Case study

#6 Oysters in the North Sea

#7 Mussels at the Atlantic coast

#8 Oysters and Clams at the Atlantic coast

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Species background and economics

Two species of oysters are produced in the North Sea region; the Pacific oyster *Crassostrea gigas* and the European oyster *Ostrea edulis*.

The main production techniques are fisheries (e.g. in Limfjord, Denmark), bottom culture (southwest Netherlands), off-bottom culture such as bags on trestles (UK and Netherlands), cages on longlines (The Netherlands, Fig. 1) and in ponds (in Norway).

Oyster culture is based on either natural recruitment or hatchery production (Fig. 2) with the former depending on environmental factors such as food supply, temperature and salinity.

Climate change (CC) is expected to affect the health and growth performance of oysters both directly via physiological responses, immuno-biological performance and acclimation or adaptation to the new environmental conditions and indirectly via changes in the frequency of Harmful Algal Blooms (HABs), jellyfish outbreaks, invasive species and/or diseases.

The most important potential effects of climate change on oyster production concern more frequent occurrence of diseases and toxic algal blooms.

In 2017, oyster production in the North Sea area was 5,280 tonnes of Pacific oysters in

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Figure 1 Bags on trestles *Credit: Pauline Kamermans, Wageningen Marine Research*

Germany, the Netherlands and the UK together and 584 tonnes of European oysters in Norway, Sweden, Denmark, the Netherlands and the UK together (output of statistical query at www.fao.org).

Pacific oysters production was largest in the Netherlands (2,900 tonnes) closely followed by the UK (2,294 tonnes).

European oyster production in the North Sea area was also largest in the Netherlands (350 tonnes), followed by Denmark (150 tonnes).

The value of the Pacific oyster landings in the Netherlands was €2.5 million in 2017 and the European oyster landings in the Netherlands was €2 million in 2017 (agrimatie.nl).

Expansion of the distribution range of non-native species such as the Japanese oyster drill (*Ocenebra inornata*) can cause mortality among juveniles. The goal of CERES was to predict the direct and indirect impacts of climate change (CC) on oyster productivity (and the resulting socio-economic effects) under different climate change scenarios and at different time horizons.

Figure 2 Hatchery produced Pacific oyster spat – Netherlands *Credits: Pauline Kamermans, Wageningen Marine Research*

Expected projections under climate change

The North Sea shows a temperature increase by 2°C in 2080-2099 under RCP 8.5 (Fig. 3). For local changes in near shore oyster culture areas such as Oosterschelde (circle in figure 3) a model with a higher spatial resolution is used as input for the biological modelling.

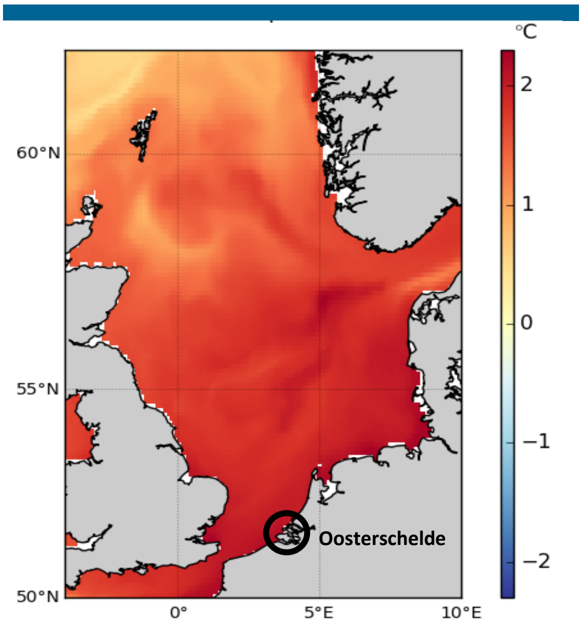


Figure 3 Difference in bottom temperature for North Sea, 2080-2099 compared to 200-2019, RCP 8.5

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 effects

The Dutch government has developed four future scenarios for the marine spatial planning in the Dutch North Sea. The scenarios show strong overlap with the four CERES scenarios:

1. Slowly forward = National Enterprise [RCP 8.5, SSP3]
2. Pragmatic sustainable = Local Stewardship [RCP 6.0, SSP2]
3. Fast forward = World Markets [RCP 8.5, SSP5]
4. Together sustainable = Global Sustainability [RCP 4.5, SSP1]

Depending on the scenario a decline or strong increase in aquaculture activities is foreseen. Developments such as building of large-scale off-shore wind farms can create multi-use opportunities for shellfish farmers.

