*Annex to - Climate change and the Common Fisheries Policy: adaptation and building resilience to the effects of climate change on fisheries and reducing emissions of greenhouse gases from fishing*

**Baltic Sea case study with the DISPLACE spatial fisheries model**

*Defining plausible, ecosystem-coherent shock scenarios*

We defined three environmental scenarios for the Baltic Sea region (current conditions, most likely conditions and worst-case scenario). These scenarios correspond to particular climatic paths, respectively no further change in the climate, intermediate IPCC scenario (RCP4.5), and one pessimistic IPCC scenario (RCP8.5). Each of these climatic scenarios leads to a series of environmental changes that would affect the individual physiology of the animals impacted and the phenology of the species. In this study, we did not relate the biological impact of these changes on the different stocks considered in a quantitative way due to a lack of empirical observations relating causal changes to an effect. Information from the literature review has instead been used to assume the nature and direction of the impact of these environmental changes on different stocks. The intensity of this biological response further depends on the scenario (Table 1). Scenarios recognize that life-history parameters are correlated, e.g. faster-growing individuals may mature smaller and be subject to higher natural mortality.

For each scenario and long-term environmental changes, assumptions are made on short-term stresses and their impacts on the biology of the stocks. The intensity and frequency of these shocks would ideally vary between the three scenarios, however. The first step was to propose plausible, ecosystem-coherent scenarios of biological responses to long-term climate change and short-term stress for the three scenarios.

In the Baltic Sea, the main environmental drivers affected by climate change and affecting the productivity of target and non-target species include increasing temperature and decreasing salinity as synthesized by the ICES WGIAB in Integrated Ecosystem Assessments (IEA) in the sub-regions of the Baltic Sea. The decrease in salinity is however less certain because more frequent influxes of saline waters from the North Sea into the Baltic Sea might counteract it. Besides this, oxygenation is likely an essential component of the conjugated effects. For example, stormy weather may decide on, e.g. the reproductive volume of cod, therefore, the strength of the incoming year classes. In addition to the fact that fishing pressure is an essential driver per se of the marine population dynamics, it is also seen as a factor creating possible trophic cascades. If the effects of fishing could be smoothed up to a certain point by compensatory effects into the food web, tipping point might also be reached. These abrupt cascading effects could ultimately stabilize the Baltic Sea marine ecosystem toward alternative regimes of relative species biomasses and productivity.

To this aim, we have run a simulation study for using a calibrated DISPLACE model application (calibrated to 2019) for the Baltic Sea system. This includes the interactions among cod, sprat and herring, flatfish, and the different national fleets at the Baltic Sea wide scale, up to the 2030 horizon.

Compared to a baseline run, scenarios are a combination of mild long term change on productivity, i.e. changing recruits and growth parameters (RCP 4.5), severe change (RCP 8.5), short term shock (i.e. massive background mortality event on the first y), a spatial range contraction, and fishing mortality (F) at FMSY or FMSY\_lower. Again, the weak point in this study will be that the effect sizes of the plausible scenarios changes are pretty arbitrary in a lack of proper empirical observations, making the lessons learnt from the simulations more qualitative than quantitative. Nevertheless, the scenario translated into changed parameters for stock productivity i.e. SSB-recruits relationships and growth (Figure 1).

The tested change would capture the long term changes in biological functions (recruitment, growth, maturation, natural mortality, reflecting possible correlations between traits), as well as long term changes in the spatial distribution.

There were no biological scenario implemented on flatfish. Hence the change in simulation outcomes on these species will be the result of changing fishing patterns only.

*Table 1. A suite of “what if” scenarios affecting the stock productivity and spatial distributions of main Baltic Stocks tested with DISPLACE. No environmental forcing is implemented in the model (… in the absence of proper proportional relationships). Tested impact with multipliers on input parameters. SSB-R stands for Spawning stock biomass-Recruits relationships deduced from the Ricker function with the two parameters alpha and beta. VBGF stands for Von Bertalanffy Growth Function with the two parameters Linf and K. M stands for natural mortality.*

