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Fishing tactics and fish quality: The case of the coastal fishery for Atlantic cod in Norway

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ABSTRACT

This study examined the effects of key fishing tactics such as the choice of fishing gear and catch size, an indicator of swift and intense fishing, on the quality of landed fish. The effects of changes in yearly TACs, and thus catch shares, vessel size (length) and vessel age on fish quality were also investigated. A data set consisting of objective quality assessments of Atlantic cod in 432 catches from the coastal cod fishery in Norway, combined with details about the same catches was analyzed. The statistical analysis showed that fishing gear affected fish quality, but to a variable degree, with gillnets and Danish seines, the preferred methods in this fishery, providing the poorest-quality fish. It was also found that catch size had a negative impact on fish quality for gillnets, handlines, and Danish seines, but not for longlines. The results indicate that fishers' tactical decisions regarding what fishing gear to use, and how swiftly and intensely to fish, may lead to poor-quality fish being landed. Although this may be economically rational for fishers in a fishery with no restrictions on the choice of fishing gear and catch sizes, and where quality-based pricing is largely absent, it may lead to a substantial reduction in value-adding opportunities in downstream processing and marketing.

1. Introduction

Previous research has consistently shown that different fishing gear, such as trawls, gillnets, traps, Danish seines, trolling rods, longlines and handlines, affects fish quality, but to a variable degree (Botta et al., 1987; Esaiassen et al., 2004; Margeirsson et al., 2010; Martínez-Garmendia et al., 2000; Mcconnell and Strand, 2000; Olsen et al., 2014; Rotabakk et al., 2011). Several studies have also found that fishing methods influence ex-vessel prices, most likely by reflecting quality differences (Asche et al., 2015; Lee, 2014; Martínez-Garmendia et al., 2000; Mcconnell and Strand, 2000; Pettersen and Asche, 2020; Sogn-Grundvåg et al., 2020, 2021a). Different fishing methods may also influence the value of fish in downstream markets. Sogn-Grundvåg et al., (2014, 2013) estimated price premiums in the UK grocery retail market to be in the 10.4–24.6% range for line-caught chilled and frozen Atlantic cod and haddock compared with fish caught with other fishing methods. In addition, Sogn-Grundvåg et al. (2019) showed enhanced product longevity for Atlantic cod and haddock products with the line-caught label compared to similar products without the label, implying reduced costs. This suggests that line-caught Atlantic cod and haddock are preferred, at least in the UK market.

The quality of fish has also been found to vary between vessels fishing with the same gear. This may be due to variations in fishing tactics[1] such as soaking time for gillnets and longlines (Esaiassen et al., 2004; Løkkeborg and Pina, 1997; Savina et al., 2016) and the size of hauls when fishing with Danish seines and trawls (Brinkhof et al., 2018; Olsen et al., 2014, 2013; Svalheim et al., 2020). Longer soaking times and larger hauls usually increase fishing efficiency and lower costs providing economic incentives that may compromise fish quality. This is so because these fishing tactics often lead to more fish dying trapped in the gear, which prohibits effective drainage of blood (Olsen et al., 2014; Rotabakk et al., 2011). Large hauls also make it difficult to bleed and process the catch effectively due to limitations in space and crew numbers (Olsen et al., 2014; Rotabakk et al., 2011), which causes

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[1] In line with Christensen and Raakjær (2006), we understand fishing tactics as short-term decisions such as where to go fishing, what gear to use, what size of haul to aim for, and so on. Strategic decisions are decisions with a longer perspective, such as building or buying vessels and investing in catch-handling equipment (Christensen and Raakjær, 2006).

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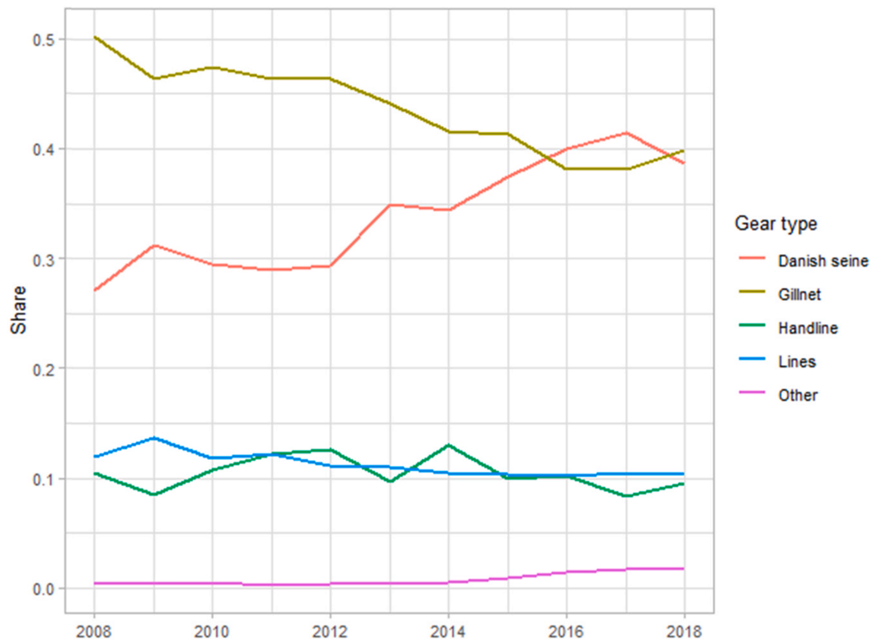

Fig. 1. The share of cod landings (by quantity) by the main fishing methods in the coastal fleet for 2008–2018.
Source: Elaborated from public data availiable from the Directorate of Fisheries (www.fiskeridir.no).

