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Fishing profiles of Danish seiners and bottom trawlers in relation to current EU management regulations

Noack, Thomas; P. Fransen, Rikke; Wieland, Kai; Krag, Ludvig Ahm; Berg, F; Madsen, Niels

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1 **Fishing profiles of Danish seiners and bottom trawlers in relation** 2 **to current EU management regulations**

3 **Abstract**

4 Danish seines and bottom trawls operate differently and have different catching processes. Both gears
5 belong to the same legislative category in European fisheries, but different management strategies in
6 other countries and critics by fishers on grouping Danish seines and trawls together indicate disagreement
7 on current gear classification. The present study compared both gears in terms of their fishing
8 characteristics and their catches of commercial species based on 16 years of observer data. Danish
9 seining is a specialized fishing method that targeted few species, but with higher total catch rates than
10 bottom trawlers. Bottom trawling is a more all-purpose fishing method that targets a larger number of
11 species and bottom trawlers use larger engines than Danish seiners. A generalized additive mixed model
12 indicated that catch rates of flatfish are generally higher for Danish seines and catch rates of roundfish
13 species are higher for trawlers. The results do not directly suggest a separation of the gears in terms of
14 legislation as the quantities of fish below current minimum size were similar, but for example future
15 survival studies may reach different conclusions. Additional factors were found to be important in
16 determining catches of both gears.

17 **KEYWORDS**

18 Common Fisheries Policy, demersal fishery, discard ban, generalized additive mixed modelling,
19 landing obligation, observer data

20 1 INTRODUCTION

21 Both Danish anchor seines and demersal otter trawls (hereafter referred to as seines and trawls,
22 respectively) are widely-used fishing gears in Denmark (total landings in 2016 by trawlers: 155917 t, by
23 seiners: 6403 t; Ministry of Environment and Food of Denmark, Danish Agrifish Agency) and many
24 other countries. Although different fishing gears are treated separately under European Union (EU)
25 regulations (e.g. beam trawls and otter trawls), seines and trawls belong to the same legislative category
26 (Council Regulation (EC) 850/98). In contrast to the EU regulations, Norwegian regulations distinguish
27 these two gears (Regulations governing the sea-fishing activities J-125-2016; Norwegian Directorate of
28 Fisheries). Owing to the differences between gear designs (e.g. lighter ground gear of seines) and
29 particularly the fishing procedures (Eigaard et al., 2016a; Herrmann, Krag, Feekings & Noack, 2016),
30 this grouping of seines and trawls has been brought into question by fishers and other stakeholders in the
31 EU. Fishers that operate seines claim a loss of more marketable fish than those using trawls when legal
32 mesh sizes are used (see Herrmann et al., 2016). This highlights the need for more detailed information
33 about the two gear types and their catches.

34 Initially, the seine was developed by a Danish fisherman specifically to catch flatfish, whereas
35 trawls are more opportunistic gears in terms of the species that they target. Today, Norway lobster (a.k.a
36 langoustine) *Nephrops norvegicus* (L.) and several fish species (roundfish and flatfish) are targeted by
37 trawlers. However, a significant proportion of the catches of both gears is discarded (Kelleher, 2005).
38 This happens for several reasons including minimum landing sizes (MLS), quota restrictions and high-
39 grading (Catchpole et al., 2013; Feekings, Bartolino, Madsen & Catchpole, 2012; Kelleher, 2005). In an
40 effort to eliminate discards, a central part of the new Common Fisheries Policy in Europe is a landing
41 obligation, which is being introduced on a fishery-by-fishery basis from 2016 to 2019 (Council
42 Regulations (EU) 1380/2013 and 2016/72). It applies to all species that “define the fisheries”, i.e. species
43 subject to catch limits should be landed. The landing obligation further introduces minimum conservation
44 reference sizes (MCRS, usually equal to current MLS) where fish below this size are not allowed to be
45 sold directly for human consumption (Council Regulation (EU) 1380/2013). The objective of this

46 landing-obligation system is to make fishers be more selective (Condie, Grant & Catchpole, 2013) and
47 to reduce bycatch instead of utilizing quota for less commercial catches (Borges, Cocos & Nielsen, 2016).
48 However, as previous studies found indications of differences in the selectivity characteristics of seines
49 and trawls as well as larger L_{50} values (length at which 50% of the fish are retained) for seines for species
50 like cod *Gadus morhua* L. (Herrmann et al., 2016; Noack, Frandsen, Krag, Mieske & Madsen, 2017),
51 proportions of fish below MCRS are likely different. Furthermore, differences in gear constructions (e.g.
52 lighter ground gears for seiners) might cause differences in the catches of Danish seines and bottom
53 trawls.

54 The aim of the present study was to use data from a perennial monitoring programme of
55 commercial vessels to establish a comprehensive dataset for describing and comparing the seine and
56 trawl fishery including their catches of commercial species, i.e. quota restricted species and/or species
57 that were directly targeted (for quotas and annual landings in Denmark in 2016, see Table S1). The
58 specific objectives were to: 1) provide an insight into whether the legal grouping of seines and trawls, in
59 terms of catches, is appropriate; 2) assess the two fishing methods in relation to the new management
60 strategies; and 3) identify catch-related problems and challenges with which the fisheries will be
61 confronted under the new landing-obligation system.

62 **2 MATERIALS AND METHODS**

63 **2.1 Data collection and selection**

64 Data for the current study originated from a national observer program (1997–2002) and a European
65 discard sampling programme (from 2002) in accordance with the European Data Directive (Council
66 Regulation (EC) 1639/2001). Data were collected during regular fishing trips (i.e. seiners were sampled
67 at daytime, trawlers were sampled at daytime and nighttime) onboard commercial fishing vessels
68 participating in the discard sampling programmes in the period from 1997 to 2012. All fishes were
69 measured for total length (TL), with Norway lobster measured for carapace length, and cephalopods
70 measured for mantle length. In cases where representative sub-samples needed to be taken, individual

71 numbers were raised to haul level following the sampling programme's standard procedure. Fishing
72 practice was assumed to be unaffected by the presence of an observer and the chosen vessels and trips
73 were assumed to be representative for the fishery in the area (Feekings et al., 2012). Further details about
74 the Danish discard sampling programme, including sampling strategy and data collection have been
75 described in Feekings et al. (2012) and in Storr-Paulsen, Birch Håkansson, Egekvist, Degel and Dalskov
76 (2010).

