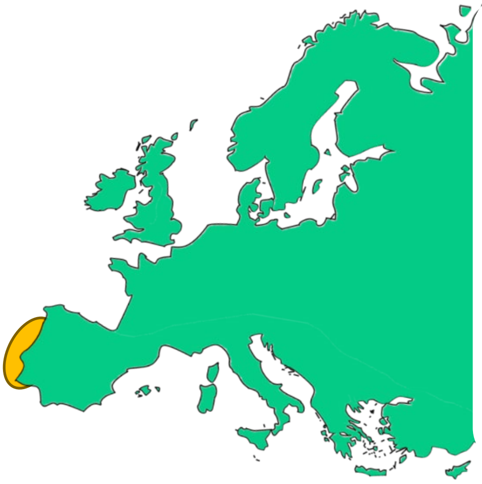
CERES

Case study



#8 Oysters and clams in the Atlantic coast

#9 Mussels in the Mediterranean

#10 Salmon in the north-east Atlantic

Species background and economics

In Portugal, the production of bivalves is an important social and economic activity, with a great growing potential, due to the edaphic-climatic and geographic conditions.

Bivalves accounted for 45% of the total Portuguese aquaculture production in 2014.

Artisanal production of bivalve mollusks is mainly based on the culture of the European clam (*Ruditapes decussatus*) (2.251 tons) and oysters (*Crassostrea* sp.) (1.085 tons) (DGRM, 2016).

Currently, France is the largest consumer of oysters reared in Portugal.

The European clam (*R. decussatus*) is widely distributed along the coastal and estuarine areas of Europe and North Africa.

This commercially valuable clam is extensively produced and harvested in Portugal where clam farming, representing 44% of all bivalve production in 2015, is an important economic sector.

Clams are produced within the inter-tidal zone where their farming depends on the seeding of plots with juveniles collected from natural beds.

Clams are harvesting at commercial size normally after 24 months.

During the last two decades, the production of European clams has markedly declined due to a combination of recruitment failure and adult mortality.

This decreases in the health and fitness of clams has likely been caused by decreases in water quality related to changes in seasonal weather patterns such as increased heatwaves.

Until the 1970s, in Portugal and France the Portuguese oyster *Crassostrea angulata* was a relevant species for the shellfish industry.

However, this species started to become affected by a viral disease in the late 1960s, and its exploitation collapsed.

To overcome this situation, *C. gigas* was illegally introduced in the 90s, despite being considered as an exotic species, and currently is an important biological and economic resource.

Figure 1 Ruditapes decussatus and Crassostrea angulata juveniles from aquaculture in SW Portugal. *Credit: Ana Margarete Matias and Ana Rato, IPMA*

Expected projections under climate change

CERES has examined the effects of two, carbon emission scenarios.

In RCP (representative concentration pathway) 4.5, the carbon concentrations are stabilised at ~650 ppm shortly after 2100 due to more rapid reduction of carbon emissions.

In RCP 8.5, emissions create concentrations of carbon up to 1370 ppm[1].

Based on projections for eastern Atlantic and Mediterranean, sea surface temperature will increase up to 2°C for Atlantic coastal areas of southern Europe by the end of this century under RCP 8.5 (Figure 2b,c). Under scenario RCP 4.5, warming is about half that projected for RCP8.5 (e.g. 1°C) (Figure 2a,c).

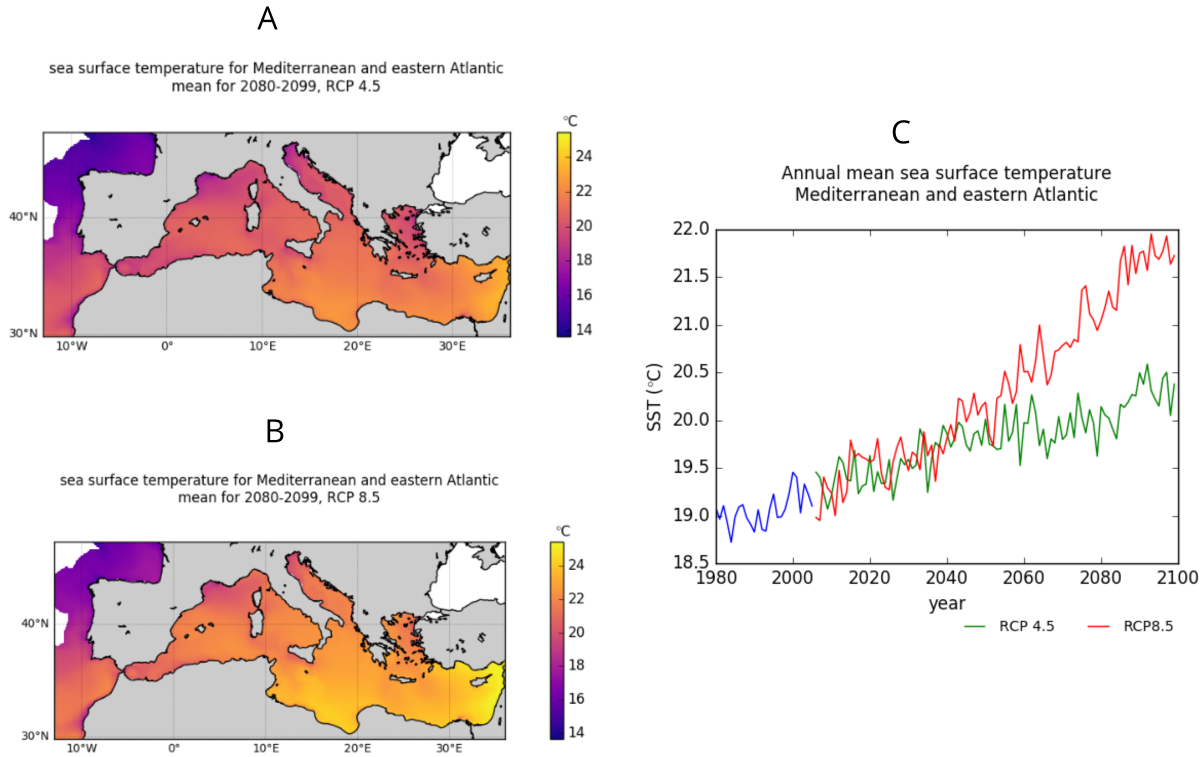


Figure 1 Projected change in sea surface temperature for the Southern European region (a,b) Mean temperatures for 2080-2099 compared to 2000-2019 under (a) RCP 4.5 and (b) RCP 8.5. (c) Annual mean for the same region. The white area at the left (a,b) is not part of the modelled domain.

