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Sea trials report

Results from sea trials made using biodegradable gillnets on cod, January – March 2019

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ABSTRACT
Gillnets made of a new biodegradable resin (polybutylene succinate co-adipate-co-terephthalate (PBSAT) were tested under commercial fishing conditions to compare their fishing performance with that of conventional nylon (PA) nets. The relative catch efficiency between the two gillnet types was evaluated over the entire 2019's winter fishing season for cod (Gadus morhua) in northern Norway.

The nylon gillnets caught 19% more fish (in numbers) than the biodegradable gillnets throughout the fishing season and generally showed better catch rates for most length classes. Any difference in breaking strength and elongation a break was detected when nets were new, and therefore it is unclear what caused the catch differences between the nets. The number of times that the gillnets were deployed affected the relative catch efficiency of the gillnets with the nylon continuously loosing efficiency compared to the biodegradable. The biodegradable gillnet catch efficiency became more similar to that of the nylon gillnet as the number of times it was deployed increased.

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1 Experimental setup

Sea trials were conducted on board the coastal gillnet boat "MS Karoline" (10.9 m LOA) throughout January and March in 2019 with the aim to further investigate the relative catch efficiency between gillnets made using biodegradable and nylon twine. The fishing grounds chosen for the tests were located off the coast of Troms (Northern Norway) between 70°21'–70°22'N and 19°39'–19°42'E, which is a common fishing area for coastal vessels from Troms.

Gillnets with a 210 mm nominal mesh opening was used for both types of gillnets, with monofilament twine thickness of 0.75 mm in the biodegradable gillnet and 0.7 mm thickness in the nylon gillnet. Since the biodegradable monofilament is approximately 10% weaker than nylon (at the same monofilemant thickness), we increased the thickness of the bionet's monofilament from 0.7 to 0.75mm expecting to match the tensile strength of the nylon nets.

We used two sets of gillnets in the experiments. Each set consisted of 16 gillnets, with eight bio gillnets (B) and eight nylon gillnets (N). The gillnets were arranged in such a way that they provided the best information for paired comparison, nylon versus bio net, accounting for spatial and temporal variation in the availability of cod. With individual sets being the basic unit for the subsequently paired analysis (described in section 2.4), it was important that within each gillnet set averaged over nets that the bio and nylon nets were approximately exposed to the same spatial variability in cod availability. This could in principle be achieved by alternating between the two types of nets after each net sheet as B-N-B-N-B-N-B-N-B-N-B-N-B-N-B-N. However, for easing of registration of fish on board in relation to the type of net in which it was caught, the alternation in net types were only applied after each second net sheet. Therefore, to make conditions as equal between net types a possible set 1 was arranged as N-BB-NN-BB-NN-BB-NN-BB-N and set 2 as B-NN-BB-NN-BB-NN-BB-NN-B. Actual measurements of the mesh openings (four rows of 20 meshes each) were taken with a Vernier calliper without applying tension to the meshes and showed that the mean mesh openings of nylon gillnets and bio gillnets were 210.6 ± 1.1 mm and 204.3 ± 2.1 mm, respectively.

2 Data analysis

We used the statistical analysis software SELNET (Herrmann et al., 2012, 2016) to analyze the catch data and conduct length-dependent catch comparison and catch ratio analyses. Using the catch information (numbers and sizes of cod in each gillnet set deployment), we wanted to determine whether there was a significant difference in the catch efficiency averaged over deployments between the nylon gillnet and the bio gillnet. We also wanted to determine if a potential difference between the gillnet types could be related to the size of the cod. Specifically, to assess the relative length-dependent catch efficiency effect of changing from nylon gillnet to bio gillnet, we used the method described in Herrmann et al. (2017) and compared the catch data for the two net types. This method models the length-dependent catch comparison rate (CCl) summed over gillnet set deployments (for the full deployment period):

