The effect of eelgrass habitats on fish species richness: A case study in Kalø Vig

Master Thesis

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Abstract

This study investigates the biodiversity differences between eelgrass habitats and control sites without eelgrass in Kalø Vig, Denmark. Using various passive gear types, and environmental variables. Biodiversity data were collected and analyzed to assess species composition, and ecological indices across habitats. Results indicate significant differences in species abundance, with species of Atlantic cod (*Gadus morhua*), corkwing wrasse (*Symphodus melops)* showing preference for eelgrass habitats while eelpout (*Zoarces viviparus*) exhibit significant higher counts in control sites. Species richness, diversity were similar between the two areas, with no significant difference. The results from active gear, however, revealed a significant difference between species richness in the two different habitat types. Efficiency comparisons among passive gear types reveal varying degrees of effectiveness, with rectangle fyke nets demonstrating superior catch rates. The double eel fyke net had the biggest mortality rate and were therefore the least efficient gear type. Atlantic cod, eelpout, goby spp (Gobius spp.) and sculpin (Myoxocephalus scorpius) all showed a significant difference between temperatures, with all of them being more abundant in colder temperatures except goby spp. Overall, this study highlights the significance of eelgrass habitats in supporting biodiversity and the urgent need for conservation actions to mitigate habitat loss and ensure the long-term sustainability of coastal marine ecosystems.

1 Introduction

Human activities, including the heightened runoff of nutrients, over-fishing, exploitation of marine habitats, and the effects of climate change, have collectively led to a deteriorated ecological condition, and are changing the biodiversity of ecosystems conditions worldwide. This has consequences for the entire trophic structure of food webs in coastal marine systems and in marine habitats Byrnes et al. [2007]. Furthermore, in the summer of 2023, oxygen depletion was deemed the worst in 20 years in Danish waters DCE [2023], and popular Danish newspapers started covering the subject more, covering the loss of cod, plaice and eelgrass Politiken [2023]. The latest report on the status of fish in the coastal zones in Danish waters, from DTU Aqua's project Key-Fishermen, show that especially numbers of flounder, cod and eelpout have decreased in recent years Pedersen et al. [2023]. A growing societal commitment to confront and resolve these challenges has spurred action throughout Denmark. Examples include the organization "Kysthjælper", in partnership with "Danmarks Sportfisker Forbund" and supported by the VELUX Foundation, which is actively engaged in the restoration of eelgrass (*Zostera marina L.*), by engaging local volunteers Kystfisker [2023]. Another example is a newly established national 'eelgrass-day', initiated by Ocean Institute and founded by Nordea Foundation, which will combine organizations and engage citizens throughout Denmark in helping restore eelgrass beds Madsen [2023]. These initiatives are important, as the process of restoring habitats such as eelgrass beds is time-consuming and laborious Flindt et al.

[2023].

1.1 Association between eelgrass and fish communities

Eelgrass (*Zostera marina L.*) meadows are known to play a crucial role in supporting diverse fish communities. A study of eelgrass beds in Sweden investigated biodiversity of macrofaunal communities between eelgrass and a non-vegetated area, and found that eelgrass beds support a higher taxonomic richness and abundance compared to a non-vegetated area (Kindeberg et al. [2022]). Another study examined fish communities in current and former eelgrass habitats across 15 estuaries in Massachusetts, U.S. The study found that fish abundance, biomass and species richness decreased significantly along a gradient of decreasing eelgrass complexity within habitats (Hughes et al. [2002]).

Eelgrass beds are important for fish as they provide food. A study on the relationship between the diet of fish utilizing eelgrass beds found that food produced within the eelgrass beds such as crustaceans, gastropods, and detritus, might account for approximately 56% of the weight of diet of the fish community studied. Furthermore, studies have shown that eelgrass beds serve as nurseries for juvenile fish and invertebrates, as it provide habitat complexity and serve as refuge (Adams [1976b]).

Eelgrass is the most widespread submersed rooted plant in northern temperate marine coastal waters (Raun and Borum [2013]) In Denmark, the records of eelgrass distributions date back to the beginning of 1900, where the distributions were wide and covered around 1/7 of all Danish marine waters. In the 1930 a world wide waste disease reduced the distribution substantially. Even as eelgrass started to recover, the distribution today is only 20-25% of what it was compared to 1900. Even though the waste disease played a huge part in the reduction, part of it can also be explained by the maximum depth at which eelgrass can grow to, which is limited by light penetration. In 1900 the eelgrass grew to depths of 5- 6meters in Estuaries and by 1990, that depth were reduced to 2-3 m (Ærtebjerg et al. [2003]). The decline of eelgrass has mainly been attributed to eutrophication and its effect on light conditions (Raun and Borum [2013]).

A study in Newfoundland investigated the effect of the European green crab (*Carcinus maenas*) on an eelgrass bed and its impacted fish communities, by comparing surveys done before and after an invasion of green crabs. Green crabs can reduce eelgrass biomass by damages caused by burrowing for shelter and digging for prey. The study found that the reduction of eelgrass was between 50%-100% depending of how long the presence of green crabs were. The study also found a decline in fish biomass, which indicated a change in the fish community structure after green crabs arrived to the area. Green crabs can therefore have cascading effects on fish communities and eelgrass, and an abundance of green crabs shows that the coastal ecosystem is unbalanced (Matheson et al. [2016]).

Another study in Beaufort, North Carolina analyzed fish populations in two different estuaries for one year. The study found that there was a significant correlation between fish biomass, temperature and eelgrass biomass, where higher water temperatures both increased grass biomass and the biomass of fishes. The study also found that some fish migrated out of the eelgrass beds and into deeper cooler waters doing temperature extremes in daytime in the summer months (Adams [1976b]).

1.2 Oxygen depletion

Oxygen depletion happens when oxygen demand is larger than the supply of oxygen to the water. Oxygen consumption happens when bacteria and micro organisms degrade and respire oxygen in the process. In Denmark it is generally considered oxygen depletion in waters when the concentration of oxygen is below 4 mg/l. Oxygen depletion can happen under the right weather conditions, assuming that eutrophication is currently present. Generally, weak winds will advance the development of oxygen depletion while stronger winds will inhibit the development of oxygen depletion. The duration of a stronger wind is depth-dependant, where strong wind can fully saturate shallow water in a shorter duration than at deeper waters, where prolonged winds or a storm might be necessary to mix the entire water column (DCE [2023]). Oxygen saturation is temperature-dependant, and saturation is higher in colder waters than warmer waters (Fondriest Environmental [2013]). Therefore, oxygen depletion in the Danish seas most frequently occur in the summer months, as they typically coincide with weaker winds and warmer water temperatures. In Denmark the Danish Centre For Environment And Energy (DCE) monitors oxygen at different stations throughout the Danish seas year-round. These stations are placed at depth where oxygen depletion usually happens because the waters aren't as well mixed DCE [2023]).

Eelgrass, like other phototropic organisms, photosynthesise during the day and respire oxygen during the night. Oxygen depletion can lead to die-offs of eelgrass, especially in warm waters, as the eelgrass' respiratory demand for oxygen exceeds the oxygen available in the water. Eelgrass can switch to an anaerobic metabolism for a short period of time, which has a lower energy output and build up toxins. Oxygen depletion in longer periods can therefore be lethal to eelgrass (Raun and Borum [2013]).

1.3 Sampling methods

Fish monitoring can provide useful knowledge about a marine ecosystem. Picking the right gear for the sampling, can however prove challenging, as fish can occupy large habitats and move long distances. A study in Portugal concluded that variation found between gears could be explained by the nature of each gear itself as some gears are more efficient in sampling particular habitats or species with particular functional traits than others (Adao et al. [2022]). Selecting the right gear type is therefore essential in conducting fish community or biodiversity assessments. A study done in Canada compared three different gear types on their selectivity, efficiency and degree of biodiversity in fish communities between summer and winter. The study found that the overall sampling efficiency and the number of different species caught was highest when all gear types were used in combination. Multiple gear types are therefore recommended in ecological assessments of fish populations and communities (Mehdi et al. [2021]).

A different approach to ecological monitoring studies, that are less disruptive to the environment which they are monitoring, is the use of cameras.

One of the most common non-destructive method is Underwater Visual Census (UVC), however that method requires clear water as well as a diver, which can incite fish to flee or hide (Zarco-Perello and Enríquez [2019]). Another options is filming with remote Underwater Video (RUV), which are cameras placed in certain positions, and will therefore not disturb fish. However a camera has a limited view, and if anything passes out of that view, it will not be recorded.

1.4 Aim and course of action

In order to get a better understanding of the ecological role of eelgrass beds, the aim of the present study is to determine abundance, diversity and fish species richness within eelgrass beds and areas without eelgrass in a bay in Kalø Vig, Denmark. Data have been collected during two field trips of one week each in September and October 2023, during night as studies show, that the biomass in eelgrass beds at night is twice as high compared to the biomass during the day (Adams [1976a]).

Observed fish species richness will be method dependent Mehdi et al. [2021], therefore, several sampling methods will be undertaken, with three types of passive gears and one active gear, and the efficiency and mortality of each gear will be evaluated. Environmental drivers, besides the presence absence of eelgrass, may affect species richness, and oxygen concentrations, water temperature, salinity, and visibility turbidity will therefore be collected as well and used in the interpretation of the results.

The sampled results will be analysed with Shannon's Diversity Index, and the significance of habitat type and gear type as well as temperature and oxygen will be analysed through general linear mixed models (GLMM).

2 Methods

2.1 Field work

The field work was conducted in Kalø Vig in the bay of Aarhus, Denmark (figure 1). The field campaign lasted a total of 16 days but was divided into two trips with the first trip running from 15th-23rd of September 2023, and the second trip from 20th-29th of October 2023. The aim of the survey was to collect biodiversity data in an eelgrass bed as well as a control site with no eelgrass. This was to be done with different types of gear, to compare their efficiency and to see if species varied across both habitat and gear type. Originally, the plan was to have four stations, two of each habitat type, in order to have replicas. Two of those stations were to placed in shallow water close to the coast, and the other two (one of each habitat type) were to be placed at a greater depth of at least 200 cm to see if depth played a factor as well. However, as that required the use of a boat, it was only partly done on field trip 1, as it depended on volunteers, weather conditions and the availability of a boat. For field trip 2 it was instead decided to establish two additional coastal stations, in order to ensure that four stations could be surveyed. The results for the single day at depth are therefore not included in the further analysis. Since the depth stations were not properly utilized during field trip 1, the amount of stations and gear placed are half that of field trip 2.

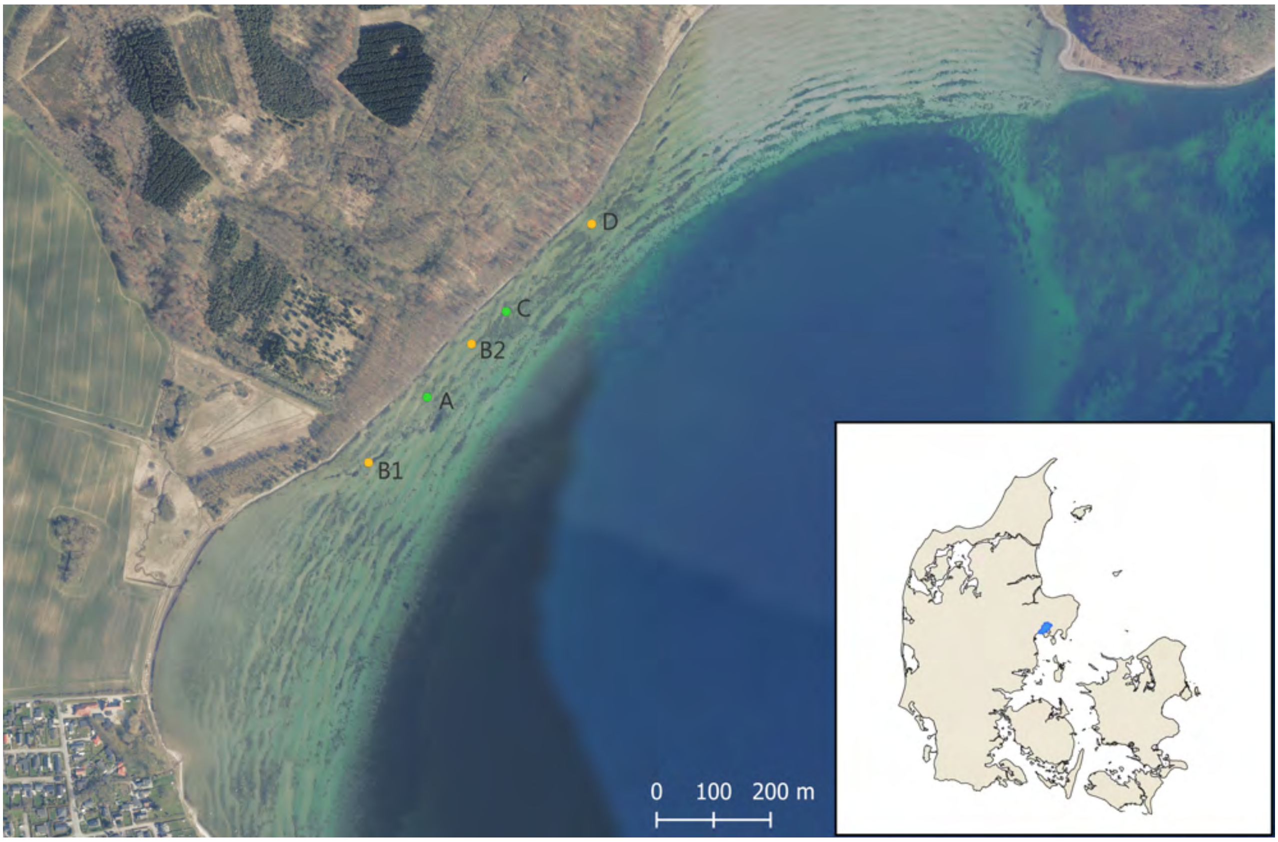
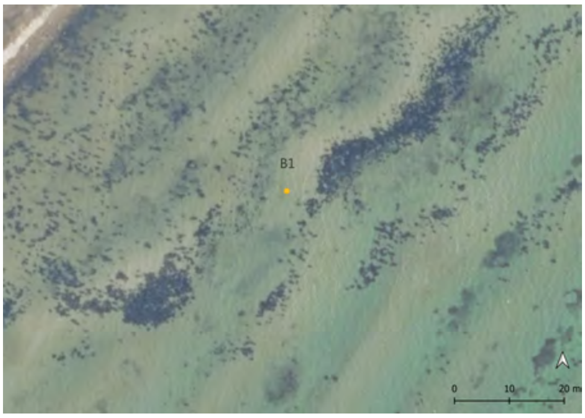


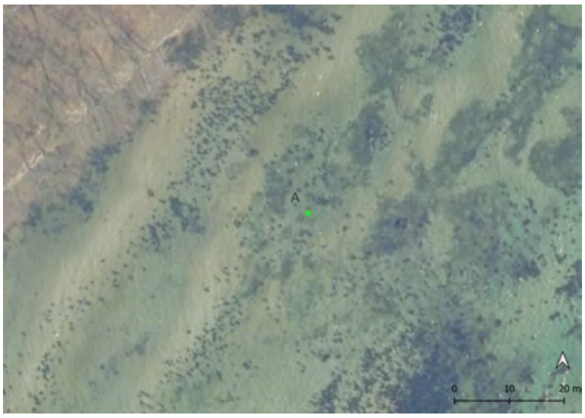
Figure 1: Map of study area with reference photo (study area in blue) made in QGIS. Green dots mark eelgrass habitats and yellow dots mark control areas. Background orthophoto are taken in spring 2023 (GeoDanmark [2023]).