However, this requires large investments and confidence that the market will expand instead of shift from near-shore to off-shore.

In addition, there was also concern about areas claimed by wind farms and nature conservation. Increased sand extraction for coastal defence can affect the shellfish industry.

Suspended matter concentrations may temporarily increase to undesired levels for shellfish farming. Another core issue to the sector is the occurrence of toxic algal blooms and diseases that intensify in warm water, which can have dramatic impacts on the sector.

Predictive models can help with that. In addition, stakeholders are interested in opportunity’s for new species, cost-efficient technological innovation (off shore, multiuse, predator control, selective breeding) and opportunities for the market (adaptation marketing strategies).

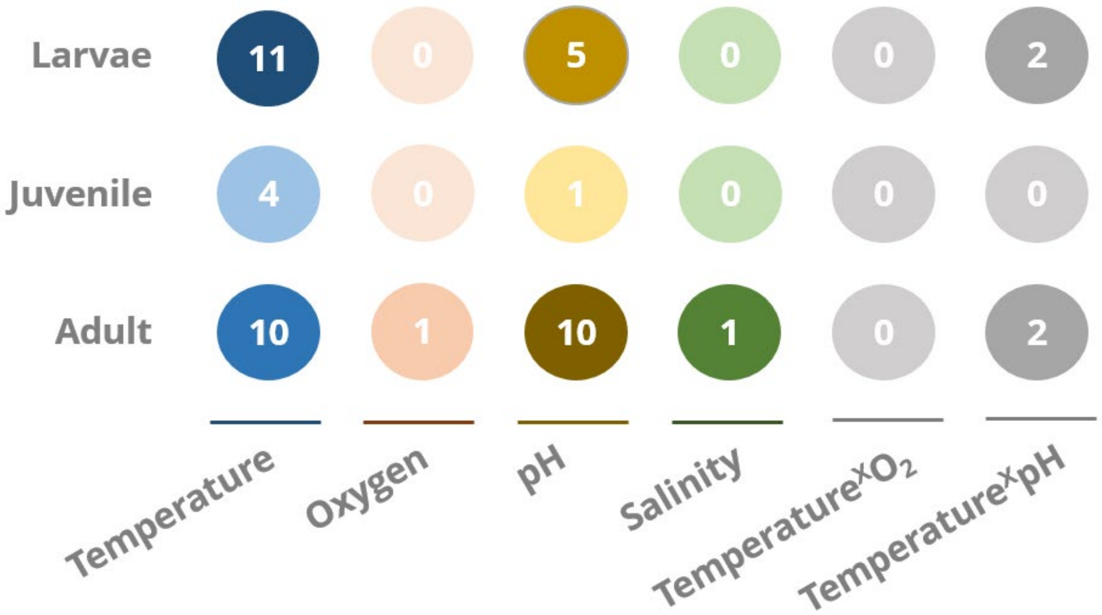
Key research needs

Differences between native European oyster and non-native Pacific oyster in adaptation to changed environmental conditions (including interactions between different environmental factors) are important in determining changes in production and potential competition between the two species.

The main environmental factors for the Netherlands are changes in temperature, food availability, salinity and oxygen concentration.

As yet, there are no signs that ocean acidifications is a problem. In addition, the occurrence of toxic algae and diseases will increase. This asks for early warning tools for toxic algae and selective breeding for resistance to diseases.

Research published on shellfish in European seas



- Oysters, consisting of 2 genera, each ranked 13 out of 28 European fish and shellfish genera reviewed here (5 studies each).
- 3 studies were performed in the North Sea. Further studies were conducted at the Atlantic Coast (5, SL 8), 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.