$$CC_l = \frac{\sum_{j=1}^{m}\{nt_{lj}\}}{\sum_{j=1}^{m}\{nt_{lj}+nc_{lj}\}} \qquad (1)$$

where nclj and ntlj are the numbers of cod caught in each length class l for the nylon gillnet (control) and the bio gillnet (treatment) in deployment j of a gillnet set (first or second set). m is the number of deployments carried out with one of the two sets. The functional form for the catch comparison rate CC(l,v) (the experimental being expressed by equation 1) was obtained using maximum likelihood estimation by minimizing the following expression:

$$-\sum_l\left\{\sum_{j=1}^{m}\left\{nt_{lj}\times ln\big(CC(l,v)\big)+nc_{lj}\times ln\big(1.0-CC(l,v)\big)\right\}\right\} \qquad (2)$$

where v represents the parameters describing the catch comparison curve defined by CC(l,v). The outer summation in the equation is the summation over length classes l. When the catch efficiency of the bio gillnet and nylon gillnet is similar, the expected value for the summed catch comparison rate would be 0.5. Therefore, this baseline can be applied to judge whether or not there is a difference in catch efficiency between the two gillnet types. The experimental CCl was modelled by the function CC(l,v) using the following equation:

$$CC(l,v) = \frac{exp(f(l,v_0,\ldots,v_k))}{1+exp(f(l,v_0,\ldots,v_k))} \quad (3)$$

where f is a polynomial of order k with coefficients v0 to vk. The values of the parameters v describing CC(l,v) were estimated by minimizing equation (2), which was equivalent to maximizing the likelihood of the observed catch data. We considered f of up to an order of 4 with parameters v0, v1, v2, v3, and v4. Leaving out one or more of the parameters v0…v4 led to 31 additional models that were also considered as potential models for the catch comparison CC(l,v). Among these models, estimations of the catch comparison rate were made using multi-model inference to obtain a combined model (Burnham and Anderson 2002; Herrmann et al., 2017).

The ability of the combined model to describe the experimental data was evaluated based on the p-value. The p-value, which was calculated based on the model deviance and the degrees of freedom, should not be < 0.05 for the combined model to describe the experimental data sufficiently well, except for cases for which the data are subject to over-dispersion (Wileman et al., 1996; Herrmann et al., 2017). Based on the estimated catch comparison function CC(l,v) we obtained the relative catch efficiency (also named catch ratio) CR(l,v) between the two gillnet types using the following relationship:

$$CR(l,v) = \frac{CC(l,v)}{(1-CC(l,v))} \quad (4)$$

The catch ratio is a value that represents the relationship between catch efficiency of the bio gillnet and that of the nylon gillnet. Thus, if the catch efficiency of both gillnets is equal, CR(l,v) should always be 1.0. CR(l,v) = 1.5 would mean that the bio gillnet is catching 50% more cod with length l than the nylon gillnet. In contrast, CR(l,v) = 0.8 would mean that the bio gillnet is only catching 80% of the cod with length l that the nylon gillnet is catching.

The confidence limits for the catch comparison curve and catch ratio curve were estimated using a double bootstrapping method (Herrmann et al., 2017). This bootstrapping method accounts for between-set variability (the uncertainty in the estimation resulting from set deployment variation of catch efficiency in the gillnets and in the availability of cod) as well as within-set variability (uncertainty about the size structure of the catch for the individual deployments). However, contrary to the double bootstrapping method (Herrmann et al., 2017), the outer bootstrapping loop in the current study accounting for the between deployment variation was performed paired for the bio gillnet and nylon gillnet, taking full advantage of the experimental design with the bio gillnet and nylon gillnet being deployed simultaneously (see Fig. 1). By multi-model inference in each bootstrap iteration, the method also accounted for the uncertainty due to uncertainty in model selection. We performed 1000 bootstrap repetitions and calculated the Efron 95% (Efron, 1982) confidence limits. To identify sizes of cod with significant differences in catch efficiency, we checked for length classes in which the 95% confidence limits for the catch ratio curve did not contain 1.0.

