Baltic cod fisheries – current status and future opportunities

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Summary

This study quantifies a set of sustainability indicators (environmental, economic, social and institutional) for the Baltic cod fisheries (western and eastern stock) and explores the effects of different alternative management options in short term (for both stocks) and longer term (for the eastern stock). Data collected are biased towards the Swedish fishing industry, but most findings are relevant for all countries exploiting the stocks.

Based on results in this study, it is evident that management actions are needed at many levels to improve the current situation. Some of the observed problems with the cod fisheries today are due to external influences, outside of fisheries management remit (such as seal conflicts, oxygen-depleted areas). Nevertheless, this should not hinder management actions on what may be better understood and managed for in a fisheries context. For the eastern stock, the most pertinent issue is mitigation of density-dependence or feeding shortages. It is urgent with further investigations on what is the most important driver such as consider risks with current selectivity and effort regime, as well as act to improve herring and sprat availability where cod is abundant. Interestingly, it is found that increased seal predation may have a mitigating effect on density-dependence of cod in a trawl-based selectivity regime (i.e. result in higher landings and improved stock structure compared to lower predation pressure); for passive gears, it is the opposite. For the western stock, decreasing fishing effort and allowing the stock to rebuild is the most urgent action.

To this end, the present governance system may improve in many ways, and it is recommended to do a thorough analysis of what may be done to improve effectiveness of accomplishing current aspirational policy objectives.
1 Introduction

Cod is one of the most important commercial fish resources in the Baltic Sea, with varying production levels and stock status over time. Today, the cod fishing industry is under severe pressure from poor condition of cod, conflicts with seals, overfishing and scientific discrepancies; cod caught in the Baltic is listed as “avoid” in the World Wildlife Fund (WWF) guide.

The World Wildlife Fund (WWF) has therefore commissioned a report outlining a broad examination of the current environmental conditions, and a forecast of plausible effects from different management scenarios.

Figure 1 The Baltic cod is in dire strait, in particular the Eastern stock which is in a very poor condition. Photo: Peter Ljungberg.

1.1 Aim of the study

The overall aim of the study is to investigate the theoretical societal and environmental effects and opportunities of different fishing scenarios for Baltic cod. This will be achieved in two steps: 1) compiling data on broad environmental pressures and societal aspects of the value chain in its current form; and 2) quantifying effects from alternative scenarios of cod fishing and utilization. The outcome of long-term scenarios for the eastern stock are based on results from an independent modelling performed by Stockholm University. Even if results are quantitative in the study, they may rather be seen as indicative, useful as a starting point in discussions on alternative management arrangements with different actors; some call for further data collection and analysis.
2 Method

The study covers both cod stocks fished in the Baltic: western Baltic cod (ICES subdivision 22-24) and eastern Baltic cod (ICES subdivision 25-32). Mixing between the two stocks occurs\(^1\), especially in the Arkona basin (SD 24); in this report they are mainly treated as separate entities (i.e. all cod caught in SD 24 are categorised as the western stock and all in SD 25 is defined as belonging to the eastern stock if no stock separation is enabled). In 2017, 7% of the eastern stock was estimated to have been caught in SD 24. The study only covers commercial fishing; for the western stock, recreational fishing is also important (estimated landing volume of 932 tonnes in 2017).

2.1 Indicators

A baseline with quantitative indicators was first established for the current situation (year 2017) based on ICES data on stock structure, fishing pattern, etc. in combination with data from the Swedish supply chain (Table 1). Using the Swedish supply chain was based on ease to access of data at the level of detail needed; Swedish fisheries also use all gears on both cod stocks, thus offering a range of fishing patterns. Compared to the whole fishery (all countries) in 2017, Sweden landed 17% of the eastern stock (active-passive gear ratio 93 and 7 % compared to the whole fishery 89 and 11% respectively). For the western stock, Sweden landed 20% of total (active-passive gear ratio 7 and 93 % compared to the whole fishery 46% and 54% respectively). The different gear segments are represented in the study by demersal trawlers (active) and gillnets (passive), even if other gears exist within each gear segments; longlines was e.g. not considered separately in the latest assessment since catches of this segment were very low, and effort has decreased considerably in recent years.

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Table 1 Indicators, assumptions and data for the Baltic cod supply chain baseline for year 2017 unless stated differently. Indicators intend to reflect different aspects of Ecosystem-Based Fisheries Management (EBFM), but not an exhaustive list. Abbreviations: SwAM = Swedish Agency for Marine and Water Management; LPUE = Landing Per Unit Effort; STECF = Scientific, Technical and Economic Committee for Fisheries.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Indicator</th>
<th>Metric</th>
<th>Assumptions and data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td>Greenhouse gas emissions (GHG)</td>
<td>t CO₂-equiv./t landed (only from fuel combustion onboard)</td>
<td>Fuel use per kg cod landed (generally the dominating contribution to a seafood product’s full GHG emissions) in the Swedish fisheries based on EU-MAP data collected and compiled by SwAM. Includes vessels landing 97% (active gears) and 92% (passive gears) Baltic cod of their total landings. Assumptions: use of diesel (MK1) with emissions of 2.54 kg CO₂e/litre².</td>
</tr>
<tr>
<td></td>
<td>Benthic pressure</td>
<td>km²/t landed</td>
<td>Assumes leadline of gillnet sweeps 2 m (maximum observed³) and 0.71 km²/h for demersal trawling⁴. Swedish logbook data was used for LPUE for trawlers (landing per trawl hour). For gillnets, LPUE (cod per meter net and day) was used⁵ for Swedish fishers; of note, this effort metric (important to represent the segment) is deficient at stock level (e.g. LPUE found at STECF). Note that LPUE varies between areas (SD 23 the Sound is much higher) and season, not taken into account here.</td>
</tr>
<tr>
<td>Size structure</td>
<td>% above 1 kg</td>
<td>Based on Swedish sales notes.</td>
<td></td>
</tr>
<tr>
<td>Ecosystem structure</td>
<td>Pelagic biomass/cod biomass</td>
<td>Estimated biomass of sprat and herring per biomass of cod in ICES SD 22-24 and 25-28 respectively¹.</td>
<td></td>
</tr>
<tr>
<td>Socio-economic</td>
<td>Employment</td>
<td>Full-time equiv. (FTE)/t cod landed</td>
<td>Based on EU-MAP data compiled by SwAM for Swedish fisheries. Covers vessels landing 92-97% Baltic cod, and only the fisheries (not the subsequent supply chain). Estimated by dividing the FTE by number of vessels in sample, multiplying with total number of Swedish vessels and divide by total Swedish cod landings for the same vessels.</td>
</tr>
<tr>
<td>Equity</td>
<td>t/vessel</td>
<td>Average annual cod landing per vessel during 2017 for trawlers and gillnetters</td>
<td></td>
</tr>
</tbody>
</table>