2.1.1 Selection of station locations

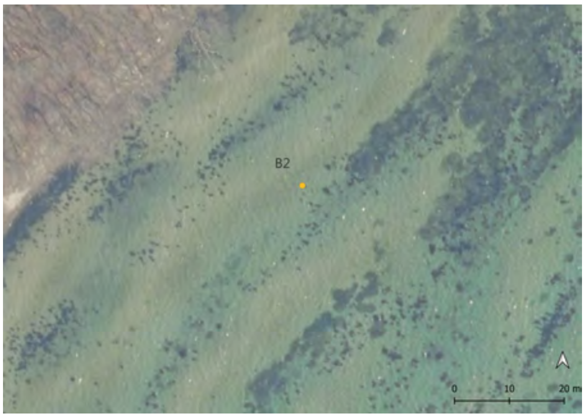
The coastal stations were placed with 100-200 m between them, which is seen in figure 1. Station A and B1 were surveyed during field trip 1 and stations A, B2, C and D were surveyed during field trip 2. The reason for moving station B1 to B2 between field trips, was that unfortunately B1 was in a conservation zone, which is active for half a year when the sea trout (*Salmo trutta trutta*) spawns in the nearby river, which corresponded with when field trip 2 was taking place (Fiskeristyrelsen [2023]). Station A and B1, were picked out with the help of volunteers of where they knew eelgrass was present. The exact location was chosen by inspecting the bottom habitat using an aqua scope. Figure 2 shows each of the five stations from an orthophoto from spring 2023 (**?**). The location of the additional stations C and D were chosen from a wish to not have two of the same habitat type next to each other, to avoid a pseudo replica. For the two eelgrass habitats chosen, station C had a slightly more dense eelgrass cover. Choosing a suitable control area was difficult, as the most bare sand-areas were sandbars, which were very shallow in depth. Therefore some vegetation in form of bladderwrack (*fucus vesiculosus*) were present in clumps at the control sites. The depth was measured daily using a secchi disc, and the average depth for all the coastal stations was approximately equal and varied between 50-120 cm depending on the tide. This depth was chosen so that it was possible to empty and place the gear even in high tide, as well as the gear still being submerged during low tide. The distance between the stations was chosen based on a trade-off of not being too close to be considered one station, while also not being too far apart, as distance greatly prolonged the time between setting or emptying gear between stations.



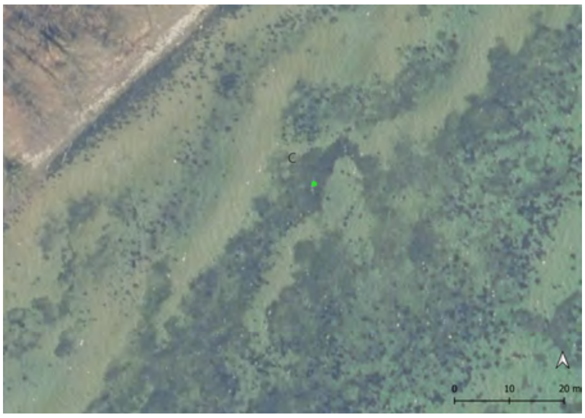
(a) Area B1 - Control



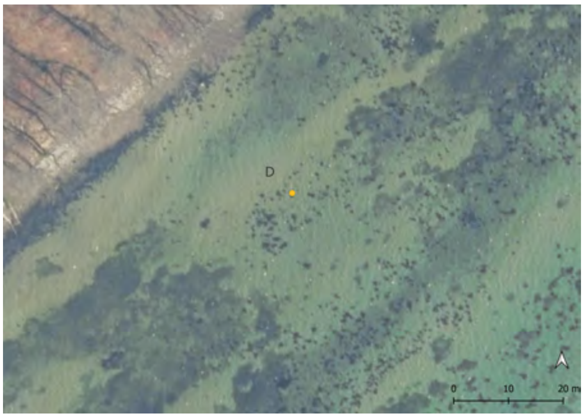
(b) Area A - Eelgrass



(c) Area B2 - Control



(d) Area C - Eelgrass



(e) Area D - Control

Figure 2: Subset of each station. Area B1 and A were used during field trip 1 and area A, B2, C, D were used during field trip 2. Green colors indicate an eelgrass habitat and yellow indicate control areas. Background orthophoto are taken in spring 2023 (GeoDanmark [2023]).

2.1.2 Passive gear types and placement

The three types of passive gear used throughout the field campaign were rectangle fyke net, double eel fyke net and rigid lobster trap. The different types of gear and an example of their placement is illustrated in figure 3.

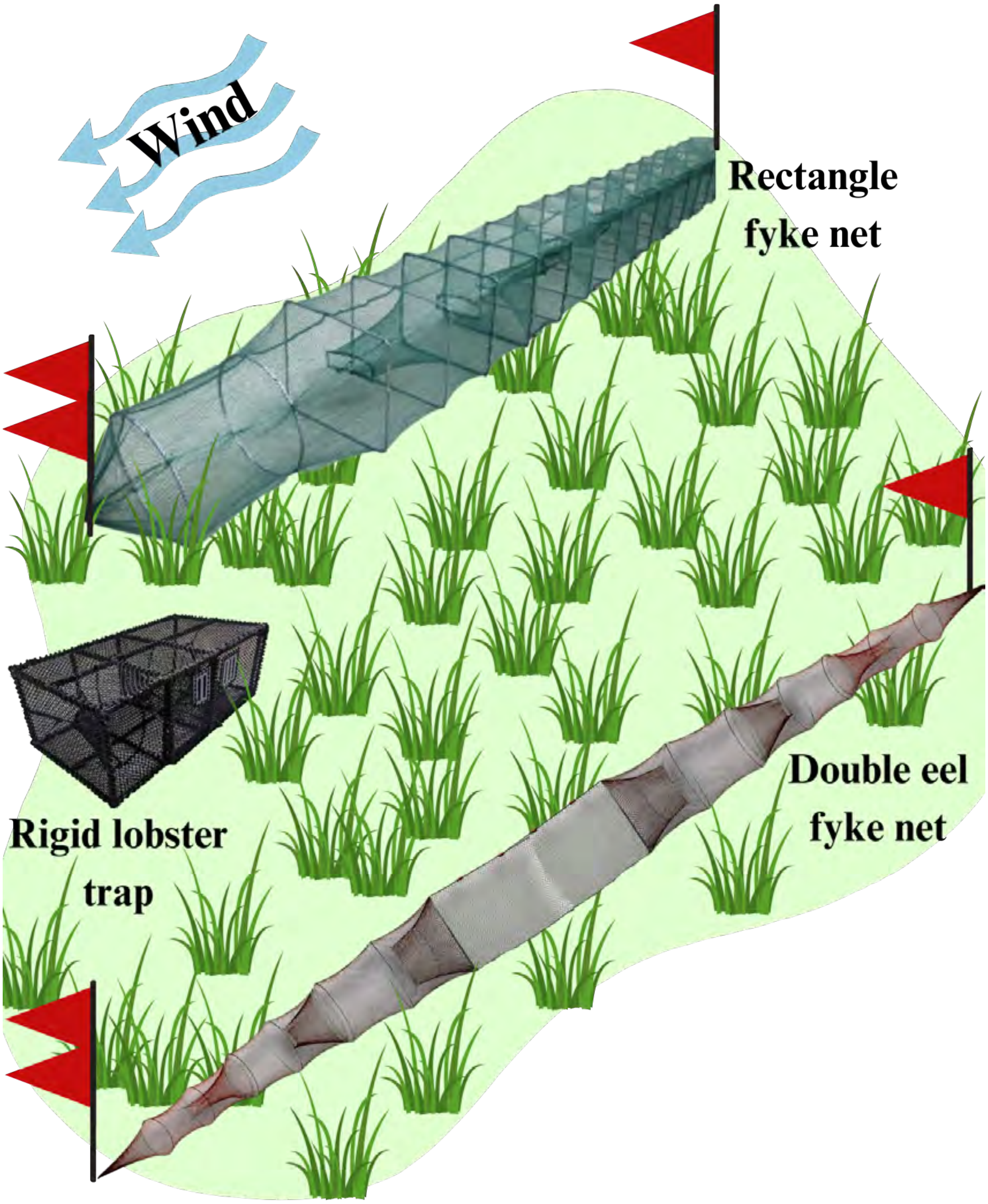


Figure 3: Example of setup of the three gear types rectangle fyke net, rigid lobster trap and double eel fyke net at a station with eelgrass.

A rectangle fyke net is made up of several rectangle boxes with openings along its sides that fish can enter but not escape again, The fish can stay in a compartment or swim towards either end, where they will be trapped. The double eel fyke is similar but consists of compartments made up of rings, there there are only two openings, with a net in the middle. If a fish swim into the net, it can swim along it and eventually into the rings. The rigid lobster trap has an opening on either side, which the fish can enter but not escape. The rectangle fyke net is the biggest and most spacious of the gears. During field work, the rectangle fyke net and the double eel fyke net were strung out with a brick in each end, and marked with a West and East buoy flag. The rigid lobster trap was tied to the same buoy flag as the rectangle fyke net, as there was a limit to the amount total buoys. The three gear types were placed in the same formation at each station; which changed daily according to the direction of wind (3). The gear was placed each day in the late afternoon before sunset, and emptied again the next day around noon. In order to standardize the experiment, the order of each station visited stayed the same, for example in field trip 2, station D was the first station to be emptied and A was the last, for all the days. Bait was not used in any of the gear.

2.1.3 Total length measurements

At each station one gear was emptied at a time, in order to shorten the time fish were being handled, to minimise the stress levels of the fish. Each individual was identified to species and measured with a length board, where the total length (TL) was determined by the most forward point of the head, to the farthest tip of the caudal fin (figure 4) If the number was between two lines, the estimated number was round down. All dead individuals were also noted and measured. In some cases where the carcasses were molested by crabs, the length was estimated. Measuring the length of the fish was handled with care and with wet hands, and fish were released again quickly hereafter. The identification of fish, were done in situ, however, if there were uncertainty about a species, or if a species had been partly eaten, pictures were taken and identifier later.

Figure 4: Length measurement of a dead flounder during field trip 2.

2.1.4 Deviations due to weather

During field trip 1, the weather was too windy between the 18th-21st of September, and only the rigid lobster traps were used on the two stations. During those two nights, three rigid lobster traps were set at each station. In order to gather more data, two rigid lobster traps, were also placed at each station during the 19th and 20th, and emptied again before night. During field trip 2, the weather was too windy for one night between the 24th and 25th of October, and only the rigid lobster traps was set for that night (FCCO [2023]).

2.1.5 Active gear type - Shrimp rake

For field trip 2, the addition of a shrimp rush survey was added, which is an active fishing gear, compared to the other gear types. An 8 x 8 m grid was marked with buoys on both an eelgrass habitat and a control area with sand. The two areas were not in the exact locations of the four stations with passive gear (A, B, C, D), in order to not interfere with those. The two areas were however chosen at the same depth, as the four stations. The shrimp rush was pushed by hand with a 45-degree angle towards the bottom, assuming a walking speed, that was maintained in the same pace, throughout the surveys. The area was covered by transects, without overlapping. This survey was performed during day-time on two separate days.

2.1.6 Oxygen measurements

Oxygen measurements were done with three miniDOT Oxygen loggers, which is a submersible instrument, that records and sample dissolved oxygen and temperature data. Prior to the field campaign, custom tripods where made for the oxygen loggers, in order to stand at the sea bottom. Weights were attached to the legs, in order for it to be more secure and stable (figure 5). The three oxygen loggers were placed for field trip one in both of the coastal stations (A and B1) as well as at an eelgrass bed in deeper waters. For field trip 2, the oxygen loggers were placed in eelgrass areas A and C and in control area D. The loggers were meant to stay in the water as long as possible, however they were taken out of the water in rough wind conditions. The oxygen data was then processed using in the miniDOT software, which calculate the dissolved oxygen saturation % based on the measured oxygen mg/L, temperature, and salinity. The salinity wasn't measured in-situ during the field campaign, instead water samples were taken in big containers, that stayed closed throughout the field trip. The salinity was later measured with a salinity measure stick in the lab at DTU-Aqua.

(a) (b)

Figure 5: MiniDOT oxygen logger (a) and custom-made tripod (b) for the oxygen loggers.

2.2 Data analysis

The data collected during the field work was logged and processed in Microsoft Excel, and the statistical models were made and run with the software R version 4.3.

