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Original Article

Same stock, different management: quantifying the sustainability of three shrimp fisheries in the Skagerrak from a product perspective

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The northern shrimp (*Pandalus borealis* L.) stock in the Skagerrak is shared by Sweden, Norway, and Denmark. Although the fishery is regulated by an annual agreement between the EU and Norway, there are also national regulations as well as differences in fleet composition and shrimp markets. In early 2014, the World Wildlife Fund gave all Skagerrak shrimp a red light in their seafood consumer guide, which led to an extensive debate, especially in Sweden, about the sustainability of this fishery. The aim of this study was to quantify a set of indicators that together give a broad picture of the sustainability of the three fisheries to provide an objective basis for a discussion on needed measures. The different indicators concerned environmental, economic or social aspects of sustainability and were quantified per tonne of shrimp landed by each country in 2012. The Danish fishery was most efficient in terms of environmental and economic indicators, while the Swedish fishery provided most employment per tonne of shrimp landed. Fuel use in all fisheries was high, also when compared with other shrimp fisheries. Interesting patterns emerged, with smaller vessels being more fuel efficient than larger ones in Sweden and Norway, with the opposite trend in Denmark. The study also demonstrated major data gaps and differences between the countries in how data are collected and made available. Various improvement options in the areas data collection and publication, allocation of quotas and enforcement of regulations resulted. Product-oriented studies could be useful to follow-up performance of fisheries over time and to identify how to best utilize the Skagerrak shrimp stock. This could involve evaluating novel solutions in terms of technology and management, based on current and future scenarios aiming to maximize societal benefits generated from this limited resource, at minimized environmental impacts.

Keywords: fisheries, LCA, northern shrimp, *Pandalus borealis*, seafood, sustainability, trawling.

Introduction

Fisheries seen from a product perspective

Capture fisheries and aquaculture form the basis for seafood supply chains delivering seafood products to retailers and consumers. In turn, the preferences of these stakeholders exert market pressure back on the suppliers of seafood and change demand for certain products, product forms or production methods, depending on a range of factors, including both traditions and trends (Jacquet and Pauly, 2007; Levin and Dufault, 2010). All actors along the supply chain therefore interact with each other and can influence the production methods. Fisheries management regulates the fishery, the first part of the supply chain of wild-caught seafood.

As most fishers comply, or try to comply, with regulations (Nielsen and Mathiesen, 2003), management has a profound influence on how fishing is undertaken and consequently on the environmental impact of the seafood products produced.

Life cycle assessment (LCA) is an established and widely used method for environmental assessment of products. It quantifies resource use and a broad suite of environmental impacts of products through their supply chain. The method is standardized (ISO, 2006a, b) and recommended as the preferred method for environmental assessment of products (EC, 2003). A broad approach is important to avoid shifting problems from one type of impact to another, or from one step of the supply chain to another.

Over the last decade, LCA has been widely used to assess environmental impacts of seafood production systems both from fisheries (Avadí and Fréon, 2013) and aquaculture (Henriksson *et al.*, 2012). Studies performed to date have shown that most impacts, biotic as well as abiotic ones, occur in the fishery (as opposed to later stages of the supply chain) and that these are highly variable mainly depending on the target species, fishing method, stock status and how the fishery is managed (Avadí and Fréon, 2013; Driscoll *et al.*, 2015; Ziegler *et al.*, 2015).

Early LCA-based management evaluations (i.e. applying life cycle methodology without performing a full-scale formal LCA) have shown that such work can give valuable insights into the importance of management decisions for environmental performance of the seafood products (Driscoll and Tyedmers 2010) and that this perspective could help broaden considerations intrinsic in management decisions (Avadí and Fréon, 2013). Most studies have compared either alternative gears or targeted species, while comparing fishing on one stock under different regulations with an LCA-based approach has been done less frequently. A study illustrated that an 80% reduction of greenhouse gas emissions may be achieved in the fishery for Tasmanian rock lobster (*Jasus edwardsii*) by shifting from maximum sustainable to maximum economic yield as the yield objective (Farmery *et al.*, 2014). Analysis of potential management scenarios in the New England fishery for Atlantic herring (*Clupea harengus*) showed that the fivefold difference in fuel intensity between midwater trawls and purse-seines in combination with spatial and temporal restrictions of midwater trawling and total allowable catch (TAC) cuts strongly affect resulting greenhouse gas emissions per tonne of herring landed (Driscoll and Tyedmers, 2010). Driscoll *et al.* (2015) showed important differences in efficiency between similar fisheries for American lobster (*Homarus americanus*) under US and Canadian regulations. It is therefore interesting to further investigate how fishing the same stock under different regulatory frameworks and with different fishing practices may result in different outputs from a product perspective.

The story of the Skagerrak northern shrimp

Northern shrimp (*Pandalus borealis*) in the Skagerrak and Norwegian Deep (ICES Divisions IIIa and IVa East) is a stock shared by three fishing nations: Sweden, Norway, and Denmark. It is considered a single stock (Knutsen *et al.*, 2015) and is fished using similar, demersal trawls of different sizes depending mainly on vessel engine power (Eigaard and Munch-Petersen, 2011). While the fisheries are managed under an annual agreement between the EU and Norway, additional national regulations have resulted in substantial differences in fleet structure and fishing practices between the three countries.