CERES research

- Performed a literature review to assess knowledge gaps on the direct effects of climate on blue mussels
- Conducted ‘common-garden’ experiments to determine CC effects (temperature x feeding level) on functional response (feeding rate versus food concentration) curves. Additional experiments examined the effects of temperature and salinity on the expression of the toxic substance Tetrodotoxin (TTX) in oysters.
- Calibrated a growth model for Pacific oysters using these new laboratory data and used the model make projections of changes in productivity under various CC scenarios. The individual growth models were 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, using a layout which reflects typical culture practices for *C. gigas* in Northern Europe.
- Studied indirect effects of CC using the ABC (Aquaculture, Biosecurity and Carrying Capacity) model that assessed the combined effects of disease and climate change on farm productivity. ABC simulates pathogen infection and transmission within and among farms, and calculates the impact on shellfish growth and mortality.
- Ranked the vulnerability of oysters to CC in relation to other, major European aquaculture target species.
- Engaged with external stakeholders (oyster farmers and policy makers) through a meeting in which socio-economic developments were discussed, a questionnaire in which information was gathered for a bow-tie analysis and a final meeting in which results were presented and discussed.

Results

Biological

Multi-stressor laboratory experiments (temperature x food concentration x oxygen saturation) were conducted on two species of oysters. Individually marked European and Pacific oysters (Netherlands) (Fig. 4) were exposed to six temperatures (3, 8, 15, 20, 25 and 30 °C) at two food regimes (2 and 10 µg Chl a L^{-1}) for 6 weeks and the growth performance, survival and physiology (clearance rate and oxygen consumption rate) were monitored weekly. Temperature and feeding level had a significant effect on i) growth with a higher optimal temperature at high feeding level, and ii) clearance rate and oxygen consumption with lower clearance at high food conditions, increased clearance rates at increased temperature at high food and increase in oxygen consumption with an increase in temperature.

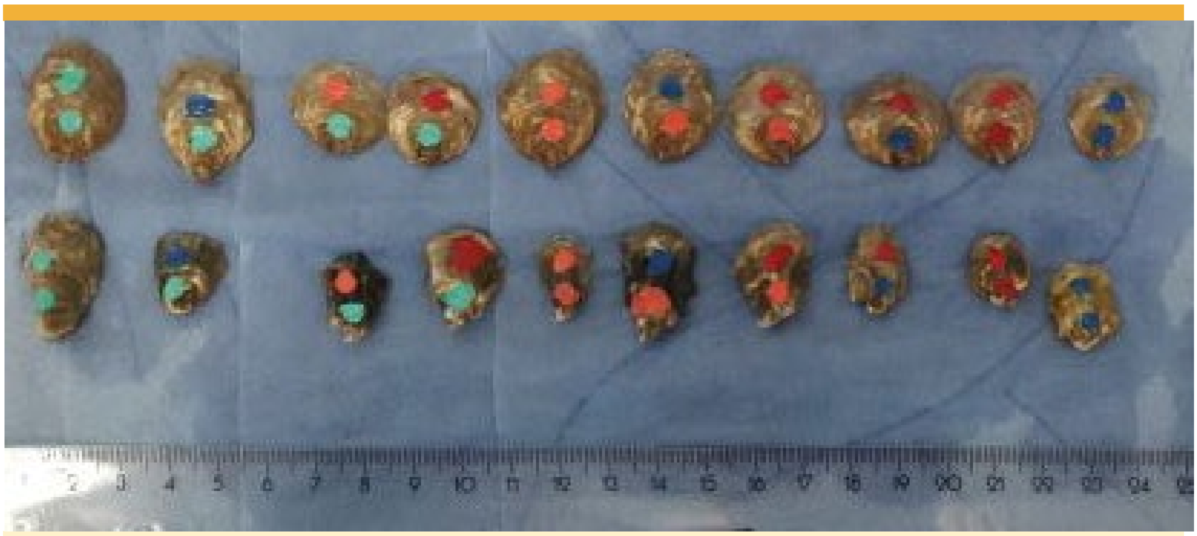


Figure 4 Marked Pacific oysters used in experiment to study combined effect of food concentration and temperature – Netherlands. *Image credit: Pauline Kamermans, Wageningen Marine Research*

Indirect effects

In the Netherlands, a new toxin was discovered in shellfish in 2015. When consumed in large amounts Tetrodotoxin (TTX) can be harmful to humans.