²https://spbi.se/uppslagsverk/fakta/berakningsfaktorer/energiinnehall-densitet-och-koldioxidemission/  
³Savina et al. (2017) Developing and testing a computer vision method to quantify 3D movements of bottom-set gillnets on the seabed. ICES J Mar Sci 75: 814-824  
⁵Based on Sara Königson in prep., assuming fishing in the Karlshamn (Sweden) area = eastern stock and fishing in the Ystad (Sweden) area = western stock.
<table>
<thead>
<tr>
<th>Dimension</th>
<th>Indicator</th>
<th>Metric</th>
<th>Assumptions and data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>for Swedish fishermen (logbook provided by SwAM). Double-counting may occur between gears and stocks.</td>
</tr>
<tr>
<td></td>
<td>Edible yield</td>
<td>% filleting yield</td>
<td>Processing industry, personal communication.</td>
</tr>
<tr>
<td></td>
<td>Landing value</td>
<td>€/t</td>
<td>Assuming 1 SEK=0.098 EUR. Based on Swedish data (yearly average) for trawl (OTB) and gillnets (GNS) from sales notes provided by SwAM.</td>
</tr>
<tr>
<td></td>
<td>Non-food catch</td>
<td>% below 35 cm (MCRS)</td>
<td>Official data from Swedish logbooks provided by SwAM. Note that misreporting occurs. For EU countries that report BMS landings, Sweden is in the upper range with 2% of total landings; others are in the range 0.2-1% (except for Germany which has exceptionally high official BMS compared to other countries, 21% of landings).</td>
</tr>
<tr>
<td>Institutional</td>
<td>Precautionary</td>
<td>% TAC overshooting</td>
<td>Discrepancy between recommended catch (by ICES) and agreed TAC in 2017 based on latest advice (31 May 2018).</td>
</tr>
<tr>
<td></td>
<td>Fleet capacity</td>
<td>Fishing mortality</td>
<td>ICES estimates in stock assessment.</td>
</tr>
<tr>
<td></td>
<td>Compliance</td>
<td>Discard/t landed</td>
<td>Total estimates per gear segment by ICES. Raised in scenarios by multiplying rates with landings from different segments.</td>
</tr>
<tr>
<td></td>
<td>Effectiveness</td>
<td>SSB relative to BMSY trigger (%)</td>
<td>The discrepancy (in %) between the most recent ICES estimate for SSB and BMSY trigger for the stocks.</td>
</tr>
<tr>
<td></td>
<td>Integration</td>
<td>Pelagic landings/cod landings</td>
<td>Official landings of sprat and herring per cod landings in ICES SD 23-24 and 25-26 respectively (where most cod is concentrated today). Based on Official Nominal Catches in 2016 provided by ICES.</td>
</tr>
</tbody>
</table>

The indicators in Table 1 are discussed in relation to current external environmental conditions (e.g. parasites, oxygen conditions, etc.), social, economic and institutional aspects of Baltic cod fisheries.

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2.2 Scenario modelling

2.2.1 Short-term scenarios

Short term is here defined as one year. The outcome of alternative fishing arrangements were investigated by raising the baseline findings (mainly environmental indicators from Table 3) into what would be the total outcome for the Baltic cod fishing today if fished differently (i.e. multiplying the per tonne indicator per stock and gear segment into total values). This is purely a theoretical estimate, from extrapolating current findings to percentage change in indicator if instead fished only with trawls or gillnets. Some of the implications of a fishing moratorium is also provided. Total volume of Baltic cod landed (incl. BMS) was as reported by ICES and was the same for baseline and the following year.

2.2.2 Long-term scenarios

The future potential for western Baltic cod is merely related to conventional overfishing, where ordinary stock assessment protocols may be used to explore scenarios. Therefore, the western stock is only included in the short-term scenario in this study (due to limited project time) – except for fuel use. Since interesting time series were obtained, correlations between stock reference points and fuel use per kg landing were done to investigate possible improvement potentials in this regard for both stocks.

For eastern Baltic cod, the future potential is different, since normal stock-recruitment relationships may be compromised today from the occurrence of fisheries-induced density-dependence\(^7\), which we here assume to occur. Theoretical changes from alternative fishing scenarios for this stock are based on results from an independent modelling study\(^8\), which essentially is based on an extension of a model presented by Svedäng and Hornborg\(^7\). In short, classic stock assessment models assume that productivity is maximized by protecting juveniles because density-dependent growth only occurs during early life stages. Recent studies, using both models and empirical data, suggest that density-dependence also could occur later in life and that productivity may instead improve from higher fishing pressure on smaller fish\(^9\). There is, however, no consensus on how density-dependent processes affect growth, and studies may have failed to statistically test alternative hypotheses than fishing to observed changes\(^10\). It is difficult to disentangle the relative importance of different drivers, and future research on Baltic cod will have to include veterinarians, microbiologists and more; this is an ongoing research topic. What can safely be said, despite all uncertainties, is that all actions should be taken into considerations to improve size structure of the stock, which is at an alarming state today.

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\(^8\)Manuscript in preparation for submission


\(^10\)Audzijonyte et al. (2016) Trends and management implications of human-influenced life-history changes in marine ectotherms. Fish Fish 17: 1005-1028
In this modelling exercise, the potential effect on the eastern stock’s size structure and abundance under alternative fishing scenarios are used to inform possible changes in supply chain indicators (landings, size structure) over time, based on views expressed in the current cod crisis (Table 2).

Some basic assumptions for all scenarios are:

- Cod smaller than 25 cm are eaten by cannibalistic cod larger than 45 cm.
- Scenarios include with and without seal predation pressure in the form of higher natural mortality ($M = 0.6$ instead of $0.3$).
- A density-dependent effect on growth is assumed for the eastern stock (growth estimated by the von Bertalanffy growth equation) implying that at higher stock number, $L_{\text{inf}}$ decreases whereas $K$ increases.
- Recruitment is based on real estimates from the assessment in 2013, motivated by the fact that this was the last year with analytical stock assessment. However, recruitment numbers are introduced stochastically. A logistic function is used to dampen recruitment as the stock number of individuals become higher.
- All sizes are assumed to have the same fecundity (no increase with size, which is known to occur). There is no recruitment failure included in the modelling.

Active and passive gear segments were not further separated by gear type. The intention of the scenarios used in the modelling was basically to illustrate different selectivity patterns: no trawl fishing (i.e. only gillnet fishing) equals to a “window-selection” – avoiding small and large individuals being caught in the fishery – whereas no fishing with passive gears (i.e. only trawl fishing) represents a selectivity pattern targeting all sizes above a certain size.
Table 2 Scenarios and model assumptions for eastern Baltic cod fishing.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Motivation</th>
<th>Assumptions made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only trawl fishing</td>
<td>Based on perceptions on influence of unregulated gillnet fishing in the early 1990s on current situation.</td>
<td>Based on current trawl selectivity, i.e. $L_c=50%$ at 43 cm, effort constant.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All individuals above 43 cm will be caught at an instantaneous fishing mortality rate of $F=1$.</td>
</tr>
<tr>
<td>Only gillnet fishing</td>
<td>Incentivising low-impact fisheries, supported by article 17 in the CFP. Pike <em>Esox lucius</em> fishing in the Baltic has window selectivity regulations, i.e. protecting small and large individuals.</td>
<td>Based on current gillnet selectivity, i.e. $L_c=50%$ at 43 cm, effort constant.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Individuals between 43 and 53 cm will be caught at an instantaneous fishing mortality rate of $F=1$.</td>
</tr>
<tr>
<td>Complete fishing moratorium</td>
<td>Has been introduced in other fisheries, such as for Atlantic cod in Canada in 1992 and Atlantic herring in the 1970s.</td>
<td>The instantaneous natural mortality rate ($M$) is set at 0.6 instead of 0.3 based on as some density-dependent mortality at no fishing is assumed without specifying the origin of this mortality.</td>
</tr>
</tbody>
</table>

11 i.e. “Within the fishing opportunities allocated to them, Member States shall endeavour to provide incentives to fishing vessels deploying selective fishing gear or using fishing techniques with reduced environmental impact, such as reduced energy consumption or habitat damage.” EU 1380/2017

2.3 Limitations and disclaimer

There will be limited time spent on collection of new data. Instead, gaps will be identified and used to inform on further data collection needs.

The authors do not warrant that the information in this document is free from errors or omissions. The results in this report are not independently peer-reviewed, and many rough assumptions are made due to limited project time/lack of data. Therefore, results are to be seen as indicative; some may require further investigations.