2.2.1 Biological diversity

In order to quantify the diversity within the two habitat types, the Shannon's Diversity Index was used, which is given by:

$$H = -\sum P_i(lnP_i) \tag{1}$$

Where H is the diversity index and P_i is the proportion of each species i in the sample. The higher the index value of H, the greater the diversity of species is within the habitat. The index uses species richness which is the total number of different species found, and how well they are distributed within the habitat. A habitat with a relatively even distribution with a higher species richness will therefore give a higher H value than a habitat with a low species richness but with a high number of fish. The H index was calculated for each type of habitat (eelgrass or control) for each of the 12 fishing days.

2.2.2 General linear mixed model

In order to explain the significant of both the diversity of fish between habitats as well as the amount of fish caught as a response to habitat type, gear type, temperature and oxygen, a general linear mixed model was used (GLMM). A GLMM is, like a general linear model (GLM) a way to model the response variable based on different predictor variables. The addition to the GLMM is that it can take random effects into account, which makes the model correct for a variable, which can capture some of the variance, without it being significant.

A GLMM to examine habitat type as a potential significant predictor of the calculated H index is given by:

$$log(H) = \beta_0 + \beta_{1_{Habitat}} + b_{Day:Month} \tag{2}$$

Where the response variable H describes the H index per night. β_0 is the intercept, which is the reference which all the other predictor variables are compared to. β_1 is the coefficients for the predictor variable, which is the fixed effect, and b is the random effect. The distribution was set to a Gaussian distribution, as the calculated H index were continuous variables and follow a normal distribution,

Two types of GLMM was used to examine fish count data. It's build on the same premise, with the improved version having more variables making it more complex. The complex version of the GLMM is given by:

$$log(N) = \beta_0 + \beta_{1_{Habitat}} + \beta_{2_{Gear}} + \beta_{3_{Temperature}} + \beta_{4_{Oxygen}} + b_{Day:Month} \tag{3}$$

Where the response variable N describes the number of each individual species caught per night per gear employment. β_0 is the intercept, which is the reference which all the other predictor variables are compared to. β_1, β_2, β_3 and β_4 are the coefficients for the predictor variables, which are the fixed effects, and b is the random effect. The simpler version of the model only uses β_1, β_2 as predictor variables. The distribution was set to Poisson distribution, as he data collected through the field trip, were count data, which is discrete data, and comes as either zero or positive integers. Count data is also typically distributed with a positive skew rather than normally distributed (Casals et al. [2015]).

For both GLMM models, a nested random effect was added with day in month, where the specific number of field work day within each of the two surveyed months, can account for some of the variance without it being a driving factor. This assumption is based on the fact that climatic variables such as wind and temperature changed daily, as well as from September to October, and also based on an assumption that the field work itself might to some degree have a disrupting effect on the area, as the field work was done in the same areas several days in a row.

To interpret the significance of each predictor variable, a 95% confidence interval was used for analysing the results, which is based on a significance level of $\sigma = 0.05$. If the P-value fell above that, it was disregarded as significant.

The model was run on individual species per gear type per night, even if the count was zero. The only data omitted from the analysis, were the fishing done by day as well as the fishing done at depth during field trip 1, as it was deemed to not be comparable enough.

For the temperature and dissolved oxygen (DO) mg/L used in the GLMM, the average per night was taken of the hours between 8 pm - 11 am for field trip 1 and 7 pm - 11 am for field trip 2, to match the hours the gear was in the water. The hour difference was because of the sun setting earlier in field trip 2, which meant the gear was placed earlier. Sometimes the gear was removed later than 11 am depending on how long emptying took, but 11 am was chosen, as it was assumed that most fish were active at night.

3 Results

It his section, the results of the data collected during the field campaign are presented, with first an overview of the total amount of fish caught per species, species richness and their distributions between habitat types. Secondly results from Shannon's Diversity Index are presented as well as results of the shrimp rake survey. Then data is being analysed through the a simple GLMM and an improved GLMM combing environmental data with the gear type and habitat. Afterwards the gear type efficiency and mortality is presented, followed by environment data of oxygen and temperature. Lastly, other observation from the field trips are noted.

3.1 Species richness and abundance

The total amount of fish caught with night fishing across both field trips, and across all the passive gear was 724 individual fish with a total species richness of 12 species as seen in table 1. These species include atlantic cod (*Gadus morhua*), corkwing wrasse (*Symphodus melops)*, european eel (*Anguilla anguilla*), eelpout (*Zoarces viviparus*), fifteen-spined stickleback (*Spinachia spinachia*), flounder (*Platichthys flesus*), goby spp. (*Gobius spp.)*), goldsinny wrasse (*Ctenolabrus rupestris*), herring (*Clupea harengus*), sea trout (*Salmo trutta trutta*), shorthorn sculpin (*Myoxocephalus scorpius*) and shrimp (not distinguished between baltic prawn or brown shrimp) . Goby spp. isn't identified as a specific species of gobies, due to uncertainty of the correct species, however most of the species caught were dark brown. Sea squirts (*Ascidiacea*) were occasionally found in gear in the eelgrass habitats, when dead eelgrass shoots were caught in the gear. This was most pronounced during field trip 1, as more dead eelgrass was tangled in the gear. Sea squirts were noted but isn't part of the analysis, as it's an immobile species attached to substrate.

Table 1: Total count of each species, distribution across habitat types and total species richness.

Species	Total	Eelgrass	Control
Atlantic cod	173	117	56
Corkwing wrasse	52	40	12
European eel	10	7	3
Eelpout	139	50	89
Fifteen-spined stickleback	9	5	4
Flounder	78	46	32
Goby spp.	36	20	16
Goldsinny wrasse	2	0	2
Herring	2	0	2
Sea trout	4	4	0
Shorthorn sculpin	148	84	64
Shrimp	71	36	35
Total no. fish	724	409	315
Total no. species	12	10	11

The species richness found in the eelgrass habitat was 10 and 11 for the control habitat (1). The species that was found exclusively in eelgrass was sea trout (found both at station A and C) and the species found exclusively in the control habitat were herring and goldsinny wrasse (both species only found at station D). The abundance of fish was 30 % higher in the eelgrass habitat type, with a total of 409 individuals compared to 315 in the control habitat. Most notably differences are the cod, corkwing wrasse and shorthorn sculpin. Eelpout is however 44 % lower in the eelgrass bed compared to the control site. The total amount of European green crabs (*Carcinus maenas*) caught in the passive gears were 11046. That means that for everyone fish caught, 12.6 crabs were caught as well. The distribution of crabs between habitats was almost equal.

3.2 Shannon's Diversity Index

Calculating Shannon's Diversity Index H based on equation 1 for each habitat type (eelgrass and control) is shown in table 2. The index seems to vary between days. The first two days in field trip 1, the H indes was below 1 in the control habitat, which corresponds to almost no fish caught in that habitat. The results from the GLMM, which compared the calculated H index between the two habitats for each of the 12 fishing days, resulted in a p-value = 0.397, indicating no significant difference of the calculated diversity between the two habitat types.

Table 2: Calculations of Shannon's Diversity Index per day.

		Shannon Diversity Index	
Day	Day	Eelgrass	Control
September (field trip 1)	1	1.29	0.00
	2	0.64	0.00
	3	1.15	0.85
	4	1.13	1.78
	5	1.54	1.70
	6	1.77	1.21
October (field trip 2)	1	1.11	1.41
	2	1.70	1.58
	3	0.80	1.10
	4	1.44	1.53
	5	1.56	1.39
	6	1.21	1.32

3.3 Shrimp rake survey

The summed result of the two shrimp rake surveys are shown in figure 6. The total amount of brown shrimps (*Crangon crangon*) are higher in the control area, but the variability of species are higher in the eelgrass bed, with a species richness of 11 compared to 2 in the control site. The size range between the species caught were between 5-17 cm, with the two longest species being the pipefish (*Syngnathus typhle*) and spinachia. Two specimen of three-spined stickleback (*Gasterosteus aculeatus*) both with a length of 5.5 cm were also caught in the eelgrass bed, which together with the pipefish were new species compared to the species caught with the three passive gear types. Other stationary species such as shells (*tritia reticulatus*) were also caught, that were only seldom caught in the passive gear, and therefore not analysed. Summarized, the shrimp rush survey displays a higher diversity in the eelgrass bed compared to the control area, with a sandy bottom.

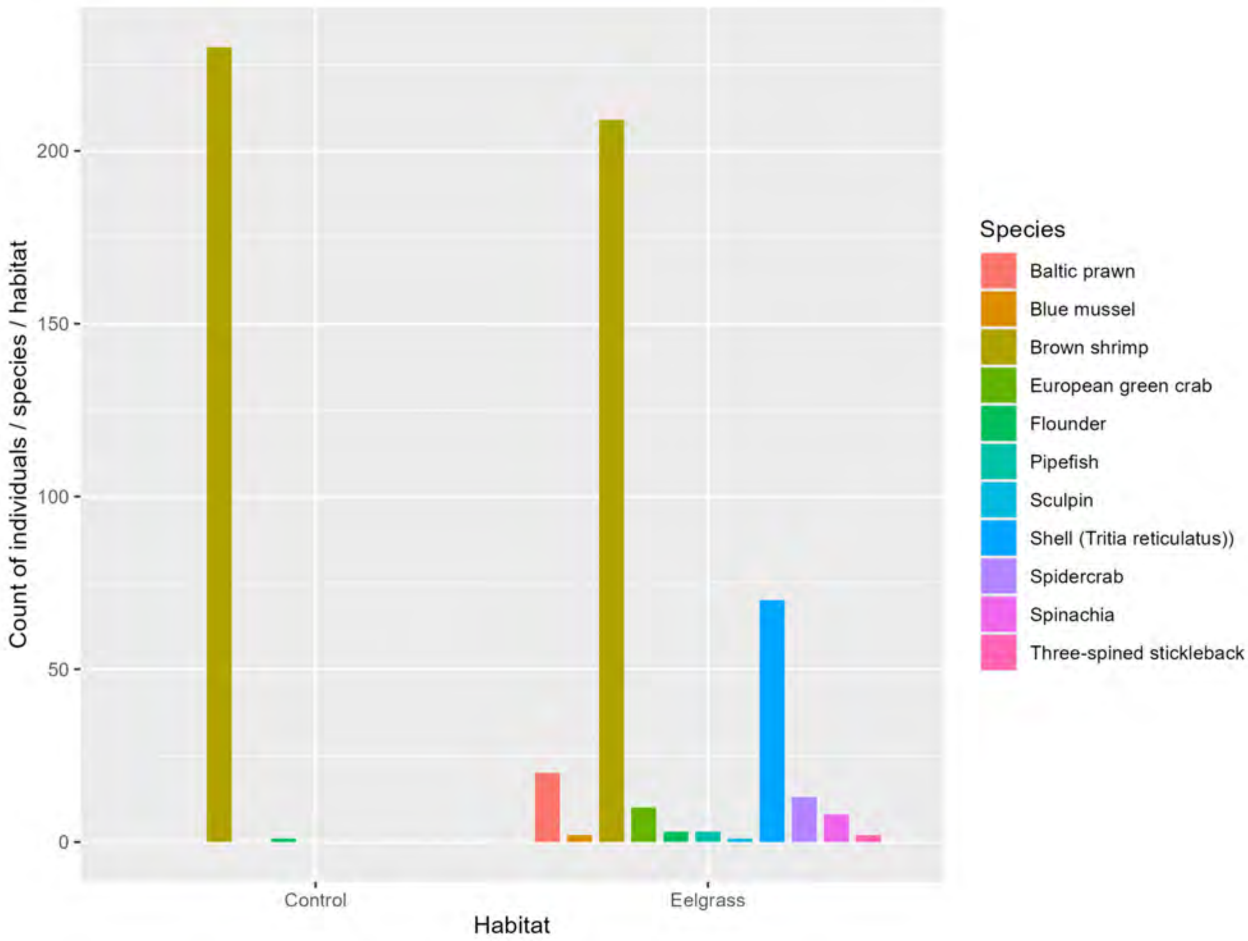


Figure 6: The summed results of two shrimp rush surveys in a control area and in an eelgrass bed.

3.4 General linear mixed model of fish count

The GLMM was run for the species; cod, eelpout, flounder, eel, goby spp, sculpin and corkwing wrasse. The results are shown in table 3. The species caught, which were not run in the model were; fifteen-spined stickleback; sea trout; herring; goldsinny wrasse, shrimp and european green crabs. The reason for exclusion were based on the few specimen caught, except for green crabs, which were excluded due to their poor model fit, based on a high Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) (>2,000). AIC and BIC are a metric to comparisons within models and their complexity based on the number of estimated parameters. Generally a low AIC and BIC are preferred when comparing models. When the GLMM had a high value for the crabs, it indicates that the model doesn't very explain the number of counts of crabs as well as it no being Poisson distributed.

The models for the seven species had AIC between 65.7-262.6 and BIC between 78.7-275.7 with eel having the lowest values making it the best fit, and cod having the highest values. All summery tables can be seen in appendix A.

The intercept was chosen to be the control habitat with the rigid lobster trap as gear type and remained the reference for all the model runs, to ease comparisons between models.

Table 3: Summery of the model runs for seven different species. The intercept is the combination of the control habitat and the rigid lobster trap. The other fixed variables are the (eelgrass habitat, and the gears double eel fyke net and rectangle fyke net. The p-values that are significant are marked in bold. The estimate indicates is the significance is positive or negative.