The stock and its fisheries have recently received major attention; in Sweden, it is perceived as a culturally iconic and traditional small-scale fishery but in early 2014 it was given a “red light” (=avoid) in the World Wildlife Fund (WWF) seafood consumer guide. This resulted in an immediate and almost total closure of Swedish markets for the local shrimp product. The WWF guide (aiming at facilitating consumer choice of seafood products) is based on a set of assessment criteria including stock status, ecosystem impacts of fishing, capacity management, and enforcement of regulations. The red light ranking was caused by a major drop in biomass following low recruitment since 2008 (ICES, 2013), in combination with illegal discarding of small shrimp, lack of enforcement and, to a lesser degree, bycatch of non-target species. Since then, the situation regarding the stock has improved and the latest scientific advice (aiming to provide a recommendation for fishing quotas for the following year) from the International Council for the Exploration of the Sea (ICES) assesses stock status and fishing pressure to be in accordance with the maximum sustainable yield framework and recommends quota increases (ICES, 2015a). However, the discard problem of small shrimp remains unresolved and the WWF ranking is still red in the 2015 version of the seafood consumer guide. A third assessment of the status of shrimp is provided by the Swedish Red List (aiming at assessing extinction risks of species), whose 2015 edition, based on the criteria of the International Union for Conservation of Nature (IUCN, 2012) and on the same data that is used by ICES, categorized northern shrimp in Swedish waters as “Near Threatened” (ArtDatabanken, 2015). While the assessments by WWF and by ICES are made every year, the Red list is updated every five years and is based on the development of the species over the last ten years.

The different messages sent by the WWF, ICES, and the Swedish IUCN Red List confuse and to various extents affect stakeholders along the seafood supply chain: fishers, chefs, politicians, retailers, and consumers. The differing messages are based on different criteria, methods as well as aims of the assessment, which lead to different outcomes. The public debate in Sweden has been characterized more by emotions and opinions than by facts, with high-profile persons stating that they still eat shrimp, while major retailers stop selling them. A scientific, quantitative assessment of the sustainability of shrimp trawling in the Skagerrak, encompassing a wide set of social, economic, and environmental impacts, is therefore useful.

Aim

Our aim was to provide an objective, quantitative baseline assessment of the sustainability of the fisheries of Norway, Sweden, and Denmark targeting northern shrimp in the Skagerrak. This was done by defining and quantifying indicators of sustainability for shrimp fishing per tonne of shrimp landed. We discuss the utility of applying a product-perspective in the management of these fisheries.

Material and methods

The three shrimp fisheries in the Skagerrak

With 58% of the TAC, Norway holds the largest quota (6346 tonnes in 2015), Denmark holds the second largest quota, with 28% (3005 tonnes in 2015), while the Swedish quota is 14% (1549 tonnes in 2015) (ICES, 2015b). In terms of fishing capacity, Norway has the largest fleet (188 vessels in 2013, of which 18 were >25 m). The Swedish shrimp fleet consists of 60 vessels (13 vessels >25 m), while the Danish fleet consists of 10 mainly larger vessels (8 vessels >25 m). In terms of quantity of shrimp quota available per vessel, the numbers above indicate that quotas are more limiting for Swedish and Norwegian vessels, compared with Danish ones. The TAC cuts from 2010 to 2013, when the stock declined, therefore affected these two fleets more. All fleets have been reduced in numbers of vessels over the last decades. In Denmark, the reduction in vessels has occurred more or less gradually over the past 30 years (Eigaard and Munch-Petersen, 2011); the latest reduction took place after the introduction of individual transferable quotas (ITQs) in 2007, after which the fleet size stabilized (ICES, 2015b). In Norway, the number of vessels has been reduced by >50% since the mid-1990s (Søvik and Thangstad, 2014). The Swedish fleet was reduced only slightly between 2009 and 2012 (SWaM, 2014a), but had been subject to a more pronounced reduction before that.

In all countries, shrimp catches are sorted on-board, often in an automated process, into three size fractions: large shrimp that are boiled directly at sea (consumed without further processing), medium-sized shrimp that are either landed raw (to be further processed on land) or discarded due to their lower value, and small (total length less than ~7 cm), currently non-marketable shrimp, which are discarded by all fleets. On average, about half of Swedish and Norwegian landings consist of large, boiled shrimp (ICES, 2015b), while in Denmark, the fraction of large shrimp was lower but has now stabilized at ~30–40% (Ulmestrand *et al.*, 2014). The remaining part of landings in all countries consists of the medium-sized fraction used by the processing industry.

Management

As Sweden and Denmark are EU member states, their shrimp quotas are based on relative stability of the TAC in line with the Common Fisheries Policy (CFP). The Norwegian quota share is fixed, based on negotiations between the EU and Norway. The three countries share a minimum mesh size of 35 mm, although many Swedish, and recently also Danish fishers, use larger meshes (45–47 mm) on a voluntary basis. There is also a requirement for all countries since 2013 to use a sorting grid when targeting shrimp in this area; Norway, however, does not require the use of the sorting grid in coastal waters fished solely by Norwegian vessels (within 4 nm from the coastline). By agreement, all countries allow the use of a so-called fish retention device (120 mm square mesh tunnel) catching large fish prevented from entering the codend by the grid. The use of the fish retention device is conditioned by the availability of adequate fishing opportunities for by-caught fish (quotas/rations).

