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Individual quotas and revenue risk of fishing portfolio in the trawl fishery

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ABSTRACT

The Norwegian bottom-trawl fleet is managed through individual vessel quotas and is generally engaged in codfish fisheries, where several species contribute to the revenue of the fishery. The revenue from the fishing exhibits substantial intra-annual variation and carries a significant degree of risk due to the presence of intrinsic volatilities in the marine environment, such as seasonal fluctuations in stock size and constant changes in market conditions over the course of a year. In the face of volatile revenue, fishers may allocate fishing effort and use a quota portfolio to minimize revenue risk. However, decisions underlying effort allocation, such as when to fish what and how much to harvest to match the catch size and remaining quota, are challenging. In this regard, a decision-making framework based on a bio-economic model is used to explore the revenue risk minimization behavior of the Norwegian codfish trawl fleet targeting three different species (cod, saithe, and haddock), given the constraints set by the quotas. The study comprises trawl catches and fishing effort as well as the prices for the frozen products of codfish to investigate the adopted harvest strategy under two different scenarios. The results indicate that a risk-minimizing strategy leads to inefficient allocation of fishing quotas and fishing effort and that potential economic losses from minimizing revenue risk outweigh the benefits. Moreover, our findings prove that enhancing revenue is more important than minimizing revenue risk for the trawlers. We argue that the spatial and temporal freedom of the trawl vessels, together with a vertically integrated trawl industry, may explain the prioritization of revenue enhancement over revenue risk minimization. The seasonal spawning aggregation of NEA cod and how this affects market prices shape the trawlers' harvest strategy of increasing fishing revenue.

1. Introduction

The Norwegian codfish bottom-trawl vessels hold fishing quotas for North-east Arctic (NEA) cod (*Gadus morhua*) as the main species, together with large quantities of other economically important fish species, such as saithe (*Pollachius virens*) and haddock (*Melanogrammus aeglefinus*) (Birkenbach et al., 2020; Salvanes and Squires, 1995). The trawl vessels are reasonably homogenous in terms of length (size) and engine power, conducting year-round operations over a vast geographical area from south in the North Sea to the sub-Arctic areas of the Barents Sea (Flaaten and Heen, 2004; Standal and Hersoug, 2014). This sector comprises companies that are vertically integrated, where adjacent stages of production process are managed under a single ownership (Dreyer et al., 2006; Hermansen and Dreyer, 2010; Isaksen, 2007).

Codfish trawlers face high levels of revenue risk (i.e., revenue variability) within a fishing year (Birkenbach et al., 2020; Hermansen and Dreyer, 2010). Revenues are generated by catch size and prices. Over the course of a fishing year, two major drivers underlie volatility in fishing revenue, namely unpredictable catch per unit of effort ((CPUE), reflecting fish availability ((Hilborn and Walters, 1992; Maunder et al., 2006)), and price fluctuations (Asche et al., 2015; Birkenbach et al., 2020; Hermansen and Dreyer, 2010). Reducing the variability of revenue is a mean to long-term economic viability (Doherty, 2000; Heady, 1952; Outreville, 1998; Sethi, 2010). A stabilized year-to-year flow of revenue helps fishers to pay off the loans that were borrowed to purchase vessels and/or additional tangible (e.g., equipment such as gears) and non-tangible (e.g., fishing permits) capitals (Holland et al., 2017; Sethi, 2010). Given its significance and the fact that the trawler fleet supplies a year-round codfish fishery, identifying the revenue risk-minimizing harvest strategy of the trawl fishery could secure the supply chain from disruptions and reinforce the Norwegian fishery.

Beside the inherent uncertainty in prices and market conditions, the migratory behavior of codfish to spawn and feed and the coexistence of a coastal fleet also targeting codfish make it more difficult to optimally allocate fishing effort to minimize revenue risks. Each winter, NEA cod, saithe, and haddock aggregate to spawn along the north-west coast of

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Norway (Bergstad et al., 1987; Godø and Michalsen, 2000; Olsen et al., 2010). The spatial overlay of cod, saithe, and haddock during wintertime results in the joint harvest of these fish stocks and heterogeneous catch compositions, where bycatch could constitute a large part of the catch, and the fishing revenue is linked across multiple species (Birkenbach et al., 2020). This catch composition might not necessarily be associated with the minimization of revenue risks. Another consequence of the spatial overlap is that fishers inadvertently consume the quota for the harvested fish species as the Norwegian fisheries management bans discard, and the total catch has to be landed (Gullestad et al., 2015; Johnsen and Eliasen, 2011). The incidental catch and reduction in quota sizes might make it difficult to adjust catch sizes and remaining quotas for the remainder of the year to accomplish revenue risk minimization.

The coastal fleet is allocated 65–80 % of the Total Allowable Catch (TAC) quota of codfish (Asche et al., 2014; Hermansen and Dreyer, 2010). Spawning aggregation (i.e., higher CPUE) leads to reduced cost per unit of catch (Hannesson, 2007; Kvamsdal, 2016; Sandberg, 2006). This, together with the limited geographical mobility of the coastal boats, encourages them to fish the cod quota during spawning aggregation. The first-hand price of cod is endogenous to the quantity harvested (Arnason et al., 2004; Asche et al., 2002; Birkenbach et al., 2020), and hence, a large supply of cod influences its price (Alizadeh Ashrafi et al., 2020; Hermansen and Dreyer, 2010). The prices of saithe and haddock are less responsive to the landing volumes (Birkenbach et al., 2020). After spawning, cod and haddock swim back to the nutritious regions of the sub-Arctic areas to feed in a less congregated manner (i.e., lower CPUE) (Bergstad et al., 1987; Trout, 1957). At this time, prices of cod and haddock increase due to lower landings, as the coastal fishers already have fished their quotas, and the supply is limited (Alizadeh Ashrafi et al., 2020; Birkenbach et al., 2020; Hermansen and Dreyer, 2010). Further complication arises from the fact that these stocks are interrelated, and changes in the CPUE of one stock can influence the price of other fish stocks (Asche et al., 2015; Birkenbach et al., 2020). Since multiple causes are implicated, it might not be easy to isolate the possible effect of variation in CPUEs on price levels to use quota in such a way to stabilize revenue.