Finally, a length-integrated average value for the catch ratio was estimated directly from the experimental catch data using the following equation:

$$CR_{average} = \frac{\sum_l \sum_{j=1}^{m}\{nt_{lj}\}}{\sum_l \sum_{j=1}^{m}\{nc_{lj}\}} \quad (5)$$

where the outer summation covers the length classes in the catch during the experimental fishing period.

2.5. Modelling the effect of number of times deployed on the length-integrated catch ratio

To investigate the effect of the number of times the gillnets were the deployed on the length-integrated catch ratio, the equation (5) was calculated for individual deployment sets such without the summation over gillnet sets. This led to a dataset consisting of pair values for number of times the gillnets were deployed and corresponding values for CRaverage. Based on this dataset, we tested if the value for CRaverage changed linearly with number of deployment times (DNO) using the following equation:

$$CR_{average}(DNO) = \alpha \times DNO + \beta_l \qquad (6)$$

The last part of the analysis using model (6) was conducted using the linear model function (lm) in statistical package R (version 2.15.2; www.r-project.org).

3 Tensile strength tests

Tensile strength tests were carried out on samples of the bio and nylon gillnets used in before and after fishing experiments using a H10KT universal tensile testing machine (Tinius Olsen TMC, PA, USA). Samples of gillnets measuring approx. 20 x 20 meshes were cut from the centre of the new and used gillnets. The tests were performed in wet conditions (at least 40 replicates for each case) according to ISO 1806. Tensile strength, defined as the stress needed to break the sample, is given in kg, and elongation at break, defined as the length of the sample after it had stretched right when it breaks (L) is given relative to the initial mesh size in percentage.

4 Results

A total of 5332 cod (*Gadus Morhua*) were caught during the 18 deployments of the two gears with 2382 individuals caught in the biodegradable gillnet and 2950 caught in the nylon net (table 1). Figure 1 outlines the length dependency for the number of cod caught within each length class and by each gillnet. The biodegradable and nylon gillnet curves each have the same frequency tendency across length classes, while the biodegradable caught less for most length classes, the most fish for both gears were caught for length classes between 88 cm and 108 cm (fig. 1).

The catch comparison curve indicated a significant difference in catch efficiency between the two materials for individuals between 92 and 111 cm (fig 2). Within this range the nylon gillnet caught a significantly higher amount of cod as these length classes had a lower value for the biodegradable gillnets. The remaining length classes were caught at approximately the same frequency by the two gillnets. The curve provides a good fit to the catch data and this can be confirmed by the fit statistics in table 2. The trend outlined in figure 2 is further emphasized in the estimated catch ratio curve (fig. 3) as the nylon catches significantly more cod for these central length classes (92 cm – 111 cm). This interval is further explained in analysis of the individual length classes of 95, 100, 105 and 110 cm where the significant difference is shown by the narrow confidence limits. For example, in the length classes of 95 and 105 cm, the biodegradable gillnets caught 80.96% (CI = 71.05-89.01) and 72.53% (CI = 63.03-85.02) of what the nylon gillnets caught, respectively (table 2). The length integrated average value for the catch ratio of the biodegradable gillnet with respect to the nylon gillnet across all deployments was 80.75%. This indicates a reduction in catch by the biodegradable gillnet on average of 19.25% compared to the nylon gillnet.

The curve provided in figure 4 displays a trend opposite to that observed in previous sea trials testing biodegradable gillnets (Grimaldo et al., 2019, 2018). The biodegradable gillnet catch efficiency became more similar to that of the nylon gillnet as the number of times it was deployed increased. As this was seen to be size dependent from the catch ratio curve of figure 3 it could be explained if the mean size distribution changed throughout the fishing season. However, it was actually found that there was a slight tendency for the mean size to increase before it stabilized (table not given). So, we have two sets of results. Regarding the overall catch efficiency, we see a length dependency. The pattern is not the same but has the same tendency as in previous studies. Regarding the number of deployments, we have managed to obtain results that are exactly opposite to those in previous studies (Grimaldo et al., 2019, 2018).

