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Impacts of environmental factors and shellfish practices on the Mont-St-Michel Bay ecosystem (France). A modelling study involving scientists and local stakeholders.

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Abstract: The macro-benthic communities of Mont-Saint-Michel Bay, located in the Norman-Breton Gulf (English Channel) along the French coast, are mainly dominated by filter-feeders which include cultivated species (oysters and mussels). The decline in shellfish farms production and the significant spreading of the invasive slipper-limpet *Crepidula fornicata* have conducted scientists and stakeholders to undertake a reflexion on the trophic balance between cultivated and wild (native or invasive non-native) filter-feeders. An ecological model of the bay was developed, coupling a 2D hydro-sedimentary model along with biological models for primary production and filter-feeder growth. The objectives of the project were first to provide indicators to stakeholders on the future evolution of the trophic resource taking in account environmental modifications and human pressure, and establish with them the scenarios to be developed by the model.

To accomplish these objectives different focus groups were organised between scientists and stakeholders. Based on these exchanges scenarios on shellfish practices, watershed runoffs and *Crepidula fornicata* spreading, were investigated through numerical modeling tools.

Then results of the models were presented to 6 stakeholders' focus groups and a social scientist has analysed first the interaction between scientists and stakeholders, second the perception of the models by the stakeholders and the ideas of stakeholders concerning the environmental problems face within the Bay.

Keywords: Ecosystem modelling, scenarios, stakeholders, primary trophic resource, shellfish farming, invasive species, Mont-Saint-Michel Bay, English Channel, France

Introduction

The Mont-Saint-Michel Bay (hereafter MSMB) is located in the western part of the English Channel along the French coast (figure 1). This bay is a large enclosed macrotidal area with an average tidal range of 10 m and a maximum one of 15 m. and with a large intertidal zone covering 250 km². Three rivers (Sée, Sélune, Couesnon) flow into the eastern part of the bay with average flow rates of 5, 9 and 11 m³/s, respectively. Due to high tidal currents, the water column is mixed that there is no vertical stratification.

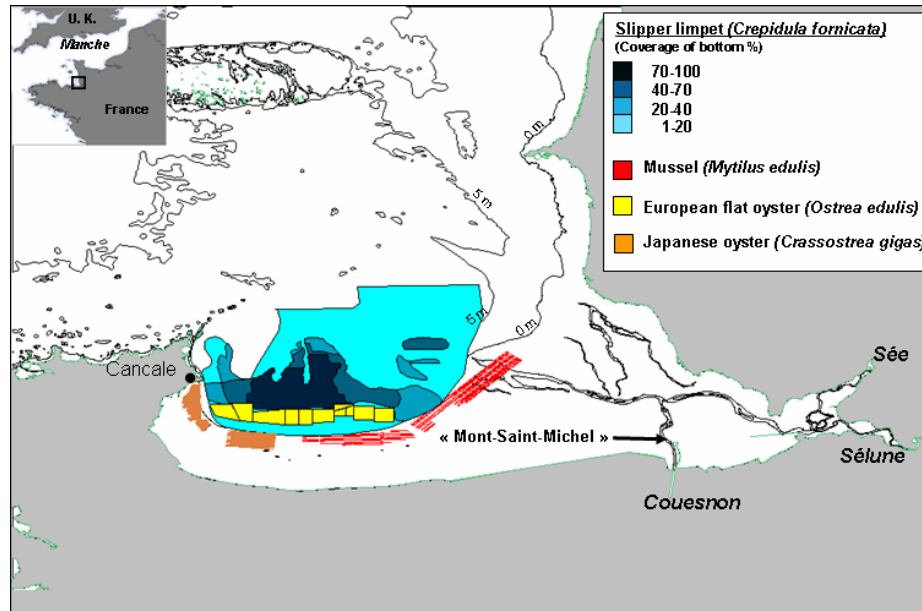


Figure 1: Location of the study area and of cultivated (oysters and mussels) and invasive (*Crepidula fornicata*) filter-feeders

The macrobenthic community in the bay is mainly dominated by filter-feeders and is typified by:

- (1) A very productive area for shellfish culture. The annual shellfish production reaches about 18.000 tons, with 12.000 tons of mussels (*Mytilus edulis*) (1st rank in France) and 6000 tons of oysters (*Crassostrea gigas* and *Ostrea edulis*). Every year, the shellfish farming induces more than 30 millions euros as economic returns. Farming structures take up the most part of the bay (figure 1). Mussels are grown on stakes arranged in linear rows on the lower part of the intertidal mudflat. Oysters are farmed in bags fixed on tables and are mostly occupy the western part of the bay.
- (2) A massive propagation of an invasive gastropod, the slipper limpet *Crepidula fornicata* (Blanchard, 1997; Blanchard and Ehrhold, 1999). The species is mainly located in the western part of the bay, north of the farming structures and spreads very quickly. Recent investigations revealed that the total biomass has increased of ca. 50% in eight years (figure 1) reaching 150.000 tons in 2004 (Blanchard, 2009). Today, the *Crepidula fornicata* biomass is the highest biomass among filter-feeders throughout the bay.
- (3) A large distribution of wild native community of filter-feeding species in the whole bay, showing densities of several hundred of individual per square meters.