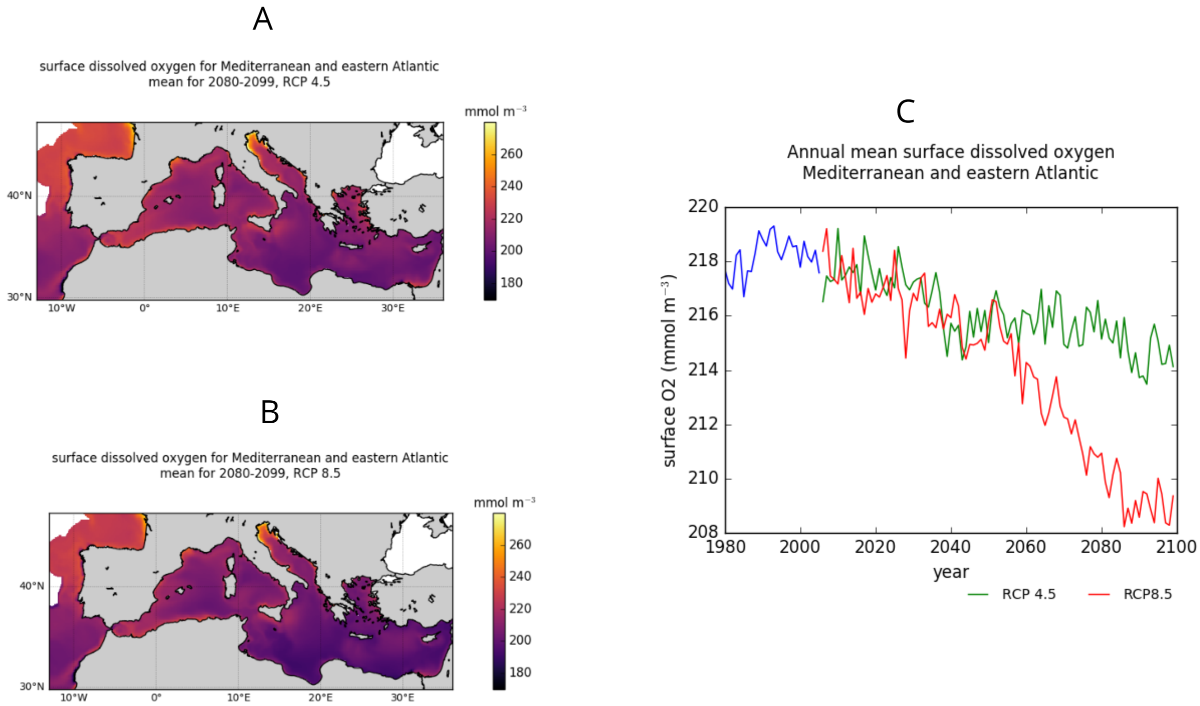


Figure 3 Projected change in sea surface dissolved oxygen for the Southern European region (a,b) Mean dissolved oxygen for 2080-2099 compared to 2000-2019 under (a) RCP 4.5 and (b) RCP 8.5. (c) Annual mean for the same region. The white area at the left (a,b) is not part of the modelled domain.

Surface dissolved oxygen will decrease up to 10 mmol m^{-3} for Atlantic and Mediterranean coastal areas of southern Europe by the end of this century under RCP 8.5 (Figure 3b,c). Under scenario RCP 4.5, warming is about half that projected for RCP8.5 (e.g. 5 mmol m^{-3}) (Figure 3a,c).

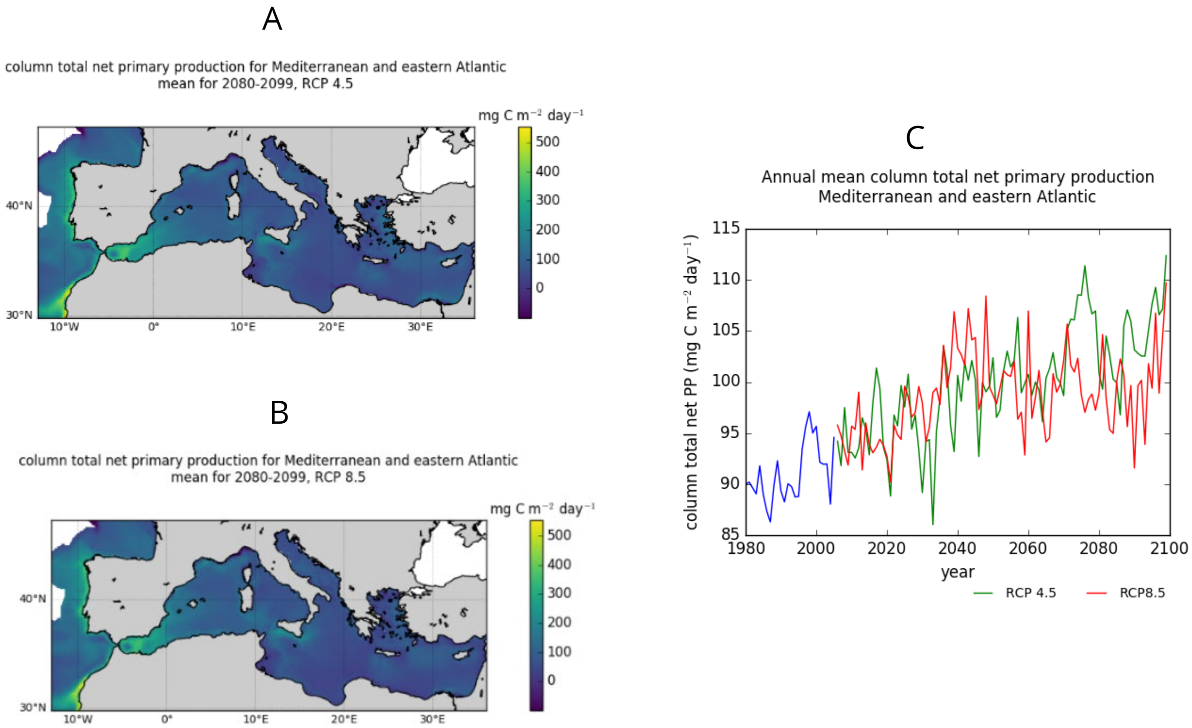


Figure 4 Projected change in column total net primary production for the Southern European region (a,b) Mean column total net primary production for 2080-2099 compared to 2000-2019 under (a) RCP 4.5 and (b) RCP 8.5. (c) Annual mean for the same region. The white area at the left (a,b) is not part of the modelled domain.

Column total net primary production will increase up to 20 mg C m^{-2} day^{-1} for eastern Atlantic and Mediterranean coastal areas of southern Europe by the end of this century under RCP 8.5 and RCP 4.5 (Figure 4a,b,c).