Considering the above-mentioned complexities, the main objective of this article is to determine the harvest strategy which leads to revenue risk minimization in codfish fishery over the course of a year and whether achieving this goal does matter for the vertically integrated trawl fleet. Under quota regulations, an important facet to minimize revenue risk is the efficiency of effort allocation and quota use. Hence, the second objective is to examine the efficiency of adaptation of the revenue risk-minimizing strategy. Since fishing quotas are valid for a given year, we conducted our analysis within the period of 1 year. A decision-making framework based on a bio-economic model was employed, where the coefficient of variation of revenue per unit of effort (RPUE) across trawl vessels over 6 consecutive years (2011–2016) was used as a revenue risk measurement. Decision analysis is one of the commonly used methods for risk management in fisheries (Harwood, 2000; Mendoza and Martins, 2006; Sethi, 2010; Vergara-Solana et al., 2019). However, there is no literature analyzing the decision-making process of trawlers in relation to revenue risk minimization, which is a new contribution of this work. Another important contribution is the consideration of bycatch in our analysis. The outcome of our analysis reveals how trawl fishers cope with unpredictable variability in fishing revenue. It also discloses the patterns of fishing effort allocation and quota use towards revenue stability. Implementing fishers' behavior in fishery management will promote the efficiency of regulatory systems (Hilborn, 1985, 2007).

2. Method

2.1. Measuring the risk of fishing revenue based on a bioeconomic model

Adopting Schaefer's (1954) harvest function to our framework, we used the following equation:

$$H_{it} = q_i \cdot E_{it} \cdot B_{it} \tag{1}$$

where H_{it}, E_{it}, and B_{it} are measurements of total catch measured in tons, the amount of fishing effort expressed in trawling hours, and stock availability expressed in tons at time t, respectively. Factor i refers to available fisheries (here: cod, saithe, and haddock). The constant factor q_i refers to the catchability coefficient of each fishery, which addresses the efficiency of fishing operations (Hilborn and Walters, 1992; Maunder et al., 2006). Eq. (1) shows unitary output elasticity in both stock and effort.

The CPUE is obtained by rewriting Eq. (1) as follows:

$$CPUE_{it} = \frac{H_{it}}{E_{it}} = q_i\ B_{it} \tag{2}$$

The CPUE is measured in tons of fish being caught per trawling hour. As it can be seen according to the underlying assumptions, $CPUE_{it}$ varies proportionally with stock biomass B_{it}, with a constant proportionality factor of q_i. Hence, CPUE can be used as an indication for fish availability (i.e., congestion and dispersion) over the course of 1 year (Maunder et al., 2006). Higher/lower values of CPUE address the availability of dense/dispersed fish stock (Maunder et al., 2006). Based on Eq. (1), the revenue function for each fishery could be obtained as follows:

$$R_{it} = p_{it} \cdot H_{it} \tag{3}$$

where R_{it} refers to the revenue generated from fishery i at time t and p_{it} shows the unit price of species i at time t, caught by trawlers, in Norwegian currency (NOK). The codfish trawlers are equipped with processing and freezing facilities and mostly deliver frozen products (Flaaten and Heen, 2004; Standal and Hersoug, 2015). Eq. (3), in terms of revenue per unit of effort (RPUE), is as follows:

$$RPUE_{it} = CPUE_{it} \cdot p_{it} \tag{4}$$

Since expected revenues of fishing trips could not be observed directly (i.e., when fishers leave the port, catch sizes and landing prices are uncertain), we used RPUE to approximate the expected fishing revenue. Trawlers take longer trips, approximately 2 weeks, and hence, the prices at the time of landing may be different from those when the fishers left the port.

To capture the revenue risk of the fishing portfolio, we used the coefficient of variation (CV) of RPUE for each fishery across vessels (Kasperski and Holland, 2013; Sethi, 2010; Sethi et al., 2014), using the following equation:

$$CV(RPUE_{it}) = \frac{\sigma_{it}}{\mu_{it}} \tag{5}$$

where CV captures the risk of RPUE of the i th fishery at time t across vessels over 6 years (2011–2016); σ_{it} and μ_{it} are the standard deviation and mean of RPUE in fishery i at time t, respectively. The greater the CV, the greater the revenue risk. Three trawl companies owned more than 50 % of the codfish quotas/vessels (Anon., 2018, pp 63). Owning multiple homogenous vessels together with vertically integrated industry facilitates information flow across vessels about the allocation of the fishing effort. This argument could justify a similar adopted harvest strategy among the trawlers. Hence, aggregation of CV of RPUE across vessels to obtain a single value for CV in each time period t would not cause a loss of important information. Under this clarification, it is also rational to assume that the vessels may also be highly homogenous in their cost structure, hence RPUE could also address the profit (i.e., henceforth we use revenue and profit interchangeably). The reason for the aggregation of CV over 6 years is to see how quotas are allocated over the course of a single fishing year to accomplish the revenue risk minimizing objective. Under the Norwegian fisheries management, quotas are distributed among the vessels annually and they are only valid to use within a given fishing year.

2.2. Proposed model

Decision analysis is an appropriate and commonly used tool in natural resource management situations where decision makers are faced with complex problems with a set of defined alternatives (Mendoza and Martins, 2006; Vergara-Solana et al., 2019). The aim of decision analysis is to assist decision-makers in systematizing the decision-making process and making the best choice between different courses of actions to achieve the goal that matters. Decisions can be classified either as mono-criterial, when only one goal is considered to evaluate its performance (e.g., minimizing revenue risk), or multi-criterial, which takes into account the interaction between two or more goals (e.g., minimizing revenue risk and generating profit) that can be contradictory (Mendoza and Martins, 2006; Vergara-Solana et al., 2019).