77 The study area focused on Skagerrak and a small area in northern Kattegat (Fig. 1). Both areas
78 represent a relatively restricted region of large commercial importance where trawlers and seiners fish
79 under similar technical regulations. These regulations have changed several times in the past, including
80 the observed period, though the changes applied to codends in seines as well as in trawls and differences
81 between legislations in Skagerrak and Kattegat were small. Before 1989, 60 mm was the minimum
82 codend mesh size in both areas but increased to 70 mm in 1989 (Kirkegaard, Nielsen & Bagge, 1989),
83 and a mandatory square mesh panel (SMP) was introduced in 2000 (Council Regulation (EC) 850/98).
84 From 2005, the minimum mesh size in codends was 90 mm (diamond mesh) or 70 mm (square mesh
85 codend including a grid), respectively (Council Regulation (EC) 27/2005). Optionally, fishers were
86 encouraged to use a 120 mm SMP, which has been rewarded by extra sea days (Council Regulation (EC)
87 27/2005). In 2011, the SELTRA panel comprising of either a 270 mm diamond mesh panel or a 180
88 SMP was made mandatory for codend mesh sizes of 90–119 mm in Kattegat (Vinther & Eero, 2013). In
89 Skagerrak, it was introduced in 2013, but with a 140 mm SMP (BEK No. 1423 of 12/12/2013) instead
90 of 120 mm. Regardless of the changes in technical regulations during the period of the sampling
91 programme, hauls with mesh sizes < 90 mm were excluded to use only comparable mesh sizes in the
92 analyses. Seiners never fished with these small mesh sizes, but trawlers did until the prohibition in 2005.
93 Since codend mesh size was expected to influence catches, the dataset was divided into two equalized
94 categories (90–109 mm and ≥ 110 mm). Regulations and technical measures for towed gears did not
95 only prescribe specific mesh sizes, but also additional selectivity devices like escape windows (Council

96 Regulation (EC) 850/98). As the specification of these devices was not sufficiently documented in the
97 dataset, the effects of device specification have not been taken into account in the analyses.

98 **2.2 Description and comparison of fishing characteristics and catches**

99 The first part of the analysis was a general comparison of both fisheries including observation
100 information (years of observation, number of observed vessels and number of observed hauls),
101 characteristics of the fisheries (engine power, haul duration, fishing depth and target species) and general
102 catch information (catch per haul, catch per hour). Where appropriate, values were calculated as mean
103 values \pm SD and a two-way analysis of variance (ANOVA) with gear and mesh size as fixed factors
104 followed by a Tukey-HSD test was used to test for significant differences between categories
105 (significance level $\alpha \leq 0.05$).

106 This looked, at the species level, into the catches of commercial species i.e. species with quota
107 in 2016 and/or explicitly targeted by the vessels considered within the dataset. After providing general
108 information about the potential existence of quota in 2016 and potential minimum size (MS as either
109 MLS or MCRS), information is provided about occurrence (observation frequency as number of hauls
110 with observation divided by the number of hauls in total) and total number of caught individuals.

111 In addition, catch rates (number per hour) were calculated and a MS ratio (number of individuals
112 below current MLS or potentially coming MCRS/total number of individuals per haul) was estimated
113 for all species that have a MS. Both measures were calculated as mean values \pm SD. Testing for
114 significant differences between the categories was done using a two-way analysis of variance (ANOVA)
115 with gear and mesh size as fixed factors followed by a Tukey-HSD test (significance level $\alpha \leq 0.05$).

116 This approach detected several significant differences between gear and mesh size categories, but R^2
117 values were very low (Table S2, Table S3), which indicated a high unexplained deviance. To account
118 for this and to find out which other factors than gear type and mesh size determined catch rates and MS
119 ratios of the different species, both measurements were investigated in more detail. Models were
120 formulated that included all additional parameters that were available from the dataset, that might be of

121 relevance in determining catch rates and MS ratios and that could affect catches of seiners and trawlers
122 differently, i.e. depth, haul duration, latitude, longitude, subsampling factor, target species, trip number,
123 vessel name, engine power, year and year quarter. Four of them (haul duration, longitude, engine power,
124 year) had to be excluded due to collinearity with other covariates (variance inflation factors > 3; Zuur,
125 Ieno & Elphick, 2010).

126 Generalized additive mixed models (GAMMs) were used to describe relationships between
127 catch rates or MS ratios and the explanatory variables to account for the unbalanced sampling design
128 between explanatory variables (e.g. different number of hauls for different gear categories). For the catch
129 rate models, a Poisson distribution was assumed because catch rate represents count data, i.e. number of
130 fish per unit of effort. Cases of over-dispersion (conditional variance exceeds the conditional mean
131 and/or presence of many zero observations) were handled using a negative binomial distribution (Zuur,
132 Ieno, Walker, Saveliev & Smith, 2009). Both distributions were applied, using a log-link function. Zero-
133 observations were included into the analysis because they form an important part of the total
134 observations. Conditions on different vessels may have differed due to vessel type, vessel size, skipper
135 effects or vessel-specific sorting behaviors (Feekings, Lewy & Madsen, 2013; Poos & Rijnsdorp, 2007;
136 Tschernij & Holst, 1999), but the data structure could be regarded as a hierarchical structure, i.e. vessel
137 – trip – haul. Therefore, vessel and trip were always included in the model, even if the model found them
138 to be non-significant. Furthermore, the subsampling factor was included as an offset in all models as the
139 ratio of individuals observed and individuals measured. It was the only variable which was transformed
140 (log-transformation).

