AD HOC REPORT ON EFFECTS OF FISHERIES AND ECOSYSTEM IMPACT ON COMMERCIAL FISH STOCKS IN THE BALTIC SEA

VOLUME 1 | ISSUE 38

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

CIEM CONSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

ISSN number: 2618-1371 I © 2019 International Council for the Exploration of the Sea

ICES Scientific Reports

Volume 1 | Issue 38

AD HOC REPORT ON EFFECTS OF FISHERIES AND ECOSYSTEM IMPACT ON COMMERCIAL FISH STOCKS IN THE BALTIC SEA

Recommended format for purpose of citation:

ICES. 2019. Ad hoc Report on Effects of fisheries and ecosystem impact on commercial fish stocks in the Baltic Sea.
ICES Scientific Reports. 1:38. 28 pp. http://doi.org/10.17895/ices.pub.5447

Author

Stefan Neuenfeldt

Contents

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

1 Background

The reformed Common Fishery Policy (CFP) relies for its implementation notably on sea-basin related multiannual plans. The first such plan was adopted for the Baltic Sea in July 2016 via Regulation (EU) 2016/1139. The implementation started with the fishing opportunities for 2017.

The Plan provides that by 21 July 2019 the Commission has to report to the European Parliament and the Council on the results and impact of the plan’s implementation on the relevant stocks and fisheries, in particular as regards the achievement of the Plan’s objectives. These objectives are:

- contribute to the achievement of the objectives of the CFP;
- aim to ensure that the populations of living marine biological resources are at sustainable levels;
- contribute to the elimination of discards by avoiding and reducing unwanted catches and by implementing the landing obligation for the relevant species;
- implement an ecosystem-based approach so as to minimize negative effects of fishing activities on the environment.

A lot of information is available, notably in the yearly stock and ecosystem advice from ICES and in reports from the Scientific, Technical and Economic Committee for Fisheries (STEFC), and DG MARE will consult BaltFish and the Baltic Sea Advisory Council on various aspects. Nevertheless, the Commission would in addition need advice from ICES on some specific aspects.

2 Request to ICES

In order to support the European Commission in the preparation of the report, ICES is requested to give advice on the following questions:

1. What are the effects of fisheries on the ecosystem in the Baltic?
2. What factors other than fisheries are affecting the stocks? To the extent it is possible to provide (elements of) a reply, what is their (relative) contribution to the overall mortality rate?

3 Effects (incl. impacts beyond targeted, size-selective extraction) of fisheries on the ecosystem in the Baltic

The Baltic Sea is a shallow, semi-enclosed, brackish sea, characterized by vertical stratification of the water column. Salty, well-oxygenated water from the North Sea occasionally enters the Baltic Sea through the Belt Seas and propagates into the deeper areas, while freshwater flows exit at the surface. Stratification limits the oxygen from reaching the deeper waters and hence the oxygen content of the bottom water depends on surface oxygen consumption and the inflows of North Sea water. Due to these hydrological characteristics, the basin has a limited diversity of fish species, dominated by marine species in the southwestern areas and a combination of marine and freshwater species in the northeastern areas. Fisheries in the Baltic Sea are focused on a few major species.

Since the early 1950s, landings of herring and sprat from the pelagic fisheries have dominated the total landings of fish from the Baltic Sea which peaked at more than 1.2 million tonnes in the mid-1970s. A decrease in sprat abundance, followed by a decline in cod in the late 1980s, led to a marked decline in total landings. Pelagic landings increased in the early and mid-1990s reflecting an increase in sprat abundance during this period. Since 2003, total Baltic Sea landings have remained fairly stable (figures 3.1 and 3.2)

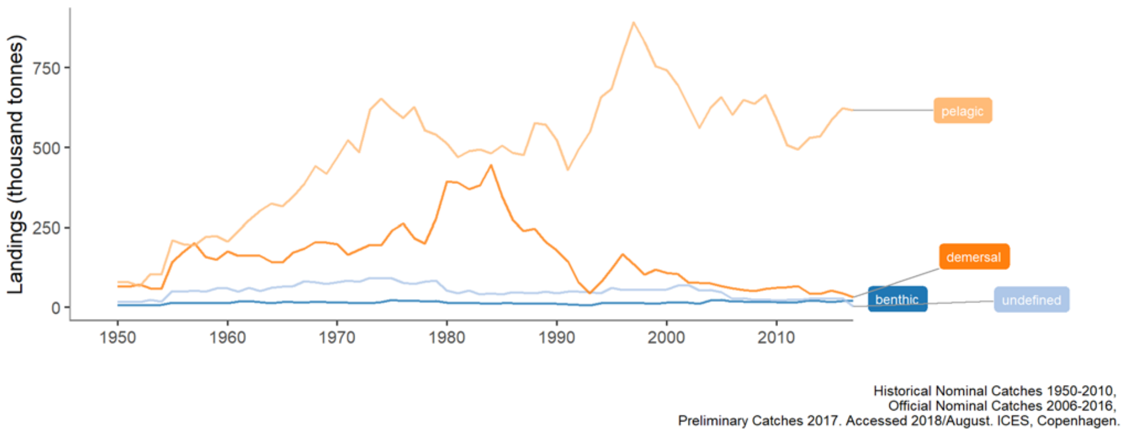

Figure 3.1. Landings (thousand tonnes) from the Baltic Sea in 1950–2017, by fish category.

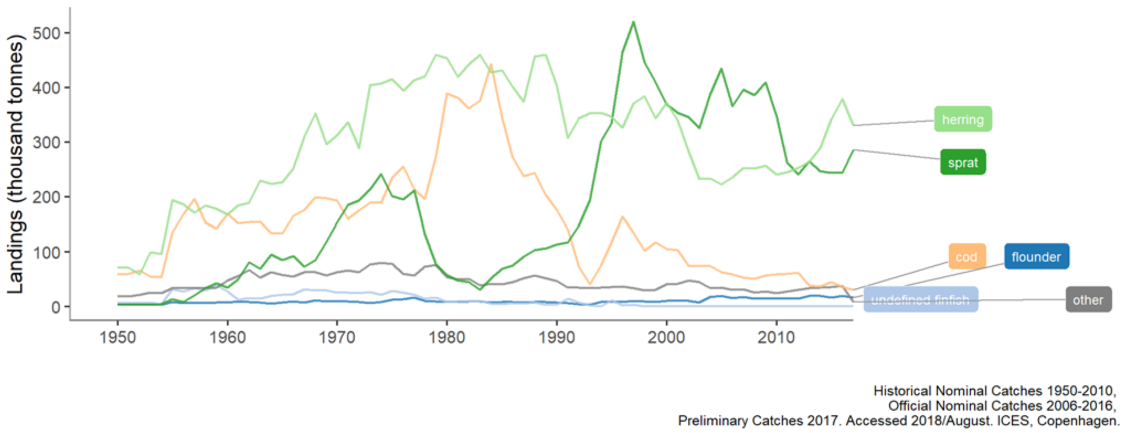

Figure 3.2. Landings (thousand tonnes) from the Baltic Sea in 1950–2017, by species. The five species having the highest landings are displayed separately; the remaining species are aggregated and labelled as "other". The "undefined finfish" category is due to inadequate reporting in early years.

There has been a decline of the total nominal salmon catches in the Baltic Sea, starting from 5636 tonnes in 1990 and decreasing to 900 tonnes in 2010. Since then, catches increased somewhat again in 2011–2014. In the last three years, the total nominal catch has again decreased, and in 2017, it was 761 tonnes, the lowest value so far recorded.

Yellow and silver European eel landings are not always reported separately, so they are combined. The European total landings of yellow and silver eels decreased from 18 000–20 000 tonnes in the 1950s to 2000–3000 tonnes since 2009. In 2017, the figure is 2280 tonnes for yellow and silver landings, combined. Most yellow and silver eel landings come from fresh, transitional and coastal waters. Also in the Baltic Sea, eel landings constantly declined and are at a historically low level for the time being. (Figure 3.3)

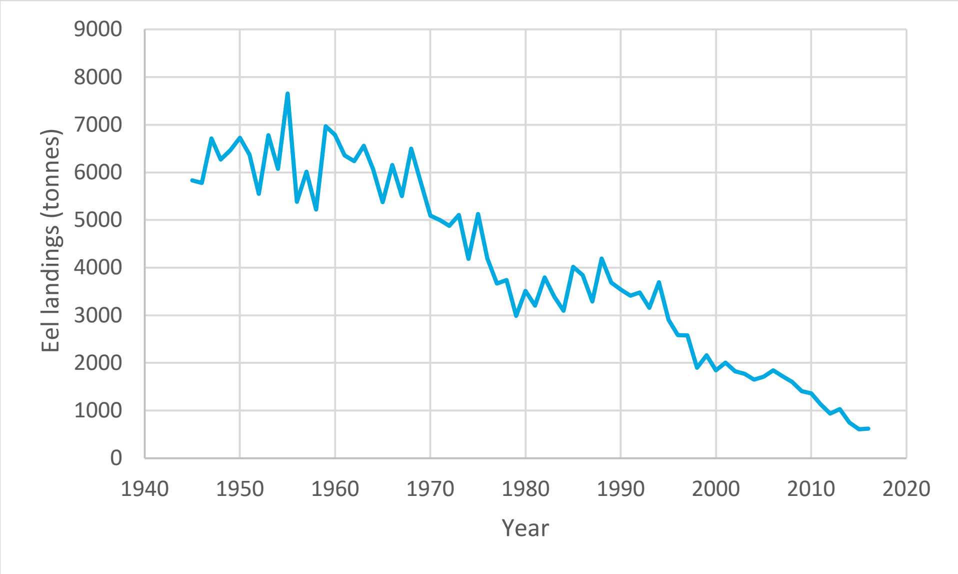

Figure 3.3. Total eel landings of Baltic countries, commercial and recreational data combined. Note that it was not possible to allocate German and Danish catches to either North- or Baltic Sea. The data are from ICES 2019.