Table 1: Catch data over all deployments

Set no.	Setting date	Fishing time (hh:mm)	Fishing depth (m) (min - max)	Accumulated number of deployments	Number of cod in bio gillnets	Number of cod in nylon (PA) gillnets	Minimum cod Length	Maximum cod length
1	24/01/19	43h 55m	40-115	1	30	38	66	124
2	24/01/19	46h 00m	48-85	1	14	30	61	124
1	26/01/19	46h 55m	40-115	2	21	31	77	113
2	26/01/19	47h 10m	48-85	2	41	47	71	123
1	28/01/19	24h 15m	40-115	3	15	20	75	114
2	28/01/19	24h 45m	48-85	3	7	13	81	112
1	29/01/19	47h 10m	40-115	4	29	37	68	118
2	29/01/19	47h 10m	48-85	4	13	30	76	109
1	31/01/19	23h 30m	40-115	5	13	20	71	107
2	31/01/19	23h 35m	48-85	5	5	10	89	106
1	04/02/19	19h 00m	40-115	6	51	54	78	120
2	04/02/19	19h 45m	48-85	6	97	99	78	118
1	05/02/19	20h 05m	40-115	7	29	55	80	110
2	05/02/19	20h 10m	48-85	7	74	103	71	120
1	06/02/19	22h 50m	40-115	8	50	49	79	122
2	06/02/19	22h 30m	48-85	8	55	95	65	121
1	07/02/19	23h 05m	40-115	9	81	107	78	121
2	07/02/19	24h 15m	48-85	9	107	125	74	125
1	08/02/19	22h 45m	40-115	10	130	133	78	116
2	08/02/19	21h 40m	48-85	10	112	125	64	123
1	09/02/19	22h 45m	40-115	11	51	77	72	122
2	09/02/19	23h 25m	48-85	11	67	71	79	124
1	10/02/19	23h 20m	40-115	12	81	100	74	125
2	10/02/19	23h 20m	48-85	12	27	33	81	117
1	11/02/19	24h 50m	40-115	13	238	286	68	127
2	11/02/19	22h 10m	48-85	13	186	225	68	126
1	12/02/19	22h 10m	40-115	14	169	213	78	122
2	12/02/19	22h 20m	48-85	14	88	125	74	123
1	13/02/19	18h 00m	40-115	15	142	157	81	121
2	13/02/19	18h 15m	48-85	15	107	125	74	118
1	28/02/19	17h 00m	40-115	16	64	71	77	123
2	28/02/19	17h 20m	48-85	16	59	73	68	118
1	02/03/19	23h 15m	40-115	18	57	73	72	121
2	02/03/19	23h 05m	48-85	18	72	100	79	125

Table 2: Catch rate and fit statistics results from the bio gillnet vs. nylon (PA) gillnet based on all deployments. Values in parentheses indicate 95% confidence intervals. DOF denotes the degrees of freedom.

Length (cm)	Catch ratio (%)
70	133.93 (69.35-228.18)
75	121.98 (83.59-196.40)
80	108.48 (82.92-163.15)
85	97.39 (79.49-127.52)
90	88.17 (75.45-101.07)
95	80.96 (71.05-89.01)
100	75.78 (66.87-83.90)
105	72.53 (63.03-85.02)
110	71.19 (58.50-94.23)
115	71.74 (54.58-105.68)
120	74.26 (47.67-114.94)
Average	80.75 (73.85-87.64)
p-value	0.2483
Deviance	64.92
DOF	58

