Applying fisheries data from the Norwegian reference fleet to study the demersal biodiversity and fisheries dynamics in two coastal areas

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Abstract

It is well established that biodiversity varies throughout the year, over many years and between areas, and that biodiversity plays an important role in the overall health and resilience of an ecosystem. As fisheries management moves towards a more "holistic" view, ecosystem-based fisheries management, the accurate and up-to-date status of biodiversity will be necessary for managers and scientists. Fisheries dependent data should be used carefully for biodiversity studies because of the narrow selectivity of commercial fishing gears. However, it is worth exploring the possible uses for determining trends in biodiversity of species accessible by commercial gears. This thesis explores the temporal changes in commercially harvested or catch biodiversity between two areas using similar fishing gears over several years. The fisheries dependent data were collected from the Norwegian reference fleet. To get a comprehensive overview of a complex topic like biodiversity, many measures were used including basic species richness, evenness and diversity indices and more complex species composition analyses. Overall, no difference was found between seasons of the same fishing area and no distinct trend in biodiversity through years of the same season and fishing area was detected. All measures of biodiversity found a significant difference between the two studied areas. However, the two areas used in this study are fished by different vessels, Britt Evelyn and Tramsegg, so further research is required to determine whether the differences observed are true variations in the catch biodiversity of the ecosystems or the difference between fishermen.

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1. Introduction

1.1. Biodiversity in ecosystem-based fisheries management (EFM)

In 2008, Norway passed the Marine Resources Act which includes a provision that states that Norwegian fisheries management should be an "ecosystem approach that takes into account habitats and biodiversity" (Anon, 2010). This document builds on previous international agreements to promote Ecosystem-based Fisheries Management (EFM) (Anon, 2010). Gullestad et al. (2017), called this document a "paradigm shift" in Norwegian Fisheries management, referring to the transition from commercially driven management to EFM. EFM is a "holistic" approach to fisheries and marine management (Gullestad et al., 2017; Punt et al., 2010), which calls for the understanding of complex ecological patterns (Tolimieri, 2007; Tolimieri et al., 2016). Biodiversity has important implications for the sustainability of ecosystems acting as an indicator of ecosystem resilience (Laamanen et al., 2017) and therefore must be considered when making fisheries management decisions (Pauly et al., 2002). Ecosystems with low biodiversity are particularly vulnerable to disturbances and thus are less resilient (Worm et al., 2006). Worm et al. (2006), found that on average when biodiversity is restored, areas are four times more productive. This knowledge supports the argument that having a good understanding of the underlying trends in biodiversity is paramount to successfully shifting to EFM.

The shift to EFM is a complicated task because it involves completely re-orienting our approach to fisheries management in order to balance the needs of all stake-holders and the needs of the ecosystem. Satisfying fishermen, processors and consumers has proven to be difficult enough without adding another level of complexity. To successfully transition to EFM, we must know about influences affecting all parts of the ecosystem including environmental and biological factors (Tolimieri, 2007). Thus, understanding oceanic trends, such as biodiversity, is of vital importance. To fully understand the complexities of biodiversity and how it changes, accurate and reliable indicators are necessary (Powers, 2010). Coastal fish assemblages have been used as indicators of ecosystem health (Sreekanth et al., 2016) and are known to experience temporal fluctuations in species diversity (Wall et al., 2003).

Biodiversity is a very broad term and includes topics like richness, evenness and species composition. Diversity can be measured on almost all scales, from the global richness gradient (Hillebrand, 2004) to genetic diversity within a species (Morris et al., 2014). Because of this complexity, ample literature exists that explores the best way to measure and analyse biodiversity (Gallardo et al., 2011; Morris et al., 2014). Despite this literature, the idea and

logistics of including biodiversity indicators into a management strategy are still being developed.

1.2. Fisheries dependant data in biodiversity studies

The overwhelming consensus agrees that biodiversity should be included when making future management decisions. However, long-term diversity studies are rare and can be expensive to conduct (Magill & Sayer, 2002). Fisheries dependent data could be useful for studying catch biodiversity, the harvestable part of the ecosystem, because catch data databases have been recorded for centuries in some areas. Many of these databases are easily accessible and include comprehensive species composition data (Powers, 2010). Gordoa et al. (2006), suggests that catch data could give some information about both target and non-target species biology, behaviour and spatial and temporal distribution. However, using fisheries dependent data to study biodiversity and species dynamics is not a commonly practiced technique. Very little literature exists using fisheries dependant data to explore diversity (Branch et al., 2010; Powers, 2010).

1.2.1. Limitations and challenges

Due to the highly selective nature of fishing, catch data is not commonly used in biodiversity studies (Branch et al., 2010; Powers, 2010). However, tools for comparing biodiversity can be used on catch data assuming that a species catchability to a specific gear type does not change over the course of the study. This study will compare demersal biodiversity available to the same gear, i.e., demersal gillnets, between season, year and fishing area.

Fisheries dependent data is not a random sample of the population. The ideal commercial fishing gear would be 100% selective for both size and species. However, this gear does not exist and because of this all fisheries face by-catch of non-target species. Catches show daily or seasonal variations in presence and abundance of certain species. These variations may be able to shed some light on the underlying trends of the ecosystem (Paighambari & Eighani, 2018).

Many factors affect catch composition; i.e. gear selectivity, gear placement, time of day or year, soak time, etc. For this study, when possible, factors such as gear type and time of year were handled separately. Other factors, like soak time, were consistent between gear types and

gear placement. The remaining factors, such as gear selectivity and catchability, are assumed constant throughout the study period.

1.3. Norwegian reference fleet (RF)

The data analysed in this study was collected by two vessels from the Norwegian Coastal Reference Fleet (CRF), fishing in two different coastal areas. The Norwegian Reference Fleet (RF) is an initiative started by the Norwegian Institute of Marine Research (IMR) in collaboration with Norwegian fisherman for the purpose of providing IMR with fishing activity and catch data as well as biological samples (length, otoliths, genetic samples, etc.). The RF has been described as "an arena where stakeholders (fishers) are invited to participate in knowledge production for fisheries management in cooperation with scientists" (Bjørkan, 2011). The RF is made up of two sectors; the high seas fleet and the coastal fleet (CRF). The high seas fleet (established 2000) is comprised of larger vessels that fish with longline, purse seine, trawl and gillnets. It includes vessels ranging from 30 – 80m that were not used in this study. The coastal reference fleet (established 2005) is comprised of 23 smaller vessels (as of 2018) ranging from 9-15m. These vessels primarily fish with gillnets and operate closer to shore. The CRF primarily targets demersal fishes with gillnets.

The vessels that comprise the RF are selected from thousands of commercial fishing vessels from all along the Norwegian coastline (Appendix 1). The Norwegian coastline is broken up into nine statistical regions that IMR use to conduct research along the coast. It is IMR's goal to have a minimum of two vessels per statistical region. Before vessels can join the reference fleet, they must apply and be selected. They are selected based on gear type, fishing pattern and location, as well as demonstrated interest in the program and ability to adhere to protocols. Once selected, the crews undergo training of proper sampling techniques and data collection protocols. The data collected by the fleet is self-sampled data from their catch and are provided to IMR to be used in fish and shellfish stock research and management. The sampling protocols used by the RF are similar to those used on IMR's research vessels to conduct surveys.

1.4. Seasonal variation in biodiversity

Seasonal changes in biodiversity have been studied extensively all over the world (e.g., Barletta et al., 2003 (Brazil); Claridge et al., 1986 (England); Iglesias, 1981 (Spain); Jin & Tang, 1996 (China); Magill & Sayer, 2002 (Scotland); Quinn, 1980 (Australia); Ribeiro et al.,

2006 (Portugal)). Most of these studies found that biodiversity is lower in autumn and winter and higher in spring and summer, with few exceptions.

Many reasons for this trend have been suggested including the Ambient Energy and Productivity hypotheses. The Ambient Energy hypothesis suggests that the short day-light and less energy available in the winter months could explain why lower biodiversity is observed (Willig et al., 2003). This hypothesis uses temperature as an indicator for energy available in the system (Willig et al., 2003). The Productivity hypothesis corresponds with the Ambient Energy hypothesis suggesting that lower energy will correlate with lower productivity and, thus, lower biodiversity (Wall et al., 2003; Ware & Thomson, 2005; Willig et al., 2003). This is supported by the global trends observing more diversity in the tropics and less near the poles (Worm et al., 2006).

On a local scale, it is well understood that the interspecies interactions that occur in the ocean are complex and can vary through space and time (Reum & Essington, 2011). The interactions between species have been shown to vary seasonally (Reum & Essington, 2008, 2011). During the summer in Puget Sound, the diets of many fish guilds (groups of species with similar ecosystem niches) converge (Reum & Essington, 2008). In the winter when the system is less productive, the fish guilds became more specialized predators with less similar diets (Reum & Essington, 2008). This was also observed in cod (*Gadus morhua*) along the Norwegian Skagerrak coast (Hop et al., 1992). This variation may be due to changes in habitat through the year (Gordoa et al., 2006; Reum & Essington, 2011) and may have a large effect on catchability and, therefore, catch data.

1.5. Trends in biodiversity through time

On an evolutionary scale, there has been an overall trend of increasing biodiversity through time, as more and more species evolve and speciate from one another (Allen & Gillooly, 2006). However, since the start of the industrial age, the trend has shifted. We are now seeing a rapid decrease in biodiversity (Greenstreet & Rogers, 2006; Worm et al., 2006). Biodiversity is being lost at all scales and it has been concluded that loss of biodiversity at any scale can lead to changes in ecosystem function (Pasari et al., 2013). Along the coast of Norway both the demersal and pelagic zones decreased in biodiversity between 1990 and 2010 (Nybø et al., 2012). However, Elahi et al. (2015), argued that change in biodiversity on a local scale is more nuanced, depending on human impact as well as local extinction and introduction.

Species introductions to an area occur in multiple ways. They can be introduced through human interference either intentionally like the Nile perch in Lake Victoria (Anderson, 1961), or accidentally like the goose barnacle in Norway (Hopkins, 2002). Species can also be introduced through changing distributions due to a changing environment (Cormon et al., 2014). On a global scale, we are seeing shifts is fish stock distributions (Cheung et al., 2013; Poloczanska et al., 2013). As waters warm, temperate species are moving further towards the poles (Poloczanska et al., 2013). On the coast of Norway, it has been observed that European hake (*Merluccius merluccius*) have been slowly moving further north (Cormon et al., 2014; Cormon et al., 2016). This is predicted to affect the overall ecosystem function because hake is a very efficient predator and will compete with previously dominant species (Cormon et al., 2016). This is an example of introduction driven by changing climate as hake distribution has been linked with sea surface temperatures (Cormon et al., 2014). Due to the nuanced nature of shifting trends in biodiversity, it can difficult to predict whether the local biodiversity with increase, decrease or remain the same through time (Elahi et al., 2015).

1.6. Biodiversity measures

Laamanen et al. (2017) defines biodiversity as the amount of variation between living organisms in a system. Biodiversity is a comparative measure that is comprised of two main factors, species richness and species evenness (Gallardo et al., 2011; Holt et al., 2012; Peet, 1974). Species richness is the total number of species collected in a single sampling event (day fished) (Holt et al., 2012; Peet, 1974). This is the most common and "iconic" index used in the measurement of biodiversity (Deng et al., 2015; Gotelli & Colwell, 2001; Holt et al., 2012; Morris et al., 2014). A common tool used to compare species richness is the species accumulation curve. This predicts the estimated number of species using the survey size, e.g., number of individuals sampled or number of samples (Deng et al., 2015). Species accumulation curves are commonly applied to ecological studies (Gotelli & Colwell, 2001). This is because they can be used to compare biodiversity across populations. For example, to compare two areas, one would collect individuals from both areas, but may be unable to collect the same number of individuals from both areas. In this case, a species accumulation or rarefaction curve can be used in order to compare the two areas.

Species evenness can be described many ways. It has been discussed as the measure of the probability of two individuals selected at random belonging to the same species (Holt et al., 2012; Peet, 1974) and the measure of the distribution of individuals between the different taxa

in a sample (Laamanen et al., 2017). Evenness can vary when the richness is the same. For example, in a catch with ten individuals and five different species. If the catch is made up of two individuals of each species, then the sample would be very even. However, if the catch is made up of five individuals of one species and two individuals of another species and then three individuals of three different species, then the sample is much less even. In both cases the species richness is five, but the evenness of the communities differs. In nature, the communities are generally more closely represented by the second example with a few dominant species and then many rare species.

1.6.1. Species accumulation and rarefaction curves

Due to the underlying uneven species composition, the amount of effort put into collecting individuals matters. Walking through the woods for 10 minutes will result in fewer observed tree species than an hour long walk in the same area. However, there is a limit to the amount of time, number of samples or number of individuals collected that will result in new species discoveries. This is reflected in the rarefaction curve (Figure 1).

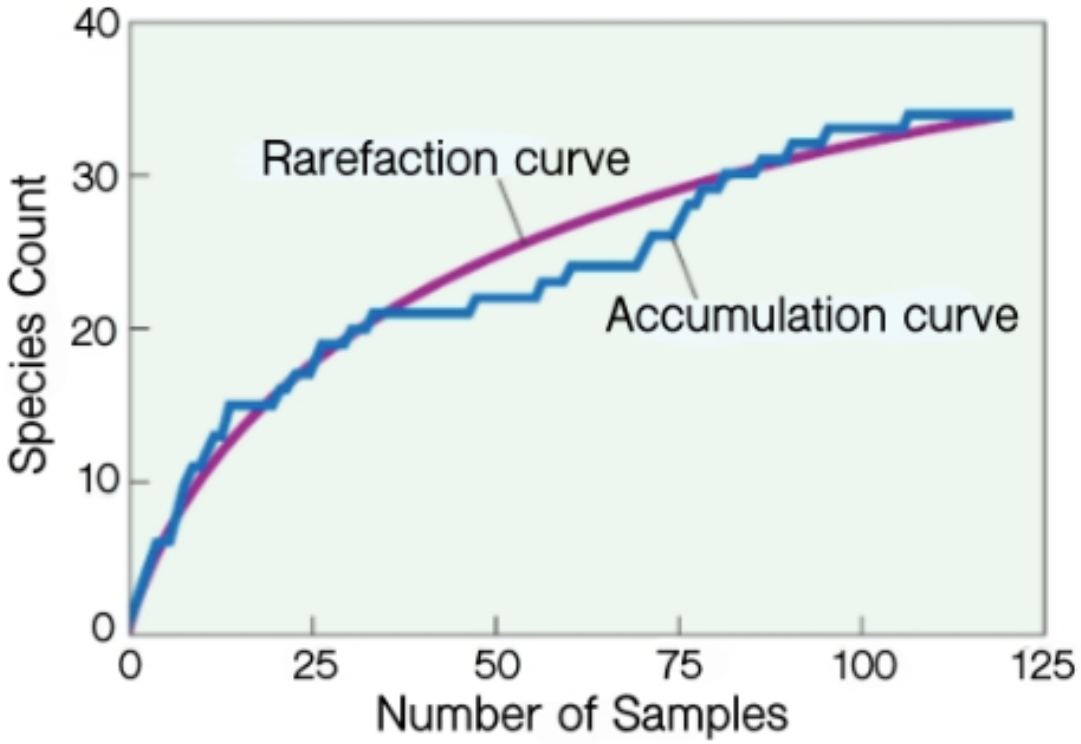

Figure 1. Species accumulation and rarefaction curves (Smith & Smith, 2015).

A rarefaction curve is built from species accumulation information (Tipper, 1979). The number of species per number of individuals or samples can vary based on the order that the

individuals are collected, so an average of all possible collection orders is used as the rarefaction curve. Figure 1 shows a species accumulation and rarefaction curve which plots the number of species as a function of the number of samples. In this case, number of samples could also be number of individuals. Note that the number of species increases with the number of samples and then the line tapers off towards an asymptote as the species become increasingly rare. The maximum number of species in an area is the true species richness. This is usually an unknown number although, if enough individuals are collected this number will be reached. Due to the cost and logistical difficulties of attaining true species richness, diversity is more often used as a comparative tool. It is more realistic to determine the species richness when the same number of individuals or samples are collected.

Although richness and evenness are generally seen as two different biodiversity measures, they are closely related and, because of this, many diversity indices incorporate both (Holt et al., 2012). The two diversity indices used in this study are Shannon-Weiner's (Shannon's) diversity index and Simpson's diversity index. Each index calculates a single diversity value for each day which can be used to compare biodiversity between different times and locations.

1.6.2. Species composition measurement tools

Biodiversity can also be studied by comparing the species composition. Species composition describes the quantity of each species in a sample. This can be done using analysis of similarities (ANOSIM) and permutational multivariate analysis of variance (ADONIS). These tests compare the species composition between different groups (seasons, years, fishing areas) (Birks et al., 2012), and are often paired with similarity of percentages (SIMPER). SIMPER is used to break down which species are responsible for the variation between the groups (Clarke, 1993). This technique is often performed to determine the "important taxa", meaning those taxa that contribute to the variation between the groups (Clarke, 1993). All of these techniques are commonly used in marine community ecology.