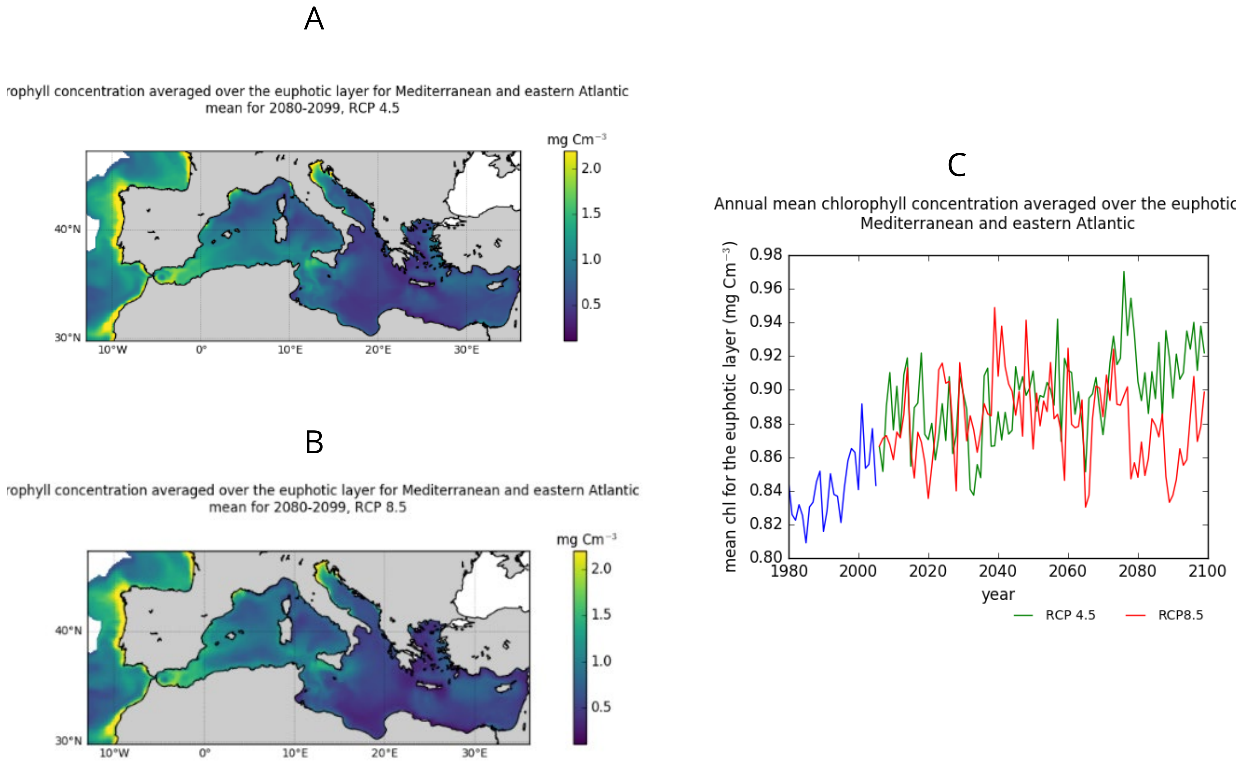


Figure 5. Projected change in chlorophyll concentration for the Southern European region (a,b) Mean chlorophyll concentration for 2080-2099 compared to 2000-2019 under (a) RCP 4.5 and (b) RCP 8.5. (c) Annual mean for the same region. The white area at the left (a,b) is not part of the modelled domain.

Chlorophyll concentration will increase up to 6 mg cm^{-3} for eastern Atlantic and Mediterranean coastal areas of southern Europe by the end of this century under RCP 8.5 and RCP 4.5 (Figure 5a,b,c).

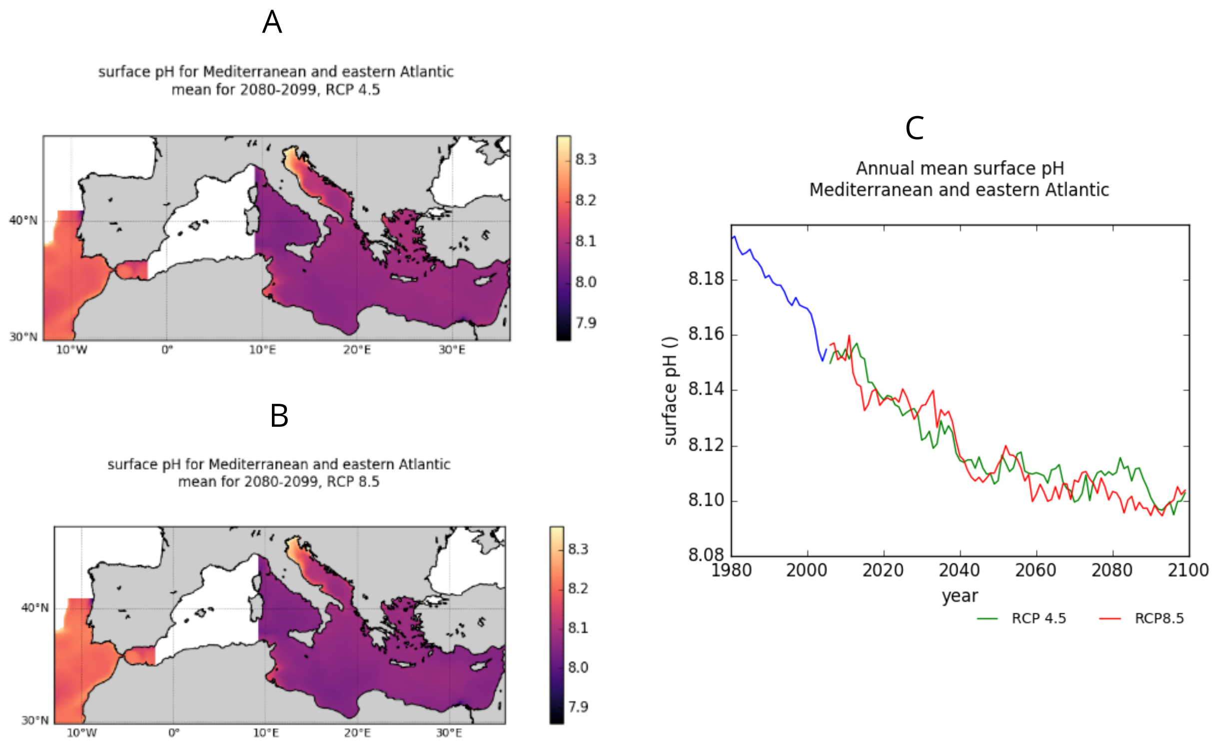


Figure 6 Projected change in sea surface pH for the Southern European region (a,b) Mean sea surface pH for 2080-2099 compared to 2000-2019 under (a) RCP 4.5 and (b) RCP 8.5. (c) Annual mean for the same region. The white area at the left (a,b) is not part of the modelled domain.

Sea surface pH will decrease up to 0.06 for eastern Atlantic and Mediterranean coastal areas of southern Europe by the end of this century under RCP 8.5 and RCP 4.5 (Figure 6a,b,c).