Fishing vessels from nine nations operate in the Baltic Sea, with the largest number of large vessels (>12 m) coming from Sweden, Denmark, and Poland. Total finfish landings from the Baltic Sea peaked in the mid-1970s and again in the mid-1990s, corresponding to peaks in the abundance of cod and sprat stocks respectively. The proportion of the total annual landings caught by each country has varied little over time, except for the redistribution of catches by former USSR countries. Total fishing effort has declined since 2003.

3.1 Discards

Discards for pelagic species in the Baltic Sea are very low, as both sprat and herring are target species and other bycatch (e.g. of sticklebacks) is also landed. The discard rates are minor for static coastal gears and even lower for pelagic trawls. A rise in benthic discard rates in 2014 is due to the inclusion of flounder stocks in the evaluation, which significantly increased the number of stocks assessed for discards (from 4 to 7 stocks). Demersal discards show a nominal overall decrease in 2015 because the of obligation to land all commercial catches of cod, salmon, herring, and sprat in the Baltic Sea that came into force in 2015. Release rates for species targeted by recreational fisheries are available for most target species and are high but vary between years and countries. Post-release mortality estimates are available for some species but further studies are needed.

3.2 Mixed fisheries

Many fishing gears catch more than one species at the same time, so “technical interactions” occur between stocks when multiple species are captured in the same gear during fishing operations.

A large proportion of the catches of herring was taken in fisheries where herring landings where at least 5% of the total landings while the amount of herring in fisheries where sprat accounts for at least 5% of the total landings was medium (Figure 3.4). The amounts of sprat were high in both the fisheries where herring or sprat accounted for at least 5% of the total catch. In the Baltic Sea, cod fisheries often capture flounder (and occasionally take plaice and whiting). Occasional fisheries for flounder frequently harvest cod. The Baltic herring fisheries often land also sprat and vice versa.

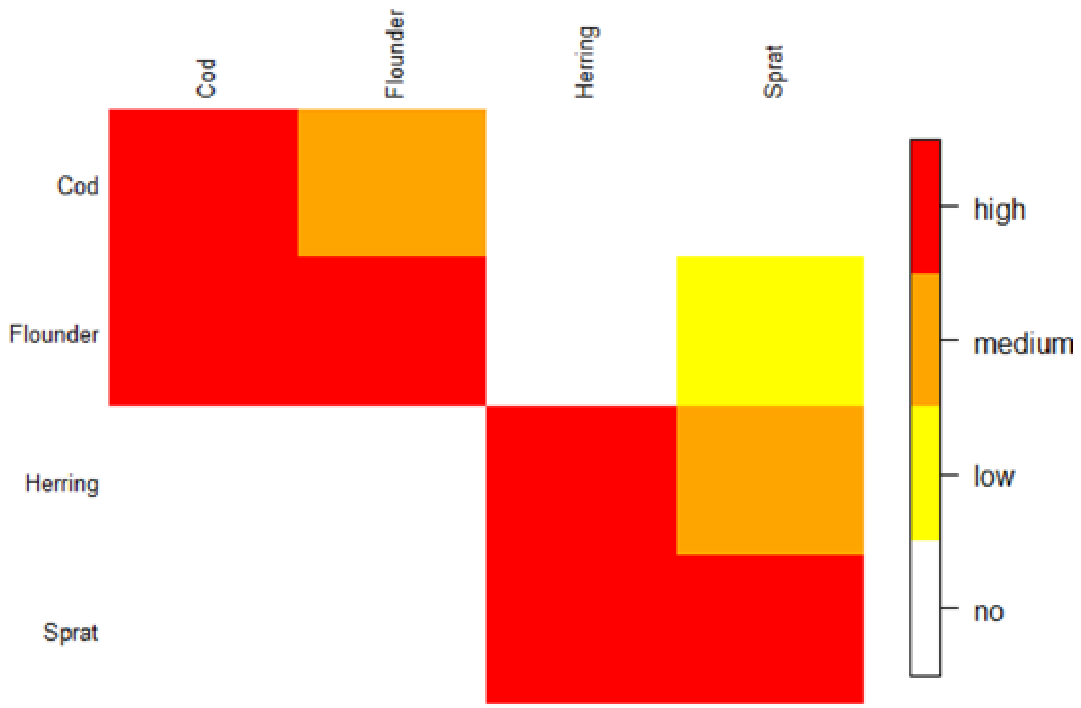

Figure 3.4. Technical interactions between the four most important commercial fish species in the Baltic Sea. The rows of the figure illustrate the fisheries where the species A was caught. Red cells indicate the species B which the A species are frequently caught together with. Orange cells indicate medium interactions and yellow cells indicate weak interactions. The column shows the degree of mixing in fisheries where species B account for at least 5% of the total landings.

The technical interaction in the Baltic pelagic fishery differs between fisheries. The majority of herring and sprat are caught with pelagic trawls. The pelagic trawlers performing a directed fishery for either sprat or herring have a very variable degree of mixing in the catches of sprat and herring. The degree of mixing varies on a spatial scale (Figure 3.5). According to logbooks and sales slips, the mixing can vary between < 5% to 40% although these percentages are not quantifiable at this stage. Given that the information available on the mixing in the directed single species pelagic fishery is based on logbooks and sales slips and thus on a trip basis, the actual mixing in the individual hauls is at present unknown. The directed herring fishery close to Bornholm in subdivisions 23–25 is reported to have less sprat in the catches than further north in the Baltic (subdivisions 27–29). Mixing of herring and sprat in the directed herring trawl fishery is highest in Subdivision 32, decreasing further north in subdivisions 30–31.The vast majority of the total herring landings in subdivisions 30–31 are not for human consumption and these tend to be mixed. The majority of the landings in the directed herring trawl fishery are for human consumption but there are also landings for industrial purposes. Herring is caught as a bycatch in the directed sprat fishery which is mainly in the central part of the Baltic. Landings in this fishery are mainly for industrial purposes, but there are also landings for human consumption. The directed sprat fishery shows the same spatial variation in mixture of herring and sprat as the directed herring fishery. There is, however, a low spatial overlap of the directed herring and sprat fishery reported.

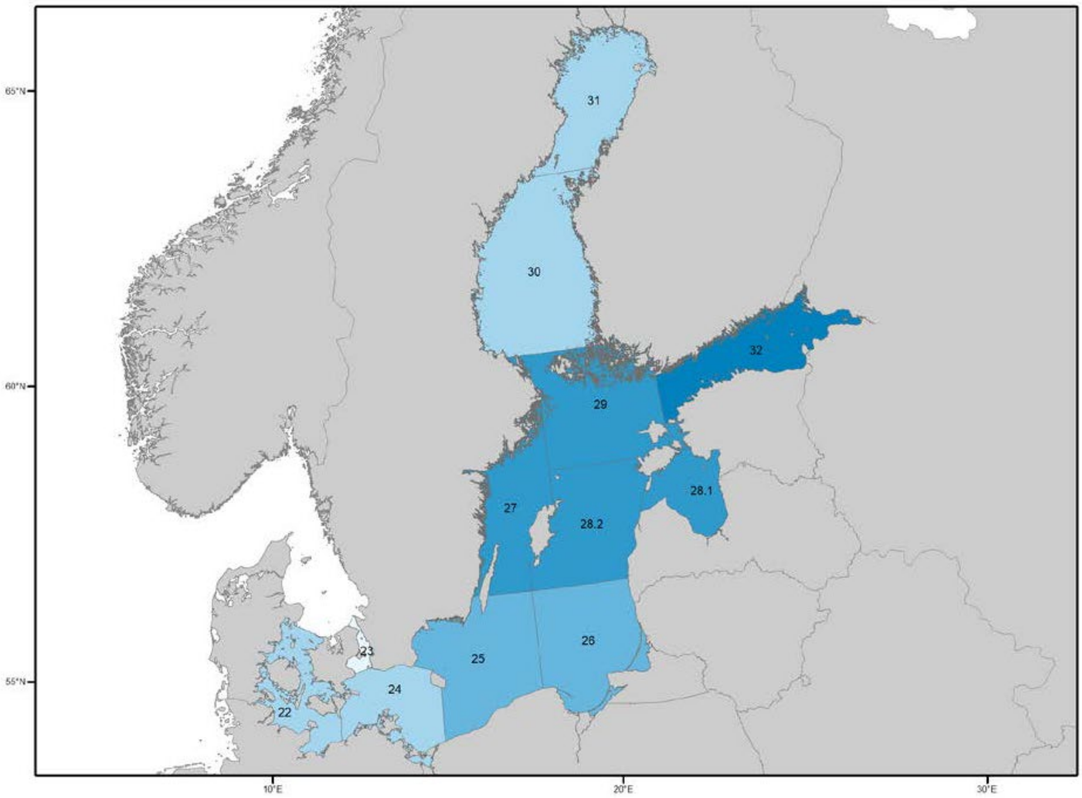

Figure 3.5. Spatial variation in reported mixing of herring and sprat in trawl fishery in the Baltic. Darker colour indicates higher mixing.

The species composition in trawl hauls in these directed fisheries is also reported to vary on a seasonal scale. Reporting from sales slips and logbooks show that there are higher concentrations of sprat in the directed herring trawl fishery in the 1st and the 4th year quarters, in particular in the northern Baltic Sea; the 1st and 4th quarters are also the main fishing seasons.

The coastal fisheries with smaller vessels targeting herring with gillnets and trapnets have a low degree of actual mixing in the catches and are predominantly clean herring fisheries with less than 5% mixing of sprat in the catches. If sprat is caught as bycatch, mixing is less than 5%.

In addition to the directed single species pelagic fishery there is a small-meshed fishery for industrial purposes which has quite a high degree of mixing of herring and sprat.

