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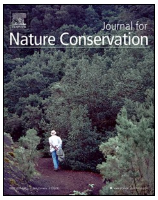

Quantification of catch composition in fisheries: A methodology and its application to compare biodegradable and nylon gillnets

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ABSTRACT

When evaluating fishing gear catches, the focus is often on a few species as opposed to the entire catch. In some fisheries this can lead to ignoring major part of catch composition. Thus, there is a need for a more holistic approach when evaluating the ecological impact of using a specific fishing gear and when comparing two or more gears. In this context, it is relevant to have a method that describes the total catch and quantifies proportions of the catch being wanted and unwanted. In this study, we outline such a method and demonstrate its applicability to catch data from a small-scale coastal gillnet fishery targeting European plaice (*Pleuronectes platessa,* Linnaeus, 1758) by comparing catch composition when using nylon and biodegradable gillnets. The results showed no significant differences in catch composition between gillnets made of the two materials. Therefore, the catch composition obtained using the more environmentally friendly biodegradable materials does not represent a barrier in this specific gillnet fishery. However, species selectivity of gillnets is still of concern as the primary target species constituted only half of the total catch composition in numbers while the rest was unwanted catch. The presented approach for quantifying and inferring the differences in catch composition can be further applied for assessing the performance of different fishing gears and their modifications.

1. Introduction

The incidental capture of unwanted species and sizes in fishing gear is widely recognised as a threat to nature conservation (i.e., Shester & Micheli, 2011; Northridge et al., 2015; Duarte et al., 2020) and can be considered as a major source of uncertainty in fisheries assessments (Gray et al., 2005a; Fauconnet et al., 2015). Consequently, many countries have established sampling programmes (e.g. Borges et al., 2005; Feekings et al., 2012) and numerous studies have looked into describing and understanding discarding practices (e.g. Borges et al., 2005; Feekings et al., 2012; Uhlmann et al., 2014; Ceylan et al., 2013; Fernandes et al., 2015; Kennelly, 2020). However, relatively few studies have examined total species composition of the entire catch, rather focusing on a few target species or few species of special concern. Such is also the case when assessing the species selectivity of fishing gears (Shester & Micheli, 2011). This can result in ignoring major part of species in the catch composition when evaluating the effects fishing gears have on the full community. Ignoring such species could lead to further declines in species richness, since fishing is known to negatively affect species of limited or no commercial value (Coleman & Williams, 2002). Hence, knowledge of total catch composition caught in fishing gears, including wanted catches consisting of primary and secondary target species, and composition of organisms of non-target species or sizes (unwanted catch) could provide information for identifying potential impacts that the fishery has on different marine species and ecosystems (Gray et al., 2005a; Senko et al., 2022).

Several examples in the literature describe different indices for quantifying species composition and species biodiversity in marine ecosystems (i.e., Whittaker, 1972; Chao, 2005; Gamfeldt et al., 2014). Such studies use these indices for quantifying changes in the environment due to, for example, increasing seawater temperatures due to climate change (i.e., Hiddink & Coleby, 2012; Bilous et al., 2022). They usually apply a combination of different measures to assess the species biodiversity. Since biodiversity is a multidimensional concept, such

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estimates include assessments of species richness, evenness and dominance (Maurer & McGill, 2011; Daly et al., 2018). Herrmann et al. (2022) used species biodiversity indices and applied a nested bootstrapping technique to account for uncertainty in the estimation and infer changes in the species composition in mesopelagic biodiversity (i.e., species richness, Shannon and Pielou indices and indices of species dominance). A similar approach of assessing the species diversity can be adapted to quantify the species composition in fishing gear catches and infer changes in catch composition when changing different parameters of the fishing gear (e.g. material type, mesh size, twine thickness etc.). Furthermore, by adapting the method used in Herrmann et al. (2022), it is possible to obtain confidence intervals and infer changes for the catch composition between different fishing gears. The aim of this study is to establish a method that allows to estimate and compare the catch composition in fisheries by adapting biodiversity indices to assess species diversity, evenness, and species dominance in fishing gear catches. Specifically, we demonstrate the application of such an approach using a case study from a gillnet fishery where the catch composition from gillnets with two different netting materials (nylon and biodegradable plastic) are compared.

Gillnets represent a particular concern due to their relatively low species selectivity if fished in areas with multiple species (Suuronen et al., 2012). This fishing gear is commonly used to harvest many different species of fish (He, 2006a; FAO, 2016). Low species selectivity in gillnets implies that in some fisheries many different species can get captured by the gear. However, relatively few studies have examined the gillnet catch rates by assessing the total catch composition (Shester & Micheli, 2011). Therefore, detailed information on catch composition in gillnets would improve the understanding of the impact of using this fishing gear on different species.

Gillnets consist of a netting wall, usually made of nylon, which is deployed vertically in the water column by having weights along the bottom and floats along the top (He, 2006a). During fishing, gillnets are soaked for varying periods of time to catch animals that swim into netting and get caught. Gillnets are usually made of nylon as this material provides good mechanical properties such as high breaking strength, elasticity and durability. Although such characteristics are desirable, they also create a concern from an environmental perspective. Globally, a significant proportion of gillnets are lost, abandoned, or discarded at sea (Deshpande et al., 2020; Gilman et al., 2021) and their degradation is slow in the marine environment (Grimaldo et al., 2019; Brakstad et al., 2022). Moreover, nylon netting contributes to macro- and microplastic pollution when it is degraded into smaller particles over time (Moore, 2008). In addition, gillnets can continue capturing marine animals when lost in the ocean (so-called “ghost fishing”). (He, 2006a; Deshpande et al., 2020). To limit the pollution caused by lost fishing gear, new biodegradable materials are being developed such as biodegradable plastics made of polybutylene succinate co-adipate-*co*-terephthalate (PBSAT) resin. Such biodegradable material aims to degrade in a shorter time compared to nylon gillnets (Brakstad et al., 2022), thus limiting the potential ghost fishing time. Furthermore, the material degrades into components that are not harmful to the marine environment (Kim et al., 2014a,b).

