TOOLBOX
AQUACULTURE

PML | Plymouth Marine Laboratory

Large scale offshore production of mussels in Lyme Bay, English Channel

SUGGESTED USERS	PLANNING PROCESS	TYPE OF AQUACULTURE
Aquaculture producers Regulators Spatial Planners	Location Pre-Application Application EIA Consultation	Shellfish

SUMMARY

We use the model system FVCOM-CSTM-ERSEM-ShellSIM to simulate the major interactions between mussel farms and the environment in order to facilitate the estimation of the production and ecological carrying capacity of an area. The tool has been applied to a rope Blue Mussels farm in Lyme Bay, UK but the system can be applied to a wide range of commercial shellfish species and aquaculture practices as well as other geographical areas. The tool can help users evaluate potential production in offshore areas, estimate key impacts and plan for mitigation strategies.

DESCRIPTION

We have built a comprehensive model system coupling a 3D hydrodynamic model (Finite Volume Coastal Ocean Model, FVCOM), to a sediment transport model (Community Sediment Transport Model, CSTM), a biogeochemistry one (ERSEM) and a shellfish growth model (ShellSIM). The unstructured grid approach of FVCOM enables variable resolution so that high resolution can be focused in areas where it is needed such as around aquaculture farms. The system resolves the most common impacts from intensive shellfish aquaculture production (detritus deposition, bottom anoxia, ammonium release and changes to benthic biomass). The fully coupled system is capable of addressing most of the requirements to explore carrying capacity in offshore shellfish aquaculture.

The tool resolves the small-scale interactions at the farm level with sub-km model resolution that resolves the spatial configuration of the farm within the environmental variability. The tool was used in Lyme Bay, UK, where offshore mussel production is expected to reach 10000 Tonnes.
The coupled model reproduces the expected growth cycle of mussels in the area (12 Months from spat to market size). Assessment of impacts with respect to a baseline (farm free) simulation shows that 5% changes in particulate depositions are closely associated with the spatial extend of the farms and the area between them and reflect the general direction of the tidal currents in the area. Some localised impacts at the 5% level can be seen 80% of the time in one 12 month cycle.

This unique modelling approach offers the possibility of considering explicitly aquaculture practices, production estimates and environmental interactions to support license applications and detailed long-term business plans.

THE ISSUE BEING ADDRESSED

UK shellfish production is usually located in relatively shallow and sheltered coastal areas. With increasing water quality issues and overcrowding of coastal space, aquaculture production is increasingly looking at offshore options. This tools addresses planning needs for large-scale offshore mussel farms using rope cultured mussels at low densities, a technique which is novel to the UK aquaculture industry but that is well established in other countries such as New Zealand. The tool can produce estimates of long-term cumulative impacts as well as identify potential multi-year production fluctuations.

THE APPROACH

To resolve the small-scale interactions at the farm level the Lyme bay domain was configured at 350m-5km high-resolution resolving sub-km scale dynamics in the area. We have setup a nested modelling approach of increasing model resolution using two model domains. For the coupled hydrodynamic-biogeochemical model we use a parent domain of 1.5km-10km resolution to drive Lyme bay model domain. The atmospheric forcing is provided by a 3 step downscaling of GFS global datasets to reach the 3km of the final model domain using the Weather Research Forecast (WRF) model. Hydrodynamic boundary conditions are extracted from the European Copernicus Marine System North West European Shelf Forecast system. River flows were extracted from a National scale hydrology model run by the Center for Hydrology and Ecology in the UK.

The mussel farm representation was guided by typical offshore mussel rope configurations adapted to the local bathymetry in Lyme Bay licensed areas. We have run all our simulations with an initial spat seed density of exactly 200 ind m^{-1} of rope and a typical rope density of 0.0076 ropes /m^2 and 10m rope lengths.

This realistic modelling approach captures changes in mussel growth in time and in response to changes in environmental conditions such as variations in stratification or food resources providing detailed estimates of interactions between the farm and environment.

THE RESULTS

The simulations correctly reproduce that blue mussels in this area can achieve a market size of 25g and 6 cm in about 13 months when grown from seed of 10mm long. The growth pattern reproduced by ShellSIM suggests that the mussels grow monotonically during the initial spring bloom and summer while growth stalls during the winter period due to insufficient food. The second spring bloom supports exponential growth and the mussels reach a marketable size (e.g. 25g and 6cm of shell length) in early summer.