Species		Estimate	Std error	P-value
Cod (Gadus morhua)	Intercept	-3.61	0.72	**6.30E-07**
	Eelgrass	0.75	0.16	**4.37E-06**
	Double Eel fyke	1.86	0.54	**0.000584**
	Rectangle eel fyke	3.70	0.51	**2.41E-13**
Corkwing wrasse (Symphodus melops)	Intercept	-2.65	0.62	**2.16E-05**
	Eelgrass	0.89	0.42	**0.0357**
	Double Eel fyke	-0.08	0.67	0.9062
	Rectangle eel fyke	1.13	0.52	**0.0302**
Eel (Anguilla anguilla)	Intercept	-4.90	1.33	**0.000222**
	Eelgrass	0.85	0.69	0.219504
	Double Eel fyke	1.77	1.16	0.127196
	Rectangle eel fyke	1.99	1.14	0.079944
Eelpout (Zoarces viviparus)	Intercept	-2.18	0.67	**0.00113**
	Eelgrass	-0.52	0.17	**0.00238**
	Double Eel fyke	1.05	0.54	0.05009
	Rectangle eel fyke	3.27	0.47	**3.08E-12**
Flounder (Platichthys flesus)	Intercept	-3.55	0.78	**5.59E-06**
	Eelgrass	0.34	0.78	0.14
	Double Eel fyke	1.47	0.87	0.092
	Rectangle eel fyke	4.11	0.76	**5.62E-08**
Goby (Gobius spp.)	Intercept	-1.82	0.58	**0.00167**
	Eelgrass	0.36	0.35	0.30604
	Double Eel fyke	-1.48	0.78	0.05581
	Rectangle eel fyke	0.60	0.41	0.14299
Sculpin (Myoxocephalus scorpius)	Intercept	-1.94	0.44	**1.07E-05**
	Eelgrass	0.28	0.17	0.098947
	Double Eel fyke	1.38	0.37	**0.000166**
	Rectangle eel fyke	2.50	0.34	**1.23E-13**

The results shown in table 3 show difference between species. Only cod and corkwing wrasse show a significant increased in the expected count of fish caught in the eelgrass compared to the control habitat. Eelpout shows a significant decrease in the expected count of fish caught in eelgrass. The difference between habitats are not significantly different for the species flounder, eel, goby and sculpin, however, the estimates are each positive, which might indicate a trend of higher counts associated with that of eelgrass. In terms of gear, the rectangle fyke net is shown to be significantly associated with higher counts of fish caught for cod, eelpout, flounder, sculpin and corkwing wrasse compared to the rigid lobster trap. The double eel fyke net shows a significant association with higher counts of cod, and sculpin compared to the rigid lobster trap. Eel and goby showed no significant difference between gear types.

3.4.1 Variance

A diagnostic test using the DHARMa package in R, done on all seven models runs. The diagnostic tests not find significant deviations from certain assumptions, such as uniformity of residuals within groups and homogeneity of variance across groups, which indicate that the models' residuals meet these assumptions. The diagnostic test are shown in appendix B. The variance quantifies how much the random intercepts deviate from the overall mean of the nested random effect of day within month, which had 12 combinations. The variance for the seven model runs was mostly between 1-2 with, except for flounder and sculpin, which had variance <0. The variance is therefore quite low for all model runs, which means there is little variability among the random effects, indicating that the day within month has minimal effect on the count of fish once the fixed effects (habitat type and gear type) are accounted for.

3.4.2 Improving the complexity of the model

In order to improve the complexity of the GLMM, obtained oxygen and temperature data from the oxygen loggers were added as predictor variables. However, as the oxygen loggers were taken out of the water during stormy weather, the data set was incomplete, especially during field trip 1. This means, that instead of 100 data points containing data from each gear employment, 28 gear employments containing data are excluded in this model run, as those didn't contain any temperature and oxygen data, with the consequence that eel isn't included, as there weren't enough data on eel within the remaining 72 data points. The results in 4 show that both temperature and DO mg/L are significant for cod and eelpout where for both species, the estimate indicates that more fish were caught with lower values. Temperature was significant for goby spp. and sculpin, where gobies were found more with higher temperatures and more sculpin were found with lower temperatures. Flounder also had a significant response to DO mg/L with, more individuals caught with lower oxygen.

Comparing the other predictor variables show changes for several species. Goby now show a significant difference in habitat types with more species being caught in the eelgrass, and eelpout now show a positive significant response to the double eel fyke, Corkwing wrasse no longer shows a significant difference between habitat types, and flounder no longer shows a significant difference between gear types, however the the standard error for both species is also relatively high for most of the parameters, indicating that something within the data is wrong. Cod and sculpin show the same significant differences between gear types as in the previous model. For all the six species the AIC and BIC improved with this model, as they all decreased a bit (Appendix A).

Table 4: Summery of the model runs for six different species. The intercept is the combination of the control habitat and the rigid lobster trap as well as a value for temperature and dissolved oxygen (DO). The other fixed variables are the eelgrass habitat, the gears double eel fyke net and rectangle fyke net and temperature and DO. The p-values that are significant are marked in bold. The estimate indicates is the significance is positive or negative.

Species		Estimate	Std error	P-value
Cod (Gadus morhua)	Intercept	36.61	12.81	**0.00425**
	Eelgrass	0.73	0.17	**1.26e-05**
	Double Eel fyke	2.4	0.74	**0.00117**
	Rectangle eel fyke	4.24	0.71	**2.59e-09**
	Temperature	-0.83	0.28	**0.00332**
	Dissolved oxyggen (mg/L)	-3.07	1.04	**0.00325**
Corkwing wrasse (Symphodus melops)	Intercept	-16.47	695.15	0.981
	Eelgrass	0.76	0.71	0.286
	Double Eel fyke	14.19	695.11	0.984
	Rectangle eel fyke	14.95	695.11	0.983
	Temperature	0.01	0.11	0.931
	Dissolved oxyggen (mg/L)	-0.03	0.71	0.961
Eelpout (Zoarces viviparus)	Intercept	15.18	5.32	**0.004349**
	Eelgrass	-0.63	0.18	**0.000517**
	Double Eel fyke	1.47	0.64	**0.022061**
	Rectangle eel fyke	3.68	0.58	**3.05e-10**
	Temperature	-0.42	0.11	**0.000163**
	Dissolved oxyggen (mg/L)	-1.23	0.44	**0.005026**
Flounder (Platichthys flesus)	Intercept	-12.73	11040	0.9991
	Eelgrass	03.94	0.24	0.1012
	Double Eel fyke	20.23	11040	0.9985
	Rectangle eel fyke	22.82	11040	0.9983
	Temperature	-0.09	0.06	0.1633
	Dissolved oxyggen (mg/L)	-0.82	0.38	**0.0308**
Goby (Gobius spp.)	Intercept	-1.24	7.10	0.8614
	Eelgrass	0.94	0.45	**0.0340**
	Double Eel fyke	-1.25	0.80	0.1182
	Rectangle eel fyke	0.83	0.45	0.0681
	Temperature	0.29	0.12	**0.0145**
	Dissolved oxyggen (mg/L)	-0.46	0.67	0.4903
Sculpin (Myoxocephalus scorpius)	Intercept	5.83	4.57	0.202263
	Eelgrass	0.32	0.17	0.064086 .
	Double Eel fyke	1.41	0.39	**0.000323**
	Rectangle eel fyke	2.52	0.37	**7.69e-12**
	Temperature	-0.25	0.08	**0.001579**
	Dissolved oxyggen (mg/L)	-0.43	0.4	0.276757

3.5 Gear efficiency and mortality

The mortality through the entire field campaign is shown in figure 7 for each gear type. It's important to keep in mind however, that the fishing pressure was more intense for the rigid lobster trap, as there were two nights during field trip 1 and one night during field trip 2, where only the lobster trap was used. The calculated mean of fish/gear/night is very similar for rigid lobster trap and double eel fyke net with 2.5 and 3 respectively. The mean number of fish/gear/night for the rectangle fyke net is 17.5 fish.

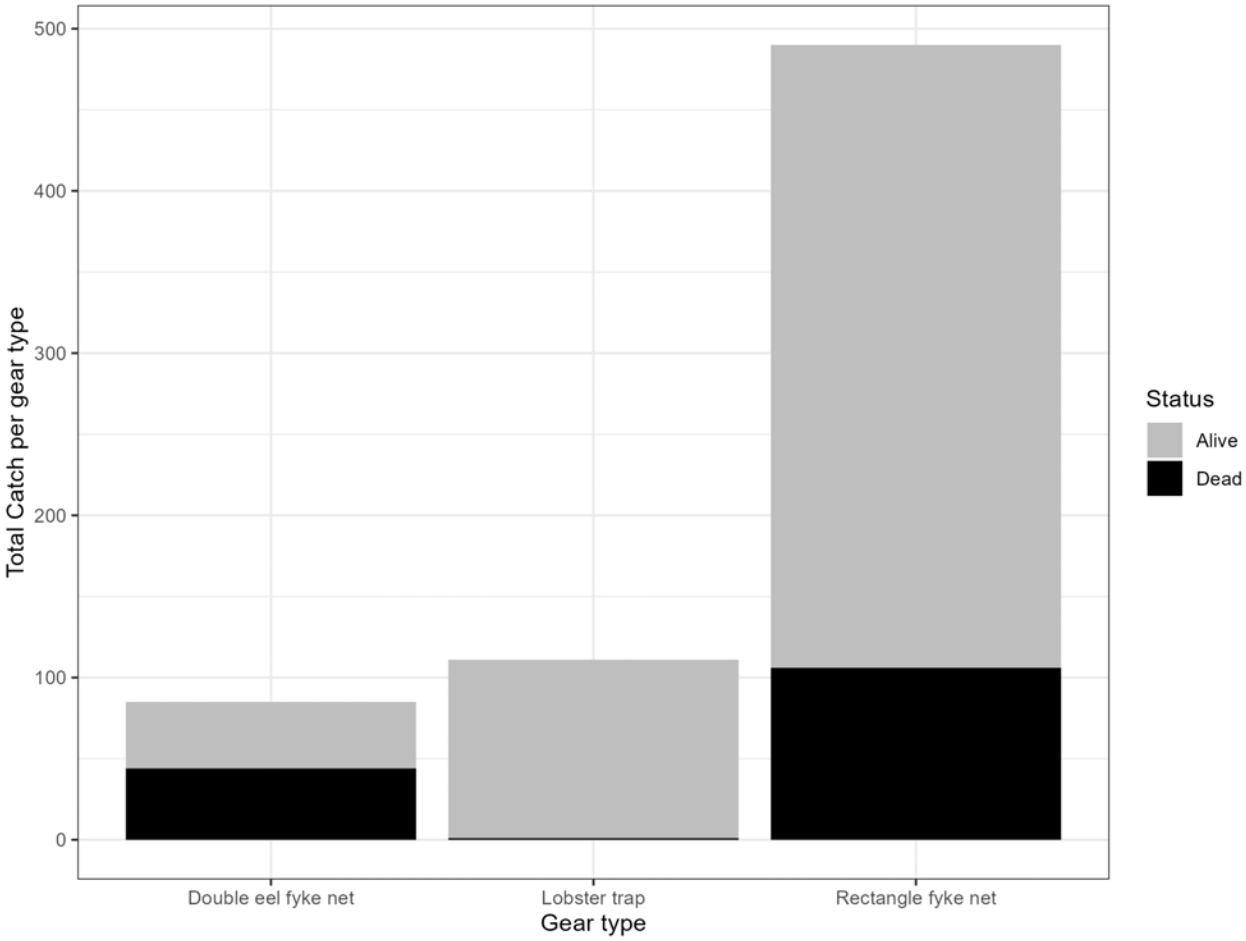


Figure 7: Total number of fish caught per gear type across both field trips. Black mark the dead fish and grey mark the fish that were alive.

The rectangle fyke net had the highest mortality count with a total of 106 dead fish throughout the field campaign, but by calculating the relationship between death and alive individuals, the percentage of morality is highest with the double eel fyke net, with a morality of 51.8 %, per fish caught. The mortality of the rectangle fyke net = 21.6 % per fish caught and the morality for the rigid lobster trap is just 0.9 % with only one dead fish. The dead species were mainly scuplin, flounder and eelpout, however the biggest cods and one sea trout and two herring were also among the dead. The total dead count of fish throughout the field campaign were 151. The distribution of the different species within each gear type is shown in appendix C.

As it was assumed that crabs were the cause of death for the fish, the mean of the amount of crabs caught in each gear type was calculated. The rectangle fyke net had the highest mean with 207 crabs/gear/night fished. The double eel fyke net had a mean of 151.9 crabs/gear/night fished, and the rigid lobster trap had 22.7 crabs/gear/night fished.

3.6 Oxygen and salinity

The salinity measured in the area were between 22-24 psu for field trip 2, which the exception of a measurement of 14.7 psu on the first day of field trip 2. This can partly be explained by the fact that the field work was conducted shortly after a storm (FCCO [2023]), which might have diluted the seawater. The plotted dissolved oxygen % for field trip 2 is shown in 8, which show the oxygen in both eelgrass beds, and in station D, which is the control area furthest away. The results were of salinity for field trip 1, were taken incorrectly and therefore couldn't be estimated in the lab later on. All three areas showed the same general pattern, with daily fluctuations in DO saturation %, where the oxygen decreased due to respiration of plants and marine organisms, and increased again in day time due to photosynthesis. All three station had a high peak in the beginning of the field trip, this could be due to the fact the salinity was lower in the beginning of the week. Station A (eelgrass) showed a slightly higher DO saturation % than the other two stations throughout the week. The oxygen loggers were taken out of the waters between the 24th and 25th as a precaution due to stormy weather.

