Species background and economics

Small pelagic fish including European anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) play an important role in the economy of fishing communities in the Bay of Biscay.

Anchovy and sardine landings are in the top 5 species in tonnage and value. They represent a fluctuating resource because of recruitment and growth variability and migratory behaviour. To cope with such resource variability, the fishing fleets have developed seasonal and multispecies strategies.

The stock of anchovy in the Bay of Biscay collapsed rapidly in 2005 and recovered slowly by 2010. The weight-at-age of both anchovy and sardine has declined, which worries the canning industry.

This trend in reduced growth could be mediated through climate change and is expected to be mediated through climate change interacting with the fishing and canning industry.

Climate change is also expected to modify the growth rate of early life stages across seasons which would impact survival and stock productivity with ramifications for future opportunities for fishing these small pelagic species in the Bay of Biscay.

Expected projections under climate change

Climate change scenarios RCP 4.5 and 8.5 were downscaled regionally using the physical-bio-geochemical POLCOMS-ERSEM model.

In the Bay of Biscay, the model projected a progressive increase in surface water (0-30m) temperature during the next 80 years with long-term (by 2100) increases of at least 2 to 3°C under the IPCC scenario RCP 8.5.

The productivity of zooplankton is projected to decline accompanied by a phenology shift towards an earlier (late-winter) bloom.

Temperature and zooplankton is projected to affect the biological traits (growth, reproduction, mortality in early life stages) in a way that tends to increase anchovy population biomass.

