmark (Olsen et al., 2010)

NCC stocks have been declining over the years, with causes such as low recruitment being pointed at as a reason for the declining stocks (Heggland, 2013; Jakobsen, 1987; Olsen et al., 2010). Unsuitable or limited habitat for coastal cod juveniles could be a factor that could cause such a low recruitment. For 0-group cod that is utilizing shallow nursery habitats, factors such as substrate and vegetation may affect the quality of the habitat. Aquatic vegetation is important for the 0-group fish to provide shelter from potential predators,

making a valuable foraging ground, and protecting the 0-group fish from physical exposure (Gotceitas et al., 1997; Heggland, 2013; Jakobsen, 1987)

Within the Porsangerfjord sea urchin grazing has been a problem (Pedersen et al., 2018). The sea urchin population causes severe damage to the kelp and other macroalgae within the fjord due to overgrazing (Eklöf et al., 2008; Norderhaug & Christie, 2009). Such overgrazing by sea urchins can leave areas barren of vegetation for years before new algae recruitment can occur (Eklöf et al., 2008). This grazing can have a devastating effect on the community that rely on the cover of vegetation for food or shelter. Ultimately over grazing by the urchins can end up destroying or limiting suitable habitat for other species.

Earlier studies suggest that the diet of 0-group saithe and 0-group cod are similar (Bromley et al., 1997; Heggland, 2013; Lie, 1961; Olsen et al., 2010). With both species eating advected prey like *Calanus*, *Caligus*; *Caligus* is a parasitic copepod family known for attacking farmed fishes like salmon (Boxshall & Bravo, 2000; Hemmingsen et al., 2020), other copepods, and krill. Amphipods and other crustacea are consumed by both species, and other fish was an important food source in the North sea (Bromley et al., 1997). The larger individuals of the 0-groups for both cod and saithe may begin to take on a more piscivorous diet (Kanopathipillai et al., 1994; Olsen et al., 2010). With increasing length, the cod feed on an almost entirely piscivorous diet, while large the saithe consumes a mixture of other fish and other prey (Bromley et al., 1997; Kanopathipillai et al., 1994; Olsen et al., 2010). With these species consuming such a similar diet it is interesting to investigate if they will have a similar diet while co-existing in the same habitat. One possibility is that they keep the same diets or alternatively they may adjust the diet due to competition. Looking into this can let us see the effects of diet overlap, and how it might affect the different species, in regard to survival and recruitment.

Diet niche width may give information regarding feeding niche width of a species (Devictor et al., 2010). Niche being the resources and area a species or sub-species need to survive, as well as its ecological role in the ecosystem (Polechová & Storch, 2008). The concept of niche and how to classify what is considered a species niche has been a subject of discussion for many years. The more modern interpretation of a niche was given by G. Evelyn Hutchinson (Colwell & Rangel, 2009; Vandermeer, 1972). Hutchinson noting that a niche is not a fixed environment around the species, but rather the dynamic way the species utilized the environment and resources around it. Niche then encompasses the resources the species uses

as well as the environment it utilizes (Colwell & Rangel, 2009). The fundamental niche is the complete collection of resources and environments a species can utilize. Some species have a larger niche, not really specializing in specific resources, these are called generalists and are more resistant to potential change as they can utilize many different resources (Devictor et al., 2010). Specialists are the opposite; they heavily specialize on being the best at utilizing a resource or environment. This makes them hard to outcompete but leaves them more susceptible to change (Devictor et al., 2010). Niches can change in response to interaction between two species, this could be due to factors such as predation or competition. This changed niche is then what we call a realized niche (Roughgarden, 1974).

In this thesis I will study 0-group cod and 0-group saithe, and their diet width and potential diet overlaps between the two species, how diet might change with habitat characteristics, and if diet compositions have changed compared to earlier. My null hypotheses will then be as followed:

H₁: Diet widths are similar and there is no dietary overlap between 0-group cod and 0-group saithe.

H₂: Fish length, fjord distance and habitat characteristics have no impact on perceived diet.

H₃: There is no change in diet of 0-group cod and 0-group saithe compared to findings in earlier studies.

The Porsangerfjord (70 – 71 °N and 25 – 26°E), will be the area for this study. It is an ideal area because it contains both 0-group cod, and 0-group saithe co-existing in the littoral zone. It also has multiple locations with varying habitat characteristics lending itself for comparing and studying. Sampling of fish will be done using a beach seine in locations where the species co-exist on each station for further analysis in the lab.

Material and methods:

Study area

Samples were gathered 22-24th of August 2023 in Porsangerfjord (Fig. 1)

In total there were 10 stations which were sampled using a beach seine. The 10 stations were; 1: Repvåg, 2: Ytre svartvik, 3: Smørfjord, 4: Indre Billefjord, 5: Holmfjord, 6: Trollholmsund, 7: Reinøya øst, 8: Rakkut, 9: Čohkaskárku, and 10: Handelsbukta, further through this paper they will be referred to as station 1 through 10.

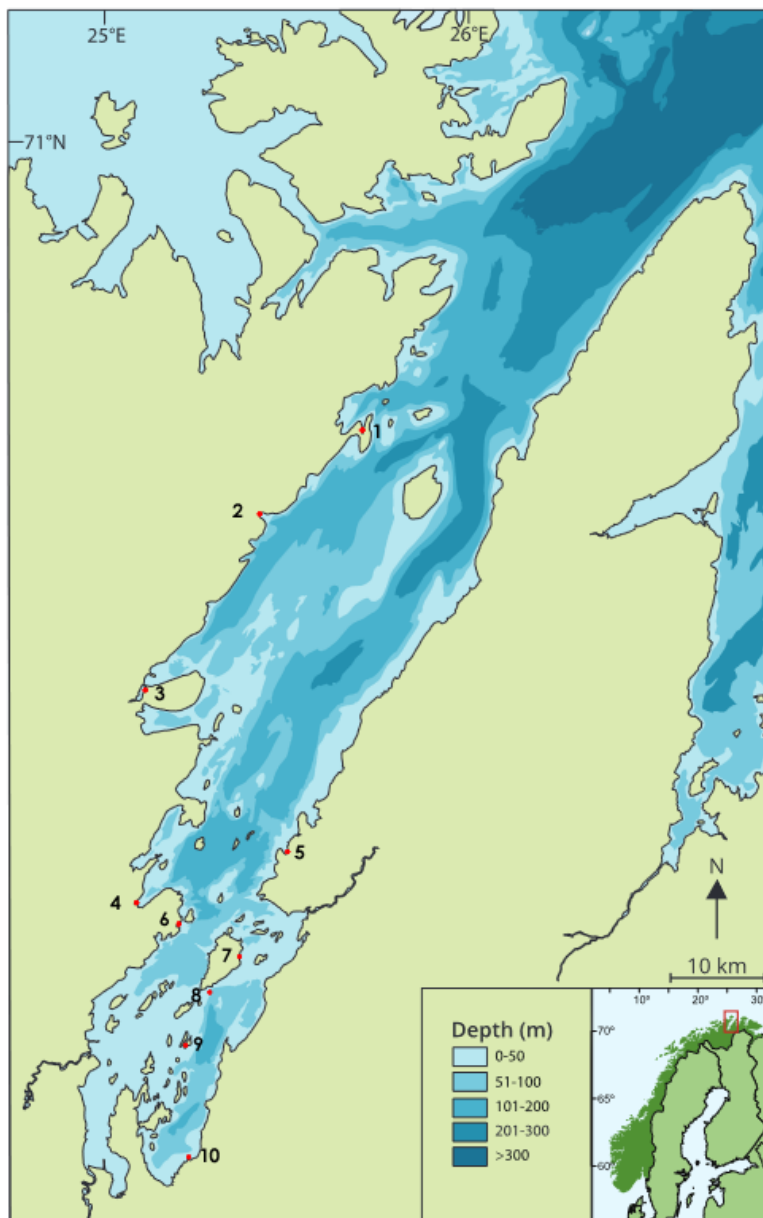


Fig.1 The different sampling locations along the Porsangerfjord. 10 stations sampled by beach seine. Map is modified from Frøydis strand (Pedersen et al., 2018).

Sampling area

Porsangerfjord is in the northern part of Norway (70 – 71 °N, 25 – 26 °E). This is the largest fjord in northern Norway, with an area of 1877m² (Pedersen et al., 2018). The Porsangerfjord lacks a shallow entrance sill, but has a few deeper sills in the inner parts of the fjord. The lack of sill in the outer part of the fjord makes it more exposed to the external influence of the Norwegian ocean current (Wassmann et al., 1996). In the inner areas of the fjord, three main rivers introduce a lot of freshwater runoff into the waters (Pedersen et al., 2018).

Sampling

Sampling was done by deploying a beach seine at the different locations. The beach seine had wings measuring 15 m each, the middle measuring 7.5 m wide, and the beach seine measuring a total length of 37.5 m without the connecting ropes. Wing height spanned from 1.15m at the rope connection point, and spanned to 2.65m, with the middle measuring 3m in height, with the collection basket measuring 1.6m. The rope attached to the seine measured 30 m. Three different mesh sizes were present in the seine. The coarse mesh (1.6cm) making up the wings of the beach seine, the fine mesh (0.4cm) making up the belly of the seine, and the collection basket had a mesh size of 0.9cm. The bottom rope was leaded to prevent floatation, and the top rope had floatation devices added to ensure the seine stretched properly (Fig. 2).