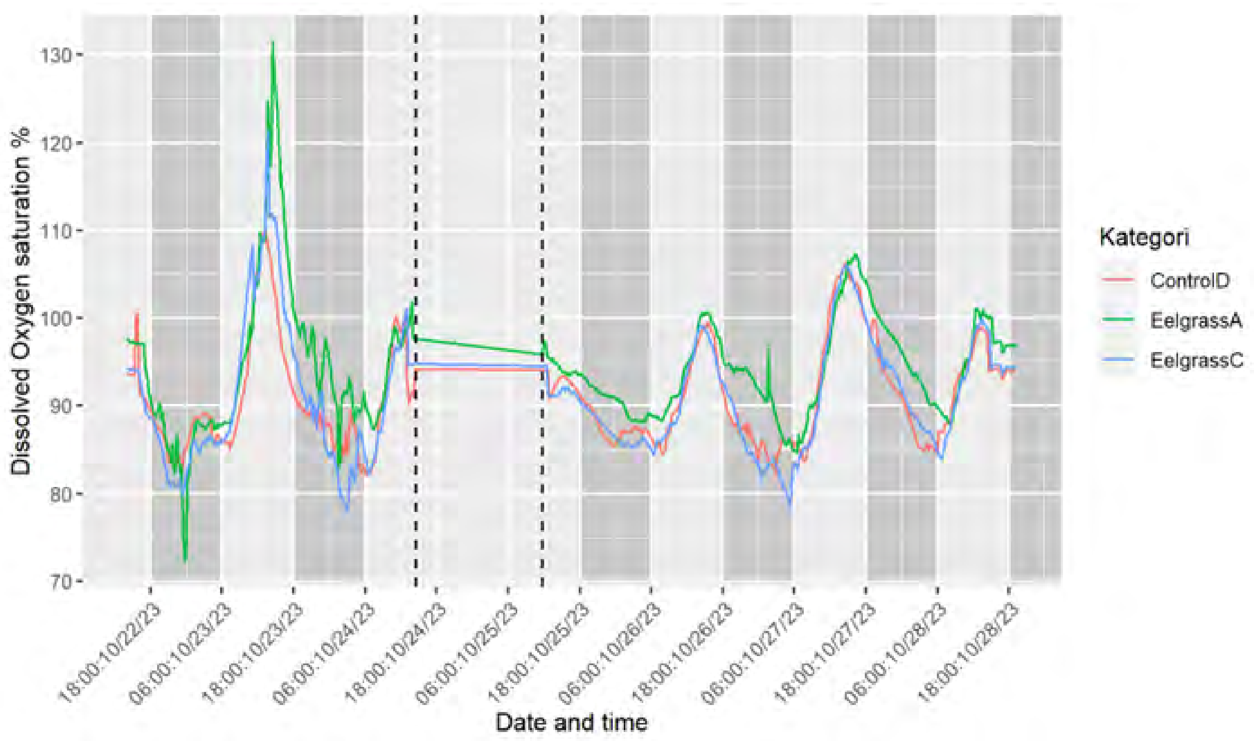


Figure 8: Dissolved Oxygen Saturation % for two eelgrass stations and one control site during field trip 2. Dark areas resemble night.

Table 5 show a summery of the three different loggers. Both eelgrass habitats show more variation with a higher maximum and lower minimum compared to the control area. All three areas show a similar high mean of DO saturation %.

Table 5: Summery of the DO saturation % for three oxygen loggers during field trip 2.

DO (%)	Min	Mean	Max	Sd
Control D	82	91.2	109.8	5.98
Eelgrass A	72.2	94.3	131.6	7.01
Eelgrass C	77.9	90.9	121.3	7.06

During field trip 1, the weather conditions were worse for several days, which meant the oxygen loggers were taken out of the water and therefore the oxygen data is incomplete (appendix D).

3.7 Temperature and catch per day

The water temperature varied between the two field trips, with a drop in temperature of around 9◦C. Figure 9 shows the average night water temperature (orange line) for each of the seven days that the oxygen loggers were recording, which only were 2 days during field trip 1 and days during field trip 2. The figure shows the corresponding total catch of fish those nights. The total amount of fish caught increased from trip 1 to field trip 2, however the fishing intensity was also higher during field trip 2, with double the amount of stations per night. The total catch drops a bit each day during field trip 2.

Figure 9: Total number of fish caught per gear type across both field trips. Black mark the dead fish and grey mark the fish that were alive.

3.8 Other observations during the field campaign

The average size for cod was 18 cm in eelgrass and 17.7 cm in control sites. For flounder the average size was 9.2 cm in eelgrass 11.3 cm in control sites.

For both field trips the visibility was noted when depth was measured. The visibility changed daily but was often poor, however since the working environment was in shallow depth, the visibility was only less than the depth on a couple of days when winds were above 8 m/s.

During field trip 1, the eelgrass was covered in sea felt (*Pylaiella littoralis*) and Ectocarpus penicillatus. Upon return a month later, most of the sea felt had disappeared again, most likely due to storms in-between the field trips. The storm also had washed up huge quantities of dead eelgrass onto the shore (figure 10). However, the field sites surveyed in this study didn't seem particularly affected in terms of loss of biomass of eelgrass.

Figure 10: Dead eelgrass washed onto shore after storm shortly prior to the beginning of field trip 2.

During field trip 1, snorkel surveys, and surveys by boat using an aqua scope went to the newly planted sea grass bed, planted in the summer of 2022. The eelgrass shoots were still present and growing, which was evident as new shoots were seen between the checkerboard formation, which is the typical method for planting eelgrass.

4 Discussion

In this section the various results and their interpretation are discussed, and compared to similar studies, followed by a discussion of the field work and model with a perspective in improvements as well as how these study results can be used.

4.1 Difference between eelgrass habitat and control site

The field campaign aimed at collecting biodiversity data using different gear types, in order to see differences between an eelgrass bed compared to a habitat without eelgrass. Two GLMM model runs were made for this purpose; a simpler model with just the habitat type and gear type as predictor variables and an improved model run with the addition of temperature and DO mg/L. Through the different model runs the results of the passive gear catch data indicate, that for the species cod and corkwing wrasse, there is a significant difference between the two habitats, with an increase in the expected number of catches in the eelgrass habitat. Corkwing wrasse didn't show this relationship in the improved GLMM model run, however many of the parameters for that species had high standard errors. Goby spp. also showed a positive significant increase with the eelgrass habitat with the improved model run. The rest of the species caught didn't show a significant difference between the two habitat types, except for eelpout, which showed a significant decrease in the number of fish caught in eelgrass. The total number of eelpout caught was 139 individuals, with 50 in eelgrass and 89 in the control habitats. The results for eelpout is surprising, as eelpout is known to prefer habitats consisting of eelgrass, stones or macroalgae, however they have also been observed to be around sandy and muddy bottom especially during winter (Carl and Møller [2019]). Flounder did not show a significant difference between habitat types. Flounder is known to prefer sandy and muddy bottoms during the day, where it will hide in the sand. During night however, it will be found in the water column to hunt or utilize currents for transport (Stubgaard [2023b]). It is therefore not that surprising that flounder was found in both types of habitats. The abundance of crabs caught was very high with a total of 11046 crabs caught, with no significant difference between the two habitats.

The Shannon Diversity Index was counted for each day, and showed some variations between the days. A GLMM was run on each individual fishing day but the results showed no significant different between the eelgrass and control habitat. The species richness was also similar with 10 species in the eelgrass bed and 11 species found in the control site, with one species being exclusive to the eelgrass, and two species being exclusive to the control areas. This might indicate the differences between habitats are not as clear in this study as other studies. A similar study with a similar aim done in eelgrass and control sites in the Swedish Skagerrak, The study found that fish species richness was was significantly higher in eelgrass habitats compared to areas where seagrass was missing, Density and biomass of fish were also generally lower in areas dominated by bare sediment compared to those in the eelgrass habitats, which especially cod being lower in the control site (Pihl et al. [2006]). This study also found cod to be significantly more abundant in eelgrass habitats. However, the species richness between habitats was the same. The Swedish study investigated eelgrass at four different stations, where three of the four stations had a full cover of eelgrass, with only one station with a patchy cover. That is different in this study, where both of the stations for eelgrass survey had a patchy eelgrass cover. The distance between the stations is also far greater than what is done in this study, as they compare different bays. Other differences in method include the use of gear type, where the Swedish study used beach seines, which is an active gear, as well as both collecting data day and night Pihl et al. [2006].

The study area of this study as shown in figure 1 and in figure 2 indicate that the borders between eelgrass beds and sand areas very rigid. The entire bay is characterized by having many smaller eelgrass beds scattered around which the fish can travel between, which was also evident in the study done by Adams [1976a], that showed that the biomass within eelgrass beds was twice as high at night compared to the day. It is therefore assumed that the species might move between the scattered eelgrass beds within the area. Another explanation, can be the use of monitoring gear, as the results from the shrimp rake survey, showed that the amount of species between the two habitats greatly varied, with the eelgrass bed catching a total amount of 11 species throughout the two surveys, while the amount of species were two for the control site. Eelgrass are therefore still beneficial to the entire ecosystem in the bay, and as the shrimp rush survey indicated, many smaller species live within the beds providing a food source for other fish. Furthermore eelgrass is a nusery ground for species such as cod, that prefers to spend its juvenile stage here Freitas et al. [2016]. Were eelgrass beds to be reduced further, it could have negative consequences for the entire marine ecosystem in the bay.

4.2 Environmental parameters

The temperature varied between the two field trips, with water temperatures around 18◦C+ in September and temperatures around 9-10◦C in October. The total number of fishes caught increased between the two field trip and one explanation is the higher fishing pressure with twice as many stations. Another explanation can be different thermal preferences for fish. Cod was one of the species which showed a rapid increase in the amount caught during field trip 2 compared to field trip 1. Cod has an upper thermal preference of <16◦C. A study at the Norwegian Skagerrak coast, showed that Atlantic cod at temperatures <16◦C selected eelgrass and macroalgae beds, but as temperatures rose, more cod would selected non-vegetated areas in deeper and cold waters (Freitas et al. [2016]). Cod did also show a significant relationship with lower temperatures in the results of the improved GLMM. Other species that showed the same significant relationship to lower temperatures were eelpout and sculpin, both species which were also caught more frequently during field trip 2. Several species of eelpout caught in October also seemed to be pregnant, which is more evident as eelpout give birth to living offspring. Eelpout is one of the environmental indicator species, as it's a stationary species and it's vulnerable towards toxins and oxygen depletion (Stubgaard [2023a]). Eelpout did surprisingly show a significant relation with DO mg/L with increased counts with a decrease in DO mg/L. The same showed both cod and flounder. The measured oxygen concentrations were however all way above the threshold for oxygen depletion of 4 mg/L ((DCE [2023]), with values between 9-10 mg/L, indicating the waters were well oxygenated. It isn't therefore necessarily concluded that those species prefer when oxygen is lower. The daily variability in oxygen might however, be driven by something like wind direction or wind intensity, which could also be a driver of several other factors influencing fish species abundance, that the model can't account for. The data for temperature and DO mg/L could only be used on 7 out of the 12 fishing days because of the weather conditions, which lead to the exclusion of 28 "gear employments". Should the study be repeated, it would improve the data set, to have more data points to compare with.

By observations of the eelgrass conditions in Kalø Vig through the two field trips, the eelgrass was found to be generally quite scattered and in September the eelgrass was covered in sea felt, which can shade the eelgrass limiting photosynthesis and create oxygen depletion do to its fast growth. Oxygen depletion however wasn't a problem in Kalø Vig, as the oxygen measurements showed a mean DO saturation % of approx. 90 % for both eelgrass and control habitats. This is most likely explained by how close to shore the field work took place, where the waters are well mixed. Most of the sea felt covering the eelgrass had disappeared upon the return on the second field trip in October, which was most likely due to a storm. The storm however also washed a lot of dead eelgrass onto shore, which would indicate that eelgrass is more exposed close to the coast, compared to if eelgrass was found at deeper depths. Any loss to the eelgrass beds surveyed in this study was however not evident. According to locals, the eelgrass beds in the area used to be a lot thicker 'back in the day', however during field trip 1, newer eelgrass planted the previous summer of 2022 by volunteers of Kysthjælper, were surveyed. The planted eelgrass seemed to still be present, as well as growing, which was indicated by the shoots between the checker fields, which the volunteers said was pattern planted in this specific case.

4.3 Difference between passive gear types

The difference between the three passive gears as seen in 3 indicate, that the rectangle fyke net is the most efficient gear for almost all species, but significantly so for cod, eelpout, flounder, sculpin and corkwing wrasse, when compared to the rigid lobster trap, but it is also assumed that it's more efficient than the double eel fyke, which only showed a significant association with higher counts of sculpin and cod in the simpler GLMM and eelpout as well in the more complex GLMM. The estimate for cod, eelpout and flounder are higher for the rectangle fyke net, which indicates, the efficiency is greater than of the rigid lobster trap for those specific species. The general efficiency of the rectangle fyke net is also evident when comparing the mean of fish caught by each setting of the gear, compared to the other gears. Due to this efficiency it isn't surprising that the rectangle fyke net also had the highest total mortality count of the three gear types (figure 7), However the the percentage of morality is highest for the double eel fyke net, making it essentially the least efficient gear type. The high mortality rate of the double eel fyke net can partly be explained by the design, which is more confined compare to the two other gear types, making it harder for a fish to avoid crabs inside the net, once it has been caught. In the other two gear types, the fish had some room to swim around making it able to avoid crabs. That also explains why sculpin were among the speciest with the highest mortality count, as it often swims towards the bottom, making it easier for crabs to catch. The design of the net also meant that more crabs were caught, because even though the rigid lobster trap and double eel fyke net had similar means of fish/gear/night with 2.5 and 3 respectively, the mean number of crabs caught per night differed, with the double eel fyke having 151.9 crabs/gear/night compared to the rigid lobster trap with 22,7 crabs/gear/night fished. In terms of the gears accessibility, the rigid lobster trap proved the easiest to fish with, as one person could do it alone. It's rigid structure and low frame also made it stable in stormy weather conditions, which the other gears weren't. But the species richness were not as high as the rectangle fyke net, so by only using rigid lobster trap, some species would be underrepresented. That also consists with Mehdi et al. [2021], that found that multiple gear types used in a survey provided the best overall sampling efficiency and species richness.

4.4 Improvements to model

Generally the GLMM is good model choice for modelling biological data when the response variable is in count data, and when multiple predictors influencing the response variable, which is often the case with field work, where everything can't be controlled. The addition of the GLMM allows for random effects, which can help explain some of the variance. In terms of the nested random effect used in this study of days within months, the variance was low for all model runs with values between 0.5-2.5. This indicates that the day within month has minimal effect on the count of fish once the fixed effects are accounted for. This was the case both the simpler GLMM (habitat type and gear type) as well as in the more complex GLMM (habitat, gear type, temperature and DO mg/L). It had been expected, that month has some effect due to a difference in water temperature from a mean 9 degrees from September to October. There were some variability of species, like the appearance of Sea trout and Herring in October, however none of these species were run in the model as their total catch number was 4 and 2 respectively.

On field trip 2, it was observed that the total catch for some species like cod were higher in the beginning of the week compared to the rest. Although the model tried to take temperatures and DO mg/L into account, as well as have the day within the month as a random effect, other variables not included could perhaps better explain these variations. For example was there an South-East storm right before field trip 2 began, which could potentially have pushed cod into the bay. Wind direction could be added to the model as well as perhaps visibility to see if they had any significant effect on the predicted catch. It was also the purpose of this study to implement salinity measurements into the model, however as the samples were taken incorrectly, only 4 samples were usable by the end. Fish, like with temperature, has different tolerances and preferences, which might be shown in the a model where that is implemented.