Biodiversity is so complex and has been a topic of interest for scientists for so long that many tools have been created to measure it. In this analysis, those tools have been narrowed down to just seven, each focusing on a slightly different aspect of biodiversity. Estimated species richness, calculated from rarefaction curves, gives an estimate of the total number of species in an area and the number of individuals one needs to collect to reach that number. Evenness assigns a value to the compositional distribution within a sample. Shannon's and Simpson's diversity indices combine richness and evenness with one focusing on rare species

(Shannon's) and the other focusing of more common species (Simpson's) (Morris et al., 2014). These four diversity measures give a single value for each day to describe all the complexity of diversity. However, this is a bit reductive. ANOSIM and ADONIS can determine if the samples have the same or different species compositions and SIMPER can show which species are contributing to the differences observed between samples. There are many more tools for measuring and comparing biodiversity that could have also been used, however, I felt these were the most appropriate given the type of data available and questions asked.

1.7. Aim of the study

The aim of this study was to use fisheries dependent data from the CRF to identify if harvestable species biodiversity varies seasonally in two Norwegian coastal fjords and if those variations are the same each year and between areas. This study will test the following null hypotheses:

(1) There is no difference between the catch diversity between seasons in the same fishing area.
(2) There is no difference between catch diversity between years of the same season in the same fishing area.
(3) There is no difference between the catch diversity between the two fishing areas.

2. Materials and Methods

2.1. Data collection

The data was collected using the protocol outlined by the Institute of Marine Research (IMR) (Mjanger et al., 2019). The sampling techniques used by the CRF are similar to those used by IMR on research surveys. The two boats selected for this study, Tramsegg and Britt Evelyn, were chosen due to their geographical separation, experience and diligence in the sampling and reporting. This time series of catch data is suitable for monitoring changes in biodiversity because it covers specific areas during a specific time period.

2.1.1. Vessel and fishing area

Data was collected from two vessels with relatively limited ranges of operation. These small coastal vessels frequently fish in the same places year after year (Powers, 2010) (Table 1).

Table 1. Norwegian Coastal Reference Fleet vessel and data collection specifications (Appendix 2 & 3).

Vessel/Statistical Region	**Years**	**Location**	**Vessel length (m)**	**Latitude**	**Longitude**	**Km^2**
Tramsegg 07/07	2010-2017	Hustadvika - Outside	13	62.933-63.260	6.979-7.882	1656
Tramsegg 07/30	2010-2017	Hustadvika - Inside	13	62.031-63.031	7.33-7.947	3552
Tramsegg	2010-2017	Hustadvika	13	62.031-63.260	6.632-7.947	9453
Britt Evelyn	2012-2017	Bjørnafjorden	9.3	59.976-60.248	5.284-5.7411	750

The time series for Tramsegg was initially separated into two areas based on Norwegian statistical regions. Statistical region 07/07 covers an area made up of mostly open ocean with a small portion including some outer coastal fjord areas. Statistical region 07/30 is further inland and covers an area of almost exclusively coastal fjords (Appendix 3).

2.1.2. Gear type

Many gear types were used by the vessels including gillnets, purse seine and pots. The gears used in this analysis are exclusively demersal gillnets (Table 2). Gear codes are used to categorize the equipment used by the fleet (Table 2) (Mjanger et al., 2019). Both vessels and statistical regions use multiple mesh sizes. Five gear types in total were used in this study (4139, 4140, 4141, 4142 and 4149). Gear type 4139 is not described by IMR but includes mesh sizes between 60 and 69mm (gear code 4115 and 4126) (Appendix 4). The others (4140, 4141, 4142 and 4149) are as described in the handbook (Appendix 4) (Mjanger et al., 2019). It is assumed that gillnet selectivity and catchability are constant between stations of the same gear type. A total of 160,419 gillnets were used over the course of the 2,019 days analysed. An average of 79 gillnets and a median of 81 gillnets were deployed each day. Because the mean and median are so similar, a summary of the data is presented as days fished with each gear type (Table 2).

Table 2. Demersal gillnet gear code descriptions (Mjanger et al., 2019), total number of days fished, and number of days fished per year for each vessel and statistical region. Bar-length defined as the measured distance between knots of open, square meshes.

Gear	**Mesh size (mm)**	**BRITT EVELYN (2012 - 2017)**		**Tramsegg Both regions (2010 – 2017)**		**TRAMSEGG 07-30 (2010 - 2017)**		**TRAMSEGG 07-07 (2010 – 2017)**	
		Total Days Fished	Days/Yr	Total Days Fished	Days/Yr	Total Days Fished	Days/Yr	Total Days Fished	Days/Yr
4139	60-69 mm bar-length	-	-	832	104	327	40.9	505	63.1
4140	70-79 mm bar-length	475	79.2	273	34.1	109	13.6	164	20.5
4141	80-89 mm bar-length	12	2	77	9.6	3	0.4	74	9.2
4142	90-99 mm bar-length	-	-	21	2.6	1	0.1	20	2.5
4149	180 mm bar-length	145	24.2	184	23	9	1.1	175	22.9
Total		**632**	**105.3**	**1387**	**173.4**	**449**	**56.1**	**938**	**117.2**

2.2. Data handling and analyses

Fauna caught and reported was identified to genus and species level when possible and reported using Aphia ID codes (Appendix 5). The species that were not demersal dwelling were removed from the analysis. This included birds (sea gulls), mammals (porpoise) and pelagic fish species (herring, mackerel, etc.). Individuals that were identified to order or family but caught less than twice a year were also removed. The data was checked, and poor-quality data was removed (Appendix 6). This includes stations that reported severely damaged gillnets (gear condition under 3) (Appendix 7).

The data was sorted into Britt Evelyn, Tramsegg all data, Tramsegg 07/07 and Tramsegg 07/30. These were treated as four separate datasets. The total number of individuals for each species was calculated for each day. This was converted to catch per unit effort (CPUE), where the effort unit is number of gillnets deployed for that day. Catch per day was used as the sampling unit because the fisherman reported count or catch weight by species each day and did not distinguish which fish was caught in each specific gillnet chain.

To classify and determine the effects of seasonality on the catch composition, the months were divided into four quarters: Winter (Jan-Mar), Spring (Apr-Jun), Summer (Jul-Sep), Autumn (Oct-Dec). Though using seasons shifted one month earlier would have better described the seasonal traits found in nature on these latitudes (i.e. day length, temperature, etc), quarters were chosen because IMR uses breaks at quarters when analysing fisheries data.

All data handling and analysis was performed in Rstudio using R version 3.5.1. The packages used include base R, Tidyverse, lubridate, reshape2, broom, vegan and rareNMtests (Cayuela & Gotelli, 2014; Grolemund & Wickham, 2015; Wickham, 2017; Oksanen et al., 2018; Robinson & Hayes, 2018; R Core Team, 2018; Wickham, 2015).

2.3. Length measurements

Vessels in the CRF collected length measurements of all species. These vessels used six different measurement strategies for taking length measurements of fish used in this study. An international standard measurement technique was used for each species. A figure showing the total list of techniques used can be found in the appendix (Appendix 8) (Mjanger et al., 2019). Fauna was recorded in two ways, as either landed (group code = 26) or as discards (group code = 23). Landed fish were reported in total catch weight per species (kilograms) and discarded fish were reported as number of individuals. Before any analysis could be performed all data was converted to number of individuals by species. For species reported in total catch weight,

individual length samples were taken at regular intervals. Generally once a week, vessels measured up to 20 individuals for each species collected. In catches with few individuals then more than one sample are measured per week.

2.4. Length weight parameters

In order to convert reported species catch weights to catch numbers, length-weight parameters for each landed species were calculated using data sampled by IMR, the same data used in stock assessments. This includes data from both the RF and research surveys. The equation used for estimating the weight of a fish based on the length is:

Equation 1. Length-Weight Conversion. $w_i = a \times L_i^b$

Where w_i is the weight of the individual, L_i is the individual length measurement. The species scaling constant is (a) and (b) is the shape parameter based on the body form of the fish species (Brodziak, 2012). The value of (b) is often close to three because the volume of a 3-dimensional object is roughly $V = L^3$ (Brodziak, 2012). In reality, this number will vary based on fish shape and even may vary within a species based on area (Gerritsen & McGrath, 2007). Length and weight were converted into centimeters and grams. The logarithm of the length and weight were plotted against each other for each species (Figure 2).

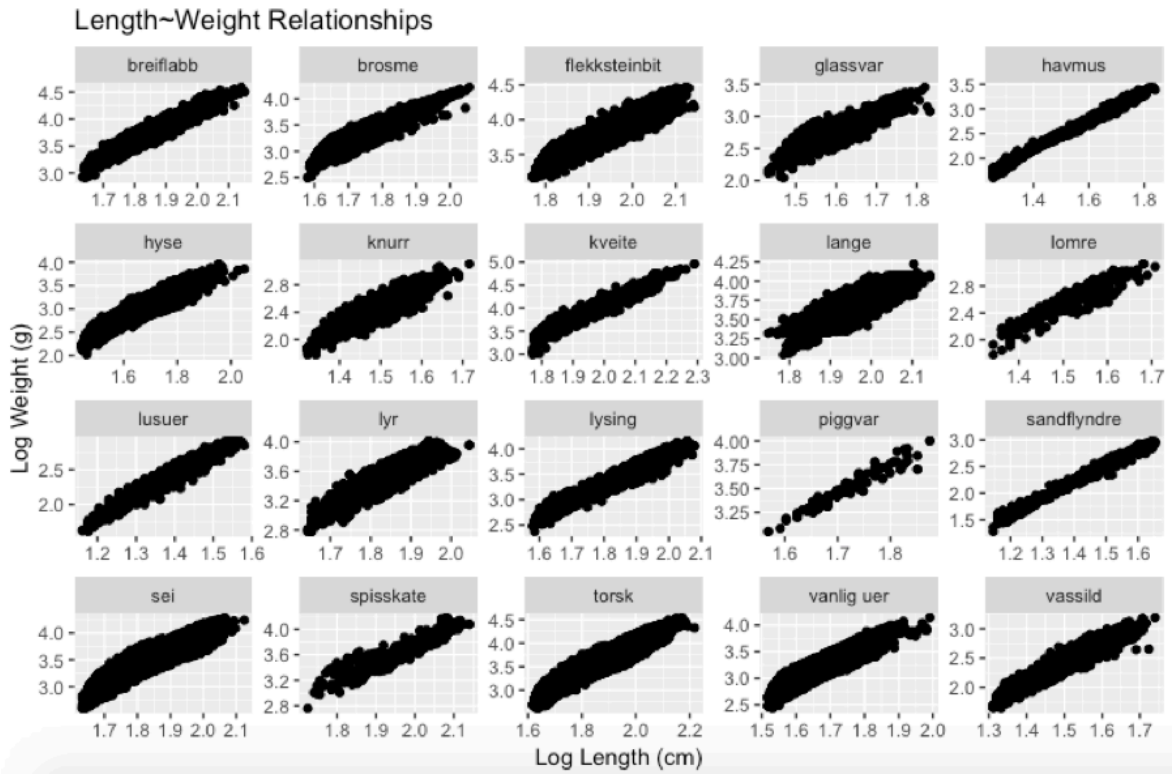

Figure 2. Log length and log weight of individuals sampled by the Norwegian Institute of Marine Research and used in stock assessments when performed.

A linear regression is performed on the logarithm length – logarithm weight plots. The slope of this line is (b) and the intercept is the antilog of (a). A list of the (a) and (b) values used can be found in the appendix (Appendix 9).

To get the most accurate length-weight parameters for each area, the parameters were calculated for samples taken from gillnets north of 62°, gillnets south of 62°, all gillnets and all gear types, respectively. Samples with too few data points ($n < 100$) or a low R^2 ($R^2 < 0.8$) were removed. For Tramsegg, gillnets north of 62° were optimal, and if data for this were not applicable, then data from all gillnets irrespective of area were used, and if all else did not meet the standards then data from all gear types and all locations were used. For Britt Evelyn, the same was true except that using gillnet values from south of 62° had priority. This ensured that the samples chosen to measure the length-weight relationship for each species in each location came from the closest sample set.

For *Chimaera monstrosa*, the samples taken from the total reference fleet data were excluded because of possible sampling error that lead to error in the data set. These fish can be difficult to measure because they use non-typical measurements techniques. *Chimaera monstrosa* is recommended to be measured from the snout to the end of the first dorsal fin

(Mjanger et al., 2019). Due to the errors in sampling from the RF, only data from IMR survey cruises were used to calculate the length-weight parameters for this fish.

For *Scophthalmus maximus*, possible misidentification led to noisy data. This flatfish can be mistaken for other species found in the same area. The stations with individuals of suspected mistaken identity were removed.

The calculated length-weight parameters were used to determine the number of individuals in the given species catch weight reported by the fishing vessels, Britt Evelyn and Tramsegg (Equation 2).

Equation 2. Number of individuals from weight conversion. $$N = \frac{W_t}{\text{mean}(w_i)}$$

where W_t is the total catch weight per species and N is the number of individuals of that species. Individual weight (w_i) is calculated using the length-weight relationship equation (equation 1) from the length measurements taken regularly on board the vessels. Though the fisherman did not measure each fish in the catch, they regularly sampled and reported lengths of all species (20 fish per week). Assuming that individuals of the same species were similar in size to those caught around the same time, the mean individual weights were coalesced in order: (1) year, month, vessel, species; (2) year, quarter, vessel, species; (3) month, vessel, species; (4) quarter, vessel, species; (5) year, vessel, species; (6) vessel, species; (7) just species. This allowed for individuals closely related in both time and space to be given more similar individual weights allowing for more accurate number of individuals to be calculated.

2.5. Species richness

Rarefaction curves were used to estimate the richness in the fishing areas based on the number of individuals and the number of species represented in the area samples. In the case of the anglerfish gillnets (gear type 4149) the comparison was taken a step further. To be able to comment on the cause of the drastic discrepancy found in the number of individuals collected, the number of individuals and the number of gillnets per day were plotted. A generalized linear model with Poisson family distribution was performed comparing number of gillnets to number of individuals for both vessels. For the range where the effort overlapped, 40 – 120 gillnets, the total CPUE was calculated. The total CPUE was defined as total number of individuals of all species divided by the number of gillnets deployed for each day. These values were plotted, and a t-test was used to verify if the difference between Tramsegg and Britt Evelyn was

statistically significant. These two figures were used to identify the cause of the discrepancy between the number of individuals reported.

To be able to compare richness between seasons, years and fishing areas, the number of species reported each day were plotted against the number of individuals reported each day using individual-based rarefaction curves. To statistically compare estimated species richness the curves were compared using the "biogTest.individual" function found in the "rareNMtests" package in R (Cayuela & Gotelli, 2014) (Table 3). The biogeographical null hypothesis, H_0, which states that there is no difference between two (or more) samples comprised of abundance data. It suggests that samples drawn randomly from different assemblages will still share similar species richness and species abundance distributions (Cayuela et al., 2015).

The "biogTest.individual" function uses a calculated test statistic, *Zobs (Z observed)*. If the *Zobs* is small than the curves can be considered similar, regardless of their species composition. In this case, the sampling events accumulate species at the same rate, but it does not matter what those species are. For this study, 200 random starts were used to create a *Zsim (Z similulated)* that was compared with *Zobs* to give P-values (Cayuela et al., 2015). If *Zobs* falls within the 5% tails of the *Zsim* bell curve than the two or more rarefaction curves being compared are considered significantly different. The "biogTest.individual" function is a randomization test that is used to statistically compare whether two or more samples are different (Cayuela et al., 2015).

2.6. Species evenness

In this study, species evenness is calculated using the Evenness index (E). This index ranges from zero to one, where zero indicates there is only one species found in the sample and a score of one indicates that there is the same number of individuals for each species present (Mulder et al., 2004). Evenness can be calculated using the following equation (Equation 3):

Equation 3. Evenness Index. $$E = \frac{H'}{\ln(S)}$$

Where H' is Shannon's diversity index (discussed below) and S is the total number of species present in the sample. For each day of fishing for each vessel, evenness was calculated. Evenness was compared using an ANOVA between seasons, years and fishing areas (Table 3).

2.7. Shannon's and Simpson's diversity indices

Shannon's diversity index (H') (Shannon, 1948) is a commonly used index that weighs more towards richness and rare species (Morris et al., 2014). High H' values represent more diverse communities (Equation 4).

Equation 4. Shannon's Diversity Index. $H' = \sum_{i=1}^{S}(pi)(ln\, pi)$

This index uses the proportion of individuals (p_i) of a specific species (i) and the total number of species (s) to measure ecosystem richness and evenness (Jin & Tang, 1996; Morris et al., 2014).

Simpson's diversity index (D) (Simpson, 1949) increases with species richness (Gamito, 2010). However, it can be sensitive to sample size because it uses absolute numbers instead of proportions like Shannon's diversity index (Gamito, 2010). Simpson's diversity index puts more emphasis on evenness and common species (Morris et al., 2014). Simpson's diversity index uses both number of species (n) and number of individuals (N) to measure the diversity of an ecosystem (Equation 5) (Gamito, 2010; Jin & Tang, 1996).