Gillnets made of biodegradable PBSAT material have different material properties such as lower elasticity and tensile strength compared to nylon gillnets (Grimaldo et al., 2019; Grimaldo et al., 2020). These differences in material properties have resulted in changes in catch efficiency for target species (Grimaldo et al., 2018a, b, 2019, 2020; Cerbule et al., 2022) due to different patterns regarding fishes’ mode of capture in gillnets (Cerbule et al., 2022) for biodegradable compared to nylon gillnets. The effect of changing from nylon to biodegradable materials has only been investigated for a few target species; however, the results of these studies suggest that it could possibly also affect the catch composition of species that are not being targeted. To demonstrate our method, we collected catch data from a costal Danish gillnet fishery in Skagerrak targeting European plaice (*Pleuronectes platessa*, Linnaeus, 1758) as the primary target species as a case study.

The gillnet fishery for European plaice constitutes one of the most important small-scale commercial fisheries in Denmark (Savina et al., 2017). Although European plaice is the main target species in this fishery, catches of secondary target species (i.e., other species with a commercial value) such as sole (*Solea solea,* Linnaeus, 1758), lemon sole (*Microstomus kitt*, Walbaum, 1792), common dab (*Limanda limanda,* Linnaeus, 1758) or brown crab (*Cancer pagurus,* Linnaeus, 1758), are also caught. However, wanted catches represent only part of the total catch composition as the catch normally contains several species (Fig. 1), part of which has no commercial value. Further, some commercial species are subjected to minimum conservation reference sizes (MCRS), where the sale of catches below the MCRS are prohibited and, therefore, this part of the catch composition is not considered commercial (European Commission, 2020), representing a challenge regarding size selection for these species. The present study demonstrates the application of the proposed method to compare e.g. different operational strategies, compare different fishing grounds, seasons or to compare different gears such as in this case, material properties of gillnets by quantifying and comparing catch composition in nylon and biodegradable gillnets in total catches, as well as in the wanted and unwanted catches.

2. Materials and methods

2.1. Experimental design and sea trials

The catch composition in gillnets for this study were quantified by recording the number of species in gillnet catches as well as the number of individuals within each species for nylon and biodegradable gillnets, separately. The catch composition of 8 nylon and 8 biodegradable gillnets were investigated during fishing trials conducted onboard a small-scale gillnet vessel targeting European plaice. The experiments were conducted over a total of 10 fishing trips during September 2021 in the Skagerrak area off the coast of Hirtshals. The fishing grounds were located between 57°36.436–57°38.012 N and 09°56.927–10°14.608E (Fig. 2; Table 1).

All biodegradable gillnets were made of PBSAT resin (Kim et al., 2017, patent EP3214133). Nylon and biodegradable gillnets were manufactured by S-ENPOL (Gangwon-do, South Korea). The nets were assembled by Hvalpsund Net AS (Denmark) for the Danish commercial plaice fishery. The nylon and biodegradable gillnet sheets were made of double knotted 0.40 mm monofilament twine. Both types of gillnets had 75 mm half-mesh size (150 mm full mesh) and were 15.5 meshes deep. Each gillnet sheet was 55 m long and they were attached to 18.0 m long float- and leadline to give a hanging ratio (E) of 0.3. The netting was sewn (fastened) to the float- and leadline every-five meshes.

The two different nets were mounted into one fleet where each nylon gillnet (N) was followed by a biodegradable gillnet (B) in an alternated order so that each material type is exposed to the same spatial variability in fish availability within gillnets: *N*-B-*N*-B-*N*-B-*N*-B-*N*-B-*N*-B-*N*-B-*N*-B. The distance between single gillnet sheets in the fleet was approximately 1 m. Consequently, all gillnets had identical soak patterns during all fishing activity (Table 1).

When the gillnets were hauled and fish unmeshed, the catch was sorted by type of gillnet (i.e., biodegradable or nylon). All fish and invertebrate mega-fauna were sorted by species during the hauling operation and number of individuals for each species counted as “total catch”. Further, the catch was sorted into wanted catch (primary and secondary target species) and unwanted catch separately.

2.2. Quantification of catch composition

To quantify catch composition in gillnets, we adapted the following biodiversity estimates: richness (Daly et al., 2018), Pielou index measuring species evenness (Pielou, 1966) and Shannon index