4.5 Improvements to method

Direct comparisons between the results of field 1 and 2 can provide a bias as field trip 2 fished much more intensely, with the addition of two extra stations. Were this study to be repeated, it would be advised to have the same number of stations between each field trip. One way to get around this, could be to compare each station individually, instead of combining the station A and C into habitat eelgrass and B and D into a control habitat. However field trip 1 also had one less night of fishing with all gear types due to weather conditions. Addressing the differences between the field trip, station B1 also moved location, which creates a bias to some degree, even if the new location was chosen on the same conditions. By combining the stations however, it was hoped that some of that bias would decrease, as the two additional stations served as replicas. The setting and emptying of gear was done in the order of D to A, during field trip 2. This was done to try and standardize the field work, and to ensure that the gears are in the water closed to the same time for each station. However, with big catches, the time between emptying gear for each station was prolonged. This could essentially improve bias, about time gear spent in water at each station, which isn't accounted for in this analysis. One way to improve the speed of the field work, and thereby decrease the time between each station, could be to exclude the length measurements of fish. This however depends on what the aim of the survey is, as the length proves some interesting insights into species in the habitat. Measuring the length of each individual fish also makes identification easier, which might otherwise not be the case, if the fish were only quickly counted. Another way to improve the field work, could be to have more than two people do the work. Ideally enough people so that each station could be emptied at exactly the same time. This would also provide the possibility of moving the stations further apart. It is unsure if that would change the results, but it would be interesting to investigate.

Generally by visiting the same site, as done in this study, the aim was to give a broader picture of the habitat and biodiversity, which could be controlled by changing environmental variables, and not just the presence or absence of eelgrass. By visiting the same location multiple times, the chance of observing changes over time is also possible. A biodiversity study in the

Skagerrak and Kattegat region spanning several years showed a decrease in the original species richness of benthic ecosystems in the region over the last seven decades, with especially a loss of rare species (Obst et al. [2017]). In general loss in species richness and decreasing fish stocks seem to be a problem among recreational and commercial coastal fishermen, however data is vital in investigating and mapping changes in abundance and distribution (Støttrup et al. [2018]). Doing a fish monitoring study is however time-consuming and it can be expensive and limited to a certain time and geographic area. In 2002 a voluntary catch registration was initiated as a collaboration between scientists and recreational fishermen, in the coastal waters of Denmark. The key-fisher project has a citizen science approach, with standardized protocol and data collection as well as fixed gear and stations, which make comparisons between areas and years easier and it improves data on a spatial and temporal scale (Støttrup et al. [2018]). By fishing in different places, and in different habitats, it will also make studies easier, like the Swedish fish study, which compared fish structures within eelgrass beds and control sites, with a far greater distance between each station than in this study (Pihl et al. [2006]).

Lastly, the method for monitoring biodiversity using passive and active gear can be revised. The aim of the field campaign was to monitor and examine fish species richness in order to get a better idea of two habitat types. The field work itself did prove to be somewhat disturbing to the habitat as it caused a total of 151 deaths, as well as the total number of fishes caught declining over time, as the week went by, which could indicate some disturbance but could also perhaps be explained by other variables not accounted for. Fish monitoring using passive and active gear however still arguably a good method for monitoring eelgrass habitats, as the visibility was often too poor for the use of cameras - which would also limit the survey to the day time.

Another method of collecting data is the beach seine used in the Swedish fish study (Pihl et al. [2006]). A study in a coastal lagoon in Portugal compared four gear types; 25 m and 50 m beach seines, beam trawl and Riley push net, and found that the combined use of 25-m beach seine and beam trawl is the preferred approach, as the beach seine targets smaller pelagic fish while the beam trawl catches more benthic species. Of the two gears, the beam trawl showed to have a significant higher species richness and a higher diversity index. In general the study also found that the species richness was higher in vegetated areas compared to non-vegetated areas in any of the gear types (Adao et al. [2022]). Using a beach seine in this area could potentially give more insight into the biodiversity of the area. It's an active tool, like the shrimp rush rake, which showed a higher diversity for the eelgrass compared to the control site. However if a beach seine was to be used, it demands a bigger area, and possibly that the stations should be placed further apart.

4.6 Perspective

The results regarding the efficiency of gear type could be applied to projects like the key-fishermen's project, that collects data about fish in coastal Danish waters. The percentage of morality, for the different gear might prove useful in getting an idea of the collected mortality in fishing with similar gear, especially that for the double eel fyke net, which was above 50%. Likewise the amount of crabs/gear and crabs/-fish, could perhaps prove some insight into other areas where those information are lacking, but where fish count data is available. Furthermore it would compare findings of this study to a similar area, where green crabs were not present in the same magnitude, to make a comparison similar to the study comparing areas before and after the invastion of green crabs, which that showed that the abundance of green crabs had a negative effect on both eelgrass and fish communities ((Matheson et al. [2016]).
Eelgrass has had a substantial reduction in distribution the pat 120 years, mainly due to waste disease and eutrophication. Construction of harbours or islands in existing eelgrass bed, will also disturb the habitat leading to a further reduction. The implications of further eelgrass loss, will have consequences for many species thereby affecting entire marine ecosystems. In order to prevent further eelgrass habitat loss, the causes for the loss needs to be addressed and reduced. That means reducing the discharge of nutrients from land, enhance conservation of eelgrass beds; both were they are today, but also based on also their potential of where they can grow to (Flindt et al. [2023]). Lastly elgrass restoration-projects might increase the distribution in areas where the potential for eelgrass is high, however, restoration-projects are usually small-scale as eelgrass restoration is time-consuming and are prone to high labour. The rising awareness through the public, however, enhances the potential for engaging more volunteers trough organisations such as Kysthjælper, or other organisations that facilitate the replanting of eelgrass. In general engaging people and making them more aware of what happens below the pristine blue surface, is important, to understand the problem and to care enough to help find a solution.

5 Conclusion

In conclusion, the comparison between eelgrass habitat and control sites revealed that the species richness was almost the same, with two species being exclusive to the control habitat and one species being exlusive to the eelgrass habitat. Calculations of Shannon's Diversity Index found no significance different between the two habitat types. Running a GLMM on habitat type and gear type showed that certain species were significantly more abundant in the eelgrass habitats, which were cod and corkwing wrasse. Eelpout showed a significant decrease number of catches in the eelgrass habitat compared to the control site. The the shrimp rush survey revealed a significant disparity in species richness, with eelgrass beds showing a substantially greater variety of species compared to control sites, indicating the importance of eelgrass habitats as crucial ecosystems for various marine species. Efficiency comparisons among passive gear types demonstrated that the rectangle fyke nets were most effective for most species, while the double eel fyke net exhibited the least efficiency, as it had the highest mortality percentage. The use of multiple gear types are however still encouraged in order to catch the biggest variety. European green crabs were abundant in great quantities through both habitats and throughout all the fishing days. This indicate that the ecosystem is somewhat out of balance, and the count of fish as well as the density of eelgrass could perhaps have been greater, if crabs were not as abundant. Atlantic cod, eelpout, goby spp (Gobius spp.) and sculpin (Myoxocephalus scorpius) all showed a significant difference between temperatures, with all of them being more abundant in colder temperatures except goby spp. Improvements to model could including the incorporation of additional environmental variables wind, and salinity to better explain variation in catch data. This study highlights the critical role of eelgrass habitats in supporting marine biodiversity in an ecosystem. Addressing these underlying causes for eelgrass loss is therefore is essential to prevent further loss together with an increased eelgrass restoration.

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6 Appendix

6.1 Appendix A

```
> #Cod
> glmm_cod1 <- glmmTMB(count ~ habitat + gear + (1|day:month), family = poisson
(link = "log"), data = dat5)
> summary(glmm_cod1)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + (1 | day:month)
Data: dat5

     AIC      BIC   logLik deviance df.resid
   262.6    275.7   -126.3    252.6       95

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 2.731    1.653
Number of obs: 100, groups:  day:month, 12

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -3.6099     0.7246  -4.982 6.30e-07 ***
habitatT      0.7453     0.1623   4.593 4.37e-06 ***
gearE         1.8569     0.5400   3.439 0.000584 ***
gearR         3.6982     0.5050   7.324 2.41e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
>
>
> #Eelpout
> glmm_eelpout1 <- glmmTMB(count ~ habitat + gear + (1|day:month), family = poi
sson(link = "log"), data = dat6)
> summary(glmm_eelpout1)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + (1 | day:month)
Data: dat6

     AIC      BIC   logLik deviance df.resid
   255.4    268.4   -122.7    245.4       95

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 2.801    1.673
Number of obs: 100, groups:  day:month, 12

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -2.1820     0.6702  -3.256  0.00113 **
habitatT     -0.5219     0.1718  -3.038  0.00238 **
gearE         1.0508     0.5364   1.959  0.05009 .
gearR         3.2650     0.4682   6.974 3.08e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
>
>
> #Flounder
> glmm_flounder1 <- glmmTMB(count ~ habitat + gear + (1|day:month), family = po
isson(link = "log"), data = dat7)
> summary(glmm_flounder1)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + (1 | day:month)
Data: dat7

     AIC      BIC   logLik deviance df.resid
   168.9    182.0    -79.5    158.9       95
```

```
Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 0.4134   0.643
Number of obs: 100, groups:  day:month, 12

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -3.5467     0.7810  -4.541 5.59e-06 ***
habitatT      0.3409     0.2312   1.474    0.140
gearE         1.4661     0.8702   1.685    0.092 .
gearR         4.1052     0.7560   5.430 5.62e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> #coef(glmm_flounder1)
>
> #Eel
> glmm_eel1 <- glmmTMB(count ~ habitat + gear + (1|day:month), family = poisson
(link = "log"), data = dat8)
> summary(glmm_eel1)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + (1 | day:month)
Data: dat8

     AIC      BIC   logLik deviance df.resid
    65.7     78.7    -27.8     55.7       95

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 2        1.414
Number of obs: 100, groups:  day:month, 12

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -4.9030     1.3279  -3.692 0.000222 ***
habitatT      0.8473     0.6901   1.228 0.219504
gearE         1.7655     1.1575   1.525 0.127196
gearR         1.9887     1.1357   1.751 0.079944 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> #head(dat8)
> #coef(glmm_eel1)
>
> #Goby
> glmm_goby1 <- glmmTMB(count ~ habitat + gear + (1|day:month), family = poisso
n(link = "log"), data = dat9)
> summary(glmm_goby1)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + (1 | day:month)
Data: dat9

     AIC      BIC   logLik deviance df.resid
   143.3    156.3    -66.7    133.3       95

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 1.669    1.292
Number of obs: 100, groups:  day:month, 12

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -1.8207     0.5792  -3.144  0.00167 **
```

```
habitatT       0.3567      0.3485   1.024  0.30604
gearE         -1.4845      0.7762  -1.913  0.05581 .
gearR          0.5950      0.4062   1.465  0.14299
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
>
> #sculpin
> glmm_sculpin1 <- glmmTMB(count ~ habitat + gear + (1|day:month), family = poi
sson(link = "log"), data = dat10)
> summary(glmm_sculpin1)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + (1 | day:month)
Data: dat10

     AIC      BIC   logLik deviance df.resid
   256.8    269.8   -123.4    246.8       95

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 0.9485   0.9739
Number of obs: 100, groups:  day:month, 12

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -1.9392     0.4405  -4.402 1.07e-05 ***
habitatT      0.2757     0.1671   1.650 0.098947 .
gearE         1.3768     0.3657   3.765 0.000166 ***
gearR         2.4954     0.3366   7.413 1.23e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
>
> #wrasse
> glmm_wrasse1 <- glmmTMB(count ~ habitat + gear + (1|day:month), family = pois
son(link = "log"), data = dat11)
> summary(glmm_wrasse1)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + (1 | day:month)
Data: dat11

     AIC      BIC   logLik deviance df.resid
   122.7    135.7    -56.4    112.7       94

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 1.163    1.079
Number of obs: 99, groups:  day:month, 12

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -2.6457     0.6229  -4.247 2.16e-05 ***
habitatT      0.8865     0.4220   2.101   0.0357 *
gearE        -0.0786     0.6673  -0.118   0.9062
gearR         1.1313     0.5219   2.168   0.0302 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

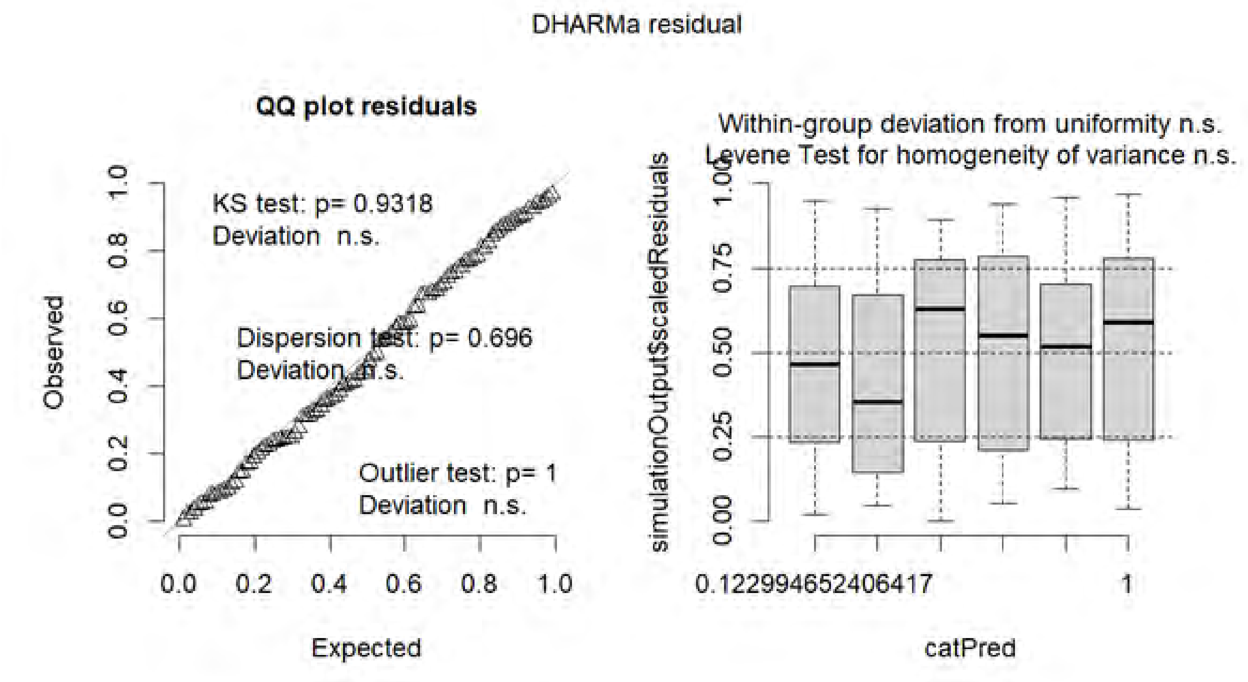
```
> glmm_cod2 <- glmmTMB(count ~ habitat + gear + temp + DO + (1|day:month), fami
ly = poisson(link = "log"), data = dat13)
> summary(glmm_cod2)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + temp + DO + (1 | day:month)
Data: dat13