As the first in Europe, the Dutch government developed and implemented a bench-mark for TTX in shellfish in 2016. TTX occurs every year for a few weeks at the start of the mussel season (end of June, beginning of July) and when the bench-mark concentration is exceeded harvest is closed until the levels are below the standard again.

Oysters accumulate the toxin more than mussels. When the shellfish are kept in clean water (depuration), the toxin disappears again. Depuration times still need to be established.

Predicted impact of climate-driven changes on oyster productivity

We have simulated oyster growth and production on a typical off-bottom farm in the Oosterschelde in the Netherlands.

The farm covers 0.5 ha where oysters are grown subtidally on trestles at a density of 800 ind. m^{-2}. Oysters reach harvest size at approx. 900 days and mortality is high (around 76% $cycle^{-1}$) and takes place mostly at the seed stage.

The Pacific oyster individual model (WinShell) and the population model (FARM) have been validated against data obtained by the farmers. Both models provided correct end-point estimates for shell length and live weight (Figure 5).

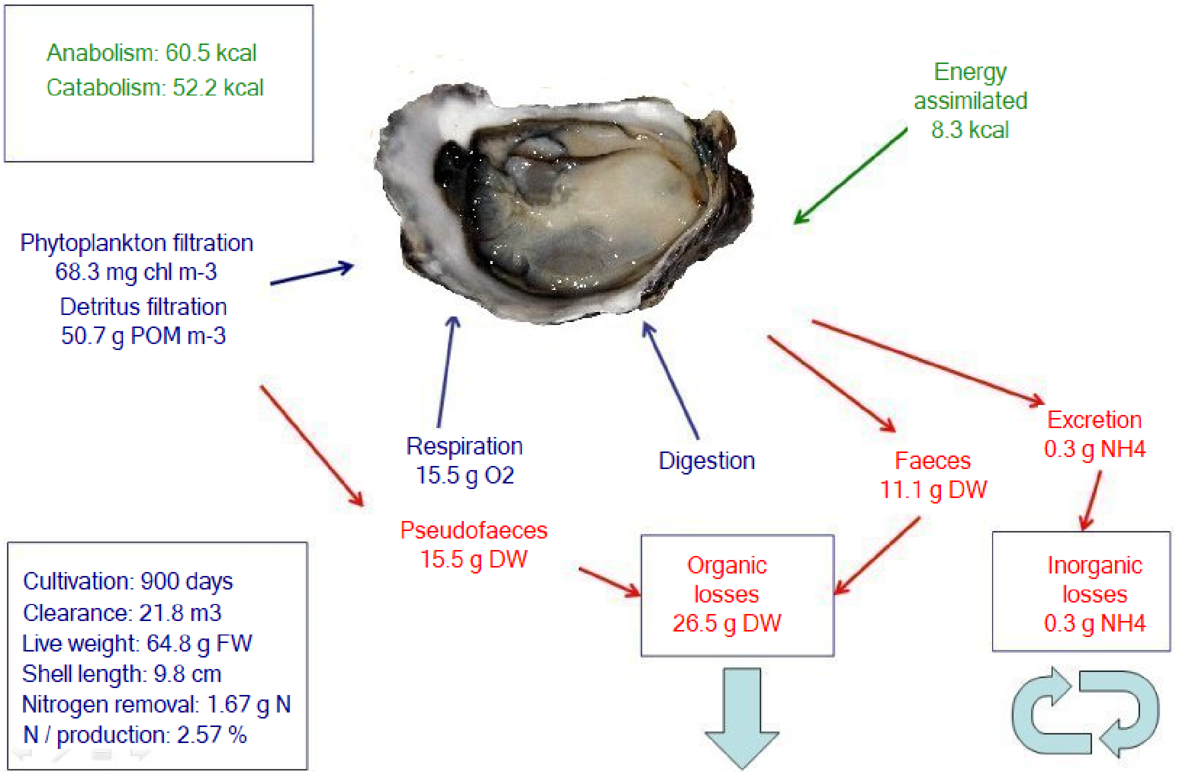


Figure 5 WinShell mass balance results for an individual Pacific oyster over a full growth cycle at the Oosterschelde farm. DW (FW): dry (fresh) weight.