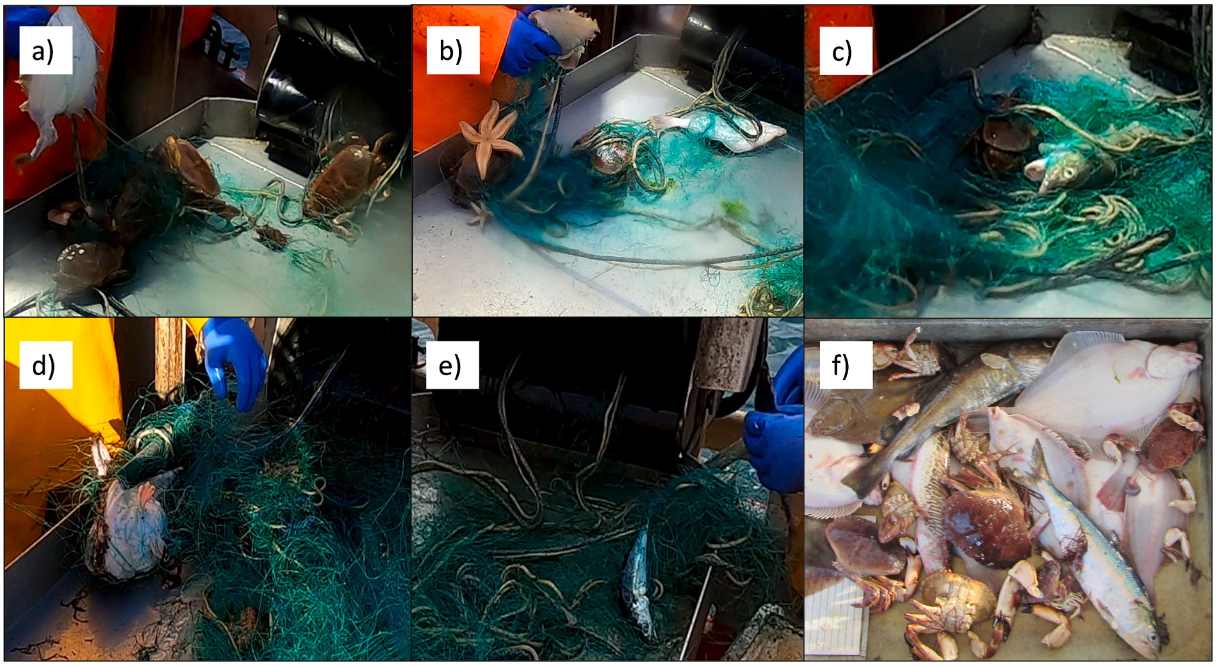

Fig. 1. Examples of species observed during gillnet retrieval process. (a) European plaice (wanted catch) and brown crab (large individuals – wanted catch); (b) brown crab, European plaice and common starfish (unwanted catch); (c) cod (wanted catch) and brown crab; (d) monkfish (wanted catch); (e) mackerel (unwanted catch); (f) European plaice, brown crab, herring (unwanted catch); swimming crab (unwanted catch), common dab, greater weever and cod.

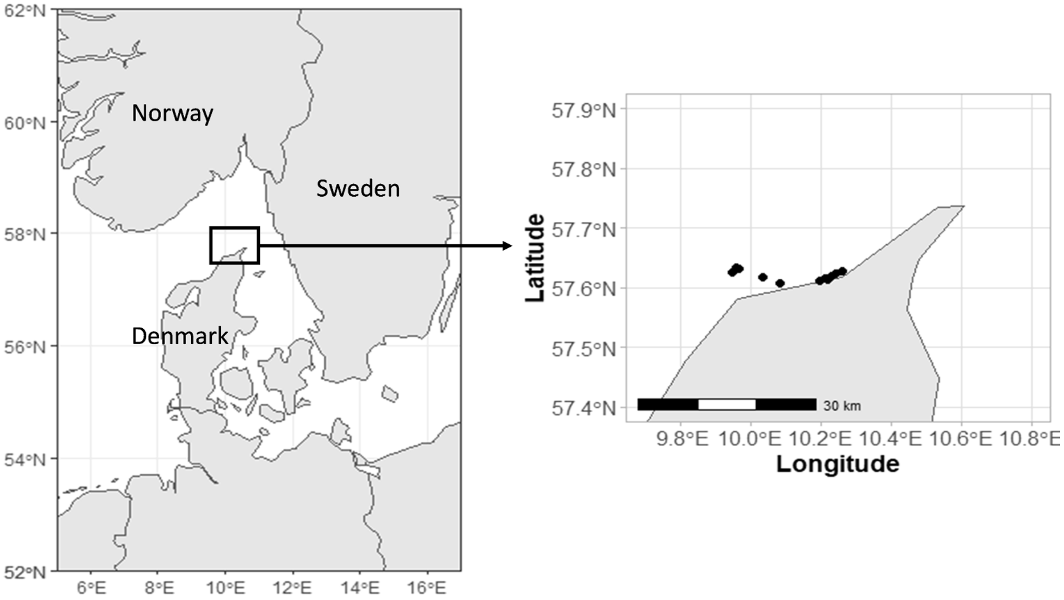

Fig. 2. Map of the positions where the gillnets were deployed.

accounting for a combination of richness and evenness of the species distribution (Shannon, 1948). Such biodiversity measures quantify aspects regarding species composition and dominance of individual species (Herrmann et al., 2022), and, therefore, can be applied to estimate the catch composition (total, wanted and unwanted catch) for each type of gillnet. We assessed the catch composition in nylon and biodegradable gillnet catches by estimating the number of species encountered in our samples and their distribution between total, wanted and unwanted catch.

The value for each of the biodiversity indices was estimated for both gillnet types separately. Further, we used cumulative dominance plots to assess cumulative proportional abundances of the species (i.e., species dominance) (Warwick et al., 2008). We determined the catch composition by calculating values of the indices averaged over all gillnet deployments contrary to using catch composition in individual netting sheets.

The different indices were estimated as described below. The value for each of the indices was estimated for nylon and biodegradable gillnets from count numbers n_{ij} for each species S_i where i is the predefined species ID and j is the gillnet deployment. Q represents the total number of species in the list.

2.2.1. *Species richness*

The richness index accounts for the absolute number of species in the

Table 1
Gillnet deployment date and time and hauling time for following day with the resulting soak time. Depth and the position where the gillnets were deployed during the trials.

Deployment	Date	Deployment time (hh:mm)	Soak time (hh: mm)	Position (start)	Depth (m)
1	10.09.2021	09:15	21:45	57°36.658N 10°11.800E	6
2	11.09.2021	08:35	21:50	57°36.988N 10°01.199E	6
3	15.09.2021	08:00	23:35	57°37.150N 10°13.826E	4
4	19.09.2021	08:35	22:50	57°36.913N 10°12.781E	4
5	20.09.2021	08:00	27:05	57°37.671N 10°15.570E	3
6	21.09.2021	12:00	23:40	57°36.436N 10°04.902E	3
7	27.09.2021	12:30	20:55	57°37.498N 09°56.927E	18
8	28.09.2021	10:30	21:00	57°37.940N 09°57.969E	18
9	29.09.2021	09:25	22:05	57°38.012N 09°57.591E	18
10	30.09.2021	11:30	21:00	57°38.006N 09°57.589E	18

catches (Maurer & McGill, 2011), and was calculated for the total as well as the wanted and unwanted catch composition in nylon or biodegradable gillnets, respectively. According to the estimation of richness (Eq. 1), all species in the sample have equal weight regardless of species abundance encountered (Daly et al., 2018). The richness was estimated as follows (Herrmann et al., 2022):

$$R_j = \sum\nolimits_{i=1}^{Q} e\left(n_{ij}\right) \quad \text{where} \quad e(n) = \begin{cases} 0 & \forall \quad n < 1 \\ 1 & \forall \quad n \geq 1 \end{cases} \tag{1}$$