With an almost tenfold price difference per kilo between medium-sized raw and lage-boiled shrimp in combination with limited quota availability, there are strong incentives to high grade (i.e. discard medium-sized shrimp). Since 2009, vessels from Sweden and Denmark are not allowed to high grade (COM/EU Reg 850/1998). The Norwegian fleet, on the other hand, has to comply with the Norwegian discard ban, which has been in force and under development since 1983 (Condie *et al.*, 2014; Gullestad *et al.*, 2015). Norway is the only country having a minimum catch size (MCS) for *Pandalus* (6 cm total length), however, landing of up to 10% in weight of shrimp below MCS is allowed in the area (Fiskeridirektoratet, 2015).

ICES estimated the total annual discard to be ~1000 tonnes (or 10% of catches) for 2011–2013, an estimate based on on-board sampling in Sweden and Denmark and considered to be highly uncertain (ICES, 2015b). Due to the large recruitment of 1-year-old shrimp in 2014, the discard for this year was estimated at >2000 tonnes (ICES, 2015b), which is higher than in previous years. Norway, with the largest fleet and the largest share of the TAC does not have a discard sampling programme and Norwegian discards have since 2009 been estimated using the Danish discards-to-landings ratio (Søvik and Thangstad, 2014); an approach adding uncertainty to the total discard estimate, and thus to the stock assessment (ICES, 2015b).

In Sweden, access to the northern shrimp fishery is given by special permits where each vessel is allowed to land a monthly ration of shrimp; this ratio is based on each vessel's track record of landings during a reference period. In Denmark, the shrimp fishery in Skagerrak has since 2007 been managed with individual and transferable vessel quota shares (VQS). These VQS were given to the Danish fishers free of charge and each vessel was allocated a share based on their landings in a reference period from 2003 to 2005; the measures were intended to reduce overcapacity and increase the economic performance of the fleet, and the system provides access only through buying existing VQS (Nielsen *et al.*, 2013). In Norway, other measures are taken to ensure continuous market supply; the total Norwegian quota is evenly allocated to three periods of 4 months each, with 40, 30, and 30% of the quota, respectively.

LCA and specific methodological choices

As mentioned, LCA performance is formalized in two ISO standards (ISO, 2006a, b). LCA typically covers abiotic resource use (e.g. energy use) and emission-based impacts (e.g. greenhouse gas emissions). Considerable efforts have been made to expand the method to quantify also fisheries-specific biological impacts in relation to the resulting seafood products. Ziegler *et al.* (2015) applied several indicators developed for this purpose in a case study of the fishing activities of a demersal trawler targeting both groundfish species and shrimp. Efforts to cover social and economic impacts are ongoing (Valdivia *et al.*, 2013), also specifically for fisheries (Veldhuizen *et al.*, 2015a, b).

Very briefly, LCA entails quantifying inputs (resources used) in relation to outputs (products, waste, and emissions) for a specified product over a defined parts of its supply chain. Resources, emissions, and impacts are then summarized across the supply chain and converted to common units for each type of environmental impact they contribute to (all greenhouse gas emissions are, e.g. aggregated into carbon dioxide equivalents) based on scientifically established cause–effect relationships (e.g. the climate forcing potential in relation to carbon dioxide). An LCA study normally covers many types of environmental impacts, but can be limited to a few or even only one, which needs to be defined. When multiple products result from a process (such as simultaneous landing of several species), resource use and impacts need to be allocated between them on a basis that needs to be defined and motivated (often the relative distribution of mass, energy content or economic value between co-products). For more detail on LCA methodology, see ISO (2006a, b) and Baumann and Tillman (2004).

To reach our goal—to quantify a number of relevant indicators of sustainability in relation to the product of the three fisheries utilizing the same stock—we decided *not* to follow formalized methodology as described in the standard. Instead, we defined an approach that is inspired by LCA in that it relates inputs to outputs and impacts. We do, for example, not translate resource use to emissions and types of environmental impact. Instead, we defined 13 indicators of sustainability that could be quantified and related to the product and illustrate important aspects of sustainability of these fisheries (Table 1). These were not formal LCA impact categories (which would imply a quantitative cause–effect relationship between disturbance and potential impacts and involve quantitative

Table 1. Indicators defined to map sustainability of shrimp fishing based on annual averages.

Category	Indicator	Definition (unit)
Economic	Shrimp landing value	Average price received by fisher (kDKK/tonne)
Economic	Total landing value (when shrimp trawling)	Average price received by fisher (kDKK/tonne)
Economic	Profitability	Income after expenses (kDKK/tonne)
Social/economic	Proportion of large shrimp landed	Tonnes large shrimp/total tonnes shrimp landed (%)
Social/economic	Quota availability	National quota in 2012/number of vessels (tonnes/vessel)
Social	Employment	Number of fishers (FTE[a]/tonne)
Social	Wage-paying ability	Shrimp landing value per fisher (kDKK/FTE)
Environmental	Seabed area swept	Area trawled per shrimp landing (ha/tonne)
Environmental	Fuel use	Fuel use in fishing (l/tonne)
Environmental	Bycatch of fish landed	Non-shrimp landings per shrimp landing (kg/tonne)
Environmental	Discard of shrimp	Shrimp discard per shrimp landing (kg/tonne)
Environmental	Discard of fish	Fish discard per shrimp landing (kg/tonne)
Environmental/economic	Catch efficiency	Landing per unit of effort (kg/h trawled)

[a]Full time equivalents.

weighting). The indicators represent an initial, rough screening: e.g. only total seabed area swept is quantified, not considering which habitat types are affected and how sensitive they are to disturbance, and bycatch of fish is only quantified in terms of how much is landed and discarded, with no reference to whether the species caught are sensitive to fishing pressure or not. Some of them are truly quantitative and additive/linear (low is good, high is bad, such as discards and fuel use), while others are more descriptive and it is less clear what is desirable (such as employment and landing value). As some of the data required are collected with a time-lag of one year, 2012 was the most recent year for which a full baseline assessment of the sustainability of the three fisheries could be made.