A first version of an ecosystem model of the bay, coupling fine hydrodynamic, primary production and filter-feeders, had been developed in the years 2002-2006 (Cugier et al., 2010). With this modelling tool, a new project based on a participative approach was later proposed in order to provide stakeholders with indicators concerning the possible evolution of the trophic resource, according to changes of environmental and human pressures. Thus, in partnership with stakeholders and local decision-makers, the objective is to improve the model so as to simulate co-decided scenarios. The expected outcomes may concern possible answers and/or new lightings to questions regarding trophic resources as well as feeding discussions that may encourage collective choices. Thus, a large part of this study mainly

consisted in meeting sessions with the various stakeholders to inform them about the project, make them propose the questions they would like us to investigate and let them deliberate about the results of the simulations.

Materials and methods

Interaction with stakeholders for the definition of the analysis framework

The project consisted in the participative building of the management issues and scenarios related to the limited trophic capacity of the MSMB. Stakeholders were consulted through either focus groups or plenary forums. The stakeholder groups were the following:

- Shellfish farmers (oysters and mussels),
- Fishing federation leaders (commercial and recreational),
- Maritime administration,
- Managers (regional water agencies, district administration, etc.)
- Environmental Non Governmental Organisations,
- Decision makers (Mayors, district elected representatives).

In a first step, the scientific team met each stakeholder separately and discussed with them about their needs and perceptions concerning the bay. Based on all these meetings and discussions, scientists proposed a list of possible scenarios that could be simulated by the numerical model of the bay. In a second step, the proposed list of scenarios was validated by a steering committee composed by one representative of each stakeholder group and the model was adapted and improved so as to simulate the selected scenarios. Finally, 6 focus groups regrouping each stakeholder were organised and simulation results were presented. The choice to organise different focus groups was based on the following motivations: permit to each stakeholder to express their ideas and opinion about the selected scenarios and avoid the domination of some stakeholders during the exchanges with scientists. During the meetings, scientists presented more than 20 scenarios and stakeholders had the opportunity to be familiarised with such tool, to ask about clarifications to scientists and to prioritise the public actions to be undertaken in the Bay. Managers, shellfish farmers and environmental NGO's were more familiar with use of models as tool for management than fishers and politicians. But all the groups tried to see if their own priorities are included in the scenarios and asked scientists why the models couldn't take in account some species (cockles, *Venus verrucosa*, etc.) or expressed their fears about the results of some scenarios as for example the reduction of nitrogen inputs in relation with implementation of good agriculture practices and its impact on shellfish farming.

The selected scenarios may be split into 3 categories:

- River nutrient loadings issue: Three main rivers provide the bay with nutrients, particularly nitrogen, but also phosphorus and silicate. Hence, these rivers contribute to stimulate the planktonic production within the bay. So, any modifications of these contributions will have an impact on the availability of the primary trophic resource, and hence on the marine populations which depend on it, especially filter-feeders. The European Water Framework Directive (WFD) imposes European countries to reduce the nitrogen inputs in order to limit eutrophication problems. For French rivers, the objective of reduction is about 30%. We agreed to test such a scenario with our model and to address the following issues: can this reduction impact the chlorophyll levels and, hence, the filter-feeders growth, especially the cultivated ones?
- Invasive species (*Crepidula fornicata*) issue: A massive propagation of the slipper-limpet (*Crepidula fornicata*) has been observed on the subtidal area of the MSMB for decades, mainly in the western part of the bay and North of the farming beds (Blanchard, 1997; Blanchard and Ehrhold, 1999). Then, a possible trophic competition for food with other filter-feeders can be raised. Well known by all the actors, this invasion is usually considered as one of the main issue for the future of the bay. Then, we explored several scenarios of *Crepidula fornicata* expansion.
- Shellfish farming practices issue: The shellfish farming in MSMB is an old activity that today remains very dynamic and represents an important source of income to the territory. Scenarios relative to the cultivated species rely on modifications of density and/or spatial distribution. For mussels, two possibilities exist to modify the density: the number of stakes that bear mussels at a given time and the density of stakes (number / for 100 m). For

oysters, the density means the number of bags per hectare. Based on shellfish farmers' requests, we modelled several modifications of farming densities.