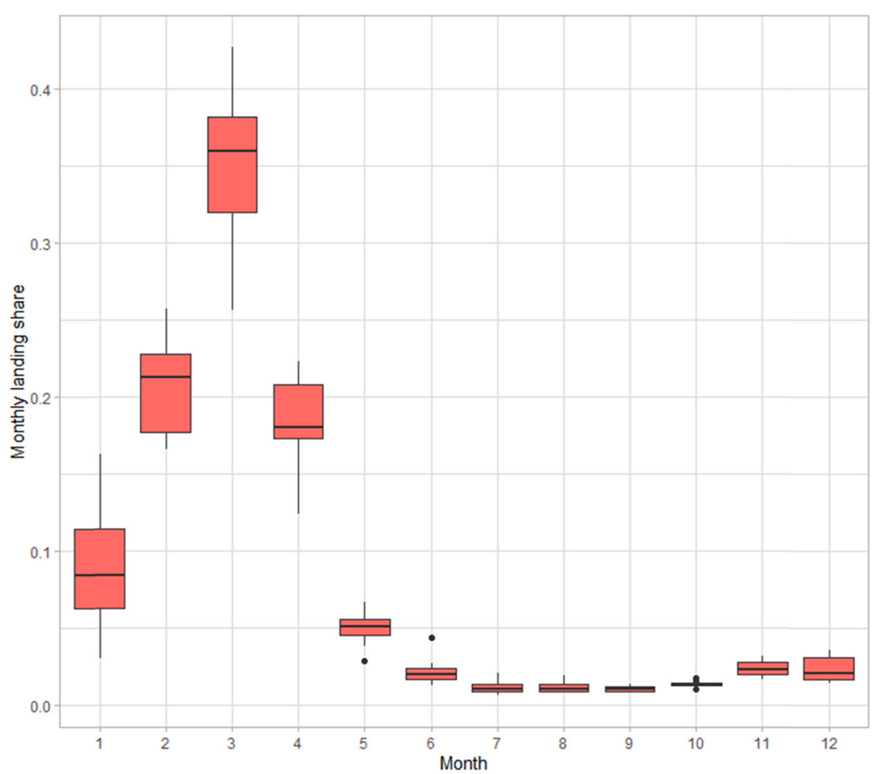

Fig. 2. Box-plot for the average monthly cod landings by the coastal fleet for 2008–2018.
Source: Elaborated from public data availiable from the Directorate of Fisheries (www.fiskeridir.no).

discolored fillets (Olsen et al., 2014; Savina et al., 2016; Svalheim et al., 2020).

Fishers' economic incentives and thus fishing tactics are also influenced and restricted by regulations. In developed countries, most fisheries of any importance are now regulated by total allowable catches (TACs) to avoid overfishing. Many fisheries are also regulated through catch shares, which incentivize fishers to maximize the quality and value of their quotas (Asche et al., 2009a; Dresdner et al., 2010; Fox et al., 2003; Grafton et al., 2000; Squires et al., 1995). Season and location closures, as well as input restrictions such as limits on the amount of gear and the vessel size, play a role in regulation as well. However, fishers adapt to regulations by changing their fishing tactics and strategies, which may lead to unintended consequences (Christensen and Raakjær, 2006; Salas and Gaertner, 2004). For example, Bertheussen and Dreyer

