Case study

#7 Mussels in the Atlantic coast

#8 Oysters and clams in the Atlantic coast

#9 Mussels in the Mediterranean

Species background and economics

Mytilus galloprovincialis, the Mediterranean mussel (Med mussel), is a bivalve filter feeder that occurs naturally in intertidal areas along the Portuguese coast including rocky shores, estuaries and coastal lagoons (Figure 1). In recent years, there has been increased interest in the development of aquaculture production of this species on the Algarve coast of Portugal.

With the implementation of new offshore companies to produce bivalves, Med mussels are often selected for this production as they are considered to have minor environmental impacts.

Although the price per kg is not high, culturing Med mussel has advantages: it is an endemic species and is well adapted to the local environment; seed can be collected naturally with suspended ropes as collectors; and it grows relatively quickly with limited handling.[1]

In 2017, aquaculture of fish and shellfish in Portugal reached 12,549 tons with a total value of €83.2 million, which represents an increase in production of 11.5% and value of 10.6% comparing with 2016. Bivalves represent 56.7% of total production with mussels providing 1,722 tons representing 14.5% of total production.[2] Still, national consumption of mussels was more than double (3,800 tons) with imports from EU countries mostly from Spain but also from New Zealand at competitive prices.

The average price of mussels sourced from aquaculture in Portugal for both national and international markets was €0.945/kg in 2017 and €0.965/kg in 2018, obviously this value varies depending on mussel size class.[2] Direct sales to restaurants can be €3.3 to €4/kg and medium-sized mussels can be sold for €2.49/kg to large supermarkets.[3]

Processing mussels increases their value and allows an extended shelf life. At retail markets, frozen mussel meat can yield prices of €14/kg. With canned mussels, there is additional added value but, interestingly, there is a lack of national production: all mussels canned in Portugal are imported, mainly from Spain.[4]

Figure 1. *Mytilus galloprovincialis* from aquaculture in SW Portugal. *Credit : Bruno Fragoso*

Expected projections under climate change

CERES has examined the effects of two carbon emission scenarios. In RCP 4.5, the total radiative forcing and carbon concentrations are stabilised after 2100 at 4.5 W m^{-2} and ~650 ppm, respectively. In RCP 8.5, emissions create concentrations of carbon up to 1370 ppm.[5]

The mean sea surface temperature (SST) in Southwest Portugal is ~ 17°C,[6] ranging from a minimum of 13.1°C recorded during a period of strong upwelling and a maximum of 25.2°C during relaxation of upwelling.

Elevated SST have recently been reported along the Algarve coast (https://www.ipma.pt/en/media/noticias/news.detail.jsp?f=/en/media/noticias/arquivo/2016/sst-algarve.07-08-16.html), whereby waters were 0.5 to 1.0°C warmer than average between July 17 and August 13, 2016.

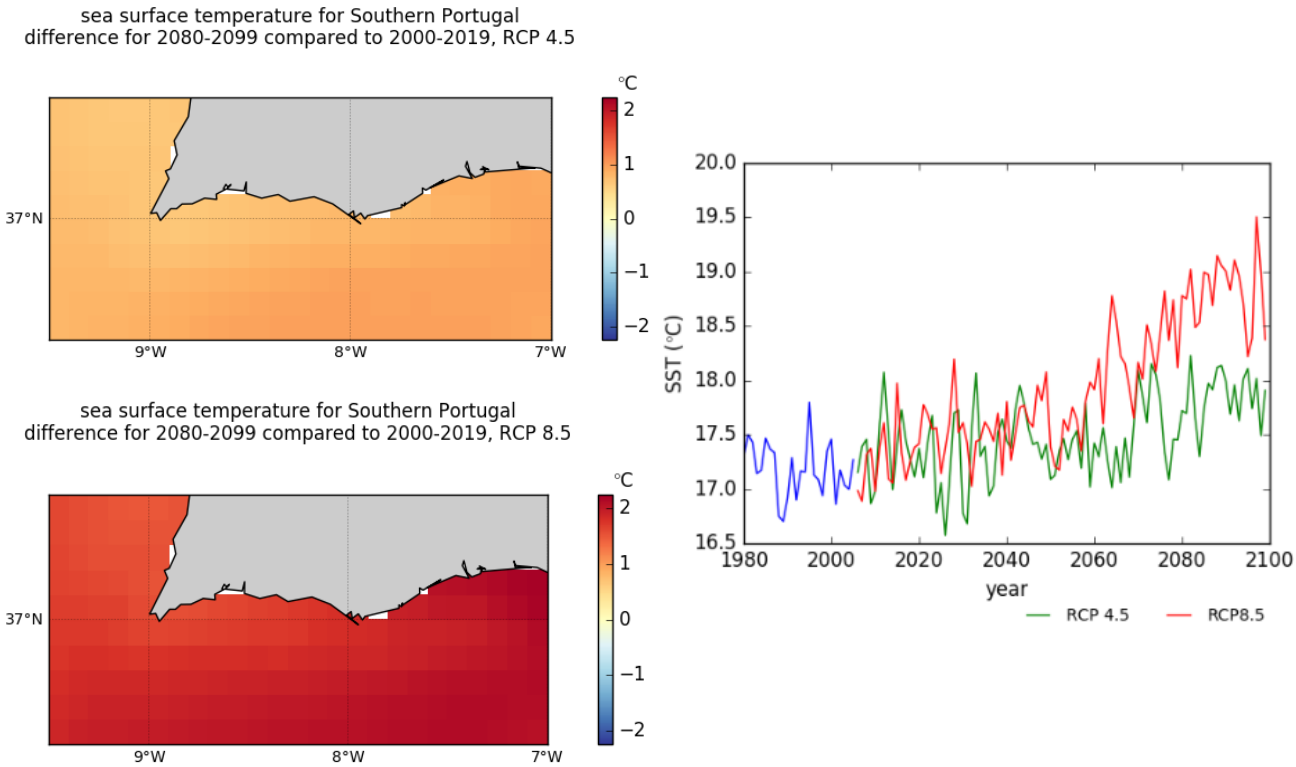


Figure 1 Projected change in sea surface temperature for the Portugal region (left panels). Difference in 20-year mean temperatures for 2080-2099 compared to 2000-2019 under (RCP 4.5 upper left panel) and RCP 8.5(lower left panel). Annual mean for the same region (right panel).

CERES climate change projections suggest that waters around the Portuguese coast will warm up to 1°C under RCP 4.5 (figure 2, upper left panel) and up to 2°C under RCP 8.5 by the end of the century, with the largest increases in the south (figure 2 lower left panel).