2.2.2. Shannon index

The Shannon diversity index is one of the most commonly used measures in species biodiversity (Maurer & McGill, 2011). By calculating the Shannon index, we considered both richness and evenness of the species abundance within each gillnet type within the total catch composition and wanted and unwanted catch. The Shannon index increases with the number of species sampled and with a more even distribution of species within the sample. Thus, the value of the Shannon index is zero in cases when only one species in a sample is observed (Daly et al., 2018). Therefore, a low value of the Shannon index implies low species diversity in the catch. The Shannon index was estimated by (Herrmann et al., 2022):

$$H_j = -\sum\nolimits_{i=1}^{Q} ln\left(\left(\frac{n_{ij}}{n_j}\right)^{\frac{n_{ij}}{n_j}}\right) \quad \text{where} \quad n_j = \sum\nolimits_{i=1}^{Q} n_{ij} \tag{2}$$

2.2.3. Species evenness

Pielou's evenness index measures how evenly the number of individuals are distributed among the species in the catches (Maurer & McGill, 2011; Daly et al., 2018) in total as well as the wanted and unwanted catch compositions. Therefore, it expresses the degree of equality in species abundance (Bandeira et al., 2013). The index is calculated as follows (Eq. 3) (Herrmann et al., 2022):

$$J_j = \frac{-H_j}{ln\left(R_j\right)} \tag{3}$$

The resulting value of Pielou's evenness index will range from 0.0 to 1.0. If the value reaches 1.0, this shows that all species in the sample are equally abundant (Kanieski et al., 2018).

2.2.4. Species dominance pattern

Further, we examined the species dominance patterns in total, wanted and unwanted catch compositions determining whether one or few species are more abundant compared to all the species in the sample (Maurer & McGill, 2011). We quantified the information about the catch composition of relative species abundances for nylon and biodegradable gillnets. Specifically, we estimated the species dominance patterns as follows:

$$d_{ij} = \frac{n_{ij}}{\sum_{i=1}^{Q} n_{ij}} \tag{4}$$

To represent species dominance patterns, cumulative dominance curves are often used. Such cumulative ranked species dominance curves show the cumulative proportional abundances plotted against the species rank. Cumulative dominance is estimated as follows (Eq. 5):

$$D_{Ij} = \frac{\sum_{i=1}^{I} n_{ij}}{\sum_{i=1}^{Q} n_{ij}} \quad \text{with} \quad 1 \leq I \leq Q \tag{5}$$

where I is the species ID summed up in the nominator (Herrmann et al., 2022).

In our study, we kept a fixed species ranking for species in all catches in the dominance curves, starting with wanted species followed by the unwanted species. This allows comparison of the steepness of the cumulative dominance curves to obtain an overview on how many species are dominant and the distribution of their relative dominance in total, wanted and unwanted catch compositions in nylon and biodegradable gillnets, respectively. The steeper the curve, the more dominated by few species is the sample, thus implying a lower diversity. Further, since dominance of some species can be low and they may not be present for some catch compositions (either wanted or unwanted catch composition), this would be shown by resulting horizontal parts in corresponding dominance curves.

2.3. Estimating uncertainty for observed catch composition

The estimation of uncertainty for the observed catch composition was based on Herrmann et al. (2022). The number of individuals of all species identified in the sample from a gillnet deployment j was defined as n_j:

$$n_j = \sum_{i=1}^{Q} n_{ij} \tag{6}$$

Because n_j is a finite number, a resampling method with replacement was used to estimate the uncertainties for the individual species counts. The resulting count numbers n_{ij} varied from one such resampling to another. By performing resamplings, we could obtain a population of data for each n_{ij}. After applying equations (1)–(5), we could generate a bootstrap population of values for each indicator measure, which we could use to obtain Efron percentile 95 % confidence intervals (CIs) (Efron, 1982) for each indicator measure and gillnet deployment j (Herrmann et al., 2022). However, to estimate the total value for the biodiversity indices for all gillnet deployments, n_{ij} in equations (1)–(5) was replaced with n_i which is given by:

$$n_i = \sum_{j=1}^{K} n_{ij} \tag{7}$$

where the summation was considered over a group of K gillnet deployments.

To account for variation between deployments when estimating the uncertainties, another resampling loop was applied (Herrmann et al., 2022). This outer resampling loop resampled with replacement K deployments over the K deployments considered. For each deployment selected, the inner resampling was conducted accounting for the finite sample size for the specific deployment. This nested resampling technique was applied 1000 times, leading to 1000 sets of n_i data. We applied equations (1)–(5) to these data to obtain a population of results for the indicators to estimate Efron 95 % percentile CIs for this estimation based on the group of stations within the area considered. The analysis was conducted using the software tool SELNET (Herrmann et al., 2012), which implements the described method.

2.4. Inferring difference in species dominance and diversity index values

To estimate differences in diversity index values for total, wanted and unwanted catch compositions in nylon and biodegradable gillnets, respectively, and to infer potential effects of changing gillnet material on the indices (Eq. 1–3), we used the ratio between values:

$$r_{y/x} = \frac{r_y}{r_x} \tag{7}$$

where r is one of the indices given by Eq. (1), (2) or (3) and x and y represent the index value for the total, wanted or unwanted catch compositions, respectively, if the comparison is within the same gillnet type. If the comparison is done between the two gillnet types, x and y are index values for the same catch composition (total, wanted or unwanted catch) for the two different gillnet types, respectively. The 95 % CIs for $r_{y/x}$ were obtained based on the two bootstrap population results for r_x and r_y, respectively (Eq. 8). As they were obtained independently of each other, a new bootstrap population of results was created using:

$$r_{y/xl} = \frac{r_{yl}}{r_{xl}} l \in [1 \cdots 1000] \tag{8}$$

In Eq. (8), l denotes the bootstrap repetition index. Based on the bootstrap population of results for $r_{y/x}$, we were able to obtain Efron percentile 95 % CIs (Efron, 1982). To determine whether the difference between the values of the indices is significant, we inspected if the 1.0 value was included in the CI for the ratio $r_{y/x}$. If the value 1.0 (or 100 % if the value is expressed in percentage) was not within the obtained CIs, then the indicator values for nylon and biodegradable gillnets differed significantly. On the contrary, when 1.0 was included in the CIs, no significant difference was detected.