Equation 5. Simpson's Diversity Index. $D = \frac{n-1}{lnN}$

Both Shannon's and Simpson's indices assume that all species of a community are represented and that they are randomly sampled (Gamito, 2010; Peet, 1974). For this study, the community is defined as all species potentially captured by the commercial demersal gillnets. It is assumed that the sampling is consistent, meaning that there is a constant chance for non-target species to be caught.

Shannon's and Simpson's diversity indices were calculated using the "vegan" package in R (Oksanen et al., 2018). The calculations were performed on the calculated CPUE matrix (Table 3). This produced a daily diversity value. An ANOVA was performed on these values to determine which seasons and years were significantly different. Where the ANOVA was significant, a Tukey's Post-hoc test was performed to determine which comparisons were significant.

2.8. Species Composition

Three strategies were used to compare the species composition; ANOSIM, ADONIS and SIMPER. All were performed using the "vegan" package in R (Oksanen et al., 2018) (Table 3).

An analysis of similarities (ANOSIM) was used to compare seasons and years by catch composition using percent abundance. ANOSIM uses a distance matrix to test the statistical significance between species assemblages between pre-determined partitions (i.e. seasons, years or fishing areas) (Birks et al., 2012).The number of permutations applied was 999. This was performed on the CPUE matrix for each dataset. Here, CPUE is defined as the daily number of individuals per number of gillnets for each species. It is recommended to use permutational multivariate analysis of variance (ADONIS) instead of ANOSIM because Warton et al. (2012) found that the function "anosim()" in R can convolute the within group and between group differences. The function "adonis2()" which could be used with this type of data tends to be more robust towards these issues. Both functions, "anosim()" and "adonis2()", were used to determine the statistical significance between the species composition of either seasons, years of the same season and fishing areas. Both used a Bray-Curtis distance matrix (Section 4.9) calculated from CPUE matrix.

A similarities of percentages (SIMPER) test was used to determine which species contributed to the dissimilarity between catch compositions. For each species present SIMPER returns the percent contribution to the average dissimilarity between the groups (Birks, 2012). SIMPER is often used in marine ecology to identify the "important taxa" contributing to the dissimilarity between samples. The test breaks down each pairwise comparison and gives a list in decreasing order of each species percent contribution to the dissimilarity between two groups (Clarke, 1993). This was used to compare dissimilarity of species composition between seasons, years of the same season and fishing areas.

2.9. Bray-Curtis distance

The Bray-Curtis distance was used in all species composition analysis tools, ANOSIM, ADONIS and SIMPER. The Bray-Curtis distance (Equation 6) is a dissimilarity measure that uses the Manhattan or city block distance (Bray & Curtis, 1957; Upton & Cook, 2007) to measure the distance between two points in multi-dimensional space. It is commonly used for measuring the distance between species data. The Bray-Curtis distance is calculated as follows:

Equation 6. Bray Curtis Distance (Warton et al., 2012). $d_{ij} = \frac{\sum_{k=1}^{p} | y_{ik} - y_{jk} |}{\sum_{k=1}^{p} (y_{ik} + y_{jk})}$

where d_{ij} is the Bray-Curtis distance between sites i and j (days fished). k is the species and y is the number of individuals or CPUE for the k species. The Bray-Curtis distance is used as the dissimilarity measure between to the two sites (days fished), i.e., the Manhattan distance between the two sites in kth dimensional space (Bray & Curtis, 1957).

The Bray-Curtis distance is a number between zero and one, where zero indicates that the two measured points have the same species composition (Upton & Cook, 2007). A measure close to one indicates that there is no similarity between the two points (Clarke, 1993). A Bray-Curtis distance was chosen for the species composition analyses because it was commonly used in related literature (Amezcua & Amezcua-Linares, 2014; Clarke, 1993; Henderson et al., 2007; Paighambari & Eighani, 2018) and is well designed for species abundance data.

Table 3. Overview of methods used to test for differences in biodiversity between seasons of the same fishing area, between years of the same season and fishing area and between fishing areas. (Vegan - (Oksanen et al., 2018); rareNMtests - (Cayuela & Gotelli, 2014); baseR – (R Core Team, 2018)).

Measure of Biodiversity	**Methods of comparing seasons, years and vessels**	**Data Type**	**Statistical Test**	**R packages and functions**
Richness	Individual-based species accumulation curves	Number of individuals	Biogeographical null model tests for comparing rarefaction curves.	Vegan::specaccum rareNMtests::biogTest.individual
Evenness	Evenness index	CPUE	ANOVA	baseR
Diversity Index	Shannon's and Simpson's diversity indices	CPUE	ANOVA	baseR
Species Composition Similarity	Analysis of Similarities	Bray-Curtis distance matrix calculated from daily CPUE	ANOSIM	Vegan::anosim
	Permutational Multivariate Analysis of Variance using distance matrix		ADONIS	Vegan::adonis2
	Similarity of percentages		SIMPER	Vegan::simper

2.10. Bonferroni correction

Due to the large number of statistical tests being performed for each analytical tool used to compare biodiversity, the possibility of Type 1 errors occurring is high. A Type 1 error occurs when a true null hypothesis is rejected (Banerjee et al., 2009). To avoid this type of statistical error the Bonferroni correction was used. For the seasonal comparison, the alpha (originally set at 0.05) was adjusted by the number of vessels and statistical regions (n = 4). For the comparison between years of the same season, the alpha was adjusted using the Bonferroni correction for the vessels and seasons (n = 16). The equation for the Bonferroni correction is:

Equation 7. Bonferroni correction (Salkind, 2007). $\alpha = \frac{a_i}{n}$

Where α is the Bonferroni corrected alpha. The initial alpha (a_i) was originally 0.05 and (n) is the number of tests. The Bonferroni corrected alphas are 0.01 for the comparisons of biodiversity between season and 0.003 for the comparison of biodiversity between years of the same season.

3. Results

A total of 330,578 demersal individuals were collected during the years of the study period (Tramsegg: 2010-2017, Britt Evelyn: 2012-2017). This was comprised of 65 species from 39 families, including fish, molluscs and crustaceans (Appendix 5). Of the five gear types used, Tramsegg fished most often with gear type 4139 and Britt Evelyn fished most often with gear type 4140, but both vessels overlapped considerably for 4140 and 4149. Both vessels fished all seasons; however, Britt Evelyn fishes mostly pots in the summer and so has far fewer days fished with demersal gillnet gear types in July, August and September. Britt Evelyn fishes with only three of the five gear types used in this study (4140, 4141 and 4149) while Tramsegg used all five gears.

Initially, Tramsegg data was divided into two statistical regions, Tramsegg 07/07 and Tramsegg 07/30. These were compared using many different tests but were not found to be significantly different from each other. They were then combined for comparison against Britt Evelyn (Table 4). The figure comparing Tramsegg 07/07 and Tramsegg 07/30 can be found in the appendix (Appendix 10).

3.1. Species richness

Of the 65 total species reported, Tramsegg reported 50 species while Britt Evelyn reported 57, with 65% overlap between the two vessels. Species specific to Tramsegg account for 10% of the total species while species specific to Britt Evelyn account for 21%.

3.1.1. Rarefaction curves

The rarefaction curves were used to compare expected richness between seasons and in general show the expected trend, an increasing curve that approaches an asymptote near the maximum richness. Due to the data available the plots vary wildly in the number of individuals per year (ind/yr) collected for each season, vessel and gear type (Figure 3).

The number of individuals collected by each gear varies between each vessel and season. By far the largest number of individuals were collected by Tramsegg in the summer using demersal gillnets with a mesh size of 60-69mm (gear type 4139). During the eight years of data collected, Tramsegg reported over 7,500 ind/yr in the summer months alone (> 60,000 individuals over the course of the study). In comparison the largest number of reported individuals from Britt Evelyn was only 6,000 ind/yr, less than half the total number (~30,000)

of individuals over the six years of data collected and comes mainly from data in the spring using gillnets with mesh size 70-79mm (gear type 4140) (Figure 3).

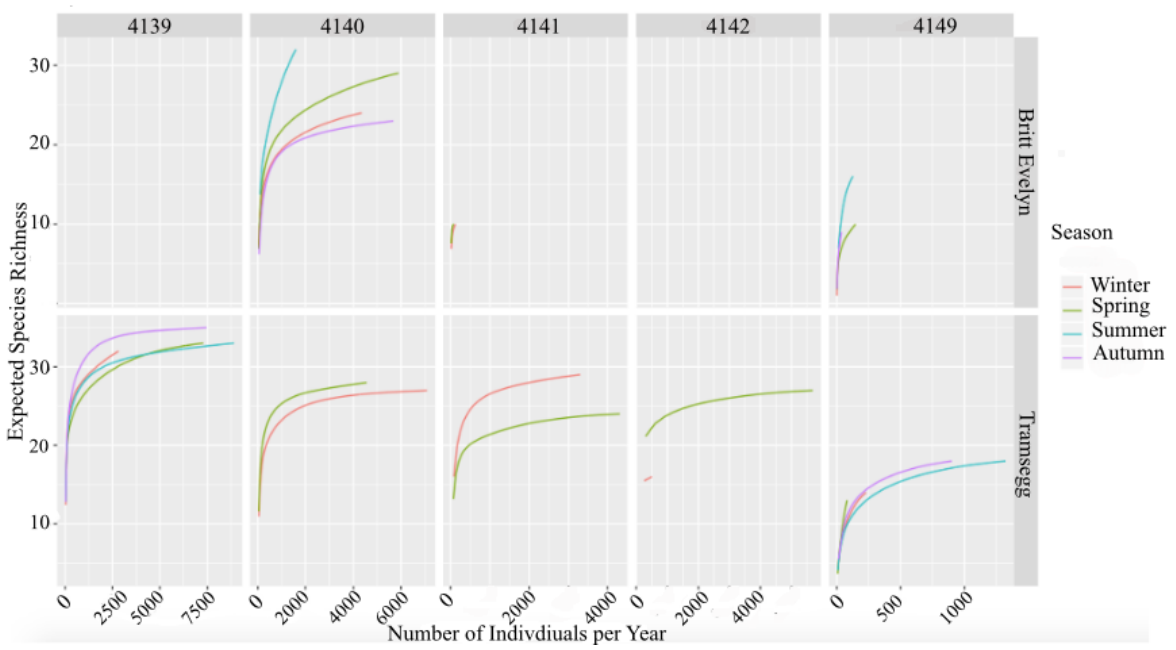

Figure 3. Species accumulation curves comparing season for each vessel and gear type (4139 – demersal gillnets with mesh size 60-69mm, 4140 – mesh size 70-79mm, 4141 – mesh size 80 – 89mm, 4142 – mesh size 90 – 99, 4149 mesh size 180mm) based on the daily catch profiles and the number of individuals caught per year.

Overall, there was no obvious trend found in Figure 3. Summer was only found to have higher predicted richness in Britt Evelyn's data while the peak season for expected richness varied by gear type for Tramsegg's data. Gear type 4139, the dominant gear type used for targeting saithe by Tramsegg had very similar season curves (range ≈ 2 species) with more individuals collected while the dominant saithe gear type used by Britt Evelyn, gear type 4140, had a much wider range (≈ 10 species) with fewer individuals collected.

The anglerfish gillnets, gear type 4149, show the lowest richness for all the gears (~18 species). Britt Evelyn reported far fewer individuals (200/yr) compared to Tramsegg (>1000/yr). Due to Britt Evelyn reporting so few individuals, the true richness trends are impossible to conclude. However, Tramsegg reported a sufficient number of individuals in both the summer and autumn in order to reach an asymptote. Both seasons show a very similar curve with autumn just slightly greater (one species) than summer.

To more deeply explore the phenomenon occurring in rarefaction curve plot (Figure 3) for gear type 4149, we asked the question, why is there such a dramatic difference between number of individuals collected between Britt Evelyn and Tramsegg? When number of

individuals and number of gears are plotted, it is clear that Tramsegg is fishing with far more effort (Number of gillnets) (Figure 4). Tramsegg fishes with up to 350 gillnets a day while Britt Evelyn only fished a maximum of 120 nets.

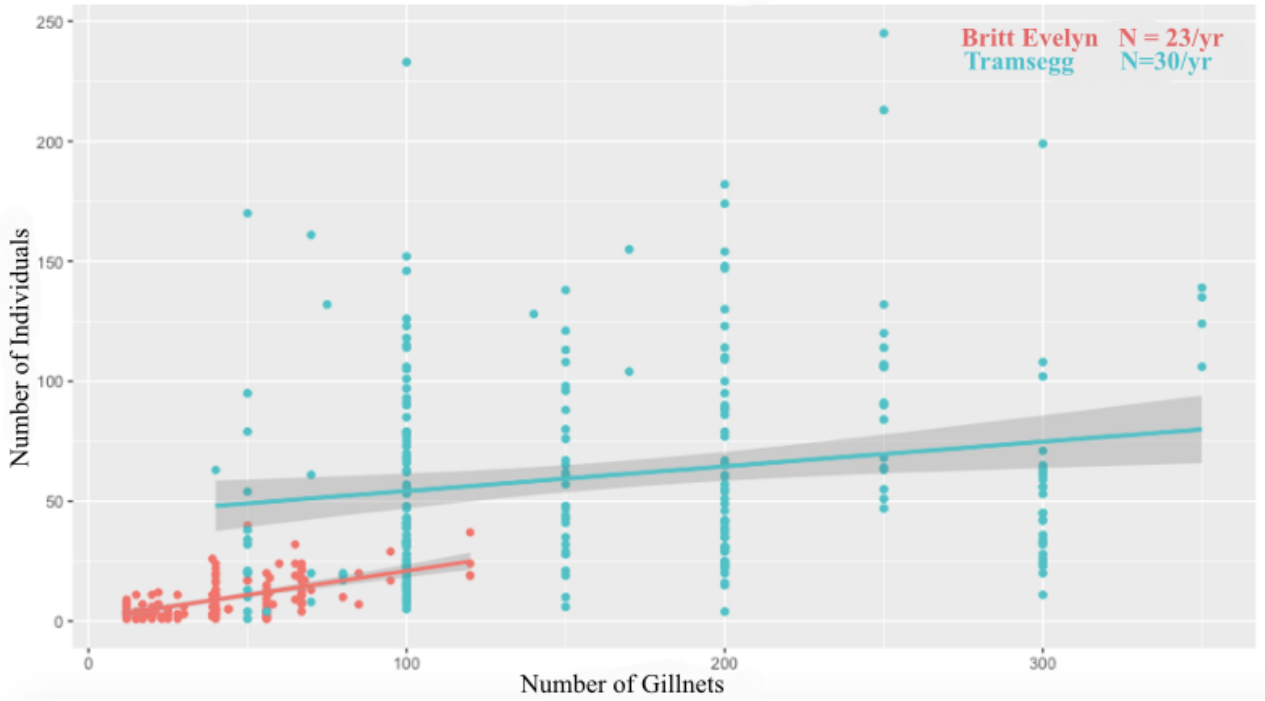

Figure 4. Number of individuals collected with gear type 4149 (mesh size 180 mm) versus number of gillnets deployed for both vessels (Britt Evelyn and Tramsegg).

Where the vessels overlapped in effort (40 – 120 gillnets) the total CPUE was calculated. This is the total number of individuals of all species per number of gillnets deployed for each day (Figure 5). This figure shows that Tramsegg catches significantly more individuals per gillnet (t-test, $p < 0.001$).

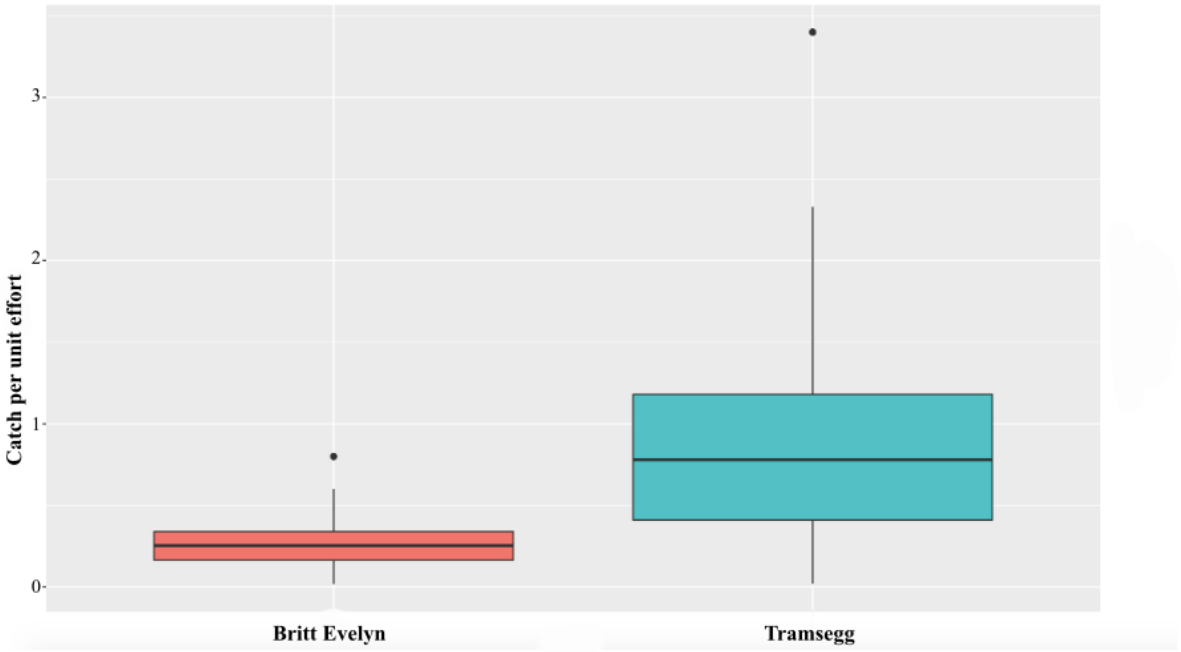

Figure 5. Total catch per unit effort calculated from number of gillnets (40 – 120) for Britt Evelyn and Tramsegg catches using gear type 4149 (mesh size 180mm). Total CPUE is calculated as total number of individuals of all species divided by total number of gillnets in the chain for each day. T-test, $p < 0.001$.