141 The following was the GAMM for catch rates per haul i (Eq. 2):

142

$$\begin{aligned} \text{Catch rate}_i &\sim \text{Poisson / negative binomial}(\mu_i, \sigma), \text{ where} \\ \log(\mu_i) &= \eta + \beta(\text{gear}_i) + \gamma(\text{mesh}_i) + \delta(\text{quarter}_i) + \zeta(\text{target}_i) + s(\text{depth}_i) + \\ &s(\text{latitude}_i) + \text{random effect (vessel}_i) + \text{random effect (trip}_i) + \\ &\text{offset (log(subsampling factor}_i)) + \varepsilon \end{aligned} \quad (1)$$

143

144 Fixed effects are the nominal covariate “gear” representing either trawl or seine, the continuous
 145 covariate “mesh” for the used numerical mesh size, the nominal covariate “quarter” for the quarters of a
 146 year, the nominal covariate “target” for the targeted species and the continuous covariates “depth” and
 147 “latitude” representing the fishing depth and the respective north-south position. “Vessel” and “trip” as
 148 nominal covariates are random effects that represent the respective fishing vessel and trip number. η
 149 describes the intercept, which represents seines that fished in quarter one and targeted cod, s is an
 150 isotropic smoothing function that was used to define smooth terms (thin-plate regression spline; Wood,
 151 2003), and ε is an error term.

152 For MS ratios, the procedures explained for the catch rate models were followed, but since ratios
 153 can take values between 0 and 1, a binomial distribution was used. Cases of over-dispersion were handled
 154 by using a quasi-binomial distribution. For both distributions, a logit-link function was applied.

155 The GAMM for MS ratios per haul i (Eq. 2) was:

156

$MS\ ratio_i \sim \text{binomial} / \text{quasibinomial} (\mu_i, \sigma)$, where

$$\begin{aligned} \text{logit}\left(\frac{\mu_i}{1-\mu_i}\right) = & \eta + \beta(\text{gear}_i) + \gamma(\text{mesh}_i) + \delta(\text{quarter}_i) + \zeta(\text{target}_i) + \\ & s(\text{depth}_i) + s(\text{latitude}_i) + \text{random effect}(\text{vessel}_i) + \text{random effect}(\text{trip}_i) + \\ & \text{offset}(\log(\text{subsampling factor}_i)) + \varepsilon \end{aligned} \quad (2)$$

157

158 The following steps of model selection and model validation were the same for both models.
 159 After estimating the model, the least significant covariate with largest P -value was removed and the new
 160 model was applied again. If there were non-significant results in the categorical terms (quarter, target),
 161 then levels were combined and the model was refitted. This was done until all remaining covariates
 162 except vessel and trip were statistically significant ($P < 0.05$). The final model was validated by checking
 163 residuals for linearity and normality (scatterplot of residuals vs. fitted values and histogram), spatial
 164 independence (scatter plot of residuals vs. position as spatial factor) and still existing patterns in relation
 165 to covariates (scatter plot of residuals vs. remaining covariates). Outliers were identified in the original

166 data and further examined, but no observations were removed since no oddities were found. Results are
167 shown for all models, which passed all steps of the validation process.

168 All analyses were done in R Statistical Software (R Core Team, 2015), using the package
169 “mgcv” (Wood, 2011) to conduct generalized additive mixed modelling.

170 **3 RESULTS**

171 **3.1 Fishing characteristics**

172 The dataset consisted of 285 and 460 fully-commercial hauls for seines and trawls, respectively (Table
173 1, Fig. 1). In relative terms, more hauls by seiners were conducted using large mesh sizes, whereas
174 trawlers used more often smaller mesh sizes (Table 1). Mean engine power was significantly lower for
175 seiners than for trawlers for both mesh size categories (Table 1) and mean haul duration for seiners was
176 less than half compared to trawlers (Table 1). Areas fished by trawlers and seiners overlapped in some
177 cases (Fig. 1), but mean fishing depth for seiners using mesh sizes ≥ 110 mm (“a” in Table 1) was
178 significantly lower than for the other categories (Table 1). Mean fishing depth for seiners 90–109 mm
179 (“b” in Table 1) and trawlers 90–109 mm (“c” in Table 1) were also significantly different, but both were
180 not significantly different to the values for trawlers using a mesh size ≥ 110 mm (“bc” in Table 1). Mean
181 total catches per haul were significantly lower for seines than for trawls, but mean catch rate for seines
182 with mesh sizes ≥ 110 mm was significantly higher than for the three other categories. All target species
183 of seiners, including plaice *Pleuronectes platessa* L. as the main target species, could also be found on
184 the target list of trawlers. The list of target species for trawlers included five species that were not targeted
185 by seines; dab *Limanda limanda* (L.), lemon sole *Microstomus kitt* (Walbaum), Norway lobster, sole
186 *Solea solea* (L.) and turbot *Scophthalmus maximus* (L.).

187 **3.2 Catches**

188 Twelve species were considered (Table 2) of which three had no quota limits in 2016 (dab, lemon sole,
189 witch flounder *Glyptocephalus cynoglossus* (L.)) in the study area, but were directly targeted by some
190 vessels. Nine of these species are subject to MS regulations, but the MCRS of Norway lobster is different
191 to the former MLS and the MS of witch flounder is only legal on a national level in some countries
192 (Table 2). All species were observed in both gear types and mesh categories, but occurrences of herring
193 *Clupea harengus* L., Norway lobster and Norway pout *Trisopterus esmarkii* Nilsson were low in seines
194 (Table 2).

195 Mean catch rates ranged 0.0–971.2 individuals per hour (Norway lobster in both seine categories
196 and in trawls 90–109 mm, respectively; Table 3). Regarding fish species, catch rates ranged from 0.1
197 (Norway pout in both seine categories) to 481.1 individuals per hour (plaice in seines \geq 110 mm, Table
198 3). Catch rates for plaice and witch flounder were significantly higher in seines and for saithe *Pollachius*
199 *virrens* (L.) and whiting *Merlangius merlangus* (L.) in trawls (Table 4). Catch rate was often significantly
200 affected when Norway lobster or plaice, as main target species of the fisheries, were the targeted species
201 (Table 4). In cases where Norway lobster was targeted, catch rates of Norway lobster and roundfish
202 increased, but catch rates of flatfish decreased. If plaice was targeted, then catch rates of Norway lobster
203 and roundfish decreased, but catch rates of flatfish increased. Mesh size was significant for four species
204 (Norway lobster, saithe, whiting, witch flounder), where catch rates decreased slightly with increasing
205 mesh size for three of them (Table 4). Season was significant for seven species (Table 4), but the
206 differences between the four seasons were species-dependent and no general pattern was found. Water
207 depth was found to be significant for all species and latitude was significant for seven of them (Table 4).
208 Since latitude and water depth were handled as smooth terms, a determination of the direction of impacts
209 has not been possible here. Vessel or trip or both random effects were significant for all species except
210 Norway pout.