Here, we treated a representative holder of a quota portfolio of cod, saithe, and haddock as a perfect foresight decision-maker, aiming to minimize revenue risk by constantly making decisions about when to fish what, whilst adhering to the quota constraints and bycatch rules (i.e., compliant fisher). The main assumptions used in the formulation of this problem are the following: Trawlers switch between target species every 2 weeks (i.e., we cannot target two different main species during the same fortnight). The assumption is considered realistic due to the high cost of frequent switching between target species. Trawlers are assumed to operate at full capacity. The time resolution is a fortnight, and one fishing year is equal to a maximum of 26 fortnights. Based on the Norwegian fisheries management, bycatch is not discarded, and fishers have to land all of the harvested fish, including the main catch and the incidental catch (Gullestad et al., 2015; Johnsen and Eliasen, 2011). This assumption necessitates that trawlers adeptly match catch size and remaining quota and reserve part of their quota for the *expected* bycatch in future hauling. For example, during the winter months and spawning season for NEA cod, saithe, and haddock along the north-west coast of Norway, the main catch inevitably includes incidentally caught species (Olsen et al., 2010). Furthermore, the following notations are used in the formulation of the proposed research question:

Sets

$i \in \{1, 2, 3\}$ Potential sets of fisheries; cod (1), saithe (2), and haddock (3)

$t \in \{1, 2, \ldots, 26\}$ Sets of fortnights

Parameter

Q_i Initial quota allocation of a representaive trawl vessel for fishery i

Decision variables

H_{it} Landing of species i in tons at time t

RQ_{it} Remianing quota of species i at time t

Business objective

$$\text{Min} \sum_{i=1}^{3} \sum_{t=1}^{26} CV(RPUE_{it}) \tag{6}$$

Here, $CV(RPUE_{it})$ indicates the revenue risk of the fishing portfolio, calculated across 61 vessels within each fortnight over 6 years (2011–2016). Eq. (6) indicates that in a given year, a representative trawler seeks to minimize the total risk of fishing portfolio revenue across species i and time period t.

Constraints

$$\sum_{t=1}^{t=26} H_{it} \leq Q_i \tag{7}$$

$$RQ_{it} = Q_i - \sum_{t=1}^{t=26} H_{it} \tag{8}$$

$$\sum_{t=1}^{t=26} E_{it} \leq \overline{E} \tag{9}$$

$$E_t \geq 0 \tag{10}$$

$$H_{it}, CV(RPUE_{it}) \geq 0 \tag{11}$$

Eq. (7) ensures that the trawler's total landings of three species (including bycatch) over the course of a fishing year do not exceed the quota allocations (i.e., compliant fisher). In addition, we used the smaller-than-or-equal sign to address the fact that misallocation of fishing effort and fishing right could lead to rest quotas at the end of the fishing year. Hence, there is a possibility that the trawlers are not able to fully exhaust their quotas. This constraint defines our first scenario. Eq. (8) implies that the landed catch, including main and bycatch species, is subtracted from the corresponding quotas. Eq. (9) indicates the time and capacity constraint of the vessel. Eq. (10) guarantees a non-negative effort. Eq. (11) implies that at each period fisher's catch as well as the risk associated with the revenue are non-negative.

In the second scenario, we assume that the representative fishing firm pursues a set of business goals, including minimizing revenue risk and generating sufficient and reasonable levels of revenue from holding this fishing portfolio. Under such circumstance, the constraint expressed by Eq. (7) becomes stricter in the cod fishery, with the following equation:

$$\sum_{t=1}^{t=26} H_{cod,t} = Q_{cod} \tag{12}$$

Since cod is the most economically valuable species in the portfolio (Birkenbach et al., 2020), constraint (12) assures that the trawler will generate sufficient money by fully exhausting the cod quota by the end of the fishing year while minimizing revenue risk.

2.2.1. Solution algorithm

Once the CV of RPUE is calculated for each fortnight and fishery across vessels via Eq. (5), it is sorted from lowest to highest to acquire what species, in which fortnight, and in which catch proportion will result in the lowest risk of portfolio revenue. This does not mean that we exhaust the quota for species with the lowest CV, because if we do so, we are left with no quota, and no more fishing is allowed for that species in future attempts. Put differently, we take the expected catch and bycatch compositions in the future landings into account that contribute to the lowest revenue risk. Hence, we constantly rebalance catch size (i.e., including bycatch) and remaining quota by tracking how much catch and bycatch the trawler might still get during the remaining fortnights to minimize the risk of RPUE of the portfolio. Assuming that a specific species that minimizes the risk is selected at a given time, if the remaining quota for this species is small, given the remaining fortnights, we choose the second-best option, as the trawler is likely to exhaust the remaining quota of the first option with the bycatches in future hauls. In order to implement this in our model, we first obtain catch and bycatch distributions for each fortnight. This information helps us to define a threshold in the quota utilization so that we take expected catch and bycatch for the rest of the year into account to make sure that we meet the business objectives while avoiding overfishing the quota portfolio. When the catch size reaches the threshold, the representative fisher has switch the fishery and choose the second best option.

In the second scenario, since we articulate the exhaustion of cod quota to generate enough revenue, we perform the same as above, albeit twice. We first go over each CV value, from lowest to highest, but skip any CV from a species different than cod. By doing so, we prioritize catching cod to generate money while minimizing portfolio revenue risk. We then perform the same procedure with all three species. When we do that, we basically skip any CV for cod, since we already have used the cod quota.

3. Data construction

We employed two different data sets to explore the risk minimizing harvest strategy of the trawl fleet. Haul-based data of 61 trawlers, including single and double trawl vessels, targeting cod, saithe, and haddock over the study period (2011–2016) were derived from the Norwegian Directorate of Fisheries (Norwegian: Fiskeridirektoratet). The total numbers of single trawl hauls targeting cod, saithe, and haddock were 86,418, 67,071, and 38,928, respectively. Almost all 61 vessels were active in all three fisheries over the 6-year-period. The haul-based records were further decomposed into estimates of catch weights of the main target together with bycatch species and allocated fishing effort. Using this information, we obtained CPUEs of main and bycatches species (see Eq. 2). Fig. 1 shows how CPUEs of cod, saithe, and haddock vary across the respective target fishery (e.g., cod, saithe and haddock) over the course of 1 year on a fortnightly basis. The spokes represent the average fortnightly values of CPUE, starting from zero and expressed in tons of fish caught per hour of trawling.

Fig. 1 indicates that the temporal variation of the cod and the haddock fisheries followed similar patterns. Cod reached the highest peak in March (5th fortnight). Similar to cod, haddock experienced a high CPUE in March (6th and 7th fortnights). The CPUEs of cod and haddock fisheries exhibited high values in the summer season in June (13th and 12th fortnights, respectively). After the summer season, the CPUE values of the cod fisheries declined and remain almost stable. Similarly, towards the end of the year, the CPUE values of haddock also declined. The saithe fishery showed lower catchability compared to the cod and haddock fisheries. In addition, temporality exhibited a different pattern, with peaks in January (2nd fortnight) and April (7th fortnight). Apart from these 2 months, the CPUE value of saithe was almost invariant and remained around 2 tons per hour of trawling. Observing high CPUE values in the winter months is primarily due to congregated fish stocks. Higher CPUE values of cod and haddock fisheries in summer are ascribed to the time when these fish species are available in the sub-Arctic regions to feed. At this time (i.e., June and July), the climatic conditions of the sub-Arctic areas have become more desirable.