Further, the difference Δd in species dominance d in the nylon (x) and biodegradable (y) gillnets was estimated by (Herrmann et al., 2022):

$$\Delta d = d_y - d_x \tag{9}$$

CIs for Eq. (9) were obtained based on separate bootstrap populations for d_x and d_y by applying the same technique as described above for $r_{y/x}$. However, when inferring for significance, we inspected if the CIs for the difference contained the value 0.0. If 0.0 value was within the CIs, no significant difference was detected (Herrmann et al., 2022).

3. Results

In total, 1280 and 1062 individuals belonging to 28 species were captured in nylon and biodegradable gillnets, respectively, during the sea trials (Table 1). From those, 12 species (821 individuals) and 11 species (631 individuals) was classified as wanted catch (primary and secondary target species) for nylon and biodegradable gillnets, respectively. The rest of the species contributed to unwanted catch (Table 2).

3.1. Estimated catch compositions for nylon and biodegradable gillnets

3.1.1. Species richness

The total, wanted and unwanted catch compositions were estimated for both, biodegradable and nylon, gillnets. Both types of gillnets showed similar catch composition (Tables 3–5). Specifically, no significant differences between the two gillnet types were observed when applying the different biodiversity index estimations (richness, Pielou and Shannon index).

The quantified species richness for the catch composition (i.e., species in the total catch composition) was 25.00 (CI: 19.40–28.40) and 22.00 (CI: 18.85–24.85) for nylon and biodegradable gillnets, respectively. The total catch composition was significantly more diverse compared to the wanted catch species for both gillnet types when the pairwise difference between them was compared (i.e., ratios of richness, Shannon and Pielou values between both gillnet types; Table 4).

3.1.2. Shannon index

There was a significant difference in diversity between unwanted and wanted catch compositions regarding species richness and Shannon index in both gillnets. Specifically, the results of the estimated indices showed significant differences between wanted and unwanted catch compositions for both nylon and biodegradable gillnets (Table 4). Species richness was significantly lower for wanted compared to unwanted catch in nylon (i.e., 55 % (CI: 41–78 %)) and biodegradable (i.e., 55 % (CI: 36–81 %)) gillnets. This showed a higher species diversity in unwanted catch compared to wanted catches in the fishery. A similar result was also reflected in the Shannon index values which for both gillnet types were significantly higher for unwanted catch compared to wanted catches (Table 4).

3.1.3. Pielou evenness index

Additionally, species across the unwanted catch composition of the catch showed higher evenness in species distribution (based on values of Pielou index) compared to wanted catches in both gillnet types. This implies that the individuals of unwanted catch are more evenly distributed among the different species compared to wanted catch where one or few species dominated. Specifically, half of the wanted catch composition in numbers was constituted by catches of the primary target species European plaice. This, therefore, implies that the catch composition for the wanted catch were characterized by higher dominance of limited number of species.

3.2. Dominance patterns

The species cumulative dominance patterns (Fig. 3) and species dominance values (Supplementary material 1) were in line with the results described above regarding species distribution in wanted and unwanted catches in both gillnet types. Fig. 3 shows dominance curves for the cumulative dominance values as estimated by Equation (5). The horizontal parts of the cumulative dominance curve (Fig. 3) show specific species that were not represented in the sample of total (grey lines), wanted catch (green lines) or unwanted catch (red lines) species, respectively.

3.2.1. Species dominance pattern in catch compositions

In both types of gillnets, fewer species contributed to the wanted catches compared to unwanted catch of all captured individuals. In the wanted catch composition, species abundance was dominated by few species. Specifically, European plaice dominated wanted catches with 74.88 % (CI: 47.59–86.36 %) in nylon gillnets and 76.23 % (CI: 52.19–87.84 %) in biodegradable gillnets. Indeed, European plaice contributed to half of the total catch composition individuals (Fig. 3)

Table 2
List of species and number of individuals sampled during the experiments. MCRS = minimum conservation reference size (Fiskeristyrelsen, 2022). Species names marked with * denote species of wanted catch.