Cod and flounder account for the highest landings of demersal species in the Baltic. The majority of the landings are made with demersal trawls but there are also significant landings with gillnets. The otter trawlers and gillnetters also land other demersal species; dab, plaice, and whiting.

There is no mixed fisheries advice developed yet for the Baltic Sea. Perceived interactions that do not occur in real life as well some subtle interactions are, however, probably missed due to the current data aggregation. Most fisheries data, including those submitted to STECF, are aggregated based on species, gear, mesh size range, ICES square, and calendar quarter. Management advice as well as the underpinning science hence lack sufficient insight in technical interactions. They may vary through time and space (e.g. interactions might vary between day and night, or between different times of year, or between different areas).

3.3 Abrasion of the seabed by mobile bottom-contacting fishing gears

Abrasion of the seabed by mobile bottom-contacting fishing gears has been investigated to describe the extent, magnitude, and effects of fishing on benthic habitats. Mobile bottom-contacting gears are primarily used in the southern areas of the Baltic Sea (Figure 3.6).

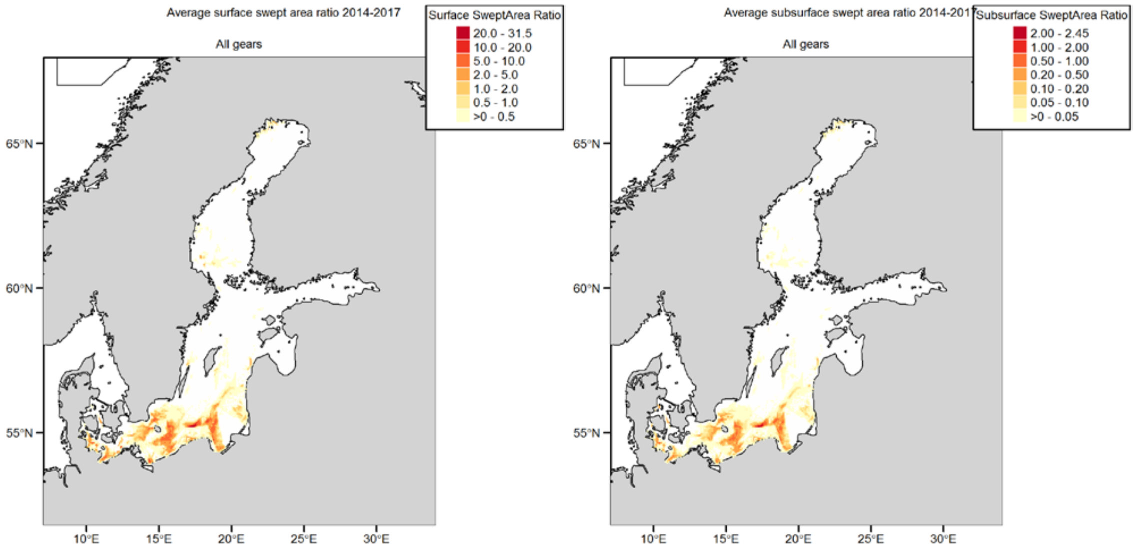

Figure 3.6 Average annual surface (left) and subsurface (right) disturbance by mobile bottom-contacting fishing gear (bottom otter trawls, bottom seines, beam trawls) in the Baltic Sea during 2014–2017, expressed as average swept-area ratios (SAR). No data from Russia are included as none were supplied.

Fishing gear disturbances of bottom substrates impact benthic communities, but little is known at the regional scale about the sensitivity of different Baltic Sea organisms and communities to these fishery-induced impacts. A qualitative approach to address this was elaborated by ICES in 2016. A mechanistic, quantitative assessment procedure based on biological principles is now under development. These approaches would be improved with further research and evidence to better parameterize models, as well as by establishing better quantitative links to other pressures (e.g. anoxia). Secondary effects of bottom trawling include smothering and resuspension of sediment and nutrients, as well as foodweb effects, but these are difficult to evaluate compared to primary effects.

3.4 Bycatch of marine mammals and seabirds

All fisheries have the potential to catch protected, endangered, or threatened species, such as seabirds and marine mammals, as non-targeted bycatch. Recording of the catch of seabirds and mammals has been undertaken in some Baltic Sea fisheries, usually where there is perceived risk of such bycatch. Seabirds can become entangled in gillnets or hooked on longlines and consequently drown. Seals can be caught in submersed trapnets and harbour porpoises entangled in gillnets, leading to the deaths of these animals.

Studies conducted between 1980 and 2005 indicated that at least 76 000 birds, mostly sea ducks, were killed annually in Baltic Sea gillnets. This number may have declined in more recent years, probably due to the consequential decline in sea duck populations. Birds that actively pursue their prey underwater were more susceptible than those that graze on the benthos. For at least four bird species, this mortality was sufficiently high to generate declines in population abundance and be unsustainable.

The only cetacean species to occur regularly in the Baltic Sea is the harbour porpoise *Phocoena phocoena*. East of the Transition Area, a large population decline has occurred in the past 50–100 years. With an estimation of 447 individuals (95% CI: 90–997), this population is listed as critically endangered by IUCN. The Belt Sea population has a much higher abundance, estimated at 40 475 (95% CI: 25 614-65 041). Dead harbour porpoises exhibiting evidence of gillnet entanglements are found and reported regularly, so it is likely that bycatch in gillnets is adversely affecting the critically endangered central Baltic Sea population.

4 Factors other than fisheries affecting the stocks

4.1 Abiotic factors

Increasing average temperature and decreasing average salinity in the Baltic are influenced by large-scale atmospheric processes illustrated by the Baltic Sea Index (BSI), a regional calibration of the North Atlantic Oscillation index (NAO). The change from a generally negative to a positive index for both BSI and NAO in the late eighties was associated with more frequent westerly winds, warmer winter and eventually a warmer climate over the area. Further, the absence of major inflow events has been hypothesized to be related to the high NAO period. An indication of this is that only two major inflows to the Baltic Sea have been recorded during the high BSI-period since the late 1980s. Contrary to what occurred in surface waters, salinity in deeper waters has increased after the early 1990s to levels as high as in 1960s–1970s.

A particular feature of the Baltic Sea since the mid-1990s has been a drastic increase in the extent of anoxic and hypoxic areas, likely due to lack of strong water inflows from the North Sea and potentially increased biological oxygen consumption on seafloor. (Figure 4.1).

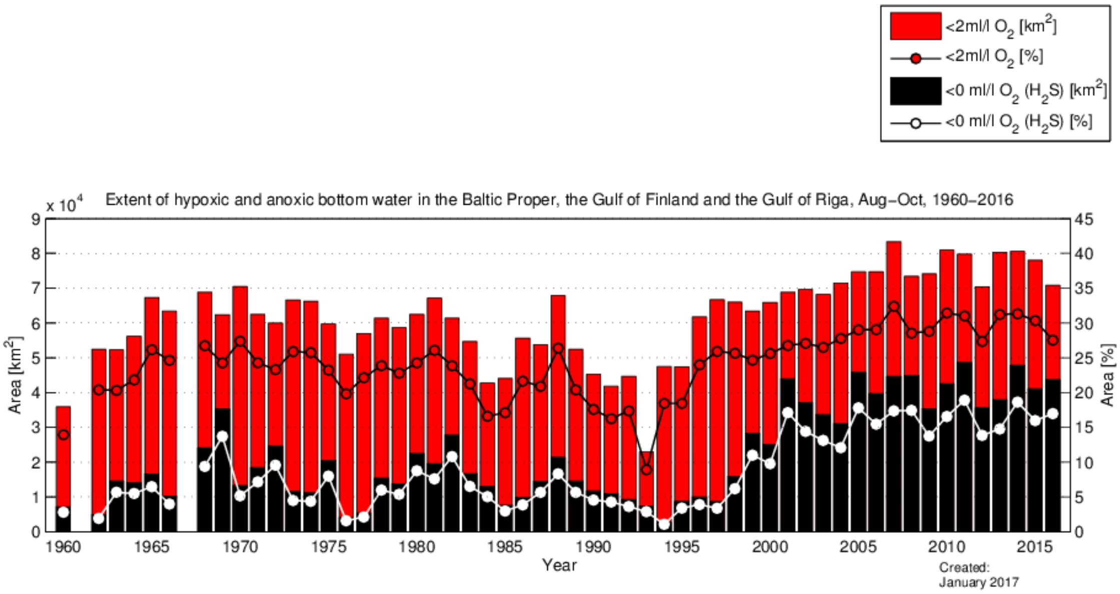

Figure 4.1. Time-series of anoxic and hypoxic seabed in the entire Baltic Proper. From the Swedish Meteorological and Hydrological Institute (SMHI) annual report.

An overview of the dynamics of the eastern Baltic cod, sprat and central Baltic herring SSB and recruitment together with the dynamics of drivers influencing the dynamics of biomass and recruitment is presented in Figure 4.2.