3.1.2. Rarefaction comparison

The biological null hypothesis test was used for comparing seasons and years of the same season for each fishing area. Neither Tramsegg nor Britt Evelyn's estimated species richness were found to vary significantly between seasons (Appendix 11). The same was found for the comparison between years of the same season (Appendix 12).

3.2. Evenness

Evenness was found to be significantly lower in Britt Evelyn's area compared to Tramsegg's area in all seasons ($p < 0.001$) (Table 4, Figure 6 and Figure 7). Both fishing areas were found to have the highest evenness in the spring. However, Britt Evelyn's area shows much larger variation between seasonal evenness means, from 0.47 to 0.55, compared to Tramsegg's area where all evenness means lie close to 0.75. The range (distance between end of whiskers of boxplot) of Britt Evelyn's evenness is much greater than the range of Tramsegg's in all seasons. In winter, for example, Britt Evelyn's evenness ranges from ~0.12 to 1 (range = 0.88), while Tramsegg's ranges from ~0.38 to ~0.95 (range = 0.57). This is almost a 30% increase in range from Tramsegg to Britt Evelyn. Neither Britt Evelyn nor Tramsegg were

found to be statistically significant in evenness between seasons or years of the same season (Table 8 and 9).

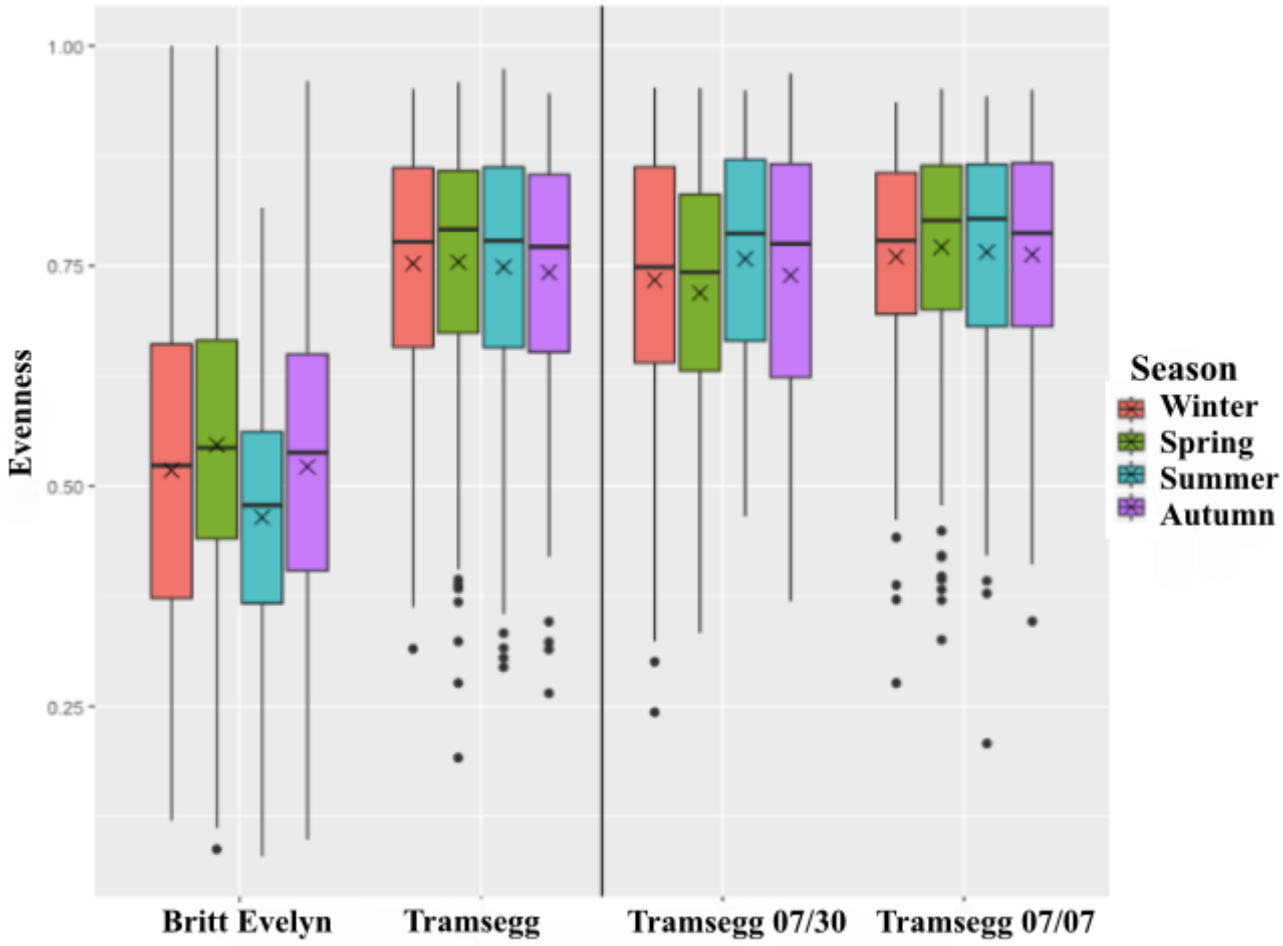

Figure 6. Evenness index measurements from daily catch data for each season. (X = mean). Britt Evelyn (2012 – 2017) and Tramsegg (2010 – 2017).

Comparing evenness from year to year of the same season finds the same pattern as overall evenness. Tramsegg's area had a much higher evenness than Britt Evelyn's. In all seasons, Britt Evelyn's catch composition was found to have the lowest evenness in 2016. Summer was an exception because Britt Evelyn only fished one year in the summer, 2013. The lowest evenness for all seasons of Tramsegg occurred in autumn of 2016 (E = 0.69). The highest value for Tramsegg is found in winter 2017 (E = 0.81), while the highest evenness value for Britt Evelyn is found in spring 2013 (E = 0.59) (Figure 7). Overall, no trend of either increasing or decreasing evenness was observed and despite some variation between years of the same season (Figure 7), none were significantly different (Table 8).

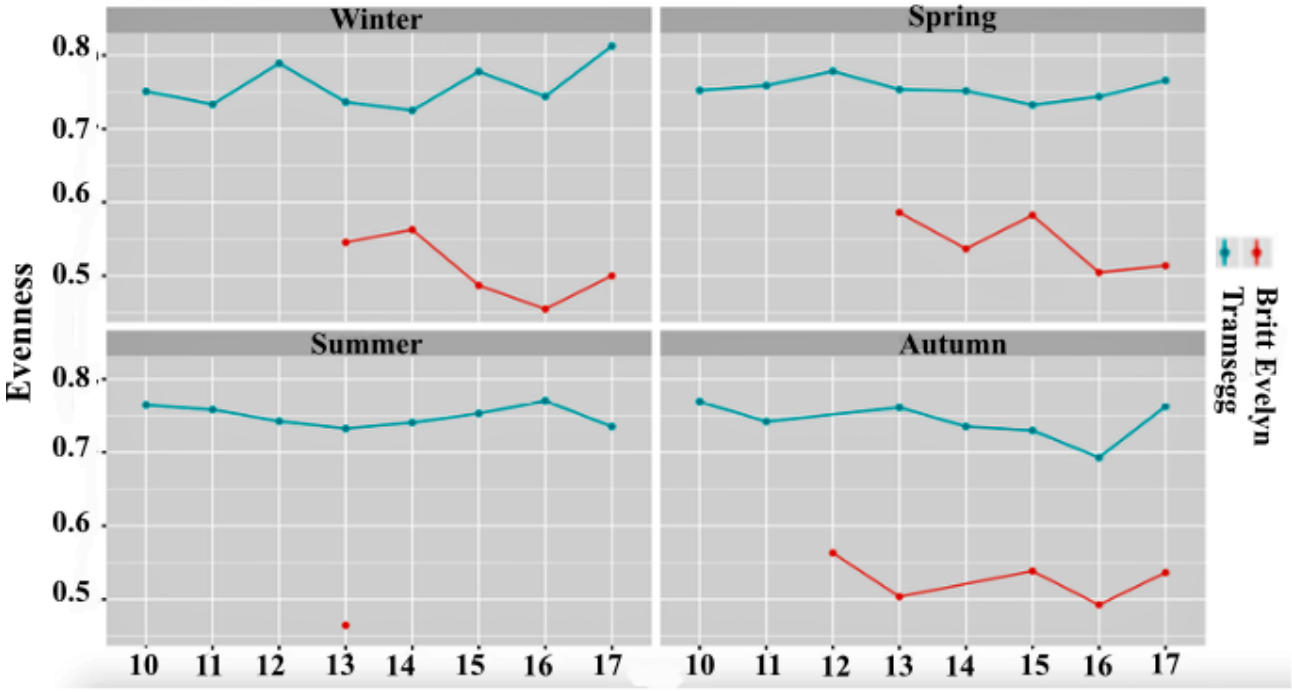

Figure 7. Evenness index measurements of between years of the same season for both vessels, Britt Evelyn and Tramsegg.

3.3. Species diversity

Between the vessels, Britt Evelyn and Tramsegg, the diversity measures are significantly different for all seasons ($p < 0.001$), meaning that the fishing areas are statistically different from one another (Table 4). However, species diversity overall did not vary significantly between seasons within the same fishing area (Table 5) and was only significantly different between years of the same season during some seasons for certain areas (Table 6). Due to the similarity between the outputs for Shannon's and Simpson's diversity indices, only Shannon's diversity index is presented. The figures for Simpson's diversity can be found in the appendix (Appendix 13 and 14).

Table 4. Table of p-values comparing Evenness, Shannon's and Simpson's diversity indices for each season between vessels or regions. Britt Evelyn compared with Tramsegg and Tramsegg 07/07 compared with Tramsegg 07/30, calculated using ANOVA ($\alpha = 0.01$).

Comparison	Season	Evenness	Shannon	Simpson
Britt Evelyn and Tramsegg	Winter	< 0.001	< 0.001	< 0.001
	Spring	< 0.001	< 0.001	< 0.001
	Summer	< 0.001	< 0.001	< 0.001
	Autumn	< 0.001	< 0.001	< 0.001
Tramsegg 07/07 and Tramsegg 07/30	Winter	0.77	0.91	0.70
	Spring	0.10	0.10	0.08
	Summer	0.55	0.94	0.71
	Autumn	0.41	0.33	0.40

3.3.1. Shannon's diversity index between seasons

For both Shannon's and Simpson's diversity indices Britt Evelyn's area was found to be less diverse than Tramsegg's area (Figure 8 & 9) (Table 4). The summer of Britt Evelyn had the lowest overall mean (H = 1.26) while spring of Tramsegg had the overall highest mean (H = 2.05). The means and medians for the seasons of Britt Evelyn varied with spring being the most diverse and being the least in the summer. The same was true for Tramsegg but by a much smaller margin (Figure 8).

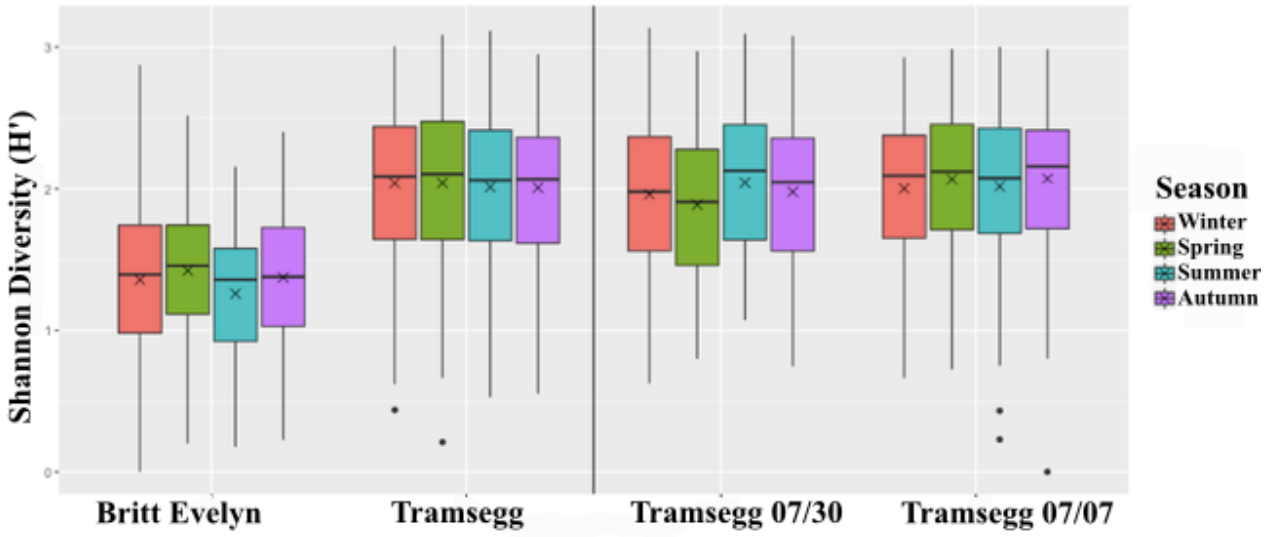

Figure 8. Shannon's diversity index measurements of daily catch data for each season (X = mean). Britt Evelyn (2012 – 2017) and Tramsegg (2010 – 2017).

Table 5. Table of p-values comparing Evenness, Shannon's and Simpson's diversity indices between the seasons for each vessel/region calculated using ANOVA ($\alpha = 0.01$).

Vessel/region	Simpson	Shannon	Evenness
Britt Evelyn	0.28	0.33	0.25
Tramsegg	0.88	0.81	0.74
Tramsegg 07/07	0.42	0.35	0.42
Tramsegg 07/30	0.98	0.89	0.98

3.3.2. Shannon diversity between years of the same season

The diversity measures plotted by year showed that Britt Evelyn's catch diversity was consistently much lower compared to Tramsegg's (Figure 7). When Shannon's diversity, Simpson's diversity and evenness indices were compared using the Bonferroni corrected alpha, neither Tramsegg's nor Britt Evelyn's areas were found to vary between years of the same season (Figure 7 and Table 6).

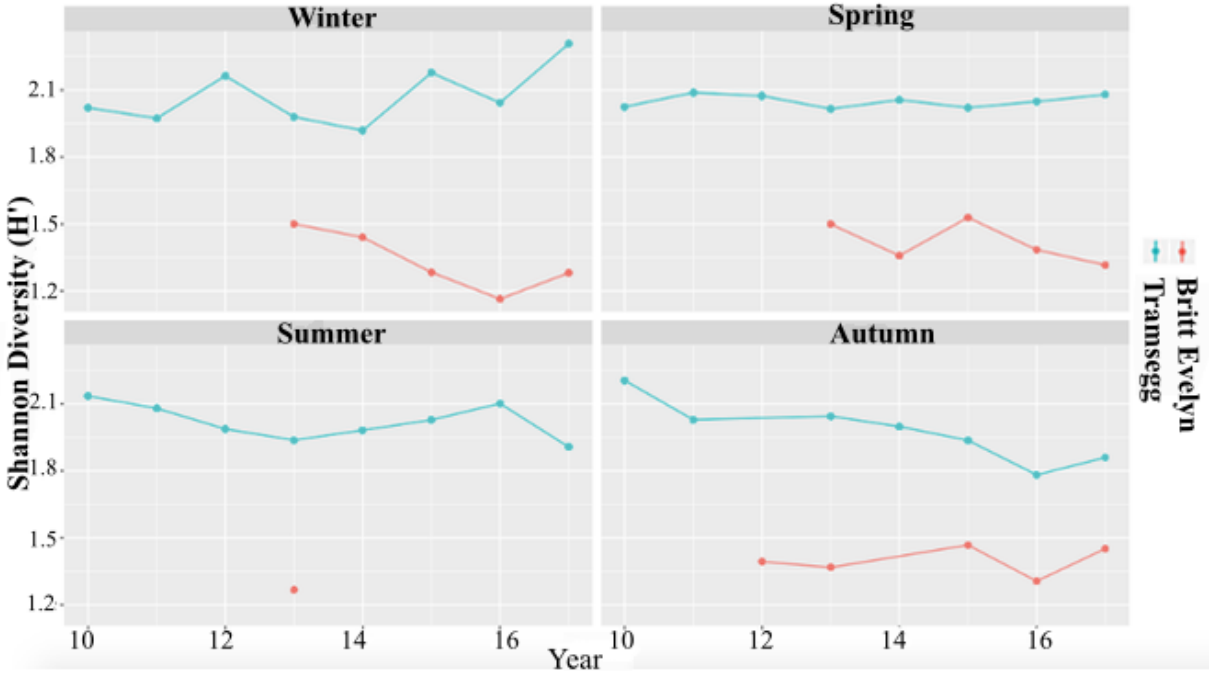

Figure 9. Shannon's diversity index measurements between years of the same season for both vessels, Britt Evelyn and Tramsegg.