The divergence between the two scenarios is evident by comparing the red and green curves in figure 2.

Projected changes in net primary production (PP) are less distinct between the RCP scenarios with a general trend of slightly increasing production under both RCP 4.5 (figure 3, left upper panel) and RCP 8.5 (figure 3, left lower panel).

Historical *in-situ* measurements in South-west Portugal indicate a decrease in PP with increasing temperature.

As a consequence, the future projections of changes in PP should be treated as uncertain (figure 3, right panel).

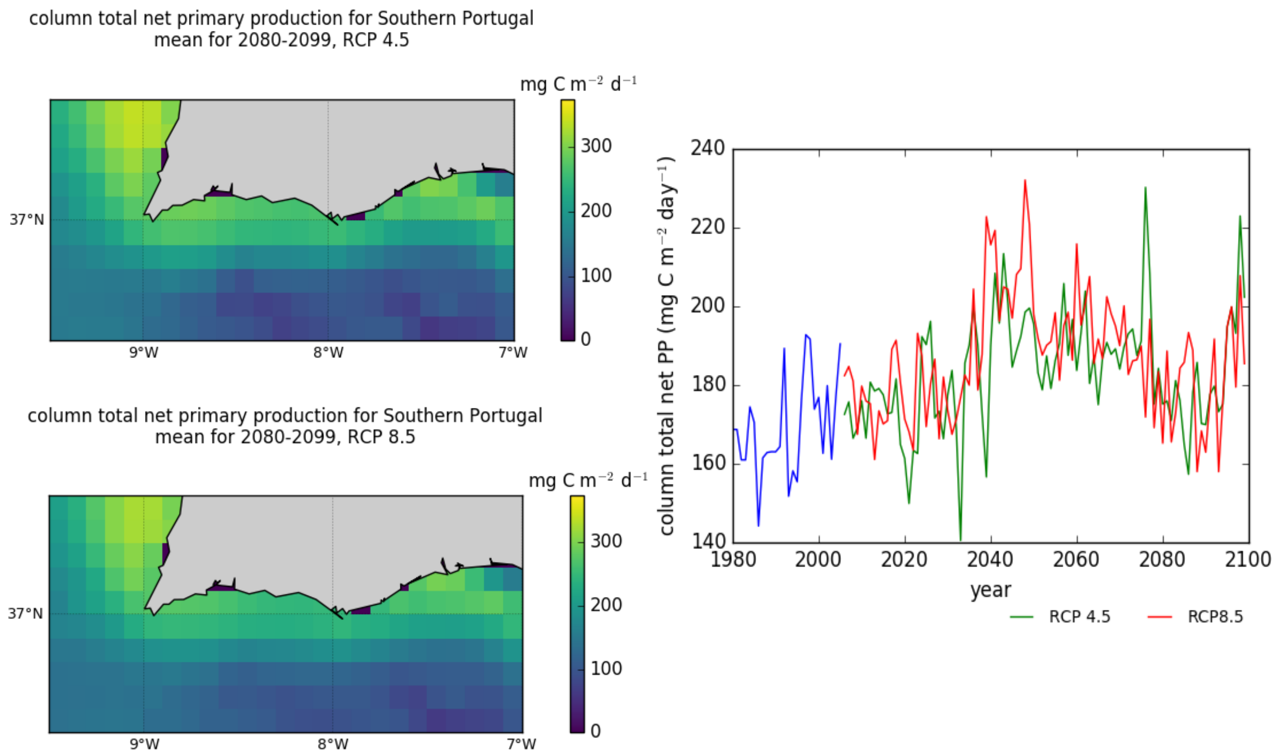


Figure 3 Projected change in net primary production (PP) for the Portugal region. Difference in 20-year mean column total net PP for 2080-2099 compared to 2000-2019 under RCP 4.5 (upper left panel) and under RCP 8.5. (lower left panel) Annual mean for the same region (right panel).

Additionally, rainfall is projected to decline in Southern Europe. The southwest area of Portugal has few rivers so these changes in rainfall are not important climate drivers.

Of primary concern for nutrient dynamics and PP will be potential changes in the strength of upwelling.

Scenarios describing future society and economy

CERES uses models to estimate economic developments in Europe's fishery and aquaculture based on select, pre-defined physical and socio-economical future scenarios.

These future scenarios were specified by industry partners and stakeholders in the first year of CERES (e.g. fish prices, fuel prices, technological advancements, regional policy issues, etc.).

'World Markets'	**'National enterprise'**
• Personal independence, high mobility and consumerism • Reduced taxes, stripped-away regulations • Privatised public services • High fossil fuel dependency • Highly engineered infrastructure and ecosystems	• National isolation and independence • Protection of national industry • High resource intensity and fossil fuel dependency • Low investment in technological development and education • Low priority for environmental protection
'Global sustainability'	**'Local stewardship'**
• High priority for welfare and environmental protection • Cooperative local society • Intense international cooperation • Increased income equality • Low resource intensity and fossil fuel dependency	• Promotion of small scale and regional economy • Less attention for global (environmental) problems • Moderate population growth • Income of industrialised and developing countries converge • No overarching strategy to manage ecosystems

Table 1 Outline of the four social-political scenarios developed by CERES partners and stakeholders

Socio-economic developments

CERES uses four scenarios to make projections of the potential environmental, social and economic impacts of climate change by combining the IPCC's RCP (representative concentration pathway) and SSP (shared socioeconomic pathways) scenarios. Scenarios are imagined, yet plausible 'futures' that are both optimistic or pessimistic, based on available projections for carbon emissions, cost of life, population growth, consumption, shellfish price and fuel costs.

In the **World Markets (WM; RCP 8.5 & SSP5**), the mussel producers will likely farm at their own risk but also at their own convenience with limited control and regulations. Demand for seafood products increases. In parallel, competition increases with international (mostly freshwater) aquaculture products with low food security and traceability available at competitive prices. While costs for energy are high, less government restrictions and bureaucracy will mean faster and cheaper permits and fixed costs. Monitoring for Harmful Algal Blooms (HAB) will likely be carried out by farmers themselves. Environmental degradation may lead to lower product quality, higher mortality and disease outbreaks.