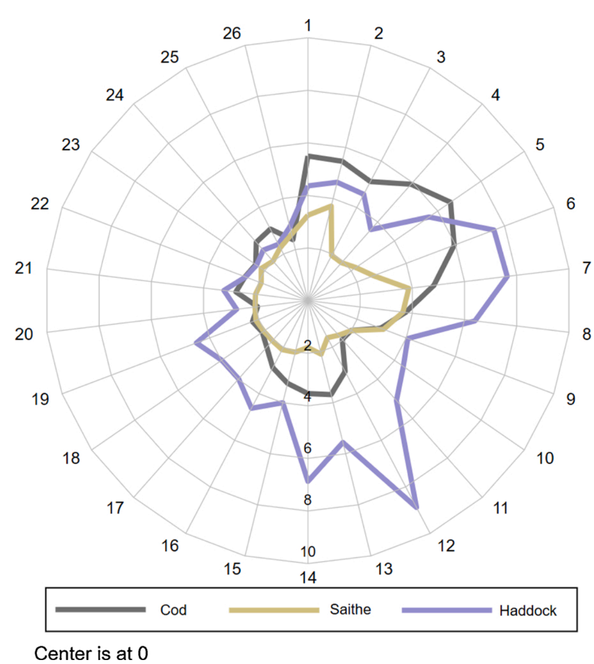

Fig. 1. Fortnightly average of CPUE (tons per trawling hour) for cod, saithe, and haddock fisheries based on individual hauls of 61 registered trawl vessels. Source: The Norwegian Directorate of Fisheries 2011–2016.

Fortnightly prices for frozen cod, saithe, and haddock, caught by trawlers during the 6 years (2011–2016), were obtained from the Norwegian Fishermen's Sales Organization (Norwegian: Norges Råfisklag). Fig. 2 depicts the average price movements of these fisheries on fortnightly basis.

As seen in Fig. 2, cod and saithe were the most and the least valuable fish stocks in the quota portfolio, respectively. At the beginning of the year, the prices of cod and haddock decline. This is the time when these fish stocks aggregate along the coastal areas to spawn (higher CPUE). In contrast, towards the end of the year, cod and haddock fetch higher prices (lower CPUE). Unlike the price patterns of cod and haddock, the first-hand price of saithe is highest in March (5th and 6th fortnights) (around 10 NOK per kilo). From April (7th fortnight), the price of saithe starts to decline and remains almost constant until the end of the year. Generally, saithe price does not fluctuate as much as the prices of cod and haddock, probably because the CPUE of saithe does not vary considerably, if we disregard January and April (see Fig. 1).

Multiplying fortnightly prices and CPUEs per haul in each fortnight yielded the corresponding RPUEs (see Eq. 4). The CVs of RPUEs across vessels were obtained by the aggregated standard deviation and mean of the fortnightly RPUEs of the three fisheries for 26 fortnights (see Eq. 5). The choice of time resolution was that the fortnightly data enables to level out random noises in harvest attributed to luck, weather conditions, and stochastics in general. Additionally, due to the availability of freezing facilities on board, trawlers take longer fishing trips – about 2 weeks on average – including running time to and from the fishing grounds.

To see how the catch composition looks in the revenue risk minimization strategy, we obtained the total of main catch and bycatch of three species per vessel over 26 fortnights to implement it in our model. To account for the quota constraints in shaping the adopted harvest strategy and to investigate whether or not the allocation of quotas was efficient, we used total landings of each species to approximate the allocated quotas. The Norwegian trawl fishery is strictly regulated through catch quotas, and fishers cannot fish more than the allocated catch shares. If they do so, overfished quotas are confiscated or highly penalized (Gullestad et al., 2015; Hersoug, 2005; Johnsen and Eliasen, 2011). In addition, the imposition of bycatch regulations in Norwegian fisheries assures that fishers land the total catch (Gullestad et al., 2015; Johnsen and Eliasen, 2011). Hence, total catch could be a reasonable approximation for the quota size. Table 1 shows the average annual quota allocation per trawl vessel in tons for three species over 2011–2016. Cod quota constituted the largest part of the quota portfolio. The quota sizes of saithe and haddock fisheries were almost similar.

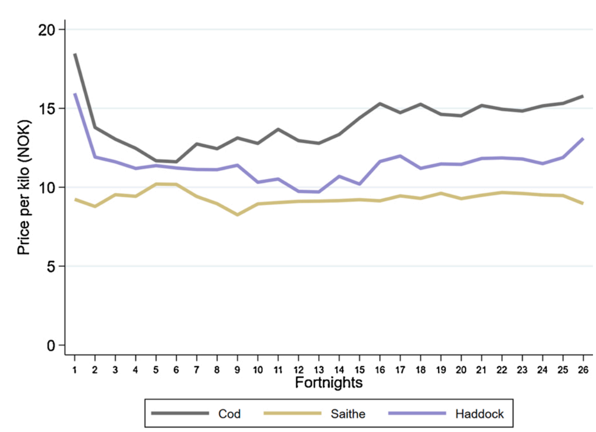

Fig. 2. Fortnightly average prices for the landed frozen products of cod, saithe, and haddock caught by the trawl fleet in 2016. Source: Norwegian Fishermen's Sale Organization.

Table 1
Calculated average annual allocations of quota per vessel in tons for cod, saithe, and haddock over 2011-2016.

Species	2011	2012	2013	2014	2015	2016
Cod	2,912.749	3,230.679	3,650.051	3,522.420	3,353.478	4,121.903
Saithe	1,588.563	1,802.133	1,414.457	1,547.285	1,334.687	1,794.641
Haddock	1,857.306	2,077.503	1,066.616	1,076.089	1,052.776	1,500.121

To obtain the *initial* quotas for a given vessel in a given year which operates in three fisheries and aims to minimize revenue risk, we determined the average of annual quota allocations for each species over 6 years, presented in Table 1. By doing so, we obtained quota sizes of 3,465.21, 1,580.29, and 1,438.4 tons for cod, saithe, and haddock, respectively. The adopted harvest strategy should be consistent with these quotas.