Table 6. Table of p-values comparing Evenness, Shannon's and Simpson's diversity indices between years for each season and vessel/region calculated using ANOVA ($\alpha = 0.003$).

Diversity Measure	Season	Britt Evelyn	Tramsegg	Tramsegg 07/07	Tramsegg 07/30
Evenness	Winter	0.06	0.88	0.29	0.61
	Spring	0.28	0.20	0.18	0.89
	Summer	0.22	0.18	0.59	-
	Autumn	0.39	0.27	0.40	-
Shannon	Winter	0.02	0.73	0.43	0.21
	Spring	0.46	0.30	0.18	0.67
	Summer	0.36	0.10	0.99	-
	Autumn	0.52	0.01	0.83	-
Simpson	Winter	0.02	0.91	0.32	0.54
	Spring	0.52	0.33	0.14	0.73
	Summer	0.55	0.24	0.92	-
	Autumn	0.45	0.12	0.89	-

3.4 Species Composition

The analysis of similarities (ANOSIM) and permutational multivariate analysis of variance (ADONIS) were used to compare catch composition. A significant difference was found in catch composition between Tramsegg and Britt Evelyn for all seasons (Table 7). Between seasons of the same fishing area there was no significant variation between the species composition (Table 8) and only for one gear type used by Tramsegg in the spring was there a difference in catch composition between years of the same season (Appendix 15).

Table 7. Table of p-values comparing seasonal catch composition between vessels using both ANOSIM and ADONIS calculated from the "vegan" package in R (Oksanen et al., 2018).

Season	P-values for ANOSIM / ADONIS comparing Britt Evelyn and Tramsegg
All seasons	0.001 / 0.001
Winter	0.001 / 0.001
Spring	0.001 / 0.001
Summer	0.001 / 0.001
Autumn	0.005 / 0.001

3.4.1. Catch composition between seasons of the same fishing area

Overall, the species composition did not vary between seasons of the same gear type for either Britt Evelyn or Tramsegg (Table 8).

Table 8. Table of p-values comparing seasonal species composition for each vessel and gear for both ANOSIM and ADONIS calculated from the "vegan" package in R (Oksanen et al., 2018).

Gear Type	Vessel	
	Britt Evelyn	**Tramsegg**
4139	-	0.65 / 0.34
4140	0.71 / 0.99	0.30 / 0.88
4141	0.89 / 0.83	0.30 / 0.39
4142	-	0.42 / 0.57
4149	0.88 / 0.94	0.65 / 0.10
All gears	0.81 / 0.73	0.14 / 0.11

3.4.2. Catch composition between years of the same season and area

In the comparison between years of the same season, ANOSIM did not detect any differences. ADONIS, the function that is recommended over ANOSIM because it is more robust (Warton et al., 2012), found significant differences using the Bonferroni corrected alpha ($\alpha = 0.003$) between years in spring for Tramsegg using gear type 4141 ($p = 0.003$). All other years of the same season, gear type and vessel were not significant ($p > 0.003$) (Appendix 15).

3.4.3. SIMPER

SIMPER was used to determine the species contributing to the most variation between seasons (Figure 10). Between Britt Evelyn and Tramsegg, a total of 20 of all 65 species reported accounted for the first 70% of variation between seasons of the same gear type. Within each gear type and vessel, the number of species that contributed to variation was between three and ten. For gear types, 1 (i.e. all gears) and 4140, Britt Evelyn had fewer number of species contributing to the overall dissimilarity. However, in gear types 4141 and 4149, the opposite was true and Tramsegg had fewer species contributing to the dissimilarity between catch compositions. For both vessels, and all gear types the composition of the contributing species varied only slightly between seasonal comparisons, meaning that each column in figure 10 are relatively similar.

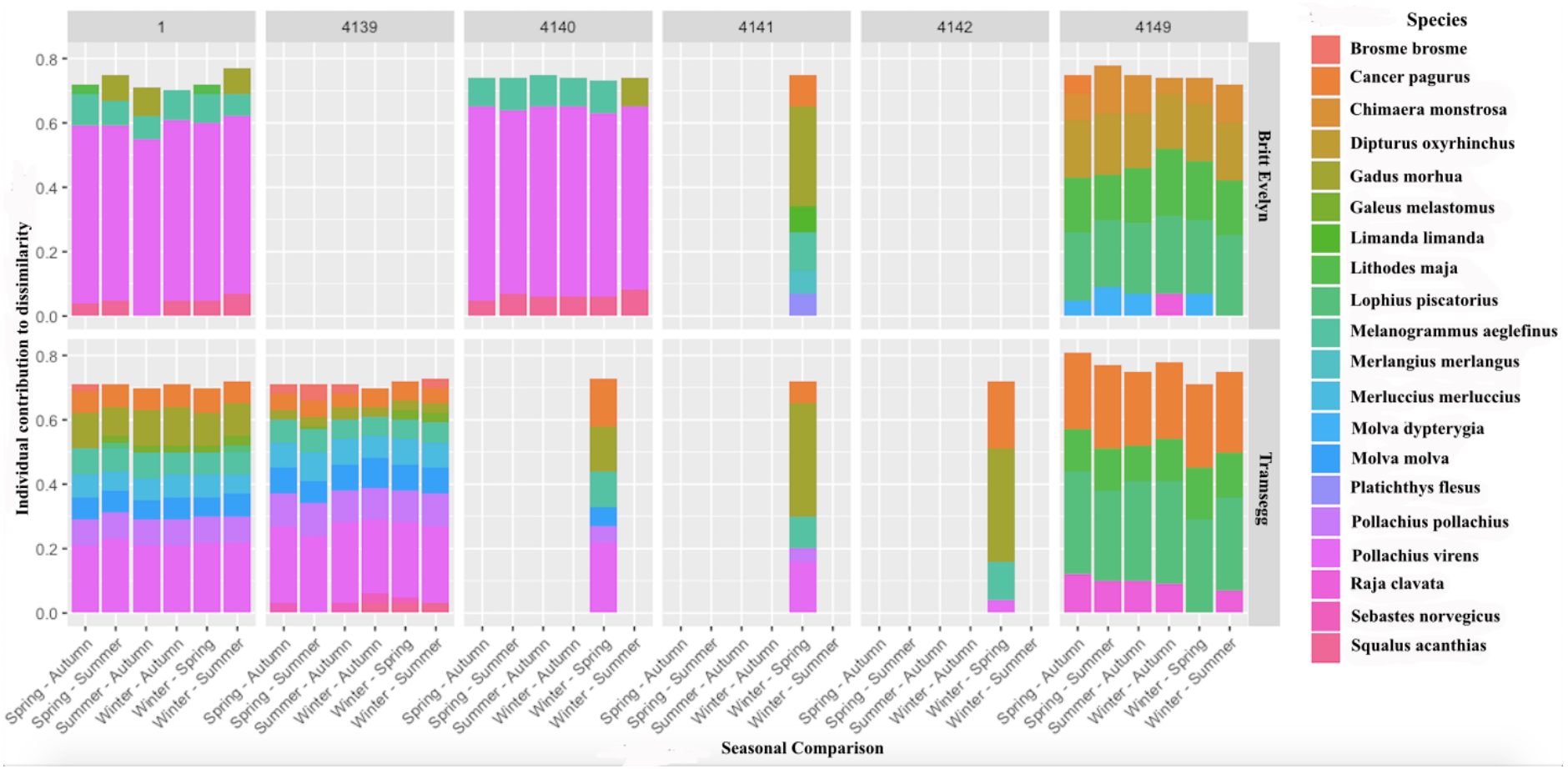

Figure 10. Results of the SIMPER analysis. Stacked bar chart of the species contributing of the first ~70% of the dissimilarity between seasons for both vessels, Britt Evelyn and Tramsegg, for all gear types (1 – All gears; 4139 – mesh size 60 – 69mm; 4140 – mesh size 70 – 79 mm; 4141 – mesh size 80 – 89mm; 4142 – mesh size 90 – 99mm; 4149 – mesh size 180mm

For **gear type 1 (all gears)**, Britt Evelyn had five species that contributed to the first 70% of the variation between the seasonal comparisons, while Tramsegg had ten species. Only three species were found in both comparisons (saithe – *Pollachius virens*, cod – *Gadus morhua* and haddock – *Melanogrammus aeglefinus*). The species that contributed the most for each vessel and seasonal comparison is saithe. Saithe individually contributed 21 – 23% of the variation in Tramsegg and 54-56% in Britt Evelyn. In Britt Evelyn, the other two species found to contribute to the dissimilarity are spiny dogfish (*Squalus acanthias*) and stone crab (*Lithodes maja*). In Tramsegg the other species contributing are pollack (*Pollachius pollachius*), brown crab (*Cancer pagurus*), common ling (*Molva molva*), hake (*Merluccius merluccius),* blackmouth catshark (*Galeus melastomus*), monkfish (*Lophius piscatorius*) and cusk (*Brosme brosme*).

Britt Evelyn did not fish using **gear type 4139**. Eleven species contributed to the variation found in the seasonal comparisons for Tramsegg. These include saithe, pollack, hake, common ling, haddock, brown crab, cod, cusk, blackmouth catshark, Norwegian redfish (*Sebastes norvegicus*) and spiny dogfish. The top contributing species for each seasonal comparison were saithe (23-25%) and pollack (10%).

Britt Evelyn fished with **gear type 4140** all seasons while Tramsegg only fished with this gear type in the winter and spring. Britt Evelyn's seasonal comparison were comprised of four species and Tramsegg's are comprised of six. Three of these species were the same, saithe, cod and haddock. The one other species found to contribute to the dissimilarity for Britt Evelyn was the spiny dogfish and the three others for Tramsegg were the brown crab, pollock and common ling. Saithe again was the dominant influencer for both vessels (Britt Evelyn ~55%; Tramsegg ~22%) followed by haddock (~10%) for Britt Evelyn and brown crab (~8%) for Tramsegg.

For **gear type 4141**, both vessels fished only in the winter and spring. In both cases, cod contributed the most to the dissimilarity (31% for Britt Evelyn and 35% for Tramsegg). Britt Evelyn was comprised of six species and Tramsegg was made up of five. With three species found in both, cod, haddock and brown crab. Tramsegg also included saithe and pollock while Britt Evelyn included common dab (*Limanda limanda*), European flounder (*Platichthys flesus*) and English whiting (*Merlangius merlangus*).

Gear type 4142 was not fished by Britt Evelyn and was only used in winter and spring by Tramsegg. Only four species accounted for over 70% of the dissimilarity (cod - 35%; brown crab – 21%; haddock – 12% and saithe – 4%).

For the dissimilarity between seasons for **gear type 4149**, Britt Evelyn was comprised of seven species and while Tramsegg only had four. All of which were also found in Britt Evelyn. Both vessel's primary contributor to dissimilarity between catches was monkfish. Both were relatively similar between seasonal comparisons. The exception to this in Britt Evelyn was spring through autumn where brown crab contributed 6% and winter – autumn where blue ling (*Molva dypterygia*) was absent, and the thornback ray (*Raja clavata*) was present. In Tramsegg, the seasonal comparison that stood out was winter through spring where the thornback ray was absent. This was because it made up 7-12% of the other seasonal comparisons.

4. Discussion

Below I have discussed the findings of this study in regard to answering the questions previously proposed. Is there a difference in catch biodiversity between seasons in the same fishing area, between years of the same season in the same fishing area and between the two fishing areas?

4.1. Question 1: Is there a difference in catch biodiversity between seasons in the same fishing area?

Overall, there was no perceived seasonal change in catch biodiversity for either vessel, Britt Evelyn or Tramsegg. The Ambient Energy and Productivity hypotheses predict that biodiversity would be higher in spring and summer and lower in winter and autumn, due to the difference in energy availability (Willig et al., 2003). This has been observed in Norwegian coastal waters (Hop et al., 1992) and was, thus, expected. This trend was not found.

For the dominant gear types used by Britt Evelyn (4140 and 4149), summer showed the highest rarefaction curves. This could indicate that the system is more diverse in the summer. However, Britt Evelyn fished fewer days with demersal gillnets in the summer. Because of this, the rarefaction curve did not reach an asymptote so should be handled with some skepticism. If all four seasons curves approached an asymptote and were found to be significant, then the result would be more trustworthy. A larger data set with many more days fished in the summer is needed to make any conclusions about the seasonal change in species richness for Britt Evelyn's fishing area.

The evenness, Shannon's diversity, and Simpson's diversity indices found no significant difference between the seasons for either vessel. The same was found when comparing species compositions with both ANOSIM and ADONIS.

Through literature and prior knowledge, we know that all over the globe demersal fish communities change seasonally (Barletta et al., 2003 (Brazil); Claridge et al., 1986 (England); Iglesias, 1981 (Spain); Jin & Tang, 2002 (China); Magill & Sayer, 2002 (Scotland); Quinn, 1980 (Australia); Ribeiro et al., 2006 (Portugal)). So, if we assume that the populations these fishermen are harvesting from do change throughout the year, why is that not reflected in any of the diversity tests performed in this study? This may be due to the highly selective nature of fishing. The fishermen know where and when to find valuable fish. Also, the communities that they are fishing from are clearly dominated by a few species that are profitable. If the compositional changes occur in the more rare or non-valuable species, the seasonality of these

communities would be much more difficult to measure using fisheries dependent data. This is one drawback to using fisheries data when studying the whole ecosystem biodiversity. Subtle shifts in composition that may have a large effect on the community dynamics could be overlooked when so much of the data is focused on only a few of the most dominant and valuable species. Nevertheless, the aim of this study was to show changes in biodiversity in the portion of the ecosystem exposed to the commercial fishing gears.

The species contributing to the dissimilarity between seasons were all commonly caught species (the SIMPER analysis). Mostly target species but some non-target species that were still reported most days. Finding few species contributing to the dissimilarity suggests that the variation between catch compositions is driven by the quantity of dominant species and not the presence or absence of rarer species. This was also found using fisheries independent data. In a study of species composition of the intertidal zone along the English channel, the same six species from a total of 27 were found to be the dominant contributors in all seasons (Selleslagh & Amara, 2008). On the western coast of Norway, the same was found using traps as the sampling tool (Arechavala-Lopez et al., 2016). In all cases, the difference between catches is the quantity of each common species, not the subtle presence or absence of rare species.

4.2. Question 2: Is there a difference in catch diversity between years of the same season in the same fishing area?

This study finds that there is no clear evidence that the biodiversity exposed to the fishing gears is either increasing or decreasing through time. It is known that biodiversity globally has been decreasing since the start of the industrial age (Greenstreet & Rogers, 2006; Worm et al., 2006), but that on a local scale, biodiversity is more related to human impacts and local extinctions or introductions (Elahi et al., 2015). This makes it difficult to predict whether biodiversity will increase or decrease over time in a given area.

The findings of this study are a bit nuanced when comparing years of the same season and fishing area. Neither species richness, evenness nor Shannon's diversity indices found a difference in biodiversity between years of the same season and fishing area. When comparing catch composition only Tramsegg fishing in the spring with gear type 4141 was found to vary between years of the same season. This may be due to a lack of data because gear type 4141 is rarely fished and, therefore, does not have many data points included in the analysis. There are many gaps in the yearly data, whole years with data not collected for some gear types. In a time-series less than a decade, this is very important to remember. A much longer time-series

is needed to determine if the fishing areas are experiencing any long-term change in biodiversity.

4.3 Question 3: Is there a difference in catch diversity between vessels/areas fished?

Initially, the data from Tramsegg was divided into the two statistical regions in which the vessel fished. However, the two areas were not found to be statistically different from one another so will not be discussed separately but together as one data set from one Tramsegg fishing area.

The two vessels used in this study, Tramsegg and Britt Evelyn, are similar in size and fishing technique but the two vessels fish in different areas. Britt Evelyn fishes at about 60°N while Tramsegg fishes further north at around 63°N. It is known that fish distributions are shifting further north (Cormon et al., 2014, 2016; Reum & Essington, 2011), but that on a local scale biodiversity is more related to human impacts (Elahi et al., 2015). Again, this makes it difficult to predict whether biodiversity will increase or decrease overtime in a given area.

Britt Evelyn reported more species overall, 57, to Tramsegg's 50, even with far less effort. The data used for Britt Evelyn had two fewer years fished than Tramsegg and did not include sufficient data from the summer months. This discrepancy in effort translated to the number of individuals reported for each vessel but not in overall richness. Tramsegg, also fished with a wider variety of fishing gears, five gear types versus Britt Evelyn's three gear types. A wider variety of mesh size should collect a wider variety of species (Hamley, 1975).

These fishermen seemed to have preferred gear types for fishing specific species. Saithe is fished primarily with gear type 4139 (60 – 69 mm mesh size) by Tramsegg and gear type 4140 (70 – 79 mm mesh size) by Britt Evelyn. This suggests that Britt Evelyn are fishing for slightly larger fish. This may explain why Tramsegg fished more because they are fishing smaller individuals and must catch more to make the same profit. However, that is assuming that the fishermen are trying to make the same amount of money each year which is unknown.