The beach seine was deployed using a waterjet boat. Two persons stood on the shoreline, 16m apart. The seine was then launched from the first person and in an arch to the other person on the shore. The seine was then hauled with an even pace towards the shore, the people hauling slowly decreasing the distance between them as they hauled. The seine was then hauled onto dry land and its content was noted down and sorted by species, and samples taken. Two such hauls were conducted on each station, with exception of Smørfjord (st 3) where three hauls had to be made due to the seine getting stuck on the rocky substrate and had to be lifted often, giving the possibility for fish escaping.

After the beach Seine had been hauled one person surveyed the seafloor where the hauls were taken using an aquascope. Estimated substrate coverage of the seafloor and noted down for the area of each beach seine haul. The categories used where; sand, gravel, stone 3-10cm, stone 10-20cm, stone 20-50, stone>50, *Ascophyllum nodosum*, *Fucus vesiculosus*, *Fucus serratus*, *Saccharina latissima*, *Chorda filum* and other annual algae, as well as the bivalve *Modiolus modiolus*.

The GPS-positions of each starting point for the beach seine hauls were noted using a handheld GPS-positioner. The samples were kept cold on ice in the field and when returning to the field station in Porsangerfjord the samples were frozen at -18°C .

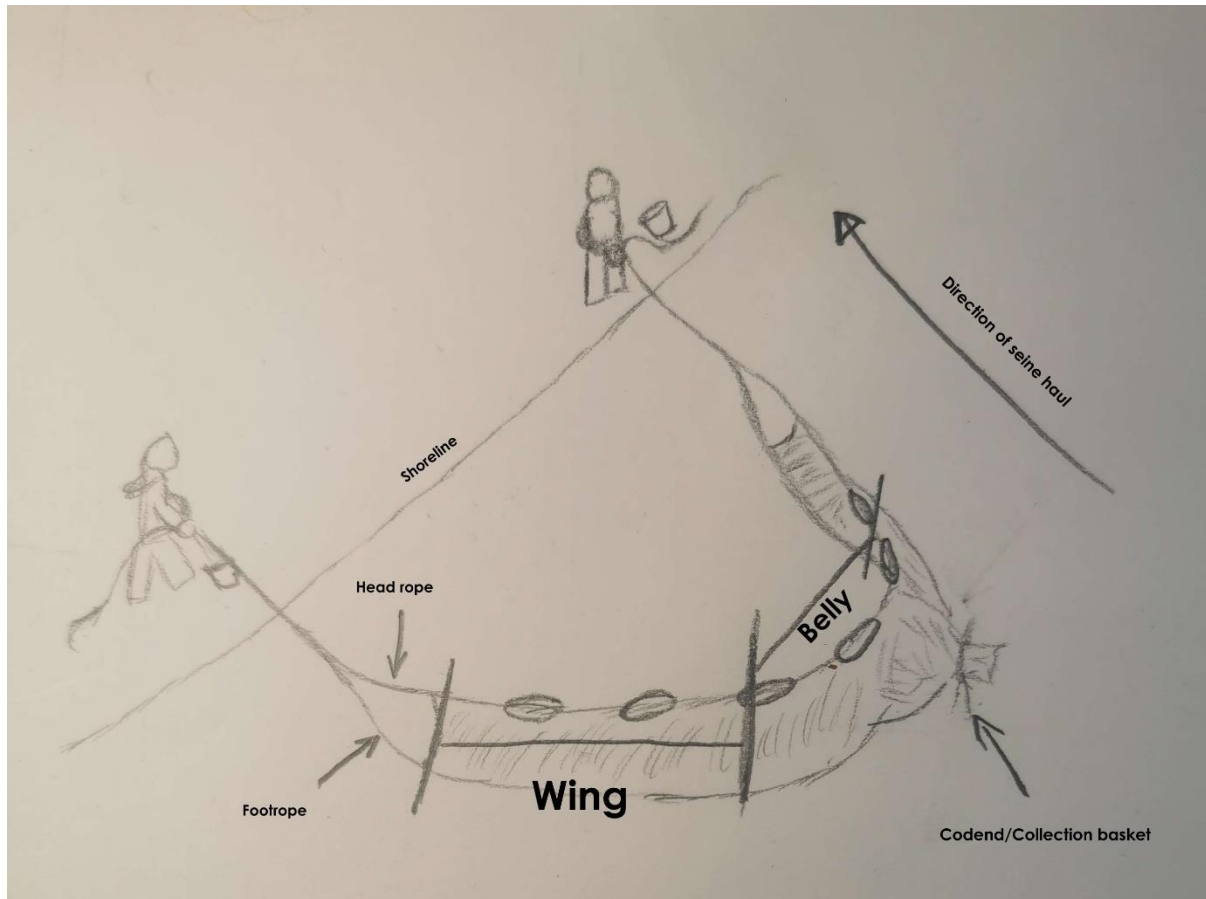


Fig.2 Drawing of the beach seine.

Laboratory analysis

In the laboratory 10 specimens of saithe and 10 of cod was analyzed from each station (for stations containing less than 10 specimens, the available samples were used). The fish was thawed and total length and wet weight were taken of each specimen. The samples were then dissected and processed. The stomach was removed and stomach contents were transferred to a transparent sheet. The emptied stomach and dissected specimen were placed into a small cup, numbered and then dried for 24 hours at 60°C . The stomach content was analysed under binoculars (Leica WILD M 10) with magnification of 8x to 80x, prey items were sorted and identified to the lowest possible taxa (with the help of Torstein Pedersen, Kim Præbel and (Enckell, 1980)) and counted. The prey items were then separated into their respective prey

groups, on the transparent sheet, and marked before being dried for 24 hours at 60 C° in a drying cabinet. Once dried the samples were weighed again until a constant weight using a precision scale (Sartorius BP 110 S), the different prey groups were also weighed until a constant weight to estimate biomass. The samples were weighed to the closest 0.1 milligram

Data treatment

The complete dataset consists of 156 specimens with 93 specimens of saithe and 63 specimens of cod sampled from the ten different stations along the Porsangerfjord. Total number of consumed prey, their combined biomass, and percentage of consumed biomass was noted (Appendix table 2, and Appendix table 3)

R (version 4.3.2) and Excel were used for graphical visualization and statistical analysis (Appendix table 4, and Appendix table 5). Packages used where Vegan 2.6-4, Readxl 1.4.3 and Dplyr 1.1.4

Non-metric multi-dimensional scaling

The statistical software R was used to perform a non-metric multi dimensional scaling (NMDSS) analysis of the diet composition of 0-group saithe and cod, and to plot the results using a dataset containing the environmental factors and diet composition samples (Appendix table 4). The NMDS plot is a way to visually presents the complex relationship between factors (Saeed et al., 2018). The NMDS was used to visualize the relationship between prey composition of individual fish and prey categories in 0-group saithe and cod. This was done for all 10 stations combined, as well as for each station separately.

Canonical correspondence analysis

R was used to perform a Canonical correspondence analysis (CCA) using package Vegan 2.6-4 (Appendix table 5). CCA is an analysis that lets us look at and visualize the relationship between factors and lets us see which factors could have the most influence on what we are studying (Ter Braak & Verdonschot, 1995). In this study CCA was used to investigate which factors that had the largest influence on diet composition. The environmental factors used here are; the stations, specie, fish total length (mm), and distance of each station from the inner end of the fjord to the fjord opening (f.distance, km). Fish length (mm) and fjord distance (km) are continuous variables while station number and predator species (saithe or cod) are categorical variables. The data used in the CCA was square root transformed to lessen any skew that might have been in the data. In the CCA-plot the length of the arrows

indicate how much of impact the different environmental factors have on the diet compositions.

Levins niche index

Levins niche index is a measure of niche breadth (Equation.1), and was used to calculate the diet niche width for the species at each station. Levins niche index is not perfect as it has its own limitations, such as not allowing for the possibility of resources existing in abundance, or that some resources are more rare than others(Krebs, 2016).

In equation 1, B is Levins measure of the niche breadth, and P_j is the proportion of prey J.

$$B = \frac{1}{\sum p_j^2} \quad (\text{Equation 1})$$

Diet overlap index

Pianka's diet overlap index was used to calculate the niche overlap between 0-group cod and 0-group saithe withing the stations (Equation 4)(Krebs, 2016). Pianka's diet overlap index puts the overlap on a scale from zero to one. The closer the value is to zero the more exclusive resource usage the species have, and the closer to one the more similar resource usage the species have (Pianka, 1974). To calculate Pianka's overlap, Piankas modification of MacArthus-Levins measure was preformed (Equation 2) (Krebs, 2016).

In equation 2, O_{SC} is the overlap between species S and C. P_{iS} is the proportion of prey group i is of the total prey used by species S. P_{iC} is the proportion of prey group i is of the total prey used by species C, and n is the total number of prey groups

$$O_{SC} = \frac{\sum_i^n P_{iS}P_{iC}}{\sqrt{\sum_i^n P_{iS}^2 \sum_i^n P_{iC}^2}} \quad (\text{Equation 2})$$

Bootstrapping

Bootstrapping was used to calculate uncertainty measures for diet width and the niche overlap (Band & Tibshirani, 1993). This was done due to the small number of fish I had for this research and was done to calculate the 95% confidence intervals and add error bars to the point estimates of the niche width and diet overlap index.