The effects of the operation at full capacity of all 3 farms was evaluated considering the export of particulate organic matter (POC) into the bottom, changes in sediment and bottom oxygen concentrations and changes to plankton concentration. Our approach has been to calculate the changes between a simulation without any aquaculture production (baseline simulation) and an exact replicate of the setup except for the presence of rope aquaculture of mussels.

For the anomaly-ratio figures, we include two contours corresponding to the 1 and 5% change in conditions with respect to the baseline simulation. All the metrics considered here show that the changes are limited to an area that include all 3 farms and extends no more than 60km^2

The flux of POC into the sediment is one of the best captured effects because of it strong signal in the simulations. The largest part of the flux takes place during the last 3 months of the growing cycle associated with the fastest growth phase. The 5% changes with respect to the baseline simulations are closely associated with the spatial extend of the farms and the area between them and reflect the general direction of the tidal currents in the area. The largest impact is located within the central farm with 80% of the time showing an effect larger than 5%. The changes to the POC flux to the sediment have associated consequences to the benthic fauna (deposit and filter feeders) represented in the model. In response to the increase in the flux, filter feeders decrease while deposit feeders increase in biomass, the 5% contour closely associated with the area of the farms.

The increase in POC deposition has a direct impact on the sediment oxygen concentration. Contrary to expectations, the sediment oxygen shows an increase with respect to the baseline simulation but only because the oxygenated layer becomes thinner.

A third aspect of the interaction is the assimilation of organic particulates by the mussels and the subsequent removal of a fraction of the pelagic planktonic ecosystem. This impact is on average smaller and much more localised than for the POC flux, never reaching 5% change and with changes exceeding 1% during ~15% of the time in one growing cycle.

The smaller impact on total chlorophyll-a is a direct consequence of the connectivity between the site and the rest of the shelf which ensures rapid flushing of the area as well as constant exchange of nutrients with deeper shelf waters.

The decrease in total chlorophyll-a is mirrored in all the other POC variables that mussels can assimilate with a knock-on effect on light transmission. In this area, organic coloured particulates exert the largest control on light attenuation and their reduction results in a commensurate decrease in light absorption.

THE BROADER APPLICABILITY

The model system can be used to explore different production scenarios to feed into the company business plan as well as into the licensing procedure. These scenarios can include changes to the farm spatial configuration (i.e. orientation, rope density) to minimise long-term impacts and increase production, but also implement management approaches (i.e. staggered production) that could help maximise both production and economic profit (e.g. sustained production over longer periods to avoid market saturation and drop in prizes)

The spatial detail of our model approach can also contribute to optimise the design of the monitoring requirements by identifying areas most at risk of impact as well as indicating the frequency of observations required (weekly, monthly, event driven).

The lack of a site-specific calibration for any of the model system parts means the model can be used in other areas. The model system is particularly well suited for estuarine and coastal locations, especially in regions that have good background data (e.g. bathymetry, digital elevation maps, river flows and associated nutrient concentrations, operational models) required to setup realistic model implementations.