211 Mean values of the MS ratios ranged from 0% (hake *Merluccius merluccius* (L.): all categories
212 except trawls 90–109 mm, Norway lobster: trawls \geq 110 mm, saithe: all categories except for trawls \geq

213 110 mm, witch flounder: seines 90–109 mm) to 50% (Norway lobster: seines 90–109 mm and trawls
214 90–109 mm, plaice: seines \geq 110 mm, whiting: both seine categories, Table 3) and differences between
215 the gear and mesh categories were small (Table 5). Gear was found to have a significant effect on the
216 MS ratio of whiting (lower for trawls), and mesh size had a negative effect on the ratios of haddock
217 *Melanogrammus aeglefinus* (L.). Season was significant for four species (cod, dab, plaice, whiting)
218 whereby season four was often the decisive season (lower ratios). Target species significantly affected
219 ratios of four species (cod, dab, haddock, Norway lobster), where Norway lobster significantly increased
220 the ratios of cod and haddock. The smooth terms depth and latitude were significant factors for five (cod,
221 haddock, hake, whiting, witch flounder) and one species (Norway lobster), respectively. Random effects
222 were also found to be of high importance; only cod did not show any significant effects of those (Table
223 5).

224 **4 DISCUSSION**

225 Fishing operation and catch profiles of commercial species for seiners and trawlers fishing in the
226 Skagerrak and the northern Kattegat were compared based on 16 years of Danish observer coverage.
227 This represents a comprehensive data source to evaluate and determine how specialized and flexible the
228 two gears are in terms of target species and catches of fish below MS. The collected data is used to
229 indicate how appropriate the legislative grouping of seines and trawls is and how challenged the two
230 fisheries will be in meeting the objectives of the landing obligation.

231 Total catches per hour were larger for seiners using mesh sizes \geq 110 mm than for trawlers.
232 Translating those to catches per swept km² based on estimates of hourly swept area by Eigaard et al.
233 (2016b) led to similar or even higher values for trawlers (seines 90–109 mm: 161.4 kg; seines \geq 110 mm:
234 274.8 kg; trawls 90–109 mm: 267.1 kg; trawls \geq 110 mm: 360.0 kg). In other words, seiners are able to
235 fish on a larger area in shorter time, but trawling collects more fish from an area than seining does.
236 Higher flatfish catch rates for seiners than for trawlers and lower engine power with an expected lower
237 fuel consumption and CO₂ emission, as also reported by Thrane (2004), demonstrate that seining is an

238 energy efficient way of catching plaice and other flatfish species. Seiners generally fished in shallower
239 waters than trawlers and are more restricted to flat areas to avoid damage to the seine ropes and the
240 lighter ground gears. As a high proportion of the herding process of seines is made up by visual stimuli
241 (seine ropes and sediment re-suspended by those), seining requires daylight to be operated efficiently.
242 Contrary, trawlers can operate during day and night time, use sweeps which are much shorter than seine
243 ropes and trawls are often equipped with devices like bobbins or use rockhopper ground gear designs to
244 protect the netting from damage by rough bottoms (He & Winger, 2010). This makes trawlers more
245 flexible as they can operate on more diverse fishing grounds, which explains the longer list of target
246 species for trawlers than for seiners. These differences highlight the disparity of seines and trawls. In
247 relation to the landing obligation, this means that seiners are more vulnerable in case quotas or stocks
248 for their few target species (mainly flatfish) are low. Contrary trawlers can shift to another target species
249 and continue fishing more easily.

250 Very low R^2 values in the ANOVA approach as well as the results of the GAMM approach
251 highlighted the importance of parameters other than gear and mesh size in determining catch rates and
252 the MS ratio. Conditional parameters such as latitude or season and random effects (vessel and/or trip)
253 were found to have significant effects on the catches of most species. This may indicate that it is primarily
254 not the gear or mesh size that is directly responsible for differences in MS ratios or catch rates between
255 the two fishing methods, but more likely the specific conditions in which the gears are used. As these
256 conditions include area and depth as factors of high importance in determining the catch rate and the
257 proportion of fish below MLS or MCRS, differences in the catches are likely between different regions
258 and habitat types. Although this indicates that ecological factors are likely to be underrepresented in
259 current fishery management plans of the EU, adding more detailed area aspects and ecological conditions
260 to future management plans might be problematic due to the diverse and complex structure of marine
261 habitats. The unexpectedly weak effect of mesh size on catch rate and particularly MS ratio has also been
262 observed previously using similar observer collected data. Feekings et al. (2012) were inconclusive about
263 the importance of mesh size on the discard rates of plaice and suggested that the heterogeneity in the

264 sampling across mesh sizes and other factors was likely the cause of this phenomenon. The high
265 importance of vessel and/or trip as random effects in determining catches was also found by several other
266 studies (Feekings et al., 2013; Poos & Rijnsdorp, 2007; Tschernij & Holst, 1999). There may, however,
267 be other influential factors (e.g. selective devices, quota availability) that could affect catch rates or MS
268 ratios. Although the regulations in the study area changed several times, potential effects on catches of
269 seines and trawls were considered to be similar because both belong to the same legislative category
270 (Council Regulation (EC) 850/98). Nevertheless, the quality of the data collected within the observer
271 programmes could be improved by a more precise recording of additional factors like an accurate
272 description of used selective devices. The currently poor recording of the use of selective devices did not
273 allow inclusion of this factor in the analyses, and this may explain why only a weak impact of mesh size
274 was found in the present study. The relatively high number of zero observations in the dataset might be
275 reduced by increasing the sample size within the observer programme. As it could also be possible that
276 conditional factors are linked and interact, effects of gear or mesh size were maybe confounded or
277 masked in the present study. One way to investigate this would be studies that compare catches of seiners
278 and trawlers under more controlled conditions. This means that additional factors such as area, depth or
279 season should be the same for both gears and that same gear configurations (e.g. number of meshes
280 around codend, length of codend extension, selectivity devices) are used or that analyses account for
281 potential differences in those.