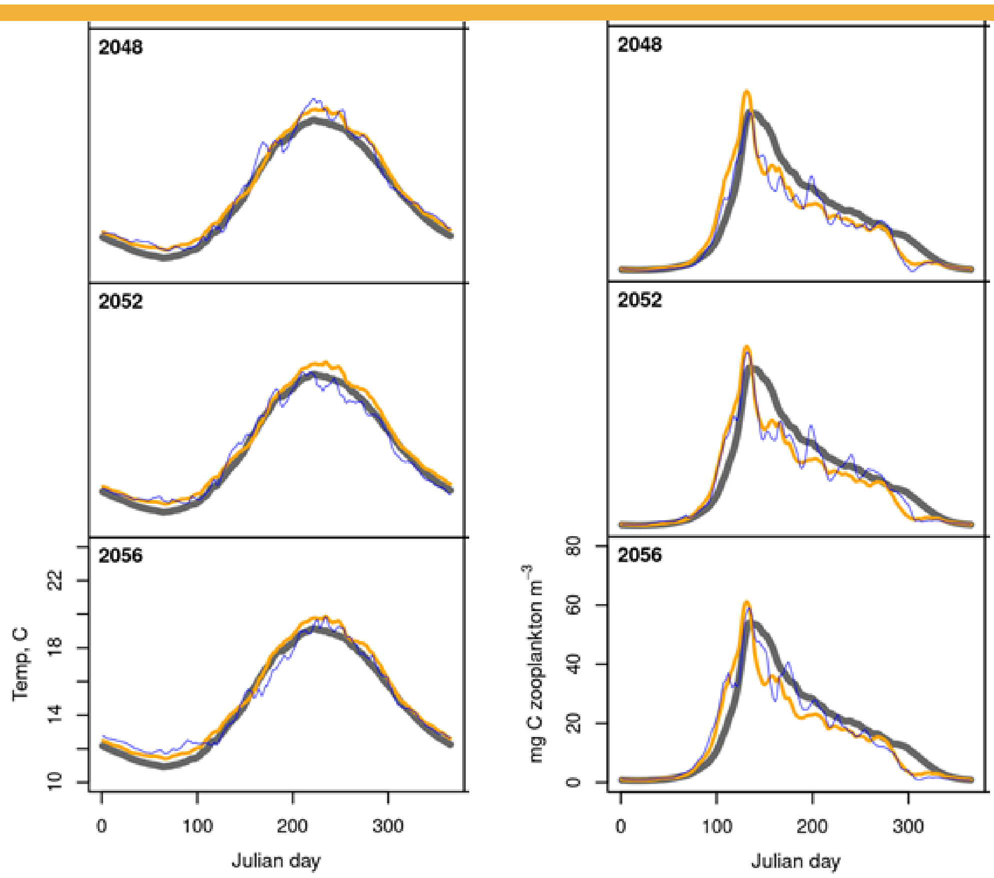


Fig 1 Annual temperature (0 - 30 m) (left) and annual zooplankton concentration (0 – 50 m, mg C m^{-3}) (right) for the climate change scenario RCP 4.5 by 2050. The gray line shows the daily climatology for the current conditions between 2000 and 2015; the yellow line represents the daily climatology of the scenario RCP 4.5 between 2040 and 2060. Blue lines show the curve in each year.

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

Fleets in the Bay of Biscay rely on a portfolio of species that they target sequentially during the year.

Changes in the accessibility of one species induces effort redistribution on other species. In order to predict potential changes in the fleets under climate change scenarios, the work considered changes in fleet behavior (change in targeted species) in response to changes in the economic, management and biological contexts. Scenarios for fish price were considered but the current management scheme was kept unchanged as well as current vessels' costs.

Fish price affected fleet predictions as much as RCP scenarios did via fish stock productivity. Adaptation of the fleets will probably be required in the future as the number of vessels leaving the fishery tended to increase.

Key research needs

Ceres analysed how temperature, zooplankton production, predation and fishing pressure interacted to impact anchovy and sardine stocks in the Bay of Biscay.

On the biological aspect, a better understanding of food quality and availability (zooplankton size spectrum, energy density and seasonal production phenology) would allow to increase the reliability of fish population projections.

On the socio-economics aspect, to progress the understanding of the conditions ensuring the viability of the fleets, a multispecies approach is required as well as the integration of markets across the full sector, from the catch to the plate.

CERES research

- Conducted a Gap analysis of knowledge of the direct effects of climate (changes in temperature, pH, salinity and dissolved oxygen) on European fisheries targets comparing across species and regions including anchovy and sardine in the Bay of Biscay;
- Performed historical time series analysis for a recent period (2000 to 2017) showing changes in fish length at age and in spawning habitat occupation as well as changes in satellite derived estimates of surface chlorophyll;
- Developed and calibrated a full-life cycle individual-based model of the anchovy population
- Projected the effects of climate change (RCP4.5 and 8.5) and different levels of fishing effort on European anchovy;
- Explored the consequences to fleet dynamics (number of vessels in different fishing strategies) of scenarios of climate change and fish price;
- Engaged local stakeholders from the fishing industry to develop a conceptual model of climate risks (BowTie diagram).