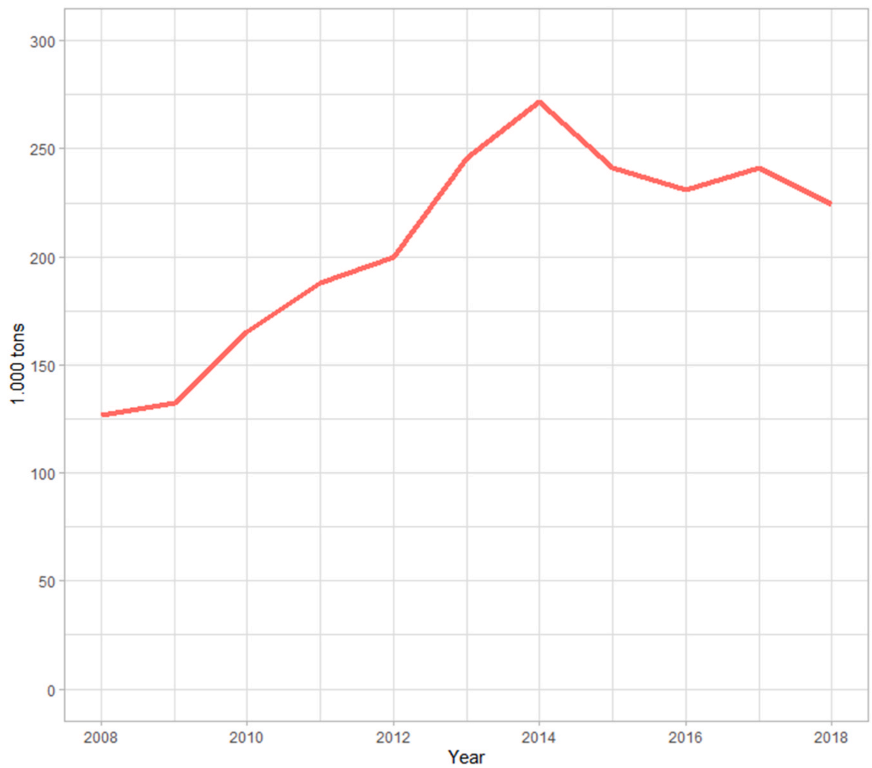

Fig. 3. Cod landings by the coastal fleet for the period 2008–2018.
Source: Elaborated from public data availiable from the Directorate of Fisheries (www.fiskeridir.no).

(2019) argue that the transferability of quotas between vessels to reduce overcapacity and improve vessel profitability may have the unintended consequence that swift and intense fishing tactics are adopted, compromising fish quality. This may also differ by species, as Birkenbach et al. (2020) also show that the incentives to spread catches over the season depends on demand characteristics.

Fishers' economic incentives and fishing tactics are also likely to be influenced by how the quality of the fish is valued in the market place. Interestingly, a recent study of the ex-vessel market for cod in coastal Norway found that quality-based pricing is largely absent (Sogn-Grundvåg et al., 2021a).[2] This is attributed to a poorly performing market with direct sales in which asymmetric information regarding fish quality and the bargaining power of fishers distort the relationship between quality and price (Sogn-Grundvåg et al., 2021a). Thus, while considering the market value of the fish, a key decision for fishers is whether to focus on swift and intense fishing, maximizing catch size at low cost but with reduced fish quality, or on less intense fishing, prioritizing good fish quality but at higher cost (Bertheussen and Dreyer, 2019; Sogn-Grundvåg et al., 2020). Various fishers may perceive this trade-off differently depending on the cost of fishing for their vessel and fishing method, which in turn may depend on the size and age of their vessel and equipment, with larger and newer vessels usually being more suitable for swift and intense fishing tactics.

The main contribution of this study was to examine how catch size, a key fishing tactic, affects fish quality, and whether this varies between fishing methods. The empirical setting of the study was the coastal fishery for Atlantic cod in Norway, where there are few restrictions on what gear to use, soaking time, or haul sizes. By using data from five consecutive years with substantial variations in TACs and thus also in vessels' catch shares, we gained insight into whether larger vessel quotas may affect fish quality negatively. The effect of vessel size and age on fish quality was also assessed. This enabled us to expand on literature focusing on fishing tactics and fish quality (Christensen and Raakjær, 2006; Esaiassen et al., 2004; Savina et al., 2016; Sogn-Grundvåg et al., 2020, 2021a), with policy implications well beyond coastal Norway.

Objective quality was assessed using the catch damage index (CDI) (Esaiassen et al., 2013) because the official quality grades in Norway are considered unreliable, as they are self-reported by buyers and may be used deliberately to influence prices (Sogn-Grundvåg and Henriksen, 2014). The official quality grades are also rather coarse-grained, as quality is reported only as "regular" or "downgraded". The quality assessment was conducted on Atlantic cod from 432 catches landed by coastal vessels fishing with gillnets, Danish seines, longlines and handlines. The quality data was combined with a second data set drawn from a database provided by the Norwegian Directorate of Fisheries, which contained details about the size of these catches, the fishing methods used, and the size and age of the vessels.

2. Materials and methods

2.1. The Norwegian coastal groundfish fishery

The coastal fishery for Atlantic cod in Norway is a significant one, supplying a large and diverse processing sector that provides fresh whole fish, fresh and frozen fillets, salted fish, clipfish and stockfish to customers worldwide. In 2018, the coastal fleet landed about 193,000 tons of Atlantic cod at an ex-vessel value of NOK 3.3 billion (EUR 344 million)[3,4].

[2] That fish buyers are hesitant to penalize fishers by lowering prices for low-quality fish has also been observed in other fisheries (MacDonald and Mazany, 1984; Wilson, 1980).

[3] There is a significant literature investigating fishing behavior for this fishery often cast in a productivity framework (see e.g., Asche et al., 2020, 2009b; Guttormsen and Roll, 2011).

[4] The coastal fleet also lands a number of other species such as seith, haddock and halibut, but as reported by Asche et al. (2015), cod is the most important species, and is targeted on most trips.

The fishery was open access until 1989, when it was closed due to the dire state of the Atlantic cod stock. A TAC based on scientific advice was set for cod, and individual vessel quotas were awarded based on previous fishing activity and vessel length. The management system has developed into one characterized by bounded transferability of fishing quotas (Johnsen and Jentoft, 2018; Standal et al., 2016). From 2008 onward, all vessels above 11 m[5] in length could increase their quotas by acquiring other vessels, scrapping one vessel, and transferring this quota to the remaining vessel. This has proved successful in the sense that overcapacity has been reduced and the profitability of the remaining vessels has improved (Zhang et al., 2018). However, it has also reduced the number of vessels and landing locations (Cojocaru et al., 2019).