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Scenarios | Species | Drivers | Multi on SSB-R Ricker alpha | Multi on SSB-R Ricker Recru beta | Multi on VBGF  Linf | Multi on VB GF K | Absolute FMSY | Massive M at y=0 | Vessel stops if choked | Spatial Range contraction |
| Baseline (i.e. FMSY) | Cod, Herring, Sprat | Productivity change | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| Mild change | Cod, Herring1 | Productivity change | 1 | 1.1 | 0.9 | 1.5 | 1 | 0 | 1 | 0 |
|  | Sprat2 |  | 1.1 | 1.0 | 0.9 | 1.5 | 1 | 0 | 1 | 0 |
| Mild change + FMSY low | Cod, herring | Productivity change | 1 | 1.1 | 0.9 | 1.5 | 1 | 0 | 1 | 0 |
|  | Sprat |  | 1.1 | 1.0 | 0.9 | 1.5 | 1 | 0 | 1 | 0 |
| Severe change | Cod, herring | Productivity change | 0.8 | 1.5 | 0.8 | 1.5 | 1 | 0 | 1 | 0 |
|  | Sprat |  | 1.1 | 1.0 | 0.8 | 1.5 | 1 | 0 | 1 | 0 |
| Severe change + FMSY low | Cod, Herring | Productivity change  + F Management | 0.8 | 1.5 | 0.8 | 1.5 | 1 | 0 | 1 | 0 |
|  | Sprat |  | 1.1 | 1.0 | 0.8 | 1.5 | 1 | 0 | 1 | 0 |
| Severe change + shoke | Cod, Herring | Productivity change | 0.8 | 1.5 | 0.8 | 1.5 | 1 | 20% | 1 | 0 |
|  | Sprat |  | 1.1 | 1.0 | 0.8 | 1.5 | 1 | 20% | 1 | 0 |
| Severe change + FMSY low + shoke | Cod, Herring | Productivity change  + F Management | 0.8 | 1.5 | 0.8 | 1.5 | 1 | 20% | 1 | 0 |
|  | Sprat |  | 1.1 | 1.0 | 0.8 | 1.5 | 1 | 20% | 1 | 0 |
| Spatial range contraction | Cod, Herring, Sprat 3 | Spatial distribution change | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 10% |
| Spatial r. contract.  + FMSY low | Cod, Herring, Sprat | Spatial distribution change + F Management | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 10% |
| FMSY + Effort max | Cod, Herring, Sprat | Continue fishing and discard | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| FMSY low + Effort max | Cod, Herring, Sprat | Continue fishing and discard | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| FMSY + 30% fuel saving when towing nets | trawlers | none | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |

Table footnote: 1increase density-dependent effects, e.g. increase of adverse inter-individual interactions from resource scarcity; 2positive effect of warmer water column temperature on sprat; 3 Process a spatial shift. e.g. a range contraction of 10 % (of each size group of a stock) toward the core area. (see GenerateSpatialShiftForBiolsceStaticAvai.R)

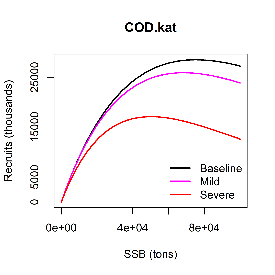
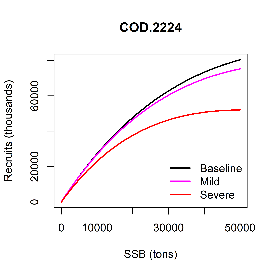
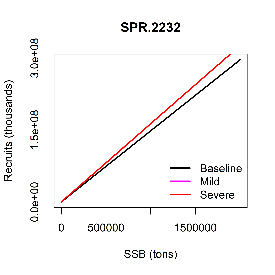
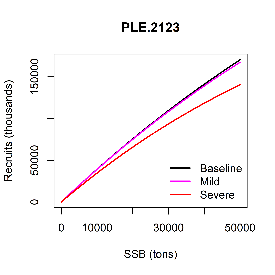
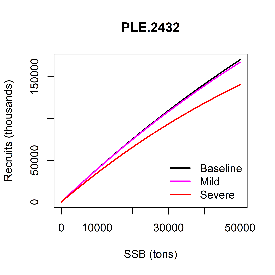
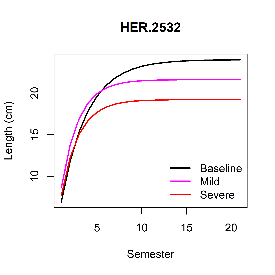
A plausible short term shock induced by climate change could result from the mortality affecting fish and other demersal animals. This may be caused by the combined effects of warmer temperature and water oxygen content. Marine populations are susceptible to low oxygen events that may increase in frequency and severity with the anticipated warming waters. Increased temperature increases metabolism for animals such as fish which require more oxygen consumed, and more detritus that trigger the microbial loop creating hypoxia areas for demersal fish and invertebrates, even more, when the stratification in the water column is increased. Even if fish can escape the unsuitable areas, benthos invertebrate species that are preyed on by fish will not survive, making fish possibly starving from the reduced resource or affecting the growth and reproduction.