We have studied the performance of the typical oyster farm in present (2000-2019), near-future (2040-2059), and far-future (2080-2099) conditions under two emission scenarios: RCP 4.5 –more conservative, and RCP 8.5 –more severe.

Oysters grow on average bigger under RCP 8.5 than under 4.5 because the low emission scenario presented more extreme temperatures –greater number of warmer and colder days– (Figure 6.A), but there are no significant differences in harvest size or farm production between emission scenarios (Figure 6A and B). The average harvest size would diminish gradually over time from 60.1 gTFW in the present time slice to 52.5 gTFW in the far-future (low-emission scenario) and from 68.6 gTFW in the present time slice to 56.3 gTFW in the far-future (high-emission scenario) (Figure 6.A).

This implies lower yields as climate change progresses, from the current 61.4 tons cycle^{-1} farm^{-1} average production to 48.7 tons (low-emission scenario) and from 55.8 to 49.4 tons cycle^{-1} farm^{-1} (high-emission scenario) (Figure 6.B).

Oysters will get less efficient over time and this is more evident under the high emission scenario. The oxygen depleted from the system is greater under the low-emission scenario because it shows the warmer temperatures (Figure 6D).

The metabolic energy expenditure will also increase as climate change progresses (Figure 6D).

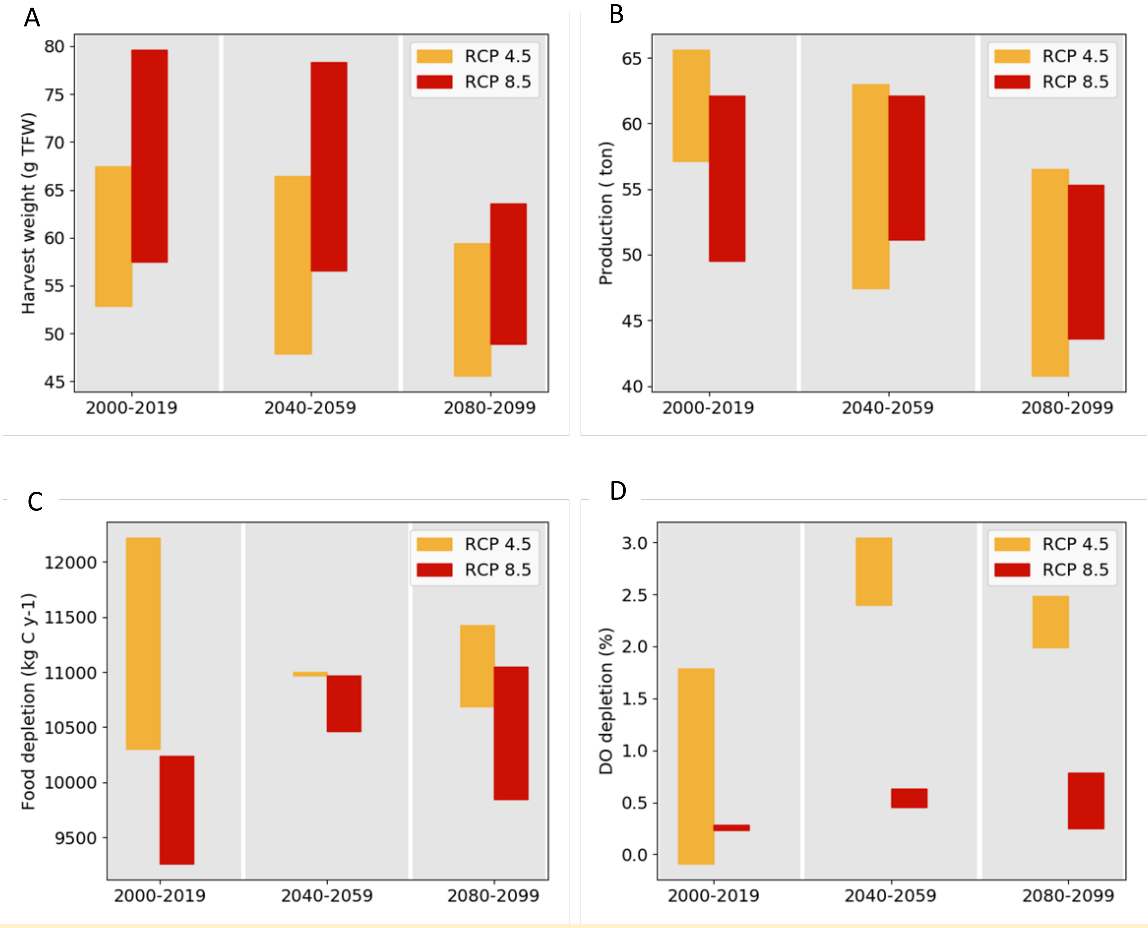