Bootstrapping works by using existing data and were set up in Excel, picking out random individuals with laybacks from the existing dataset and compiling them into a new one (bootstrap replicate). The bootstrap sampling was repeated 600 times and niche overlap was calculated for each replicate, making it possible to use these replicates to calculate a 95%

confidence interval for diet width index and diet overlap index using the percentile method (Band & Tibshirani, 1993).

Results

Numbers of 0-group caught and analysed and fish lengths

0-group saithe catches were larger than for cod at all stations (Fig. 3). At three stations (st 1, 6 and 9), only 0-group saithe was caught with the beach seine.

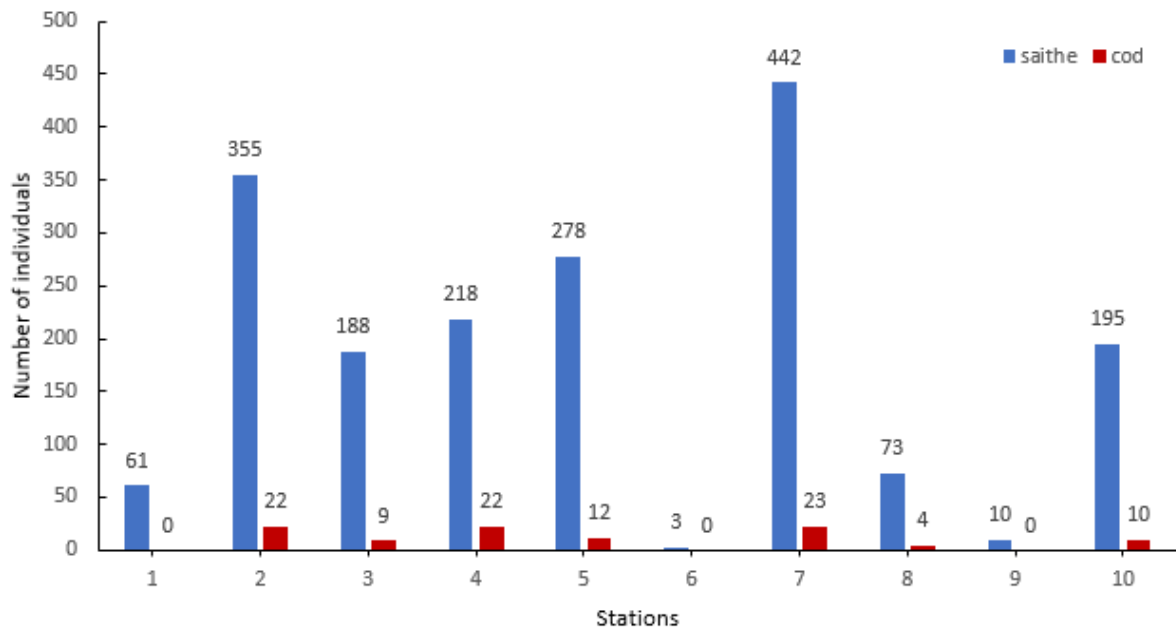


Fig.3 Total number of 0-group individuals caught at each station along the Porsangerfjord. Two hauls were taken at each station (with exception of station 3 where 3 hauls were taken), and here the numbers of 0-group saithe and cod for all hauls at each station have been combined.

Preferably twenty fish would have been collected from each species on each station. However, due to few fish at some stations that was not possible, and we had to use the fish that were available to us. Up to 10 fish of each species were dissected per station where feasible, in stations where there were not enough fish the available fish were used (Fig. 4).

Except for station 5, median total length for 0-group saithe was longer than 0-group cod (Fig. 5). Average total length of saithe and cod were 59.33 mm (SD = 10.57 mm, n= 92) and 52.08 mm (SD = 10.95 mm, n = 61) respectively. The two species seem to have similar size on most stations except for station 10 where the cod on average was much smaller than the saithe (Fig. 5).

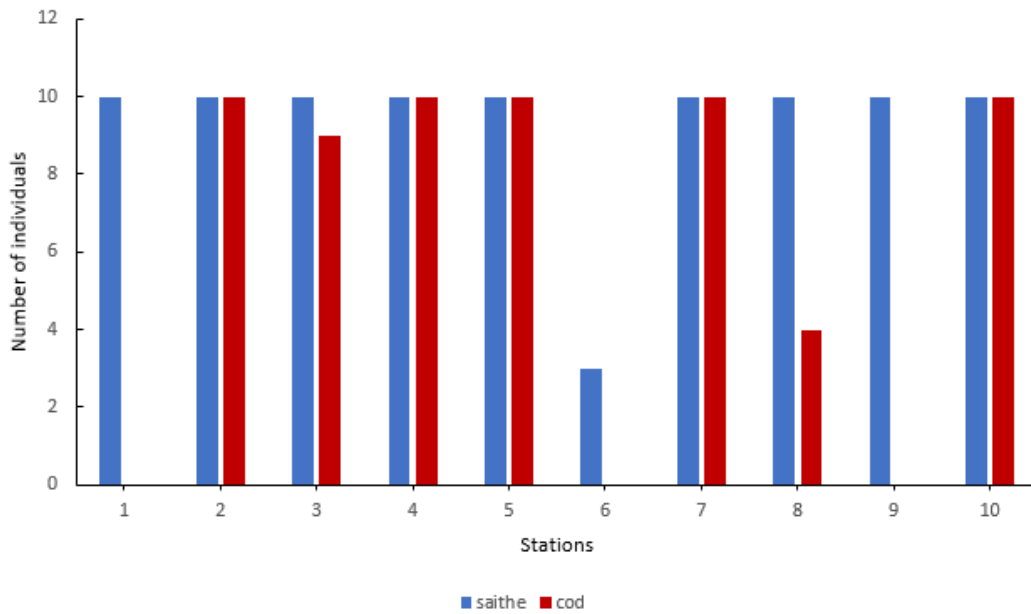


Fig.4 The number of specimens that were analysed in the laboratory from each station. 0-group saithe here represented in blue, and 0-group cod in red.

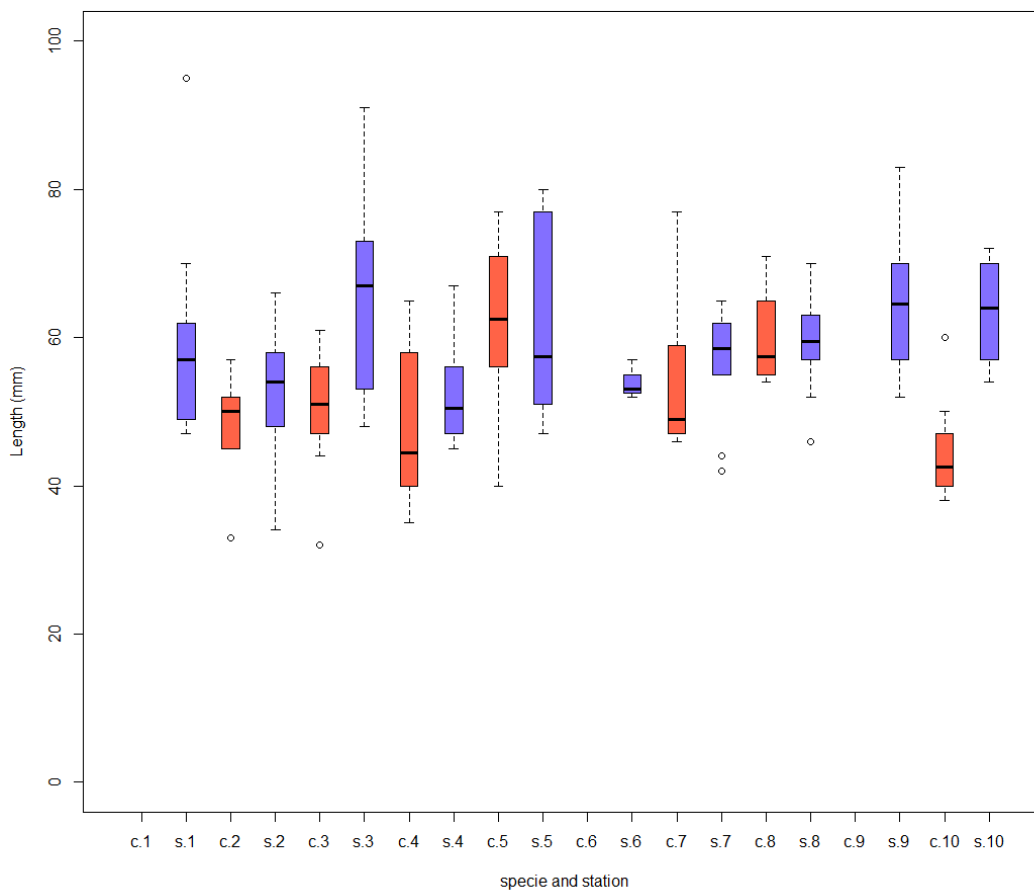


Fig.5 Boxplot showing the total length of the fish processed in the laboratory, sorted by station and specie. 0-group saithe is shown in blue and 0-group cod is shown in red. The black line within the box showing us the median. The coloured box under the median shows the lower 25% quantile, while the upper box shows the higher 25% quantile. The whiskers show the upper and the lower values of the data, excluding outliers which are shown as circles in the plot.