In the pelagic system, the primary productivity (phytoplankton) may also reduce drastically by reduced mixing of water layers or short term events. These episodes may induce high mortality anomalies to heavily environmentally-driven recruits such as those of pelagic species.

In the meantime, there are continual directional changes to species distributions that are ongoing in background. Hence, the possible spatial shift of species distribution induced by a changing climate is an additional issue. Hence, Mackenzie et al. (2007) predicted a change in the fish community in terms of biomass and a change in the spatial distribution, for example, due to the contraction of the ranges of marine species. The resource base supporting individual communities could likely be displaced, affecting the economics of fisheries and the communities. Natural geographical boundaries in the Baltic Sea is limiting this northward shift movement in response to changing climate. The Baltic Sea being semi-closed, the finfish and shellfish in the Baltic Sea will more be affected by a contraction of the range of the species distribution toward their core areas, even more when some of these species are already at the edge of their natural distributions dictated by their tolerance range in environmental conditions.

Beside biological scenarios, the modelling platform is capable of assuming different fishermen behavior or other fleet-related effects. Hence we included a scenario related to the decision of individual vessel to not stop fishing even if the quota of the limiting stock is reached (so-called “Effort max” scenario in a mixed fisheries context, see ICES WGMIXFISH). We also included a scenario that assume a hypothetical 30% fuel saving during towing the nets that would arise from designing innovative trawls.

From the simulation outcomes, we expect to calculate a range of metrics to quantify resource (and economic) resilience based on the trends in simulated stock size concerning limit and trigger reference points and the temporal dynamics of these changes.

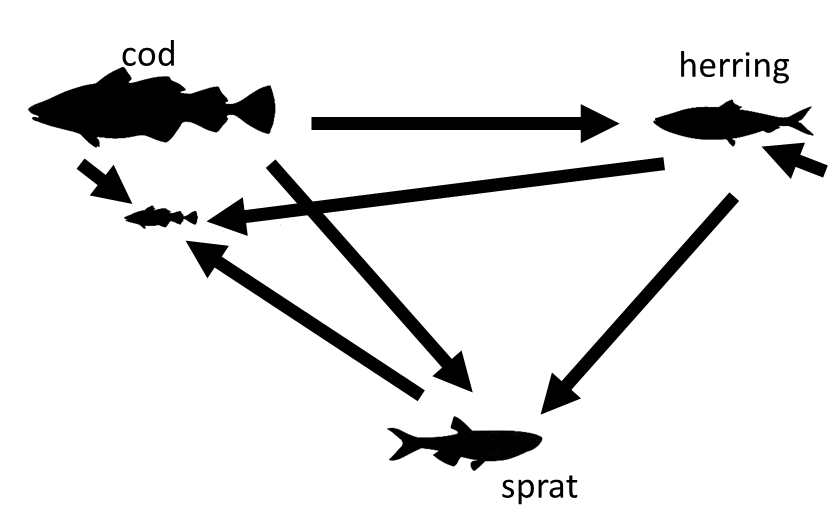
C:\Users\fbas\AppData\Local\Microsoft\Windows\INetCache\Content.Word\VBFC_scenarios_SPR.2232.tiff

*Figure 1. Stock-recruits relationships based on the Ricker model for predicting the number of recruits at y+1 depending on the spawning stock biomass SSB at y. Each Baltic Sea stock assumed affected by the three climate scenarios.*

*Conditioning DISPLACE on the Baltic Sea fish stocks system*

We used the DISPLACE modelling platform (Bastardie et al. 2014) as a comprehensive management strategy evaluation tool to assess how fish stocks and fisheries are affected by different spatial fishery management options under climate change scenarios. The core of DISPLACE is a spatial bio-economic model for simulating the movement of individual fishing vessel agents combined with an underlying spatial population dynamics model. In DISPLACE, individual agents optimize their decision-making on the fly depending on their given catch rates by zones and the expected cost to reach the zone and return to the harbour. Each vessel depletes the target stocks individually, which further depends on the gear type in use.