2.4 Structure of the report

The report initially describes the present situation of the Baltic Sea and cod fisheries from an Ecosystem-Based Fisheries Management (EBFM) perspective (external environmental influences, institutional setting and social, economic and environmental sustainability) and present baseline indicators for the cod supply chains. Scenarios are then explored to finally provide some recommendations to policy, industry, researchers and NGOs in a discussion and conclusion section.
3 Cod fishing in the Baltic Sea today

3.1 External environmental influences

Ecosystem changes are often caused by a number of underlying factors, of which some are synergetic. The conditions for cod fisheries in the Baltic have changed dramatically over time from a combination of changes in ecological conditions and cod biomass. Cod abundance was record-high in the 1980s, followed by severe overfishing and some recovery about a decade ago. Today, the western stock is overfished whereas the eastern has no fishing reference points. The eastern stock has gone through particularly severe changes, with two out of three former spawning areas abandoned (probably linked to oxygen depletion and fishing pressure in the latter part of the 1980s) and alarming condition (weight at age, highly skewed size-structure). It has thus been pointed out that it is important today to acknowledge that both present and future cod fishing in the Baltic needs to adopt a new baseline with lower and more variable cod biomass, even at a very low fishing pressure.

Today, the two cod stocks have both a red light in the WWF consumer guide. The western stock is an example of classical overfishing, with lower than optimal biomass and too high fishing mortality. However, there’s both scientific consensus and disagreements on reasons behind problems seen in the eastern cod stock today; all potential causes seen (such as oxygen depletion) are not within the remit of fisheries management or is even possible to manage at all due to e.g. unknown causes behind. From a positive side, no large changes in oxygen levels has occurred since the 1970s in the Bornholm basin, and according to the Swedish Meteorological and Hydrological Institute (SMHI) database, the oxygen development by depth also suggests stable or a slightly improving situation in the basin since the 1980s. The correlation between cod condition today and occurrence of hypoxic areas (e.g. Casini et al. 2016) is therefore not all that simple; areas where there is increasing trend in hypoxia/anoxia are mainly located east and north of Gotland, i.e. in the deeper parts of the Gotland basin, areas which were abandoned by cod already in late 1980s. More research on the topic is needed – especially since there is not even consensus on if cod growth rate in the eastern stock really has declined due to difficulties with age reading.

The open-sea fish community in the Baltic Sea is considered to be relatively species poor. Up to 80% of the biomass is shared between cod, herring, and sprat. There’s accordingly been considerable research in the trophic linkages in the Baltic, and so-called regime

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Cardinale & Svedäng (2011) The beauty of simplicity in science: Baltic cod stock improves rapidly in a "cod hostile" ecosystem state. MEPS 425: 297–301
18 Carstensen et al. (2014) Deoxygenation of the Baltic Sea during the last century. PNAS 111: 5628-5633
shifts. MacKenzie and colleagues\textsuperscript{20} suggested a weak coupling between trophic levels in the Baltic, since cod biomass increased in the 1940s-50s despite low biomass of herring and sprat. It is interesting to note that cod were not skinny in the 1980s when, in particular, sprat abundance was low. Since then, other papers have shown stronger links between species in the Baltic, illustrating the important role of fishing on ecosystem changes\textsuperscript{21}; spatial overlap for cod, sprat and herring is today recommended to be accounted for in fisheries management\textsuperscript{22}. It is also important to note that historically (e.g. in the 1980s), size structure of cod was very different, which more individuals at larger sizes (even 80 cm). Furthermore, there has been considerable spatial re-arrangements of cod and prey species (herring and sprat). ICES recognises low spatial overlap between cod (contracted to the south) and sprat (increasing in the north), and see a decrease in consumption rate and food intake of the eastern stock since the early 1990s\textsuperscript{1}. However, the relationship between off-shore and coastal fish communities have been less studied and are still not sufficiently understood. Furthermore, potential interactions between cod and flounder in the Baltic has recently begun to be better understood, suggesting increased competition\textsuperscript{23}.

**Seals are causing increased nuisance to fishers** in the Baltic sea. Depredation (visible and hidden) and damage to gears can be substantial\textsuperscript{24}. Concerns are therefore often expressed by industry related to predation pressure from seals with increased abundance (and is accordingly also investigated in this study in the long-term scenarios). Diet studies have shown that seals prefer fatty fish such as herring and sprat\textsuperscript{25}, and the contribution of cod in seal diets has varied over time, probably based on supply\textsuperscript{26}. However, another problem seen with increasing seal abundance is the occurrence of parasites associated to seals that infect cod livers. Parasite prevalence in cod differs between different areas at larger scales (less parasite load further north even if seal abundance is higher, possibly due to salinity conditions\textsuperscript{27}) and more locally (between gear segments, less parasites in off-shore trawling whereas higher load closer to the coast where seals are more abundant).

Weather conditions may also affect cod catches in the fishery: if the direction of the wind is from the northeast, cod catches go down (called the “broom”\textsuperscript{28}). This situation observed by fishers is a short-term variability on a local scale caused by weather (but may be prevailing at times). Effects from climate change (long-term changes at larger scales) are however more difficult to predict but are likely to result in more extreme weather

\begin{itemize}
  \item \textsuperscript{23} Orio (2019) Understanding the spatiotemporal dynamics of demersal fish species in the Baltic Sea. Doctoral thesis No. 2019:7 Swedish University of Agricultural Studies, Department of Aquatic Resources
  \item \textsuperscript{26} MacKenzie et al. (2011) Could seals prevent cod recovery in the Baltic Sea? PLoS ONE, 6(5)
  \item \textsuperscript{27} Lunneryd et al. (2015) Sealworm (Pseudoterranova decipiens) infection in grey seals (Halichoerus grypus), cod (Gadus morhua) and shorthorn sculpin (Myxocephalus scorpius) in the Baltic Sea. Parasitology research, 114(1), 257-264.
  \item \textsuperscript{28} Baltic cod fisheries representative, Pers. Comm
\end{itemize}
events such as the heatwave during the summer of 2018. The overall effect on Baltic cod from climate change is difficult to predict; this is based a combination of changes such as increased water temperature, more extreme weather events, changes in precipitation and more. Indications so far suggest that **cod biomass in the Baltic will decrease with climate change** effects (such as higher water temperatures and lower salinity and oxygen)\(^{29}\); fisheries need to adapt to a new and more uncertain environment in the form of e.g. more precautionary quotas.

### 3.2 Institutional setting

As a result of the multiple stressors and uncertainties related to primarily eastern Baltic cod fisheries described in brief above, a **more precautionary approach is needed**, and is also in line with current EU legislation and policies\(^ {30}\). Factors that could be managed, such as fishing mortality, is arguably easiest; this is analogous to regulate the speed of a car differently on a multi-lane, straight highway in daylight compared to a smaller and more variable road at night. However, contrary to the extra precaution needed, there are several institutional components that could be questioned and are further discussed in this chapter.

Ecosystem-Based Fisheries Management (EBFM) entails **science-based decision making**\(^ {31}\). Accordingly, the tasks and resources required of the most important fisheries-science provider to the EU (ICES) is snowballing as scope of management increases. However, even if density-dependence is acknowledged to occur for the eastern stock (even though the reason why differs between researchers, i.e. is it caused by the ecosystem in the form of oxygen-depletion or by the fishing pressure), it is problematic that management agencies are not acting through e.g. investigating this in detail through e.g. a special request to ICES. It is even more alarming that current scientific recommendations are not followed; quota setting by politicians instead exceeds scientific advice for both cod stocks. This situation, called “political overfishing” has been going on for long for the Baltic fish stocks. In all EU waters, 2/3 of agreed TACs between 2001 and 2018 have continuously been set above scientific advice, even if the percentage change between scientific recommendation and agreed TAC has gone down from 42% to 8% in all EU waters; TACs for the Baltic in 2019 had 5 of 10 TACs exceeding scientific advice\(^ {32}\). In 2017, the agreed TAC was 60% above the advised catch by ICES for the western stock and 37% above for the eastern stock respectively (Table 3). Quota uptake for the eastern stock was however only 77% in 2017 (including discard and BMS landings), and it has been even lower in recent years. The driver behind why politicians choose to continue to set quota above scientifically recommended levels is therefore a mystery for an outsider; the full TAC has not been fished since 2009\(^ {1}\). **Poor transparency** behind political decisions on TAC is noted\(^ {33}\).