The coastal fishing fleet is diverse, ranging from small and medium-sized to large vessels frequently delivering fresh catches to local fish buyers, often daily during the season. The vessels in the coastal fleet may target Atlantic cod with any fishing gear except trawl or purse seine. Fig. 1 shows the share of cod landings by the four main fishing gear types in the coastal fleet. It can be seen that a substantial share of the cod is caught using gillnets and Danish seines. It can also be seen that landings from Danish seines are increasing and that those from gillnets are decreasing. It should be noted that some vessels change gear during the season depending on how efficient the different methods are. For example, Danish seiners may change to gillnets when the cod is widely distributed, reducing the efficiency of Danish seine and favoring gillnets.[6]

The coastal cod fishery in Norway has a strong seasonal profile reflecting the yearly spawning migration of the cod from its feeding grounds in the Barents Sea to the coast of Norway. This is evident from the monthly landing pattern for the coastal fleet illustrated in Fig. 2. Generally, about 35% of the cod is landed in March and about 75% in the three winter months of February, March and April. This landing pattern indicates that there are large seasonal variations in catchability. This pattern emphasizes the benefits of intense and swift fishing tactics, as concentrating fishing effort in the high season implies reduced harvesting costs (Bertheussen and Dreyer, 2019; Hermansen and Dreyer, 2010).

Variations in the TAC for cod may also influence fishing tactics, as increasing vessel quotas may create incentives for swift and intense fishing in the high season. Fig. 3 shows that the annual catches by the coastal fleet have varied considerably over time, with a peak in 2014, the first year covered by this study. The coastal fleet is an important segment of this fishery, being allocated about 57% of the TAC for cod. Oceangoing trawlers (31%) and longliners (8%) are the other main quota recipients, which mainly freeze their catches on board and sell those catches through an auction or directly, but these sales channels are not open for fresh catches from the coastal fleet (Sogn-Grundvåg and Zhang, 2021b).

The catches are landed directly at fish buyers' processing plants, where the fish are gutted (if this has not already been done onboard), weighed and processed. Fresh Atlantic cod is a versatile raw material that is processed into a wide variety of products depending on the setup of the plants, including different types of fresh and frozen fillets, and different stockfish, saltfish and clipfish products (Gordon et al., 1993; Mazany et al., 1996). The volume of each product form that is produced is at least partly dependent on relative prices and market conditions (Asche and Hannesson, 2002). The quality of the raw fish influences the share of high-value products that can be made from a catch (Esaiassen et al., 2013; Margeirsson et al., 2010, 2007, 2006; Mazany et al., 1996). For example, a catch consisting of flawless fish will afford the fish buyer full freedom in terms of choosing a mix of products that maximizes the output value of the fish.

[5] The license length is the physical length of the vessel that had the fishing license at December 21, 1998. This length defined vessel quotas from that date.

[6] Eggert and Tveteras (2004) was the first study to show that economic and biophysical factors influence gear choice.

Table 1
Catch-damage-index* for Atlantic cod (Esaiassen et al., 2013).

Damage	Description		Score
Dead in gear	Flawless	Live when brought on board	0
	Serious	Distinct dead fish character	2
Gear-related damage	Flawless	No skin marks from gear	0
	Moderate	Stripes in the skin, fin damage	1
	Serious	Deep marks in skin/muscle causing blood extravasation and/or crushing	2
Bruises	Flawless	No red discoloration on skin	0
	Moderate	Red discoloration located below the pectoral fin or close to the tail fin	1
	Serious	Red discoloration located above the pectoral fin or in the tail and mid-part	2
Gaffing damage	Flawless	No incision other than in the head	0
	Moderate	Incision in belly/tail	1
	Serious	Incision in loin/back	2
Poorly bled	Flawless	Empty blood vessels, white neck/belly	0
	Moderate	Some blood remaining in belly vessels	1
	Serious	Blood in vessels, blood in neck/belly	2
Skin abrasion	Flawless	Undamaged, glossy skin, no descaling	0
	Moderate	Minor descaling	1
	Serious	Severe descaling, perforated skin	2
Pressure injuries	Flawless	No injuries	0
	Moderate	Squeezed in tail part	1
	Serious	Broken back, squeezed in loin part	2

*The category of "biting injuries" from the original CDI was not included because such damage hardly occurred in our samples.

2.2. The objective quality assessment

Between 2014 and 2018, quality assessments were conducted on 432 catches delivered by 195 different coastal vessels to six different processing plants in northern Norway. The assessments were conducted in February, March, and June. Two assessors from a research institute visited one processing plant at a time and worked from about 8AM until midnight, or as long as there were vessels coming in to land their catches. When one catch had been assessed, the next one in line was chosen, but catches with less than 50 fish were not assessed. In addition, because the majority of vessels fished with gillnets, vessels fishing with jigs, longlines or Danish seines were chosen over gillnetters when they arrived at the same time as the gillnetters.