Model features

A 2D hydrodynamic model (SiAM model, Cugier and Le Hir, 2002) was coupled with a classical primary production model by considering nutrient cycles and two phytoplankton groups, namely diatoms and non-siliceous algae (including harmful flagellate species) and one zooplanktonic component, the diatom-grazer mesozooplankton. The application to MSMB is described in Cugier et al. (2010).

The benthic filter-feeder model includes:

- 3 grown species: Blue mussel (*Mytilus edulis*), European flat oyster (*Ostrea edulis*), Pacific oyster (*Crassostrea gigas*)
- 1 invasive species (*Crepidula fornicata*)
- 8 wild native species : *Abra alba*, *Cerastoderma edule*, *Glycymeris glycymeris*, *Lanice conchilega*, *Macoma balthica*, *Paphia rhomboides*, *Sabellaria alveolata*, *Spisula ovalis*

Mussels and Pacific oysters are modelled thanks to ecophysiological models based on Dynamic Energy Budget (D.E.B.) theory (Kooijman, 2000). These models allow simulating individual growth based on environmental conditions (temperature, food). For the other species in the model, only their impact on the ecosystem is analysed. For European flat oysters and invasive species, two main processes are considered: filtration and biodeposition (faeces and pseudofaeces). The first one contributes to deplete chlorophyll in the water column while the second one contributes to stimulate primary production because of organic matter deposition on the bottom. Filtration and egestion laws that consider environmental parameters such as water temperature or suspended matter concentration derived from ecophysiological models previously published (Barillé *et al.*, 1997).

Ecophysiological parameters for wild native filter-feeders are much more difficult to find in the literature. Often, only average filtration rates are available. Thus, only the filtration process is considered for these species in this study.

River boundary conditions (daily average for flows and monthly or bimonthly measurements for concentrations) were provided by *Seine-Normandie* Water Agency for Sée and Sélune, and by *Loire-Bretagne* Water Agency for Couesnon. Meteorological data came from Météo-France local station. Harmonic components of tide at the sea boundary were provided by the Service Hydrographique et Oceanographique de la Marine (SHOM: French Navy Oceanographic Department). Finally, main seaward boundary concentrations came from the operational modelling of French Brittany coast, developed in the PREVIMER project (see website: www.previmer.org).

Real densities of filter-feeders were introduced into each mesh of the computation grid after an interpolation process through Arcview GIS tools. Mussels and oysters densities came from the French Marine Administration seabed registry. *Crepidula fornicata* and native wild filter-feeders data came from specific benthic surveys.

Some examples of results

Each scenario was simulated and results compared to the current situation, which is considered as the reference situation. The chosen reference year is 2006 mainly because of the availability of data required for model forcing and validation. The model was validated by comparing in-situ measurements with simulations for environmental parameters (chlorophyll a, nutrient concentrations, temperature, salinity,...) and for oysters or mussels growth (measured evolution of weight in several location). All these validations were shown to stakeholders in order to prove the model ability to reproduce the ecosystem functioning.

The following discussion focuses on the impact on the growth performance of oysters and mussels. The weight obtained after one year of simulation in each scenario is compared to those obtained in the reference situation. Results are displayed through maps of differences (in %) compared to reference. Because results are numerous, it is impossible to present all of them in this paper. The choice was made to focus only on two examples concerning the

Crepidula fornicata scenarios. Indeed, the becoming of this invasive species appears to be one of the main problems of the future of the bay.

Because of its potential trophic competition, many users or stakeholders worry about the evolution of the trophic equilibrium within the bay if this species expands at the same rate in the future. In order to evaluate this question, we decided with them to test a scenario for a 10 year-term that may increase the *Crepidula fornicata* biomass up to 250 000 tons. A very high impact is observed on the growth of oysters and mussels (figure 2A): 7 to 17% of weight lost is found for mussels that are farmed within the central bay. The most impacted sectors are those which are the closer from the *Crepidula* bank. Oysters are also strongly impacted with weight lost reaching 10 to 12%.

Since mid 2009, an industrial project started exploiting *Crepidula fornicata*. It aims at collecting fresh slipper limpets to turn them into ready-cooked meals. Based on the estimation of an annual removing of 4000 tons per years the stock may reach approximately 210 000 tons in 10 years. The same patterns are obtained, compared to the previous scenario but the impact for shellfish growth is lower (figure 2B). The loss in weight of oysters or mussels remains lower than 10%. This improvement of growth is significant and not negligible compared to the previous scenario. The exploitation of *Crepidula fornicata*, even if it can not stop the invasion, should reduce it and thus limit the potential trophic competition with cultivated species. Weight lost is expected in all case but less dramatically in the second scenario.