4. Results

Fig. 3 shows how the CV of RPUE of the three species varied over the course of a fishing year. The CV of RPUE of cod varied in a wider range in comparison to those of saithe and haddock fisheries. Haddock showed the least fluctuation in RPUE, probably because increase/decrease in CPUE offsets decrease/increase in price. RPUE of cod exhibited a lower volatility at the beginning of the fishing year, probably due to the opposite effect of high values of CPUE and low prices. After the seventh fortnight (April), when the price started to rise, the CV of RPUE of cod increased. In contrast, saithe showed more fluctuations at the beginning of the year, with its peak in January, due to high values of CPUE (see Fig. 1). After May, the CV of RPUE of saithe showed less fluctuations in comparison to cod. One possible explanation is that in this period, both CPUE and the price of saithe remained almost stable (Figs. 1 and 2).

4.1. Scenario 1

Fig. 4 reveals the catch composition (upper panel), quota utilization (middle panel), and generated revenue from the adopted harvest strategy (lower panel) to minimize revenue risk under the scenario that minimizing revenue risk is the only business objective to achieve. Since the CV of RPUE of cod fluctuated within a wider range for most of the year (Fig. 3), a trawler whose aim is to minimize the volatility of portfolio revenue redirects fishing effort to haddock and saithe fisheries. The middle panel of Fig. 4 shows how the quotas are allocated to accomplish this business objective. Here, trawlers only use half of the allocated cod quota, but fully exhaust saithe and haddock quotas as the revenues from saithe and haddock fisheries carry less fluctuations (Fig. 3). The cod quota is used in March-May and July-August, and unused cod quota means that minimizing revenue risk leads to inefficient allocation of fishing effort. This is not expected to be the case in real fishing practice as quotas are markedly expensive, notably the cod quota, and having leftovers of cod quota is a significant economic loss. The lower panel of Fig. 4 shows how these three fisheries contribute to the total revenue from the risk-minimizing harvest strategy. The total revenue from this harvest strategy was around 60 million Norwegian kroner (NOK).

4.2. Scenario 2

Fig. 5 shows the results of the second scenario where the trawler aims to minimize revenue risk while generating a *sufficient* and *reasonable* amount of revenue. The upper, middle, and lower panels of Fig. 5 show catch composition, quota utilization, and generated revenue of this harvest strategy. The upper panel of the figure shows that trawlers used the cod quota early in the fishing year (January-mid April) as well as towards the end of the year. From fortnights 10–13, trawlers partook in saithe fishery when both CPUE and price were almost stable (Figs. 1 and 2). A busy time for haddock fishery is winter, when the CPUE is high and the price is low. However, a part of the haddock quota was used in July (fortnight 14−15-16), when the CPUE is still high and the prices are still low (Figs. 1 and 2). The middle panel shows that the representative trawler can fully exhaust the fishing quota portfolio. This is a win-win situation for the fishing company as the trawler meets two important business objectives simultaneously. The lower panel of Fig. 5 shows the revenue of the fishing portfolio, decomposed by target species. The total revenue of the adopted harvest strategy was around 80 million kroner.

5. Discussion

5.1. First scenario

In the first scenario, we assume that the only business objective of the trawlers is to minimize revenue risk. Under such circumstance, the

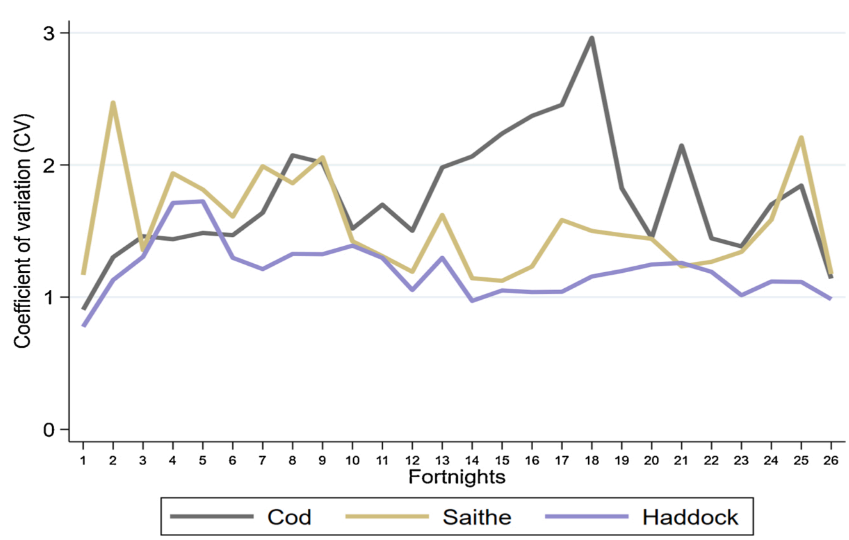

Fig. 3. Fortnightly values of coefficient of variation (CV) of RPUE of three species (cod, saithe, and haddock) over the course of a fishing year, caught by a trawl fleet.