Prey composition

Sixteen different prey categories were found during dissection, and two bivalve groups were combined into one bivalve category, so in total my data contains 15 different prey groups. In addition to these 15 groups, a group of miscellaneous matter is present comprising biomass that was too digested to be classified to a specific prey group. There is also a group of inorganic material such as stone that was found in stomachs. This stone group was later removed from the data before the NMDS and CCA analysis since it was indigestible inorganic material.

Some prey groups were unique for one predator species. Fish eggs, copepods, other crustaceans and isopoda were unique for 0-group saithe and other Amphipoda for 0-group cod (Fig. 6B, Appendix table 1). Five prey groups made up more than 5% of the organic stomach content of saithe (Appendix table 2); harpacticoid copepods, gastropods, bivalves, the copepod sea-lice *Caligus elongatus* and shrimps. 0-group cod had four prey groups which made up more than 5% of organic stomach content; harpacticoid copepods, bivalves, fish and shrimps (Fig. 6A, Appendix table 3). Thus, harpacticoid copepods, bivalves and shrimps were prey with high importance as prey in both saithe and cod.

Though numerous in the stomach content, both the bivalves and gastropods were small in size (Appendix table 2 and Appendix table 3). The bivalves averaging a size of around 0.27mm and the gastropods at around 0.67mm. the gastropods found were a mixture of pelagic and benthic, with the benthic gastropods dominating in my samples.

There are clear differences between the predator species, where certain prey groups make up more of the consumed biomass in one species than the other (Fig. 6A & B). Harpacticoid copepods have similar proportion prey biomass values around 10 % in most stations for 0-group saithe, but made up a larger proportion of the consumed biomass for 0-group cod in station 2, 4, 7 and 10 (Fig. 6B). Fish made up a large portion of the consumed biomass for cod in station 3, 5 and 7 (Fig. 6B) but makes up a lesser amount of biomass in the saithe. It should be mentioned that in the saithe samples the fish were digested to a point they were

almost unidentifiable except for the otoliths, and the fish found within the saithe stomachs were all cod. The stomach samples of cod were more intact, and fish prey consisted of saithe, cod and lesser sand eel (*Ammodytes* sp.). In station 2 we see a massive difference in diet composition between the cod and the saithe and the consumed biomass of saithe in station two was mostly comprised of the parasitic copepod *Caligus elongatus* (Fig. 6A).

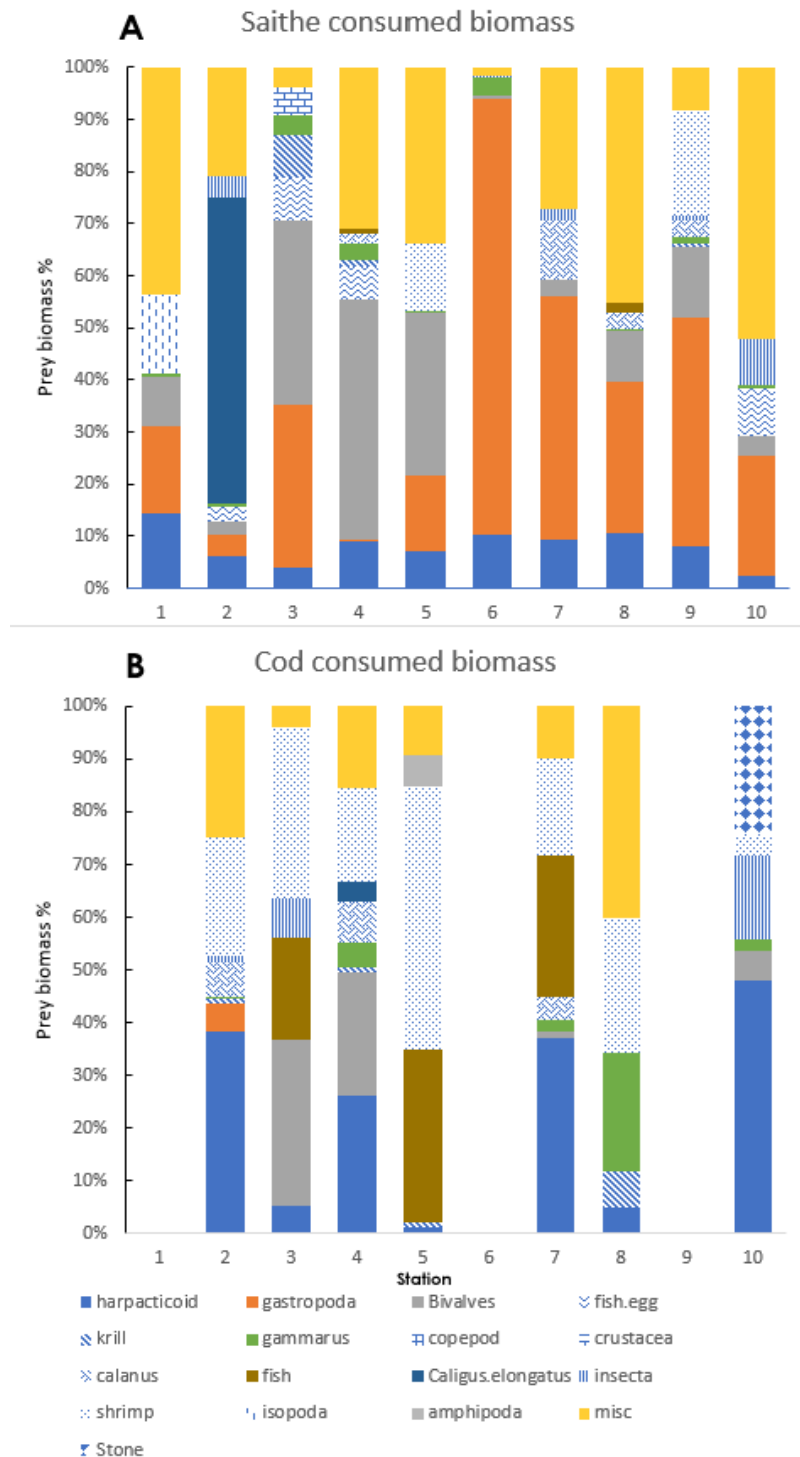


Fig.6 Consumed prey of saithe (A) and cod (B) as percentage biomass.

Substrate coverage along the fjord

The substrate data was compiled into Excel giving us fig 7. Gravel and the different stone sizes were combined into a group simply labelled stone to give a better and less cluttered figure. Substrate coverage in station 1 and 6 are similar, mainly being composed of stone and with little macroalgae. In contrast, station 2,3,4,5,7,8 and 10 had at least 40% macroalgae coverage (Fig. 7). At station 9, sand had nearly 70% coverage. The macro algae present where; *Ascophyllum nodosum*, *Fucus vesiculosus*, *Fucus serratus*, *Saccharina latissima*, *Chorda filum* and other annual algae, as well as the bivalve *Modiolus modiolus*.

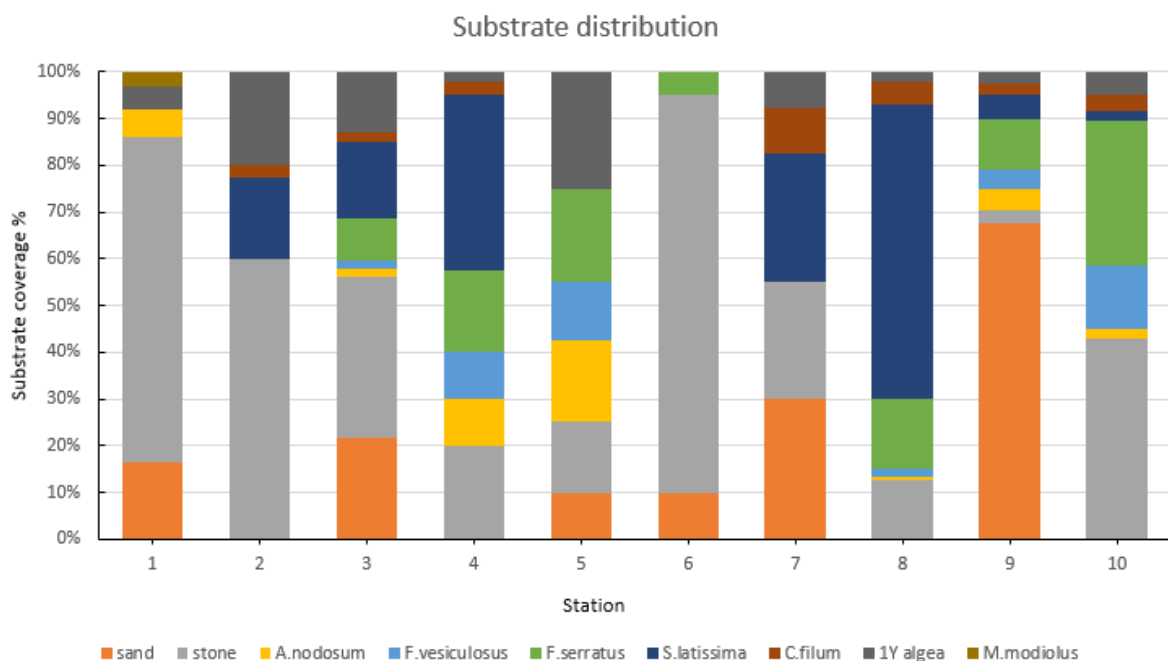


Fig.7 Substrate coverage distribution at the different station. Values are average for the beach seine hauls at each station. The algae and bivalves represented here with a shortened form of their Latin name.