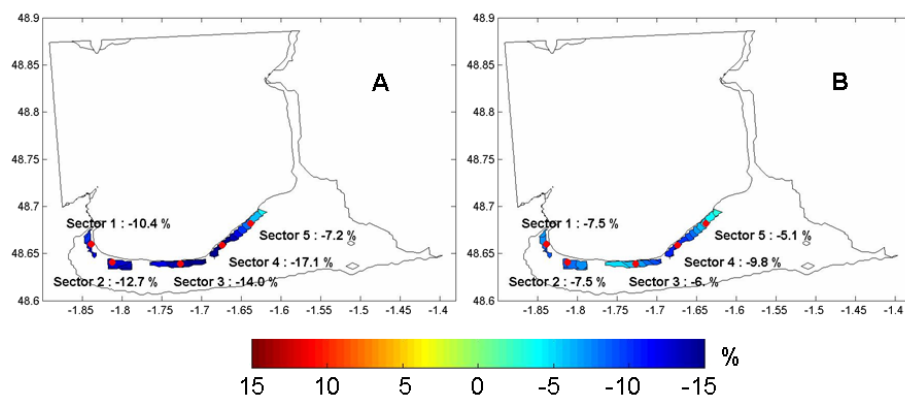


Figure 2: Simulated scenario considering an expansion of *Crepidula fornicata* up to 250 000 tons (A) or 210 000 tons (B). Differences with reference situation for final weight after one year for oysters (sector 1 and 2) and mussels (sector 3, 4 and 5).

Discussions and conclusions

Scenarios should be classified into two categories: (1) Probable evolutions on which humans can not really intervene on management (or only a little). This concerns mainly the expansion of *Crepidula fornicata* which is inescapable, even if a commercial exploitation is being developed and may perhaps shrink the biomass. It also concerns the reduction of nitrogen loadings by rivers in accordance with the European Water Framework Directive (WFD) (2) possible evolutions of farming practices that are controlled by shellfish farmers and maritime administration.

The results of these scenarios were presented and discussed with stakeholders of the bay during several meetings. These scenarios were well perceived by stakeholders and some ideas about the future management of the bay were expressed. Such results allowed a hierarchic classification of potential impacts to pave the way for what could be considered in priority by stakeholders. Mussel's farmers found that the results of models improved their decision concerning the development on the east part of the bay of their farms. One environmental NGO criticised the scenarios because they are answering more to shellfish farming needs than their needs. But all stakeholders discovered with surprise that the main problem faced within the Bay is the rapid expansion of invasive species (*Crepidula fornicata*) and its impact to the development of others species. All agree on the need to stop its expansion in the nearest future but the ways to reach this objective are different. For

local politicians shellfish farmers are the first victims and they should finance projects aiming the stop of this expansion. Some mayors considered that this problem should not benefit public money as they considered mussels' farmers rich and able to finance such projects. This wasn't the opinion of the district politicians who are looking to finance a project undertaken by some shellfish farmers aiming the use of *Crepidula fornicata* for human consumption. The exploitation of this invasive species should perhaps limit the loss in growth performance which can affect oysters and mussels due to trophic competition. But this commercial activity just starts and there is no guarantee yet that this should be perpetuated in the future for economic and market reasons. Nevertheless, it represents an element of control that stakeholders are now aware of. Such results may help them to search political and economic support to improve their projects against the expansion of this species.

The implementation of nitrogen reduction imposed by the WFD is a different case. This scenario was asked by shellfish farmers who worried about its impact on the growth of mussels and oysters. They were satisfied to know that this reduction will induce very limited effects to shellfishes. For them now, this issue represents less importance than those of the expansion of *Crepidula fornicata*. For managers and environmental NGO's this result will facilitate their action because shellfish farmers will not be opposed against the implementation of WFD.

Thus, the *Crepidula fornicata* expansion together with a nitrogen reduction leads the bay towards a decrease in chlorophyll level and food availability for filter-feeders. Nevertheless, scenarios exploring modification in farming densities show that a potential control may exist, which could, counterbalance this decreasing.

The trophic status of the bay constantly evolves. Stakeholders of the bay are now in the possession of important elements which will help them to appreciate better this evolution. Shellfish farming represents the main human activity within the intertidal bay and it can play an important role in the modification of ecosystem functions. Simulations showed that increasing farming densities of mussels and oysters should be avoided and the appropriate management of densities may improve food availability, productivity and revenue. The reduction of farming densities, even if it is considered to be a good opportunity to get a better yield from the common resource (phytoplanktonic production), does not seem so easy to be accepted by all stakeholders. Scientists expect that the results of simulations provided the necessary knowledge to all stakeholders and could contribute to raise collective actions and designation of public policies.

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