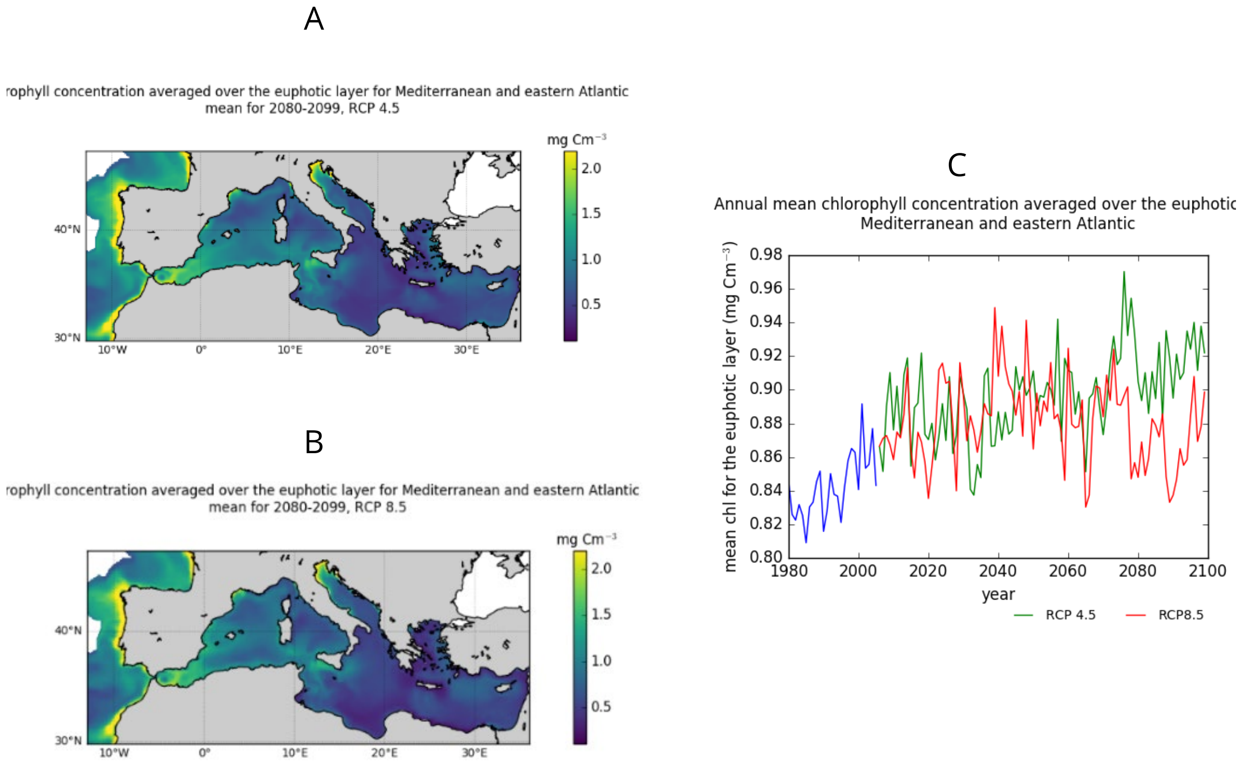


Figure 7 Projected change in chlorophyll concentration for the Southern European region (a,b) Mean chlorophyll concentration for 2080-2099 compared to 2000-2019 under (a) RCP 4.5 and (b) RCP 8.5. (c) Annual mean for the same region. The white area at the left (a,b) is not part of the modelled domain.

Sea surface salinity will increase up to 0.2 psu for eastern Atlantic and Mediterranean coastal areas of southern Europe by the end of this century under RCP 8.5, and up to 0.1 psu under RCP 4.5 (Figure 7a,b,c).

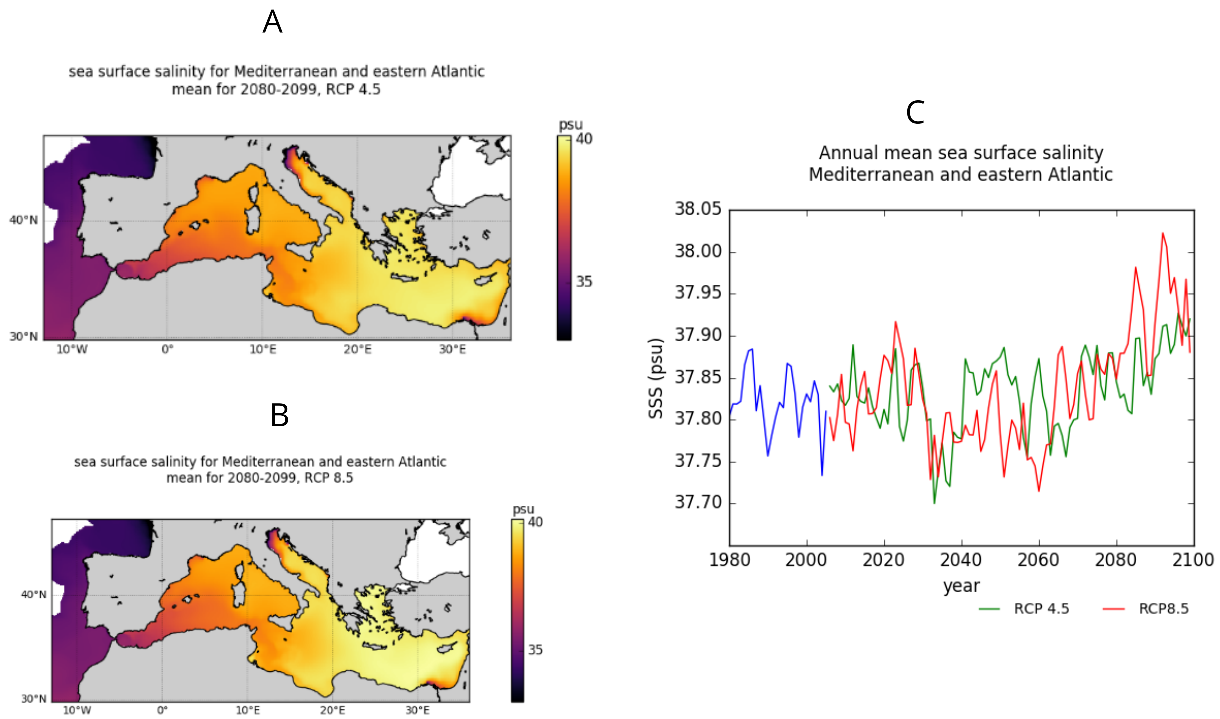


Figure 8 Projected change in sea surface salinity for the Southern European region (a,b) Mean sea surface salinity for 2080-2099 compared to 2000-2019 under (a) RCP 4.5 and (b) RCP 8.5. (c) Annual mean for the same region. The white area at the left (a,b) is not part of the modelled domain.

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'

- Personal independence, high mobility and consumerism
- Reduced taxes, stripped-away regulations
- Privatised public services
- High fossil fuel dependency
- Highly engineered infrastructure and ecosystems

'National enterprise'

- 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'

- High priority for welfare and environmental protection
- Cooperative local society
- Intense international cooperation
- Increased income equality
- Low resource intensity and fossil fuel dependency

'Local stewardship'

- 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

The Portuguese government has defined aquaculture as strategic sector, and has established financial frameworks to boost production, which is expected to triple by 2023, reaching 30 000 t.

Under the four RCP scenarios[6], the projected seafood demand for Portugal decreases except in the World Markets Scenario (RCP 8.5 SSP5), where demand is projected to increase 100,000 t by 2100.

This increase in demand is explained by the demographic and *per capita* GDP growth that is expected to occur under this scenario.

The expected scenario for Southern Europe and Mediterranean aquaculture is the global sustainability scenario, protecting the public and preventing the deterioration of marine environments.

Under this scenario, it is expected a strong decrease in human population, but a moderate economic growth in *per capita* GDP.

A decrease in *per capita* consumption of seafood is expected, following the decrease in human population growth, with major consequences for the future demand for marine aquaculture products.

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.

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.

Binding international quality standards are reached and this results in strict regulation of aquaculture practices as well as 'traceability'.

Ecolabel certification schemes assume greater prominence (e.g. organically produced, 'fair-trade', ethically produced, sustainably produced). Expansion of large-scale offshore aquaculture facilities together with windfarms offshore are expected, as well as wide-scale technology transfer between countries. It will become increasingly difficult to obtain licences to build new aquaculture facilities because of environmental concerns.

Key research needs

There is currently a lack of knowledge on how direct and indirect effects of climate change will alter the farming of bivalves (mussels, clams and oysters).

Controlled experiments are needed to test how factors such as temperature and salinity interact with prey availability to impact the growth and survival of different species.

Moreover, these experiments can contribute as general improvements to the industry and will make the sector more resilient to the potential negative (or positive) effects of climate change.

