Modelling interactions and feedbacks between Integrated Multi-Trophic Aquaculture and the receiving environment in the North and Aegean Seas

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Introduction

Integrated multi-trophic aquaculture (IMTA) has been identified as a promising solution for the sustainable development of aquaculture in many recent studies (Chopin et al., 2012). Benefits include waste recovery or transformation, increased growth and diversity of produced species and improved use of coastal area (Reid et al., 2011). These depend, however, on the scale of its application and on the characteristics inherent to the receiving environment. IMTA models come in crucial at the stage of designing IMTA setups to understand and predict their benefits and limitations.

In the scope of the EU H2020 IMPAQT project, we developed two far-field models (called herein North Sea model and Aegean Sea model) to investigate the effects and benefits of IMTA faming at two pilot sites that contrast in their farm settings and natural environment. The first site produces *Sacharina latissima* and blue mussels (*Mytilus edulis*) off the Dutch coast, in the Rhine region of freshwater influence, i.e., a nutrient rich environment with high throughflow. The second site is located in a more sheltered and highly oligotrophic environment, off the Turkish coast, and tests the benefits of growing *Ulva rigida* and mussels (*Mytilus galloprovincialis*) in the vicinity of seabass cages. We present here results of first scenario runs and discuss insights gained through these experiences.

Material and Methods

The two IMTA models are set up using coupled hydrodynamic and water quality modules from the Delft3D Flexible Mesh Suite (https://www.deltares.nl/en/software/delft3d-flexible-mesh-suite/). The horizontal and vertical grid resolutions are adapted to correctly resolve local flow patterns and stratification and capture the effects of the farms on water quality. The hydrodynamic module simulates currents, water levels, salinity and temperature. The water quality module incorporates biogeochemical processes affecting the growth of seaweed and mussels, and that can be affected by the dynamics of these living species (i.e., nutrient cycling, primary production and air-water exchanges). Special attention was paid to representation of phytoplankton dynamics to account for competition with seaweed species in nutrient-poor environments. The effects of fish cages are represented as additional nutrient and organic carbon loads. Seaweed and mussel metabolism dynamics are explicitly modelled, allowing for the simulation of feedback processes in the food chain, which is pivotal to IMTA.

Results and discussion

With the current model implementation, the North Sea results show that seaweed and mussel production can be increased to 10 tons/ha of seaweed and 5 tons/ha of mussels within a 6 km^2 farm, with very little environmental impact (in terms of nutrient depletion and oxygen concentrations and phytoplankton biomass). Upscaling of IMTA farming to potential future designated areas, further offshore and outside of the influence area of the Rhine plume would be more fruitful in terms of seaweed production, and less in terms of mussel production. This is due to higher nutrient turnover due to higher mixing, and lower phytoplankton biomasses (hence lower food availability for mussel cultivation). The environmental impacts of IMTA development in these areas, such as decrease of nutrient concentrations and of chlorophyll-a, is more visible, especially where water velocities are the lowest and hence retention times highest. Results also show advantages of IMTA farming, since, in the tested scenarios, mussel oxygen consumption is overcompensated by production by seaweed photosynthesis.

Results from the Aegean Sea model show that in such an oligotrophic environment, the additional nutrient input provided by fish production (and subsequent increase in phytoplankton biomass) is indispensable to be able to produce mussels. According to the model, the current IMTA model scenario does not show a clear reduction in nutrient emissions (and associated environmental impact) compared to fish monoculture. The level of nutrient concentrations remains too low for the survival of *Ulva rigida*, which is unable to extract the extra nutrient loads from the system. In the future, the Aegean Sea model could be used to test the potential cultivation of seaweed species better adapted to oligotrophic environments (provided nutrient uptake and growth parameters are available for these species), and its benefits for nutrient reduction.

While the North Sea model was validated against routine water quality measurements throughout its domain, this step has not been yet carried out for the Aegean Sea model due to the lack of available data. Before being fit for operational use, these IMTA models should be also validated against temporal data describing farm dynamics (e.g., mussel and seaweed biomass time series and time series of nutrient emissions).

In a next step, these models could be refined by including feedback effects of seaweed fronds on the flow (increase in drag). These are at the moment not implemented, which might lead to an overestimation of nutrient flows through the farms, when seaweed densities are high, and thus to an overestimation of seaweed growth at the larger scale.

Conclusion

This work shows the different responses of (and interactions between) IMTA farm components and their footprint on the environment in both nutrient-rich and nutrient-poor environments. It also helps identifying controlling processes, which should be incorporated in future models, to improve their predictive value.

The models are currently valuable research tools to get more general insight in how ecosystems react to aquaculture and to assess the response of individual species to an increase in competition or an increase in food availability. It is clear that the current IMTA models still need some further development before they can be fully relied upon to take decisions, either regarding the management of a farm or the management of an ecosystem by regulators. However, the first developments are encouraging and open up various application potentials, both for farmers and for regulators.

References

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