Under the **National Enterprise (NE; RCP 8.5 & SSP3)**, the mussel producers may benefit because exports and imports are economically discouraged with the main aim to supply national demand on seafood products, based on national preferences (marine species such as high value bivalves). Food security standards are adequate, but there is little concern for the environmental impact of farms. Well established rights of use will secure priority for national companies and demand for seafood will be stable or increase only slightly due to the relatively small market size. Government incentives may be provided to enhance national production. The industry is however highly regulated and slow administrative processes to adapt to industry needs may increase production costs. As a concession HAB monitoring may be improved to potentially reduce farm closures.

Local Stewardship (LS; RCP 6.0 & SSP2), may favour the production of locally adapted mussels from small scale companies (mostly family based) that have traditional value. Certification schemes will increase the value of the product, which can favour mussel price. Production costs will be higher (fuel, equipment) and trade will be reduced as most of the consumption will be local. Of high concern is the environmental impact of farms, the quality of the product and food safety. As in the NE scenario the government provides compensation against HAB as incentive to producers. Demand will be dependent on the regional consumption and preferences but also the influx of tourists that can significantly increase the demand for seafood products.

Global Sustainability (GS; RCP 4.5 & SSP1) could favour the production of mussels due to their comparatively low environmental impact. Exports should increase as countries with higher purchasing power and environmental awareness will take most of the products. Diversification of products though transformation adding increased value and longer shelf life products that allows exports. Governance for aquaculture will be under tight regulations to ensure environmental sustainability of the activity and co-use with other activities would be fostered.

Aquaculture production for Portugal is projected to have a positive increase until 2030 reaching 8488t.[7] In comparison to other European countries, these levels are still relatively low. The Portuguese government has defined aquaculture as a strategic sector, and has established financial frameworks to boost production, which is expected to triple by 2023, reaching 30 000t. Under the four RCP-SSP scenarios,[7] the projected seafood demand for Portugal decreases except in the World Markets Scenario (RCP 8.5 SSP5) where demand is projected to increase 100,000t by 2100. This increase in demand is explained by the demographic and *per capita* GDP growth that is expected to occur under this scenario.

Currently, both for the administrative and the environmental aspects, the expansion of aquaculture and other activities in this region has been highly regulated by the government. This includes monitoring for food security and disease particularly with regards to HAB. The current scenario in this region seem to follow the direction of the RCP 4.5 Global Sustainability scenario, with increasing costs of production mitigated by valuing the product’s quality and by efforts to achieve certification for sustainable aquaculture.

Key research needs

The vulnerability/sensitivity of the Med mussel to the environment is not a major issue, but its suitability as an economically viable species for aquaculture, is highly sensitive to climate change, particularly warming.

For SW Portugal, the primary production is regulated by the occurrence of upwelling which brings cold and nutrient rich water promoting increased chlorophyll. In contrast, the occurrence of warm waters from the Mediterranean area during upwelling relaxation periods represents a reduction of phytoplankton abundance (reduced chlorophyll-a, increased transparency) followed by reduced mussel condition, affecting the spawning performance and increasing susceptibility to disease.

For example, an extended period of warm water led to a complete failure of mussel recruitment in 2017.

The greatest, yet indirect CC impact, which farmers are facing is the intensification of HAB from the diatom *Pseudo-nitzschia* spp and a number dinoflagellates that produce toxins which can induce Amnesic Shellfish Poisoning (ASP), Diarrhetic Shellfish Poisoning (DSP) and Paralytic Shellfish Poisoning (PSP) with potential to cause severe health problems or even death.[8]

Weekly government monitoring in established monitoring zones ensures that all harvesting must cease in the respective zones if legal toxicity limits are exceeded. This leads to farm closure periods (see figure 4), which can be extensive, even up to two years in an extreme case.

HAB are intensifying in parallel with climate change,[9] and it is conceivable that they may increase in frequency and severity.

Figure 4 Closure periods for mussel sales from the Sagres region of SW Portugal (red shading) due to toxins in 2019. Credit: http://www.ipma.pt/pt/bivalves/index.jsp

CERES research

- A review of the published research to identify gaps in knowledge on how Med mussel is affected by factors directly influenced by climate change (temperature, pH, oxygen and salinity).
- A contribution to an experiment to test the combined effects of temperature (3, 8, 15, 20, 25°C) and chlorophyll concentration (2, 10 µg/L on the growth and physiology of Med mussel (Sagres, Portugal) and blue mussel (Netherlands, Denmark) to provide additional data to improve current physiological models.
- Experiments to examine how projected changes in temperature and pH (ocean acidification) influence the response of Med mussel to HAB; specifically, with regard to PSP from the dinoflagellate Gymnodinium catenatum (figure 5)
- Winshell mass balance model based on an individual Med mussel grown at an offshore farm has been incorporated into a local-scale Farm Aquaculture Resource Management (FARM) model to provide data for projecting climate-driven changes on production potential.
- Implementation of a Bow-tie Analysis to reflect stakeholder concerns about the current and future factors affecting Med mussel production.
- Development of a probabilistic Bayesian Belief Networks (BBN) model linking biological projections with economic consequences and policy measures to test whether the current management system can cope with identified risks under the CERES scenarios, particularly, impacts from HAB on annual profits.