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\(^{30}\) In EU 2017/1970 on TAC for Eastern Baltic cod, a precautionary approach is recommended due to current uncertainties, referring to article 9.2 in EU 1380/2013.

\(^{31}\) Long et al. (2015) Key principles of marine ecosystem-based management. Mar Pol 57: 53-60

\(^{32}\) For historical account, see https://neweconomics.org/2019/02/landing-the-blame-overfishing-in-the-north-atlantic-2019


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An important component of fisheries management in general is to balance capacity with the resource. In Sweden, for example, the annual average cod landing per vessel for the dominating gear segment (trawlers) was almost double in 2012 compared to today (around 200 t/vessel instead of 100 t/vessel, although highly variable between vessels)\(^{34}\). There is thus capacity enough to catch larger volumes, yet the full quota has not been taken for years for the eastern stock. Landings per vessel has also been higher than present for the western stock; this stock has however reference points clearly indicating signs of overfishing (biomass and fishing mortality) – combined it may be said that **fleet capacity is not balanced with the resource.** Some countries (Latvia, Germany and Poland) report on overcapacity in their Baltic cod fisheries and plans for reducing effort\(^ {35}\).

Since considerable misreporting is known to have occurred for Baltic cod fisheries\(^ 1\), the enforced landing obligation in the EU was intended to eliminate wasteful practices and improve data quality for assessments. Starting on 1\(^{st}\) of January 2015, the landing obligation was enforced for cod, salmon, sprat and herring in the Baltic Sea. This implies that no part of the catch of these species may be discarded at sea, and individuals below minimum conservation reference size (MCRS) are not to be sold for human consumption. When enforced in 2015, the MCRS was lowered for cod from 38 cm to 35 cm (based on high prevalence of small cod in catches); for herring there’s no MCRS in the Baltic. Furthermore, there is a survivability exemption for cod and salmon caught in trap nets, pots, fyke-nets and pound nets. However, **poor compliance** is evident\(^ 4\) (see also Table 3). As an example, official catches of non-food cod (below MCRS) in Sweden has been between 2-4% of total cod landings whereas “last haul data”\(^ {36}\) inspections and onboard observer data note 12.5% and 15-18% respectively; similar patterns are seen in Danish fisheries\(^ {37}\). Plausible reasons for illegal discard are resistance to change practise, economic losses, lack of buyers and inconvenient handling processes of small cod\(^ {37}\). Furthermore, the goal for Swedish onboard observers is to sample 24 trips per year, with the results raised based on total number of fishing trips\(^ {38}\). This goal has not been achieved in recent years, in particular in 2015 with the landing obligation was enforced and only 5 out of 24 trips could be conducted\(^ {37}\); sampling is dependent on the willingness of the skippers to accept observers onboard – even though it is mandatory. Since the catch is known to vary between trips, estimating catch composition on less samples further increases uncertainty. Introduction of a landing obligation in the Baltic cod fisheries, the first in the EU, has accordingly failed to deliver intended benefits (e.g. improved data quality for assessments and landing of all quota-restricted catches).

In July 2016, a multi-annual management plan for cod, sprat and herring was adopted by the EU parliament\(^ {39}\). This indicates a **political will of improved institutional integration.** Following the plan, these species should be fished at a level allowing for Maximum Sustainable Yield (MSY), while also allowing conservation of plaice, brill,
flounder and turbot. For the western cod stock, this implies introduction of fishing mortality ranges $F$ (0.15–0.26 and 0.26–0.45) depending on the SSB in the intermediate year compared to the MSY B-trigger level. Another example of integration is the inclusion of recreational catches in stock assessment of the western stock in recent years. However, **institutional capacity may be questioned in terms of implementation:** there is still overfishing of some stocks, the eastern cod stock is unable to follow the management plan due to lack of reference points to fisheries, and further investigations of potential bycatch of cod in pelagic fisheries may be needed. In times of poor status of herring stocks and/or decreased food intake in cod is identified, it could also be questioned if industrial fisheries for pelagic fish should be maintained in cod-abundant areas (in particular SD 24–26 where landings are large; Table 3) but instead need an increased flexibility in management objectives. When herring stock status in the Baltic where compromised in the 1970s, only herring fishing for human consumption was allowed. This kind of management directive would provide more benefit to the ecosystem (prey availability) and supply chain (value-adding and employment is higher for human consumption preparation compared to industrial use).

Area and seasonal closures are often integral parts of EBFM and continuously scrutinized. For the Baltic cod fisheries, there are several area and seasonal closures aiming to protect the stock. The effectiveness may however be questioned. A recent study of the effect of current measures found that they could risk unintended detrimental effects on the stock; small area closures are highly demanding (complex and data-demanding) and may cause effort displacement (e.g. a seasonal restriction may cause temporal effort displacement and thus increased disturbance during peak spawning; a spatial closure risk not protecting large cod outside of protected area where effort may increase), whereas larger and seasonal closures are more robust with less risks to be counterproductive. More research is needed on the topic.

To this end, for a data-rich and intensively studied ecosystem with comparatively few species, the fisheries science provision to the governance system is both extensive – and full of questions. For example, it is worrying that there’s still no robust reference points for the eastern Baltic cod stock, given the vast amount of data collection and research effort. However, arguably of more concern, is the governance system in itself. There are many promises (aspirational objectives in policy documents) but limited effectiveness (enforcement and results in operational indicators). One component is stakeholder engagement; this has been put forward as an important component of good governance, and EU fishing policy has increased participation in decision-making – but with questionable outcome. Since the situation of the two Baltic stocks exhibit little improvement (see e.g. SSB and TAC overshooting in Table 3), there are no obvious benefits evident for overall sustainability with the current processes. Fisheries advice is today provided by ICES, which are evaluated and processed by the European Commission’s Scientific, Technical and Economic Committee for Fisheries (STECF), the Baltic Sea Advisory Council (BSAC, an advisory body with representatives from fisheries

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40E.g. ICES 2018 WGBFAS reports that the German pelagic trawl fishery targeting herring in SD24 had an estimated discard of cod of 29.5 t in 2017.


and other stakeholders, mainly environmental NGOs), and finally BALTFISH (regional body including eight EU Member States around the Baltic Sea) before the decision-making of the EU Commission. An important task ahead may thus be to address the legitimacy of power of different actors in governance of Baltic cod fisheries to be able to disentangle what may be done to put the two cod stock in the green light categories – in ICES advice and WWF’s consumer guide.

3.3 Social sustainability

ICES reports an overall effort (in kW-days) for trawls and gillnet in the cod fisheries declined in the central Baltic between 2012-2015. Few fishing vessels contribute to the majority of landings in terms of volume. The passive gear segment has lower landings per vessel compared to trawlers (Table 3). The small-scale coastal fleet (vessels smaller than 12 m) thus offers more employment opportunities in the Baltic compared to the large-scale fleet. STECF reports that the small-scale fleet involves 65% of FTE, but only contribute to 9% of the landing volume (but 22% of landing value); this is seen also for the Baltic cod fisheries (Table 3). Cuts in quotas may affect small-scale coastal fisheries hard, as seen when the quota was cut by 50% for the western stock in 2017. In this sense, equity is also an important principle of EBFM. In ongoing discussions on introduction of catch shares, regional quotas are seen as useful for equity. One example is found in Sweden, in the form of so called “coastal quotas” that are allocated to local Baltic fishers, around 1 400 tonnes (~19 % of the total cod quota) of western and eastern cod in the Baltic.