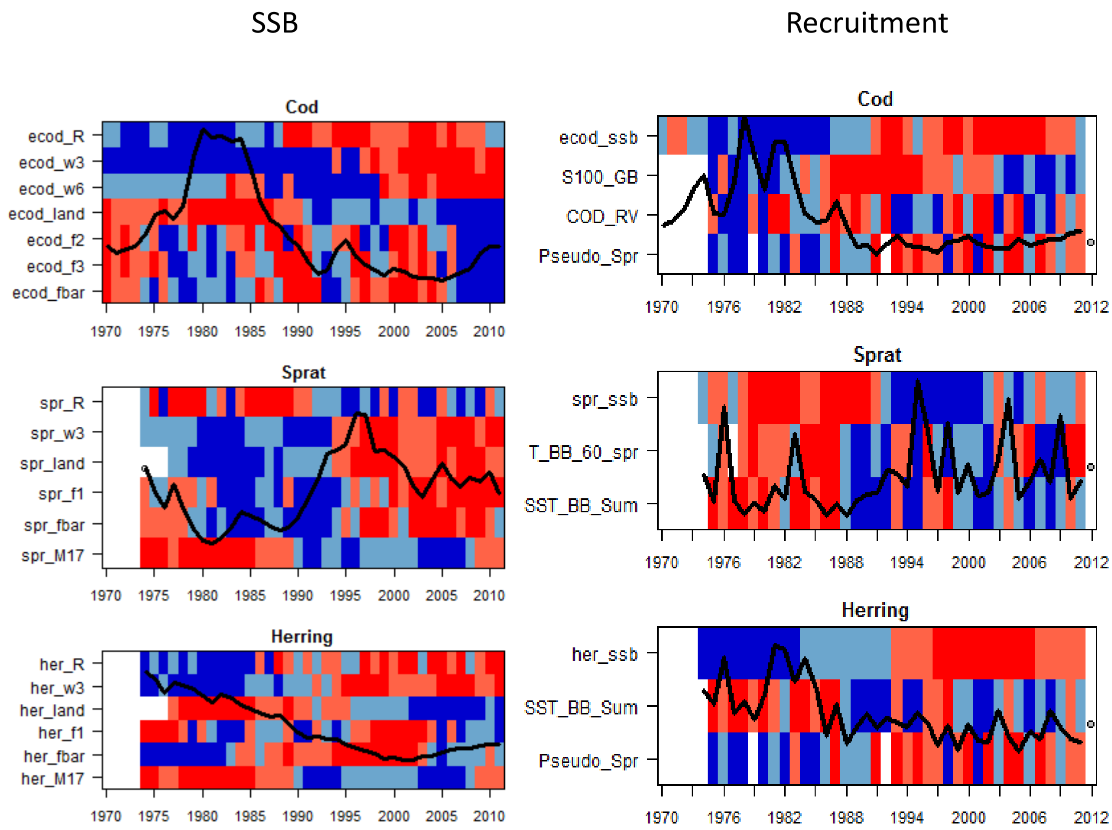

Figure 4.2. Temporal changes in indicators influencing the SSB and recruitment of the eastern Baltic cod, sprat and central Baltic herring. The colours refer to quartiles of the values observed in the time-series, high values are marked with blue and low values with red colours, except for mortality where the colours are inversed. The lines show the trends in SSB and Recruitment of the stocks, the dots for recruitment in the final years show the values used in short-term forecast (R-recruitment; w-weight-at-age; land-landings, f-fishing mortality-at-age; M-natural mortality (average of ages 1–7); S100_GB- salinity at 100 m depth in Gotland Basin; COD_RV- cod reproductive volume, Pseudo_Spr-abundance of Pseudocalanus in spring; T-BB-60_spr- temperature at 60 m depth in spring in Bornholm Basin; SST_BB_Sum- Sea surface temperature in summer in Bornholm Basin).

Environmental conditions for Eastern Baltic cod recruitment of year classes 2010–2011 were assessed by the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea. This assessment was made based on an indicator of the limiting abiotic conditions for cod egg survival, the reproductive volume (Figure 4.3), found to be the most encompassing indicator of the significant indicators of environmental conditions of cod recruitment.

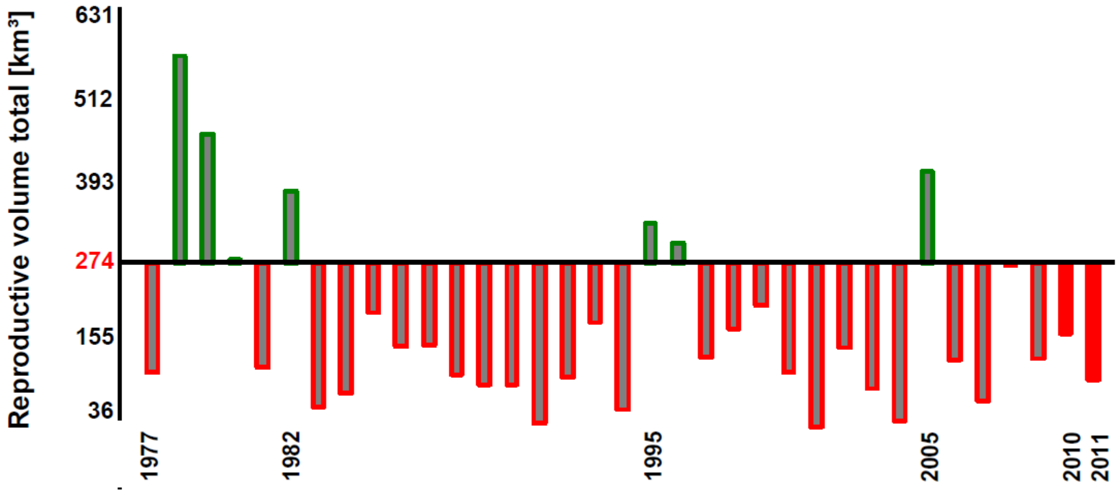

Figure 4.3. Time-series of reproductive volume for Eastern Baltic cod. Relationships between each variable and residuals from cod recruitment (back shifted) vs. cod SSB were derived during WGIAB 2013, using linear models of first or second-order polynomials for year classes 1977–2009. Bars indicate the values relative to the reference value of each variable (derived from the fitted relationships on cod recruitment residuals, as the point where there is no environmental effect on recruitment); green bars indicate beneficial environmental conditions and red bars poor conditions for cod egg survival. This shows the poor conditions for cod recruitment for the year classes 2010–2011 (corresponding to recruitment of age 2 in 2012–2013).

4.2 Changes in spatial distributions

Fish distribution has changed considerably during the past decades. The Eastern Baltic cod, in parallel with the decrease in its stock size, contracted its distribution to the southern areas since the mid-1980s. The sprat stock on the other hand, increased mostly in the northern areas of the Baltic Proper, which has been interpreted as a spatial predation release effect. As a consequence of the spatial relocation of the sprat stock to more northern areas, the growth of sprat decreased mostly in these areas, indicating a spatial density-dependent effect. The current low spatial overlap between predator (cod) and prey (sprat), at least in some seasons, implies changes in the strength of the predator–prey relationship from the 1970s–1980s. Moreover, the reallocation of the sprat population in the northern Baltic proper implies a spatial differentiation in the strength of intraspecific and interspecific competition among clupeids.

Evidence highlighting the importance of coastal shallow waters as major nursery and feeding grounds for pre-mature young cod and to some extent mature individuals keeps increasing during very recent years. Standardized Baltic International Trawl Surveys (BITS) cover mostly deeper waters (>15 m water depth) and thus possibly misestimate abundances of species inhabiting coastal areas.

4.3 Species interactions and parasites

The considerations for the Baltic Sea cover the eastern cod stock, the central herring stock, and the sprat stock. Eastern Baltic cod is a predator on herring, sprat, and juvenile cod (Figure 4.4). This predation by cod forms the main interactions among these stocks.

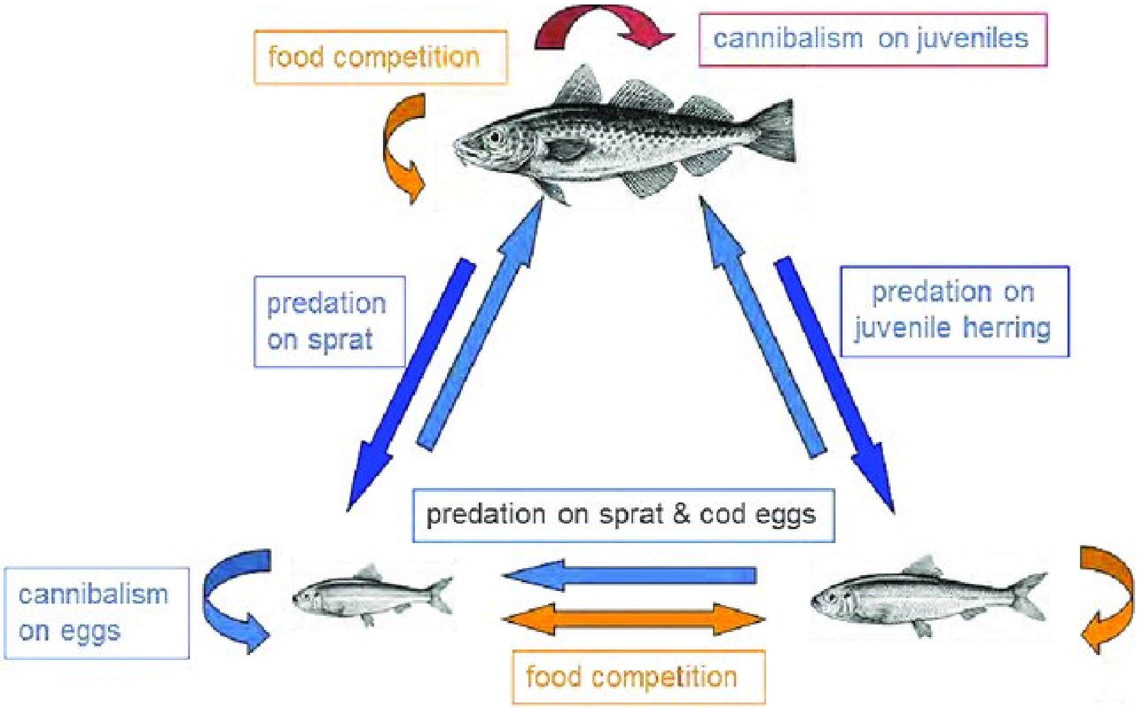

Figure 4.4. Main fish species interactions in the Baltic Sea; cod, herring and sprat.