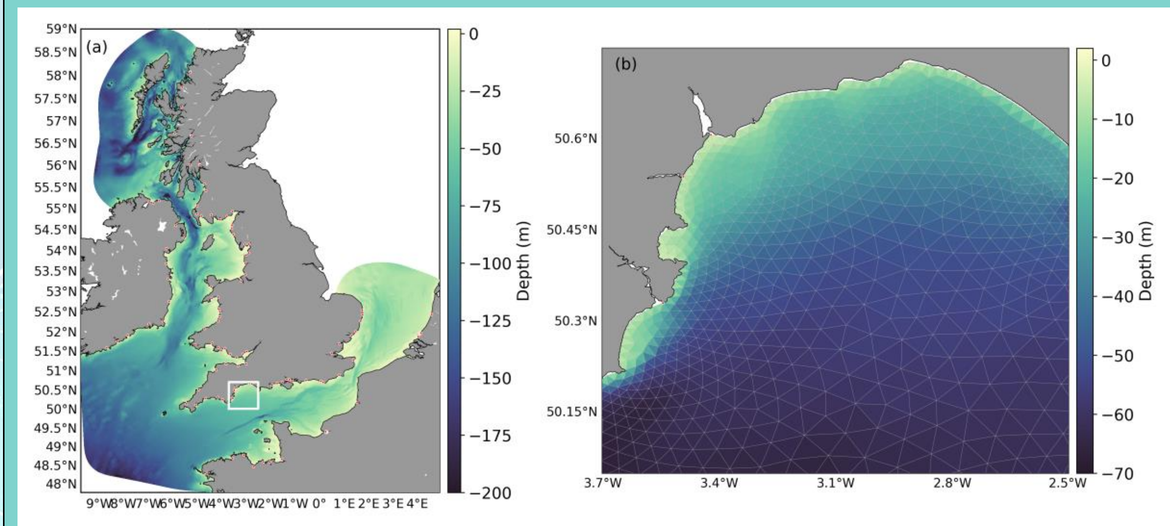


Figure 1 a) Bathymetry of parent model domain and location of rivers flowing into the domain. b) Detail of the mesh in the Lyme Bay area covered by the high-resolution model implementation.

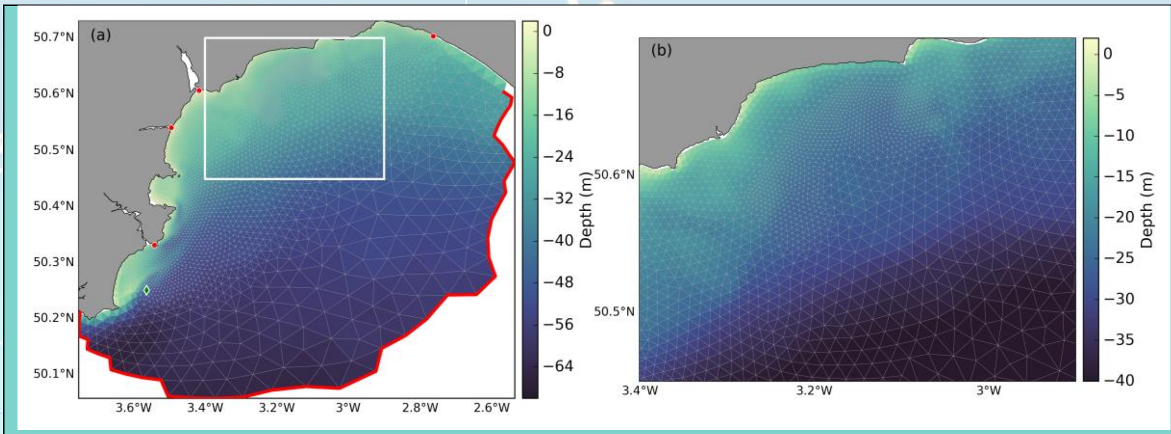
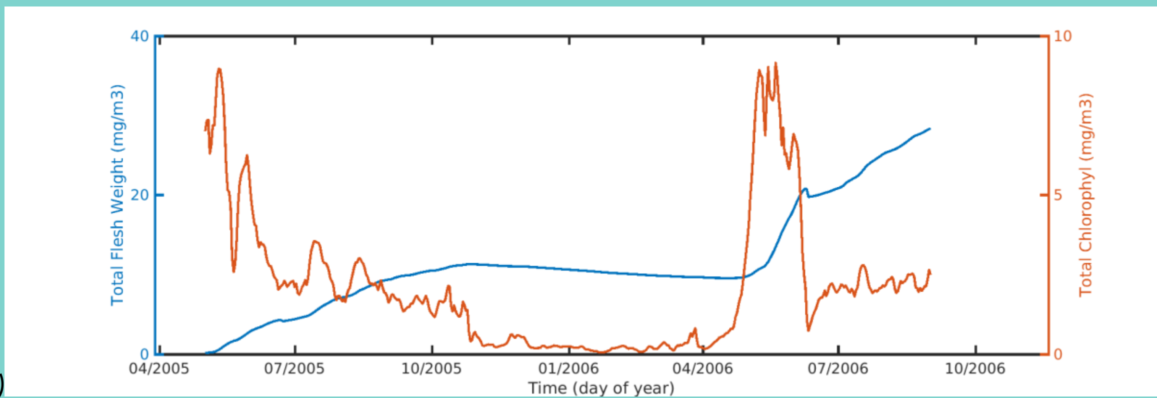