Non-metric multi-dimensional scaling

Non-metric multi-dimensional scaling was used to look at how similar diet composition were in 0-group saithe and cod individuals. Each point on the NMDS plot (Fig. 8) represents one individual. The distance between the different prey categories shows how often the prey category is found in the same stomach sample, the closer together the more common, the further away the more rare. The polygons in fig. 8 indicate that when are looking at the entire fjord, diet composition of individual 0-group cod and saithe seem to be overlapping a lot, with some cod seemingly having some other prey groups in addition to those of the saithe.

Looking at each of the stations separately (Fig.9), we can see that the overlap between 0-group saithe and cod varies from station to station. Stations 2, 3, 4, 5 and 10 seem to have a lot of overlap between the species while station 7 has less overlap and station 8 has almost no overlap. So even though the overall total NMDS-plot of dimension 1 and 2 show us an almost complete overlap, the plots for each station show that the overlap seem vary between the stations.

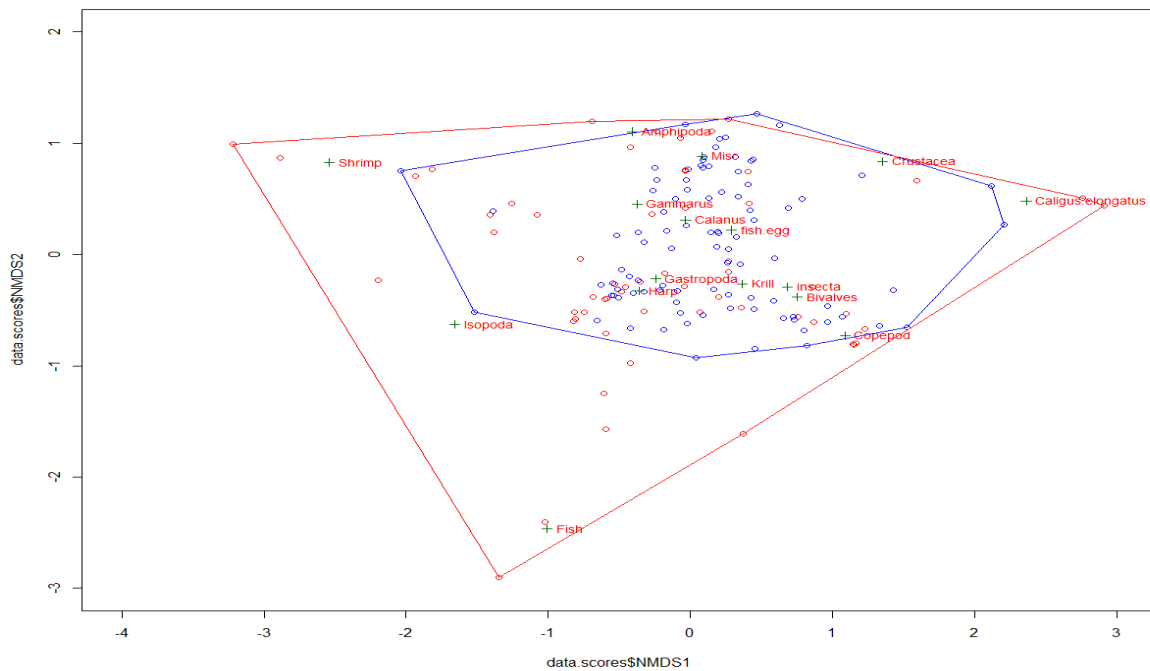
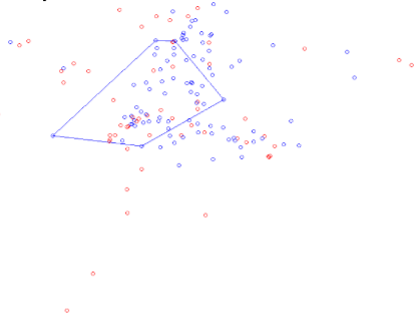
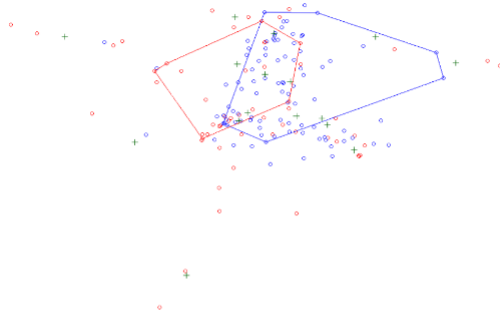


Fig. 8 Non-metric multi-dimensional scaling plot containing all the individuals from all 10 stations in Porsangerfjord. Each dot representing an individual, 0-group cod (Red) and 0-group saithe (Blue). The polygons enclose each of the species perceived dietary niche. Green “+” symbols indicate positions of each prey group.

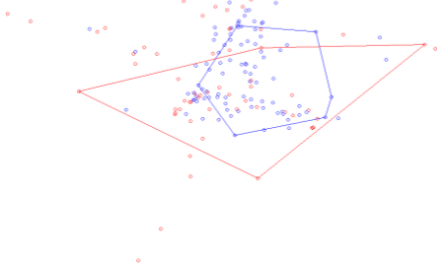
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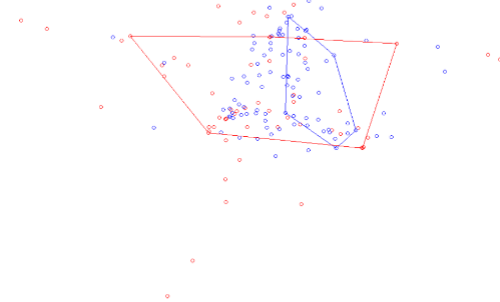
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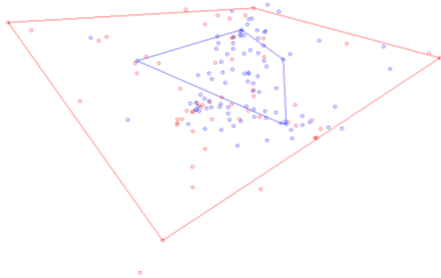
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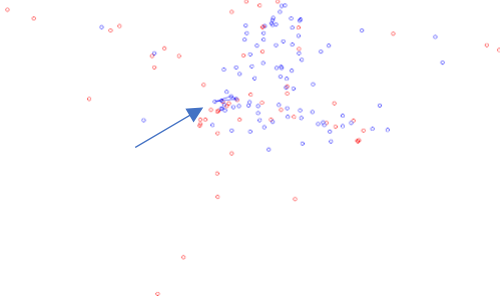
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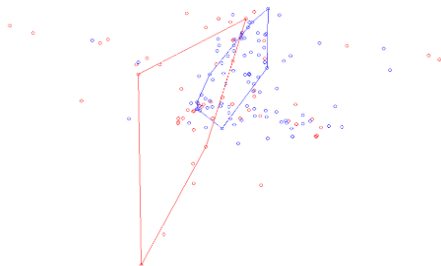
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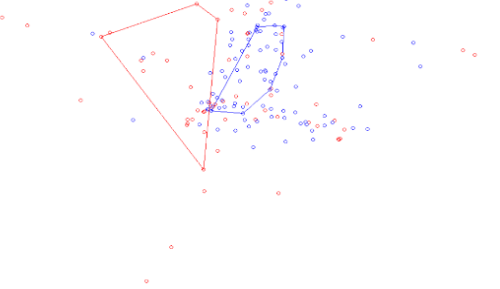
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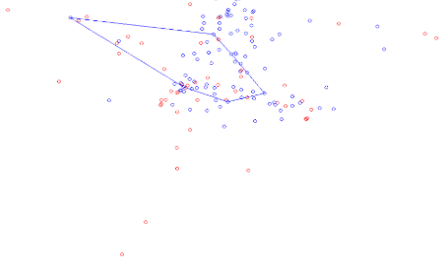
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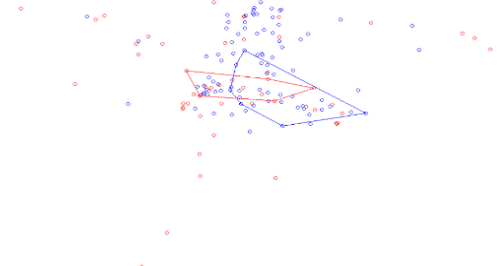


Fig. 9 Non-metric multi-dimensional scaling plots for dimension one and two for the 10 different stations sampled in Porsangerfjord Red and blue polygons enclose diet compositions of 0-group cod and saithe, respectively. The arrow is pointing to a small saithe polygon in station 6

Canonical correspondence analysis

The factors with largest impacts (longest arrows) are station and predator species with species 2 (cod) associated with negative values along CCA axis one with prey groups Amphipoda, fish and shrimp (Fig. 10). Along CCA axis two station 3 points towards positive values associated with prey group crustacea, while station 2 points towards negative values with prey group *Caligus elongatus* which is a dominating prey group at this station (Fig. 10). The continuous environmental variable fjord distance is pointing nearly to the same direction as station 2. The other prey groups and station arrows are near the center of the plot and the variable fish length is short and associated with prey group krill (Fig. 10). In total, this indicate that the most important environmental factors that affect diet composition are which station the fish (0-group saithe and cod) are sampled at, and if the fish is a 0-group cod or saithe.

