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Summary

Our individual-vessel based bio-economic modeling approach (www.displace-project.org) evaluates the harvesting dynamics using information about fishing ground preferences and experienced vessel-specific catch rates. The assessment computes the daily decision-making of the fishing vessels and the individual or overall economic and stock status indicators together with the size-based spatial distribution dynamics of the main fishery resources. In this application to the western Baltic Sea sprat, herring and cod fisheries of Danish, Swedish and German commercial vessels (>12 m) the biological interactions (fish predation mortality) are included by a dynamic coupling to the Stochastic Multi Species model (SMS) on annual basis, under the mitigation from the "yet to be implemented" NATURA 2000 zonation in the area. The spatial technical interactions between vessels revealed to be the predominant factors affecting the fishery profit and the energy efficiency while species interactions play a minor role, albeit increasing the final profit estimates. Interestingly, the zonation affects the profit depending on the biological interactions from a spatial effect on the size composition of the stocks, therefore the fish size composition in the landings originating from different fishing areas. Such a model coupling contributes to the integration of different spatial activities in certain sea areas considering the combined effects of technical and biological interactions and dynamics for reducing potential inefficient management and use of space according to the aims of both EU CFP regulation (No 1380/2013) and EU MSP (2014/89/EU) directive.

Introduction

In the competition for marine space with other sectors, the fishing catch sector needs to integrate impacts from other activities and directives than the EU Common Fishery Policy (CFP) regulation, i.e. the EU Marine Strategy Framework directive (MSFD) and the Marine Spatial Planning (MSP) directive and ensuring an ecosystem based approach to fisheries management considering biological, technical and spatial interactions in the ecosystem and fishery system. The present scenarios evaluation should unravel the relative and integrated effects of the technical interactions (arising from different vessels exploiting the same stocks or shifting stocks affecting fishing mortality), the biological interactions (arising from predator-prey relationships determining natural mortality) and the spatial interactions (arising from different stock size compositions exploited by different vessels possibly restrained by spatial zoning).

Materials and Methods

The DISPLACE approach frames a management support tool (Figure 1; Bastardie *et al.* 2015) handling high amounts of quantitative data in an integrated modeling framework (logbooks-VMS data, survey data, etc.). This is for facilitating the understanding of the ecological-economic fishery dynamics and interactions at sea, reproducing observed patterns at the fishing trip level and evaluating the effect of alternative harvest and exploitation scenarios on performance indicators of fishing or harbours communities. The interlinked interactions is modelled at the fish stock and vessel scale and few km squared resolution such as the effort displacement toward other areas and potentially sensitive habitats, concentration of the pressure in a narrow space and consequences in cost for fishing, underlying commercial stock developments , biological interactions, and landing composition is rather precisely estimated. DISPLACE is coupled to SMS (Lewy and Vinther 2004) on an annual basis and SMS forecast the western Baltic species abundances at the start of each year

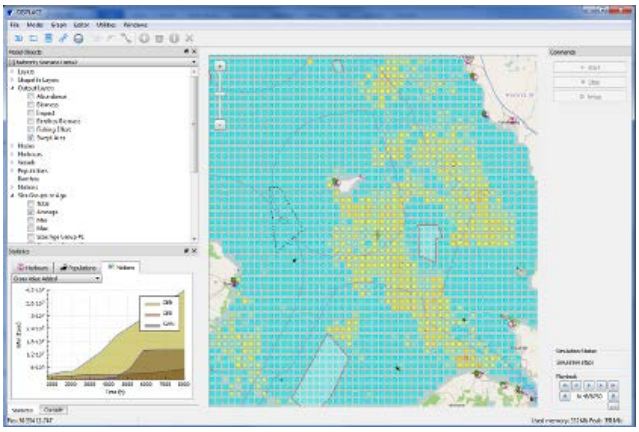

Figure 1. A snapshot of the DISPLACE model user interface with geodata and simulation outcomes on a grid of 3 by 3 km.

from the previous catches, the recruitments, and the parameterized species interactions (from stomach content data and analysis).