In the Baltic Sea, fisheries target a relatively small number of species, mostly finfish as cod, herring and sprat, and also flatfish of commercial interest. This study focuses on the most important species and stocks in terms of fisheries resources in the Baltic Sea. Cod, herring, and sprat constitute about 95% of the total commercial catch in terms of catch weight (ICES, 2018). The ICES Baltic Fisheries Assessment Working Group (WGBFAS) focus on assessing 17 stocks that we have integrated into the DISPLACE model. Besides stock number-at-age issued by the last available ICES analytical assessment estimates (2019), we included fish life-history and ontogenetic growth for modelling the different populations with a body size-based model. Processes affecting population dynamics are often size-dependent (such as growth, mortality, maturity, condition, settling, and recruitment). Fishing is also a selective process that applies differently along with animal body size. Hence, the model handles 14 size groups (5 cm length groups) pooled in 3 size categories (small, medium, and large animals) for describing size-specific spatial distributions and marketable categories (Bastardie et al., 2014). From Von Bertalanffy growth parameters (infinite length Linf, the growth rate K and t0 parameters), we generate stock-specific growth transition matrices (GTM) using the Von Bertalanffy growth curve model for simulating individual stochastic growths (see Bastardie et al., 2014). We run the same procedure to also obtain Age-Length Keys ALKs. In order to account for predator-prey trophic interactions between fish species (Figure 2), we informed the DISPLACE size-spectra model (based on Blanchard et al. 2014) with specific growth parameters, Winf as the asymptotic weight in grams and k as the standard metabolism factor in yr-1, and diet preferences (Jacobsen et al., 2014, 2017). The stochastic trajectories modelled in DISPLACE arise from two additional parameters inducing the stochastic trajectories: CV for lognormal error added on recruits is 0.2, and CV for lognormal error added on quarterly-based growth transition matrix is 0.1.



*Figure 2. Trophic interactions implemented in the DISPLACE application with the sizeSpectra module option modelling calculating additional M2 predation, besides the background size-based natural mortality. Cannibalism of juveniles by adult fish is present for cod and herring.*

The baseline scenario has some default DISPLACE options on the fleet dynamics activated: focus\_on\_high\_profit\_grounds, TACs, FMSY, area\_monthly\_closure, discard\_ban, stopGoingFishingOnFirstChokedStock, and on the population dynamics that are: sizeSpectra and stochasticGrowth. Details on biological and fisheries parameters and other input data can be found on the GitHub online repository https://github.com/frabas/DISPLACE\_input\_Baltic21

The simulation study aims at extrapolating the stock trajectories to domains where there is some uncertainty about the central parameter values (i.e. future stock productivity and spatial distribution), and describing possible courses of the system, depending upon a choice of parameter values that are likely to be impacted by the climate change effects. As described by Harfoot et al. (2014[)](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.12482#jpe12482-bib-0058) in Mouquet et al. (2015), these anticipatory predictions are therefore not meant to represent the actual future. The fact that the projection do not match reality does not count against the validity of the underlying hypotheses. Instead, the simulation study should be regarded as a guide for present action.

*DISPLACE Baltic Sea simulation study outcomes*

Most fish stocks projection showed spawning biomass SSB stock increased, and mortality F reduced at the horizon 2030 for the baseline runs applying the current F-MSY strategy to Baltic fisheries (Figure 3). Kattegat cod (COD.kat), Herring (HER.2532), Sprat (SPR.2232) are the exception and showed declining/collapse trends in SSB and increased in F compared to the reference points and initial states, and plaice (PLE.21.23) a marked increase in F (Figure 3).

There is, however, substantial uncertainty in the future status of cod stocks both in Kattegat and Western Baltic. For both stocks, the beforehand calibration of the final runs led to affect weight at age with a factor of 30 the COD.KAT and 5 the COD2224 for obtaining similar simulated levels of historical assessed SSBs and Fs by ICES. Such calibration is a sign of imperfect knowledge on these two stocks regarding either L50 Maturity, weight-at-age or estimated N-at age, or a mixture of all these population features in the meantime. Extra caution should also be paid to the COD 2224 status since we observed this stock could collapse in the simulations when an East to West migration of adults is implemented. Migration is a factor known to currently affect the perceived status of the west cod stock (Hussy et al. 2016, Bastardie et al. 2017), affecting the accuracy of catch limits to be advised (also due to averaging the weight at age in West between East and West) putting the stock at high risk of collapse when repeated imbalanced TACs are advised in the management procedure. Besides this, in the simulations the western herring stock HER.3a22 reached possibly unrealistic biomass level (up to 40 times the initial levels).