282 Despite the pronounced effects of conditional parameters, significant differences were found in
283 catch rates between seines and trawls for several species. The results indicated that catch rates of flatfish
284 were generally higher for seiners and catch rates for roundfish species were higher for trawlers.
285 Significant differences in MS ratios were only found for whiting, which is not directly targeted. Thus,
286 the results of the present study for fish below MS provide no clear findings to challenge the legislative
287 grouping of seines and trawls into the same category. In the context of the landing-obligation system,
288 the results indicate that both fisheries will be affected as catches of both gears were up to 50% individuals

289 below MCRS, e.g. for the most important target species of both gears (Norway lobster and plaice,
290 respectively).

291 Future studies that investigate survival of discards in the two fisheries may reach different
292 conclusions if, for example, survival rates are higher for seines than for trawls. Shorter haul durations,
293 shallower fishing grounds and smaller total catches were found in seines than in trawls. Besides the late
294 entry of fish into the net and the corresponding short time within the gear (Herrmann et al., 2016; Noack
295 et al., 2017), these are all factors that have positive impact on the survivability of discarded fish (van
296 der Reijden et al., 2017). Previous studies on discard survival focused on different types of trawling like
297 beam trawling (Depestele, Desender, Benoît, Polet & Vincx, 2014; Uhlmann et al., 2016; van der Reijden
298 et al., 2017) and otter trawling (Methling, Skov & Madsen, 2017), but no studies have so far investigated
299 discard survival probabilities for Danish seines. Future discard survival studies should include these and
300 compare results to trawl studies. Because temperature, storage and handling time were also found to
301 affect survival (van der Reijden et al., 2017), these factors should be considered in such studies as well.

302 The minor differences in MS ratios between the gears indicate that if both gears will be grouped
303 together for the foreseeable future, challenges like the handling and storage (Sardà, Coll, Heymans &
304 Stergiou, 2015) or the later sale of this less valuable part of the catch are probably similar for both. To
305 account for the mismatch in the size of caught Norway lobster and MLS (carapace length: 40 mm), the
306 MCRS is reduced to 32 mm carapace length. However, the approach of excluding mesh sizes < 90 mm
307 in the present study in order to compare only similar mesh sizes likely ignored considerable amounts of
308 Norway lobster and fish below MS in trawl catches. The majority of the trawl fleet in the
309 Skagerrak/Kattegat area used mesh sizes below 90 mm until 2005 to fish for their main target Norway
310 lobster, which requires the use of small mesh sizes (Krag, Frandsen & Madsen, 2008). Today they use a
311 mesh size of 90 mm. The smaller fleet of seiners usually uses larger mesh sizes as they do not target
312 Norway lobster. Mesh sizes of 120 mm are normally used to avoid catches of smaller fish. For flatfish-
313 targeting active fisheries (e.g. Danish seining), an obvious way to reduce the number of small individuals
314 in the catch could be an increase in the codend mesh size (Glass, 2000; Krag et al., 2008). As trawlers

315 target different species of fish, but also crustaceans, different options are needed and increases in mesh
316 size could be supported by selective devices (e.g. escape panels or grids) as an option to exclude
317 unwanted fish (Frandsen, Holst & Madsen, 2009; Valentinsson & Ulmestrand, 2008). However, research
318 is still needed to improve their selective properties. The present study reveals trawling to be an
319 opportunistic and flexible fishing method, able to target several different species on a variety of different
320 substrata, whereas seining is specialised on catching primarily flatfish efficiently. Highly specialized
321 fishing gear can be challenged in fast changing biological and management systems. Contrary to trawlers,
322 seiners will not have the opportunity to switch to other fisheries in the case of low market prices or low
323 quotas. Therefore, combining the advantages of trawlers and seiners could be a conceivable approach
324 which is already recognized by the industry as several of the new fishing vessels coming into the fleet
325 are combination vessels capable of both trawling and demersal seining (Scottish seining or fly-shooting).
326 Such combination vessels give the fishers high efficiency in accessing the available fisheries and a high
327 flexibility to continuously optimize the catch composition, as needed under the new landing obligation,
328 to optimize the vessel's quota capitalization.

329 Another relevant point in relation to the introduction of the landing obligation is the shift from
330 a landing quota regime to a catch quota management (CQM) regime in order to reduce discards. As fish
331 below MLS or MCRS are of lower value than larger individuals, fishing without discarding would result
332 in lower incomes for the fishers. An analysis of the results of CQM-trials from Denmark concluded, for
333 instance, that earnings of fishers following this system would be less compared to fishers harvesting
334 according to the conventional rules if no compensation would be given to them (Msomphora & Aanesen,
335 2015). Compensations like extra quota or more days at sea resulted, however, in a higher gross income
336 for fishers following the new system (Msomphora & Aanesen, 2015).

337 The present study found Danish seining to be an efficient fishing gear for catching flatfish, which
338 is restricted to flat fishing grounds. Trawlers are more flexible in terms of fishing areas and target species
339 and catch roundfish more efficiently. Numbers of fish below MS were similar for seines and trawls, but
340 may have been different if mesh sizes < 90 mm would have been included in the study. Additional factors

341 that are relevant in terms of comparing seines and trawls are the efficiency of selective devices and the
342 survivability of discards as both are likely affected by the differences (gear design, fishing procedure)
343 between both gears.