				Number of individuals						–	–	–
				Nylon gillnets			Biodegradable gillnets			–	–	–
Species ID	Species name	Common name	MCRS (cm)	Total	Wanted	Unwanted	Total	Wanted	Unwanted			
1	*Pleuronectes platessa* (Linnaeus, 1758)*	European plaice	27	671	626	45	538	481	57			
2	*Solea solea* (Linnaeus, 1758)*	Sole	24	10	10	0	13	13	0			
3	*Gadus morhua* (Linnaeus, 1758)*	Cod	30	26	16	10	20	12	8			
4	*Limanda limanda* (Linnaeus, 1758)*	Common dab	–	90	42	48	89	39	50			
5	*Scopthalmus maximus* (Linnaeus, 1758)*	Turbot	–	42	25	17	46	20	26			
6	*Platichtyes flesus* (Linnaeus, 1758)*	Flounder	–	17	17	0	10	8	2			
7	*Cancer pagurus* (Linnaeus, 1758)*	Brown crab	–	153	73	80	125	51	74			
8	*Molva molva* (Linnaeus, 1758)*	Common ling	–	0	0	0	1	1	0			
9	*Lophius piscatorius* (Linnaeus, 1758)*	Monkfish	–	4	3	1	3	2	1			
10	*Zeugopterus punctatus* (Bloch, 1787)*	Topknot	–	2	1	1	3	2	1			
11	*Scomber scombrus* (Linnaeus, 1758)*	Mackerel	20	76	6	70	64	2	62			
12	*Microstomus kitt* (Walbaum, 1792)*	Lemon sole	–	1	1	0	0	0	0			
13	*Merlangius merlangius* (Linnaeus, 1758)*	Whiting	23	5	1	4	1	0	1			
14	*Asterias rubens* (Linnaeus, 1758)	Common starfish	–	71	–	71	79	–	79			
15	*Pollachius pollachius* (Linnaeus, 1758)	Pollock	30	2	–	2	0	–	0			
16	*Trachinus draco* (Linnaeus, 1758)	Weeverfish	–	2	–	2	1	–	1			
17	*Portunus* (Weber, 1795)	Swimming crab	–	77	–	77	56	–	56			
18	*Hyas araneas* (Linnaeus, 1758)	Spider crab	–	5	–	5	2	–	2			
19	*Carcinus maenas* (Linnaeus, 1758)	Shore crab	–	8	–	8	1	–	1			
20	*Anguilla anguilla* (Linnaeus, 1758)	Eel	40	0	–	0	1	–	1			
21	*Pagurus bernhardus* (Linnaeus, 1758)	Hermit crab	–	6	–	6	6	–	6			
22	*Syngnathus* (Linnaeus, 1758)	Pipefish	–	4	–	4	1	–	1			
23	*Raja clavata* (Linnaeus, 1758)	Thornback ray	–	2	–	2	0	–	0			
24	*Aurelia aurita* (Linnaeus, 1758)	Common jellyfish	–	0	–	0	1	–	1			
25	*Myoxocephalys scorpius* (Linnaeus, 1758)	Shorthorn sculpin	–	1	–	1	1	–	1			
26	*Clupea harengus* (Linnaeus, 1758)	Herring	18	2	–	2	0	–	0			
27	*Eutrigla gurnardus* (Linnaeus, 1758)	Grey gurnard	–	2	–	2	0	–	0			
28	*Raniceps raninus* (Linnaeus, 1758)	Tadpole fish	–	1	–	1	0	–	0			

Table 3
Values of different biodiversity indices estimated for nylon and biodegradable gillnets and divided into species as total, wanted and unwanted catch.

	Nylon gillnets			Biodegradable gillnets		
Index	Total	Wanted	Unwanted	Total	Wanted	Unwanted
Richness	25.00 (19.40–28.40)	12.00 (09.69–13.69)	22.00 (15.61–25.61)	22.00 (18.85–24.85)	11.00 (08.41–12.41)	20.00 (16.40–23.40)
Shannon	01.80 (01.40–02.22)	01.02 (00.64–01.64)	02.28 (02.01–02.47)	01.76 (01.35–02.16)	00.97 (00.60–01.55)	02.15 (01.94–02.29)
Pielou	00.56 (00.43–00.72)	00.41 (00.26–00.65)	00.74 (00.68–00.79)	00.57 (00.43–00.71)	00.40 (00.24–00.67)	00.72 (00.66–00.78)

Table 4
Ratios (%) between values of different biodiversity indices estimated for nylon and biodegradable gillnets and divided into species as total, wanted and unwanted catch. Values in parentheses represent 95% confidence intervals.

	Nylon gillnets			Biodegradable gillnets		
Index	Wanted / total	Wanted / unwanted	Unwanted / total	Wanted / total	Wanted / unwanted	Unwanted / total
Richness	48.00 (39.33–60.20)	54.55 (41.28–78.42)	88.00 (76.72–94.70)	50.00 (37.01–67.49)	55.00 (36.50–81.11)	90.91 (78.79–99.00)
Pielou	73.39 (59.06–91.74)	55.59 (35.85–86.80)	132.02 (103.42–169.40)	70.96 (55.18–93.82)	56.09 (34.98–90.62)	126.51 (102.92–160.88)
Shannon	56.66 (44.76–75.31)	44.69 (27.29–77.74)	126.77 (96.78–164.01)	55.05 (42.81–74.15)	44.90 (26.93–75.88)	122.61 (98.36–156.28)

Table 5
Ratio for index values for biodegradable vs nylon gillnets (%). Values in parentheses represent 95% confidence intervals.

	Biodegradable vs nylon gillnets		
Index	Total	Wanted	Unwanted
Richness	88.00 (67.46–117.70)	91.67 (66.83–121.83)	90.91 (65.68–131.61)
Pielou	101.76 (68.61–146.66)	98.39 (46.37–185.01)	97.51 (86.51–109.44)
Shannon	97.72 (67.51-138.47)	94.94 (42.44-178.84)	94.51 (82.08-108.75)

with 51.81 % (CI: 27.80–67.23 %) and 50.66 % (CI: 26.46–66.55 %) captured in nylon and biodegradable gillnets, respectively. The rest of the total catch composition was dominated by brown crab (11.81 % (CI: 05.78–22.42 %) and 11.77 % (CI: 06.67–20.92 %), for nylon and biodegradable gillnets, respectively) and other secondary target species such as common dab and mackerel among others. Thus, there were less species contributing to the wanted catch composition in nylon and biodegradable gillnets compared to the total catch composition. There was a large variation of species regarding the unwanted catch composition in both nylon and biodegradable gillnets (Fig. 3). Some species were recorded in only a few gillnet deployments.