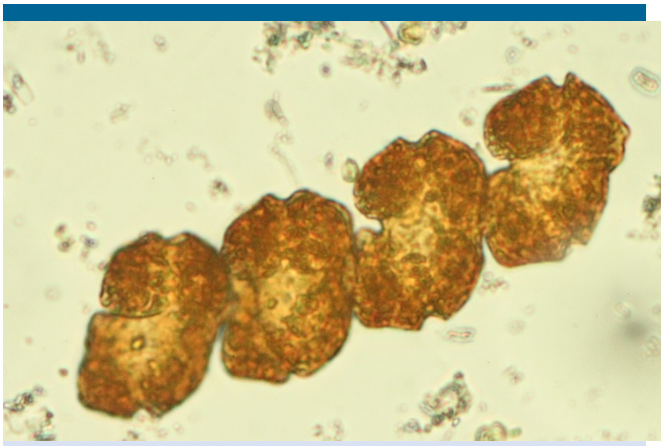
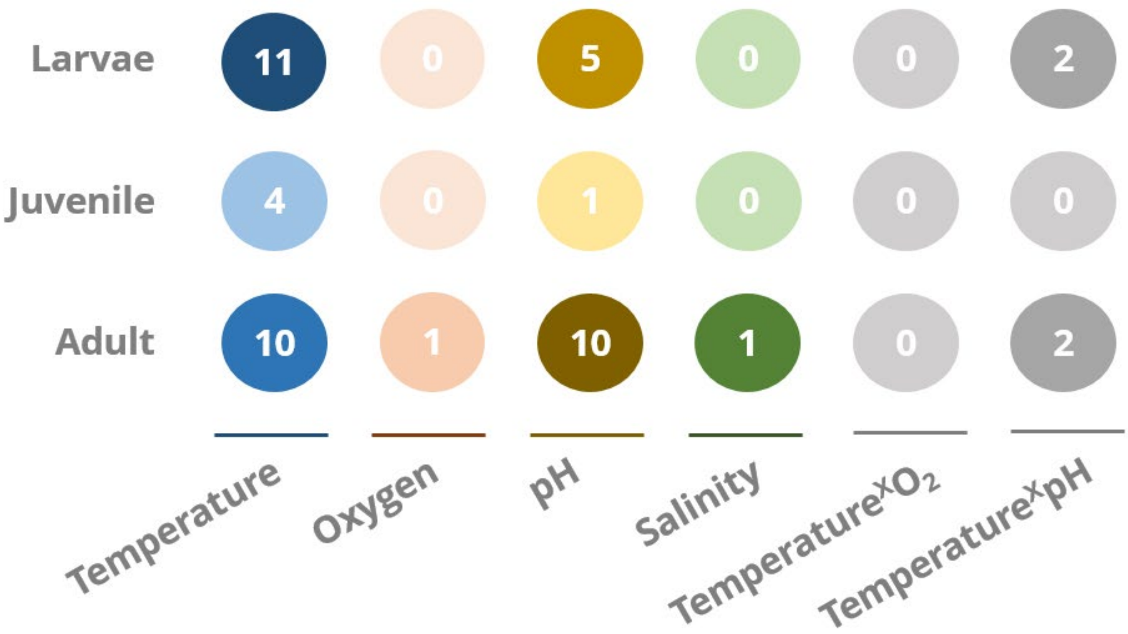


Figure 5. *Gymnodinium catenatum,* Portugal*. Credit : Bruno Fragoso, Sagremarisco*

Biological consequences



- Mytilus spp., comprising two species, ranked 3 out of 37 European fish and shellfish genera reviewed here (20 studies).
- 1 study was found in the Atlantic coast area. Further data is found in SL 5 (14) and 10 (3), further European areas (2) and outside Europe (8).
- Studies on Mytilus spp. were equally found in countries adjacent to the North Sea and Spain.
- The majority of studies focused on adults and studied pH and temperature
- The most common response studied was growth, followed by mortality and physiology

Physiological experiments in the Netherlands

Regarding the CERES research on mussel, the combined effects of food availability and temperature showed that different optimal temperatures for growth were observed depending on the species and their origins.

Med mussel is well adapted to higher shifts in temperature with upper food supplies resulting in higher optimum temperatures for growth.

Neither Med nor Blue mussel survived temperatures over 30ºC.

Physiological experiments in Portugal

Mussels were acclimated for 21 days and then exposed to *G. catenatum*, for 5 days (uptake), followed by 10 days with non-toxic diet (elimination). The highest PSP content were observed at day 5 in mussels in the control conditions which exceeded the international seafood safety limits.

Under climate change scenarios, significantly lower PSP content was observed in mussels under scenarios with the lowest levels occurring in warm-acclimated mussels, followed by acidification. However, the interaction of both parameters did not reveal an additive effect.

Lower toxin elimination was observed in warm-acclimated mussels. In mussels not exposed to toxic algae, highest genotoxicity damage levels were registered in mussels under combined effects of warming and acidification at the end of the experiment. When mussels were exposed to *G. catenatum*, DNA damage in both gills and hepatopancreas significantly increased just after the uptake period.

The treatments representing the acidification scenario and the interaction of warming with acidification revealed higher DNA damage than control conditions, highlighting a synergistic impact. DNA damage decreased in all treatments at the end of the elimination period, although the reduction was subtle in mussels under interaction of warming and acidification.

This trial shows that changes of global conditions may lead to lower PSP accumulation in mussels, but also to slower elimination rates and to a synergistic effect on DNA damage, implying possible consequences for the mussel's DNA.[10]

Implementation of Winshell and FARM models

The direct effects of CC were studied using physiological models that were calibrated using CERES experimental data to improve the prediction of CC effects on mussel growth where the Med mussel individual model was incorporated into the local-scale Farm Aquaculture Resource Management (FARM) model to examine direct climate-driven responses on harvest and environmental effects of culture at the farm scale,[11] using a layout which reflects offshore culture practice for *M. galloprovincialis* in Southern Europe (for example figures 6 and 7).

Figure 6 Hanging mussels in longlines after socking, Portugal. *Credit: Gary Littler, University of Ulster*

The Med mussel growth and production has been simulated for a typical offshore farm in the Algarve coast (SW Portugal).

The farm covers 10 ha where mussels are stocked at a density of 312 ind. m^{-2} in long-lines.

Mussels reach harvest size at approximately 550 days and mortality is low (around 10% $cycle^{-1}$).

The mussel individual and local-scale models have been validated against the Portuguese current production protocol (figure 7).

Figure 7 Detail of socking mussels, Portugal. Credit: *Gary Littler, University of Ulster*

The performance of the typical offshore Mediterranean mussel farm is shown for the present (2000-2019), the near-future (2040-2059), and the far-future (2080-2099) conditions under two emission scenarios: RCP 4.5 –more conservative, and RCP 8.5 –more severe.