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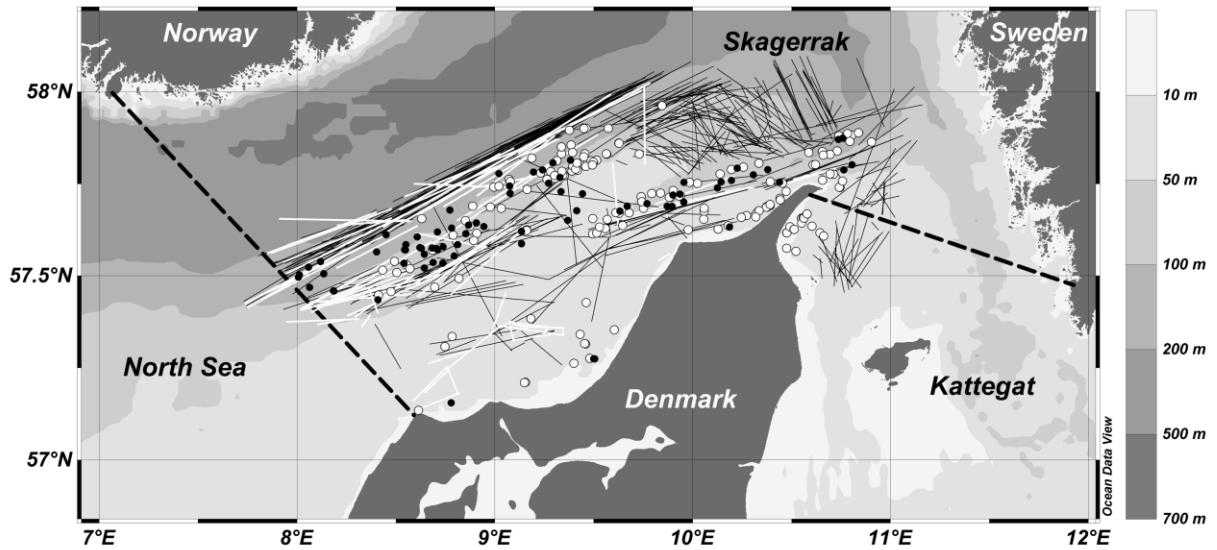
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441

442 Figure 1. Study area and location of fishing operations separated by gear and mesh size category.
443 Danish seines 90–109 mm (black dots as anchor points, n = 80). Danish seines ≥ 110 mm (white dots as
444 anchor points, n = 205). Demersal otter trawls 90–109 mm (black lines as haul tracks, n = 381).
445 Demersal otter trawls ≥ 110 mm (white lines as haul tracks, n = 79). Grey shading notes bathymetry of
446 the study area.



447

1 Table 1. General gear comparison using mean values \pm standard deviation including df (degrees of freedom) and
 2 adjusted R² as measure of explained deviance. Mean values that are not sharing a letter (a, b, c) are significantly
 3 different (two-way ANOVA and post-hoc Tukey-HSD test; $\alpha \leq 0.05$). Target species (according to skipper) describe
 4 species targeted by the different gear categories in descending order, number in parenthesis reflects number of hauls
 5 targeting this species.

	90–109 mm		≥ 110 mm		df	adj. R ²
	Seine	Trawl	Seine	Trawl		
Years		11	16	14	11	-
Vessels (no.)		11	55	22	19	-
Engine power (kW)	214.9 \pm 90.0 a	404.4 \pm 194.1 b	169.6 \pm 105.2 a	457.2 \pm 265.5 b	741	0.30
Hauls (no.)		80	381	205	79	205
Haul duration (min)	172.0 \pm 23.9 a	369.7 \pm 101.2 b	154.7 \pm 35.9 a	356.2 \pm 101.6 b	741	0.60
Fishing depth (m)	75.1 \pm 39.2 b	109.2 \pm 68.1 c	52.4 \pm 38.0 a	92.3 \pm 67.5 bc	739	0.15
Catch per haul (kg)	464.9 \pm 320.1 a	879.9 \pm 589.6 b	700.5 \pm 772.5 a	1151.4 \pm 1527.3 c	741	0.05
Catch per hour (kg)	161.4 \pm 111.2 a	146.9 \pm 93.8 a	274.8 \pm 294.6 b	198.0 \pm 261.9 a	741	0.07
Target species (No. of hauls)	Plaice (60) Witch flounder (8) Cod (7) Haddock (5)	Norway lobster (222) Cod (59) Saithe (32) Plaice (26) Witch flounder (16) Sole (13) Haddock (11) Lemon sole (2)	Plaice (103) Cod (68) Haddock (21) Witch flounder (11) Saithe (2)	Plaice (37) Saithe (10) Cod (9) Haddock (9) Witch flounder (4) Lemon sole (3) Norway lobster (3) Dab (2) Turbot (2)		

6

1 Table 2. Species overview including information about potential existence of quota in 2016, potentially
 2 existing minimum size (cm), total number of observed individuals and occurrence (ratio of hauls with
 3 observation to total number of hauls) separated by gear (seine (S) and trawl (T)) and mesh size categories (in
 4 mm).

Species	Scientific name	Quota	Minimum size (cm)	Individuals	Occurrence (%)			
					90–109		≥ 110	
					S	T	S	T
Cod	<i>Gadus morhua</i> L.	yes	30	151964	98	96	88	91
Dab	<i>Limanda limanda</i> (L.)	no	-	174856	81	46	81	67
Haddock	<i>Melanogrammus aeglefinus</i> (L.)	yes	27	154929	78	84	53	72
Hake	<i>Merluccius merluccius</i> (L.)	yes	30	13215	70	64	30	41
Herring	<i>Clupea harengus</i> L.	yes	18	6399	9	37	6	22
Lemon sole	<i>Microstomus kitt</i> (Walbaum)	no	-	24794	91	67	64	62
Norway lobster	<i>Nephrops norvegicus</i> (L.)	yes	total: 13, carapace: 4 ¹	1910743	1	72	1	14
Norway pout	<i>Trisopterus esmarkii</i> (Nilsson)	yes	-	13425	4	30	6	9
Plaice	<i>Pleuronectes platessa</i> L.	yes	27	498873	96	85	99	82
Saithe	<i>Pollachius virens</i> (L.)	yes	30	54705	41	60	20	56
Whiting	<i>Merlangius merlangus</i> (L.)	yes	23	46714	35	70	21	48
Witch flounder	<i>Glyptocephalus cynoglossus</i> (L.)	no	- ²	65207	79	80	47	52

5 ¹ new: total length: 10.5; tail length: 5.9; carapace length: 3.2

6 ² no Minimum Landing Size (MLS) on EU level, but local MLS of 28 cm in Germany, Denmark, Scotland, Sweden and parts of
 7 England

- 1 Table 3. Catch rates (ind./h) and minimum size (MS) ratios (individuals below minimum landing size (MLS) or
- 2 minimum conservation reference size (MCRS)/total no. of individuals) \pm SD separated by gear and mesh size.