The assessments were performed on individual fish picked from the process line after they had been gutted. The fish coming through the process line were mixed in terms of quality and size, because it is not conventional for fishers in this fishery to sort fish by these criteria onboard the vessel. Thus, in order to ensure that fish of different sizes and quality levels were randomly picked, the following selection rule was followed: when the first fish had been assessed, the second fish was the next fish passing by on the process line, and so on. The quality assessments were time-consuming exercises, as the two assessors needed about 1–2 h to assess 50 cod.

Between 25 and 184 (53 on average) fish were picked from each catch and assessed using the CDI (for other applications of the CDI, see e.g.: Rotabakk et al., 2011; Brinkhof et al., 2018; Savina et al., 2016). All visible damage to the fish was registered in accordance with the predefined categories outlined in Table 1.[7] The registered damage was

[7] It should be noted that the CDI does not include flaws such as soft flesh and fillet gaping, because these are rarely visible until several days after the fish has been landed. In addition, the CDI does not include the condition factor of the fish, which may vary depending on the fishing method used. For example, cod caught by gillnets are usually larger and in better condition than cod caught by longlines (Esaiassen et al., 2004; Huse et al., 2000; Ovegård et al., 2012). Large and well-conditioned cod are usually preferred for the production of saltfish and clipfish.

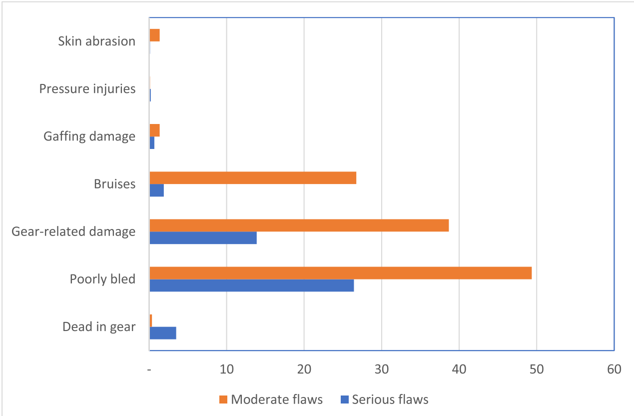

Fig. 4. The average share (%) of cod in catches with serious and moderate flaws by damage category for the whole sample and period (2014–2018).

scored as "0" (flawless), "1" (moderate) or "2" (serious) based on the extent to which the value of the final products was compromised. When the value of the end products in processing was compromised, the damage was considered "serious" and a "2" was scored (Esaiassen et al., 2013). This was done for every category except "dead in gear," which, when observed, was always regarded as serious damage. If the damage was considered not to compromise the value of the end product, a moderate flaw (1) was registered. However, three or more moderate flaws on a fish were considered to compromise the value of the end product made from that fish. Compromised value was here considered when the share of lesser-value products such as fish mince in fillet production or "sortido" in saltfish production increased at the expense of higher-value products such as fresh loins or "primeira" saltfish (Esaiassen et al., 2013).

Fig. 4 shows the share of fish being registered with serious and moderate damage for all catches in the sample across the different categories in the CDI. Poor bleeding, gear-related damage and bruises were the most common forms of damage.

Fig. 5 presents the average share of serious damage for the different categories in the CDI, by fishing method. Fig. 5 shows that gillnets performed most poorly, as almost 40% of catches had serious damage related to poor bleeding and about 25% of the fish had serious gear-related damage. The relatively high share of poorly bled fish for gillnetters may be related to long soaking time, often implying excessive struggle for the fish, which makes it difficult to bleed the fish effectively (Olsen et al., 2014). Danish seiners also had a relatively high share of poorly bled fish, which may relate to large hauls and too few crew members to bleed the fish effectively (Olsen et al., 2014).

As suggested by Esaiassen et al. (2013), the scores for the individual fish and categories can be incorporated into a catch-damage index, which indicates the suitability of the fish in a catch for processing. In order to examine the effect of fishing methods, catch size and other factors on fish quality, we created two quality indices or variables. *Quality-1* was calculated as the share of the sampled fish in each catch assessed with one or more serious flaws. *Quality-2* included this and fish with three or more moderate flaws in each catch. Thus, *Quality-2* was a stricter measure of quality than *Quality-1*. Table 2 shows the share of downgraded cod by fishing method for the two quality variables.

Table 2 shows large quality variations between fishing methods. The difference between the two quality indices is small for handline and Danish seine, indicating that these fishing methods provide a small share with three or more moderate flaws. Longlines and gillnets, on the other hand, provide more fish with three or more modest flaws. The standard deviations for the two quality variables show that there is considerable variation in the quality indices between catches, which may indicate differences in fishing tactics and thus also a potential for quality improvements.

The average size of catches across fishing methods varied substantially. The smallest average catches were delivered by vessels fishing with handlines (351 kg, SD: 412) followed by longlines (1394 kg, SD: 1399), gillnets (1584 kg, SD: 2651) and Danish seines (6789 kg, SD: 9885). Thus, the average catches for Danish seines were almost 20 times larger than for handlines, illustrating considerable differences in catching capacity between vessel groups. For all four fishing methods, the standard deviations were larger than the means, implying substantial within-group variations in catch sizes, which may reflect differences in fishing tactics between vessels.