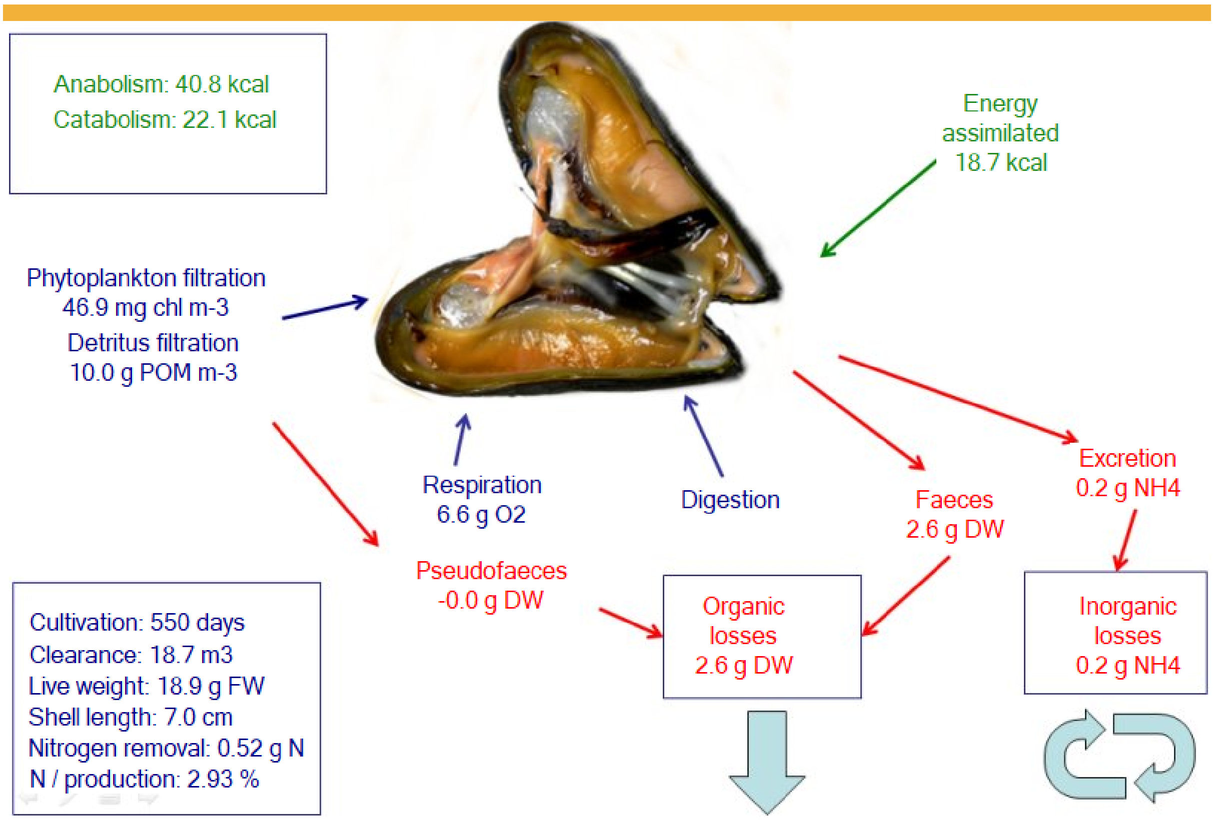


Figure 8. WinShell mass balance results for an individual Med mussel over a full growth cycle at the offshore farm. DW (FW): dry (fresh) weight.

Mussel weight at harvest is very similar under both emission scenarios (Figure 3A).

Same applies to production yield and profit with no significant differences between RCP 4.5 and 8.5 at any time slice, although the average values are greater under 8.5 scenarios – except in the far-future when values for both emission scenarios are very similar (Figure 3 A-C). The better growth performance under the high-emission scenarios is reflected in the greater consumption of food and lower energy expenditure of these mussels and can be mainly explained by greater Chl-a concentrations (Figure 3 D-E). Slightly better average yields and profits were obtained at the mid-term time slice (Figure 3 A-C).

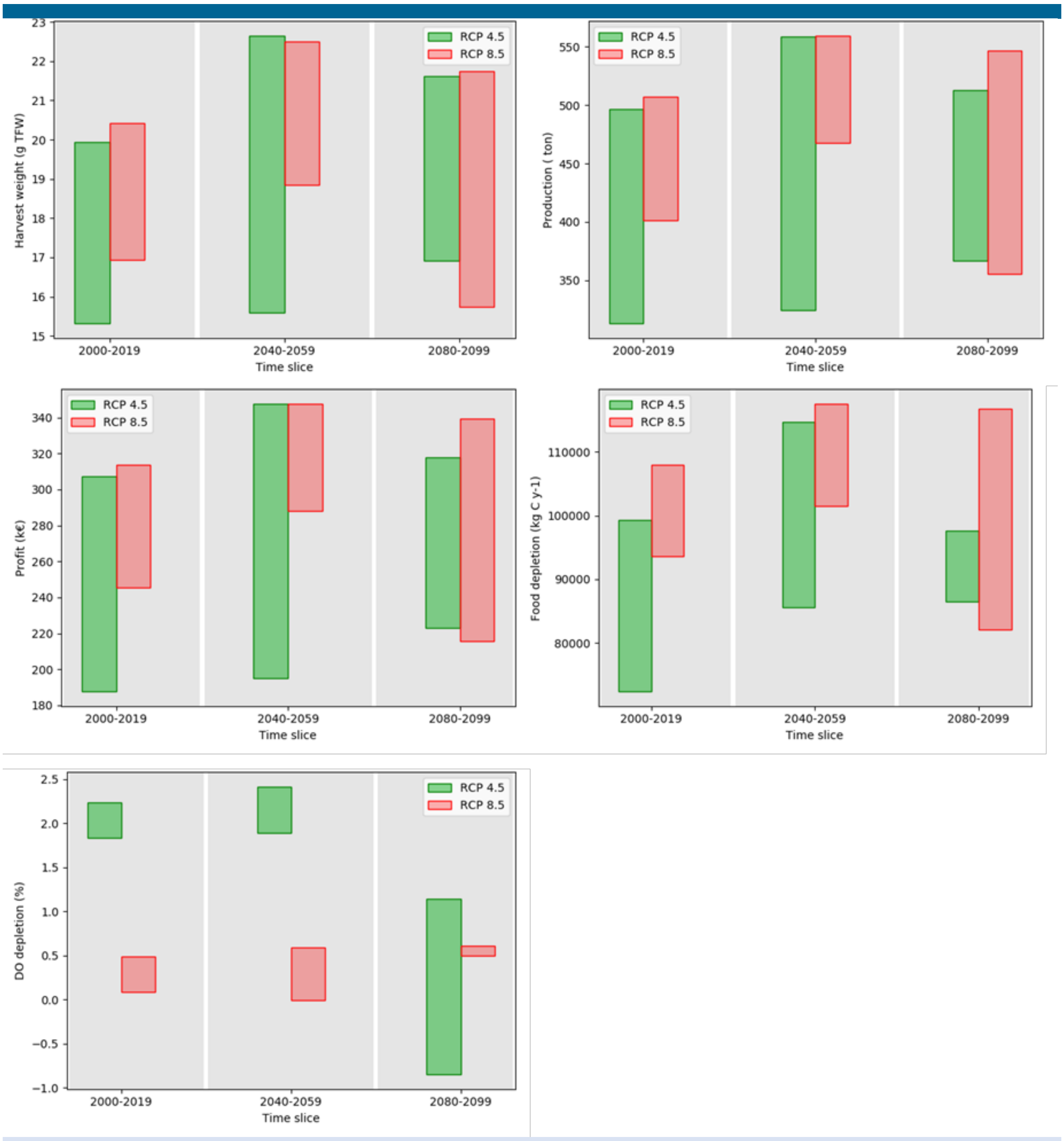


Figure 9 Range of FARM outputs for the typical Med mussel offshore farm in Portugal under the different climate change scenarios. Green and red bars represent the range (spread) of simulation values for the low- and the high-emission scenario, respectively. The drivers for the different climate change scenarios were obtained from the POLCOMS model. LW: live weight; DO: dissolved oxygen.