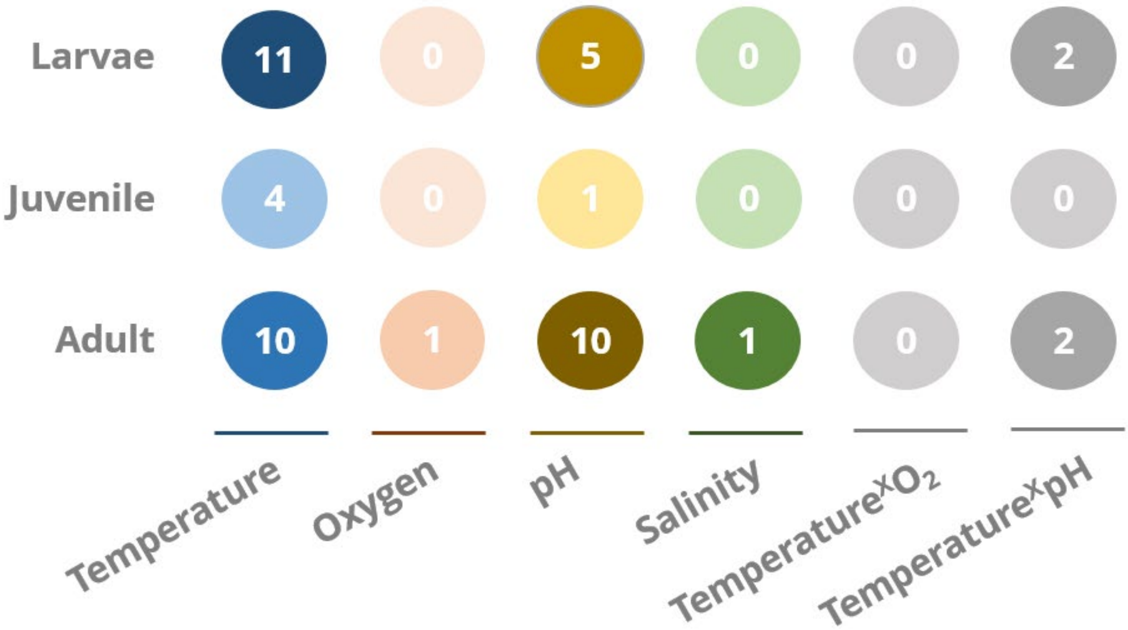
Examples of its application include the development of modelling tools for more effective spatial planning and sustainable management of farms currently competing for space in coastal areas.

Also, the product differentiation and creation of new markets can be beneficed by assessing the behaviour of an alternative species (Portuguese oyster, *C. angulata* and Pullet carpet shell, *Venerupis senegalensis*) under different climate changes scenarios.

CERES research

- Reviewed the published research to identify gaps in knowledge on how clams and oysters are affected by factors directly influenced by climate change (temperature, pH, oxygen and salinity)
- Conducted controlled laboratory experiments examining the combined effect of temperature and salinity on survival and behaviour of juveniles and adults oyster *C. angulata* and European clam (*R. decussatus*)
- Engagement with external stakeholders (e.g. shellfish farmer’s association) to gain their perspectives on the risks and potential mitigation measures associated with climate change.

Biological consequences



- Oysters, consisting of 2 genera, each ranked 13 out of 28 European fish and shellfish genera reviewed here (5 studies each).
- 5 studies were performed in the North Sea. Further studies were conducted at the North Sea (3, SL 6), outside the SL areas (2) and outside Europe (7).
- Most studies were conducted in France (6)
- Growth and mortality were the most common response studied
- Temperature was investigated in all studies on oysters, partly including interactions with other stressors.

- Ruditapes spp. ranked 2 out of 28 European fish and shellfish reviewed here (21 studies).
- Most studies were conducted in Portugal (13) and Spain (4).
- Research focus mainly lay on adults (13).
- All response variables were well covered.

Direct effects

Juvenile and adult of European clams and Portuguese oysters were exposed for 120 hrs to one of eight temperatures (5; 15; 20: 23; 26; 29; 32; 35°C) at one of nine salinities (0; 5; 10; 15; 20; 25; 30; 35; 40). For each T x S condition, 3 replicates were used and survival and behaviour were assessed every 24 hours.

Aquaria were maintained at 12 light: 12 dark photoperiod and continuous aeration. Animals were fed with equal diet (50% *Isochrisys galbana* + 50% *Chaetoceros calcitrans*), seawater were renewed every day, and temperature and salinity levels re-established. Dead organisms were removed when identified.

In juveniles, the highest survival occurred at salinities between 25 and 40 and temperatures below 29°C.

For adult clams, high survival occurred at salinities between 20 and 40 at temperatures between 20-23°C.

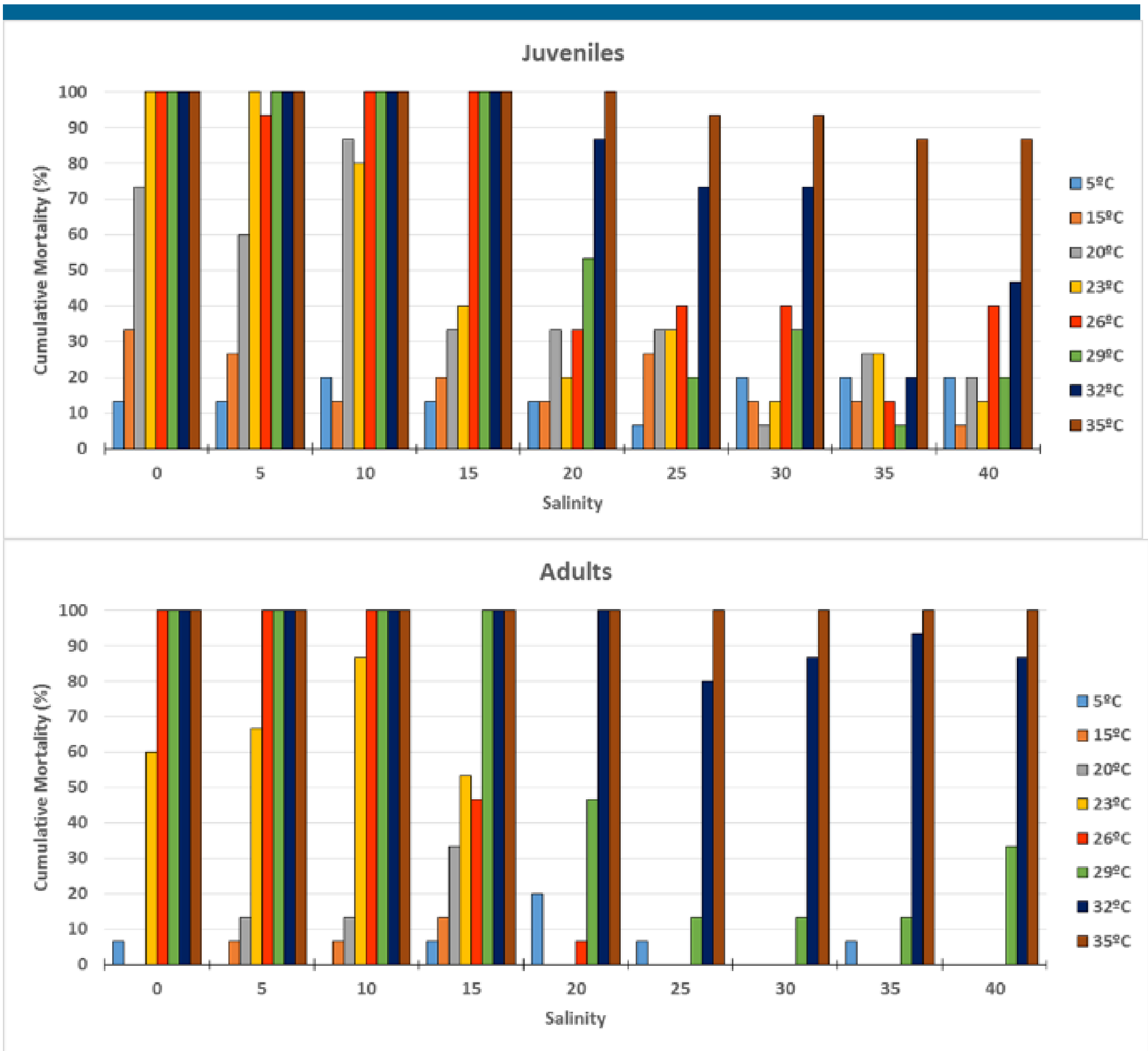


Figure 8 Combined effect of temperature and salinity on mortality in juveniles and adults of European clams (*Ruditapes decussatus*)**.**

The behavioural activity of juveniles increased with increasing salinity and was maximum at 20°C at a salinity of 40.