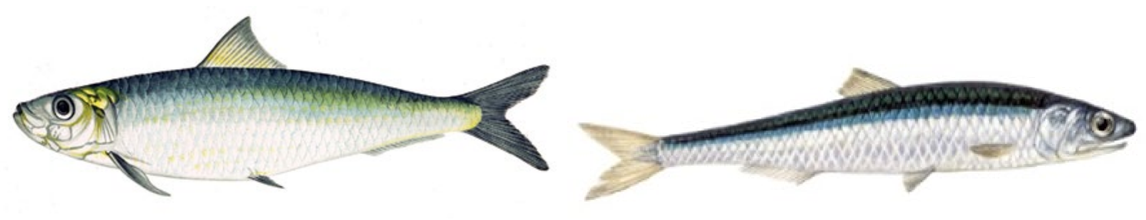
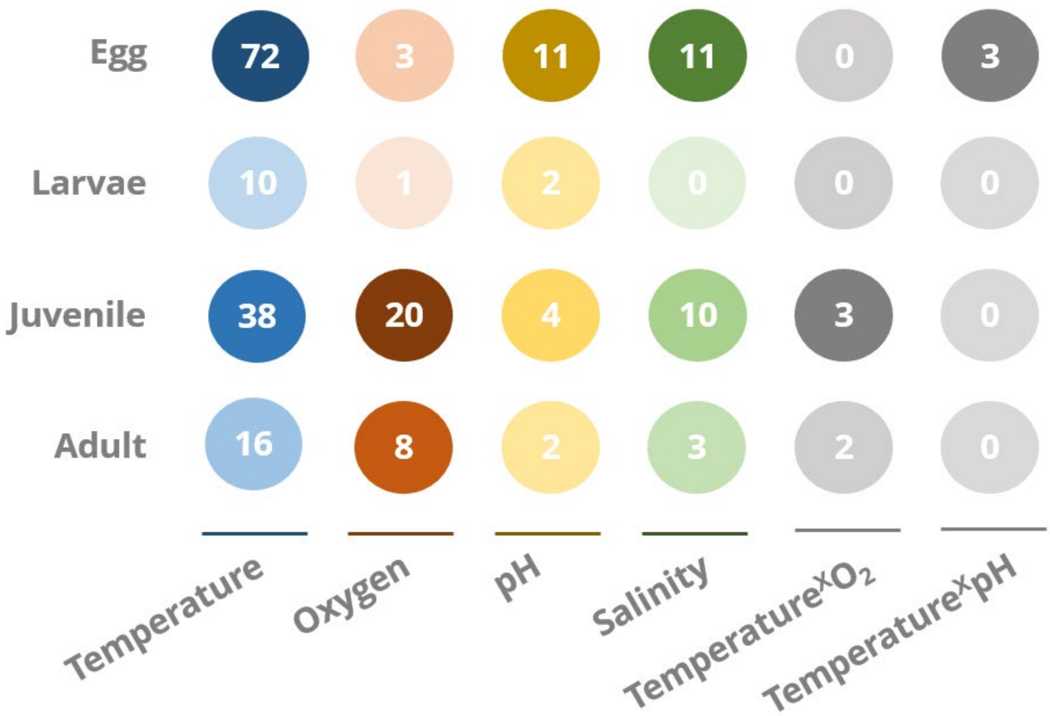


Fig 2 Sardine (left) and anchovy (right)

Results

Research published on finfish in European seas



- Sardine ranked 17 out of 28 European fish and shellfish genera reviewed (4 studies). Anchovy ranked 13 out of 28 (5 studies).
- All studies on Sardine and Anchovy within SL 22 were done in Spain (5) and Portugal (2).
- All studies were focusing on embryos, including larval stages once
- Temperature was the only stressor analysed.
- The most common response studied was development (6).

Biological

The analysis of satellite derived images for the period 2000-2017 showed that chlorophyll was lower in autumn and temperature higher since 2009 compared to the earlier part of the time series.

This correlated with a decrease in anchovy and sardine length at age in the recent period. Spawning grounds at the shelf break formerly used by large sardine were abandoned since 2009.