In this study, the product studied was defined as a tonne of shrimp landed by each fleet. A tonne of landed shrimp consists both of large, boiled shrimp and medium-sized, raw shrimp, in different proportions as described above. This implies an *assessment of the utilization of the available quota* rather than the actual products, motivated by the fact that both long- and short-term decisions change the size and species composition of the catches. Fish is often by-caught in shrimp trawling, either due to *not* using a sorting grid or using it in combination with a fish retention device to recollect the larger and most valuable fish. This represents a multi-output situation where a decision has to be made regarding how upstream resource use should be partitioned between fish and shrimp. As, in our opinion, the shrimp product should not "benefit" from being landed together with fish species (many of which are in need of rebuilding), all resource use and impacts were placed on the shrimp and none on the fish part of the landings. Our results are therefore only valid for the shrimp part of the landings, which is an important limitation.

Only the fishing phase was studied, as our intention is to illustrate the implications of how quotas are utilized differently by the three countries from a product perspective, rather than identifying which parts of the supply chain contribute most to overall impacts. Another important choice was to focus only on the shrimp trawling activities of the vessels involved, although in Norway and Sweden, shrimp vessels are also engaged in other fisheries. It is therefore important to keep in mind that our analysis covers only the shrimp trawling and not other fishing activities they may be engaged in.

Data sources

Fisheries data (logbooks and landing sales notes) for the three countries from 2010 to 2013 were used. On-board observer data on actual catches were available only from Sweden and Denmark, collected following the EU Data Collection Framework (DCF). Data from the vessel monitoring system (VMS) were used for Sweden and Denmark to estimate trawling speed and steaming time. Social and economic data such as annual fuel use, landing value, employment, and various costs were more readily available from Norway, from an annual profitability study based on a questionnaire which is sent to a representative sample of vessels for each fleet segment. The data from this survey, although representing a small, but representative, sample of the fleet, are available for research, and we used the data from the participating vessels that landed shrimp in Skagerrak. As part of the DCF, a similar survey on costs and fuel use is undertaken in all EU member states every year. In Sweden, this survey is sent to the entire fishing fleet by the Swedish Agency for Marine and Water Management (SWaM) and it is mandatory for fishers to return it. The data from the SWaM survey, however, are not available for research other than in a highly aggregated format; the situation is similar in Denmark. The aggregated data were not useful for our purpose, and a modelling approach was used instead to calculate seabed and fuel use (see Modelling fuel and seabed use). Similarly, in the Danish fishery, the data for employment in the DCF were considered to be inaccurate for this purpose. Instead, it was assumed that boats <12 m employed two fishers, 12–24 m three fishers, and 24–40 m four fishers. A similar estimation was done for the Swedish fishery to verify the DCF data, which was also used to assess profitability.

Modelling fuel and seabed use

A theoretical model developed by Bastardie *et al.* (2010, 2013) was used to model fuel consumption for the vessels of the different fleets. The model estimates fuel use based on vessel engine power and fishing activity separated into fishing and steaming time (Equation 1).

$$FUI = E \times (0.236 \times P + 3.976) + S \times 0.75 \times (0.236 \times P + 3.976). \quad (1)$$

where FUI is the annual fuel use intensity of the vessel (l), E is the annual fishing time (hours trawled), P is the engine power (kW), and S is the annual steaming time (hours steamed). The model was informed with combined logbook and VMS data for Swedish and Danish vessels. In lack of Norwegian VMS data, the calculation for Norway was based on logbook data where date and hour of start and stop of trawling operations as well as departure and arrival in port are registered per fishing operation; the trawl speed was set to three knots based on expert knowledge about the fishery. Steaming time could not be estimated for 23% of the fishing trips due to errors in departure and/or arrival dates in ports. For these trips, the trawling time was used as the duration of the whole fishing trip, thus the steaming time for Norway is underestimated. Excluding the data (see below) could have been an option, but a large part of the Norwegian fishery is not covered by the data (see Data availability below) so we preferred to keep it, despite the errors in it.

For seabed area swept, a similar model for calculation of door spread (the width between otter boards in seabed contact during trawling, in m) from vessel engine power was used (Eigaard *et al.*, 2015) (Equation 2).

$$\text{Doorspread} = 5.10 \times P^{0.47}. \quad (2)$$

Results

Data availability

An important finding was that there were substantial differences in data collection and data availability between the three countries fishing the same stock. Logbook data (including landings and fishing effort) were readily available in all countries, on a detailed level. Logbooks cover the shrimp fisheries well, except in Norway where only vessels $\geq$15 m were required to record logbook data in 2012. These vessels (36 of the fleet of 195) in 2012 landed less than half (43%) of Norwegian shrimp landings in the area. The main part of the Norwegian landings (2075 tonnes, i.e. more than Swedish landings) is hence fished by vessels that are not required to keep logbook records. In addition, for vessels <11 m length, no fishing license is required and these vessels in 2012 landed $\sim$22% of Norwegian shrimp landings (770 tonnes, or approximately half of Swedish landings). The economic data that is collected (including landing value, costs, employment, and fuel use) were on the other hand easily available in Norway, but only covered a small proportion of the fleet (10 of 195 vessels). Therefore, whenever the same type of data could be taken from logbook and profitability study, the former was chosen at it was considered to be more representative. It is therefore important to note that some indicators for Norway are quantified based on data from 10 vessels and some on data from 36 vessels. The impact of the large fleet of small vessels remains unknown and is not included in our results. In Denmark and Sweden, economic data collected by authorities were inaccessible on a vessel level and theoretical models were used instead. Discard data were available for Sweden and Denmark, but represents a small sample size in both countries ($\sim$1% of the effort).