Species	Catch rate				MS ratio			
	90–109 mm		≥ 110 mm		90–109 mm		≥ 110 mm	
	Seine	Trawl	Seine	Trawl	Seine	Trawl	Seine	Trawl
Cod	47.7 \pm 48.3	38.3 \pm 51.9	54.2 \pm 109.2	47.2 \pm 64.4	0.2 \pm 0.2	0.4 \pm 0.3	0.3 \pm 0.3	0.1 \pm 0.2
Dab	38.3 \pm 75.8	51.8 \pm 127.2	74.6 \pm 178.2	40.9 \pm 142.1	–	–	–	–
Haddock	38.3 \pm 47.5	40.9 \pm 82.8	33.1 \pm 76.8	62.2 \pm 115.2	0.1 \pm 0.2	0.4 \pm 0.4	0.2 \pm 0.3	0.1 \pm 0.2
Hake	2.6 \pm 5.6	5.0 \pm 10.2	1.9 \pm 8.0	1.1 \pm 2.2	0.0 \pm 0.0	0.2 \pm 0.3	0.0 \pm 0.0	0.0 \pm 0.1
Herring	0.2 \pm 0.7	2.5 \pm 8.0	0.3 \pm 2.1	1.0 \pm 4.1	0.2 \pm 0.4	0.1 \pm 0.3	0.4 \pm 0.4	0.2 \pm 0.3
Lemon sole	14.6 \pm 14.5	6.4 \pm 21.1	5.1 \pm 12.3	8.2 \pm 14.6	–	–	–	–
Norway lobster	0.0 \pm 0.2	971.2 \pm 1952.0	0.0 \pm 0.0	30.2 \pm 153.5	0.5 \pm 0.0	0.5 \pm 0.3	0.0 \pm 0.0	0.3 \pm 0.3
Norway pout	0.1 \pm 0.8	5.3 \pm 27.1	0.1 \pm 0.8	0.5 \pm 2.7	–	–	–	–
Plaice	280.1 \pm 689.7	60.3 \pm 148.4	481.1 \pm 849.7	146.1 \pm 194.1	0.2 \pm 0.2	0.4 \pm 0.4	0.5 \pm 0.4	0.3 \pm 0.4
Saithe	2.7 \pm 14.0	15.3 \pm 49.1	3.9 \pm 44.6	22.5 \pm 82.8	0.0 \pm 0.1	0.0 \pm 0.1	0.0 \pm 0.2	0.1 \pm 0.2
Whiting	0.9 \pm 2.2	20.8 \pm 37.1	1.1 \pm 4.3	4.1 \pm 9.1	0.5 \pm 0.4	0.4 \pm 0.3	0.5 \pm 0.4	0.1 \pm 0.2
Witch flounder	33.2 \pm 63.1	17.1 \pm 30.7	17.4 \pm 45.2	6.7 \pm 11.5	0.0 \pm 0.0	0.2 \pm 0.3	0.1 \pm 0.2	0.0 \pm 0.1

3

1 Table 4. Model results for catch rates (log-transformed) including significance levels. Smooth terms and random terms given as estimated degrees of
 2 freedom (edf).

3

Species	η	Predictors								Explained deviance (%)
		Categorical term estimates				Smooth term (edf)		Random term (edf)		
		Gear (trawl)	Mesh	Season	Target	Depth	Latitude	Vessel	Trip	
Cod	2.3***				Plaice (-0.5)***	2.8***	7.6***	34.2***	128.8***	72.1
Dab	0.3*				Dab (5.3)**	2.9***	4.4***	36.1*	112.7**	88.9
Haddock	0.6***			4 (0.5)*		3.0***		38.3**	133.2**	87.0
Hake	-3.1***			2 (1.5)** 3 (1.9)*** 4 (1.8)***	Haddock (-0.6)** Norway lobster (1.1)***	1.0***	9.0**	58.7	128.9*	88.7
Herring	-1.9***			3 (-1.6)*	Plaice (-2.7)***	2.4**		25.7	83.1*	91.3
Lemon sole	0.1			2 (0.6)**	Dab (3.2)* Norway lobster (-1.4)*** Saithe (-1.3)*	2.8***	4.8**	21.9	93.5***	77.8
Norway lobster	14.7***		-0.1***		Haddock (-1.8)** Norway lobster (2.2)*** Plaice (-3.9)***	2.5***		50.3**	85.2**	97.7
Norway pout	-4.9***				Norway lobster (1.5)***	3.0***	7.8***	49.4	63.2	89.6
Plaice	2.9***	-0.9***		4 (-0.6)***	Dab (3.7)*** Norway lobster (-0.7)*** Plaice (0.5)***	2.8***		34.3	127.3*	92.3
Saithe	-5.9***	1.1**	0.0*	2 (1.5)*** 3 (1.3)*** 4 (1.3)***		2.8***	1.4*	0.0	123.5***	92.6
Whiting	5.0**	1.2*	-0.0*	2 (-2.0)*** 3 (-1.3)*** 4 (-0.8)***	Plaice (-1.7)***	2.7***		36.6	128.0*	89.8
Witch flounder	4.5***	-1.3***	-0.0***		Witch flounder (0.5)*	2.9***	2.1*	13.6	111.3***	85.3

4 Significance levels: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; η = intercept (gear: Danish seine, season: 1, target: cod)

5

- 1 Table 5. Model results for minimum size ratio (individuals below minimum landing size or minimum conservation reference size/total no. of
 2 individuals, logit-transformed) including significance levels. Smooth terms and random terms given as estimated degrees of freedom (edf).