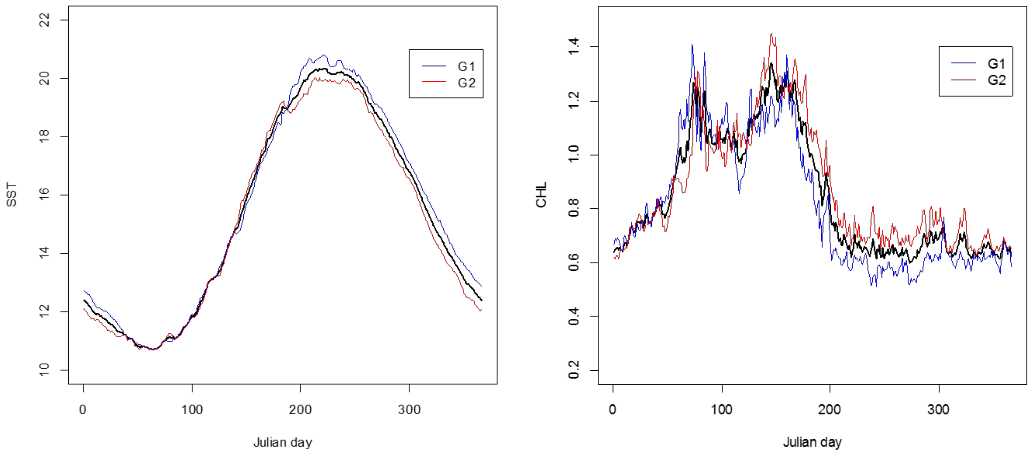


Figure 3 Seasonal variation in SST (left) and chlorophyll_a (right) derived from daily satellite images. Black: average for 1999-2017. G1 and G2: groups of years resulting from a classification. Years G1 have been more frequent since 2009.

To better investigate the energy transfer from the environment to individuals and population and understand past population dynamics, a bio-energetic, full-life cycle individual-based population model was developed for anchovy in the Bay of Biscay.

Mortality due to winter starvation varied from year to year and contributed significantly to determining recruitment. Fishing mortality interacted with environmental forcing on biological traits and had key effects on historical changes in the population. Three periods were contrasted: 2002-2005: collapse; 2005-2009: fishery closure; and 2009-2015: population recovery. The high fishing mortality was critical in the collapse of the population. Lack of good recruitment before 2004 could not compensate for the high fishing mortality.

The good survival and recruitment in 2004 was offset by high winter mortality and low fecundity in that same year, leading to the lowest biomass of the time-series in 2005. Without a fishing closure, the recovery would not have been possible. Limiting the fishing pressure after 2009 favoured the increase of the population biomass at a time of average recruitment.

Two future scenarios of climate change were considered, RCP 4.5 and 8.5 and two time frames, 2040-2060 ("mid-century"), and 2080-2100 ("end of century"). From the physical-bio-geochemical (POLCOMS-ERSEM) model runs, average daily values over the Bay of Biscay of surface (0-30m) water temperature and food (zooplankton concentration) were calculated in order to force the bio-energetic full-life cycle individual-based anchovy population model (0d-DEB-IBM model). Today's fishing management scheme was applied.

The patterns predicted in the anchovy population are due to three key factors: temperature, zooplankton concentration throughout the year, and the seasonal phenology of zooplankton production.

An earlier zooplankton bloom in late winter together with increased temperature

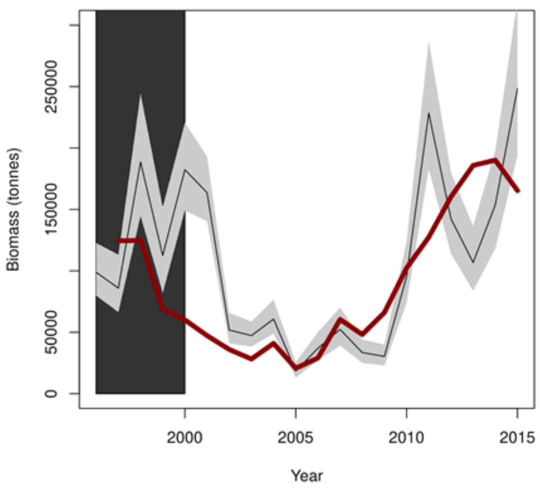


Fig 4 Hindcasted anchovy population SSB in the period 2000-2017 with the bio-energetic individual-based population model forced with temperature and zooplankton concentration.

decreased the mortality of juvenile anchovy during winter and, thus, favoured population recruitment.

The decrease in zooplankton production, however, impacted the individual growth of older fish. In comparison to the hindcast (2000-2017) period, the biggest projected changes at the level of the individual are expected to occur under scenario RCP 8.5 by the end of the century.