     AIC      BIC   logLik deviance df.resid
   213.1    229.1    -99.6    199.1       65

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 0.4885   0.6989
Number of obs: 72, groups:  day:month, 7

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  36.6145    12.8082   2.859  0.00425 **
habitatT      0.7302     0.1672   4.367 1.26e-05 ***
gearE         2.3979     0.7385   3.247  0.00117 **
gearR         4.2413     0.7122   5.955 2.59e-09 ***
temp         -0.8255     0.2811  -2.936  0.00332 **
DO           -3.0724     1.0440  -2.943  0.00325 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> glmm_eelpout2 <- glmmTMB(count ~ habitat + gear + temp + DO + (1|day:month),
family = poisson(link = "log"), data = dat14)
> summary(glmm_eelpout2)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + temp + DO + (1 | day:month)
Data: dat14

     AIC      BIC   logLik deviance df.resid
   190.6    206.5    -88.3    176.6       65

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 0.08278  0.2877
Number of obs: 72, groups:  day:month, 7

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  15.1781     5.3225   2.852 0.004349 **
habitatT     -0.6272     0.1807  -3.472 0.000517 ***
gearE         1.4663     0.6405   2.289 0.022061 *
gearR         3.6805     0.5846   6.296 3.05e-10 ***
temp         -0.4231     0.1122  -3.771 0.000163 ***
DO           -1.2319     0.4391  -2.805 0.005026 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> glmm_flounder2 <- glmmTMB(count ~ habitat + gear + temp + DO + (1|day:month),
family = poisson(link = "log"), data = dat15)
> summary(glmm_flounder2)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + temp + DO + (1 | day:month)
Data: dat15

     AIC      BIC   logLik deviance df.resid
   136.7    152.7    -61.4    122.7       65

Random effects:
```

```
Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 0.05531  0.2352
Number of obs: 72, groups:  day:month, 7

Conditional model:
             Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.273e+01  1.104e+04  -0.001   0.9991
habitatT     3.939e-01  2.403e-01   1.639   0.1012
gearE        2.023e+01  1.104e+04   0.002   0.9985
gearR        2.282e+01  1.104e+04   0.002   0.9983
temp        -8.704e-02  6.244e-02  -1.394   0.1633
DO          -8.194e-01  3.794e-01  -2.160   0.0308 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> glmm_eel2 <- glmmTMB(count ~ habitat + gear + temp + DO + (1|day:month), fami
ly = poisson(link = "log"), data = dat16)
> summary(glmm_eel2)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + temp + DO + (1 | day:month)
Data: dat16

     AIC      BIC   logLik deviance df.resid
      NA       NA       NA       NA       65

Random effects:

Conditional model:
 Groups    Name        Variance  Std.Dev.
 day:month (Intercept) 1.588e-48 1.26e-24
Number of obs: 72, groups:  day:month, 7

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) 137.3891        NaN     NaN      NaN
habitatT     -0.4055        NaN     NaN      NaN
gearE       290.5806        NaN     NaN      NaN
gearR       290.1751        NaN     NaN      NaN
temp         -3.3468        NaN     NaN      NaN
DO          -40.5442        NaN     NaN      NaN
> glmm_goby2 <- glmmTMB(count ~ habitat + gear + temp + DO + (1|day:month), fam
ily = poisson(link = "log"), data = dat17)
> summary(glmm_goby2)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + temp + DO + (1 | day:month)
Data: dat17

     AIC      BIC   logLik deviance df.resid
    90.0    105.9    -38.0     76.0       65

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 0.6431   0.8019
Number of obs: 72, groups:  day:month, 7

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -1.2398     7.1001  -0.175   0.8614
habitatT      0.9445     0.4454   2.120   0.0340 *
gearE        -1.2528     0.8018  -1.562   0.1182
gearR         0.8267     0.4532   1.824   0.0681 .
temp          0.2868     0.1173   2.446   0.0145 *
DO           -0.4648     0.6738  -0.690   0.4903
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

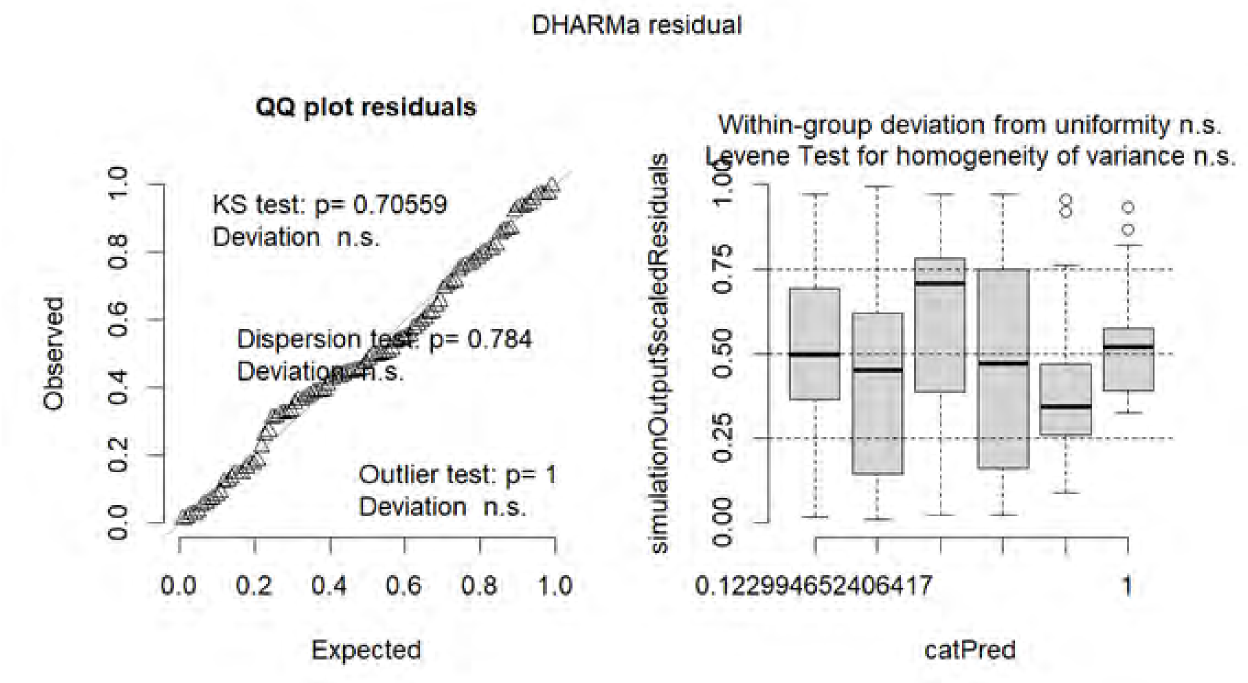
```
> glmm_sculpin2 <- glmmTMB(count ~ habitat + gear + temp + DO + (1|day:month),
family = poisson(link = "log"), data = dat18)
> summary(glmm_sculpin2)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + temp + DO + (1 | day:month)
Data: dat18

     AIC      BIC   logLik deviance df.resid
   213.6    229.6    -99.8    199.6       65

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 0.1134   0.3367
Number of obs: 72, groups:  day:month, 7

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  5.82885    4.57118   1.275 0.202263
habitatT     0.31691    0.17116   1.852 0.064086 .
gearF        1.41707    0.39409   3.596 0.000323 ***
gearR        2.51568    0.36756   6.844 7.69e-12 ***
temp        -0.25148    0.07959  -3.160 0.001579 **
DO          -0.43415    0.39917  -1.088 0.276757
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> glmm_wrasse2 <- glmmTMB(count ~ habitat + gear + temp + DO + (1|day:month), f
amily = poisson(link = "log"), data = dat19)
> summary(glmm_wrasse2)
 Family: poisson  ( log )
Formula:          count ~ habitat + gear + temp + DO + (1 | day:month)
Data: dat19

     AIC      BIC   logLik deviance df.resid
    59.4     75.2    -22.7     45.4       64

Random effects:

Conditional model:
 Groups    Name        Variance Std.Dev.
 day:month (Intercept) 1.09e-10 1.044e-05
Number of obs: 71, groups:  day:month, 7

Conditional model:
              Estimate Std. Error z value Pr(>|z|)
(Intercept) -16.474837 695.149443  -0.024    0.981
habitatT      0.758529   0.710905   1.067    0.286
gearF        14.186748 695.108602   0.020    0.984
gearR        14.945275 695.108486   0.021    0.983
temp          0.009683   0.112418   0.086    0.931
DO           -0.034516   0.707883  -0.049    0.961
```

6.2 Appendix B

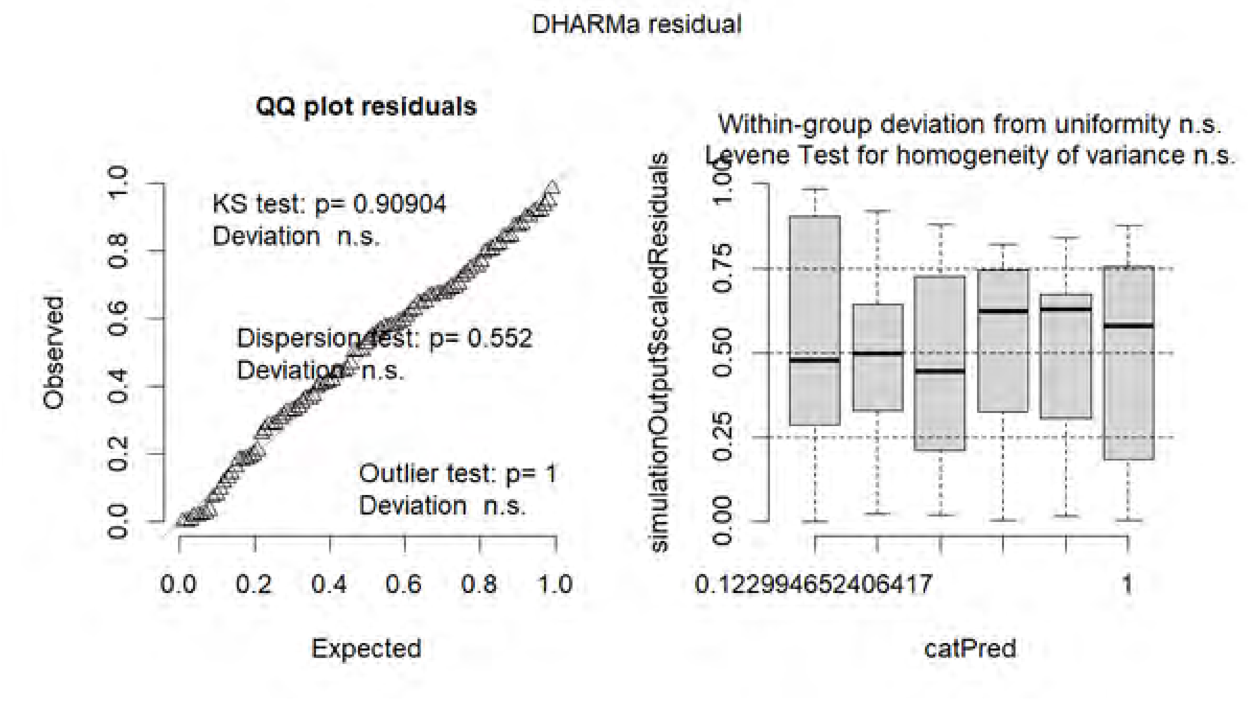
Cod


DHARMa residual
QQ plot residuals
KS test: p= 0.9318
Deviation n.s.
Dispersion test: p= 0.696
Deviation n.s.
Outlier test: p= 1
Deviation n.s.
Observed
Expected
0.0 0.2 0.4 0.6 0.8 1.0
Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00 0.25 0.50 0.75 1.00
0.122994652406417
1
catPred