Results and Discussion

When the vessels focus on the most rewarding fishing grounds depending on their own experience this led to a higher overall fishing profit and energy efficiency, while slightly affecting the distribution of profit among the vessels (Figure 2). Surprisingly, these higher profits were made out of smaller amount of landings on sprat, herring and cod and less efficient fishing from lower CPUEs overall (Figure 2) on these species. The lower CPUEs were not the result of a crowding effect when vessels focused on more narrow areas but rather because the vessels displaced effort towards targeting more high value fish stocks.

When adding the zonation it affected the trip planning of the vessels by increasing the overall steaming time, making the trips less frequent and longer which led to a net increase in effective effort. Yet, the profit could still be higher than the baseline even if the CPUEs and the overall landings greatly decreased, and the zonation adversely affected the overall energy efficiency.

Both estimates of profit and energy efficiency were higher when including biological interactions in the simulations. This is due to different size compositions (larger individuals) and a change in the landing composition compared to baseline simulations. Inclusion of the biological interactions did not affect the individual trip planning as such.

Looking at the effect at the individual vessel scale there was an overall positive correlation between a gain in the profit and a gain in the energy efficiency but this was not true for all the vessels. While the overall effect was positive on both indicators for most vessels, some few vessels actually decreased their efficiency depending on their activities.

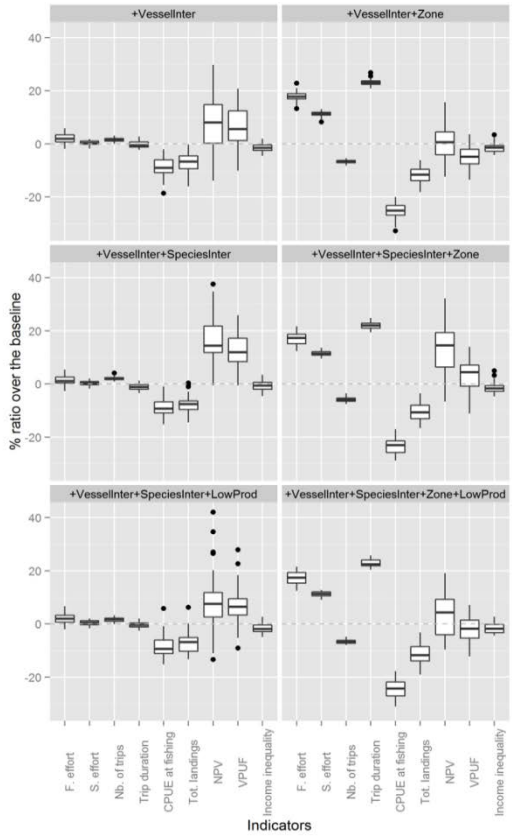

Figure 2. Box and whisker plot (N=50) of indicators from averaged and integrated variables over the simulation time (period 2012-2017).

Typically, the effect of the technical interactions and the zonation is larger than accounting for the biological interactions with respect to the fishery economy, but the species interactions impact very much the perception of the population estimates, the latter from very much lower and more fluctuating SSBs than the default situation (baseline scenario). The higher fishing mortalities when the low productivity scenarios occur confirms that the population - therefore landings - are generated from smaller fish bringing back the stocks to a similar situation of not taking into account the biological interactions.

The model outcomes show that the biological interactions do not affect the vessel trip planning and spatial fishing effort allocation while they affect very much the perception of the stocks over time. By contrast, the technical interactions lead to a change in vessel behaviour while not affecting the overall stock abundance in general. This relative decoupling might be due to (i) the predominant stabilizing constraints introduced by the EU management measures (long term targets from the multispecies long term management) on the amount that can potentially be harvested; (ii) the importance of the shift in targeting towards other more high value species and areas than exploiting the cod, sprat and herring in the western Baltic Sea; (iv) the lack of sensitivity of the catch rates to a change in local abundance or stock size composition.

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