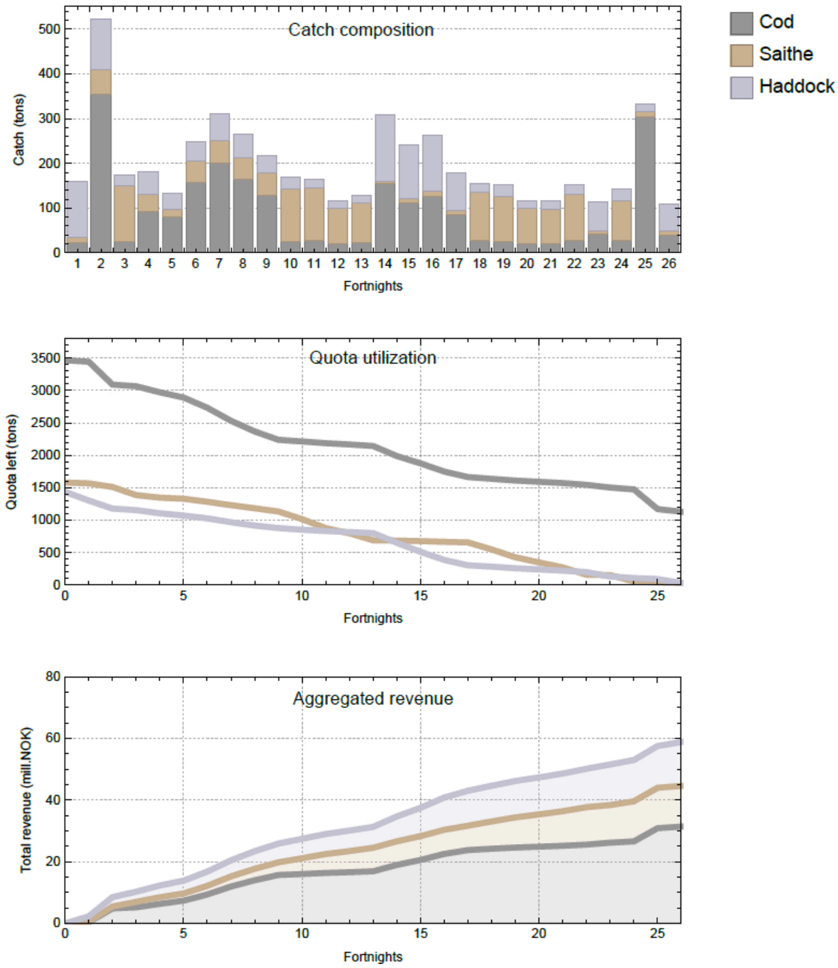

Fig. 4. Catch composition, quota utilization, and revenue of fishing portfolio for the first scenario over 26 fortnights.

results show that trawlers give up on cod fishery and operate in haddock and saithe fisheries because the CV of RPUE cod is higher during most periods compared to those of saithe and haddock. The Norwegian quota systems are heavily built upon the "use-it-or-lose-it" principle, and if trawlers cannot manage to fully exhaust their cod quota, just a negligible portion of the unfished quota will be awarded in the subsequent year (Hersoug, 2005). Hence, in reality, fishers would not forgo the use of their cod quota for the sake of minimizing revenue risk as refraining from cod fishery is considered a huge economic loss. The revenue attributed to this harvest strategy is 60 million NOK. The trawler could have enhanced the potential revenue by taking a riskier harvest strategy by partaking in cod fishery. Moreover, the un-used cod quota implies that minimizing revenue risk leads to inefficient allocation of fishing effort in the trawl fishery.

5.2. Second scenario

Under this scenario, the representative trawler pursues two objectives simultaneously; to minimize revenue risk and to generate a sufficient and reasonably good amount of revenue. The result from this scenario shows that the representative trawler minimizes revenue risk while also managing to fully exhaust the quotas. Under this scenario, the fisher adopts a harvest strategy that is associated with a higher revenue risk in comparison to the strategy that was merely based on revenue risk reduction (i.e., strategy that is associated with the least revenue risk where some of the expected return was eliminated by refraining from cod fishery to lower the variability of the RPUE of the portfolio) and enhances the total revenue by 20 million kroner.

The harvest pattern in the upper panel of Fig. 5 brings the additional insights that revenue/portfolio enhancement is a more important business objective for codfish trawlers than minimizing revenue risk. A recent work by Birkenbach et al. (2020) investigated the profit maximizing harvest strategy of the Norwegian codfish trawl fleet. The authors indicate that trawlers need to spread the landings of cod (i.e., high-value species) over the course of a year, while for the less commercially important species (saithe in their study), the quota should be consumed over a short period. The reason behind this harvest strategy to maximize profit is that the Norwegian trawlers face a downward-sloping demand schedule for cod (Arnason et al., 2004; Asche et al., 2002; Birkenbach et al., 2020), and hence, spreading cod catch over the fishing year enables trawlers to take advantage of price fluctuations. Saithe supply is not as responsive as the cod fishery to price fluctuations, and the demand curve for saithe is flatter than for cod. This could be due to the limited demand of saithe. Because of the lack of or the little fluctuation in saithe price, the saithe quota should be consumed within a short period. This harvest pattern is shown in the upper panel of Fig. 5, where cod landings are spread out over the season and saithe landings are concentrated during fortnights 8–13.

Relatedly, Alizadeh Ashrafi et al. (2020) investigated the harvest strategy of Norwegian trawlers targeting cod and concluded that Norwegian trawlers are profit-oriented and respond to fluctuations in cod price and CPUE by reallocating fishing effort. They conclude that trawlers land large catches of cod as soon as the fishery opens, which is followed by a sudden drop in the catch size of cod. Toward the end of the year, trawlers increase their cod catches. This harvest pattern has also emerged from our model, shown in the upper panel of Fig. 5, where the