Regardless of these uncertainties, applying different F-strategies facing climate change long term effects or episodic stress, the simulation study anticipates that the regional response to applying FMSY-lower make little difference and is not beneficial for all stocks to ensure a level above the reference points at the horizon 2030. In case the F-MSY-lower strategy is followed, this will be sufficient to counteract the effect of climate change for SPR.2232 (at RCP4.5 level), but is not robust for east cod COD.2532, and does not help for declining herring HER.2232 and collapsing cod COD.KAT (Figure 3). In addition to this, such climate-induced change could worsen the declining status of SPR.2232 (Figure 3).

The response of the stock status to a range contraction of cod, sprat and herring population spatial distribution affected positively the COD.2532, is beneficial to herring and plaice stocks, and minimize the reduction of SPR.2232 (Figure 3). This is likely due to reduced access to the productive fishing grounds that become out of the range of the smaller coastal vessels with lower mobility capability (usually using passive gears). This led to recovery and a possible future under exploitation of the Baltic herring stocks. In addition to this, because the degree of overlap will change, the likelihood that the predator-prey relationships in the ecosystem would be altered is high under a scenario of range contraction, also diminishing the predation of cod on herring and sprat.

Applying the FMSY-lower strategy to all stocks simultaneously is beneficial on the fleet indicators leading to a more than 10% increase in income for bottom-contacting gears that comes with more energy-efficient fisheries (+5%, Figure 4). This is mainly the result of the demersal trawling fleets not choked on the North Sea and Baltic Sea cod stocks. The same effort is applied at sea from a similar number of trips, but each of them may have higher catch rates when the resource levels is better aligned with the TACs. Indeed if TACs are not limiting landings are strongly increased. Greater short-term opportunities on flatfish stocks induce slightly more revenue for vessels using passive gears as well.

Long-term climate-induced effects on the environmental drivers led to an even larger fleet revenue (NPV ca. >20%) and energy efficiency (ca. >10%), from higher landings on Baltic cod seeing its overall abundance decreasing. Lower anticipated landings on the Baltic herring stocks, sprat and plaice is not counteracting this outcome at this fleet aggregation level (Figure 4).

The possible appearance of a shock on top of the long term climate effect of RCP8.5 background change is actually adversely impacting the fleet income and the energy efficiency, unless the FMSY-lower strategy applied, in this case correcting for the loss of opportunity induced by the shock (especially on Baltic and North Sea cod) and by decreased catch rates if long term change applied (Figure 4).

In case of a spatial range contraction, the economic income and energy efficiency is strongly affected with a loss by more than 20%. This is the result of limiting landings realized on COD.2224, COD.2532, and flatfish for passive gears, and HER.3a22 and HER.2532 for active gears (Figure 4).



*Figure 3. A bi-dimensional plot of average scenario outcomes on F/FMSY and SSB/SSBtrigger as simulated temporal trajectories from 2020 to horizon 2030. The wished green corner for the yearly drift of the indicators is the top left (i.e. increase in SSB, reduction in F, compared to initial values).*

**

**

*Figure 4. Fleet indicators integrating the differences to baseline (i.e. the FMSY-strategy alone) over the entire simulation period for selected scenarios. Indicators: Fishing Effort, Steaming Effort, Swept Area, Number of Trips, Trip duration, CPUE at fishing, Landed kg, Net Present Value (NPV), Value Per Unit of Effort (VPUF), and income inequality.*



*Figure 5. Simulated accumulated contribution margin (in millions euros, firsty removed) over the 10y for selected scenarios.*



*Figure 6. Monthly gross added value (GVA) calculated as a monthly average per vessel from all vessels fishing in the Baltic Sea combined for a selection of scenarios.*



*Figure 7. Monthly Value Per Unit Fuel (VPUF) as a proxy for energy efficiency calculated as a monthly average per vessel from all vessels fishing in the Baltic Sea combined for a selection of scenarios.*





*Figure 8. Monthly gross added value (GVA) calculated as a monthly average per vessel from all vessels fishing in the Baltic Sea combined for a selection of scenarios comparing compliance to the Landing Obligation (i.e. default is “stop fishing if choked”) to non-compliance (continue fishing and discard i.e. “effort max.” scenarios).*





*Figure 9. Monthly Value Per Unit Fuel (VPUF) calculated as a monthly average per vessel from all vessels fishing in the Baltic Sea combined for a selection of scenarios comparing compliance to the Landing Obligation (i.e. default is “stop fishing if choked”) to non-compliance (continue fishing and discard, i.e. “effort max.” scenarios).*