Economic consequences

Current problems

There are two major economic consequences for mussel farming in SW Portugal, i) extended periods of low food availability (chlorophyll) during upwelling relaxation that compromises the mussel condition, thereby reducing acceptability by the market; and ii) the occurrence of HAB toxins in mussel meat above safety levels for human consumption.

Apart from closure of the market to mussel sales, the high incidence of HAB reported along the Algarve coast in the last years could negatively affect the condition and reproductive cycle of mussels. Previous studies reported a reduction in somatic (body) growth and gonad build-up due to the reduction of filtering capacity in presence of toxic phytoplanktonic cells.

In general, the closure periods vary from weeks to months, according to the intensity and duration of the toxic bloom and the ability of each bivalve species to eliminate the toxins from their tissues.

Closure periods due to HAB in 2018 showed significant economic impact on the mussel production area in the SW Portugal, with the months July to September continuously closed due to toxins, and nearly two weeks in May and October

Potential future threats

Although there are currently no outbreaks of known mussel diseases in SW Portugal, there is potential for future outbreaks.

Figure 10 shows maps for optimal infection days for the protozoan *Marteilia refrigens* that are parasitic on bivalves.

There is clearly an increase for potential infection for the 2050-RCP emission scenarios (bottom left panel in Figure 9).[12]

Nonetheless, the greatest economic threat to the European production of mussels could come from third countries, where production has increased considerably over the past few years concomitant to the decrease in European production. Countries such as New Zealand and Chile are considered as a real threat with low priced, and good quality mussels, flooding the European market.[13]

Climate-ready solutions

Figure 11 is a map of Europe showing an assessment to climate vulnerability. Portugal has one of the higher scores for this assessment and, thus, it is important to analyse whether there are mitigation measures available using an acceptable industry-standard system that enables the integration of all elements of these social ecological systems.

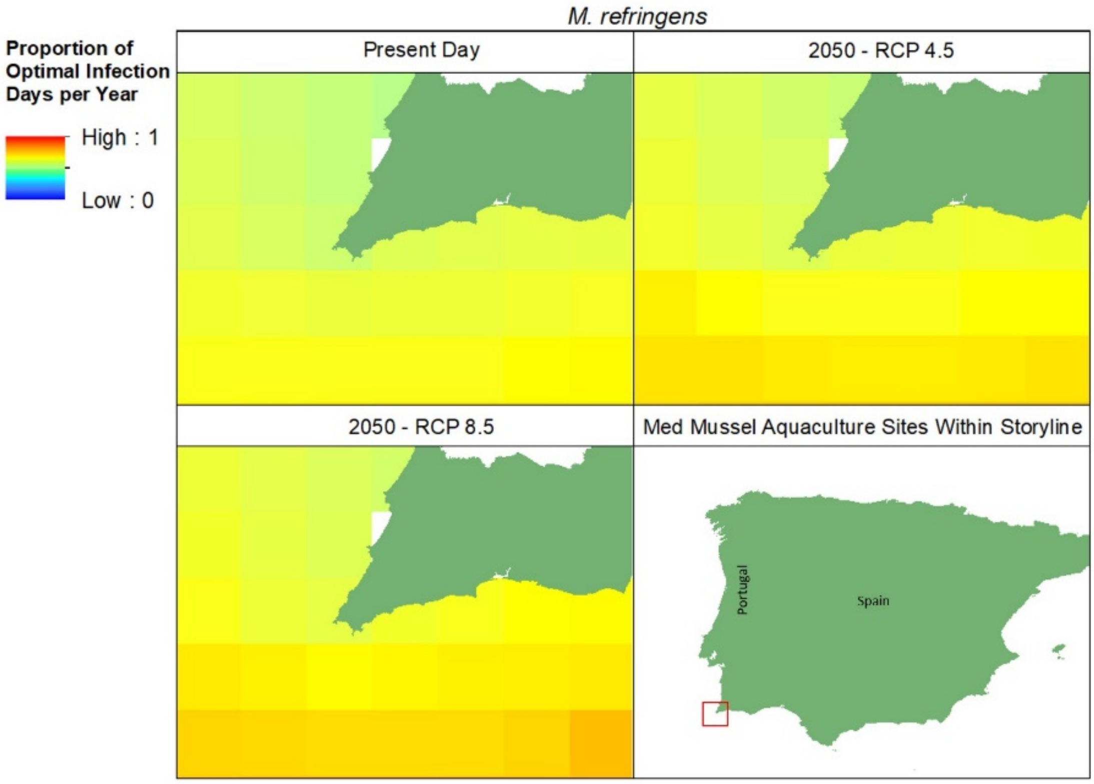


Figure 10 Potential for infection of Med mussel by *M. refrigens*

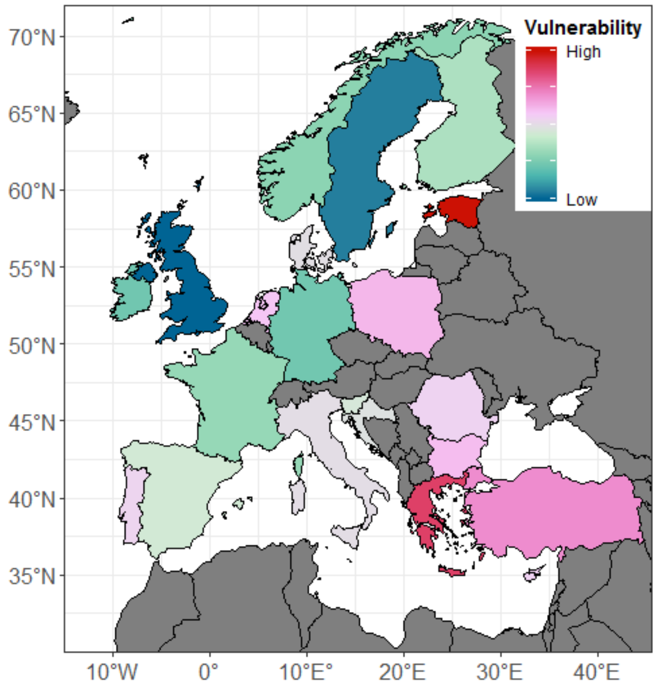


Figure 11 Climate vulnerability assessment for Europe. Colour scale is linear in the value of the corresponding score, but is presented without values, as they have little direct meaning. *Picture credit: Myron Peck*

With CC in mind, stakeholders have been consulted to evaluate present and potential future problems for Med mussel offshore aquaculture as well as identifying how these problems might be mitigated.