Figure 2 The model domain and bathymetry (a) and zoom subset (b). Red circles indicate the position of freshwater sources. The red line corresponds to the common set of nodes with the parent model that ensures volume and mass conservation at the boundaries.



a)

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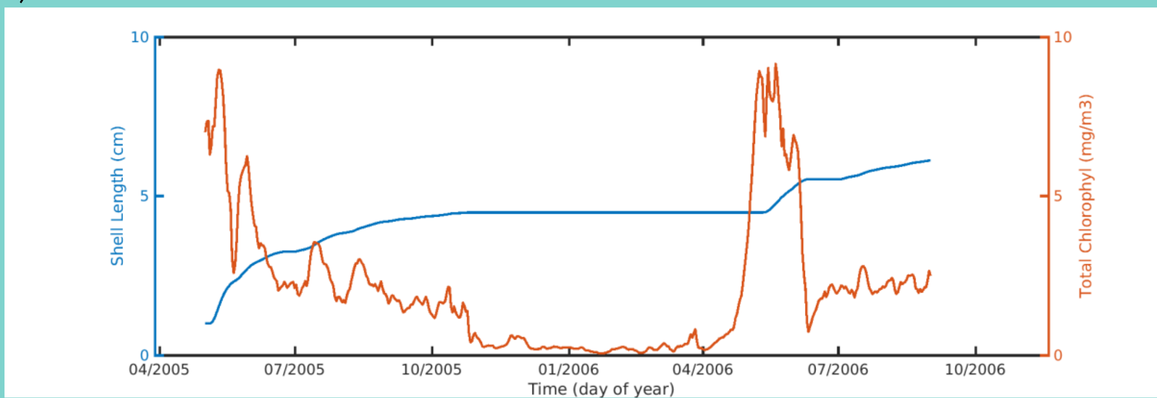
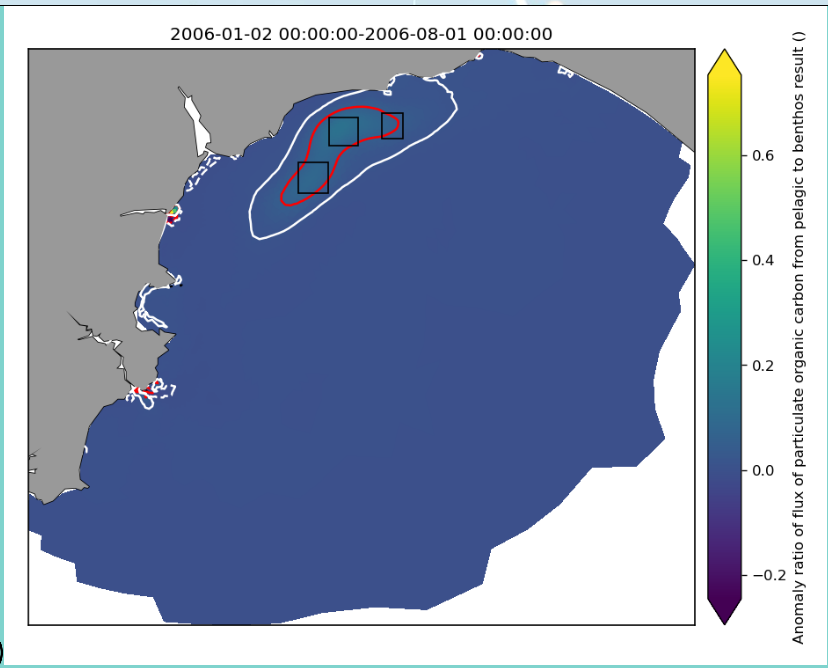


Figure 3 Time evolution of the median total chlorophyll-a (red) in the central farm integrated over the water column and 10 random model nodes in the central farm and the characteristic total fresh weight of individual blue mussels (a) and the shell length (b) (blue) in those same model nodes during one growing cycle.