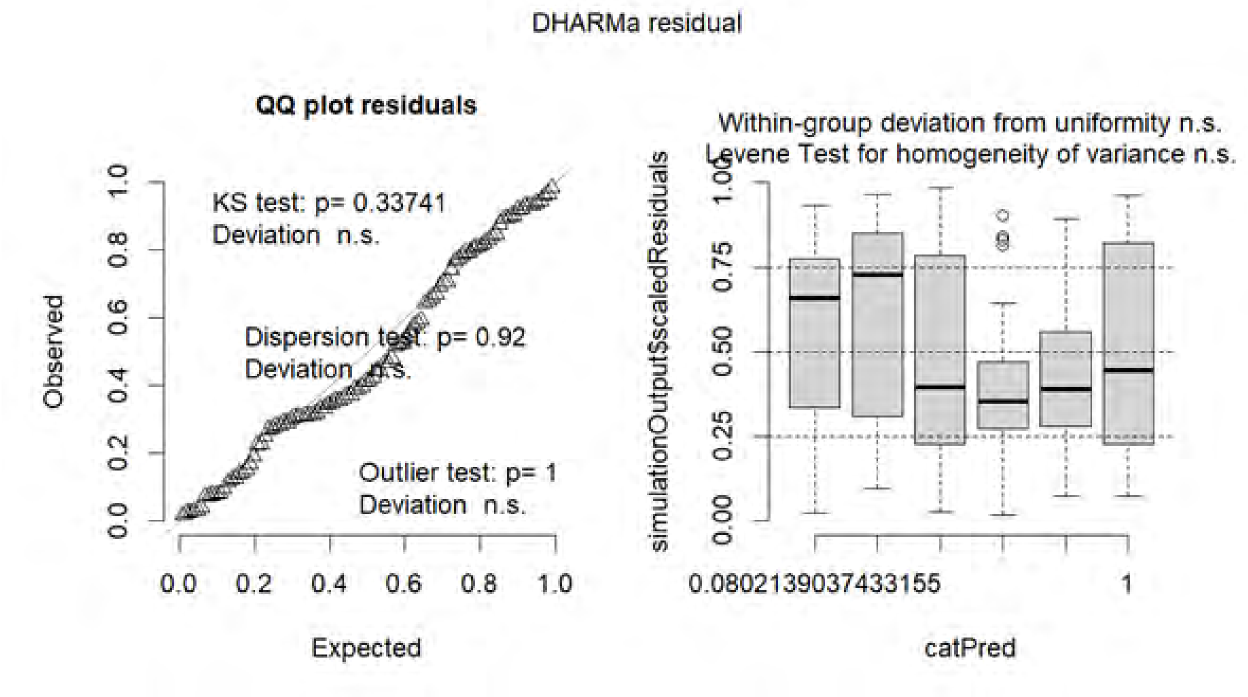
Eel


DHARMa residual
QQ plot residuals
KS test: p= 0.70559
Deviation n.s.
Dispersion test: p= 0.784
Deviation n.s.
Outlier test: p= 1
Deviation n.s.
Observed
Expected
0.0 0.2 0.4 0.6 0.8 1.0
Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00 0.25 0.50 0.75 1.00
0.122994652406417
1
catPred

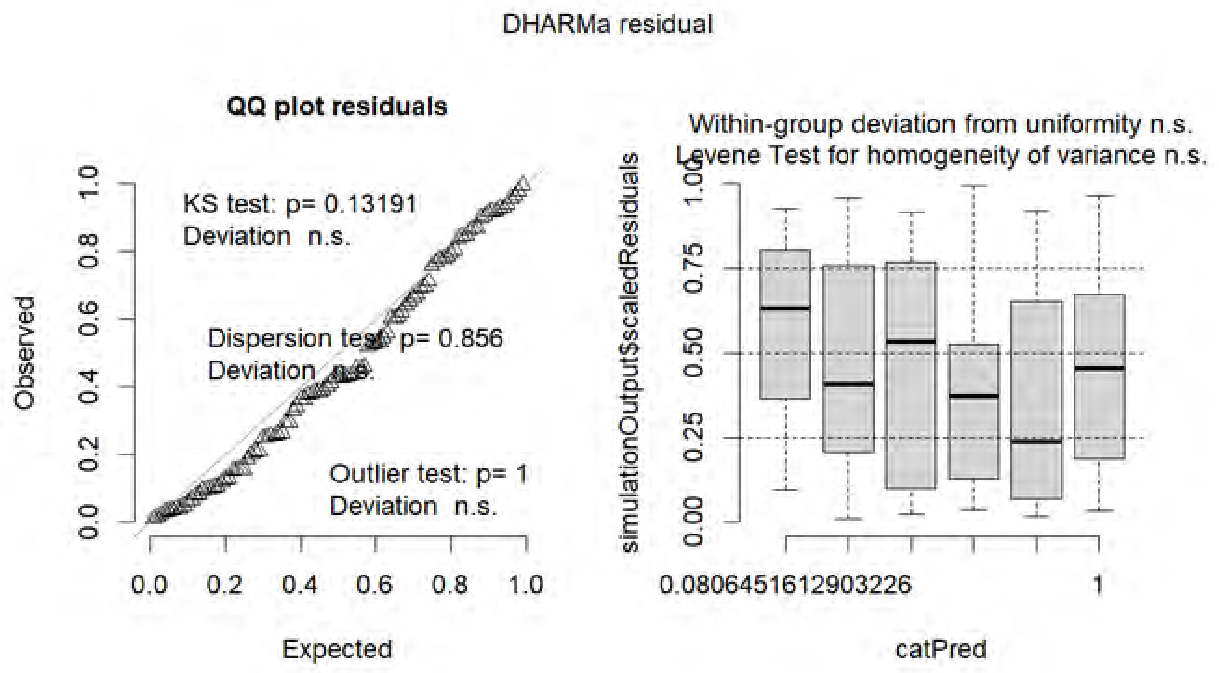
Eelpout



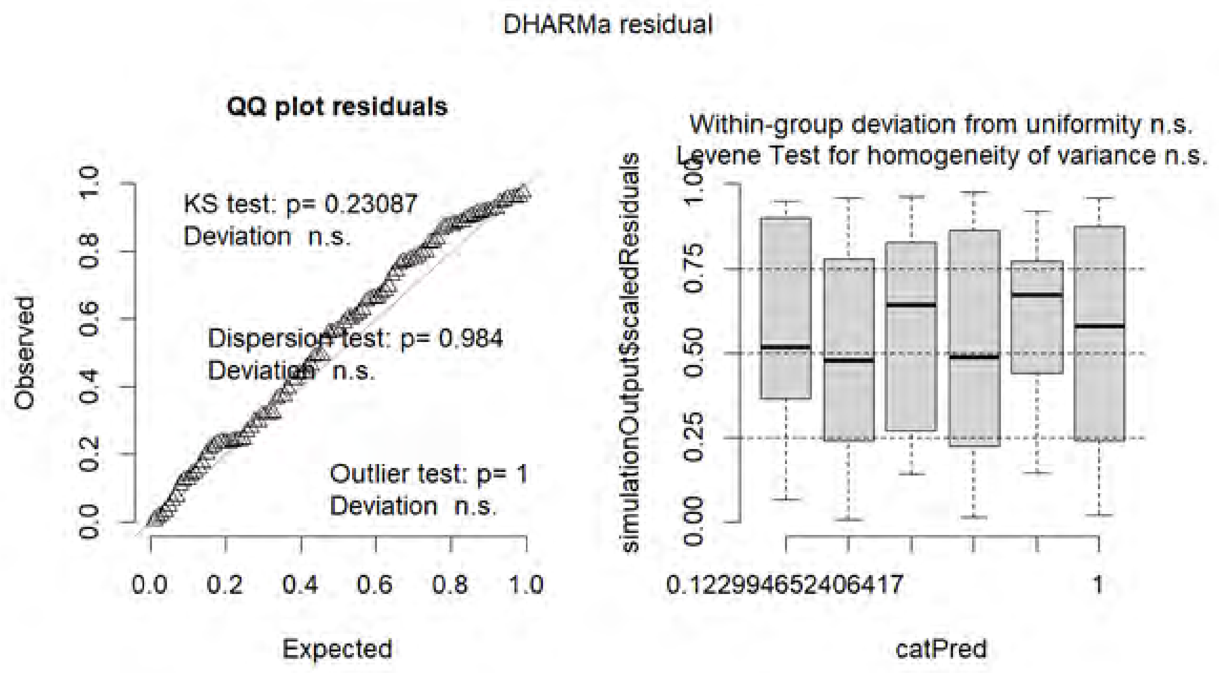
Goby



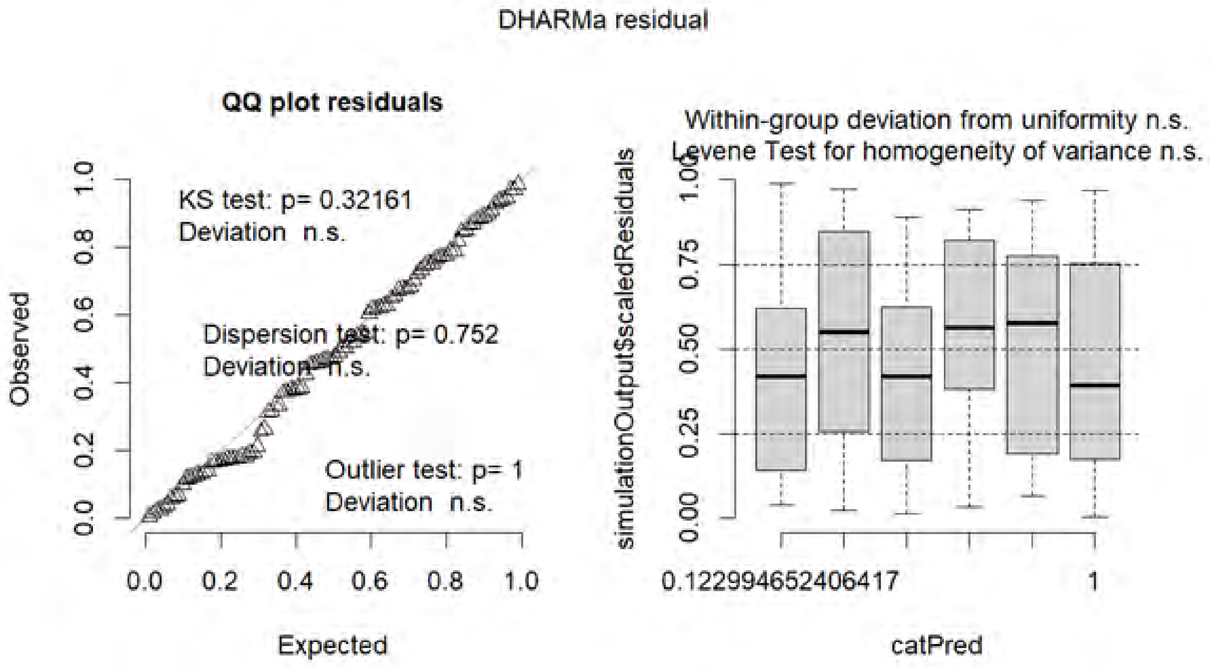
Corkwing wrasse



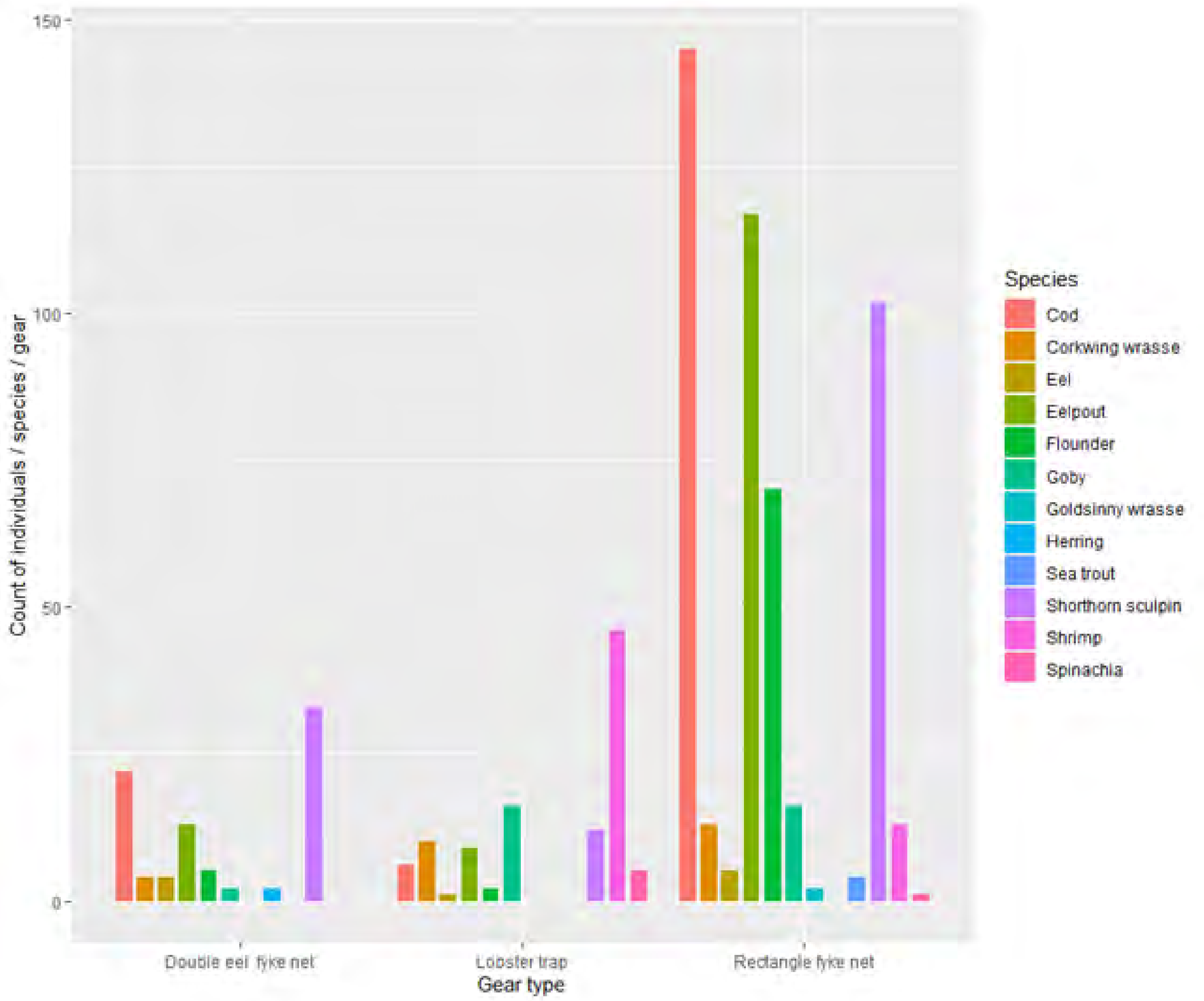
Sculpin



Flounder


DHARMa residual
QQ plot residuals
KS test: p= 0.32161
Deviation n.s.
Dispersion test: p= 0.752
Deviation n.s.
Outlier test: p= 1
Deviation n.s.
Observed
Expected
0.0
0.2
0.4
0.6
0.8
1.0
Within-group deviation from uniformity n.s.
Levene Test for homogeneity of variance n.s.
simulationOutput$scaledResiduals
0.00
0.25
0.50
0.75
1.00
0.122994652406417
1
catPred

6.3 Appendix C



6.4 Appendix D