In the Baltic, multispecies analyses indicate that trade-offs have existed between fishing on cod or herring and sprat. Increased fishing pressure on cod may increase the risk of a low cod stock size, thereby reducing cod predation on sprat and herring and allowing great survival and growth in these two prey species. Increased fishing pressure on herring and sprat may have a negative impact on the condition and growth of cod (by reducing the forage available for cod) and result in lower cod yields. The magnitude of the interaction between the species depends on the spatial and temporal overlap among the three stocks. Nowadays, the cod stock is on such a low level that its impact on herring and sprat mortality rates can be considered to be very low. On the other hand, decreasing fishing pressure on sprat might not necessarily improve cod condition and recruitment, because the main bottleneck for cod these days is the absence of benthic food. Cod might not reach the condition necessary to forage on sprat.

Differences in the distributions of cod and herring and sprat imply that an increase in eastern cod landings will not necessarily result in a major increase in herring and sprat stock sizes (and hence catching opportunities.

There are other important species interactions. The thiamine deficiency syndrome M74 is a reproductive disorder, which causes mortality among yolk-sac fry of Baltic salmon. The development of M74 is caused by a deficiency of thiamine in the salmon eggs that, in turn, is suggested to be coupled to an abundant but unbalanced fish diet with too low a concentration of thiamine in relation to fat and energy content. The intake of thiamine for Baltic salmon in relation to energy and fat remains lowest by eating young clupeids, especially young sprat, and the total biomass of sprat in the Baltic main basin and salmon growth are positively correlated. A large sprat stock may have a positive impact on salmon growth but may also increase M74 and thereby mortality of Baltic salmon fry.

Seal predation on cod has increased regionally. Three seal species occur regularly in the Baltic Sea: grey seal *Halichoerus grypus*, harbour seal *Phoca vitulina*, and ringed seal *Phoca hispida*. Grey seals occur throughout the Baltic Sea and the population grew rapidly from 2000 to 2014, before levelling off at above 30 000 individuals. Harbour seals mainly occur in the southern Baltic Sea and the population in this area had an estimated growth rate of 8.4% between 2002 and 2014.

The neighbouring Kalmarsund population had a lower growth rate. The population of ringed seal in the Gulf of Finland is low, at around 100 animals, and is listed as vulnerable by IUCN. This is probably due to recent lack of ice for breeding during winter. The Bothnian Bay population of ringed seal exceeds 10 000 animals.

Fish serve as transport hosts to a range of parasites, with potential negative effects on fish health. In the Baltic Sea, the grey seal *Halichoerus grypus* (Fabricius) population has increased markedly since the early 2000s. *H. grypus* is the main final host to the liver worm *Contracaecum osculatum* (Rudolphi, 1802), a parasitic nematode to which cod *Gadus morhua* (Linnaeus) is one of several transport hosts. Recent investigations have shown a marked increase in prevalence and abundance of infection of this parasite in livers of *G. morhua* inhabiting the central Baltic Sea. Prevalence and abundance of *C. osculatum* sensu stricto in *G. morhua* livers differ significantly between east and west Baltic Sea, with highest levels of infection occurring in the low-salinity central (eastern) Baltic areas. Highly infected fish in the east have significantly lower condition factors than their westerly, less infected conspecifics. Spatial differences in local seal abundance and seal species, salinity and feeding ecology may explain the observed differences in *C. osculatum* infection between eastern and western *G. morhua*.

4.4 Decreased feeding opportunities for small cod

Post-settlement, prespawning cod feed almost exclusively on benthic prey. A recent reversal has occurred in the ontogenetic development of feeding level over body length, resulting in present feeding levels of these small cod that indicate severe growth limitation and increased starvation-related mortality. Young cod manifest the low growth rate and high mortality rate in a reduction in size-at-age and low population abundance. The low feeding levels most probably result from a decrease in benthic prey availability due to increased hypoxic areas. Under the current environmental regime environmental forcing likely dominates the changes in consumption and growth rates of Atlantic cod in the Baltic Sea by reducing the availability of benthic prey. This food reduction is amplified by accumulation of cod of smaller size competing for the scarce benthic resources. Only the fish with feeding levels well above average will survive, though growing slowly (Figure 4.5). These results suggest that the relation between consumption rate, somatic growth and population density, as well as its consequences for species interactions and ecosystem functioning, are environmentally mediated and hence not stable under environmental change.

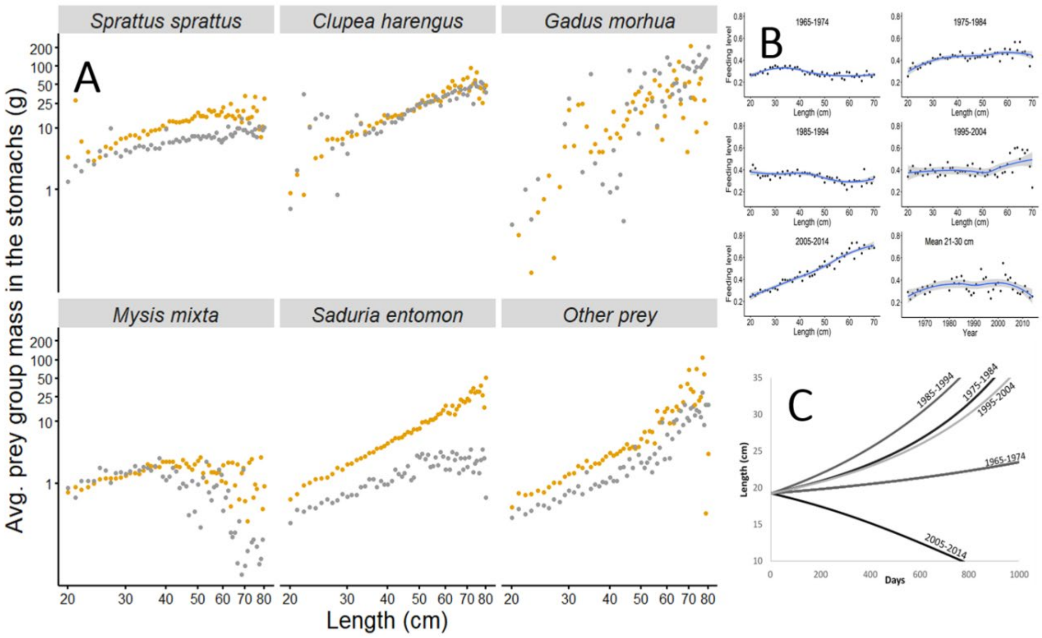

Figure 4.5. A Diet composition in *Gadus morhua* stomachs by mass before 1988 (orange) and after 1994 (grey). The transition period between ecological regimes from 1988 to 1993 is left out. B Feeding levels of *Gadus morhua* by length during the past five decades. LOESS-based smoothed trends are plotted in blue together with shadowed confidence limits. The lower right panel: feeding level over time for *G. morhua* of 21–30 cm total length. C Simulated average growth trajectories of *Gadus morhua* in the total length range 20–35 cm for the five decades covered by the stomach sampling programme

4.5 The invasive Round Goby

The round goby has established in all Baltic Sea sub-basins and is continuously increasing its range and abundance in recently colonized habitats. The species has become the predominant fish species in many coastal areas and poses strong predatory pressure essentially on epibenthic molluscs. It has also become an important prey species in areas where it is numerous, with signs of individual-level benefits for some piscivorous fish.

It is suggested that the high densities of round goby in the Lithuanian coast have locally depleted dense blue mussel banks. In regions where round gobies have become abundant, they have themselves become important prey items to both avian and fish predators: round goby is the main food item for cod and perch in the Gulf of Gdańsk, increasingly important prey for perch in Estonia, and also an important prey item for Great cormorant and Grey heron, contributing locally up to 60–95% to their diets. In Lithuania round gobies were found in the diet of most piscivorous fish species including turbot or even such species as shorthorn sculpin. Certain piscivorous and commercially valued fish can actually benefit from round goby, corroborated by better individual-level performance and higher length-at-age values after the invasion.

5 Acknowledgement

This review has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement PANDORA, No 773713.

6 References

ICES 2018. ICES Fisheries Overviews: Baltic Sea. https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2018/2018/BalticSeaEcoregion_FisheriesOverviews_2018_November.pdf

ICES 2018. ICES Ecosystem overviews: Baltic Sea https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2018/2018/BalticSeaEcoregion_EcosystemOverview.pdf

ICES. 2018. Report of the Baltic Salmon and Trout Assessment Working Group (WGBAST), 20–28 March 2018, Turku, Finland. ICES CM 2018/ACOM:10. 369 pp.

ICES. 2018. Final Report of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB). 16-20 April 2018. Tartu, Estonia. ICES CM 2018/IEASG:08. 44 pp.

ICES. 2019. Report of the Joint GFCM/EIFAAC/ICES Working Group on Eels (WGEEL), 3–10 October 2017, Kavala, Greece. ICES CM 2017/ACOM:15. 36 pp.

ICES WGBFAS 2019 report draft, available at ICES.

Puntila, R., Strake, S., Florin, A-B., Naddafi, R., Lehtiniemi, M., Behrens, J. W., ... Yurtseva, A. (2018). Abundance and distribution of round goby (Neogobius melanostomus): HELCOM Baltic Sea Environment Fact Sheet 2018. HELCOM.

Sokolova, M, Buchmann, K, Huwer, B, Kania, PW, Krumme, U, Galatius, A, Hemmer-Hansen, J & Behrens, JW 2018, 'Spatial patterns in infection of cod Gadus morhua with the seal-associated liver worm Contracaecum osculatum sensu stricto from the Skagerrak to the central Baltic Sea' Marine Ecology - Progress Series, vol. 606, pp. 105-118. https://doi.org/10.3354/meps12773

7 Reviews

7.1 Review 1 by Maciej T. Tomczak, Stockholm University

Review of ICES Working document to support Advice on EU Special Request on "Report on the implementation of the Baltic Sea Multiannual Plan"

Date: 05 June 2019
Audience to write for: advice drafting group, ACOM,

General Comments

Review of the working paper: "Effect of fisheries and ecosystem impact on commercial fish stocks in the Baltic Sea" as a basis to answer to EU special request on the evaluation of the Baltic EU MAP done by Stefan Neuenfeldt, DTU-Aqua.