*Figure 10. Monthly gross added value (GVA) calculated as a monthly average per vessel from all vessels fishing in the Baltic Sea combined for a selection of scenarios comparing FMSY vs FMSYlower in a situation or the absence of climate change.*





*Figure 11. Monthly Value Per Unit Fuel (VPUF) calculated as a monthly average per vessel from all vessels fishing in the Baltic Sea combined for a selection of scenarios comparing FMSY vs FMSYlower in a situation or the absence of climate change.*

*Overall effect*

At the entire Baltic basin scale, the overall economic return appears to be beneficial in the long run with the F-MSY strategy and opportunities are gained when applying a systematic FMSY-low strategy (Figures 5 and 6). The FMSY-low strategy is not limiting the fisheries even in a situation of increasing stocks, and because of increasing stocks. The energy efficiency is also stable over the long run at the Baltic wide scale (Figure 7). The climate change is in overall positively affecting the anticipated revenue and the F-MSY-low strategy is enable to counteract the loss on some stocks. Unexpectedly, simulations shows that a shock may also slightly improve the anticipated revenue by stimulating the stock productivity (i.e. counteracting the density dependence effects). This except if the climate-induced change on the harvested stocks translates into a contraction of the stock distribution. In this latter case, the gross value added becomes negative due to fixed and variable costs exceeding landings incomes and other revenues (Figure 6). The energy efficiency is also severely affected by longer trip duration and lower catch rates. This is likely the result of some part of the stocks becoming out of range of small coastal fisheries. Besides this, non-compliance to the LO increases energy efficiency (Figure 9), but with dramatic consequences on the GVA (Figure 8) from the underlying long-term stock declining developments (results not shown). FMSY-strategy is also more rewarding for the fleet economy than FMSY-lower (Figures 10 and 11).

Following the F-MSY-lower strategy is likely to increase the catches made by fleets fishing upon the central part of the Baltic Sea for cod fish (Figure 14, spatial distribution of catches). The effect of climate is to reduce these increased opportunities. However, when using lower FMSYs could have shocked the Baltic cod, sprat and herring fleets, the benefit on recovering populations might have been counteracted with the negative long term climate trend effect redirecting the pressure on eastern cod. The range contraction significantly reduces the spatial extent of the fishing ground but increases the fishing opportunities on the core areas, even if mostly farther from the coastline.



*Figure 14. Simulated average spatial distribution of catches at the 2030 horizon time for the baseline scenario in (a) (applying the FMSY strategy), and relative to the baseline for a selection of scenarios (b) to (e).*

*Fleet-specific effects*

However, climate change will likely reduce the benefits from lower yield in future for particular national fleets (Figure 12). It is apparent that none of the national fleets except the Danish fleet will benefit for the climate change and some shock events, especially because the pathways under the baseline F-MSY strategy are on declining trends. Besides this, none of the fleets might gain from a spatial range contraction, likely from a redistribution of resources spatially that make part of it inaccessible.



*Figure 12. A bi-dimensional plot of average scenario outcomes on country-based ratios of VPUF/VPUFi and GVA/GVAi as simulated temporal trajectories from 2020 to horizon 2030. Countries are den: Denmark, swe: Sweden, deu: Germany, pol: Poland, est: Estonia, lva: Latvia, ltu: Lithuania, fin: Finland. The ratio at 1 on both indicators (symbol ‘+’) gives the initial estimates in 2020—the wished green corner for the drift of the indicators in the top right.*

The climate change-induced effects on the fleet economy in the Baltic Sea is also likely dependent upon the types of fishing methods (Figure 13). Passive gears (GNS) lose in all scenarios. Pelagic OTM and PTM will also lose in GVA along with a gain in energy efficiency for PTM. On the contrary, SDN and OTB showed a marked improvement of both GVA and energy efficiency following the FMSY strategies but downplayed by the climate-induced effects. PTB will gain on GVA but lose on energy efficiency.



*Figure 13. A bi-dimensional plot of average scenario outcomes on metier-based ratios of VPUF/VPUFi and GVA/GVAi as simulated temporal trajectories from 2020 to horizon 2030. Metiers/gear used are 3: GNS, 10: OTB, 11: OTM, 14: PTB, 15: PTM, 17: SDN. The wished green corner for the drift of the indicators in the top right.*

*More efficient fuel use effects*

Unexpectedly, vessels saving fuel when towing (e.g. from limiting the hydrodynamic drag required to tow the gear in contact with the bottom, or assuming less fuel intense gear specification for pelagics) did not lead to better development of anticipated revenue from fishing (Figure xx).