Comparison of indicators across countries

The differences in fleet structure, quota distribution, and market situation for different shrimp fractions lead to considerable differences. Each Danish vessel has $\sim$10 times more shrimp quota to fish than Swedish and Norwegian ones, and the proportion of large shrimp landed is inversely correlated with quota availability (Figure 1). Danish vessels are considerably larger than Swedish and Danish ones, as described earlier.

The high proportion of large shrimp in Sweden is reflected in a higher landing value per tonne of shrimp and also per tonne of total landings in shrimp trawling (Table 2). In all countries, shrimp make up a high proportion of the total landing value from shrimp trawling. The analysis is based on data from 2012, i.e. before the sorting grid became mandatory (2013), explaining why the bycatch of fish (either landed or discarded) is considerable (Table 2, Figure 2). Discarding of both fish and shrimp was higher in Sweden than in Denmark, while for Norway it is unknown (Figure 2). This difference between Sweden and Denmark is somewhat surprising since the fleets fished in the same areas and the sorting grid was already partially implemented in Sweden at the time. The seabed area swept was on the other hand larger in Norway, which is due to the fixed trawl speed of three knots used in the Norwegian calculation, which is higher than the trawl speeds of 1–3.5 knots occurring in Swedish and Danish VMS data.

Danish vessels fish slightly more fuel efficiently than the others according to our model (Figure 3a), but variability is large within each fleet as indicated by error bars. Compared with alternative, available data sources from Sweden (questionnaires from fishers and the SWaM survey) and Norway (the annual profitability

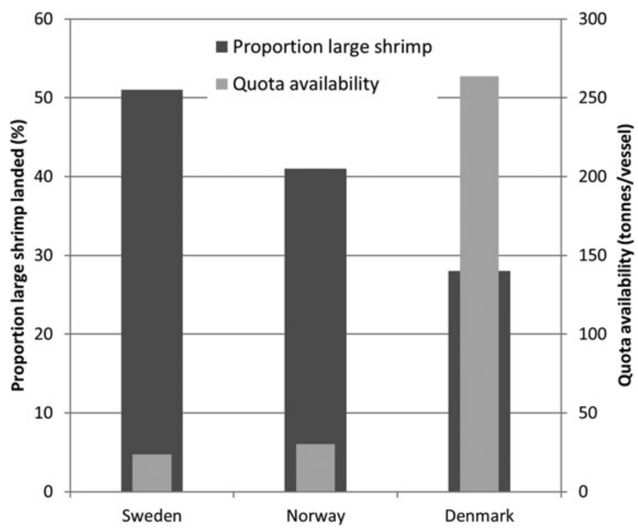

Figure 1. Shrimp quota availability per vessel and proportion of large shrimp in shrimp landings in each country.

Table 2. Quantified indicators for shrimp fishing in 2012.

Indicator	Sweden	Norway	Denmark
Shrimp landing value (kDKK/tonne)	60	41	50
Total landing value (when shrimp trawling) (kDKK/tonne)	67	54	55
Profitability (kDKK/tonne)	−24	5	–
Proportion of large shrimp landed (%)	51	41	28
Quota availability (tonnes/vessel)	24	30	260
Employment (FTE/tonne)	0.1	0.05	0.02
Wage-paying ability (kDKK/FTE)	590	1200	2500
Seabed area swept (ha/tonne)	1200	1500	930
Fuel use (l/tonne)	5720	5730	4470
Bycatch of fish landed (kg/tonne)	470	400	230
Discard of shrimp (kg/tonne)	200	–	70
Discard of fish (kg/tonne)	650	–	380
Catch efficiency (kg/h trawled)	24	36	37

Data on profitability are lacking for Denmark and discard data are not collected in Norway.

study), the model of fuel use seems to overestimate consumption compared with what fishers state in surveys in Sweden, but underestimate it compared with the Norwegian profitability study. It is hard to say which estimate is most accurate, but the sample size of surveys, including the profitability study, is low and variability high.

Further analysis of the fuel use in relation to vessel size indicates different trends for the different fleets; smaller Swedish and Norwegian vessels were more fuel-efficient than larger ones, whereas the opposite trend is seen for Danish vessels (Figure 3b). The smallest vessel category does not exist in Denmark and there are few (2–3) vessels in the two medium-sized categories (12–18 and 18–24 m), still it looks like these are less efficient than the largest Danish trawlers. The fuel efficiency of the two medium-sized categories is similar in all three countries (3000–5000 l tonne^{-1} or 3–5 l kg^{-1}).