In contrast, almost no activity was observed in adults at low salinities, reaching its maximum activity at temperatures of 5°C and 29°C, and at salinity of 40.

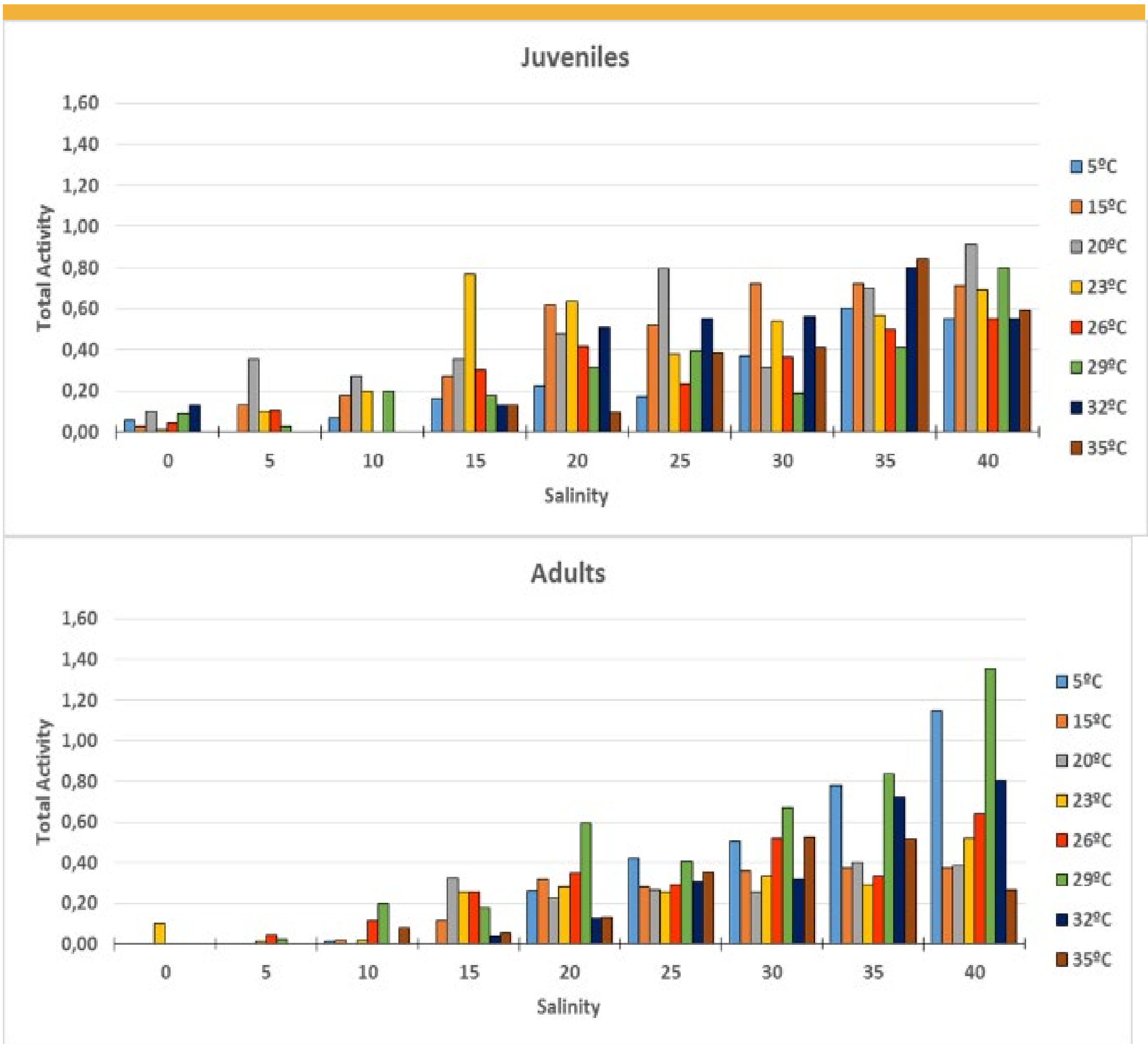


Figure 9 Combined effect of temperature and salinity on activity in juveniles and adults of European clams (*Ruditapes decussatus*).

Such conditions my lead to recruitment failure of European clam and greatly compromise the exploitation of the species.

Oysters were very resistant to the combined effect of temperature and salinity during the 5-day period.

Mortality was only observed at salinities below 15 at high temperatures.

Survival of both juveniles and adults was optimal at salinities between 20 to 40 at all temperatures tested.