Both fishermen used the anglerfish gillnets (gear type 4149, 180 mm mesh size) for fishing monkfish. Unfortunately, the two vessels caught very different volumes making it difficult to compare. The discrepancy in the quantity of fish caught could come from many sources. There could be a difference in effort or a difference in the underlying population that would lead to one fisherman catching more than the other. When the number of gillnets and

number of individuals collected are plotted for both vessels, it appears that Tramsegg is fishing more intensely for monkfish. They deployed more gears per day for more days.

To answer the second question, "is there more monkfish in Tramsegg's fishing area?". The effort (number of gillnets) where the vessels overlapped was used. The total CPUE (total number of individuals of all species per number of gillnets fished) showed that Tramsegg had an almost three-times higher median CPUE than Britt Evelyn. This suggests that the population of monkfish that was fished by Tramsegg was roughly three times larger than the population being fished by Britt Evelyn. This estimation comes from the catch equation (Equation 8).

Equation 8. Fisheries catch equation (Sparre & Venema, 1998). $C = F \times B$

Where (C) is catch, (F) is fishing mortality and (B) is biomass of the population. Fishing mortality is made up of effort and catchability (Sparre & Venema, 1998). So, if catchability is assumed constant, then catch per unit effort can be used as a proxy for biomass, CPUE $\approx$ B (Sparre & Venema, 1998). The reason Tramsegg caught so many more individuals using the anglerfish gillnet (gear type 4149) is because they were fishing more intensely on a larger population.

Overall, Britt Evelyn reported more species in a shorter time period. However, the rarefaction curves did not predict higher species richness compared to Tramsegg. For gear types that could be compared the maximum species richness was remarkably similar for both vessels (~30 species for gear type 4140 and ~15 species for gear type 4149). The findings of estimated richness were not echoed for evenness. Britt Evelyn was found to have a much less even species composition with a much higher range. This could mean that the ecosystem Britt Evelyn was fishing was more diverse because the daily catches varied more. However, this could also mean that Britt Evelyn had a less predictable fishing pattern. It is possible that some days they caught a wider variety of species but relatively few of each including the target species, while other days they caught high quantities and a narrower variety of species. If Tramsegg's gillnets reliably hauled up the same species in a predictable ratio, it could explain why Tramsegg had higher evenness with a narrower range. Both Shannon's and Simpson's diversity indices found a difference between Britt Evelyn's and Tramsegg's fishing area. Britt Evelyn's area was found to be less diverse. This may have been due to the relatively equal expected species richness and the lower evenness, as evenness is calculated using Shannon's diversity index (Mulder et al., 2004).

For both species composition analyses, ANOSIM and ADONIS, Britt Evelyn and Tramsegg were found to be significantly different. To explore whether this difference was driven by the difference in target species quantity or in the rare species presence or absence in an area, the SIMPER analysis, often paired with ANOSIM (Clarke, 1993; Grazia Pennino et al., 2016; Paighambari & Eighani, 2018; Selleslagh & Amara, 2008; Warton et al., 2012), was used. In both cases the SIMPER analysis showed that the variation between the species contributing to the change in catch composition was exclusively due to the commonly caught species, either target species or the non-targets that were caught most days. This trend was also found in other fisheries independent studies (Arechavala-Lopez et al., 2016; Selleslagh & Amara, 2008). This common species dominance suggests that the variation is driven by the difference between "good" versus "bad" fishing days. On "good" fishing days, the fishermen would go back to shore with many individuals of one or two high priced species, the target species. On bad fishing days they will catch fewer individuals overall and catch more lower value or unwanted fish, the non-target species. For the smaller gear types used to target saithe, Britt Evelyn's data showed fewer species contributing to the variation in the SIMPER analysis where the opposite was true for the larger anglerfish gillnets. This could mean that there are more "bad" days of fishing for Britt Evelyn in the smaller meshed gear types and fewer in the larger meshed gear types. The opposite could be said for Tramsegg's fishing patterns. If there are fewer species contributing to the variation between seasons, it could mean that there is a larger range of catch composition profiles. More species contributing means that there are smaller changes between the commonly collected species (Grazia Pennino et al., 2016).

Overall, it is impossible to distinguish the vessels from the fishing area in this study. Neither fisherman have fished in the other's area, meaning that it cannot be concluded whether the differences in biodiversity observed came from the underlying populations or from the different fishing practices of the fishermen. To truly separate the ecosystem from the fisherman, the vessels would need to fish in each other's areas or a research survey would need to be performed in both areas to determine whether this strategy for comparing areas is sufficient.

4.4. Sources of error

There could be many sources of error in this study. Before any tests could be performed on the data, it had to be converted to a useable format. The quantity of fish was reported as either total catch weight by species (kilograms) or number of individuals (Mjanger et al., 2019). Converting catch weights into number of individuals has many steps and, therefore, many

opportunities for introduced error (Brodziak, 2012). There could be errors in the initial length measurement sampling, as was found in the *Chimaera monstrosa* samples where the sampling technique is non-standard, or there could be misidentified species as seen in the *Scophthalmus maximus* samples. Though these errors were removed, more subtle examples may have been missed while cleaning the data. This data was used to calculate the length-weight relationship parameters for each species by area, then weight of individuals and then final total number of individuals for each species. The final numbers were rounded up, so no species present would be lost. While this is logical, it could be a source of error when discussing number of individuals seeing as they are not raw counts but rounded estimations.

Another source of error is that fisheries dependent data is not a random sample of the environment (Hamley, 1975). This study only measured the biodiversity of the demersal species available to the gear but may still be non-ideal because fishermen know how to best catch fish. Fishermen seek out and understand the best techniques for catching the highest quantity of target species while hopefully minimizing the number of non-target or by-catch species. Fisheries science in general struggles with the many unknowns of fishing, such as catchability (Godø, 1994; Pennington & Godø, 1995). Though assumed constant in this study, in reality catchability will change through the year as fish migrate or change their feeding habits (Reum & Essington, 2011) as well as over time as fishermen become more skilled at catching fish (Godø, 1994).

In this study, seasons were defined as quarters. This was chosen because of how IMR breaks up the data when doing analyses. However, this assumes that factors such as daylight or temperature have little effect on demersal communities. It may have been more correct to define seasons more traditionally (Dec, Jan, Feb – Winter; Mar, Apr, May – Spring; Jun, Jul, Aug – Summer; Sep, Oct, Nov – Autumn).

Another error source could be the gaps in the data: i.e., no data reported for some years, seasons and gear types. This could be eliminated through further conversations with the fishermen. Asking why they didn't fish with specific gears during specific times. Further, asking if it was because there was something happening biologically with the fish or because their boat was down or possibly because the market wasn't at a level that made fishing for those species cost effective or if the weather was too bad. Many factors (biological, social, economic, etc.) affect the fisherman's choice of whether to fish and what for. This makes it impossible to know just by studying the reported data. Another way to clear this up may be to use a longer time series. Having more fished years may help to clarify if catch diversity changes through time.

Statistical errors could also influence the results of this study. Type I and type II errors, also known as alpha and beta errors respectively, occur when a true null hypothesis is rejected (type I) or a false null hypothesis is kept (type II) (Banerjee et al., 2009). These can occur when the samples taken are not representative of the underlying trends of the whole population. Because it is impossible to collect all of the organisms in a demersal habitat, a sample is taken that is hopefully representative of the underlying ecosystem (Banerjee et al., 2009; Bender & Lange, 2017). When a p-value ($a = 0.05$) is calculated and found to be significant, it is saying that there is a 95% chance that the difference truly exists in the population and a 5% chance that what is seen is significant only because of the sample taken (Banerjee et al., 2009; Bender & Lange, 2017). If we play this logic out, it means that if we run 20 tests we will likely find one significantly different relationship just because 1/20 times the samples taken did not accurately represent the underlying population. The most common way that these types of errors are avoided is by increasing sample size because the larger the sample, the more likely it is to be representative of the population (Banerjee et al., 2009). When this cannot be done the Bonferroni correction is used (Bender & Lange, 2017), as is the case in this study.

4.5. Implications for management

To further explore the role this data set could play in informing future management decisions, it is important to remember that the data collected for this study are from species sampled as a part of the Norwegian reference fleet whose purpose is to collect biological data and to inform IMR (Bjørkan, 2011; IMR, 2013). This means that the fishermen reported far more than they landed. Of the 57 species collected by Britt Evelyn, only 43 species were landed (75%). Even fewer were landed by Tramsegg, just 27 of the 50 species captured were landed (52%). Of the species landed, the proportion of landed versus discarded individuals varied greatly (Appendix 16). For saithe, Britt Evelyn was found to have a much higher CPUE than Tramsegg. However, for all other commonly targeted species (cod, haddock, pollack, common ling, hake, cusk), Tramsegg reported a much higher CPUE. This may be because Tramsegg fishes primarily with a slightly smaller gillnet mesh size (60 – 69 mm mesh size instead of Britt Evelyn's 70 -79 mm mesh size) or because Tramsegg has a higher density of these species in the fishing area or just because the fisherman prefers to land those species.

Tramsegg fished with a far greater effort than Britt Evelyn. That is why when the total catch weight (Appendix 17) is compared, Tramsegg reports a larger total catch weight per year even though Britt Evelyn has a much higher CPUE and land a higher percentage of the saithe

they catch. It may be interesting to look at all of the vessels in the fleet to see if some factor or fishing behavior not used in this study can predict what proportion of the species are landed and which proportion of individuals of the target species are discarded.

4.5.1. Gillnet selectivity

No sampling tool can collect 100% of the community so concerns of gear selectivity should be considered in all biodiversity studies. Most fisheries independent research surveys use trawls to collect individuals for biodiversity studies (Hyndes et al., 1999; Jin & Tang, 1996; Mueter & Norcross, 2000; Powers, 2010; Selleslagh & Amara, 2008; Tolimieri, 2007). In this thesis, commercial gillnets were used. Both have selectivity curves that leave some of the population untouchable by the gear (Cochrane & Garcia, 2009; Gabriel et al., 2005; Hamley, 1975) and, thus, out of the scope of the study.

Many factors affect how many and what type of fish will be caught in a gillnet (Hamley, 1975; Potter & Pawson, 1991). The two main factors are the gillnet selection curve and the ecosystem where the gillnet is deployed. It is important to remember that all gillnets have a bell-shaped selection curve, meaning that the net has the potential to catch fewer of the smaller and larger range individuals and most of the peak size individuals that encounter the gear (Hamley, 1975; Potter & Pawson, 1991). Commercial demersal gillnets are chosen because they dominate the Norwegian coastal demersal fisheries and will hopefully catch the largest amount of the most desired size and species. So, the target species determine the mesh size chosen (Cochrane & Garcia, 2009; Hamley, 1975; Potter & Pawson, 1991). This could have some pretty profound influences on the data used in this study. Species that are considered "rare" in this study may not be rare because they are uncommon in the ecosystem but because the mesh size used is only able to collect a small portion of the species length distribution. The second most important factor that affects the quantity and size of the fish caught is the species composition and length distribution of the population that are being sampled (Potter & Pawson, 1991). Fish of a certain size and species must be present in the area and must encounter the gear to be caught by the gillnet (Cochrane & Garcia, 2009; Hamley, 1975; Potter & Pawson, 1991). In this study, it is impossible to separate whether a species is considered rare because of the gear selection curves of the commercial gillnets used or because they are truly not common in the population.

4.6. Conclusions and future recommendations

This study found no detectable difference in biodiversity between seasons in the same fishing area. Only certain gear types and seasons were found to be different over the years of the same season in the same fishing area, but no overall trend in biodiversity could be concluded from these findings. The areas fished by the two different vessels are significantly different from one another. However, this is conflicting. The overall richness suggested that Britt Evelyn's fishing area had higher biodiversity even with a much lower effort than Tramsegg while the Shannon's and Simpson's diversity indices, which include both richness and evenness, found Tramsegg's area to be more diverse than that of Britt Evelyn's. When fishing with the smaller mesh sizes, Tramsegg seemed to have less variability in the catches than Britt Evelyn while the opposite was found for the much larger, anglerfish gear type. More data and more vessels could help determine if these patterns are true reflections of the ecosystem or just a difference in a "fisherman effect". Where this difference isn't from the population but from the person sampling from the population. Many factors (biological, economical and sociological) affect where, when and how hard a fisherman fishes.

This technique of exploring the biodiversity could give some insight on the areas in sampling that are needed for more ecosystem-based fisheries management and could potentially answer biologically important questions; are species compositions changing through time? Are new fish contributing to the dissimilarity between years or seasons? The analytical tools used in this study could answer some of these questions if given enough data points over a long enough times series. These tools could also be used for corroborating fisherman's observations of a changing area. Fisherman's observations could also be used to corroborate these findings. For future research, I suggest using more vessels from the fleet and combining this with research surveys to determine if the difference observed between the two fishing areas truly reflects the difference in ecosystem or just the difference between the fishermen. Using a longer time series, could make the trends between years of the same season clearer. To determine if there is a difference between season, I would recommend setting the data breaks to the true seasons instead of quarters as well as combining the reference fleet data with some abiotic factors such as daylight, temperature, etc.

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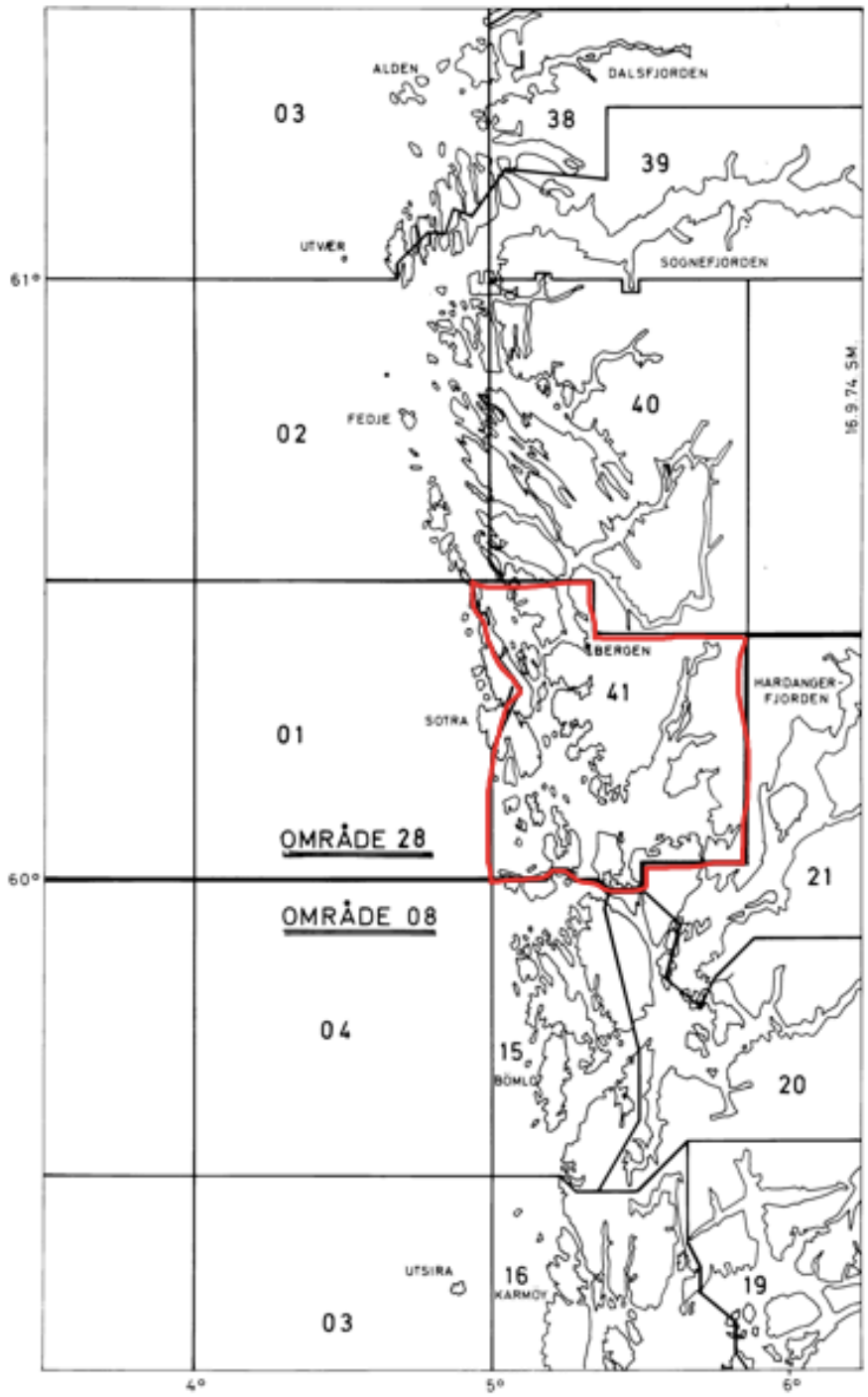
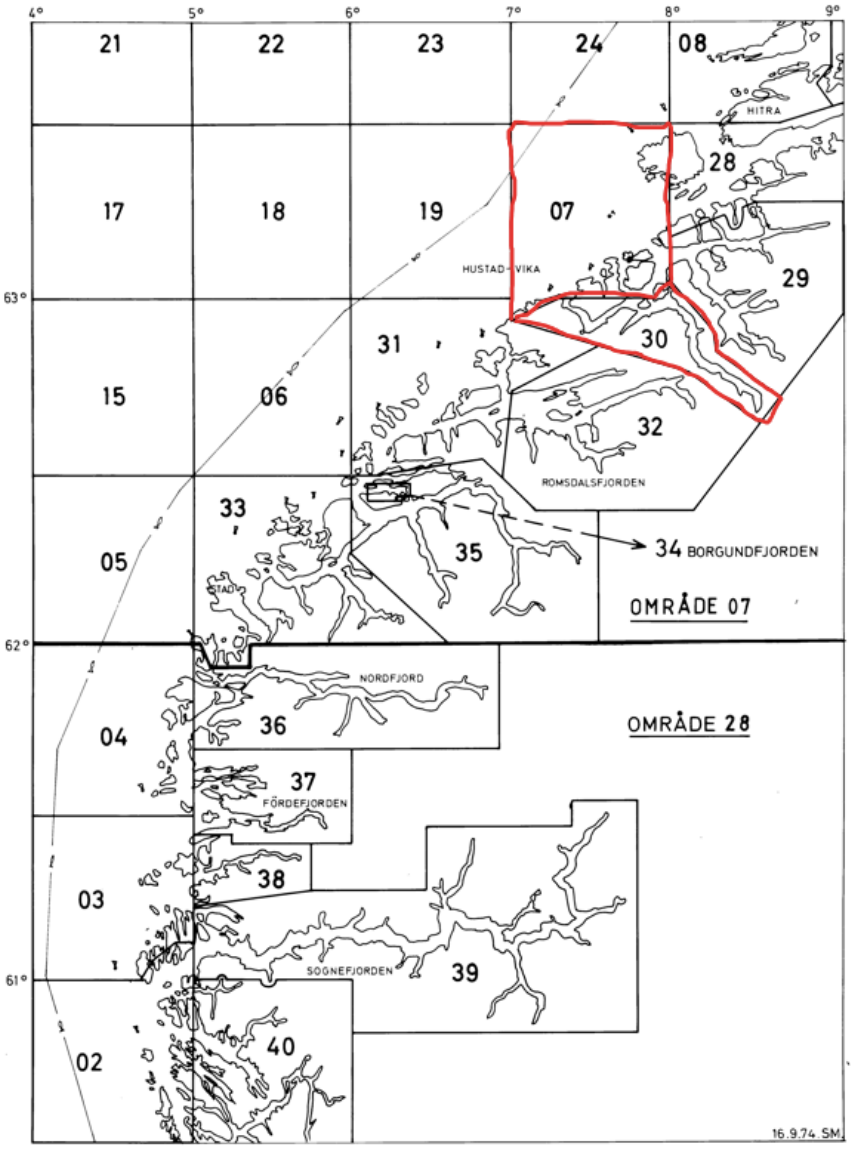
6. Appendix