An inverse correlation was found between the two social indicators employment and wage-paying ability (Figure 4). The country providing most employment per tonne shrimp landed (Sweden) also has the lowest shrimp landing value per fisher and hence the lowest ability to pay wages in that particular fishery. The data used were verified by making assumptions of employment based on vessel length (as was used for Denmark throughout due to lack of data). When modelled in this way, Swedish employment was lower, but still by far the highest. Activities in other fisheries, excluded from this analysis, may outbalance this result, which could be studied by analysing all fishing activities of a vessel over a year rather than only the shrimp trawling, as we have done here.

Full results are presented in Table 2.

Temporal trends

For some indicators, data allowed analysis over time. The fuel use seems to be rather stable over the period 2010–2013 (Figure 5a). As for discard of shrimp, trends have fluctuated in both Sweden and Denmark (Figure 5b). Fish discard has decreased both in Denmark and Sweden and the proportion of large shrimp has decreased in Swedish landings.

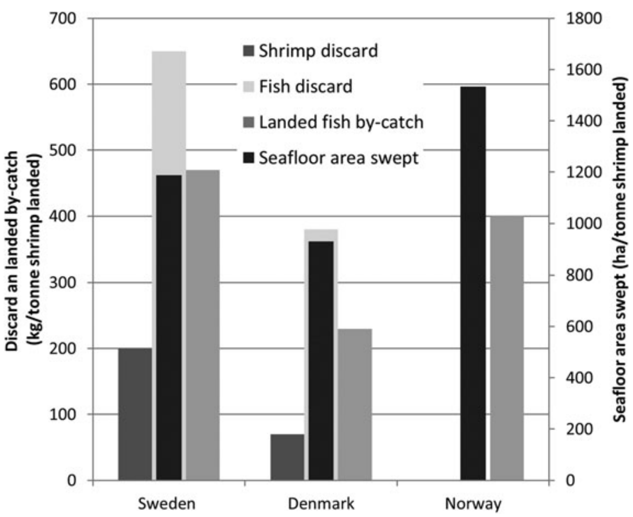

Figure 2. Biological indicators per country. Norwegian discard (shrimp and fish) is unknown.

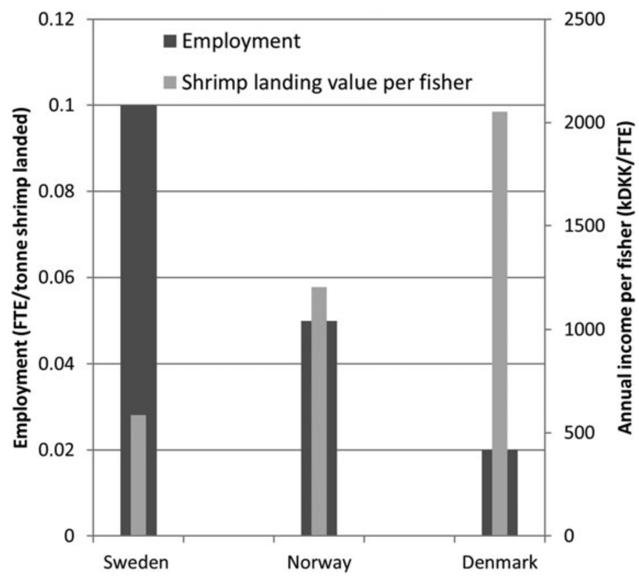

Figure 4. Social indicators of the three shrimp fisheries.

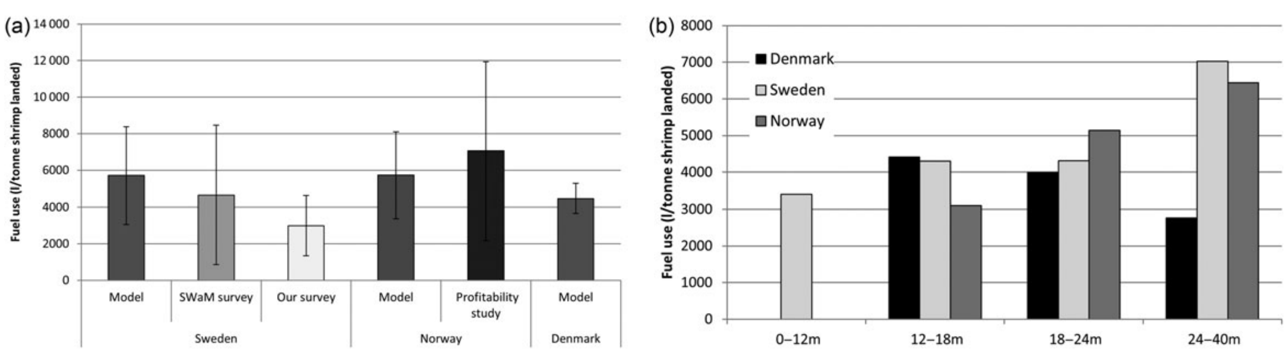

Figure 3. Fuel use (a) as weighted average ± standard deviation in the studied fisheries using various data sources: model, based on engine power following Bastardie *et al.* (2010, 2013); SWaM survey, the annual economic survey performed in Sweden by SWaM; our survey, data obtained directly from four Swedish shrimp trawlers; profitability study, annual survey performed in Norway; and (b) as weighted average per vessel size segment in the Swedish fishery (data for 2010–2012), the Danish fishery (data for 2010–2013), and the Norwegian fishery (data for 2012). Note that for some combinations of country and size segment, we only have data for 2–3 vessels, therefore differences should only be seen as indicative.