*Figure xx. Monthly gross added value (GVA) calculated as a monthly average per vessel from all vessels fishing in the Baltic Sea combined for a selection of scenarios comparing FMSY vs FMSYlower in a situation or the absence of climate change.*



*Figure xx. A bi-dimensional plot of average scenario outcomes on F/FMSY and SSB/SSBtrigger as simulated temporal trajectories from 2020 to horizon 2030. The wished green corner for the yearly drift of the indicators is the top left (i.e. increase in SSB, reduction in F, compared to initial values).*

*Concluding remarks*

**All the plots can be retrieved from a R Shiny app online**

**The recommendation for managers:**

**1. Target/optimisation is no use. Think about minimizing the impacts of fisheries as the CFP specify it.**

**2. Keep us in the green zone**

**3. A fleet-based approach to identify who contribute the most to degradation, or who will be hit the most by the management or the climate change**

**4. Unfortunately the interpretation of anticipated benefit can be hard because possible opportunity loss either from degraded stocks….or from improved stocks when the TAC is choking! So the important thing is to match opportunities with allowances….which is a nightmare when technical and biological interactions are the rule………**

**4 no obvious link with the energy use intensity….compensatory/rebound effects.**

**4. account for “collateral” effects i.e. on the ecosystem**

**5. think about including climate-aware fisheries management/harvest control rules/constancy among references levels (no contradiction between the ones for sensitive species and habitat, and the ones for commercially exploited species. No saying anything about mixed fisheries and choke species)**

**6. Obvious compling to cross-check and do a viability check for the ecosystem: use the outcomes for informing ecosystem models? E.g. use the effort time series or the exploitation patterns from different scenarios as input to EwE?**

Overall, the simulation study shows that the F-MSY-lower does not really provide better pathways for future stock developments compared to F-MSY, and is not more robust to climate change effects, including short-term shocks. Surprisingly, the simulations showed that these shocks might actually be beneficial when following the FMSY-strategy (likely from counteracting density dependence effects and effects mediated by the trophic interactions).

Because FMSY should be considered as a limit and not a target per se, fishing at FMSY up to Fupper has regularly been criticized for putting future stocks at risk. The rationale for Fupper is to help the fishing sector to cope with possible choke species by mitigating the mixed fisheries issue often ignored. Here it is shown that indeed some TACs might choke some fisheries from time to time. Our findings also shown that sticking to F-MSY lower is not rewarding for fishing in the short to medium term, because limiting the fishing opportunities with early closure. It does not appear that following a F-MSY strategy in the actual FMSY ranges is sufficient to counteract the risk induced by a changing climate, which seems especially acute on the Baltic herring stocks. The undesired trajectories are even more pronounced when vessels are not complying with the LO (i.e. GVA declines along with stock developments on collapse trajectories if vessels continue fishing after being choked). It comes as no surprise for modelers that it is indeed not coherent to increase the fishing pressure beyond FMSY and the associated operating variable costs to likely achieve poor yield and put some of the stocks (especially the short-lived ones like the pelagic herring and sprat) at risk of collapse (see, e.g. the discussion in Earle 2021 in ICESJMS doi:10.1093/icesjms/fsab037), as the Baltic Sea MAP would allow.

When the LO is fully enforced, the simulations suggest that the greatest uncertainty for the stocks and the fisheries in facing climate change would arise from how the stock distribution would react spatially to a change in environmental drivers and tolerance limits. The loss or the redistribution of fishing areas and opportunities might not be compensated for, even if the stock is developing better under the FMSY-lower strategy.

Finally, fishing to FMSY should address other environmental concerns, including fishing impacts on the seafloor and the benthic habitats. Such evaluation requires additional information to ensure the sustainability of the impact, as different fishing methods combine with the vulnerability of the habitat and the intensity of the fishing. We first expected the energy efficiency to be related to the fishing footprint on such other ecosystem components of the marine ecosystem. However our simulation study show that the link is not straightforward, as saving fuel might sometime lead some vessels to spend more time at sea instead of less. Hence, it is not apparent to the scientific community what is the best scientific rationale in advising special fishing gears in different areas. It might also be recognized that ten times fishing with less impacting gears might be just as harmful as one time fishing with more impacting fishing gear, which requires the trade-offs in fisheries management to be made well explicit. It is expected that evaluating the respective energy efficiency of different types of gears might help reconcile this apparent dilemma as, for now, the more energy-efficient fishing methods are also likely the less impacting gears. To minimize such effects, (e.g. the harmful fishing gears are also the ones spending more fuel at sea), management should also ideally account for spatial (e.g. closed areas) and non-spatial effort management (e.g. effort reduction plans) besides the output control TAC management.