Species	η	Predictors								Explained deviance (%)
		Categorical term estimates				Smooth term (edf)		Random term (edf)		
		Gear (trawl)	Mesh	Season	Target	Depth	Latitude	Vessel	Trip	
Cod	-1.6***			4 (-1.1)***	Norway lobster (0.6)*	3.0***		80.3	117.2	72.0
Haddock	2.1		-0.0**		Norway lobster (1.2)*** Saithe (1.4)**	2.2***		24.0***	12.3	45.8
Hake	-5.3					2.0***		61.2	74.0*	89.9
Norway lobster	-0.7*				Haddock (-1.3)* Norway lobster (-1.2)*** Saithe (-0.9)* Witch flounder (-1.8)***		1.0**	35.7***	32.6	64.7
Plaice	-1.9***			4 (-1.2)**				80.6*	116.9**	78.6
Whiting	-1.0**	-1.0*		2 (1.0)** 4 (-1.1)**		1.2***		21.9	69.4*	67.7
Witch flounder	-3.9**					1.0**		69.1	113.1***	89.4

- 3 Significance levels: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, η = intercept (gear: Danish seine, season: 1, target: cod)

1 **Supplementary material**

2 Table S1. Quota in Skagerrak-Kattegat area (Ministry of Environment and Food of Denmark, Danish Agrifish
3 Agency) and total annual landings (t) of commercial species in Denmark for 2016.

Species	Quota in Kattegat/Skagerrak (t)	Total annual landings in Denmark	
		Bottom trawls	Danish seines
Cod	Kattegat: 233; Skagerrak: 3747	15584	941
Dab	-	779	294
Haddock	3400	1233	334
Hake	1334	1739	109
Herring	16538	664	0
Lemon sole	-	1122	35
Norway lobster	8513	4088	0
Norway pout	99907*	19627	0
Plaice	Kattegat: 2089; Skagerrak: 9234	15356	4392
Saithe	4091*	3238	7
Whiting	926	309	13
Witch flounder	-	1239	164

4 *incl. North Sea

5 Table S2. Catch rate (individuals/h) as mean value \pm standard deviation including df (degrees of freedom) and
6 adjusted R² as measure of explained deviance. Mean values that are not sharing a letter (a, b, c) are significantly
7 different (two-way ANOVA and post-hoc Tukey-HSD test; $\alpha \leq 0.05$).

Species	Catch rate				df	adj. R ²
	90 - 109 mm		≥ 110 mm			
	Seine	Trawl	Seine	Trawl		
Cod	47.7 \pm 48.3 a	38.3 \pm 51.9 a	54.2 \pm 109.2 a	47.2 \pm 64.4 a	741	0.00
Dab	38.3 \pm 75.8 a	51.8 \pm 127.2 a	74.6 \pm 178.2 a	40.9 \pm 142.1 a	741	0.00
Haddock	38.3 \pm 47.5 ab	40.9 \pm 82.8 ab	33.1 \pm 76.8 a	62.2 \pm 115.2 b	741	0.01
Hake	2.6 \pm 5.6 ab	5.0 \pm 10.2 b	1.9 \pm 8.0 a	1.1 \pm 2.2 a	741	0.03
Herring	0.2 \pm 0.7 a	2.5 \pm 8.0 b	0.3 \pm 2.1 a	1.0 \pm 4.1 ab	741	0.03
Lemon sole	14.6 \pm 14.5 b	6.4 \pm 21.1 a	5.1 \pm 12.3 a	8.2 \pm 14.6 ab	741	0.02
Norway lobster	0.0 \pm 0.2 a	971.2 \pm 1952.0 b	0.0 \pm 0.0 a	30.2 \pm 153.5 a	741	0.10
Norway pout	0.1 \pm 0.8 ab	5.3 \pm 27.1 a	0.1 \pm 0.8 b	0.5 \pm 2.7 ab	741	0.01
Plaice	280.1 \pm 689.7 b	60.3 \pm 148.4 a	481.1 \pm 849.7 c	146.1 \pm 194.1 ab	741	0.11
Saithe	2.7 \pm 14.0 ab	15.3 \pm 49.1 b	3.9 \pm 44.6 a	22.5 \pm 82.8 b	741	0.01
Whiting	0.9 \pm 2.2 a	20.8 \pm 37.1 b	1.1 \pm 4.3 a	4.1 \pm 9.1 a	741	0.11
Witch flounder	33.2 \pm 63.1 b	17.1 \pm 30.7 a	17.4 \pm 45.2 a	6.7 \pm 11.5 a	741	0.02

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9 Table S3. Minimum size (MS) ratio (individuals below minimum landing size (MLS) or minimum conservation
 10 reference size (MCRS)/total no. of individuals) \pm standard deviation including df (degrees of freedom) and
 11 adjusted R² as measure of explained deviance. Mean values that are not sharing a letter (a, b, c) are significantly
 12 different (two-way ANOVA and post-hoc Tukey-HSD test; $\alpha \leq 0.05$).

Species	MS ratio				df	adj. R ²
	90 - 109 mm		≥ 110 m			
	Seine	Trawl	Seine	Trawl		
Cod	0.2 \pm 0.2 ab	0.4 \pm 0.3 c	0.3 \pm 0.3 b	0.1 \pm 0.2 a	693	0.08
Haddock	0.1 \pm 0.2 a	0.4 \pm 0.4 b	0.2 \pm 0.3 a	0.1 \pm 0.2 a	543	0.17
Hake	0.0 \pm 0.0 a	0.2 \pm 0.3 b	0.0 \pm 0.0 a	0.0 \pm 0.1 a	388	0.11
Herring	0.2 \pm 0.4 a	0.1 \pm 0.3 a	0.4 \pm 0.4 a	0.2 \pm 0.3 a	173	0.02
Norway lobster	0.5 \pm 0.0 ab	0.5 \pm 0.3 b	0.0 \pm 0.0 a	0.3 \pm 0.3 a	284	0.04
Plaice	0.2 \pm 0.2 a	0.4 \pm 0.4 bc	0.5 \pm 0.4 c	0.3 \pm 0.4 ab	664	0.05
Saithe	0.0 \pm 0.1 a	0.0 \pm 0.1 a	0.0 \pm 0.2 a	0.1 \pm 0.2 a	345	0.00
Whiting	0.5 \pm 0.4 b	0.4 \pm 0.3 b	0.5 \pm 0.4 b	0.1 \pm 0.2 a	372	0.06
Witch flounder	0.0 \pm 0.0 a	0.2 \pm 0.3 b	0.1 \pm 0.2 a	0.0 \pm 0.1 a	501	0.14

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