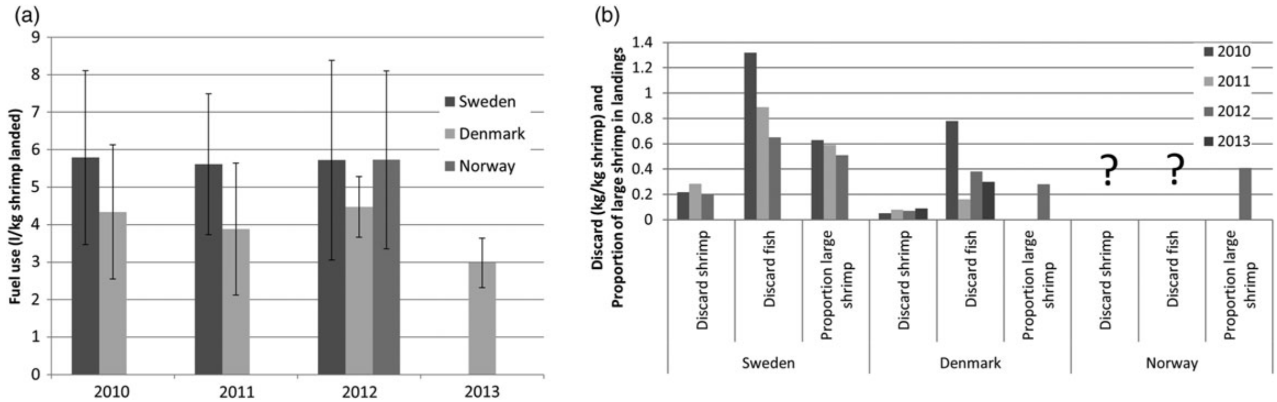

Figure 5. (a) Temporal trends in fuel use (weighted averages ± standard deviation) and (b) temporal trends in fish and shrimp discard and in proportion of large shrimp in landings.

Discussion

Is the Skagerrak shrimp fishery sustainable? It depends on how these indicators are weighted, which ultimately comes back to prioritization between management objectives. The stock is today considered to have a sustainable fishing mortality, while there are major improvement potentials in terms of other dimensions of sustainability. Some of the indicators evaluated here are taken into account by the three organizations providing sustainability assessments for the species/stock (ICES, WWF, and IUCN), while others are not, such as fuel efficiency and socio-economic viability. This study has taken a novel approach to sustainability assessment of fisheries to compare the performance of the three national fisheries from a product perspective. The quantified indicators together provide a broad picture of the sustainability of the fisheries. No country performed best with regard to all indicators. The Danish fleet was most efficient with regard to environmental and economic indicators, while the Swedish fleet employed most fishers per tonne of shrimp landed. Given the illustrated trade-offs between different indicators, it is up to management to prioritize between objectives and take management actions if needed. If environmental and/or economic objectives are prioritized, the Danish management model is preferable. If, on the other hand, socio-economic objectives are prioritized, the Swedish and Norwegian models are performing well, at the expense of other objectives.

While employment was defined as a social indicator, it can be questioned whether it is socially sustainable if it results in low wage-paying ability and even negative profitability (Table 2). However, shrimp trawling is not the only fishery Norwegian and Swedish vessels and fishers are engaged in and therefore the conclusions about social and economic performance presented here are only valid for their shrimp fishing activities. Fishers could, e.g. fish for Norway lobster (*Nephrops norvegicus*) with the same boat, with another boat or on the boat of someone else to improve their overall profitability.

The fuel use of all three fleets was very high compared with other fisheries (Parker and Tyedmers, 2015), even when compared with other shrimp fisheries which are found at the high-end of fuel use of fisheries globally (Parker and Tyedmers, 2015, Ziegler *et al.*, 2015). The main factor determining the overall fuel efficiency of the three fleets was the LPUE (kg shrimp landed per hour trawled), which in turn is largely driven by fluctuations in stock size and fishing capacity. The higher proportions of boiled, large shrimp in Norwegian and Swedish landings compared with Danish ones indicate more discards in the former countries (verified by on-board-sampling for Sweden). The on-board boiling of shrimp as such does not affect fuel efficiency as natural gas is used for this purpose. Discarding of shrimp necessarily leads to lower LPUE and thus lower fuel efficiency per landed tonne. In relation to the fuel efficiency estimates and global comparisons above, it is important to note that the stock biomass and TAC both were on an all-time low level in the year studied (2012).

The differences in fuel efficiency are also interesting to discuss from a vessel size perspective due to the contrasting trends between the countries and what this may imply for suitable management actions to take. One possible explanation for the pattern seen in Sweden (increasing fuel inefficiency with vessel size) is overcapacity in the fleet. The Danish fleet is considered to be in balance with the available quota (ICES, 2015b), while overcapacity in the Swedish fleet is estimated to be 30–40% where particularly the larger vessels have been pointed out as non-profitable (SWaM, 2014a). Both historical and current quota allocation has favoured small-scale fishers, implying that they, relatively seen, have larger monthly rations available. As larger quota available means lower incentives to discard, this could indicate that smaller trawlers in Sweden and Norway discard less than large and medium-sized ones (opposite in Denmark), which could explain their higher fuel efficiency. This is supported by similar LPUE values in the different vessel size segments, although one would normally expect higher LPUE for larger vessels. For Swedish demersal fisheries in general, vessel size has been reported not to be a major determining factor of fuel efficiency (Ziegler and Hornborg, 2014). Crustacean trawl fisheries, however, represented an exception, with larger vessels being more fuel intensive than smaller ones, in line with the findings here. The study by Ziegler and Hornborg (2014) concerned the years 2002–2010, i.e. a period preceding that of the present study. Results are not fully comparable, also because the data for fuel use in that study were based on the aggregate DCF economic data, which were dismissed here in favour of a modelling approach.