TODO: Probability plots to exceed or keep below references points

TODO: provide estimates in terms of per cent change for both stock development and fleet economy, and time for recovery, if any.

*Limitations of the present simulation study*

The study is not addressing possible important drivers in population dynamics, including:

* Predictions of harmful algal blooms and eutrophication zones;
* Identification of impact of climate change on species diversity;
* Possible effect of a change in land use in the Baltic Sea catchment area including effects of pollution;
* Possible helpful management option such as the design of marine protected areas and other management measures;
* Understanding seasonal patterns of fish spawning and spatial migration.

The study is not addressing possible important drivers in fleet dynamics, including:

* Possible different fishing styles (e.g., risk takers vs risk adverse fishers etc.)
* Profitability at the company level (possibly owning several vessels)
* Insurance against risks provided by POs or fishing communities, or quota swapping
* Fishing outside known historical footprint
* An abrupt change in catching power from technological innovations
* Market integration and prices dynamics from external markets

*References*

Bastardie, F., Nielsen, J. R., & Miethe, T. (2014). DISPLACE: a dynamic, individual-based model for spatial fishing planning and effort displacement - integrating underlying fish population models. Canadian Journal of Fisheries and Aquatic Sciences, 71(3), 366-386. <https://doi.org/10.1139/cjfas-2013-0126>

Bastardie, F., Nielsen, J. R., Eero, M., Fuga, F., & Rindorf, A. (2017). Effects of changes in stock productivity and mixing on sustainable fishing and economic viability. ICES Journal of Marine Science, 74(2), 535-551.

Blanchard, J.L., Andersen, K.H., Scott, F., Hintzen, N.T., Piet, G. and Jennings, S. (2014), Evaluating targets and trade-offs among fisheries and conservation objectives using a multispecies size spectrum model. J Appl Ecol, 51: 612-622. <https://doi.org/10.1111/1365-2664.12238>

Hüssy, K., Hinrichsen, H-H., Eero, M., Mosegaard, H., Hansen, J. H., Lehmann, A., & Lundgaard, L. S. (2016). Spatio-temporal trends in stock mixing of eastern and western Baltic cod in the Arkona Basin and the implications for recruitment. ICES Journal of Marine Science, 73(2), 293-303. https://doi.org/10.1093/icesjms/fsv227

ICES 2021. Baltic Fisheries Assessment Working Group (WGBFAS). ICES Scientific Reports .3:53. 717pp. https://doi.org/10.17895/ices.pub.8187

[Idongesit E. Ikpewe](https://besjournals.onlinelibrary.wiley.com/action/doSearch?ContribAuthorStored=Ikpewe%2C+Idongesit+E), [Alan R. Baudron](https://besjournals.onlinelibrary.wiley.com/action/doSearch?ContribAuthorStored=Baudron%2C+Alan+R), [Aurore Ponchon](https://besjournals.onlinelibrary.wiley.com/action/doSearch?ContribAuthorStored=Ponchon%2C+Aurore), [Paul G. Fernandes](https://besjournals.onlinelibrary.wiley.com/action/doSearch?ContribAuthorStored=Fernandes%2C+Paul+G) 2020 Bigger juveniles and smaller adults: Changes in fish size correlate with warming seas

MACKENZIE, B.R., GISLASON, H., MÖLLMANN, C. and KÖSTER, F.W. (2007), Impact of 21st century climate change on the Baltic Sea fish community and fisheries. Global Change Biology, 13: 1348-1367. <https://doi.org/10.1111/j.1365-2486.2007.01369.x>

Jacobsen, N. S., Gislason, H., & Andersen, K. H. (2014). The consequences of balanced harvesting of fish communities. *Proceedings of the Royal Society B-Biological Sciences*, *281*(1775). <https://doi.org/10.1098/rspb.2013.2701>

Mouquet, N., Lagadeuc, Y., Devictor, V., Doyen, L., Duputié, A., Eveillard, D., et al. (2015). Predictive ecology in a changing world. J. App. Ecol. 52, 1293–1310. doi: 10.1111/1365-2664.12482