a)



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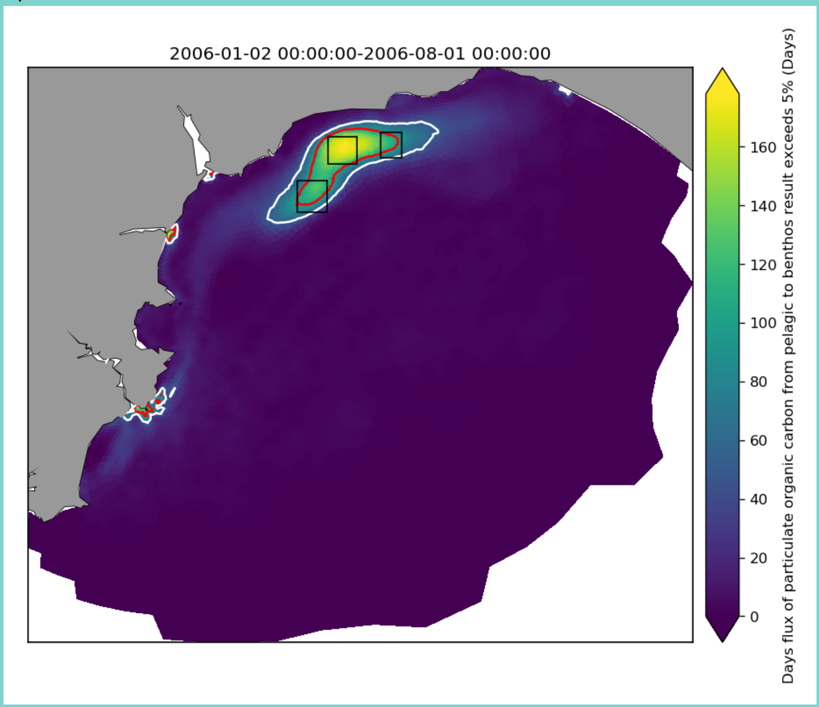


Figure 4. Spatial distribution of metrics of shellfish production impacts. Anomaly of the flux of Particulate Organic Carbon to the benthos. This includes contribution from pelagic plankton production as well as detritus originating from mussels. Shown is the farm scenario minus the baseline simulation. The red and white contours correspond to a 1% and 5% per cent change respectively with respect to the baseline simulation or 50 and 100 days.

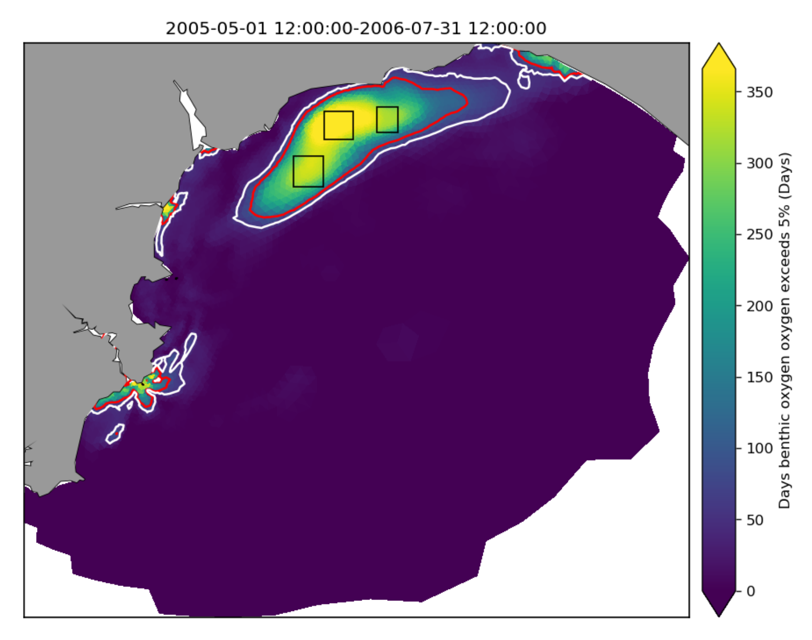


Figure 5 Days during which the sediment oxygen concentration exceeds a 5% change with respect to the baseline simulation.