Individual growth and energy density increased more rapidly under this scenario while, in RCP4.5 and at mid-century in both RCPs, growth was lower than in the hindcast period. The condition of individuals is expected to increase for age 1 individuals, but not for older individuals. The average fecundity of the population is expected to increase under scenario RCP 8.5, and slightly decrease under scenario RCP 4.5.

In summary, under climate change, the population of anchovy in the Bay of Biscay is expected to increase except for scenario RCP4.5 by 2050.

A lower food concentration in the future scenarios could lead to a population of smaller individuals, counteracting the effect of higher temperature on the growth of individuals. The shift in the zooplankton production phenology determines the better performance of the population in the long-term future, by favouring overwintering of adults and enhancing early larval survival.

Fishing mortality at today's rate could cause the population to collapse under RCP4.5 in the near future. In all other scenarios, current fishing rates were sustainable.

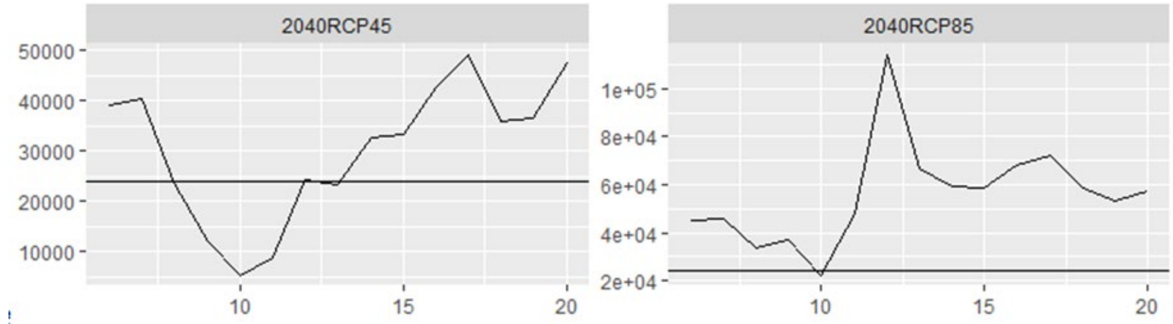


Fig 5 Anchovy SSB (tonnes) under RCP 4.5 and RCP 8.5 for 2040-2060. The horizontal line is the precautionary biomass limit (24000t) below which the TAC is reduced.

Economic consequences

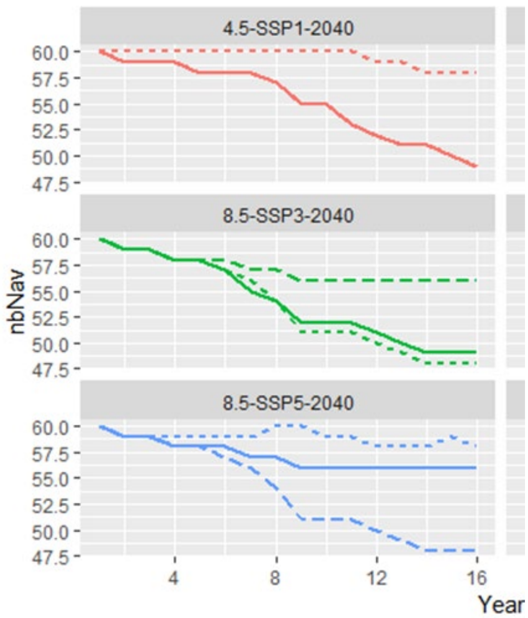


Fig 6 Total number of vessels in the pelagic fishery predicted for 2040-2056 under climate scenarios RCP 4.5 and 8.5 and fish price scenarios in Global Sustainability, National Enterprise and World Markets. Solid line: average price, dashed lines: max and min prices

For each price scenario, the average, the minimum and the maximum increase in prices were simulated.

The fleet behavior model predicted the reallocation of vessels within the known fishing strategies.

A fleet behavior model (statistical utility model) was fitted for the hindcast period 2000-2017. The model predicted in each year, the probability to switch between one of three fishing strategies identified or to leave the fishery. Catches were converted into revenues by multiplying by the average price of the species.