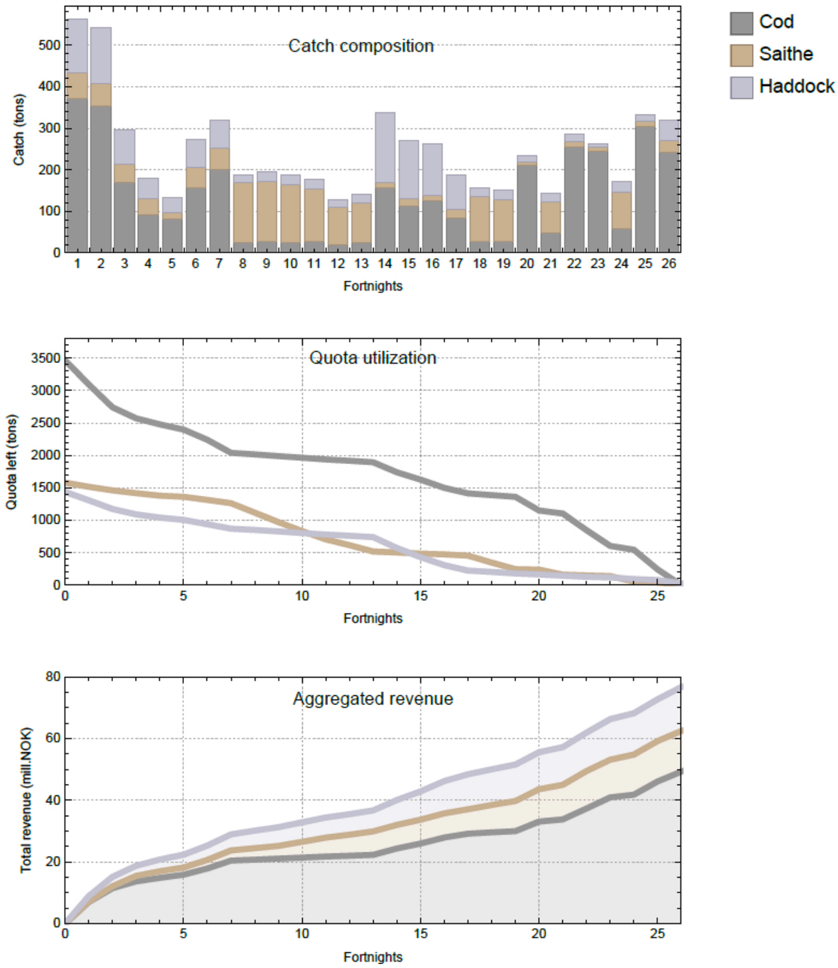

Fig. 5. Catch composition, quota utilization, and revenue of fishing portfolio for the second scenario over 26 fortnights.

cod catch is largest at the beginning of the year. The sudden drop in cod landings is detectable during fortnights 8–13, along with the substitution of cod fishery with saithe fishery. As seen in the upper panel of Fig. 5, cod landings increase toward the end of the year.

One explanation for the large landings of cod at the beginning of the year might be the effect of stock aggregation on reducing the cost per unit of effort (Hannesson, 2007; Kvamsdal, 2016; Sandberg, 2006). Proximity to the shore and higher fish densities provide opportunities for both the coastal and the high sea fleet to operate at lower costs (Hannesson, 2007; Kvamsdal, 2016; Sandberg, 2006). The sudden drop in cod landings at the beginning of the year and the shifting from the cod fishery to other available fisheries, despite the high values of CPUE of the cod fishery (see Fig. 1) and the lower cost per unit of effort, could be explained by the impact of the behavior of coastal fishers. Cod fishery is the most important fishery during winter; 65–80% of the cod quota is granted to the coastal fishers (Asche et al., 2014; Hermansen and Dreyer, 2010). The less advanced technology of the coastal boats limits their geographical mobility, which means that coastal fishers cannot chase NEA cod after spawning when the stock swims back to the high-sea areas of the Barents Sea. Hence, the spawning migration along the north-west coast of Norway during the winter months provides an unprecedented opportunity to exhaust the cod quota. The large supply of cod lowers its price (Hermansen and Dreyer, 2010) (Fig. 2), motivating trawlers to adjust their fishing effort by reallocating to more profitable fisheries (saithe and haddock) and reserving the cod quota for the periods at the end of the year, when the price is higher (Alizadeh Ashrafi et al., 2020; Hermansen and Dreyer, 2010) (Fig. 2). The authors conclude that during the winter months the reduction in price of cod is larger than the reduction in cost of catching cod, hence cod fishery is not profitable for the trawlers.

5.3. Industry structure and fleet characteristics

Norwegian codfish trawl fishery is a vertically integrated seafood industry, and a single fishing firm owns and coordinates various adjacent stages of the supply chain from harvesting fish to processing the catch as well as distributing and selling the products (Dreyer et al., 2006; Hersoug and Leonardsen, 1979; Isaksen, 2007). Incentives for mass production to increase economic efficiency, together with motivations to build a sustainable consumer market with a steady supply of codfish throughout the year, have driven the Norwegian codfish trawl industry to vertically integrate (Hersoug and Leonardsen, 1979; Isaksen, 2007). The combinatory process and lack of proprietary boundaries work as a hedging mechanism and lessen the risk exposure by providing a higher control over the industry and markets relative to non-integrated businesses (e.g., coastal fishers) (Porter, 1980; Riordan, 1990; Sethi, 2010). Moreover, bottom-trawl vessels are larger in size and equipped with powerful engines and freezing facilities, which brings flexibility in terms of temporal and spatial allocation of fishing effort. The vertical integration, together with temporal and spatial freedom, can work as a risk reduction mechanism to cope with revenue fluctuations. Under this circumstance, minimizing revenue risk is not a large concern for the trawl fishers.

6. Conclusion

In this article, we developed an intra-annual revenue risk-minimizing strategy for the Norwegian bottom-trawl targeting cod, saithe, and haddock, with the aim to investigate whether this goal governs the effort allocation decisions. We then evaluated whether adopting this harvest strategy is economically efficient in terms of quota utilization. On this basis, we built a decision-making framework of a highly complex decision problem, where fishers are faced with a wide range of choices about when and what to target and how much to fish while adhering to the quota and bycatch regulations. Our results demonstrate that this kind of risk is not an important source of concern for the trawlers, and minimizing revenue risk leads to an inefficient quota use over the course of a year. We speculate that the integrated industry as well as trawler's freedom to traverse over time and across space attenuate trawlers' exposure to revenue volatility. Our results also suggest that the Norwegian trawler fleet places greater prominence on increasing revenue/profit rather than minimizing revenue risk. Seasonal patterns in NEA cod aggregation/dispersion and the economic consequences (e.g., price fluctuations based on supply) shape the bottom-trawlers' fishing strategy.

CRediT authorship contribution statement

Tannaz Alizadeh Ashrafi has developed the research question, concept and idea. She has also prepared the manuscript. Data gathering and interpretation have been also done by her.

Shaheen Syed has helped with the study design and method.

Arne Eide has read the manuscript several times and gave comments to improve the manuscript.

Declaration of Competing Interest

The authors report no declarations of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fishres.2021.105990.