The cause-effect relationship between flourishing coastal communities and resource management is not easy to disentangle – which comes first and what are the prerequisites for one or the other to function satisfactory are being investigated around the world. The Baltic cod fishing industry is sensitive to market conditions. When eastern Baltic cod fishery lost its certification by Marine Stewardship Council (MSC), industry had a more difficult time to sell the catch, e.g. Espersen A/S has reduced their purchase. Edible yield is also important to markets, where historical filleting yield has been around 40-42% for Baltic cod; now it is considerably lower (Table 3). With the red light in the WWF consumer guide, many Swedish markets have closed due to procurement criteria and retail standards on sustainable seafood; since fisheries management actions has failed to address concerns addressed, the Swedish processing industry have as a result been increasingly exporting cod to other countries such as France.

There are also different challenges for different gear segments. From different targeting patterns and vessel sizes, the passive gear fisher is more sensitive to environmental conditions than the trawl fisher. Small-scale fishing boats are sensitive to weather conditions and may be more accident prone, especially if the fisher...

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46 Svein Jentoft, UiT/The Arctic University of Norway, Östersjöfiske 2020, Simrishamn 181116
48 http://www.fiskonline.se/hem.html
operates alone. Passive gear segments are more sensitive to local environmental conditions, such as fishing in areas with high seal abundance — directly through depredation and indirectly through potential parasite loads. In the southern Baltic, damage to cod fishing gears has doubled for gillnets between 2010 and 2014 (from 13% to 32%); longlines are even harder hit (from 13% to 49% respectively), but at lower economic losses compared to gillnets.

3.4 Economic sustainability

Profitability is affected by a range of factors, one being markets. The cod fishing industry in Sweden reports that it is strongly economically affected by consumer-directed initiatives. The red light in the WWF consumer guide contributed to a decrease in landing value by 38% between 2008 and 2009, to be increased a few percentages when eco-certified in 2011 and then decreased again. However, use of landing value may be misleading in estimates of fisheries profitability. A cod of two kilos may be worth €100 — rather than €1 that is reported — for a small-scale fisher who takes care of the whole value chain sea to plate. Local and small-scale fishing may therefore contribute considerably more to regional economic turnover and employment than larger vessels that catch larger volumes but with different supply chains. Furthermore, Norwegian export of cod to the European whitefish market, which Baltic cod also enters, has increased in recent years from larger volumes caught. The value of Baltic cod has as a result decreased due to small sizes of fish compared to e.g. Norwegian cod; combined, this contributes to poor profitability of the Baltic cod industry.

The total small-scale coastal fishing fleet in the Baltic Sea suffered €18.4 million net losses in 2015 (Danish, Finnish, Polish and Swedish being the most unprofitable), and the effort in this segment is decreasing the most. Market conditions and fishing opportunities are repeatably mentioned as contributing factors. Low Impact Fishers of Europe (LIFE) emphasises the importance of large fish rather than quantity to their segment; sizes above 40 cm is needed. Thus, size structure of the cod stock also affects profitability, where larger sizes enable improved catch utilization and filleting yield (Table 3) and, as a result, economy of the industry. The larger sizes of cod in the western stock today implies a higher filleting yield compared to the eastern stock). Catch utilization is also important to the economy of a fishery, and the proportion of catch below MCRS is not benefitting fishing economy (even if the official percentage today is low).

Profitability is also affected by catch quality. Quality of fish landings may be vulnerable to weather conditions, where part of the catch may have to be discarded. Extremely poor condition of cod individuals has affected potential use for human consumption, and increased prevalence of parasites has come with extra processing time; both issues are predominantly seen for the passive gear segment, operating closer to the coast. In other fisheries, where cod is in better condition and there is less conflict with seals, trawl-

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49 HaV (2014) Sälpopulationernas tillväxt och utbredning samt effekterna av sälskador i fisket. Havs- och vattenmyndighetens rapport 2014-12-30
50 Rune Wikström, Skärgårdsfiskarna, Östersjöfiske 2020, Simrishamn 181116
52 Swedish processing industry representative, Pers. Comm.
caught cod may be of poorer quality compared to longline-caught cod\textsuperscript{53}, which may offer opportunities for marketing and improved profit. However, studying Baltic cod landing values per gear type, gillnet-caught cod still yields higher prices per kilo landed compared to landings by trawls (Table 3). Perhaps this is related to the fact that mean weight (g) per length class for e.g. the eastern stock is lower for cod landed for human consumption by trawlers compared to passive gears, ranging 85-91\% of the equivalent length class for cod 35-49 cm\textsuperscript{1} (i.e. leaner cod in this size interval are less likely to be caught in gillnets than fatter fish). Furthermore, the industry complain about poor quality of cod caught with in particular longlines and pots, where again the Swedish sales notes are in stark contrast: cod caught with pots or lines have a higher landing value than trawl-caught ones from the western stock (around 1 300-1 400 €/t instead of 1 000 €/t), and similar value or slightly higher (longlines) for the eastern stock.

**Management objectives** also influences the economy of fisheries, where e.g. Maximum Economic Yield (MEY) has been put forward as more beneficial to the economy and the ecosystem compared to Maximum Sustainable Yield (MSY), the latter the objective of EU fisheries. Several bio-economic models have been used to evaluate Baltic cod fisheries. One example\textsuperscript{54}, called for a new MSY strategy for the eastern Baltic cod fishery, “ecologically-constrained Maximum Economic Yield” (eMEY), which would include ecological criteria and short- to medium-term economy. They conclude that their approach is better for net cost reductions per year than current practise of setting TAC, and results in more stability in catch advice. Furthermore, through quantification of the costs of deviating from advice enabled by this approach, transparency of decision-making is enhanced. More papers support the many benefits from transition from MSY to MEY for eastern Baltic cod\textsuperscript{55}.

The EU contributes with **various kinds of subsidies to the fishing industry, indirectly or directly affecting profitability of the Baltic cod fisheries**. Directed aid comprises of tax rebates of fuel and refunds for seal-damaged catch and gears, other more indirect, subsidies directed to the processing sector in the form of investments in processing and marketing from the European Fisheries Fund. Refund of energy tax or carbon dioxide tax for fisheries in e.g. Sweden was 1 700 SEK (=167 EUR) /m\textsuperscript{3} in 2017\textsuperscript{56}.

Seal damages in Swedish fisheries was in 2014 estimated to result in economic loss of 0.3 EUR per year (excluding hidden damage), of which half are attributed to the southern Baltic\textsuperscript{49}.

### 3.5 Environmental sustainability

In an EBFM context, **management should try to minimize environmental impacts** of fisheries. Catch per unit effort (CPUE) is important to resource use and environmental impacts of a fishery in product-based sustainability assessments, such as

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\textsuperscript{53} Rotabakk et al. (2011) Quality assessment of Atlantic cod (Gadus morhua) caught by longlining and trawling at the same time and location. Fish Res 112: 44-51


\textsuperscript{56} https://www.skatteverket.se/foretagochorganisationer/skatter/punktskatte/energiskatter/verksamhete rmsedlagreskatt/jordbrukskogsbrukvattenbruk/bransle_4.15532c7b1442f256baebbb2.html

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Life Cycle Assessment. If more effort is needed to catch the fish, more inputs (such as fuel use) are required for less output (kg cod). For the same fish stock, environmental pressures such as benthic disturbance and discards, are also decided by gear type – and increase with poor stock status.

Based on data on fuel use in cod fisheries found in this study, it seems like the eastern Baltic cod fishery is more energy-intensive than the western Baltic cod fishery today (seen in greenhouse gas emissions in Table 3). Per kilo landing in 2017, fishing with active gears for eastern Baltic cod required 0.4 l/kg landing and 0.7 l/kg for passive gears (i.e. higher than when trawling); separating between gears was not possible for western Baltic cod fisheries, but required overall less fuel inputs per landing, 0.4 l/kg, compared to eastern Baltic cod fishing. At Baltic Sea scale\textsuperscript{35}, the small-scale fleet (all fisheries) has been found to generally be more fuel efficient than the large-scale fleet, except for towed pelagic trawls and purse seines (mainly targeting shoaling sprat and herring, which are in general more energy-efficient practices). Other estimates of fuel consumption for Swedish cod fishing in the Baltic (from 1997-1999) are 0.3 l/kg cod when gillnetting, and 1.4 l when trawling respectively\textsuperscript{57}. These older estimates were based on another data collection approach, and not separated by stock – thus not directly comparable with estimates in this study – but illustrate the opposite than found here, i.e. trawling was more energy-intensive than gillnetting at the time. Further investigations on the topic may be needed.