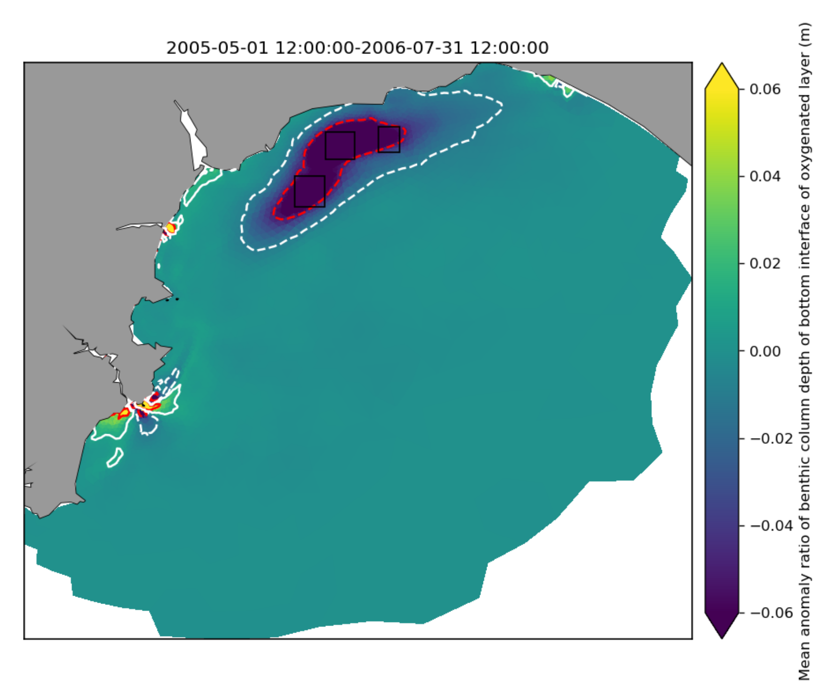
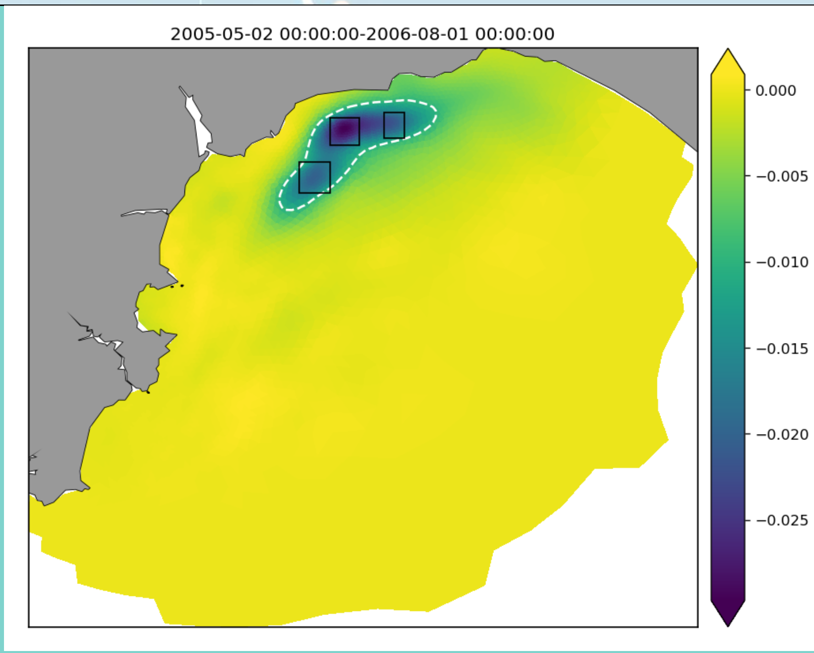


Figure 6 Mean anomaly ratio for the depth of the sediment oxygenated layer showing a shallowing of the redox horizon

a)