2.3. Statistical approach

The two dependent variables, *Quality-1* and *Quality-2*, reflected the share of fish with quality levels considered to reduce the economic value of each catch to the processor. These shares ranged between 0% and 100% points. There were 24 catches without any flaws for *Quality-1*, and 19 for *Quality-2*. Accordingly, we used tobit regression to estimate the model, which considered the censored pattern of the dependent variables. The basic specification was:

$$Quality_i = a_0 + b_2 CatchSize_i + c_1 Age_i + d_1 Length_i + e_1 Handline_i + e_2 Longline_i + e_3 DanishSeine_i + \sum_{o=2}^{5} w_o Year_{o,i} + Residual_i \quad (1)$$

where *Residual* was the error term, *Year* was a dummy for the sample year with 2014 as the base. Further, *Quality* was the quality index. As we used two different independent variables, we estimated Model A for *Quality-1* and Model B for *Quality*-2. *Catch-Size* was the size of each catch in kilograms, *Age* was the age of each vessel and *Length* was the length of each vessel. *Handline*, *Longline*, and *Danish-Seine* were dummy variables for the different fishing methods, with gillnet as the base.

In order to test whether catch size influences fish quality for each fishing method, we modified the baseline specification by adding interaction terms between *Catch-Size* and fishing methods, as follows:

$$Quality_i = a_0 + b_2 CatchSize_i + c_1 Age_i + d_1 Length_i + e_1 Handline_i + e_2 Longline_i + e_3 DanishSeine_i + f_1 CatchSize_i{:}Handline_i + f_2 CatchSize_i : Longline_i + f_3 CatchSize_i : DanishSeine_i + \sum_{o=2}^{5} w_o Year_{o,i} + Residual_i \quad (2)$$

Following the literature (Huang et al., 2010; Pagnozzi and Saral, 2019), we calculated the marginal effects after estimating the models. The marginal effect yielded the percentage point change in *Quality-1* (or *Quality-2*) in response to a one-unit change in the explanatory variables (for the dummy variables, from zero to one). For the modified specification, Eq. (2), the coefficient of the stand-alone variable, *Catch-Size* measured the impact of the size of catches on the quality indices for gillnet, the base category. A significant coefficient of an interaction term for a particular fishing method indicated that the impact of the size of catches on the quality index for this fishing method differed from gillnets (the base). Table 3 presents definitions and descriptive statistics for the variables.

The reported means of each dummy variable in Table 3 are the number of observations (catches) within each category as a proportion of the total number of observations for the category. For example, handlines accounted for 9% of the total number of catches during the sample period, and 13% of the catches were from 2014.

3. Results

Table 4 presents the estimation results for the baseline specification and the full specification with the interaction terms for Model A and Model B, namely Regressions 1, 2, 3, and 4. McFadden's (1974) pseudo-R^2 value is 0.106 and 0.107 for the two regressions for Model A, and is 0.165 and 0.166 for the two regressions for Model B. For each model, the regression for the specification with more variables (with interaction

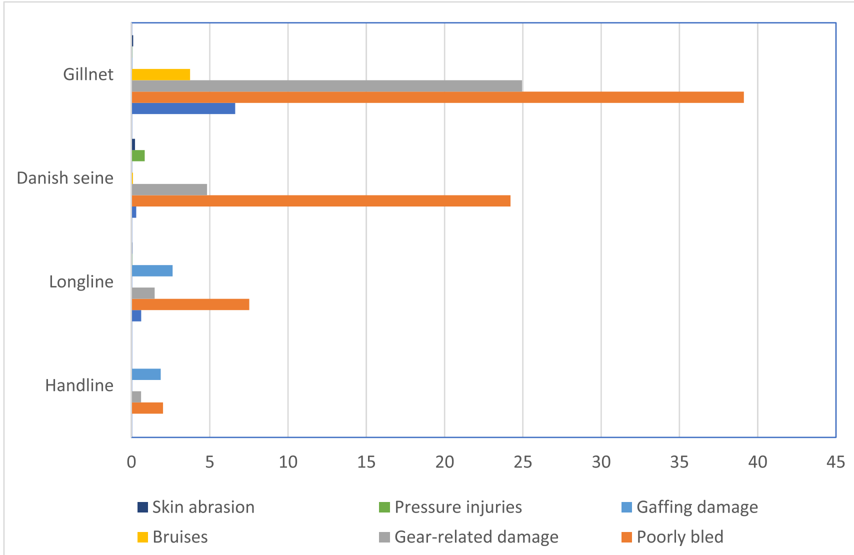

Fig. 5. The average share (%) of cod in catches with one or more serious flaws by damage category by fishing methods for the whole sample and period (2014–2018).

Table 2
The average value (in %) of the quality variables by fishing methods.