For the Baltic cod fisheries, benthic pressure varies considerably between but also between stocks gears (in terms of area affected), where demersal trawling affects a considerably larger area than passive gears per kilo landing (Table 3). When trawling, seafloor area impacted is higher per kilo cod from the western stock compared to the eastern stock, whereas when using gillnets, seafloor disturbance per kilo cod is lower for the western cod stock respectively. There are different gears used within the active and passive segments that are not included in this estimate. Trawlers for cod in the Baltic also use pelagic trawls, which have no contact with the seafloor, however marginal in e.g. the Swedish fishery (approximately 2% of cod landings between 2008 and 2017). In the passive gear segment, longlines are also operating (and have no seafloor impact), and seal-safe cod pots, with unknown impact.

As seen in Table 3, discard rates vary considerably between gear segments. ICES is well aware of misreporting in the Baltic cod fisheries, despite the landing obligation, and use discard data from on-board observer programmes instead of official data in assessments. The observer data on discards is highly variable but in general considerably higher than logbook data (estimated at 11% for the eastern stock and 4.8% for the western for 2017\textsuperscript{7}). Total discard at sea for the eastern stock was 3 238 t in 2017, of which active gears stood for 93%. Of these discards, 214 t came from SD 24 (ICES protocol split these discards and landings between the stocks due to mixing). The discard composition comprised of 28 % in number in length class 35-37 cm (i.e. legal size), possibly indicating poor condition.

\textsuperscript{57} Ziegler et al. (2003) Life cycle assessment of frozen cod fillets including fishery-specific environmental impacts. Int J LCA 8: 39-
In terms of overall fishing pressure in the Baltic, the latest HELCOM report\(^{58}\) states that **only three out of nine assessed fish stocks in the Baltic are in a good status** (fishing pressure and biomass); an additional eight stocks couldn’t be assessed, indicating insufficient research and knowledge. The same report indicates a slightly worse overall environmental situation in the Bornholm basin (most important area for the eastern cod stock) compared to the Arkona basin (western cod stock). Furthermore, since abundance of cod-sprat-herring are strongly coupled through trophic interactions, research is ongoing on how to best represent this in advice to management through e.g. exploring the game theory concept of Nash equilibrium in defining multi-species MSY\(^{1}\). ICES calls for a spatial management plan for fisheries that catch sprat to improve feeding conditions for cod\(^{19}\), but this is difficult today due to lack of necessary information on the eastern stock (such as the indicator Ecosystem structure in Table 3).

**Size structure of the Baltic cod stocks has changed considerably** over time\(^{59}\), a well-established indicator of effects from fishing, with considerably less large individuals present today. The development is increasingly dramatic for Baltic cod stocks with increased prevalence of trawl-based selectivity, i.e. fishing pressure on all individuals above a certain size\(^{60}\). It has been put forward, that for the eastern cod stock, trawling has been the dominating fishing method since 1950s – and there was still a balanced size structure in the late 1970s. Instead, it is claimed that it was the rapidly expanding and uncontrolled gillnet fishing for (in particular) large cod by Polish and Estonian fishers in the 1990s that disrupted the size structure, leaving few large individuals\(^{61}\). There are other sources pointing at considerable unreported landings of cod in the early 1990s, roughly 40% according to ICES\(^{5}\), also attributed to Polish fisheries\(^{62}\), even though gear-specific data is not given. However, the fishing pressure of different gears are more complicated; the selectivity of trawls has dramatically increased towards selecting larger individuals since the 1990s\(^{63}\). Further investigations are needed, and effects of high fishing mortality with gillnets are thus explored in this study (see 4.2 Longer-term scenarios).

**Trawlers pose low risk of marine bird and mammal bycatch, but gillnet can be more problematic**\(^{19}\). Gillnet fishing risk by-catch mortality both for seabirds (at least four species are at risk of decline at present Baltic gillnet effort) and adversely affect depleted mammal populations (in particular harbour porpoise). It has been estimated that between 1980 and 2005, at least 76 000 birds were annually killed in Baltic Sea gillnets\(^{19}\). Drifting gillnets have for these reasons been banned since 2008.


\(^{60}\) Svedäng & Hornborg (2017) Historic changes in length distributions of three Baltic cod (Gadus morhua) stocks: Evidence of growth retardation. Ecol evol 7: 6089-6102


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3.6 Combined baseline

The combined baseline of the current status of the Baltic cod stocks are given in Table 3, separated by gear segment (active and passive) when possible and relevant. Observe that some indicators are based on Swedish data but here represent all Baltic fisheries (see Methods section 2.1 for data behind). Data also represent the stock and gear segment combined; there is however high variability within different segments. Examples include discard rates (varies e.g. between ICES SDs for the western stock, with active gears 17.5% in SD 24 whereas only 4.1% in SD 22 and 23), tonne per vessel and employment between different countries, etc.
Table 3 Baseline for Baltic cod fisheries today (2017).

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Indicator</th>
<th>Metric</th>
<th>Eastern stock (SD 25-32)</th>
<th>Western stock (SD 22-24)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Trawlers</td>
<td>Passive</td>
<td>Trawlers</td>
</tr>
<tr>
<td>Environmental</td>
<td>Greenhouse gas emissions</td>
<td>g CO₂-equiv./t landed</td>
<td>1.1</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>Benthic pressure</td>
<td>km²/t landed</td>
<td>2.4</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Size structure</td>
<td>% above 1 kg</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ecosystem structure</td>
<td>Pelagic biomass/cod biomass</td>
<td>Cannot be estimated (eastern Baltic cod has no estimated SSB)</td>
<td></td>
</tr>
<tr>
<td>Socio-economic</td>
<td>Employment</td>
<td>Full-time equiv./t cod landed</td>
<td>0.02</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>Equity</td>
<td>t/vessel</td>
<td>116</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Edible yield</td>
<td>% filleting yield</td>
<td>30-33%</td>
<td>33-35%</td>
</tr>
<tr>
<td></td>
<td>Landing value</td>
<td>€/t</td>
<td>876</td>
<td>1231</td>
</tr>
<tr>
<td></td>
<td>Non-food catch</td>
<td>% below 35 cm (MCRS)</td>
<td>1.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Institutional</td>
<td>Precautionary</td>
<td>% TAC overshooting</td>
<td>37%</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>Fleet capacity</td>
<td>Fishing mortality (age 3-5)</td>
<td>undefined</td>
<td>0.6 (range 0.3-1.2)</td>
</tr>
<tr>
<td></td>
<td>Compliance</td>
<td>Discard/t landed</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Effectiveness</td>
<td>SSB relative to Bₘₛᵧ trigger</td>
<td>below proxy</td>
<td>-30%</td>
</tr>
<tr>
<td></td>
<td>Integration</td>
<td>Pelagic landings/cod landings</td>
<td>5.2 (SD 25) and 8.2 (SD 26)</td>
<td>1 (SD 22) and 4.5 (SD 24)</td>
</tr>
</tbody>
</table>
4 Alternative management

4.1 Short-term scenarios

A complete fishing moratorium would, most likely, not have a detectable effect on cod stock structure and productivity after a year and are thus not addressed. The societal consequences depend on what is being compared. Based on findings in Table 3 extrapolated to all Baltic cod landings, a fishing moratorium would be the equivalent of €28 million lost in landing value (value chain not included; Table 4). From a food security perspective, roughly 29 000 tonnes of cod (or 9 800 tonnes edible seafood product) would be lost, corresponding to the annual global average seafood consumption of 1.4 million people\textsuperscript{64}. Seen from an EU economic perspective, losses would be marginal: total landing values from the Baltic only contribute to 3% of EU total landing value, of which cod contributed to 23%\textsuperscript{35}.