Review cover the background document check, but not the advice draft itself. Review will be focus to identify whether the background information is good enough to provide advice, to highlight points where the documentation may contain errors, identify missing key points and, if relevant, to include suggestions for improvement.

Working paper reviewed here is should be a summary of subject "Effect of fisheries and ecosystem impact on commercial fish stocks in the Baltic Sea" and act as a basis to answer to EU special request on the evaluation of the Baltic EU MAP.

Two main questions were requested by EU to ICES to give advice on:

1. What are the effects of fisheries on the ecosystem in the Baltic?
2. What factors other than fisheries are affecting the stocks? To the extent it is possible to provide (elements of) a reply, what is their (relative) contribution to the overall mortality rate?

Presented document not fully cover requested subject and answer the questions given by EU Commission.

Document is written well with good structure, give a background on Baltic Sea environment, biology and fisheries however need major improvements. I'm aware about data and information limits as well as time constrains for Special request, but points I would like to point out are missing from document and affect the final conclusion. For identified issues please see section below

Section "Effects (incl. impacts beyond targeted, size-selective extraction) of fisheries on the ecosystem in the Baltic"

In section "Effects (incl. impacts beyond targeted, size-selective extraction) of fisheries on the ecosystem in the Baltic" document give a summary of i) long-term fish landings, ii) discard, ii) mixed fisheries, iv) abrasion of the seabed by mobile bottom-contraction fishing gear and v) by-catch of marine mammals and seabirds.

That section needs to answer the question and give an information about **Effect of fisheries on ecosystem.** Information describe at points i) and iii) could act as a background, but do not provide information about effect of fisheries on ecosystem. Extraction of marine species from ecosystem and mix fisheries are the cause of changes in the ecosystem not an effect. There are number of studies showing fisheries effect on stocks and whole ecosystem and need to be included.

Points ii, iv and v summarize the changes and effect, but very briefly and conclusions need to be elaborated to answer the what it means for biota and ecosystem as a whole.

State of the fish stocks are the main effect of fisheries, would be better to present status of stocks, indicating where fisheries are the most affecting and highlight what are the consequences for ecosystem. In light of the new Baltic MAP it is necessary to highlight ecosystem process where fisheries are the main factor: as i.e. removal of top predators, trophic cascade or regime shift. That is important to include in the document and advice since Baltic Sea ecosystem are under changes and that's of course affect productivity of the fish stocks.

There are number of points missing in terms of fisheries impact and effect on Baltic ecosystem what cannot be neglected even if the data and knowledge are limited:

- Selective extraction of fish due to selective gears (cause the changes in population structure) see Svedang and Hornborg (2017);
- Ghost nests and lost fishing gears;
- Spatial distribution of pelagic fisheries (catches and effort) and effect of clupeids catches effecting Eastern Baltic Cod stock food availability.

I would suggest to add to the document extensive literature review to describe the effect of fisheries in the Baltic Ecosystem on the top of the information from Ecosystem and Fisheries Overview.

Section: Factors other than fisheries affecting the stocks

In the section **Factors other than fisheries affecting the stocks** document need to provide information - "what factors other than fisheries are affecting the stocks? To the extent it is possible to provide (elements of) a reply, what is their (relative) contribution to the overall mortality rate?"

Author pointing the right factors and processes as i) abiotic factors (as Oxygen, salinity, temperature, reproductive volume etc.) for main commercial fish species (cod, sprat and herring, salmon), ii) changes in spatial distribution, iii) species interactions, iv) decreasing feeding opportunities for small cod, v) the invasive Round Goby, and summarize them well. However, **effect** could be better described and highlighted.

My suggestion for improvement are: in point i) abiotic factors data should be up to date, since document will act to support advice on future MAP, at point ii) changes in spatial distribution visualization - would be a good add (together with mapped pelagic fleet fishing effort), at iii) describe foodweb as a whole not only main commercial species interactions include also lower trophic level and potential cod food availability affected by pelagic fisheries in the southern Baltic Sea.

Despite that section is a synthesis of factors affecting only fish stocks, there are missing quantification of productivity/mortality and relative contribution to the overall mortality rate what was specifically asked in the request. Number of modelling work (also at ICES framework e.g. WGSAM key runs with predation pressure quantification) has been done regarding that issue, addressing relevant questions: Costalago *et al.*, 2019; Bauer *et al.*, 2019; Bauer *et al.*, 2018; Horbowy *et al.*, 2016; Hansson *et al.*, 2017; Gårdmark *et al.*, 2013.

Aspects of the climate change, nutrients management and human perspective in the long-term run are also missing. If that working document needs to support advice drafting on new Multi Annual Management Plan for Baltic fish stocks document need to cover also those aspects. If advice will cover more then only fishing opportunities effect and harvest control rules than working document should contain also exploratory scenarios of ecosystem development under cumulative pressures with highlighted role and effect on/of fisheries i.e. Bauer *et al.*, 2018.

Conclusion

In current version Working Document do not provide full information **on effect of fisheries on ecosystem** (first question). For description of pressures and state Fisheries (FOs) and Ecosystem Overviews (EOs) exists as an ICES product. It is recommended to improve the first part of document.

Results and tools of modelling technics are unutilized at the working document, especially for quantification of relative contribution. Especially that that information's are available at ICES framework. However, it seems to be an effect of time limitation. It could be good to add information and results from ecosystem models as an evaluation and quantification of factors.

References

Costalago, David, Barbara Bauer, Maciej T. Tomczak, Karl Lundström, and Monika Winder. "The necessity of a holistic approach when managing marine mammal–fisheries interactions: Environment and fisheries impact are stronger than seal predation." Ambio 48, no. 6 (2019): 552-564.

Bauer, Barbara, Jan Horbowy, Mika Rahikainen, Nataliia Kulatska, Bärbel Müller-Karulis, Maciej T. Tomczak, and Valerio Bartolino. "Model uncertainty and simulated multispecies fisheries management advice in the Baltic Sea." PloS one 14, no. 1 (2019): e0211320.

Bauer, Barbara, HE Markus Meier, Michele Casini, Ayoe Hoff, Piotr Margoński, Alessandro Orio, Sofia Saraiva, Jeroen Steenbeek, Maciej T. Tomczak, and Handling editor: Marta Coll. "Reducing eutrophication increases spatial extent of communities supporting commercial fisheries: a model case study." ICES Journal of Marine Science 75, no. 4 (2018): 1306-1317

Horbowy, Jan, Magdalena Podolska, and Katarzyna Nadolna-Ałtyn. "Increasing occurrence of anisakid nematodes in the liver of cod (*Gadus morhua*) from the Baltic Sea: Does infection affect the condition and mortality of fish?." Fisheries research 179 (2016): 98-103.

Hansson, Sture, Ulf Bergström, Erik Bonsdorff, Tero Härkönen, Niels Jepsen, Lena Kautsky, Karl Lundström et al. "Competition for the fish–fish extraction from the Baltic Sea by humans, aquatic mammals, and birds." ICES Journal of Marine Science 75, no. 3 (2017): 999-1008.

Gårdmark, Anna, Martin Lindegren, Stefan Neuenfeldt, Thorsten Blenckner, Outi Heikinheimo, Bärbel Müller-Karulis, Susa Niiranen et al. "Biological ensemble modeling to evaluate potential futures of living marine resources." Ecological applications 23, no. 4 (2013): 742-754.

Svedäng, Henrik, and Sara Hornborg. "Historic changes in length distributions of three Baltic cod (*Gadus morhua*) stocks: Evidence of growth retardation." Ecology and evolution 7, no. 16 (2017): 6089-6102.

7.2 Review 2 by Michele Casini, Swedish University of Agricultural Sciences

Date: 12 June 2019

Technical Minutes

Review of ICES working paper "Effects of fisheries and ecosystem impact on commercial fish stocks in the Baltic Sea" to support Advice on EU Special Request on "Report on the implementation of the Baltic Sea Multiannual Plan"

Introduction

The reformed CFP relies for its implementation notably on sea-basin related multiannual plans. The implementation started with the fishing opportunities for 2017. The Commission has to report to the European Parliament and the Council on the results and impact of the plan's implementation on the relevant stocks and fisheries, in particular as regards the achievement of the Plan's objectives.

In order to support the Commission in the preparation of the report, ICES is requested to give advice on the following questions:

1. What are the effects of fisheries on the ecosystem in the Baltic?
2. What factors other than fisheries are affecting the stocks? To the extent it is possible to provide (elements of) a reply, what is their (relative) contribution to the overall mortality rate?

General Comments

The question 1 concerns the effect of the fisheries on the Baltic ecosystem, however the working document lists and characterize the different potential sources of the (direct) fisheries impact, but does not present the indirect effects.

Regarding the question 2, the Working document presents a summary of factors, other that fisheries, affecting the stocks, but some additional information could be given to make the message clearer and some additional factors can be added. Also, the Working document do not try to quantify the relative contribution of the factors to the total mortality rate as instead requested, but in literature there are estimations (even if preliminary) that can be presented.

Specific suggestions

Question 1

Concerning question 1, the indirect effects on the ecosystem of fishing on the respective target stocks should be presented.

I would present the literature on trophic cascades, and therefore the indirect effects of fishing at the apex of the foodweb (i.e. fishing on cod) on cod prey (sprat and herring) and further down the foodweb (zooplankton and phytoplankton). Papers by Casini (e.g. Casini *et al.*, 2008) and Möllmann *et al.* (2008) can be used for example.

Beside the points and literature suggested above, the Working paper can also consider the notes presented at the European Parliament in 2011 and the corresponding reports (Casini, 2011; Eriksson, 2011) where the effects, other than fisheries, on the main Baltic stocks and the direct and indirect effect of fishing on the Baltic ecosystem, have been reviewed.

In the "Discards" section I would provide the survival rate estimates available, even if not certain.