Figure 6 FARM outputs for the typical North Sea Pacific oyster farm under different climate change scenarios. Orange and red represent the range (spread) of simulation values for the low- and the high- emission scenario, respectively. LW: live weight; DO: dissolved oxygen.

Indirect effects of CC

The ABC model was parameterised for the oyster herpes virus disease and was used to simulate an OsHV outbreak in the typical Dutch Pacific oyster farm.

In order to assess the combined impacts of disease and climate change we have simulated an early, mid and late virus release (30-days outbreak 31, 396 and 761 days after culture starts) for the three climate change scenarios under RCP 8.5.

In this case, the increase of seawater temperature as CC progresses led to an increase in the number of days above the minimum temperature limit for the oyster herpes virus (>16°C) that translates into a greater exposure to disease: 2, 13 and 26 days of exposure in the present, near- and far-future scenarios (Figure 7). This led to lower average sizes at harvest and greater mortality due to disease as CC progresses, and thus lower yields and profitability (Figure 7). Shifts in seasonality can generate a similar response as rises in temperature.

We observed a similar impact on the number of harvestable animals but greater impact on harvestable biomass based on timing of pathogen release, as dead animals will be greater in the late-stage pathogen scenario (Figure 8). The timing of pathogen release changes the ratio of harvestable biomass, dead biomass, and therefore farm productivity and profitability.