If only passive gears were to be used, here represented by use of gillnet, most indicators were estimated to improve (Table 4). However, greenhouse gas emissions for the eastern cod stock risk to increase. This is the result of recent increase in fuel consumption per cod landing for the passive gear segment, possible an effect from seal damages (lowers landing per unit effort). Some indicators where not raised to total values, such as the indicator for equity, since they were considered to be too fleet-specific (representing the Swedish fleet structure). Still, based on the baseline results, this indicator would increase (unknown with how much) with only passive gear fisheries; it is however questionable if the trawlbers see this development as increasing equity. Furthermore, accident risks and working conditions were not addressed here, and may come out as less favourable for small-scale passive gear fisheries. Potential risks with lost nets causing ghost fishing and bycatch of marine mammals and birds from increased gillnetting were also not addressed quantitatively. Evaluating the potential effect on unintentional bycatch from increased gillnetting is problematic since 1) the most dramatic changes to populations of birds and mammals have already occurred during times of higher fishing effort compared to present levels (i.e. depletion has already occurred); 2) even if bycatch levels may be low today, they are alarming since every individual is more important today; and not least, 3) lack of data.

It is however important to acknowledge that there are constraints to only using passive gears. Even if quotas and effort most likely need to be reduced regardless, it is uncertain if the same volume could be landed as today using only passive gears. One attempt to allocate the full commercial quota to passive gears was made for the western stock in Sweden in 2017. This resulted in an opening to trawl fishing at the end of the year, since the quota was likely not be filled. Furthermore, the coastal conflict with seals will likely continue to increase with increasing seal abundance. Only using passive gears would require increased use of seal-safe gears developed, such as pots\textsuperscript{24}. These gears have not been evaluated in this analysis, but would most likely offer advantages to gillnets in terms of potential problems raised above with unintentional bycatch.

\textsuperscript{64} FAO (2018) The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. Rome. Licence: CC BY-NC-SA 3.0 IGO.
In a scenario with only trawl-fishing, most indicators indicate a negative development except for greenhouse gas emissions, which may decrease (Table 4). However, as discussed before, there is lesser seal interaction in the trawl fishery (less damage of catch) and possibly also less occurrence of parasites.

Table 4 Theoretical short-term changes of commercial Baltic cod fisheries for the different fleets. Note that these figures must be interpreted with extreme caution, there are many rough assumptions behind (see methods section). Some data (e.g. from the Swedish DCF on the western stock) could not be separated for passive and active gears; these indicators cannot be quantitatively evaluated in scenarios (indicated as n/a). Red figures are to be interpreted as a negative development whereas green a positive.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Metric</th>
<th>Baseline (2017)</th>
<th>Only fishing with gillnets (% change to baseline)</th>
<th>Only fishing with trawls (% change to baseline)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Eastern stock</td>
<td>Western stock</td>
<td>Eastern stock</td>
</tr>
<tr>
<td>Cod landings</td>
<td>t (incl. BMS)</td>
<td>25 496</td>
<td>3 923</td>
<td>0</td>
</tr>
<tr>
<td>Carbon footprint</td>
<td>CO₂-equiv. (t)%</td>
<td>29 265</td>
<td>3 986</td>
<td>+57</td>
</tr>
<tr>
<td>Benthic pressure</td>
<td>km²</td>
<td>53 642</td>
<td>7 688</td>
<td>-96</td>
</tr>
<tr>
<td>Edible yield (high)</td>
<td>t edible</td>
<td>8 414</td>
<td>1 373</td>
<td>n/a</td>
</tr>
<tr>
<td>Landing value</td>
<td>million €</td>
<td>23</td>
<td>4-4</td>
<td>+35</td>
</tr>
<tr>
<td>Non-food catch</td>
<td>% below 35 cm</td>
<td>179</td>
<td>32</td>
<td>-74</td>
</tr>
<tr>
<td>Compliance</td>
<td>t discard</td>
<td>3 452</td>
<td>191</td>
<td>-41</td>
</tr>
</tbody>
</table>

4.2 Longer-term scenarios

The trends in fuel consumption over time (data from this study) in relation to stock reference points revealed interesting patterns. Fuel consumption per landing for the western stock increase with higher fishing mortality, even if the correlation is extremely weak\(^{66}\). Tentatively, with a sustainable fishing mortality for the stock of 0.2 (equivalent to \(F_{\text{MSY}}\) in the management plan\(^{1}\)), this could reduce the fuel consumption per kilo landing (and in the end emissions) with 26% (unknown time perspective, requires rebuilding). For the eastern stock, this correlation was less straightforward. No fishing mortality is today estimated by ICES, so the correlation had to be done with indicative stock status (catch per hour). During times of improved stock status (by this metric), the correlation showed that trawlers increased their fuel consumption – whereas passive gears decreased theirs respectively. This may be the result of vessels in the sample/methodology, or is based on real circumstances, such as different targeting patterns and landings being compromised from seal damage; further investigations would be interesting.

\(^{65}\) Note that the figure behind is per tonne landing, which includes 92-97 % cod

\(^{66}\) \(y=0.104x+0.275; r^2 = 0.06\)
Figure 1 Fuel use per kilo landing over time for the a) eastern cod stock fisheries, where black line represents the active gear segment, grey the passive gear segment respectively; and b) western stock respectively, where the gear segments could not be separated. Source: SwAM, based on EU-MAP data.
4.2.1 Model results

Only the eastern stock was included in the longer-term modelling on potential changes in size-structure and abundance from alternative fishing arrangements. Preliminary results indicate that a complete fishing moratorium would result in the highest abundance of larger individuals (roughly 90 million above 40 cm). The scenario with only fishing with passive gears (i.e. window selectivity, saving the smaller and larger individuals) may yield the second largest number of larger individuals, stabilizing the stock at around roughly 70 million individuals above 40 cm (with low seal predation; M=0.3) and landings of around 60 000 tonnes; as a comparison, 30.3 million individuals are today above 38 cm in landings\(^1\). With the only trawling scenario (i.e. a selectivity having equal fishing mortality on all fish above 40 cm) with low seal predation (M=0.3), the model showed a continuous decreasing trend in fish above 40 cm and landings, with accelerating pace. Interestingly, at high seal predation pressure (M=0.6), the cod population may instead be stabilised in the only-trawl scenario – in contrast with the low seal predation option – at around 35 million cod individuals above 40 cm, with similar landing volume as of today (25 000 tonnes); the equivalent for gillnet fishing would be around 40 million individuals above 40 cm and landings of roughly 50 000 tonnes. This implies that seal predation has a positive effect on cod size structure in the only trawl scenario, whereas less so in the only gillnet scenario. All scenarios have a high fishing mortality (F=1) which perhaps is nothing to strive towards, thus unrealistically high landing volumes; the fishing mortality rates were chosen to push the model hard to be able to see potential effects.