Question 2

The Working paper should be clearer about the mechanisms linking the presented stressors and the response of the stocks. For example, an increase in anoxic areas was presented (and I agree it is a very important factor affecting many organisms in the Baltic Sea) but its effect on the stocks was not clearly presented. Here I would mention the contraction (also towards more shallow areas) of demersal fish, cod and flounder, for example (Orio *et al.*, 2019).

I would also be clearer about the other factors in general, for example what RV (reproductive volume) is and how it affects the stocks (cod) should be made clearer. Much of the evidence of the effects of the different factors on the stocks are in shown in Figure 4.2 but I think it could be useful to spell the main messages out in the text.

In the section about "Species interactions" I would also add the potential cod-flounder interaction. The increased flounder stocks could have been due to a decline in large cod (since large cod, as there were in the past, feed on flounder) and nowadays the large flounder stocks might hinder cod recovery by competition for benthos. Another option is to insert the cod-flounder interaction at the end as done for the Round goby.

In the same section "Species interactions" I would not exclude the potential advantage for cod to have more pelagic prey, since we know that also large cod, which can feed on sprat (and herring), is also very slender. Actually the larger the cod is, the slender it has become since the mid-1990s.

The sentence "Differences in the distributions of cod and herring and sprat imply that an increase in eastern cod landings will not necessarily result in a major increase in herring and sprat stock sizes (and hence catching opportunities." is wrong somewhere. Maybe it meant "Differences in the distributions of cod and herring and sprat imply that an increase in eastern cod landings will not necessarily result in a major decrease in herring and sprat stock sizes (and hence catching opportunities."

I would add a part explaining the decline in cod condition and the estimates done to try quantify the mortality associated to this decline (Casini *et al.*, 2016). Also, there are estimates of mortality due to parasite infestations (Horbowy *et al.*, 2016) that can be also added to address Question 2. I also wonder if there are some seal predation mortalities estimates to be added (maybe also from models as Ecopath). Some of this literature, and additional information about sources of mortality for cod, has been also reviewed in WKBEBCA (ICES 2017) and WKIDEBCA (ICES 2018).

Beside the points and literature suggested above, the Working paper can also consider the notes presented at the European Parliament in 2011 and the corresponding reports (Casini, 2011; Eriksson, 2011) where the effects, other than fisheries, on the main Baltic stocks and the direct and indirect effect of fishing on the Baltic ecosystem, have been reviewed.

References

Casini, M. (2011). Ecosystem shifts in the Baltic Sea. In "Regime shifts in marine ecosystems: how overfishing can provoke sudden ecosystem changes". Directorate General for Internal Policies. Policy Department B: structural and cohesion policies, European Parliament. PE 474.557. doi: 10.2861/52551.

Casini, M., Eero, M., Carlshamre, S. and Lövgren, J. (2016). Using alternative biological information in stock assessment: condition-corrected natural mortality of Eastern Baltic cod. ICES Journal of Marine Science, 73: 2625-2631.

Casini, M., Lövgren, J., Hjelm, J., Cardinale, M., Molinero, J.C. and Kornilovs, G. (2008). Multi-level trophic cascades in a heavily exploited open marine ecosystem. Proceedings of the Royal Society B, Biological Sciences, 275: 1793-1801.

Eriksson, B.K. (2011). Does overfishing promote algal blooms? Directorate General for Internal Policies. Policy Department B: structural and cohesion policies, European Parliament. PE 474.461. doi: 10.2861/57083.

Horbowy, J., Podolska, M., Nadolna-Ałtyn, K. (2016). Increasing occurrence of anisakid nematodes in the liver of cod (Gadus morhua) from the Baltic Sea: Does infection affect the condition and mortality of fish? Fisheries Research 179 (2016) 98–103.

ICES (2017). Report of the Workshop on Biological Input to Eastern Baltic Cod Assessment (WKBEBCA), 1–2 March 2017, Gothenburg, Sweden. ICES CM 2017/SSGEPD:19. 40 pp.

ICES (2018). Report of the Workshop on Evaluation of Input data to Eastern Baltic Cod Assessment, 23–25 January 2018, ICES HQ, Copenhagen. ICES CM 2018/ACOM:36 pp.68.

Möllmann, C., Muller-Karulis, B., Kornilovs, G., and St John, M. A. (2008). Effects of climate and overfishing on zooplankton dynamics and ecosystem structure: regime shifts, trophic cascade, and feeback loops in a simple ecosystem. ICES Journal of Marine Science, 65: 302–310.

Orio, A., Bergström, U., Florin, A.-B., Lehmann, A., Šics, I. and Casini, M. (2019). Spatial contraction of demersal fish populations in a large marine ecosystem. Journal of Biogeography, 46: 633-645.

8 Author's comments to review points

Both reviews are very constructive and I cannot see any point where I would strongly object. With the time given I tried to accommodate as many reviewer comments as possible. It has, however, been impossible to update the presented time-series, or to expand to the whole ecosystem-management, although I consider these issues relevant.

Review	Comment
There are number of points missing in terms of fisheries impact and effect on Baltic ecosystem what cannot be neglected even if the data and knowledge are limited: Selective extraction of fish due to selective gears (cause the changes in population structure) see Svedang and Hornborg 2017 Ghost nests and lost fishing gears, Spatial distribution of pelagic fisheries (catches and effort) and effect of clupeids catches effecting Eastern Baltic Cod stock food availability.	The first two points are now added in the supplementary paragraph' indirect effects of fishing on the ecosystem'. The last point is addressed under 'Potential advantages for cod to have more pelagic prey'
Author pointing the right factors and processes as i) abiotic factors (as Oxygen, salinity, temperature, reproductive volume etc.) for main commercial fish species (cod, sprat and herring, salmon), ii) changes in spatial distribution, iii) species interactions, iv) decreasing feeding opportunities for small cod, v) the invasive Round Goby, and summarize them well. However, **effect** could be better described and highlighted. My suggestion for improvement are: in point i) abiotic factors data should be up to date, since document will act to support advice on future MAP, at point ii) changes in spatial distribution visualization - would be a good add (together with mapped pelagic fleet fishing effort), at iii) describe foodweb as a whole not only main commercial species interactions include also lower trophic level and potential cod food availability affected by pelagic fisheries in the southern Baltic Sea.	These comment are highly useful and I support to update the time-series regularly. It is, however, impossible for me due to time constraints to do this in the frame of this working paper.
Despite that section is a synthesis of factors affecting only fish stocks, there are missing quantification of productivity/mortality and relative contribution to the overall mortality rate what was specifically asked in the request. Number of modelling work (also at ICES framework e.g. WGSAM key runs with predation pressure quantification) has been done regarding that issue, addressing relevant questions: Costalago *et al.* 2019; Bauer *et al.,* 2019; Bauer *et al.,* 2018; Horbowy *et al.,* 2016; Hansson *et al.,* 2017; Gårdmark *et al.,* 2013.	The multispecies model generating predation mortality rates are mentioned in the original working document. I added a paragraph on 'Quantifying natural mortality rates of cod', elaborating on the probably, yet unquantified, increase in natural mortality due to starvation. The Costalago *et al.* paper does not use seal diet data from an area where cod are abundant. The lack of overlap between input data and model domain makes it difficult to interpret the output. Hence, seal induced mortality estimates are, in my opinion, currently not suited to be applied in a management context. Please note also, that Horbowy *et al.* 2016 is not giving an indication for the impact of parasite infection on cod mortality. It is still unclear, if the low condition is a consequence of parasite infection, or if it actually is the other way around.
Aspects of the climate change, nutrients management and human perspective in the long-term run are also missing. If that working document needs to support advice drafting on new	This is probably beyond the scope of this request that explicitly addresses effect of fisheries on the ecosystem and vice versa. However, especially the role of

Review	Comment
Multi Annual Management Plan for Baltic fish stocks document need to cover also those aspects. If advice will cover more then only fishing opportunities effect and harvest control rules than working document should contain also exploratory scenarios of ecosystem development under cumulative pressures with highlighted role and effect on/of fisheries i.e. Bauer *et al.,* 2018.	nutrients in the Baltic Sea should be seen in tight connection to hypoxia (mentioned in the additional paragraph 'Abiotic forcing on recruitment'). I support this comment.
Concerning question 1, the indirect effects on the ecosystem of fishing on the respective target stocks should be presented. I would present the literature on trophic cascades, and therefore the indirect effects of fishing at the apex of the foodweb (i.e. fishing on cod) on cod prey (sprat and herring) and further down the foodweb (zooplankton and phytoplankton). Papers by Casini (e.g. Casini *et al.,* 2008) and Möllmann *et al.* (2008) can be used for example. Beside the points and literature suggested above, the Working paper can also consider the notes presented at the European Parliament in 2011 and the corresponding reports (Casini, 2011; Eriksson, 2011) where the effects, other than fisheries, on the main Baltic stocks and the direct and indirect effect of fishing on the Baltic ecosystem, have been reviewed.	I added an additional paragraph on 'Indirect effects of fishing on the ecosystem' that contains these and reviewer 1's comments.
In the "Discards" section I would provide the survival rate estimates available, even if not certain.	I added information on survival rate estimates in the section on 'Indirect effects of fishing on the ecosystem'.
The Working paper should be more clear about the mechanisms linking the presented stressors and the response of the stocks. For example, an increase in anoxic areas was presented (and I agree it is a very important factor affecting many organisms in the Baltic Sea) but its effect on the stocks was not clearly presented. Here I would mention the contraction (also towards more shallow areas) of demersal fish, cod and flounder, for example (Orio *et al.,* 2019).	I added an additional paragraph on 'Contraction of demersal fish stocks' spatial distribution towards more shallow areas'
I would also be clearer about the other factors in general, for example what RV (reproductive volume) is and how it affects the stocks (cod) should be made clearer. Much of the evidence of the effects of the different factors on the stocks are in shown in Figure 4.2 but I think it could be useful to spell the main messages out in the text.	I added a paragraph on 'Abiotic forcing on recruitment'
In the section about "Species interactions" I would also add the potential cod-flounder interaction. The increased flounder stocks could have been due to a decline in large cod (since large cod, as there were in the past, feed on flounder) and nowadays the large flounder stocks might hinder cod recovery by competition for benthos. Another option is to insert the cod-flounder interaction at the end as done for the Round goby.	I added a paragraph on cod-flounder interactions.
In the same section "Species interactions" I would not exclude the potential advantage for cod to have more pelagic prey, since we know that also large cod, which can feed on sprat (and herring), is also very slender. Actually the larger the cod is, the slender it has become since the mid-1990s.	I discussed 'Potential advantages for cod to have more pelagic prey' in a new separate paragraph.
The sentence "Differences in the distributions of cod and herring and sprat imply that an increase in eastern cod landings will not necessarily result in a major increase in herring and sprat stock sizes (and hence catching opportunities." is wrong	The sentence is actually meant the way it stands in the document. The idea is: Catching more cod will not