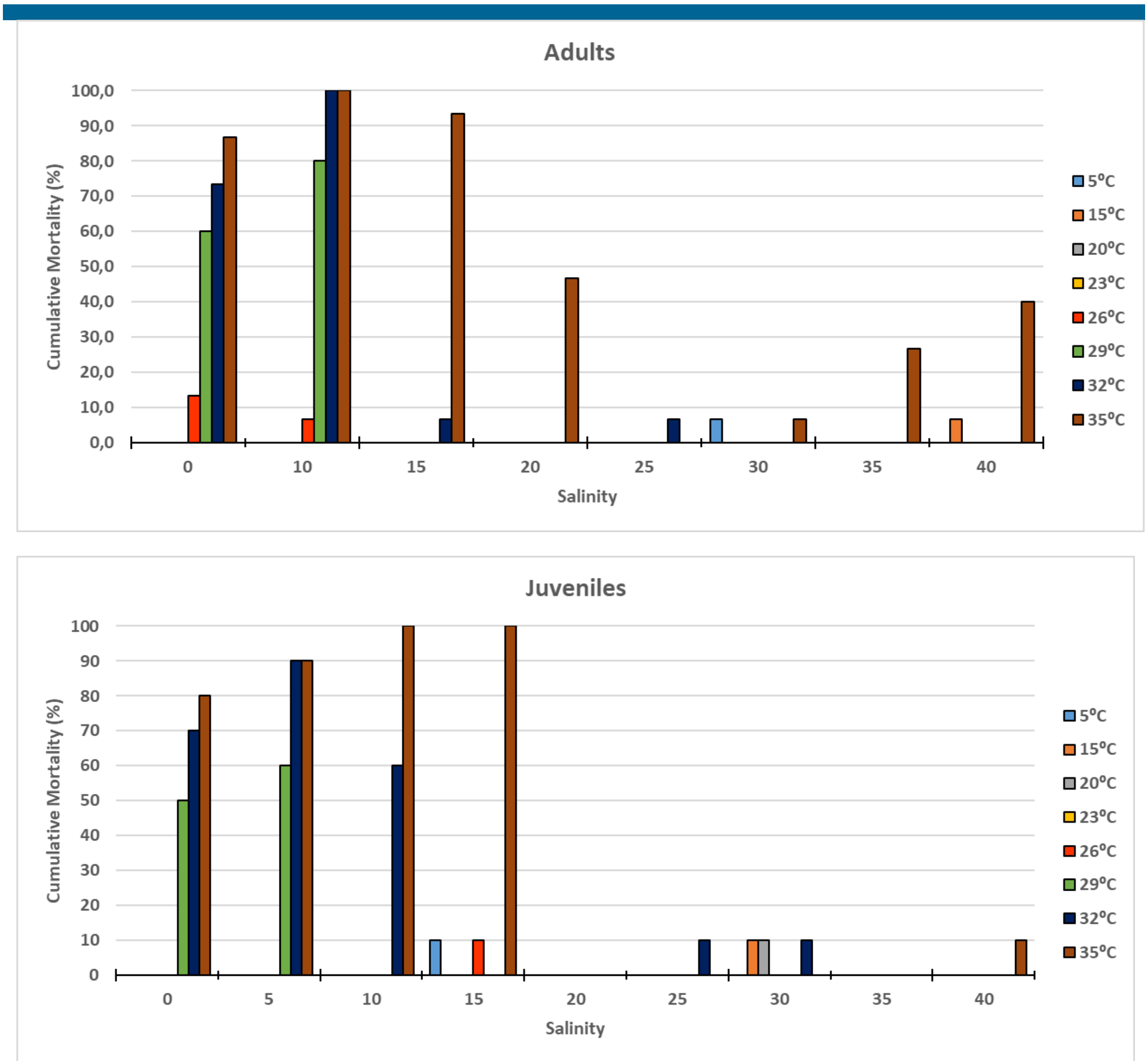


Figure 10 Combined effect of temperature and salinity on mortality in juveniles and adults of Portuguese oyster (*Crassostrea angulata*).

Climate changes in south of Portugal are expected to be characterized by heavy and sporadic rainfall and high temperatures that will contribute to a drastic reduction in salinity and an increase in seawater temperature.

The results clearly indicate that in these conditions, juveniles of *R. decussatus* may suffer higher mortalities if confronted with periods of low salinity and high temperatures.

On the other way, abrupt reductions in salinity will lead to high mortality of *C. angulata* (either in adults and juveniles). Adults may suffer higher mortalities from the combination of low salinity and high temperatures.

Climate-ready solutions

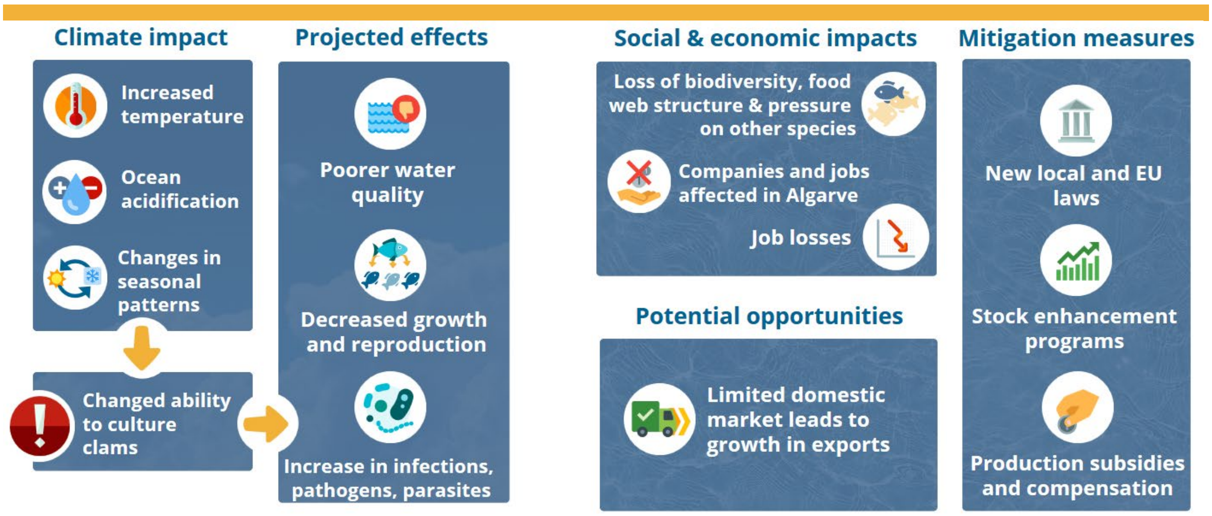


Figure 11 Bowtie created based on stakeholder feedback through questionnaire for European clam production in South Portugal. All full BowTies available http://bit.ly/CERESbowties2020 *Image: Katy Smyth*

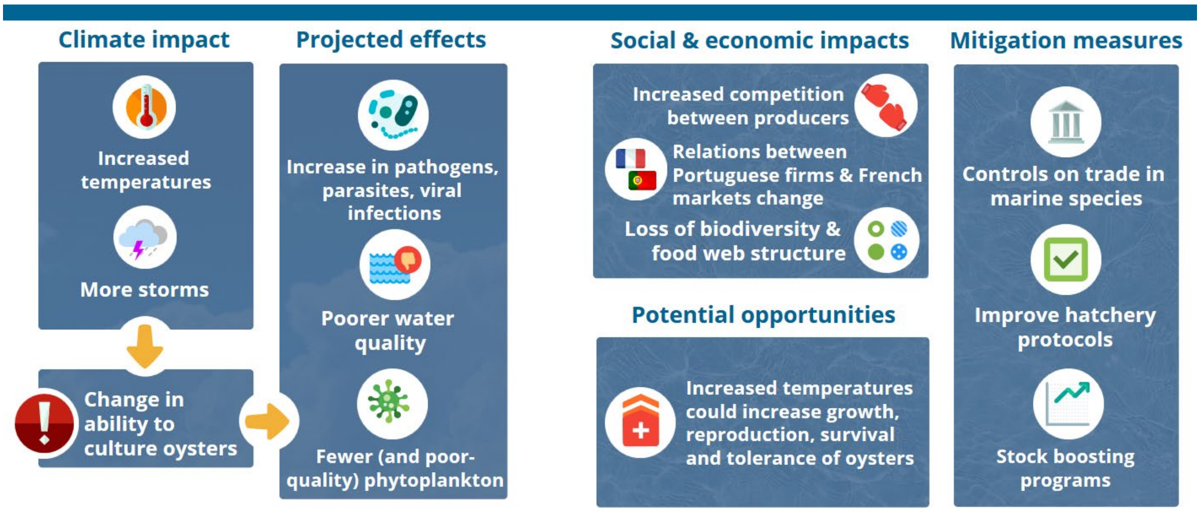


Figure 12 Bowtie created based on stakeholder feedback through questionnaire for oyster production in South Portugal. All full BowTies available http://bit.ly/CERESbowties2020 *Image: Katy Smyth*

Vulnerability analysis

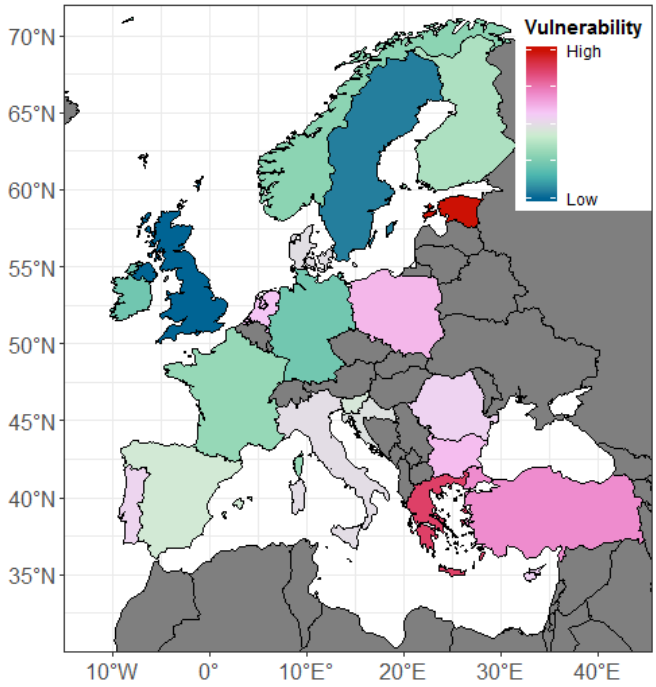


Figure 6 Climate vulnerability assessment for Europe. Colour scale is linear in the value of the corresponding score, but is presented without values, as they have little direct meaning. *Picture credit: Myron Peck*