In order to predict future changes in the pelagic fishery structure, the fleet behavior model was coupled to the bio-energetic anchovy population model under different scenarios. The anchovy population projections under RCP 4.5 and 8.5 for the two time horizons were crossed with three future fish price scenarios (Global Sustainability, World Markets, National Enterprise: see D1.2).

The effect of fish price was important in the projection results.

The ability of vessels to switch between strategies and the sharing of the quota among vessels created non linearity in the response of fleets to prices.

Losses of vessels in the strategy targeting anchovy as main species occurred for the time slice 2040-2056.

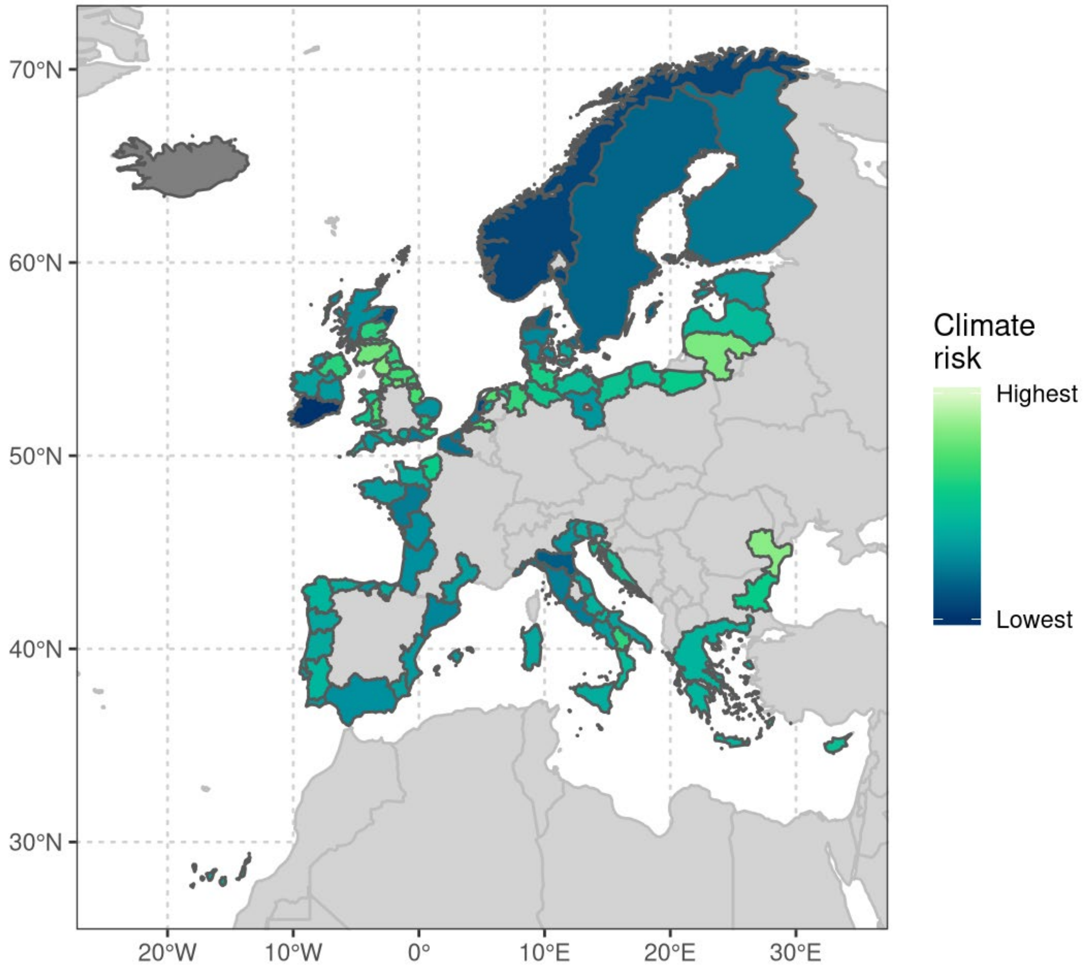


Figure 7 Map of the regional climate risk. Colour scale is linear in the value of the corresponding score, but is presented without values, as they have little direct meaning. National-level borders are shown for reference. *Credit : Mark Payne*

A climate vulnerability assessment for the European fisheries sector was conducted using the IPCC climate-risk assessment framework, including aspects of climate hazard, exposure and vulnerability.