Review	Comment
somewhere. Maybe it meant "Differences in the distributions of cod and herring and sprat imply that an increase in eastern cod landings will not necessarily result in a major <u>decrease</u> in herring and sprat stock sizes (and hence catching opportunities."	release herring and sprat from cod predation, because their overlap is limited.
I would add a part explaining the decline in cod condition and the estimates done to try quantify the mortality associated to this decline (Casini *et al.*, 2016). Also, there are estimates of mortality due to parasite infestations (Horbowy *et al.,* 2016) that can be also added to address Question 2. I also wonder if there are some seal predation mortalities estimates to be added (maybe also from models as Ecopath). Some of this literature, and additional information about sources of mortality for cod, has been also reviewed in WKBEBCA (ICES 2017) and WKIDEBCA (ICES 2018).	I added a paragraph on 'Quantifying natural mortality rates of cod, herring and sprat'. Horbowy et al. write "The increasing discrepancy between the expected intensity according to des Clers' model (or any model exhibiting an increase in intensity with length) and the intensity observed or modelled using the GLMs may approximately reflect an increase in the natural mortality of infected fish. However, how this discrepancy can be transferred into estimates of natural mortality is not clear." As mentioned above, predation of cod on seal from the Ecopath is not reliable in a management context (this is just my opinion), because the seal diet data do not fit the model domain.
Beside the points and literature suggested above, the Working paper can also consider the notes presented at the European Parliament in 2011 and the corresponding reports (Casini, 2011; Eriksson, 2011) where the effects, other than fisheries, on the main Baltic stocks and the direct and indirect effect of fishing on the Baltic ecosystem, have been reviewed.	The notes have been considered and are used in the new supplementary paragraphs.

9 Added sections after the review

9.1 Indirect effects of fishing on the ecosystem

Fishing gears abandoned or lost at sea are an unsolved and “silent” problem. It continuously catches fish, birds and marine mammals for many years at the seabed causing degradation of the marine environment. In the framework of the pilot project carried out by WWF Poland with the support of BalticSea2020 in 2011, it was estimated that each year approximately 10 thousand of nets are lost or abandoned in the Baltic Sea. In addition, approximately 450 tonnes of fishing nets are entangled on ship wrecks in the Polish Economic Zone. Research has also proved that the fishing pressure exerted by lost nets could ranges from 20% of the usual net capacity after three months, up to 6% after 27 months. Because they do not readily degrade, ghost nets continue to trap and kill marine life, including fish, birds and sea mammals until they are removed from the sea.

Although there is a landing obligation in the Baltic Sea from 2015, discards were still estimated to occur, based on-board sampling by most countries. The total discards for Eastern Baltic cod, for example, in 2018, in subdivision 25-32, were estimated to 3103 t (not including any BMS landings), which constituted 16% of the total catch in weight. This was an increase from 11% in 2017 and the highest discard rate since the introduction of the landing obligation. 91% of the estimated discards in weight was caught by active gears. Mortality due to discarding cannot be quantified, but has to be considered substantial. This mortality is, though, included in the fishing mortality rates estimated, because the discards are included in the landing figures that form the basis for the stock assessment. However, any discarding not accounted in the landing figure, as for example in other fisheries, might be a significant source of fisheries induced mortality.

Eastern and Western Baltic cod have gone toward more truncated size structures between 1991 and 2016, in particular for the Eastern Baltic cod, whereas the Öresund cod show no trend. Size-selective fishing may disrupt fish population dynamic stability and lower natural productivity might amplify the effects of selective fishing.

Fisheries have a large impact on the upper trophic levels of the Baltic ecosystems. This impact has been shown to cascade down the foodweb. A four-level community-wide trophic cascade exists in the open Baltic Sea. The reduction of the cod (*Gadus morhua*) population directly affected its main prey, the zooplanktivorous sprat (*Sprattus sprattus*), and indirectly the summer biomass of zooplankton and phytoplankton (top–down processes). Bottom–up processes and climate–hydrological forces had a weaker influence on sprat and zooplankton, whereas phytoplankton variation could be explained solely by top–down mechanisms. Hence, in order to e.g. dampen the occasionally harmful algal blooms of the Baltic, effort should be addressed not only to control anthropogenic nutrient inputs but also to preserve structure and functioning of higher trophic levels.

9.2 Contraction of demersal fish stocks’ spatial distribution towards more shallow areas

Large changes in the spatial and depth distribution of cod and flounder in the Baltic Sea have occurred in the last four decades. From the late 1980s the mean depth of both adult cod and flounder distributions has decreased, while that of juvenile cod has increased, and that the depth ranges have contracted, probably due to a combination of hypoxia in deep waters and increase in predation risk in shallow waters. The net effect of these changes is that adult cod, juvenile cod and flounder overlap more, which may increase the intra- and interspecific interactions. This information is highly relevant both for marine spatial planning and for EBFM as it can be implemented, for example, in spatially explicit stock assessment or multispecies models.

9.3 Abiotic forcing on recruitment

The ecosystem changes in the Baltic Sea are synthesized by the ICES WGIAB (2008 and subsequent reports) in Integrated Ecosystem Assessments (IEA) conducted for seven subregions of the Baltic Sea: i) the Sound (ÖS), ii) the Central Baltic Sea (CBS), encompassing the three deep basins, Bornholm Basin, Gdańsk Deep and Gotland Basin; iii) the Gulf of Riga (GoR), iv) the Gulf of Finland (GoF), v) the Bothnian Sea (BoS), vi) the Bothnian Bay (BOB) and a coastal site in the southwestern Baltic Sea (COAST). The updated IEA (ICES WGIAB, 2015) corroborated the correlation between temperature and salinity, and included 2014 values for the abiotic factors being tracked.

The main drivers of the observed ecosystem changes vary somewhat between subregions, but they all include the increasing temperature and decreasing salinity. These are influenced by large-scale atmospheric processes illustrated by the Baltic Sea Index (BSI), a regional calibration of the North Atlantic Oscillation index (NAO). The change from a generally negative to a positive index for both BSI and NAO in the late eighties was associated with more frequent westerly winds, warmer winter and eventually a warmer climate over the area. Further, the absence of major inflow events has been hypothesized to be related to the high NAO period. An indication of this is that only two major inflows to the Baltic Sea have been recorded during the high BSI-period since the late 1980s. Contrary to what occurred in surface waters, salinity in deeper waters has increased after the early 1990s to levels as high as in 1960s–1970s.

The suggested driving forces of the observed regime shift in all subregions, decreasing salinity and increasing temperature, are both consequences of climate change.

A particular feature of the Baltic Sea since the mid-1990s has been a drastic increase in the extent of anoxic and hypoxic areas, likely due to lack of strong water inflows from the North Sea and potentially increased biological oxygen consumption on seafloor

The environmental impacts on cod, herring and sprat recruitment have to be seen in this context. Cod eggs are fertilized at salinities >11 and the eggs die at oxygen concentrations <2 ml/l. The water volume that consists of a water with salinity >11 and oxygen >2 ml/l is called the reproductive volume. The fraction of the total eggs produced that survives until the larval stage has been shown to depend on the size of the reproductive volume.

Recruitment patterns of Baltic Sea sprat (*Sprattus sprattus*) were correlated to time-series of (*i*) month- and depth-specific temperature conditions and (*ii*) larval drift patterns inferred from long-term Lagrangian particle simulations. From the latter, an index was derived that likely reflected the variable degree of annual larval transport from the central, deep spawning basins to the shallow coastal areas of the Baltic Sea. The drift index was significantly ($P < 0.001$) correlated to sprat recruitment success and explained, together with sprat spawning-stock biomass, 82% of the overall variability between 1979 and 2003. Years of strong larval displacement towards southern and eastern Baltic coasts corresponded to relative recruitment failure, while years of retention within the deep basins were associated with relative recruitment success. The strongest correlation between temperature and recruitment occurred during August in surface waters, explaining 73% of the overall variability.

The relationship between herring recruitment and single parameters such as temperature or salinity is not so clear.

9.4 Cod-flounder interactions

During recent years, the flounder stocks have increased simultaneously with the decrease of the cod stock. The increase in flounder might at least partially have happened due to the release from cod predation, as especially large cod are almost absent these days. Flounder is currently not included in the multispecies models for the Baltic Sea. Therefore, there are no estimates of predation mortality rates available.

9.5 Potential advantages for cod to have more pelagic prey

Cod have potentially an advantage in having have more pelagic prey in the regions where cod occur. Also large cod, which can feed on sprat (and herring), is also very slender. Actually the larger the cod is, the more slender it has become since the mid-1990s.

9.6 Quantifying natural mortality rates of cod

Natural mortality values adjusted for low cod condition were up to 40% different compared with the assessment assuming a constant M = 0.2. These estimates could be used in combination with other estimations of additional mortality (such as seal predation and parasite infection), which are expected to be available in due course, to adjust the natural mortalities used in analytical stock assessment.