Fishing methods	Quality-1 (SD)	Quality-2 (SD)
Gillnet	43.88 (11.37)	68.11 (12.13)
Danish seine	27.54 (18.49)	28.54 (18.63)
Longline	10.91 (8.94)	14.06 (10.98)
Handline	4.73 (9.98)	5.11 (10.36)
Whole sample	32.30 (19.38)	46.28 (28.43)

Table 3
Definitions and descriptive statistics for the variables.

Variable	Definition	Mean	SD
Quality-1	Share of fish in catches assessed with one or more serious damages	32.3	19.4
Quality-2	Share of fish in catches assessed with one or more serious damages or three or more moderate damages	46.3	28.4
Catch-Size	Logarithmic size of catches in kilograms	6.92	1.43
Age	Logarithmic vessel age in years	2.83	0.80
Length	Logarithmic vessel length in meters	2.66	0.40
Dummy for fishing methods			
Gillnet (base)	Dummy (1 for Gillnet, 0 otherwise)	0.55	0.50
Handline	Dummy (1 for Handline, 0 otherwise)	0.09	0.29
Longline	Dummy (1 for Longline, 0 otherwise)	0.13	0.34
Danish seine	Dummy (1 for Danish seine, 0 otherwise)	0.23	0.42
Dummy for year			
2014 (base)	Dummy (1 for 2014, 0 otherwise)	0.13	0.33
2015	Dummy (1 for 2015, 0 otherwise)	0.19	0.40
2016	Dummy (1 for 2016, 0 otherwise)	0.25	0.43
2017	Dummy (1 for 2017, 0 otherwise)	0.30	0.46
2018	Dummy (1 for 2018, 0 otherwise)	0.13	0.33

terms) has a greater pseudo-R^2 value than the regression with fewer variables. However, the difference is marginal. For Models A and B, the two regressions provide similar estimates regarding the level of significance and direction, except for fishing methods, where there are substantial differences in the two regressions under each model. This is attributed to the interaction terms included in the full specifications (Regressions 2 and 4).

3.1. Model A

We now consider the estimates in Regressions 1 and 2 under Model A. Table 4 shows that the coefficients of *Catch-Size* and *Length* in Regression 1 are significant and positive, indicating that increasing catch sizes and larger vessels have an increased share of fish with serious quality flaws (*Quality-1*). The insignificant coefficient of *Age* indicates that vessel age does not affect *Quality-1*.

For the individual dummies for fishing methods, Regression 1 shows that gillnets (the base) provided catches that had a 38.3, 34.4% and 24.1% point higher share of fish with serious flaws (*Quality-1*) than catches with handlines, longlines and Danish seines, respectively. The estimates of fishing methods in Regression 2 are generally lower in absolute values than their counterparts in Regression 1, although only one of the three interaction terms in Regression 2 is significant.

The dummy variables for years are significant and negative in both regressions. The quality of fish was the poorest in 2014 (the base) when the TAC and thus vessel quotas for cod were the largest during the sample period (see, Fig. 3).

The interaction terms between *Catch-Size* and handline or Danish seine are not significant. This indicates that the impact of catch size on fish quality is the same for gillnets, handlines, and Danish seines. The interaction term between *Catch-Size* and longline is significant and negative, which is the opposite of the dummy for *Catch-Size* (2.63 versus 2.24), indicating that catch size does not affect fish quality for longline. This is reasonable, as longliners haul hooks one by one, which allows for time to bleed and handle the fish properly. For longliners, increasing catches would imply larger fish per hook, more hooks with fish or longer lines set.

3.2. Model B

In Model B, the coefficients reflect the impact of the explanatory variables on the share of fish with three or more moderate flaws as reflected in the dependent variable *Quality-2*. Except for fishing methods, the estimates are not substantially different between the baseline specification (Regression 3) and the full specification with interaction terms (Regression 4). As in Model A, *Catch-Size* and *Length* are significant in the two regressions of Model B, indicating that catch size and vessel length affect fish quality negatively for both *Quality-1* and the stricter *Quality-2*. The estimate for *Age* is significant and positive in Model B, indicating that older vessels are more likely to land fish with moderate flaws.

Table 4
Estimation results of the tobit models.

Variable	Model A: Quality-1				Model B: Quality-2			
	Regression 1		Regression 2		Regression 3		Regression 4	
Catch-Size	1.9771	***	2.6396	***	2.0253	***	2.7812	***
	[0.3326]		[0.4489]		[0.3524]		[0.4756]	
Age	0.4568		0.4241		1.0650	**	1.0338	**
	[0.4776]		[0.4773]		[0.5058]		[0.5054]	
Length	4.9046	***	4.4120	**	4.8374	**	4.3000	**
	[1.8724]		[1.8810]		[1.9833]		[1.9913]	
Dummy for fishing methods								
Handline	-38.264	***	-29.380	***	-62.633	***	-52.316	***
	[1.4996]		[7.4391]		[1.5875]		[7.8610]	
Longline	-34.360	***	-19.459	***	-55.135	***	-39.207	***
	[1.2095]		[6.3680]		[1.2790]		[6.7358]	
Danish seine	-24.064	***	-17.530	***	-46.983	***	-38.900	***
	[1.6502]		[6.0808]		[1.7474]		[6.4395]	
Dummy for years								
2015	-3.2920	**	-3.5324	**	-6.7219	***	-7.0016	***
	[1.3946]		[1.3969]		[1.4776]		[1.4794]	
2016	-8.9628	***	-9.0745	***	-10.167	***	-10.309	***
	[1.3456]		[1.3464]		[1.4252]		[1.4254]	
2017	-10.233	***	-10.277	***	-9.3872	***	-9.4315	***
	[1.2977]		[1.2950]		[1.3741]		[1.3703]	
2018	-7.7644	***	-7.8966	***	-4.3357	***	-4.4843	***
	[1.5408]		[1.5395]		[1.6311]		[1.6288]	
Interaction								
Catch-Size * Handline			-1.5112				-1.7551	
			[1.3225]				[1.3961]	
Catch-Size * Longline			-2.2402	**			-2.3929	**
			[0.9395]				[0.9932]	
Catch-Size * Danish seine			-0.8713				-1.0741	
			[0.7571]				[0.8020]	
McFadden's pseudo-R^2	0.106		0.107		0.165		0.166	
Observations	1083		1083		1083		1083	