Each fishery had its own issues related to how data are collected and made available, even though sampling is relatively harmonized in EU countries. The largest, and perhaps most surprising, data gap was the lack of logbook data for all Norwegian vessels <15 m, making up 80% of the Norwegian fleet in number of vessels and almost half of the landings in 2013 (Søvik and Thangstad, 2014). At present, we cannot say anything about the way these small vessels fish and this is a major source of uncertainty in the overall assessment of the impacts of shrimp fishing in the Skagerrak area. Very little attention is given to this fact in the public debate about the sustainability of Skagerrak shrimp fisheries. Another major data gap is the lack of discards data for Norwegian fisheries in general. In the scientific advice from ICES, the Danish discards-to-landings ratio is used to estimate Norwegian discards (ICES, 2015b), with no motivation behind the rationale to choose Danish over Swedish discard data. If Norwegian discard practices are in fact more similar to Swedish practices (as indicated by fleet structure and size composition of landings), the overall discard would be severely underestimated. Finally, all types of economic data were difficult to obtain in sufficient detail for Denmark, despite this country actually performing best regarding these aspects when modelled using indirect data. As a result, profitability is in general an uncertain indicator due to lack of data. This is true also for the Swedish and Norwegian fisheries. The profitability of the Swedish shrimp fishery was found to be negative, but had been positive in the two preceding years (2010 and 2011). Despite being based on uncertain and aggregate DCF economic data, profitability is a result of many factors, including fuel prices, landing value, and quota availability. As mentioned, in 2012, the stock biomass and TAC were on an all-time low level. Swedish fishers are also engaged in other fisheries over the year, which can compensate for temporary low profitability in the shrimp fishery.

Despite uncertainties and data inconsistencies, could this type of approach be useful as an improvement basis for the Skagerrak shrimp fishery or other fisheries? From our analysis, improvement options in several areas emerge; data collection and publication, quota allocation and enforcement of existing regulations. In Denmark, making the economic data available on a vessel basis would enable analysis and comparison of these indicators. Also in Norway, central improvement opportunities concern data collection, for vessels <15 m and for discards in general. In Sweden and Norway, changed quota allocation to fleet size segments could result in improved efficiency, but this would require further study. The Swedish fishery cannot become sustainable without dealing with current overcapacity. Our results could be used as a basis for which direction to take in this process. The extent of illegal discarding of medium-sized shrimp that is occurring (ICES, 2015a) suggests that enforcement activities would need to be improved, although Swedish authorities state that the frequency of inspections does not need to be increased (SWaM, 2014b). However, improved collaboration and data exchange between authorities of the three countries and cross-checking of data for vessels fishing in the same area using the same gear would be helpful to take action against the problem with illegal discarding. Improved trawl designs and spatial and temporal closures to minimize unwanted catches such as small shrimp without increasing other impacts could be further optimized. A systems perspective on fisheries in the management framework could help identifying more overall sustainable solutions and enable more integrated decision support (Ziegler *et al.*, in press). A long-term goal could be achieving results-based management in this fishery with quotas being distributed according to best practice. This is well in line with Article 17 of the new CFP allowing fishing rights to be distributed "on the basis of objective and transparent criteria."

Major changes have taken place in the shrimp fisheries in Skagerrak and the Norwegian Deep since our year of assessment, 2012. First of all, the stock size is now increasing after strong recruitment in 2014 (ICES, 2015b), which has resulted in a TAC for 2016 which is more than double compared with the TAC in 2012. Despite the problems described, the Swedish fishery was recently MSC certified (MSC, 2015), just passing the standard which resulted in a number of conditions to be met by the fishery within a certain timeframe. As certified fisheries are by definition given a green light in the WWF consumer guide, Skagerrak shrimp are now green if Swedish, red if Danish and yellow if Norwegian, based on unspecified measures taken in the Norwegian fishery. We note that the ranking at present is completely opposite to the outcome of environmental performance of the fisheries from our study. Both the Norwegian and Danish fisheries currently undergo MSC assessment and are likely to become certified during 2016. The use of the sorting grid, first on a voluntary basis and since 2013 as a mandatory measure, has changed the composition of the catches and reduced discarding of fish significantly. In Sweden, monthly vessel rations can now be pooled across vessels, which has resulted in fewer active shrimp vessels since 2015 and the introduction of a variety of ITQs is being proposed by the main Swedish producer organization. It would be most useful to follow-up the initial results presented here to understand how performance changes over time. Modelling the indicator development of various management scenarios, based on the methods and results presented here, would provide valuable guidance on the overall sustainability of regulatory changes. Applying a systems perspective could also involve evaluating the use of new technology such as creels, which are used in a viable fishery on the same species in Atlantic Canada. For creel-caught Canadian shrimp, marketing of the product with its (presumed) sustainability and geographic identity was a key feature in achieving a profitable fishery. This example illustrates that fishing regulations are not only a matter of sustainable fisheries, but also the foundation of the subsequent seafood supply chain and are affected by market demand. Overall, lessons could be learned from countries that have managed to turn less sustainable shrimp fisheries into sustainable ones, such as Australia and Canada.

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