In CERES, the information obtained from stakeholders has been processed further through a bow-tie analysis which is an accepted conceptual model for analysing legislation and policies for managing the environmental risks of human activitie.[14]

Additionally, a BBN has been implemented to develop a fully quantified probabilistic model to test the impact of environmental, economic and management changes.[15]

Bow-tie Analysis

The bow-tie for Mediterranean mussel offshore aquaculture has been produced from the contribution of five stakeholders to a CERES online questionnaire. The information from this consultation is shown in figure 12

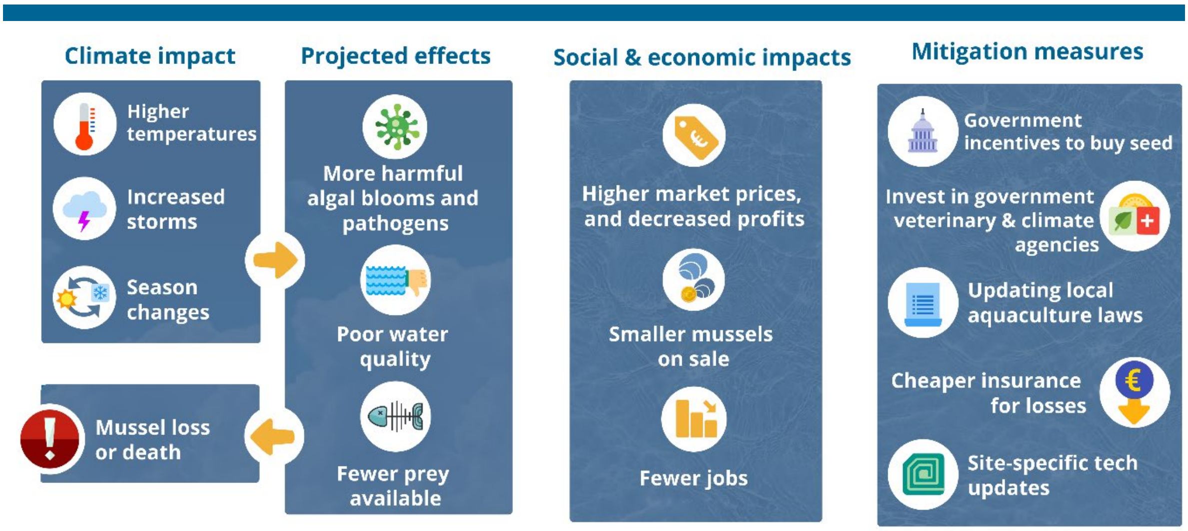


Figure 12 Bow-tie based on stakeholder feedback from a questionnaire for offshore mussel production SW.Portugal.

The narrative presented with a bow-tie diagram can be difficult to interpret, the main outcomes from the interactions with the stakeholders are summarised in figure 12.

Bayesian Belief Network (BBN) for SW Portugal

Bayesian Belief Network[16] approach has been used to test the impact of environmental, economic and management changes on annual profit under various CERES scenarios (figure 13).

Specifically, the model allows testing of individual and combined risks of changes in temperature, chlorophyll, HAB induced farm closure, the production system, mussel prices, costs, mortality and spat recruitment failure.

The tested management measures include the government compensation scheme for HAB (Portaria n°111/2016), a currently discussed protocol for thermal processing to reduce PSP toxin from mussel tissue, and the option of processing fresh mussels into cooked, half-shelled and de-shelled products.

This is seen as potential mitigation measure since cooked products have an extended shelf life which provides flexibility for the farm during periods of closure.

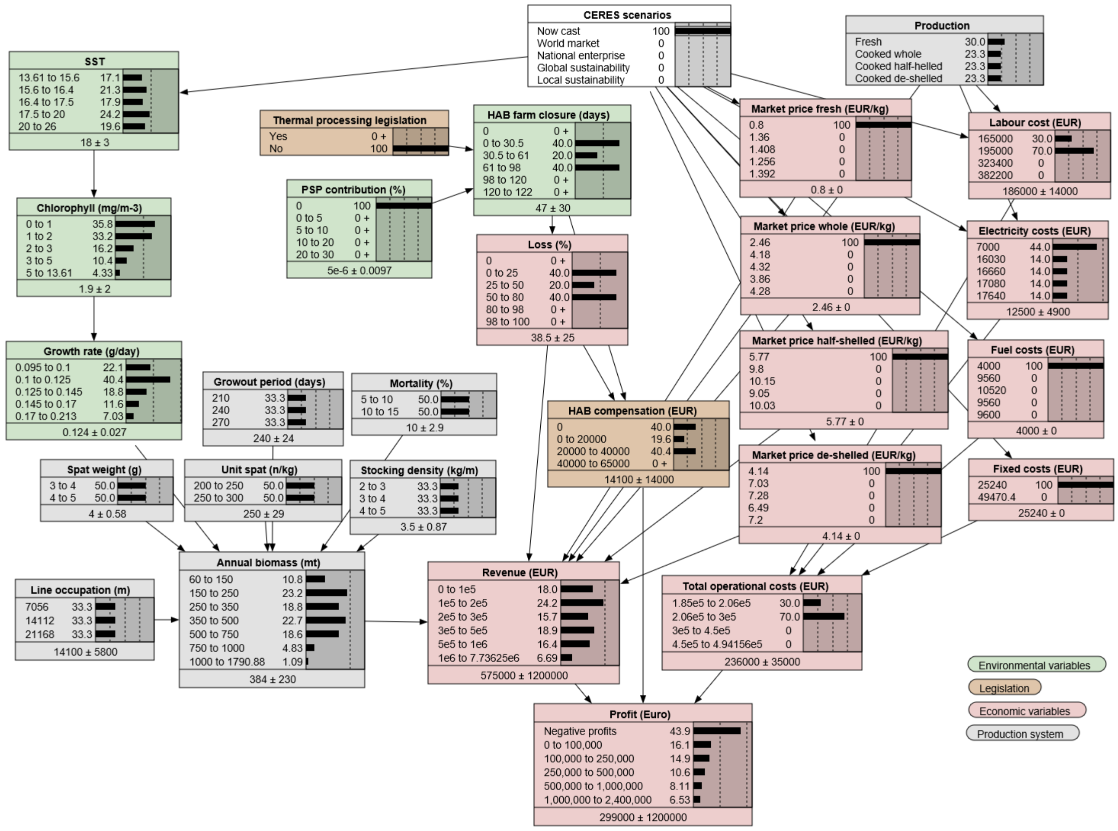


Figure 13 Current BBN model for mussel culture in Southern Portugal.