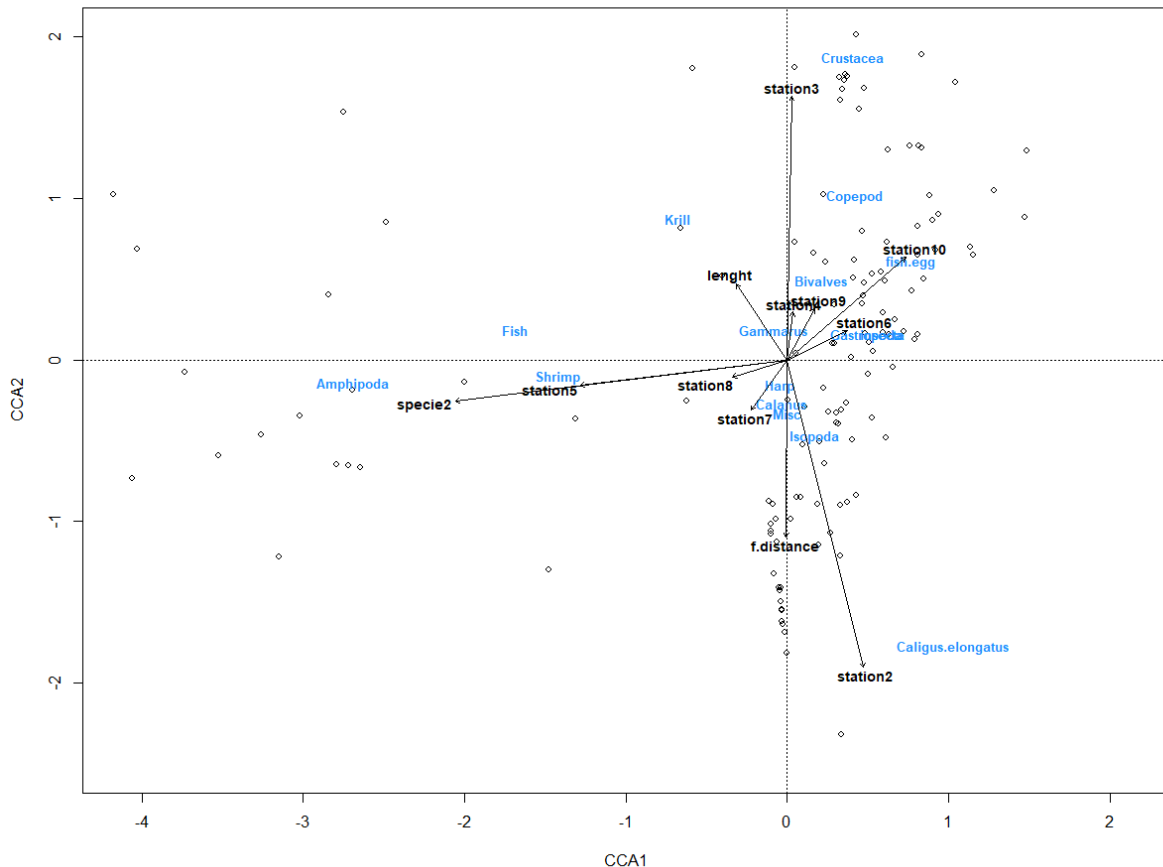


Fig.10 Canonical correspondence analysis showing the impact the different factors; fish length, fjord distance, predator species (species 2 is cod) and station have on the diet composition of 0-group cod and saithe. Prey groups are shown in blue.

Levins niche index with Pianka's modification show that the niche width of 0-group cod and saithe vary between different stations (Fig. 11). The niche index is generally similar for 0-group saithe and cod at the same station. The average Pianka diet overlap values between the 0-group species indicate relatively low overlap at the outer station 2 followed by higher overlap in the middle wester part of the fjord (st. 3 and 4) and lower overlap in the easter and inner part of the fjord (st. 5, 7, 8 and 9) (Fig. 12). The 95% confidence intervals for the diet overlap at each station are relatively large (Fig. 12).

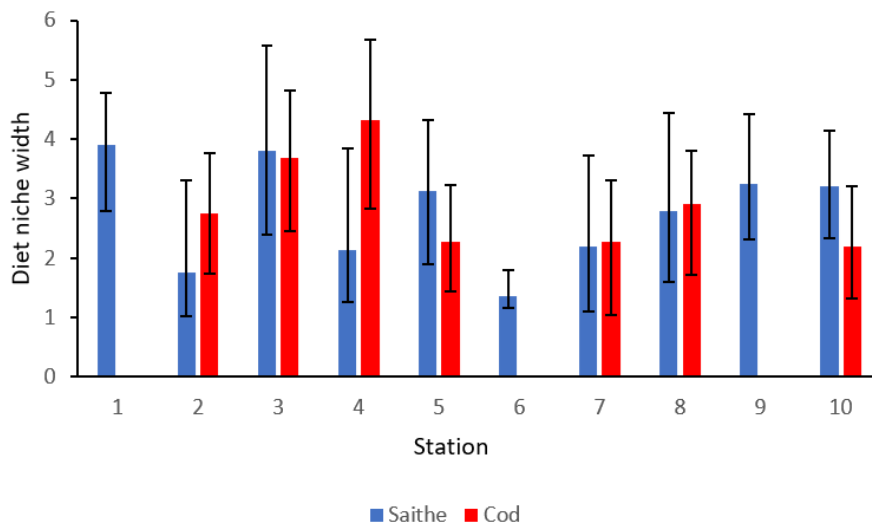


Fig.11 Levins niche width diet for diet composition for 0-group cod (red) and 0-group saithe (blue) in Porsangerfjord. Error bars show us the 95% confidence intervals calculated using bootstrapping.

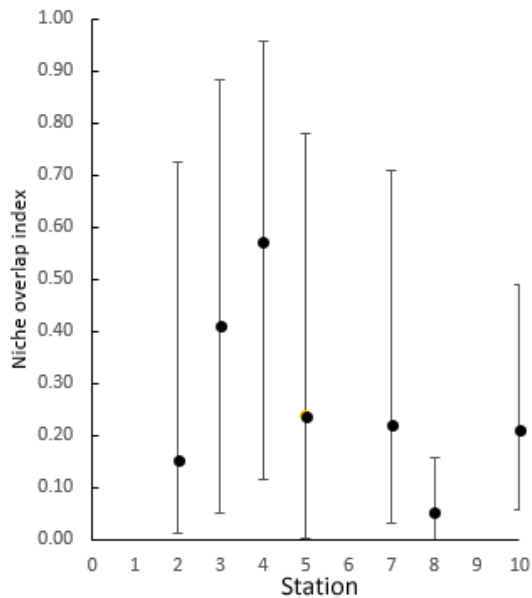


Fig.12 The average Pianka's diet overlap index for diet between 0-group saithe and cod for stations where they co-occur. Error bars show the 95% confidence intervals calculated by bootstrapping.

Discussion

Diet width and overlap in diet composition between 0-group saithe and cod

Bromley et al. (1997) show in their study that the diet of cod and saithe at the 0-group stage have similar prey composition and would then tell us that there is potential for overlap while co-existing. In my data that's what has been found. When looking at the data we see that both 0-group saithe and 0-group cod share similar prey groups. Harpacticoid copepods, bivalves and shrimps were important common prey items for both 0-group cod and saithe. Other prey groups were also found to be consumed by both 0-group saithe and 0-group cod in my samples. This all tells us that there was an overlap between their diets.

In the Nmds plots done for the different stations, there was to some degree overlap in the polygons for 0-group cod and 0-group saithe in most stations where they both are present. Some stations show a larger overlap than others. The overlap was visually larger in the outer and middle parts of the fjord.

The niche width of both 0-group cod and saithe between the stations were also similar to each other. Looking at the niche width there are some small differences between the 0-group cod and saithe between the stations, but for the most part we see a large similarity in the diet width. The niche width does not tell us that they have the prey on the same species, but it can

tell us if one species is more specialized than the other. In station 2 there is a significant difference between the niche width of 0-group saithe and cod, this could be attributed to the large consumption of *Caligus elongatus* by saithe in this station. Saithe could then be seen as specializing in this prey group. Gastropods are also mostly only consumed by saithe and could be a prey group they specialize in. The overall picture is that both 0-group cod and 0-group saithe are mostly generalists in terms of diet, with saithe showing signs of specializing in the consumption of gastropods, fish eggs, and *Caligus elongatus* in my samples.