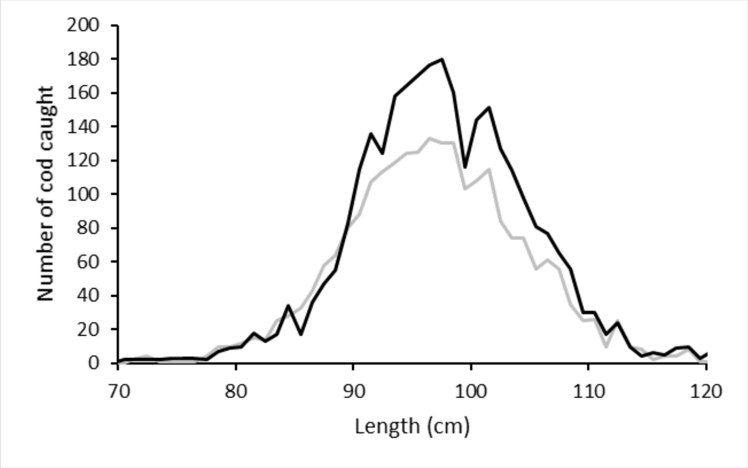

Fig. 1: The size distribution of fish caught with each type of gillnet (the black curve is for the nylon gillnet and the grey curve is for the bio gillnet).

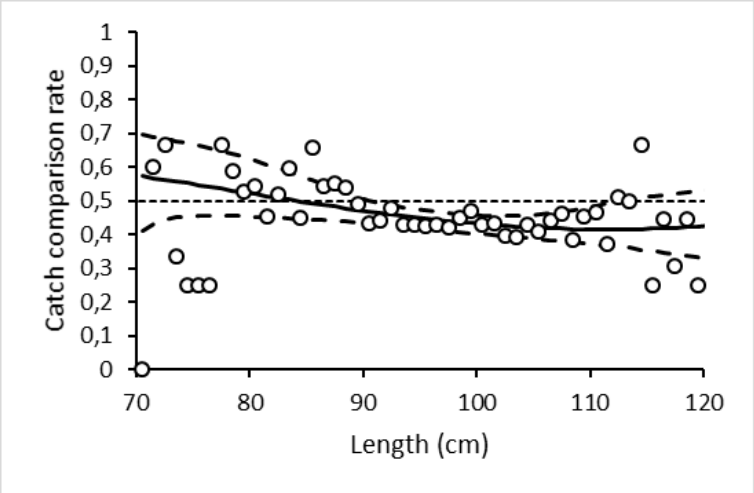

Fig 2: The catch comparison based on the total deployments, circle marks indicate the experimental rate and the curve indicates the modelled catch comparison rate. The dotted line at 0.5 indicates the baseline where both types of gillnets fish the same amount. The stippled curves indicate a 95% confidence interval for the estimated catch comparison curve.

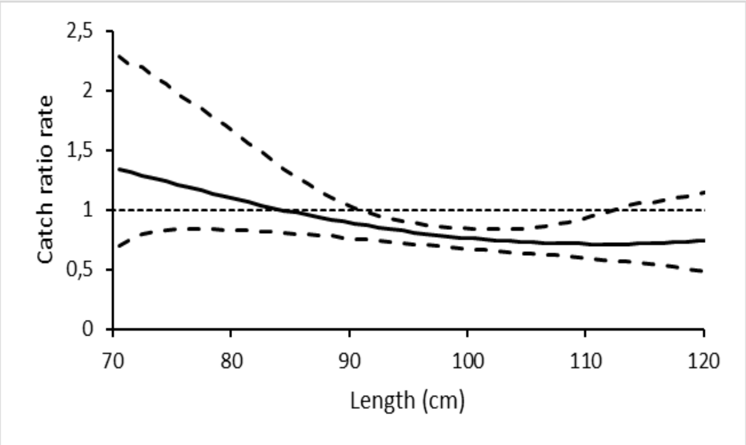

Fig 3: The estimated catch ratio curve based on all of the deployments (solid line). The dotted line at 1.0 indicates the baseline where fishing efficiency of both gillnet types is equal. The stippled curves represent a 95% confidence interval of the estimated catch ratio curve.