Appendix 1. Map of Norway showing the location of the vessels from the Norwegian Coastal reference fleet as of 2013. The two vessels used in this study (Britt Evelyn and Tramsegg) are highlighted in red. Image sourced from Norwegian Institute of Marine Research (IMR, 2013).

Appendix 2. Map of Britt Evelyn's fishing area between the years 2012 and 2017 along the western coast of Norway, statistical region 28/41 highlighted in red. (Mjanger et al., 2019).



Appendix 3. Map of Tramsegg's fishing area between the years 2010 and 2017 along the western coast of Norway. Statistical regions 07/07 and 07/30 highlighted in red. (Mjanger et al., 2019).



Appendix 4. Gear Codes used in this study as described by the Norwegian Institute of Marine Research. (Mjanger et al., 2019). Gear codes 4115 and 4126 combined and referred to as 4139.

41 Bottom nets/ Midwater nets

15 Demersal gillnet. Monofilament. 10 omfar.
26 Demersal gillnet. Monofilament. 66 mm mesh.
40 Demersal gillnet. Unspecified. 70 - 79 mm mesh.
41 Demersal gillnet. Unspecified., 80 -89 mm mesh.
42 Demersal gillnet. Unspecified. 90 - 99 mm mesh.
49 Demersal gillnet. Unspecified. 180 mm mesh

Appendix 5. List of all species collected by demersal gillnets in good condition by both Britt Evelyn (2012 – 2017) and Tramsegg (2010 – 2017) with Aphia ID code, Latin, English and Norwegian names.

Aphia.ID	***Latin Name***	**English Name**	**Norwegian Name**
105812	*Galeus melastomus*	Blackmouth catshark	Hågjel
105814	*Scyliorhinus canicula*	Small - spotted catshark	Småflekket rødhai
105820	*Galeorhinus galeus*	Tope shark	Gråhai
105824	*Chimaera monstrosa*	Chimaera	Havmus
105865	*Amblyraja radiata*	Thorny skate	Kloskate
105869	*Dipturus batis*	Common skate	Storskate
105870	*Dipturus linteus*	White skate	Hvitskate
105871	*Dipturus nidarosiensis*	Black skate	Svartskate
105872	*Dipturus oxyrinchus*	Longnosed skate	Spisskate
105873	*Leucoraja circularis*	Sandy ray	Sandskate
105883	*Raja clavata*	Thornback ray	Piggskate
105894	*Rajella fyllae*	Round skate	Rundskate
105913	*Etmopterus spinax*	Velvet belly	Svarthå
105923	*Squalus acanthias*	Spiny dogfish	Pigghå
107205	*Lithodes maja*	Stone crab	Trollkrabbe
107253	*Homarus gammarus*	European lobster	Hummer
107254	*Nephrops norvegicus*	Norwegian lobster	Sjøkreps
107276	*Cancer pagurus*	Brown crab	Taskekrabbe
107374	*Geryonidae trispinosus*	Three-spined geryon	Dypvannskrabbe
126175	*Genus - Sebastes*	non-specific - Redfish	Uerslekten
126436	*Gadus morhua*	Cod	Torsk
126437	*Melanogrammus aeglefinus*	Haddock	Hyse
126438	*Merlangius merlangus*	English whiting	Hvitting
126440	*Pollachius pollachius*	Pollock	Lyr
126441	*Pollachius virens*	Saithe	Sei
126444	*Trisopterus esmarkii*	Norway pout	Øyepål
126446	*Trisopterus minutus*	Poor cod	Sypike
126447	*Brosme brosme*	Cusk/tusk	Brosme
126459	*Molva dypterygia*	Blue ling	Blålange
126461	*Molva molva*	Common ling	Lange
126484	*Merluccius merluccius*	Hake	Lysing
126501	*Phycis blennoides*	Greater forkbeard	Skjellbrosme
126503	*Urophycis chuss*	Red hake	Skjeggbrsome
126554	*Lophius budegassa*	Black-bellied angler	Svartflabb
126555	*Lophius piscatorius*	Monkfish	Breiflabb
126715	*Argentina silus*	Greater argentine	Vassild
126716	*Argentina sphyraena*	Lesser argentine	Strømsild
126757	*Anarhichas denticulatus*	Northern wolffish	Blåsteinbit
126758	*Anarhichas lupus*	Atlantic wolffish	Gråsteinbit

126792	*Callionymus lyra*	Common dragonet	Vanlig fløfisk
126957	*Acantholabrus palloni*	Scale-rayed wrasse	Brungylt
126964	*Ctenolabrus rupestris*	Goldsinny	Bergnebb
126965	*Labrus bergylta*	Ballen wrasse	Berggylt
127136	*Glyptocephalus cynoglossus*	Sea witch	Smørflyndre
127137	*Hippoglossoides platessoides*	American plaice	Gapeflyndre
127138	*Hippoglossus hippoglossus*	Atlantic halibut	Kveite
127139	*Limanda limanda*	Common dab	Sandflyndre
127140	*Microstomus kitt*	Lemon sole	Lomre
127141	*Platichthys flesus*	European flounder	Skrubbe
127143	*Pleuronectes platessa*	European plaice	Rødspette
127146	*Lepidorhombus whiffiagonis*	Megrim	Glassvar
127149	*Scophthalmus maximus*	Turbot	Piggvar
127160	*Solea solea*	Dover sole	Tunge
127185	*Oncorhynchus mykiss*	Steelhead trout	Regnbueaure
127214	*Cyclopterus lumpus*	Lump fish	Rognkjeks
127251	*Helicolenus dactylopterus*	Black-bellied rosefish	Blåkjeft
127254	*Sebastes mentella*	Beaked redfish	Snabeluer
127255	*Sebastes viviparus*	Norway redfish	Lusuer
127427	*Zeus faber*	John Dory	St.petersfisk
150637	*Eutrigla gurnardus*	Grey gurnard	Knurr
151324	*Sebastes norvegicus*	Golden redfish	Vanlig uer
151501	*Labrus mixtus*	Cukoo wrasse	Blåstål
158960	*Coryphaenoides rupestris*	Roundnose grenadier	Skolest
274877	*Chelidonichthys lucernus*	Tub gurnard	Rødknurr
325342	*Subclass - Coleoidea*	non-Specific – Coleoidea	Tiarmete blekkspruter

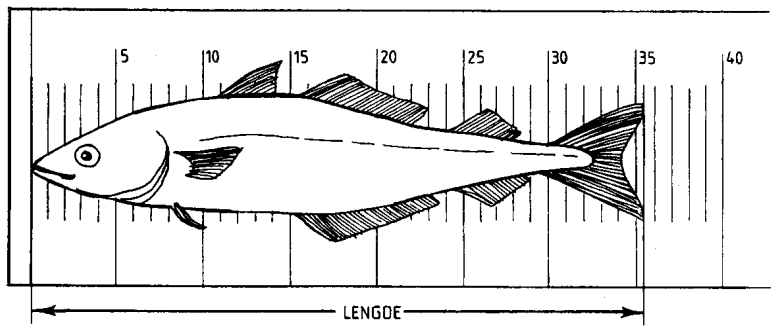
Appendix 6. Total number of rows and percentage of data removed from the total data set.

Data removed	**Number of lines removed**	**Percent of total data set**
Damaged demersal gillnets (Gear state less than 3) (Appendix 7)	2392	<1%
Other Gear Types (Pots)	23019	7%
Birds	92	<1%
Mammals	34	<1%
Pelagic fish	9664	3%
Other (i.e. non-IDed individuals)	61	<1%
TOTAL	**35262**	**11%**

Appendix 7. Categorization of gillnet damage status as described by the Norwegian Institute of Marine Research (Mjanger et al., 2019).

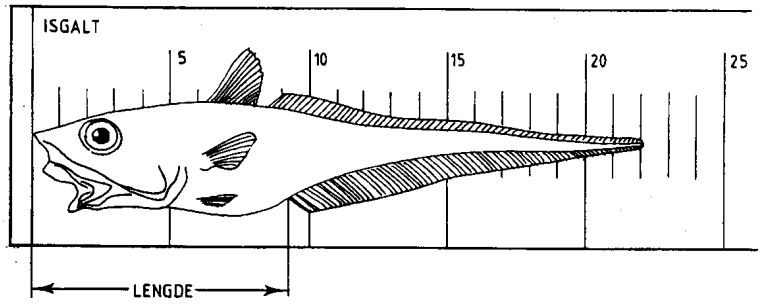
GEAR STATE (dropdown menu)	The state of the gear after a haul/cast.	
	Not observed	blank
	Gear is OK.	1
	Gear has small damages, no damages of essential importance for selection and catch. (F. ex. the gear has minor damage in the front part).	2
	Gear is damaged. Some fish may have escaped. (F. ex. the gear has damaged to the bellows and transition).	3
	Gear has long gashes or is missing large sections of netting, codend is intact.	4
	Gear is torn, small catch.	5
	Gear is ruined, no catch.	6
	Gear is lost.	7

Appendix 8. Fish length measurement techniques as described by the Norwegian Institute of Marine Research (Mjanger et al., 2019).

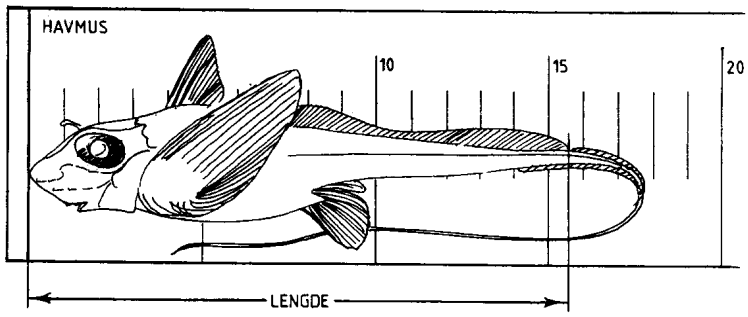


FORK LENGTH, from snout to the middle of the caudal fin, (code I).

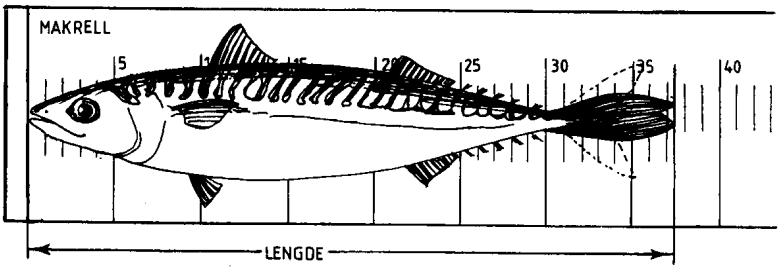
STANDARD LENGTH, from snout to bone knot in the caudal peduncle, (code J).



ALL OTHER SPECIES than those mentioned below are measured from snout to the
End of the caudal fin in a natural position, (code E).



GRENADIER
measured from the snout to the first finray of the anal fin, (code G).



RABBITFISH
measured from the snout to the posterior end of the first dorsal fin, (code H).

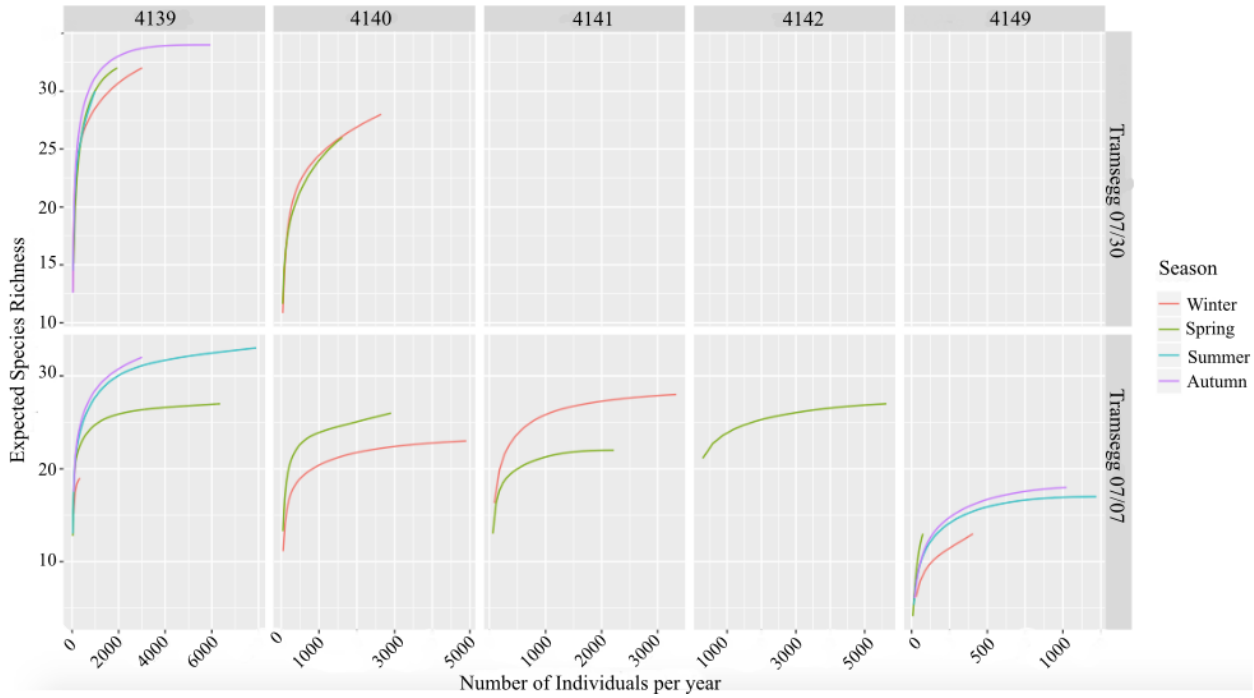
MACKEREL
measured from snout to the end of the caudal fin when it is pinched together, (code F).

Appendix 9. List of Length-Weight Parameters. Length-Weight relationship parameters calculated from individuals sampled by the Norwegian Institute of Marine Research and used in stock assessments.