These figures are only indicative, it is uncertain what the carrying capacity of the present ecosystem is for cod and how increased effort with passive gears could be realised. Looking at the trends in the use of gillnets, the future prospects look problematic, in particular the eastern stock. Since 2008, there has been a continuous decline in number of vessels and landing per vessel in Sweden for the eastern stock\(^67\). This is likely an effect of a combination of causes, such as lack of large fish and conflicts with seals (damage to catch and gears). For the western stock, the trend is more stable both in terms of number of vessels and landings per vessel. With a yearly growth rate of 7.4 % for harbour seal in the southern Baltic during 2003-2014, and grey seals also showing an almost linear population growth rate in the Baltic\(^49\), conflicts are escalating. For cod fishing in the southern Baltic, the damage frequency has increase from around 15% in 2008 to over 30% for gillnets and nearly 50% for longlines in 2014. With this in mind, and assuming seal abundance is linearly correlated with seal damaged gears and catches, the outlook for the coastal, passive gear fishery in the southern Baltic look grim, unless the industry is successful in switching to seal-safe gears. However, with a higher density of large cod, less soaking time (gear in water) may be needed, and accordingly, potentially less seal damages. Trials with Danish seine is also ongoing, which allegedly has less seafloor disturbance than demersal trawling (but is not assessed here) and could avoid seal damages\(^68\). Even so, it still remains to be seen if change in fishing strategy will allow for increased abundance of large fish again.

\(^{67}\) Based on Swedish logbooks

\(^{68}\) https://www.sfpo.se/nyheter/salsakert-snurrevadsfiske-som-alternativ-till-bottentralning-och-garn?category=

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5 Discussion

Baltic cod populations are unique in the sense of being adapted to the brackish environment of the Baltic – the eastern stock may even be seen as evolving towards being a separate cod species. A complete collapse of in particular the eastern stock is therefore most risky, perhaps even riskier than the infamous Canadian cod collapse in 1992 (which still has not recovered); Baltic cod is not easily replaced as it adapted to brackish environment and is genetically well-separated from other cod. In Canada, it was later found that catch-per-unit-effort for cod was better sustained in trawling than in static gears, all the way to collapse, due to aggregation of the stock; this illustrates the ability of active gears to keep on chasing to the very last fish while the static gears render unprofitable first, and should bring caution to the Baltic cod fisheries.

In this study, different selectivity was attributed to different gear types. Similar selectivity may however be achieved with both trawls and gillnets; effects of trawling depend both on selectivity regime and effort. In general terms, there is little evidence of benefits seen from protecting the juveniles, except for acceptance by industry. There are other means to achieve recruitment objectives, such as effort restrictions. Interestingly, market demand (when a product can be sold) seems to be more important than biological parameters (such as length for maturity) when setting size limits. Furthermore, as prices are often higher for larger fish than smaller, the market would steer fishing selectivity towards larger individuals, especially if the quota is restricting (this is however not the case for eastern Baltic cod). In theory, demersal trawls may also achieve similar selectivity to passive gears through technical solutions such as sorting grids; however, protecting large fish through use of sorting grids in a trawl would not be accepted by the fishing industry. Is may thus be concluded that there is mostly a need for change in market preferences to avoid selective targeting of large fish.

There is also perhaps need for a more adaptive management. An important and common general management objective in fisheries is to maximize yield (productivity). The prevailing practice in EU fisheries is to protect juveniles from fishing pressure and has been the management objective in Baltic cod fisheries. However, in other fisheries (such as pike in the Baltic), the objective is to maximize yield by protecting large and highly fecund individuals; in this sense, implementing a the same type of selectivity in the fishery for eastern Baltic cod is not too far off. Selectivity in Baltic cod fisheries has however a long history. The eastern stock had one of the first EU regulations where selective devices were stated in legislation and has gone through a total increase of 15

70 Rose & Kulka (1999) Hyperaggregation of fish and fisheries: how catch-per-unit-effort increased as the northern cod (Gadus morhua) declined. Can J Fish Aquat Sci 56: 118-127
72 Suuronen & Sarda (2007) The role of technical measures in European fisheries management and how to make them work better. ICES J Mar Sci 64: 751-756
75 EU Reg. 2250/95
cm since early 1990s\textsuperscript{37}. It was also the first EU fishery to implement the landing obligation; path dependence may be difficult to break.

Even if there are several external stressors in the Baltic sea, it may also be time to see the elephant in the room: increased selectivity and the landing obligation has failed to deliver a viable fishery, new measures are needed. ICES notes that “the relative harvest rate for larger cod (especially cod > 45 cm) is higher than the average relative harvest rate of the stock”\textsuperscript{41}. There is thus scope for improvement regarding fishing mortality of older and larger fish (i.e. selectivity or effort); how scientists and managers choose to address the issue remains to be seen.

Another aspect that may require increased attention is to investigate if there is need to increase level of detail in management in terms of acknowledging and protecting potential sub-populations. The western stock comprises of a sub-population in the Sound (SD 23), with larger individuals, probably separated from the surrounding cod stocks through behaviour\textsuperscript{76}. The eastern stock also includes cod caught in the Sea of Åland area (ICES SD 29). Recent investigations indicate that there might be a separate stock of cod reproducing in the area\textsuperscript{77}. The genetic differences are small, but they have better growth rates compared to cod from the southern part of the Baltic; there is also a lack of seal parasites. Cod catches in this area has increased in recent years, highly valued by local fishermen. However, most recently, catch rates have dramatically decreased\textsuperscript{78}. The reasons are unknown and calls for further investigations; if there are sub-populations of cod with restricted spatial distribution, effort displacement into these areas in times of poor status in other areas may cause adverse effects on an emerging local population.

At last, this study has taken a relatively crude approach to the Baltic cod fisheries. Some baseline indicators with Swedish basis may not be representative for other member states, such as Equity and Employment (different fleet structures). Other indicators exhibit variability between countries, making “true” figures highly uncertain, such as Non-food catch and Compliance (considerable underreporting occurs). Even so, there are some important insights had that point towards further investigations, such as the both negative and positive role of seals. Based on the outcome for cod abundance and size structure from the different scenarios it is perhaps also interesting with a thorough cost benefit analysis: given the important role cod has in the Baltic sea ecosystem and current performance of, in particular the eastern stock’s, supply chain indicators – at what price does Baltic cod generate larger societal value in the sea than from the value chain?

\textsuperscript{76} Svedäng et al. (2010) Migratory behaviour and otolith chemistry suggest fine-scale sub-population structure within a genetically homogenous Atlantic cod population. Environ Biol Fish 89, 383–397.


\textsuperscript{78} \url{https://www.svt.se/nyheter/lokalt/uppsala/kris-for-torsken-i-alands-hav}; \url{https://www.svt.se/nyheter/lokalt/uppsala/minskat-torskbestnad-slur-hart-mot-fiskare}
6 Conclusion and recommendations

- Avoid continued burden-of-proof on external factors for current situation (seals, oxygen-deficit areas) and initiate actions where possible, i.e. in fisheries, such as:
  - Rule out selectivity-induced density-dependent growth for eastern Baltic cod or act upon it (further decrease mesh size and effort, or introduce window-selectivity that protects large cod)
  - Decrease fishing pressure on herring and sprat in ICES SD 24–26, where cod is mainly concentrated today.
- Passive gear fisheries have many benefits over active gears, in short- and long-term perspectives, even if there are also trade-offs and challenges today. This analysis did not investigate in detail differences between gears within the fishing segment, such as the potential of seal-safe fishing gears. For continued sustainable development of Baltic cod fisheries:
  - Investigate the prospects of seal-safe fishing gears at larger scale
- For the eastern Baltic cod, current path indicates alarming consequences whereas a fishing moratorium would provide most effects on ecosystem structure and function (abundance and presence of large cod); only fishing with passive gears may achieve similar effects but lower cod biomass. Effects of seals vary depending on scenario and gear. Thus:
  - The operational objective of degree of accepted trade-offs should be discussed in an Ecosystem-Based Fisheries Management context
- Initiate a governance analysis of Baltic cod fishing to identify where the problems of the current system are most pertinent and act accordingly. This analysis should include:
  - legislative bodies: today not effective, transparent nor accountable (e.g. rules are broken by politicians through political overfishing, fishers are documented to illegally discard and avoid onboard observers)
  - current scientific provision: which data and analysis are used by different stakeholders for different purposes, how external research findings are utilized in ICES scientific advice, etc.

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