The Pianka diet overlap values showed larger overlap in the outer and middle stations in comparison to the ones located further into the fjord. This corresponds with what we see in the NMDS-plots where the polygons are more tightly overlapping in the outer part of the fjord.

Pianka's and Levin's index are not a perfect niche indexes as they assume that every food source is of the same size, and none are in abundance (Krebs, 2016). This limitation of the model can make it inaccurate, but as we do not have the necessary data to conduct other analysis's this is the best indexes we could use. At station 8 there were less diet overlap. This lack of overlap could come from the fact that there were only four cod sampled and analysed at this station. More individuals sampled could have shown a larger dietary niche for the cod, making the overlap more noticeable or significant.

I conclude that there is an overlap between the diets of 0-group cod and 0-saithe within Porsangerfjord. With the largest overlap occurring in the outer parts of the fjord.

Effect of fish length, fjord distance and habitat characteristics on diet composition

Larger predators have the possibility to consume larger prey, making them prey on more biomass rich species (Dabrowski & Bardega, 1984; Mihalitsis & Bellwood, 2017). This is in line with Bromley et. al. (1997) where they found that cod would switch over to larger prey at a larger size, becoming more piscivorous. In my study we can see hints of this in station 5 where we find the largest individuals of cod whose diet is dominated by fish and shrimps. My CCA showing that fish length was not the most important factor could be due to me only looking at 0-group cod and 0-group saithe. These 0-group fish have a limited size range, and a study with a larger size range of fish could paint a different picture.

Advectioned prey have been considered to be an important food source for fish species in fjords in southern Norway, and fjord distance could play an important role in advection (Asplin et al., 1999; Norderhaug et al., 2005). Advectioned species are found in higher abundances at the

fjord opening and diminishes the further you go into the fjord. This could affect the diet of the fishes further into the fjord. However, in my study we cannot clearly see if this is happening as it might be limited or offset by station habitat differences as I found few advected prey groups in the analysed stomachs, but a higher abundance of benthic prey which could be locally produced in the stations.

The multivariate analyses indicated a relatively large station effect on diet composition. The substrate coverage for the different stations varied between stations with a dominance of macroalgae coverage to stations dominated by stone and sand. Macroalgae coverage is considered to be important for shelter of prey animals and 0-group fish. We would expect higher prey diversity in habitats with more algae coverage (Heck Jr & Thoman, 1981; Norderhaug et al., 2005; Norkko, 1998). These locally produced prey such as gammarids, harpacticoid copepods and gastropods are important in the diet of both 0-group cod and saithe (Heck Jr & Thoman, 1981; Norderhaug et al., 2005). Station 4, 5 and 8 have the highest algae coverage, and the NMDS-plot for these stations show a large diet width for both 0-group cod and 0-group saithe at these stations, though to a lesser extent for saithe. This could be a result of inter-specific interactions with the cod, or that the cod is efficient in exploiting prey that are abundant in macroalgae covered areas. On the opposite side of the substrate coverage spectrum, we have station 6 with very little algae coverage. Here only saithe was caught in the beach seine and its diet width is much lower than in other stations and the diet of saithe was dominated by *Gastropoda*. This could be contributed to a lack of other prey as a consequence of poor algae coverage, or the fact that we only managed to acquire a few saithe (n = 3) to analyse from this area.

The CCA showed that the most important environmental factors that had an impact on the diet composition were predator species (cod or saithe) and station. This suggests that if we took a random sample of 0-group in Porsangerfjord their diet would be dictated by if it was a cod or a saithe, and in which station it was collected. With stations being such an important factor for the diet composition, and the fact that the stations have diverse substrate coverage indicates that habitat characteristics play an important role for the diet composition of both 0-group cod and 0-group saithe within the fjord.

It is interesting that stations 1, 6 and 9 are all stations with limited or no macroalgae coverage and are also the stations where we caught no cod. Algae cover is considered to be an important factor in nursery areas and for recruitment of different fish species (Gotceitas et al.,

1997; Heggland, 2013; Norderhaug et al., 2005), so the lack of cod in those stations could point toward cod being more reliant on the algae coverage to prosper and thrive. This has not been proven as fact within this paper, but is a notable observation that could be useful to research further.

I conclude that predator species (cod or saithe) and station has the largest impact on diet composition. Part of the large station impact could be because of the importance of locally produced prey species. Fish length could be an additional factor, but due to the limited size range of fishes in this study we see little correlation. A further study could improve on this and potentially use a larger size range.

Diet of 0-group saithe and 0-group cod in 2023 compared to earlier studies.

Research into diet of 0-group saithe and 0-group cod in the Porsangerfjord has been done before, when Ulf Lie (1961) studied the diet of 0-group saithe in the opening of the fjord, and when Kristin Heggland (2013) investigated the diet of 0-group cod. The results from these studies can be compared with my data to see if there are any major differences.

The Lie (1961) study took place outside of Honningsvåg (70° 58' 33" N, 25° 58' 59" E). This area is in the outer part of Porsangerfjord. Lie (1961) found that the 0-group saithe in the fjord had a diet largely comprised of Copepoda and the three largest copepod groups, measured as numbers found in stomach contents, where *Calanus finmarchicus*, *Metridia lucens*, and Harpacticoida. Harpacticoida dominated the samples in sheer amounts as Ulf Lie (1961) found that the number of Harpacticoida in the stomach samples were nearly ten times the number of any other prey groups. Other prey groups found in Ulf Lie's study were Ampipoda, Isopoda, Mysidacea, Euphausiacea, Insecta, and Copelata. These other prey groups made only a small fraction of the consumed prey, and copepods dominated the stomach samples in this study (Lie, 1961). It should be mentioned that Ulf Lie's research is not perfect for diet comparison because his study area was not similar to my own.

Heggland (2013) used the same stations as in Porsangerfjord as in my study, and Heggland found that the three largest prey group, measured as number of prey, in the diet of 0-goup cod within the fjord in August 2012 was Harpacticoida, small pelagic copepods and Bivalvia larvae. Harpacticoida dominating in terms of numbers of prey, with approximately six times the number of prey compared to the small pelagic copepods, and over thirty times the Bivalvia larvae. Other prey groups present were; Crustacea, Amphipoda, large Calanoida,

Cladocera, faecal pellets, Gastropoda, Insecta, Isopoda, Krill, Ostracoda, Polychaetae, and shrimp (Heggland, 2013). These other prey groups appeared in smaller numbers in the stomachs but some of them are close in number to the number of Bivalvia larvae.

Looking at my own results (Appendix table 2 and Appendix table 3) we can see some similarities and differences from the earlier studies. Harpacticoida was still a central prey group in my study for both 0-group cod and 0-group saithe as I found large numbers of Harpacticoida in the analysed stomachs. However, Harpacticoida was not the prey group with the largest number of prey. The largest prey group within my samples were small bivalves, amounting to three times the number of Harpacticoida in my saithe samples, but being around the same number as harpacticoid prey within my cod stomach samples.

Harpacticoida was found in the similar large numbers as consistent with Lie (1961) and Heggland (2013), though there were much less of other pelagic copepods found in my samples, as small benthic copepods (Harpacticoida) were more present. There were less other Crustacea and Amphipoda within my samples as well compared to the previous studies. Gastropods, mostly benthic but some pelagic, and fish eggs were two prey groups found in my saithe samples which were not present in Lie's samples. This could in part be explained by the difference in research area as well as time of year, as Ulf Lie was performing their research in the middle of October compared to my sampling which took place in August. Gastropods have been observed to have a higher abundance in the plankton in the earlier months of the year, with their abundance dwindling towards the autumn and winter months (Michelsen, Nilssen, et al., 2017; Michelsen, Svensen, et al., 2017). Pelagic bivalve larvae have been observed to have a higher abundance in the plankton within the Porsangerfjord in August, with their abundance dropping off towards October (Michelsen, Nilssen, et al., 2017; Michelsen, Svensen, et al., 2017). This could be an explanation to why I found more bivalves and gastropods within my samples, compared to previous studies.

I conclude that my study finds a similar diet to the ones reported in Lie (1961) and Heggland (2013). There are differences between my study and previous data as well. I found much less pelagic copepods in my samples than previous studies. These differences could be attributed to the fluctuating availability and abundance of prey items.

Limitations of the study

This study is not perfect and thus contains some shortcomings. By understanding these shortcomings, we can see the weaknesses of the study and in further endeavours we can rectify or modify the new study to avoid these shortcomings.

In my study a small number of fish were sampled, this was both because I had limited time to work through all the stomach samples in the laboratory, as well as there were a limited number of fish caught. For a further study it would be ideal to analyse more fish samples to get a better picture of the prey composition in the diet. With the few fish I had we got a limited look into the diet compositions which was fortified using bootstrapping. It is not an ideal method, but it was the best I could do with the time and resources left.

I only sampled one time close to the end of August. This gave me a limited snapshot into the diet composition of 0-group cod and 0-group saithe. Other studies (Sandneseng, 2006) sampled throughout the entire autumn period, seeing a change in the diet composition over this period. An idea for a further study could be to do multiple samplings over a longer time period. This comes with the added bonus of being able to see if the diet composition changes during the sampling period. Sampling over a time period like this could help us see what prey groups are available and how they might change in abundance.