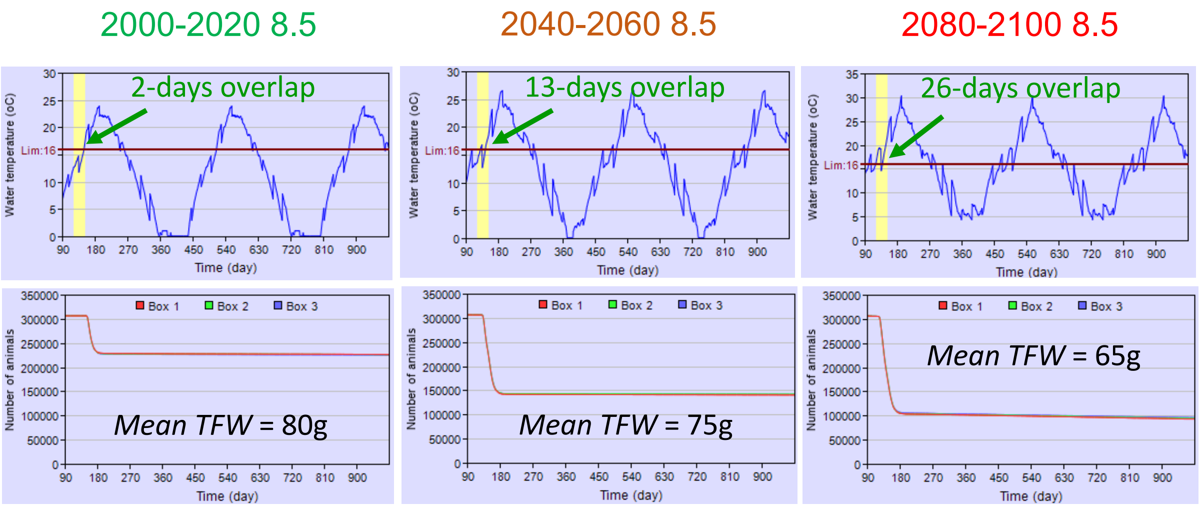


Figure 7 Above: temperature time series during the *C. gigas* culture cycle for the three time slices under RCP 8.5, showing the days of overlap with disease. Below: mortality associated with disease and mean weight at harvest.

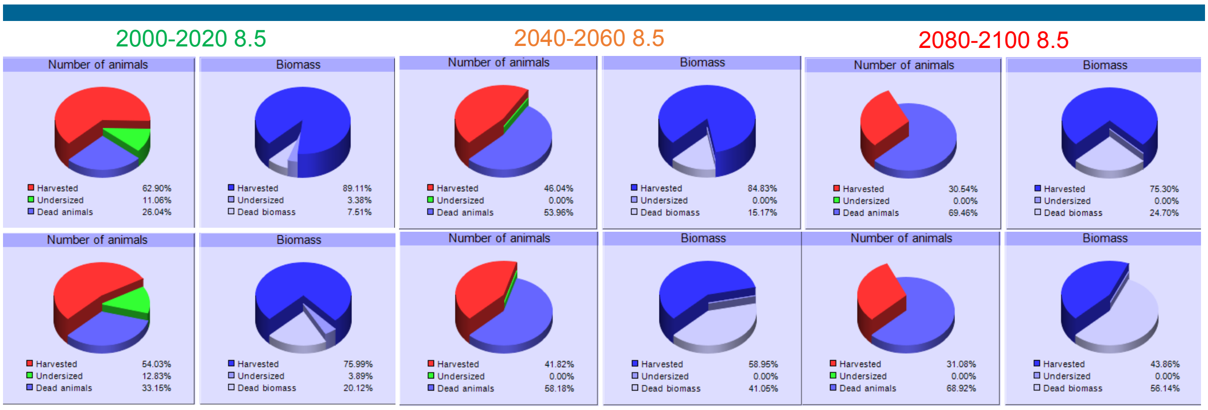


Figure 8 Number of harvestable individuals and harvestable biomass at the end of the culture cycle for the three climate change scenarios under RCP 8.5.

Climate-ready solutions

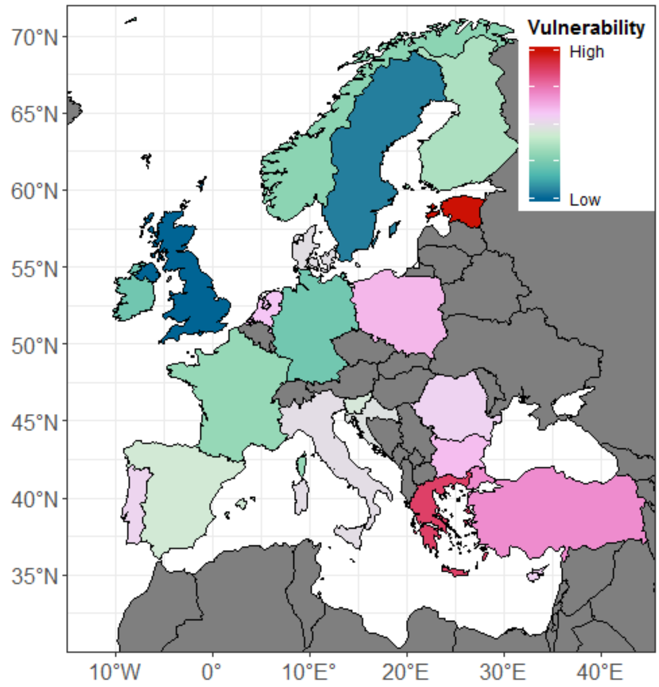


Figure 6 Climate vulnerability assessment for Europe. Colour scale is linear in the value of the corresponding score, but is presented without values, as they have little direct meaning. *Picture credit: Myron Peck*

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 EU28 as well as Norway and Turkey – was ranked and relative values are shown (right)

By 2050 in RCP8.5, warming caused little change in the suitability of culture conditions for most species in most regions, including oysters in the North Sea. Direct effects of warming were small.