References

Alizadeh Ashrafi, T., Eide, A., Hermansen, Ø., 2020. Spatial and temporal distributions in the Norwegian cod fishery. Nat. Resour. Model. 33 (4), e12276.
Anon, 2018. Norsk fiskerinæring. Norsk Sjømatnæring Anno 2030?, p. 63 nr. 3.
Arnason, R., Sandal, L.K., Steinshamn, S.I., Vestergaard, N., 2004. Optimal feedback controls: comparative evaluation of the cod fisheries in Denmark, Iceland, and Norway. Am. J. Agric. Econ. 86 (2), 531–542.
Asche, F., Gordon, D.V., Hannesson, R., 2002. Searching for price parity in the European whitefish market. Appl. Econ. 34 (8), 1017–1024.
Asche, F., Bjørndal, M.T., Bjørndal, T., 2014. Development in fleet fishing capacity in rights based fisheries. Mar. Policy 44, 166–171.
Asche, F., Chen, Y., Smith, M.D., 2015. Economic incentives to target species and fish size: prices and fine-scale product attributes in Norwegian fisheries. Ices J. Mar. Sci. 72 (3), 733–740.
Bergstad, O., Jørgensen, T., Dragesund, O., 1987. Life history and ecology of the gadoid resources of the Barents Sea. Fish. Res. 5 (2–3), 119–161.
Birkenbach, A.M., Cojocaru, A.L., Asche, F., Guttormsen, A.G., Smith, M.D., 2020. Seasonal harvest patterns in multispecies fisheries. Environ. Resour. Econ. 75 (3), 631–655.
Doherty, N., 2000. Innovation in corporate risk management: the case of catastrophe risk. In: Dionne, G. (Ed.), Handbook of Insurance. Kluwer Academic, Boston, pp. 503–539.
Dreyer, B., Isaksen, J.R., Bendiksen, B.I., Rånes, S.A., 2006. Evaluering Av Leveringsplikten. Fiskeriforskning, Tromsø.
Flaaten, O., Heen, K., 2004. Fishing vessel profitability and local economic link obligations–the case of Norwegian trawlers. Mar. Policy 28 (6), 451–457.
Godø, O.R., Michalsen, K., 2000. Migratory behaviour of north-east Arctic cod, studied by use of data storage tags. Fish. Res. 48 (2), 127–140.
Gullestad, P., Blom, G., Bakke, G., Bogstad, B., 2015. The "Discard Ban Package": experiences in efforts to improve the exploitation patterns in Norwegian fisheries. Mar. Policy 54, 1–9.
Hannesson, R., 2007. A note on the "stock effect". Mar. Resour. Econ. 22 (1), 69–75.
Harwood, J., 2000. Risk assessment and decision analysis in conservation. Biol. Conserv. 95 (2), 219–226.
Heady, E.O., 1952. Diversification in resource allocation and minimization of income variability. J. Farm Econ. 34 (4), 482–496.
Hermansen, Ø., Dreyer, B., 2010. Challenging spatial and seasonal distribution of fish landings—the experiences from rural community quotas in Norway. Mar. Policy 34 (3), 567–574.
Hersoug, B., 2005. Closing the Commons: Norwegian Fisheries From Open Access to Private Property. Eburon Academic Publishers, Utrecht.
Hersoug, B., Leonardsen, D., 1979. Bygger De Landet?: Distriktspolitikk Og Sosialdemokrati 1945-1975. Pax Forlag, Oslo.
Hilborn, R., 1985. Fleet dynamics and individual variation: why some people catch more fish than others. Can. J. Fish. Aquat. Sci. 42 (1), 2–13.
Hilborn, R., 2007. Managing fisheries is managing people: what has been learned? Fish Fish. 8 (4), 285–296.
Hilborn, R., Walters, C.J., 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall, New York.
Holland, D.S., Speir, C., Agar, J., Crosson, S., DePiper, G., Kasperski, S., Perruso, L., 2017. Impact of catch shares on diversification of fishers' income and risk. Proc. Natl. Acad. Sci. U.S.A. 114 (35), 9302–9307.
Isaksen, J.R., 2007. Upstream Vertical Integration and Financial Performance: the Case of the Norwegian Fish Processing Industry. PhD thesis. The Arctic University of Norway (UiT), Tromsø.
Johnsen, J.P., Eliasen, S., 2011. Solving complex fisheries management problems: what the EU can learn from the Nordic experiences of reduction of discards. Mar. Policy 35 (2), 130–139.
Kasperski, S., Holland, D.S., 2013. Income diversification and risk for fishermen. Proc. Natl. Acad. Sci. U.S.A. 110 (6), 2076–2081.
Kvamsdal, S., 2016. Technical change as a stochastic trend in a fisheries model. Mar. Resour. Econ. 31 (4), 403–419.
Maunder, M.N., Sibert, J.R., Fonteneau, A., Hampton, J., Kleiber, P., Harley, S.J., 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. Ices J. Mar. Sci. 63 (8), 1373–1385.
Mendoza, G.A., Martins, H., 2006. Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. For. Ecol. Manage. 230 (1–3), 1–22.
Olsen, E., Aanes, S., Mehl, S., Holst, J.C., Aglen, A., Gjøsæter, H., 2010. Cod, haddock, saithe, herring, and capelin in the Barents Sea and adjacent waters: a review of the biological value of the area. Ices J. Mar. Sci. 67 (1), 87–101.
Outreville, J.F., 1998. Theory and Practice of Insurance. Kluwer Academic, Boston.
Porter, M.E., 1980. Competitive Strategy: Techniques for Analyzing Industries and Competitors. Free Press, New York.
Riordan, M., 1990. What is vertical integration? In: Aoki, M., Gustafsson, B., Williamson, O.E. (Eds.), The Firm as a Nexus of Treaties. Sage, London, pp. 94–111.
Salvanes, K.G., Squires, D., 1995. Transferable quotas, enforcement costs and typical firms: an empirical application to the Norwegian trawler fleet. Environ. Resour. Econ. 6 (1), 1–21.
Sandberg, P., 2006. Variable unit costs in an output-regulated industry: the fishery. Appl. Econ. 38 (9), 1007–1018.
Schaefer, M.B., 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Inter-Am. Trop. Tuna Comm. Bull. 1 (2), 23–56.
Sethi, S.A., 2010. Risk management for fisheries. Fish Fish. 11 (4), 341–365.
Sethi, S.A., Reimer, M.N., Knapp, G., 2014. Alaskan fishing community revenues and the stabilizing role of fishing portfolios. Mar. Policy 48, 134–141.
Standal, D., Hersoug, B., 2014. Back to square one? Fisheries allocation under pressure. Mar. Policy 43, 236–245.
Standal, D., Hersoug, B., 2015. Shaping technology, building society; the industrialization of the Norwegian cod fisheries. Mar. Policy 51, 66–74.
Trout, G., 1957. The Bear Island Cod: Migrations and Movement. Ministry of Agriculture and Food Fisheries Investigations, p. 21. Series 2.
Vergara-Solana, F., Araneda, M.E., Ponce-Díaz, G., 2019. Opportunities for strengthening aquaculture industry through multicriteria decision-making. Rev. Aquac. 11 (1), 105–118.