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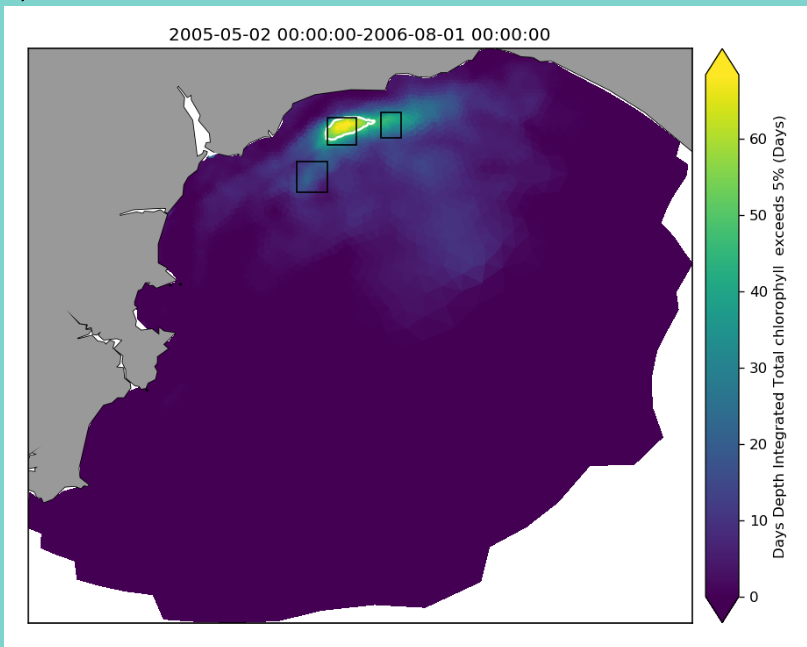

Figure 7 Impact of mussel production on total chlorophyll-a during the full first growing cycle.

SWOT ANALYSIS	
STRENGTHS	Spatially explicit and dynamic two-way coupling of shellfish production and environment without the need for site specific calibration of parameters.

WEAKNESSES	Complex tool that requires specialist skills and infrastructure to run.
OPPORTUNITIES	Capable of simulating different production scenarios to study how interannual variability can modulate farm-environment interactions and affect realised production. Contributions to the medium-term management of farms, for example identifying areas better suited within the leased farm area or evaluating approaches to maximise mussel size vs overall farm production.
THREATS	The tool requires access to large quantity of data (e.g. regional scale hydrodynamic and atmospheric model simulations) that might not be available in all regions. For European waters, these are accessible through the European Copernicus Marine environment monitoring service (CMEMS).

CONTACT INFORMATION	Plymouth Marine Laboratory Prospect Place, PL13DH, Plymouth, Devon, UK Ricardo Torres, PhD, MSc, BSc rito@pml.ac.uk
LINK	Butenschön, M., Clark, J., Aldridge, J. N., Allen, J. I., Artioli, Y., Blackford, J., Bruggeman, J., Cazenave, P., Ciavatta, S., Kay, S., Lessin, G., van Leeuwen, S., van der Molen, J., de Mora, L., Polimene, L., Sailley, S., Stephens, N., Torres, R., 2016. ERSEM 15.06: a generic model for marine biogeochemistry and the ecosystem dynamics of the lower trophic levels, Geosci. Model Dev. 9(4), 1293-1339, doi:10.5194/gmd-9-1293-2016. Chen, C., H. Liu, and R. C. Beardsley, An Unstructured Grid, Finite-Volume, Three-Dimensional, Primitive Equations Ocean Model: Application to Coastal Ocean and Estuaries, Journal of Atmospheric and Oceanic Technology, 20(1), 159-186, doi:10.1175/1520-0426(2003)020(0159:AUGFVT)2.0.CO;2, 2003. Hawkins, A.J.S., Pascoe, P.L., Parry, H., Brinsley, M., Black, K.D., McGonigle, C., Moore, H., Newell, C.R., O'Boyle, N., O'Carroll, T., O'Loan, B., Service, M., Smaal, A.C., Zhang, X.L. and Zhu, M.Y. 2013. Shellsim: a generic model of growth and environmental effects validated across contrasting habitats in bivalve shellfish. Journal of Shellfish research, 32(2): 237-253. Warner, J. C., C. R. Sherwood, R. P. Signell, C. K. Harris, and H. G. Arango, Development of a three-dimensional, regional, coupled wave, current, and sediment-transport model, Computers & Geosciences, 34(10), 1284-1306, doi:10.1016/j.cageo.2008.02.012, 2008.