Farming oysters is inherently vulnerable because there is less control of the production cycle and the fact that most firms are relatively small with low adaptive capacity.

Most countries in the southern North Sea have made good progress implementing climate adaptation plans and have relatively strong national economies.

Bottom up mitigation measures

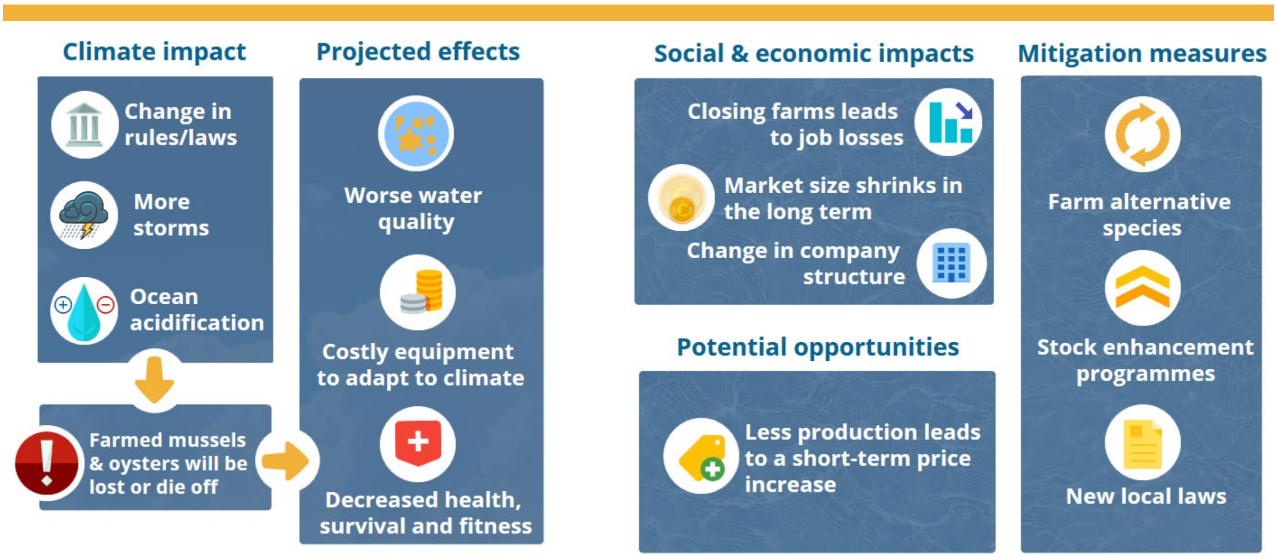


Figure 7 BowTie analysis based on stakeholder feedback. Full bowtie available at *http://bit.ly/CERESbowtie56*

Policy recommendations

Dutch shellfish farmers have shown to be flexible to changes in their harvest. After the severe winter in 1963 killed almost all European flat oysters the farmers switched to a different oyster species.

To ensure this flexibility in the future and prepare for climate change, room for experimentation is desired. It is important that national policy facilitates experimentation with new techniques through providing licences and space for these activities.

E.g. investment in off-shore production is only feasible when the farmers are allowed to experiment for many years and, when successful, can remain on that location to earn back the investment.

To counteract economic consequences of climate-change related shifts in growth and mortality Dutch shellfish farmers should focus more on quality of the product and less on bulk production.

Since the Netherlands' climate adaptation plans are mainly about security against flooding the sector should develop a plan for climate adaptation in the future.

Further reading

CERES publications

Soma K, SWK van den Burg, et al. 2018. Social innovation–A future pathway for Blue growth?, Marine Policy 87, 363-370.

Soma K, SWK van den Burg, et al. 2019. Assessing social innovation across offshore sectors in the Dutch North Sea, Ocean & Coastal Management 167, 42-51.

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