3.2.2. Pairwise difference in species dominance in biodegradable versus nylon gillnets

The pairwise difference in cumulative dominance (delta) curves (Fig. 4) shows the differences in species dominance for total, wanted and unwanted catch compositions in biodegradable versus nylon gillnets. No significant differences between gillnets using the two materials were

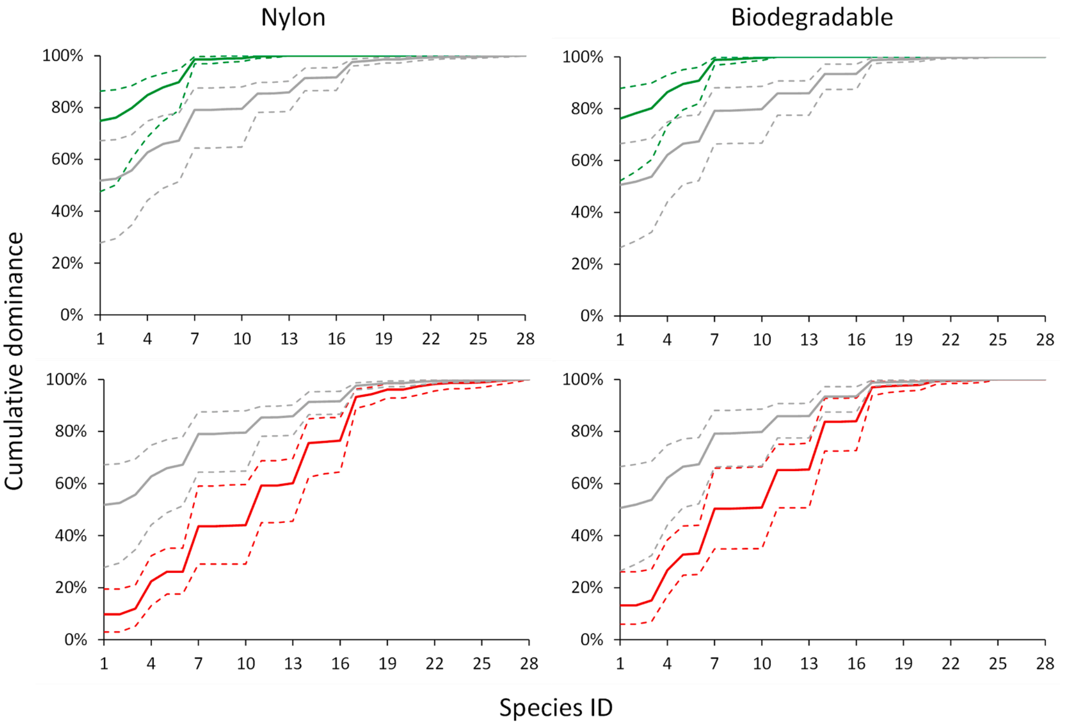

Fig. 3. Cumulative dominance curves for nylon gillnets (left) and biodegradable gillnets (right). Grey curve represents dominance curve for total catch composition by particular gear material while green and red line – species that were classified as wanted and unwanted catch, respectively. Dashed lines are 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

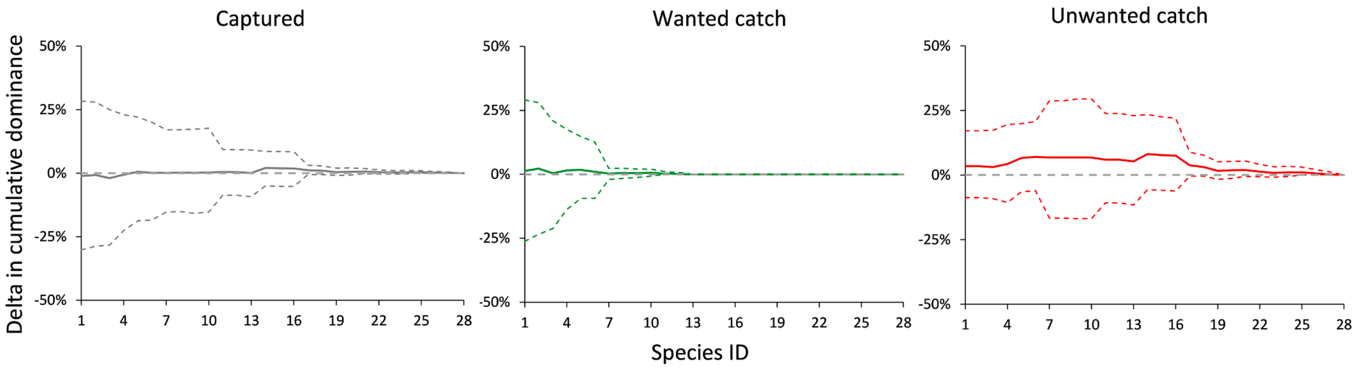

Fig. 4. Pairwise difference in cumulative dominance curves for biodegradable versus nylon gillnets for total (left), wanted (middle) and unwanted (right) catch species. Dashed lines are 95% confidence intervals.

detected regarding catch composition in species dominance as the results included 0.0 within the obtained CIs.

4. Discussion

In this study, we used data from a Danish coastal gillnet fishery directed at European plaice to quantify and compare the catch composition in biodegradable and nylon gillnets. The comparison was done by estimating the ratios between the diversity index values and by using the delta approach (Herrmann et al., 2022) to cumulative dominance plots. Furthermore, the application of the nested bootstrapping (Herrmann et al., 2022) made it possible to infer changes in catch composition between the fishing gear types. Both biodegradable and nylon gillnets showed similar catch composition regarding species recorded as total, wanted and unwanted catch. The primary target species, European plaice, dominated the wanted catch for both types of gillnets, with other species in the wanted catch consisting of several secondary target species. However, our results showed significant differences in composition regarding wanted and unwanted catches in this fishery, with European plaice constituting half of the total catch composition for nylon and biodegradable gillnets. This showed that a large part of the total catch composition, expressed as number of individuals, in this fishery is made up by different unwanted species (20.00 (CI: 16.40–23.40) for biodegradable and 22.00 (CI: 15.61–25.61) for nylon gillnets).

Since European plaice only constituted half of the total catch composition, considering only the target species in this fishery would ignore the other half of the species (in numbers) affected by the particular fishery since 28 different species were captured during this study. Thus, the diversity of the total catch composition was higher compared to what ended up in the wanted catch composition (i.e., 11 and 12 species). The remaining species only contributed to unwanted catch in this fishery. In future studies, this approach can be supplemented by accounting for these patterns expressed not only as number of individuals for each species but also in weight which was not done in this study due to time constraints during the trial.