Note: *** and ** indicate significance at the 0.05 and 0.10 level, respectively.

As for regressions 1 and 2 under Model A, all the year dummies in Model B are significant and negative. Compared to Model A, the magnitudes of the coefficients of fishing methods are much larger in Model B. For example, the share of handline-caught fish with serious and moderate flaws is 52.3% points lower than for gillnet-caught fish (Regression 4), but for fish with only serious flaws, the difference is 29.3% points (Regression 2). Thus, when moderate flaws are included in the quality index, the difference between gillnet and other fishing methods becomes much larger.

Regarding the interaction terms, the estimation results for Regression 4 (under Model B) and Regression 2 (under Model B) are similar. The negative impact of catch size on fish quality applies to gillnet, handline and Danish seine fishing. As for Model A, the interaction term for *Catch-Size* and longline is significant and negative, which is the opposite of the dummy for *Catch-Size* (2.78 versus −2.39), indicating that catch size does not affect fish quality for longline fishing.

4. Conclusions

Because landings of poor-quality fish influence downstream value-adding opportunities negatively, and because a decline in fish quality during harvest can never be regained in later stages of the value chain (Østli et al., 2013), it is preferable for society that the landed fish be of good quality. This study provides comprehensive insights into the effect that key fishing tactics such as fishing methods and catch sizes might have on fish quality in a fishery with few restrictions on gear choice and fishing intensity, and in which quality-based pricing is largely absent.

The statistical analysis showed large variations in fish quality between fishing methods. Using the strictest measure of fish quality (*Quality-2*) as the dependent variable, gillnets provided fish that had a 52.3, 39.2% and 38.9% point higher share of poor-quality fish than catches with handlines, longlines and Danish seines, respectively, holding other factors such as catch size, year, vessel length and vessel age constant. The analysis also showed that catch size, a measure of fishing intensity, had a negative impact on fish quality for gillnet, handline, and Danish seine fishing, but not for longline fishing.

Moreover, the year dummies (2015–2018) were significant and negative compared to 2014, holding other factors such as fishing methods and catch size constant. This indicates that the quality of fish was the poorest in 2014, when the cod quota was at its highest. This suggests that other factors than fishing methods and catch sizes influence fish quality. A short fishing season combined with large vessel quotas may lead to economic incentives to fish in poorer weather and stronger ocean currents, which may influence fish quality negatively because under such conditions, the fish is exposed to more stress during the catch operation. In addition, poor weather conditions may lead to rougher fish handling, also affecting fish quality negatively.

Explanations for the high share of poor-quality fish observed here can probably be found in how fishers adapt to biological, economic and regulatory constraints. The strong seasonality of the fishery, combined with large quotas, may lead to economic incentives to more intense fishing with the most efficient fishing methods—that is, gillnets and Danish seines. The high share of cod catches landed with these fishing methods (almost 80% in 2018) and their high share of poor-quality fish suggest that fish of low quality is not penalized with lower prices in the ex-vessel market, at least not to such an extent that fishers change their fishing tactics. Thus, to increase profits, it is rational for fishers to choose the most efficient fishing gear and swift and intense fishing, maximizing catch size at low costs. Given that fishers, and in particular those fishing with gillnets and Danish seines, are not provided with economic incentives to land fish of good quality, policy makers may consider gear restrictions and reductions in the size of vessel quotas as possible interventions to reduce the high share of poor-quality cod landed by the coastal fleet.

CRediT authorship contribution statement

Geir Sogn-Grundvåg: Conceptualization, Writing – original draft preparation, Writing – reviewing and editing. **Dengjun Zhang:** Conceptualization, Methodology, Formal analysis, Writing – reviewing and editing. **Edgar Henriksen:** Conceptualization, Writing – reviewing and editing, Project administration, Funding acquisition. **Sjurdur Joensen:** Conceptualization, Methodology, Investigation, Writing – reviewing and editing. **Bjørn-Inge Bendiksen:** Conceptualization, Investigation, Writing – reviewing and Editing. **Øystein Hermansen:** Writing – reviewing and editing.

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.

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