- A climate vulnerability assessment (CVA) was conducted on the European aquaculture sector using the FAO model of Exposure + Sensitivity + Adaptive Capacity.
- The CVA included the physiological and farming methods of seven species (Atlantic salmon, sea bass, sea bream, trout, carp, mussels, oysters and clams) representing > 95% of the value for the region.
- Based on available economic data, the vulnerability of 22 countries – the top producers in the Europe28 as well as Norway and Turkey – was ranked and relative values are shown (right)
- By 2050, warming associated with RCP8.5 caused little change in the suitability of culture conditions for most species in most regions, including clams and oysters in the North Sea. Although direct effects of warming were small, inter-tidal areas may warm strongly and decreases in rainfall and potential heatwaves were not included in this assessment.

- Farming shellfish is inherently vulnerable due to the lack of control of the production cycle and the fact that most firms are very small (family-level) with very low adaptive capacity.

- At the national level, Portugal has made good progress towards implementing a national climate adaptation plan but much of its current aquaculture production relies on clam culture.

For bottom-up - mitigation measures

Clams:

- Increase government incentives subsidies to improve production technologies & compensation payments to mitigate the cost of massive mortalities.
- Adapt new technologies aiming to improve hatchery protocols of the most important parameters affected by climate change.
- Development stock enhancement programs with resistant & adapted spat.
- Reinforcement of dredging in lagoon systems, in order to increase water renewal and consequently food availability.
- Incentivise catch/culture of unexploited bivalve species.
- Promote production of alternative stock, e.g. *Venerupis senegalensis*.
- Promote the eating of unexploited bivalve species to increase their value.
- Improve farm management by placement in areas of climate refugia (areas with low probability of CC impacts).

Oysters:

- Improve fisheries management based on model production areas with low probability of CC affects.
- Increase subsidies to improve production technologies and compensation payments to mitigate the cost of massive mortalities.
- Improve hatchery protocols with gradual alterations of the most important parameters affected by CC aiming to produce more adapted spat.
- Promote the creation of new rearing systems.
- Create programs with the incentive to catch unexploited bivalves.
- Promote restocking programs.
- Cost efficient production technologies.
- Encourage tourists to consume alternative shellfish products.

Policy recommendations

Clams:

- Control of illegal spat & adult catch in natural bank aim to increase spawning stock.
- Adopt and reinforce EU Invasive alien species regulation.
- Promote the eating of unexploited bivalve species to increase their value.
- Create measures to control the catch and commercialization of natural spat and transfer between ecosystems.
- Adapt the local law to the new climate conditions.
- Support the producers in case there is a need to change the productive structure.

Oysters:

- Adopt new legislation on animal welfare and adjust coastal production areas.
- Control programme for disease.
- Improve sanitary control of imported spat.
- Improve EU invasive alien species regulation.

Further reading

CERES publications:

1) Rato, A., Joaquim, S., Matias, A. M., Marques, A., Matias, D. (2018). Combined effect of salinity and temperature on mortality and behaviour of European clams *Ruditapes decussatus*. Book Abstract. 48th WEFTA 2018, 15th-18th October, Lisboa, Portugal.

Other publications:

2) Botelho M.J., Soares F., Matias D., Vale C., 2015. Nutrients and clam contamination by Escherichia coli in a meso-tidal coastal lagoon: Seasonal variation in counter cycle to external sources. Marine Pollution Bulletin, 96(1-2), 188-196. doi: 10.1016/j.marpolbul.2015.05.030.
3) Carregosa V., Velez C., Soares A.M.V.M., Figueira E., Freitas R. (2014). Physiological and biochemical responses of three Veneridae clams exposed to salinity changes. Comparative Biochemistry and Physiology. 177:1-9.

4) M. Clark, M. Thorne, A. Amaral, F. Vieira, F. Batista, J. Reis, D. Power. 2013. Identification of molecular and physiological responses to chronic environmental challenge in an invasive species: the Pacific oyster *Crassostrea gigas*. Ecology and Evolution 3 (10): 3283-3297.
5) Massapina C., Joaquim S., Matias D., Devauchelle N., 1999. Oocyte and embryo quality in *Crassostrea angulata* (Portuguese strain) during a spawning period in Algarve, South of Portugal. Aquatic Living Resources, 12 (5), 327 – 333.
6) Matias D., Joaquim S., Leitão A., Massapina C., 2009. Effect of geographic origin, temperature and timing of broodstock collection on conditioning, spawning success and larval viability of *Ruditapes decussatus* (Linné, 1758). Aquaculture International 17, 257-271.
7) Matias D., Joaquim S., Matias A.M., Leitão A., 2016. Reproductive effort of the European clam *Ruditapes decussatus* (Linnaeus, 1758): influence of different diets and temperatures. Invertebrate Reproduction & Development, 60 (1): 49-58. http://dx.doi.org/10.1080/07924259.2015.1126537.
8) Matias D., Joaquim S., Matias A.M., Moura P., Teixeira de Sousa J., Sobral P., Leitão A, 2013. The reproductive cycle of the European clam *Ruditapes decussatus* (L., 1758) in two Portuguese populations: Implications for management and aquaculture programs.
9) Matias D., Joaquim S., Ramos M., Sobral P., Leitão A., 2011. Biochemical compound's dynamics during larval development of the carpet-shell clam *Ruditapes decussatus* (Linnaeus, 1758): Effects of mono-specific diets and starvation. Helgoland Marine Research 65 (3), 369-379.
10) Barros P., Sobral P., Range P., Chícharo L., Matias D. 2013. Effect of sea-water acidification on fertilization and larval development of the oyster *Crassostrea gigas*. Journal of Experimental Marine Biology and Ecology 440: 200-206
11) Range P., Chícharo M.A., Ben-Hamadou R., Piló D., Matias D., Joaquim S., Oliveira A.P., Chícharo L.. 2011. Calcification, growth and mortality of juvenile clams *Ruditapes decussatus* under increased pCO2 and reduced pH: Variable responses to ocean acidification at local scales? Journal of Experimental Marine Biology and Ecology. 396, 177-184.
12) Anacleto P., Maulvault A.L., Lopes V.M., Repolho T., Diniz M., Nunes M.L., Marques A., Rosa R.. 2014. Physiological ecology does not explain invasive success: an integrative and comparative analysis of biological responses in native and alien invasive clams in an ocean warming context. Comparative Biochemistry and Physiology Part A. 175: 28–37.

13) Sousa J.T., Joaquim S., Matias D., Ben-Hamadou R., Leitão A., 2012. Evidence of non-random chromosome loss in bivalves: Differential chromosomal susceptibility in aneuploid metaphases of *Crassostrea angulata* (Ostreidae) and *Ruditapes decussatus* (Veneridae). Aquaculture 344-349, 239-241.

14) Sousa J.T., Matias D., Joaquim S., Ben-Hamadou R., Leitão A., 2011. Growth variation in bivalves: New insights into growth, physiology and somatic aneuploidy in the carpet shell *Ruditapes decussatus*. Journal of Experimental Marine Biology and Ecology 406, 46-53.