The results in this case study should be interpreted with caution as they are based on a limited number of gillnet deployments during one fishing season and using one fishing vessel. Further, the trials were performed by slightly changing the fishing area in order to capture cod in sufficient numbers. However, we believe that the collected data are well suited for demonstrating our concept of making a more holistic evaluation of the gillnet performance in the particular fishery. The difference between biodegradable and nylon gillnets did not show any statistical significance regarding the catch composition in wanted and unwanted catch compositions, and the two gillnet types were subjected to the same conditions regarding the factors that could affect the catch composition (i.e., the fishing area, fishing depth, time of deployment, vessel, and gillnet soaking time).

In our study, biodegradable and nylon gillnets showed similar catch composition. These results show that use of new biodegradable gillnets would not increase vulnerability of species being affected by the biodegradable gillnets compared to traditionally used nylon nets. Since no differences were detected by changing gillnet material from traditionally used nylon to biodegradable plastics, the catch composition would not represent a barrier for implementing biodegradable materials in this commercial gillnet fishery. However, the differences in the material properties between biodegradable and nylon nets are expected to increase with the use of the gear (Grimaldo et al., 2020; Cerbule et al., 2022) due to a faster degradation of the biodegradable netting (Brakstad et al., 2022). Therefore, further experiments using the developed method involving repeated deployments would be necessary for determining the effect of long-term use of the biodegradable and nylon gillnets on the catch composition.

In this study, we quantified species richness, evenness and species dominance, as well as cumulative dominance within fishing gear catches. Such an approach can move the field beyond focusing on a few commercial species, which is typically the case when analysing the selectivity of fishing gears, to one that provides a more detailed overview of the entire catch. The presented approach has some similarities when compared to Fauconnet et al. (2015) who aimed at assessing how fishing pressure is distributed across the species community using estimates of species richness and evenness. However, the method described in this study can provide a direct comparison, and it considers the hierarchical structure in uncertainties (i.e., between and within gillnet deployments) and uses a nested bootstrapping approach when estimating biodiversity indices. This further allowed inferring differences between the gears using the delta approach (Herrmann et al., 2022).

The approach developed here for estimating and comparing catch composition for all species caught, both wanted and unwanted, was applying indices that are used for analysing species biodiversity (i.e., Greenstreet et al., 2012; Farriols et al., 2017; Taylor et al., 2017). This approach can provide additional information that can be useful when assessing the impact fishing gears have on the marine ecosystem, since only focusing on the wanted species may not reflect the actual species composition that is caught in a fishery (Eliasen et al., 2019). Furthermore, this approach can be used when analysing data collected during larger data collection programmes for catch and discard sampling (Feekings et al., 2012; Suuronen & Gilman, 2020). These data collections are often based on extensive time series covering all seasons since the targeting behaviour and species composition can have temporal variations (Feekings et al., 2012). The methods developed here would provide an additional way for monitoring changes and allow comparisons between fishing gear types and assess catch compositions in different areas and between different seasons. Specifically, since the abundance and composition of species varies by fishing area and/or period of time, it is, therefore, affecting catch composition of both wanted and unwanted catch. This can result in obligations for fishing vessels to change the fishing grounds and area closures. Therefore, assessing catch composition has the potential to identify fisheries that in different fishing areas, seasons or under different operational patterns may result in desired or undesired levels of environmental impact.

The presented method can be applied in other studies for quantifying and inferring the differences in catch composition in various fisheries and using different fishing gear configurations. Further, the method could be used when grouping the observed species in the total catch composition into functional groups when assessing fisheries impacts on endangered, threatened and vulnerable species. Normally in a fishery, there is an interest in reducing catches of both undersized individuals of target species and catches of non-target species, even if the exact effect on the ecosystem is unknown (Bellido et al., 2011) and to reduce the sorting time during the gear retrieval. In gillnets, the species selectivity can be changed by, for example, different properties of the gear such as hanging ratio (Gray et al., 2005b), gillnet height (He, 2006b), mesh size (Fonseca et al., 2005, Lucchetti et al., 2020; Soe et al., 2022) or netting material (Gray et al., 2005b), or by changing fishing depth (Soe et al., 2022) and soaking time (Savina et al., 2017). However, changes in such properties could also affect the catch rates of wanted and unwanted species differently. Therefore, an assessment of suitable gear properties by quantifying catch composition is necessary. Further, this method could also be applied in studies assessing not only gillnets but also the catch composition of other fishing gears such as trawls, especially when targeting multiple species or in fisheries with high levels of unwanted catches such as in Norwegian lobster (*Nephrops norvegicus,* (Linnaeus, 1758) fishery (Melli et al., 2018). Specifically, this approach can have the potential to be utilized when analysing data collected in large data collection programmes such as discard sampling programmes. The proposed method can involve challenges regarding the data collection process because of the need to identify each species captured by the gear which can be challenging during commercial fishing. However, this process can in the future be optimized by the use of, for example, electronic monitoring to assess compositions of wanted and unwanted species (i.e., Suuronen & Gilman, 2020; Khokher et al., 2022) and to detect and count the species during data collection using e.g. artificial intelligence and machine learning (French et al., 2020; Sokolova et al., 2021). Therefore, there is a potential that the developed method can be used to describe catch composition for fisheries and monitor spatial and temporal developments in species richness, diversity and dominance to guide the development of more sustainable fisheries providing we are able to link catch composition to ecosystem effects.

CRediT authorship contribution statement

Kristine Cerbule: Conceptualization, Investigation, Formal analysis, Visualization, Writing – original draft. **Esther Savina:** Funding acquisition, Writing – original draft, Supervision. **Bent Herrmann:** Conceptualization, Software, Writing – original draft, Supervision. **Roger B. Larsen:** Writing – original draft, Supervision. **Jordan Paul Feekings:** Conceptualization, Writing – original draft. **Ludvig Ahm Krag:** Conceptualization, Writing – original draft. **Alina Pellegrinelli:** Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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