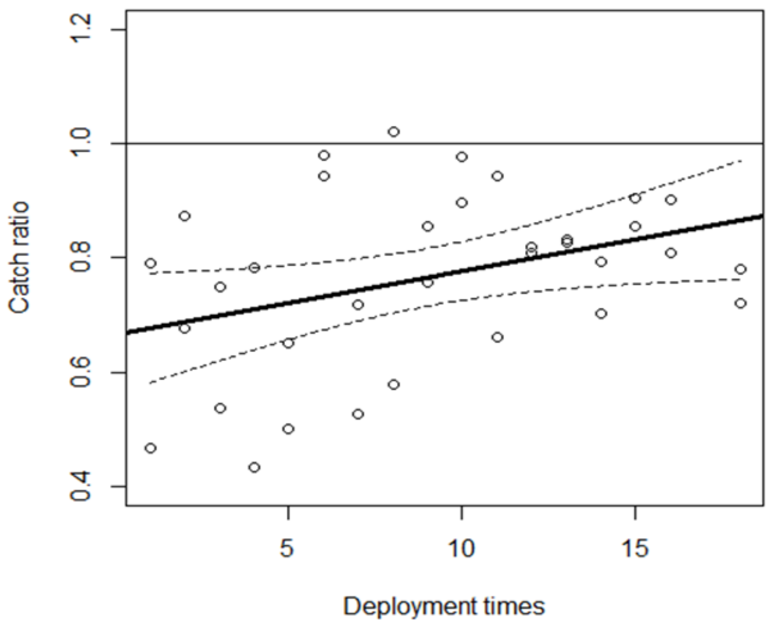

Fig. 4: The fit of linear model testing of the effect of the times deployed on the average catch ratio. The horizontal line at 1.0 indicates the point at which both the biodegradable and the nylon gillnets fish equally. The circle marks indicate the experimental length-integrated catch ratio (average catch ratio) for the individual deployments. The thick line indicates the modelled effect of times deployment on the average catch ratio. The two stipple curves indicate a 95% confidence interval for the linear model.

Tensile strength tests shoved no significant differences in tensile strength and elongation at break between new bio and nylon nets. When used, nylon and bionets lose 3.6% and 5.3 % of their tensile strength and 18% and 4.6% of their elongation at break (Table 3).

Table 3: Mean tensile strength (kg) and elongation at break (%) with 95 % confidence intervals (in brackets) for new and used gillnets.

Sea trial	Netting	Tensile strength (kg)			Elongation at break (%)		
		New	Used	%	New	Used	%
Winter season 2019	0.70mm Nylon	22.6 (22.9–23.2)	21.7 (20.9–22.4)	−3.6	40.0 (39.2–40.9)	32.6 (24.6–25.9)	−18.5
	0.75mm Biodegradable	22.5 (22.0–22.9)	21.3 (20.7–21.9)	−5.3	39.2 (38.5–39.8)	37.3 (36.7–37.9)	−4.6

5 Discussion and conclusion

The nylon gillnets caught 19% more fish (in numbers) than the biodegradable gillnets throughout the fishing season and generally showed better catch rates for most length classes. Any difference in breaking strength and elongation a break was detected when nets were new, and therefore it is unclear what caused the catch differences between the nets.

The number of times that the gillnets were deployed affected the relative catch efficiency of the gillnets with the nylon continuously loosing efficiency compared to the biodegradable. The curve provided in figure 4 displays a trend opposite to that observed in previous sea trials testing biodegradable gillnets (Grimaldo et al., 2019, 2018). The biodegradable gillnet catch efficiency became more similar to that of the nylon gillnet as the number of times it was deployed increased. As this was seen to be size dependent from the catch ratio curve of figure 3 it could be explained if the mean size distribution changed throughout the fishing season.

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