In my NMDS I did not use the lengths of the caught fish. This is something that could have been included in the analysis. A possible analysis could have been to divide the samples into length groups and then using these length groups I could see if certain sizes are focused on certain prey groups. This could have been used to attempt to test if there was a relationship between predator size and prey size. Even though my CCA showed length was not a main factor with the same impact as species (0-group saithe or cod) or station. It is still a potential factor and doing an NMDS with length groups could show some correlation between length and prey preference.

Summary

There was a clear diet overlap between the saithe and cod in the stations where they both are present. Both 0-group saithe and cod shared Harpacticoida, bivalves and shrimps as some important common prey groups. The overlap varied from station to station and is seemingly larger in the outer and middle parts of the fjord. Though not verified it may look like there is some inter-specific interactions between the species that shift their realized niche.

The differences in habitat between stations measured by bottom substrate coverages seem to play an important role in the perceived diet of 0-group cod and 0-group saithe. In contrast, fish length and fjord distance seem to have a lesser influence on the diet composition.

In summary we see that my results on diet composition show similarities with studies by Lie (1961) on 0-group saithe and Hegglund (2013) on 0-group cod. There are some discrepancies that might be due to the time of year these samples were taken or potentially to differences in sampled locations. My samples had much less pelagic copepods in comparison with earlier studies, and I found large a large number of *Caligus elongatus* in some saithe samples. Even with these discrepancies we see some similarities between my samples and the others.

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Appendix

Appendix table 1 Presence of prey groups in cod and saithe at the various stations. S signifies 0-group saithe, and C signifies 0-group cod

Prey/station	1	2	3	4	5	6	7	8	9	10
Harpacticoid	S	S+C	S+C	S+C	S+C	S	S+C	S+C	S	S+C
Gastropoda	S	S+C	S	S	S	S	S	S	S	S
Bivalves	S	S	S+C	S+C	S	S	S+C	S	S	S+C
Fish.egg		S	S	S						S
Krill		C	S	S+C	C			C	S	
Gammaridae	S	S+C	S	S+C	S	S	S+C	S+C	S	S+C
Copepod				S						
Crustacea					S					
Calanus		C		S+C	S+C		S+C	S	S	
Fish			C	S	C		C	S		
Caligus elongatus		S		C					S	
Insecta		S+C	C			S	S		S	S+C
Shrimp		C	C	C	S+C		C	S+C		C
Isopoda	S									
Amphipoda					C					

Appendix table 2 Prey groups, number of prey, mean weight pr prey, and prey dry mass in saithe stomachs from the Porsangerfjord (n=93)

Prey groups	Total no. prey	Prey dry mass (g)	Mean weight pr prey (mg)	% of consumed biomass
Harpacticoida	1917	0.0683	0.036	10.44
Gastropod	1112	0.2767	0.249	49.40
Bivalves	7518	0.1024	0.013	13.14
Fish eggs	298	0.0302	0.101	3.84
Krill	6	0.007	1.167	0.89
Gammaridae	43	0.0096	0.223	1.81
Copepods sp.	6	0.0001	0.017	0.01
Crustacea sp.	1	0.0038	3.8	0.48
Calanus sp.	41	0.0194	0.473	2.47
Fish sp.	3	0.0012	0.4	0.15
<i>Caligus elongatus</i>	99	0.0591	0.597	7.52
Insecta	45	0.0267	0.593	3.45
Shrimp	4	0.0338	8.45	4.30
Isopoda	73	0.0164	0.225	2.09
Amphipoda	0	0	0	0

Appendix table 3 Prey groups, number of prey, prey dry mass, mean weight pr prey, and % and consumed biomass in cod stomachs from the Porsangerfjord (n=63)

Prey groups	Total no. prey	Prey Dry mass (g)	Mean weight pr prey (mg)	% of consumed biomass
Harpacticoida	1563	0.0441	0.028	17.19
Gastropod	5	0.0018	0.36	0.66
Bivalves	1872	0.0155	0.008	5.99
Fish eggs	0	0	0	0
Krill	10	0.004	0.4	2.94
Gammaridae	33	0.0111	0.336	8.81
Copepods	0	0	0	0
Crustacea	0	0	0	0
Calanus	11	0.0057	0.518	2.08
Fish	6	0.0506	8.43	18.67
<i>Caligus elongatus</i>	1	0.0009	0.9	0.33
Insecta	13	0.0046	0.354	1.76
Shrimp	17	0.0916	5.388	39.24
Isopoda	0	0	0	0
Amphipoda	1	0.0064	6.4	2.34

Appendix table 4 R script for performing the various nmDS calculations and plotting

```

#NMDS
#make community matrix - extract columns with abundance information
com = df1[,22:ncol(df1)]
#
#Rename variables, better for plotting
names(com)

names(com)[names(com) == "harpacticoid"] <- "Harp"
names(com)[names(com) == "F_egg"] <- "fish.egg"
View (com)
names(com)
#
#
any(is.na(com))
which(is.na(com))
#which(is.na(m_com))
#
#Turn abundance data frame into a matrix to do multivariate analysis
m_com = as.matrix(com)
View(m_com)
#
set.seed(123)
nmDS = metaMDS(m_com, distance = "bray",k=3)

nmDS
View(nmDS)

#
plot(nmDS, type = "t")

```

```

#
m_com
#
m_com[,1:16]
set.seed(123)
nmds = metaMDS(m_com[,1:16], distance = "bray",k=3)
View(nmds)
#
#
plot(nmds, type = "t")
#
#extract NMDS scores (x and y coordinates) for sites (rows) from newer versions of vegan package
data.scores = as.data.frame(scores(nmds)$sites)
data.scores$Species = df1$specie
data.scores$Length = df1$lenght(mm)`
data.scores$Location = df1$station
View(data.scores)

#nmds$species[,1]
nmds$species[,2]

plot(nmds)
#
#

plot(data.scores$NMDS1,data.scores$NMDS2, xlim=c(-4,3),ylim=c(-3,2))
points(data.scores$NMDS1[which(data.scores$Species=="c")],data.scores$NMDS2[which(data.sc
ores$Species=="c")],
      xlim=c(-2,2), ylim=c(-1,1), col="red")
points(data.scores$NMDS1[which(data.scores$Species=="s")],data.scores$NMDS2[which(data.sc
ores$Species=="s")],
      xlim=c(-2,2), ylim=c(-1,1), col="blue")
points(nmds$species[,1],nmds$species[,2], xlim=c(-3,2), ylim=c(-1,1), col="darkgreen",pch=3)
text(nmds$species[,1], nmds$species[,2], row.names(nmds$species), cex=0.6, pos=4, col="red")
Plot_ConvexHull(xcoord = data.scores$NMDS1[which(data.scores$Species=="s")], ycoord =
data.scores$NMDS2[which(data.scores$Species=="s")], lcolor = "blue")
Plot_ConvexHull(xcoord = data.scores$NMDS1[which(data.scores$Species=="c")], ycoord =
data.scores$NMDS2[which(data.scores$Species=="c")], lcolor = "red")

#Plotting for selected stations, st is station number, look through the different stations
st=1
Plot_ConvexHull(xcoord = data.scores$NMDS1[which(data.scores$Species=="s" &
data.scores$Location == st)], ycoord = data.scores$NMDS2[which(data.scores$Species=="s"&
data.scores$Location == st)], lcolor = "blue")
Plot_ConvexHull(xcoord = data.scores$NMDS1[which(data.scores$Species=="c" &
data.scores$Location == st)], ycoord = data.scores$NMDS2[which(data.scores$Species=="c"&
data.scores$Location == st)], lcolor = "red")

```


Appendix table 5 R script for performing a CCA

```
#Need environmental variables for CCA
#Extract environmental variables
keeps = c("station","specie","lenght","temp","f.distance")
env=df1[keeps]
env2=env
env2$specie=recode(df1$specie, "s"=1,"c"=2)
View(env2)
#
#

mm_com=as.data.frame(m_com[,1:16])
View(mm_com)
cc3 <- cca(env2, mm_com)
plot(cc3, scaling = 1)
#
#
cc3 <- cca(env2, mm_com)
plot(cc3, scaling = 1, xlim=c(-3,3), ylim = c(-1,1))
#
#
#Habitat.MVA.DOV$Location as.factor(Habitat.MVA.DOV$Location)

env2$station=as.factor(env2$station)
env2$specie=as.factor(env2$specie)
#env2$temp=as.factor(env2$temp)
#env2$f.distance=as.factor(env2$f.distance)
s_com <- sqrt(mm_com)
cc4<-cca(mm_com ~ lenght+ specie + station+f.distance+temp, data = env2)
cc4<-cca(s_com ~ lenght+ specie + station+f.distance+temp, data = env2)
plot(cc4)

View(env2)
###
###
plot(cc4, type="n", scaling = 0, xlim=c(-4,4), ylim=c(-4.5,2))
points(cc4, display="bp", col="red", cex=0.7, font =2)
points(cc4, display="sites", pch=21, cex=0.8, choices = c(1,2), col = "black")
text(cc4, display="species", col="dodgerblue", cex=0.65, font =2)
text(cc4, display="bp", col="black", cex=0.7, font =2)
```