A suite of 18 scenarios were considered, initially, only the CERES projections for temperature and chlorophyll, mussel prices and fuel and electricity costs, but subsequently these scenarios were regionalised further to include the following assumptions:

- For the **World Markets (WM)** scenario, legislation remains inactive. The length of the farm closures are reduced but there is an increase in the mean mortality from 7.25% to 16.1%. It is assumed that all mussels will be processed for export as de-shelled product, given the lower market price (consumers will go for low value) and de-shelled mussels are often produced when mussel shells are fouled with other organisms that are not appealing to consumers thereby increasing the cleaning costs.
- For the **National Enterprise (NE)** scenario, the legislation (PSP processing and HAB compensation) is enforced as an incentive. As in the previous scenario, farm closures are assumed to decrease with a simultaneous increase in mortality by assuming the same changes in the probability distributions.

- For the **Local Stewardship (LS)** scenario, most of the mussel production will be sold as fresh, because the product will be sourced locally and doesn't need to travel long distances. A reduced volume of product (10%) can be transformed to increase shell life and to supply specific local markets.
- For the **Global Sustainability (GS)** scenario, all the mussel production will be processed and packaged, cooked as whole mussel and half-shell mussel, which allows the highest revenue from the product. The main purpose is to export the products to reach markets that demand environmental and sustainable products and are willing to pay for the sustainable and certified products. A long shelf life product is obtained through processing with ideal characteristics for export.

Finally, the impact of potential management measures for mitigating risk has been tested under the assumption of equal and increased HAB occurrence and subsequent farm closure. The results illustrate the high uncertainty that farmers will likely face. While mean profit is predicted to significantly increase in 17 out of 18 scenarios, especially if processing is introduced, there is a similar probability for both zero profits as well as high profit margins. Mitigation measures, if implemented, may circumvent these risks mostly by managing closure due to HAB. Biological changes have relatively little influence on annual production (40 mt annually). Whether benefits can be gained will also depend on demand for different processed products. Three main results have emerged from the scenarios.

- First, projected changes in SST and Chla has little impact on annual biomass (maximum increase of 40 mt or 4 % under RCP8.5). This is not surprising given that the Med. Mussel is still well within its optimum growth conditions and projected changes until 2050 are relatively small (on average 0.2 to 0.4°C increase in SST and 0.33 to 0.4 mg/m3 increase in Chla between the baseline and future conditions).

- The second result is the identified high risk (uncertainty), despite the prediction for exceptional increases for mean annual profit in 17 out of the 18 scenarios. For the regionalised scenarios, increases ranged from 47% for the World Market scenario to 1000% for the Global Sustainability scenario, respectively. However, these numbers can be deceptive. In almost half of the scenarios there is a similar likelihood of having either no profits or high profits. Indeed, half of the scenarios, show that no profit is the most likely outcome (ranging from 22% to 48%), whereby farmers may make fortune in a good year and face bankruptcy in a bad year.

- The third result includes management measures which can significantly contribute to increases in profits, but they do not all have the same capacity to reduce risk. Processing mussels into high(er) level products has the potential to increase profits and to provide a buffer against economic losses from HAB induced farm closure. However, this depends on the product. Whole cooked and half-shelled mussels provide on average more than three times the revenue compared to fresh and cooked de-shelled products. Processing increases the shelf life and therefore provides greater flexibility to react to demand.

However, if HAB farm closures intensify, harvest levels may be reduced thereby increasing the risk of no profits. An early warning system of HAB occurrence would certainly help to plan harvests.

In most scenarios where HAB compensation has been provided, uncertainty and risk of negative profits decrease significantly. If PSP processing is introduced in the future it would not aid farmers because current PSP contribution to farm closure is so low (0-5%) that this procedure would have minimal effect on annual profit.

Although if community composition did in fact change towards PSP producing dinoflagellate, this could have a significant effect.

Importantly, the PSP processing procedure only works at low toxicity levels and only when canned mussels are produced.

In summary, if the tested management measures are implemented, they can help alleviate some of the risks of mussel farming but only within limits. Offshore mussel farming will always be a high risk - high pay-out endeavour with permanent trade-offs.

Even though, CC related effects, as predicted under CERES suggest little additional risk, local evidence of warming, intensification of HAB and recruitment failure make the Algarve coast a test case for extreme events directly and indirectly related to CC that may shed light onto what may happen in the future.

Policy recommendations

- Aquaculture is of strategic national importance to Portugal, but there needs to be an increased coherence between governance, research and industry to address gaps in policy and to improve all aspects of how the aquaculture industry operates. A good example would be an improvement to the ponderous licensing procedure.

- A strategic marketing policy is also required to ensure that mussel sales from Portugal are economically viable and can compete with both the classical producers (Spain, France) and more recent producers (Chile, New Zealand).

- There is serious problem with HAB in Portugal. Improvements to mandatory monitoring by increasing the response time for publishing the results from samples and by reducing the size of the monitoring areas would be beneficial to framers. Also, a fully functional insurance scheme to compensate farmers for extensive periods of farm closure.

- Although there is a strategic plan for aquaculture (2014-2020), this plan does not specifically mention adaption to CC, except to avoid erosion to protect coastlines. There should be a specific policy focus on the effects of CC on aquaculture.

- In relation to CC, there also needs to be active engagement with farmers to ensure that any potential opportunities are taken to culture different species based on suitability maps and environmental requirements, as well providing the adequate culture practice.

- Institutions responsible for governance of aquaculture in Portugal should also look at how other countries, such as New Zealand, have developed successful offshore aquaculture over a relatively short time period. Long term funding (7 years) is provided to the industry in collaboration with researchers to resolve any problems affecting the industry.[17]

Further reading

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