				Britt Evelyn			Tramsegg		
Aphia ID	**Latin Name**	**English Name**	**Norwegian Name**	**a**	**b**	**Data Set**	**a**	**b**	**Data Set**
105824	*Argentina silus*	Greater argentine	Vassild	0,087	3,223	all	0,087	3,223	all
126759	*Anarhichas minor*	Spotted wolffsih	Flekksteinbit	-	-	-	0,183	2,865	gillnet north
105872	*Brosme brosme*	Cusk, tusk	Brosme	0,179	2,880	gillnet south	0,216	2,780	gillnet north
126436	*Chimaera monstrosa*	Chimaera	Havmus	0,142	2,945	all	0,142	2,945	all
126437	*Dipturus oxyrinchus*	Long-nosed skate	Spisskate	0,121	2,926	all	0,121	2,926	all
126440	*Eutrigla gurnardus*	Grey gurnard	Knurr	0,110	3,102	gillnet	0,190	2,927	all
126441	*Gadus morhua*	Cod	Torsk	0,183	2,839	gillnet south	0,183	2,836	gillnet north
126447	*Hippoglossus hippoglossus*	Atlantic halibut	Kveite	0,091	3,244	gillnet	0,111	3,154	all
126461	*Lepidorhombus whiffiagonis*	Megrim	Glassvar	0,160	2,861	gillnet	0,088	3,263	gillnet north
126484	*Limanda limanda*	Common dab	Sandflyndre	0,140	2,989	all	0,103	3,229	gillnet north
126555	*Lophius piscatorius*	Monkfish	Breiflabb	0,184	2,922	gillnet south	0,149	2,964	gillnet north
126715	*Melanogrammus aeglefinus*	Haddock	Hyse	0,123	3,077	gillnet south	0,098	3,131	gillnet north
127138	*Merluccius merluccius*	Hake	Lysing	0,081	3,208	gillnet	0,140	2,989	all
127139	*Microstomus kitt*	Lemon sole	Lomre	0,111	3,154	all	0,146	2,866	gillnet north
127140	*Molva molva*	Common ling	Lange	0,115	2,967	gillnet south	0,150	2,969	gillnet north

127146	*Pollachius pollachius*	Pollack	Lyr	0,171	2,890	gillnet	0,176	2,861	gillnet north
127255	*Pollachius virens*	Saithe	Sei	0,128	3,034	gillnet south	0,110	3,102	gillnet
150637	*Sebastesnorvegicus*	Golden redfish	Vanlig uer	0,129	3,150	gillnet	0,160	2,861	gillnet
151324	*Sebastes viviparus*	Norway redfish	Lusuer	0,190	2,927	all	0,128	3,154	gillnet north

Appendix 10. Species accumulation curves for t30 – Tramsegg 07/30 and t7 - Tramsegg 07/07 by gear type (4139 – demersal gillnets with mesh size 60-69mm, 4140 – mesh size 70-79mm, 4141 – mesh size 80 – 89mm, 4142 – mesh size 90 – 99, 4149 mesh size 180mm).



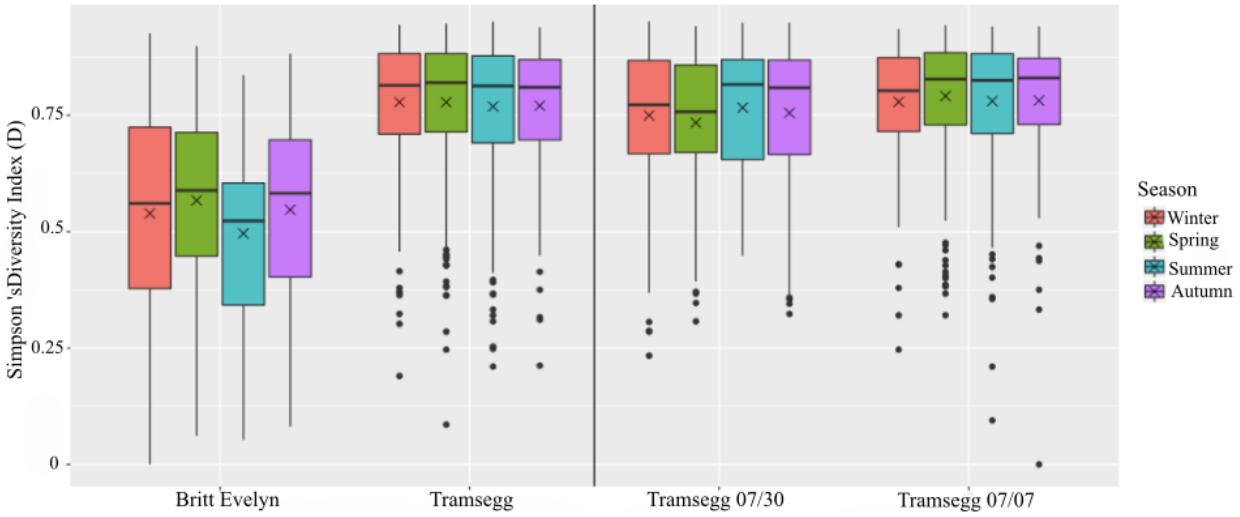
Appendix 11. Table of p-values from the biological null hypothesis test "biogTest.individual" comparing rarefaction curves between seasons by gear type. Function found in the "rareNMtests" package (Cayuela & Gotelli, 2014). Bonferroni corrected alpha (a = 0.01).

Vessel	**4139**	**4140**	**4141**	**4142**	**4149**
Tramsegg	0.34	0.28	0.99	-	0.10
Britt Evelyn	-	0.03	-	-	0.16

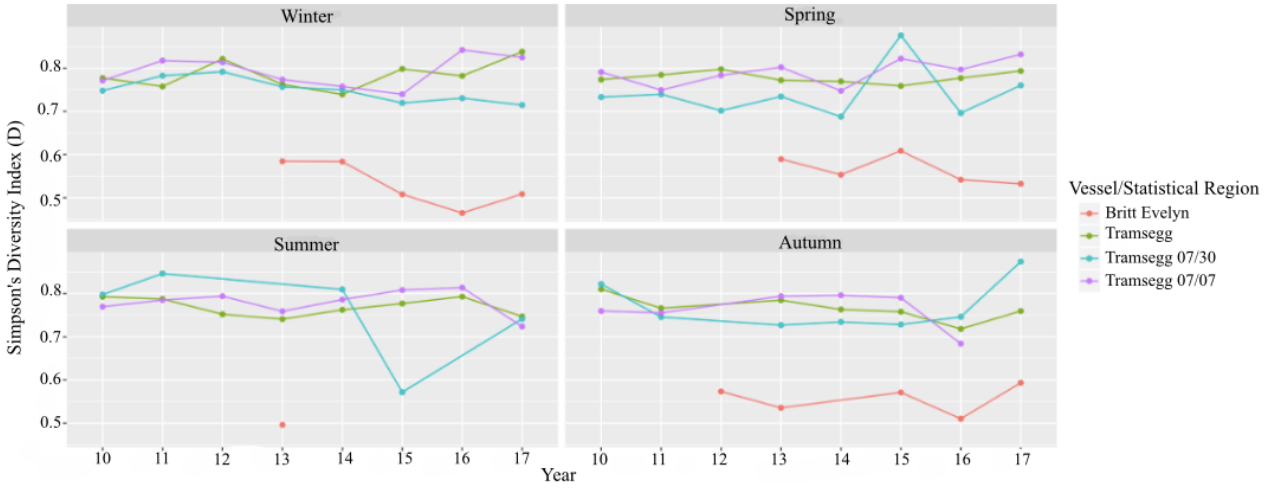
Appendix 12. Table of p-values from the biological null hypothesis test "biogTest.individual" comparing rarefaction curves between years of the same season and gear type. Function found in the "rareNMtests" package (Cayulea & Gotelli, 2014). Bonferroni corrected alpha (a = 0.003).

Gear Type	Season	Tramsegg	Britt Evelyn
4139	Winter	0.50	-
	Spring	0.03	-
	Summer	0.50	-
	Autumn	0.76	-
4140	Winter	0.54	0.08
	Spring	0.50	0.72
	Summer	-	-
	Autumn	-	0.88
4141	Winter	0.66	0.28
	Spring	0.20	-
	Summer	-	-
	Autumn	-	-
4142	Winter	-	-
	Spring	-	-
	Summer	-	-
	Autumn	-	-
4149	Winter	0.50	0.06
	Spring	0.50	0.60
	Summer	0.60	-
	Autumn	0.52	0.99

Appendix 13. Boxplot of Simpson's diversity values for all vessels and statistical regions comparing seasons of the same vessel and statistical region (x = mean).



Appendix 14. Boxplot of Simpson's diversity values for all vessels and statistical regions comparing years of the same season.



Appendix 15. Table of p-values comparing years of the same season for each vessel and gear type using both ANOSIM and ADONIS calculated from the "vegan" package in R (Oksanen et al. 2018). Bonferroni corrected alpha (a = 0.003).

Gear type	**Season**	**ANOSIM / ADONIS comparison between years of the same gear type and season**	
		Britt Evelyn	**Tramsegg**
4139	Winter	-	0.590 / 0.69
	Spring	-	0.61 / 0.41
	Summer	-	0.56 / 0.28
	Autumn	-	0.22 / 0.18
4140	Winter	0.37 / 0.29	0.15 / 0.008
	Spring	0.64 / 0.02	0.36 / 0.21
	Summer	-	-
	Autumn	0.93 / 0.05	-
4141	Winter	0.65 / 0.57	0.86 / 0.49
	Spring	-	0.47 / **0.003**
	Summer	-	-
	Autumn	-	-
4142	Winter	-	-
	Spring	-	-
	Summer	-	-
	Autumn	-	-
4149	Winter	0.63 / 0.56	0.33 / 0.37
	Spring	0.92 / 0.97	0.64 / 0.64
	Summer	-	0.81 / 0.61
	Autumn	0.49 / 0.93	0.86 / 0.95

Appendix 16. Complete list of species and catch per unit effort (CPUE) per 1000 gillnets. CPUE calculated as total number of individuals collected per total number of gillnets used over the course of the study. Percent landed from reported data. Tramsegg (2010 – 2017) and Britt Evelyn (2012 – 2017).

Species	**Britt Evelyn CPUE/1000 nets (Percent Landed)**	**Tramsegg CPUE/1000 nets (Percent Landed)**
Anarhichas denticulatus	-	<0.01 (100%)
Anarhichas lupus	1.1 (100%)	0.3 (32%)
Anarhichas minor	-	<0.01 (0%)
Acantholabrus palloni	0.5 (0%)	-
Amblyraja radiata	8.5 (0%)	76.5 (0%)
Argentina silus	1.9 (0%)	5.9 (0%)
Argentina sphyraena	-	0.1 (0%)
Brosme brosme	128.8 (99%)	2800.9 (97%)
Chelidonichthys lucernus	<0.01 (0%)	-
Cyclopterus lumpus	0.1 (0%)	20.8 (0%)
Callonymus lyra	<0.01 (0%)	-
Chimaera monstrosa	281.4 (5%)	305.7 (0.2%)
Cancer pagurus	35.1 (0%)	265.5 (1%)
Coryphaenoides rupestris	0.2 (60%)	0.1 (0%)
Coleoidea	0.1 (50%)	19.6 (0%)
Dipturus batis	-	0.8 (0%)
Dipturus linteus	5.0 (99%)	-
Dipturus nidarosiensis	-	<0.01 (0%)
Dipturus oxyrinchus	55.3 (85%)	3.9 (0%)
Eutrigla gurardus	14.9 (56%)	388.0 (0.1%)
Etmopterus spinax	158.6 (0%)	-
Glyptocephalus cynoglossus	96.4 (49%)	12.8 (0%)
Galeorhinus galeus	<0.01 (100%)	0.0 (0%)
Galeus melastomus	29.0 (0.1%)	503.0 (0%)
Gadus morhua	1478.4 (98%)	7736.9 (96%)
Geryonidae trispinosus	0.2 (0%)	-
Helicolenus dactylopterus	1.0 (82%)	-
Homarus gammarus	<0.01 (0%)	<0.01 (0%)
Hippoglossus hippoglossus	2.3 (54%)	1065.1 (21%)
Hippoglossoides platessoides	16.1 (1%)	-
Labrus bergylta	0.6 (81%)	6.3 (0%)
Lophius budegassa	0.2 (100%)	-
Leucoraja circularis	-	15.1 (0%)
Limanda limanda	23.4 (4.2%)	82.5 (0%)
Labrus maixtus	0.8 (8%)	8.5 (0%)
Lithodes maja	64.6 (1%)	72.7 (0.1%)
Lophius piscatorius	200.5 (95%)	3330.4 (99%)
Lepidorhombus whiffiagonis	225.5 (19%)	492.9 (0.1%)

Melanogrammus aeglefinus	8813.9 (97%)	10740.1 (92%)
Molva dypterygia	26.2 (50%)	6.8 (0%)
Microstomus kitt	8.4 (82%)	382.9 (0%)
Merlangius merlangus	15.9 (1%)	407.7 (0.1%)
Merluccius merluccius	290.3 (69%)	6032.7 (70%)
Molva molva	839.1 (96%)	5758.3 (93 %)
Nephrops norvegicus	1.4 (41%)	1.2 (0%)
Oncorhynchus mykiss	<0.01 (100%)	-
Phycis blennoides	0.1 (100%)	21.8 (0%)
Platichthys flesus	13.5 (60%)	-
Pleuronectes platessa	8.4 (95%)	28.7 (1%)
Pollachius pollachius	1467.6 (95%)	5395.7 (90%)
Pollachius virens	53639.6 (93%)	29978.3 (89%)
Raja clavata	7.8 (27%)	97.0 (2%)
Rajella fyllae	0.5 (0%)	-
Squalus acanthias	1400.0 (75%)	534.8 (1%)
Scyliorhinus canicula	0.1 (0%)	5.2 (0%)
Scophthalmus maximus	0.2 (100%)	0.3 (33%)
Sebastes mentella	0.1 (100%)	-
Sebastes norvegicus	2.5 (89%)	1417.1 (87%)
Solea solea	0.3 (11%)	-
Sebastes viviparus	95.1 (28%)	420.3 (0%)
Sebastes.spp	-	12.4 (72%)
Trisopterus esmarkii	0.9 (0%)	<0.01 (0%)
Trisopterus minutus	25.3 (0%)	321.1 (0%)
Urophycis chuss	-	0.3 (0%)
Zues faber	2.3 (97%)	1.3 (0%)

Appendix 17. Total catch weight (kg) reported for Britt Evelyn (2012 – 2017) and Tramsegg (2010 – 2017) and total catch weight per year (kg) for both vessels.

Species	Britt Evelyn		Tramsegg	
	Total catch weight	Total catch weight per year	Total catch weight	Total catch weight per year
Anarhichas lupus	117.5	19.6	296	37
Anarhichas minor	-	-	12	1.5
Brosme brosme	16273.6	2712.3	887808	110976
Chelidonichthys lucernus	0.3	0.1	-	-
Chimaera monstrosa	441.3	73.6	25	3.1
Coleoidea	3.7	0.6	-	-
Coryphaenoides rupestris	4	0.7	-	-
Dipturus linteus	696	116	-	-
Dipturus oxyrinchus	16661.5	2776.9	-	-
Eutrigla gurnardus	68.5	11.4	18	2.25
Gadus morhua	179841.6	29973.6	5982214	747776.8
Galeorhinus galeus	12.5	2.1	-	-
Galeus melastomus	1	0.2	-	-
Geryonidae trispinosus	-	-	-	-
Glyptocephalus cynoglossus	769.2	128.2	-	-
Helicolenus dactylopterus	19.8	3.3	-	-
Hippoglossoides platessoides	1.7	0.3	-	-
Hippoglossus hippoglossus	648.9	108.2	82635	10329.4
Labrus bergylta	13.8	2.3	-	-
Labrus mixtus	0.7	0.1	-	-
Lepidorhombus whiffiagonis	1095.5	182.6	18	2.3
Limanda limanda	14.4	2.4	-	-
Lophius budegassa	84.1	14	-	-
Lophius piscatorius	83158.4	13859.7	4876715.7	609589.5
Melanogrammus aeglefinus	792656.8	132109.5	2950812.8	368851.6
Merlangius merlangus	4.5	0.8	-	-
Merluccius merluccius	32073	5345.5	1401606	175200.8
Microstomus kitt	113.2	18.9	14	1.8
Molva dypterygia	3654.8	609.1	-	-
Molva molva	172173.2	28695.5	6441256.9	805157.1
Nephrops norvegicus	2.6	0.4	-	-
Oncorhynchus mykiss	4	0.7	-	-
Phycis blennoides	14	2.3	-	-
Platichthys flesus	130.6	21.8	-	-
Pleuronectes platessa	181.2	30.2	67	8.4
Pollachius pollachius	124542.6	20757.1	2218680	277335
Pollachius virens	6537231.6	1089538.6	12279766	1534970.8
Raja clavata	267	44.5	836	104.5
Scophthalmus maximus	32.3	5.4	199	24.9

Sebastes mentella	1.8	0.3	-	-
Sebastes norvegicus	130.1	21.7	156739.7	19592.5
Sebastes spp	-	-	469	58.6
Sebastes viviparus	255.1	42.5	3.4	0.4
Solea solea	0.4	0.1	-	-
Squalus acanthias	122034.4	20339.1	-	-
Todarodes sagittatus	2.8	0.5	-	-
Zeus faber	100.2	16.7	-	-
Total in tonnes	**8085 t**	**1347 t**	**37280 t**	**4660 t**