The risk of European fishing fleets (421) and regions (102) to climate-driven changes in fish stocks was assessed based on the ecological characteristics of species landed (157 species in EU STECF) and the economic characteristics of these analysis units.

Considerable variation exists in climate risk, even within a single country (e.g. the UK), due to regional differences in the traits of species landed and economic indicators such as the dependence on fishing and the GDP / capita of fleets (e.g. GDP / capita). Risks are relatively low for Scandinavian countries due their relative wealth.

Fleets in this storyline have a low climate risk.

Low climate hazard of the stocks are strengthed by the general nature (low exposure) and moderate profitability (vulnerability) of the fleets.

Policy recommendations

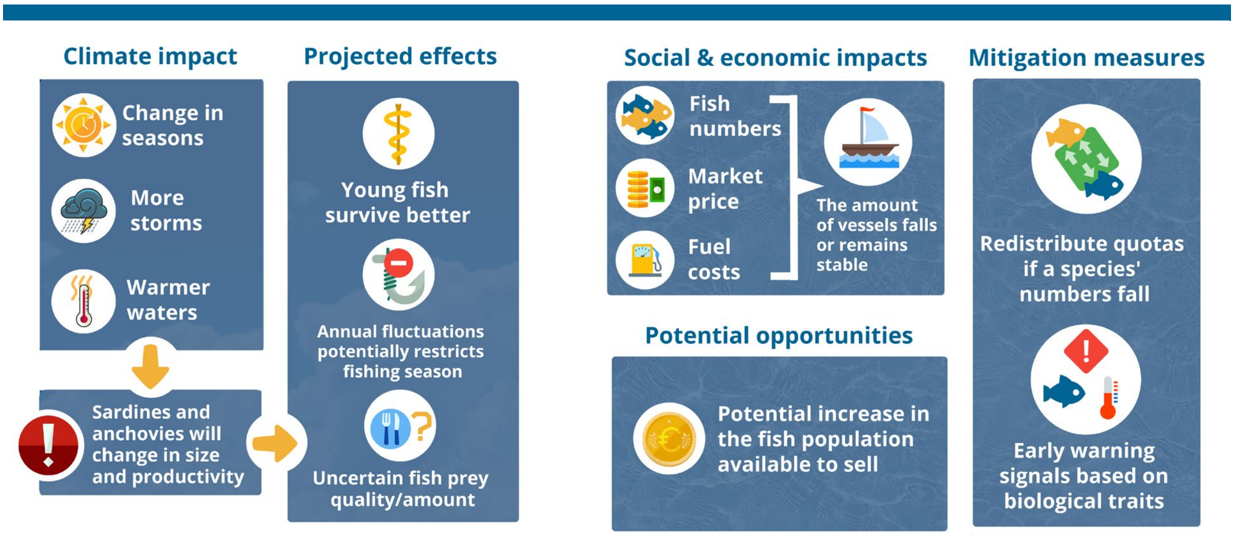


Figure 8 BowTie analysis based on stakeholder feedback. Full bowtie available http://bit.ly/CERESbowtieRazim

Based on the bowtie and internal discussions, recommendations include:

- A multispecies management system that allows reallocation of effort over a portfolio of key species for the viability of the fleets
- Maintenance of the population phenotypic diversity to optimise its adaptation opportunity and capacity
- New regulations for increasing authorised fishing areas, a pluri-annual management plan, and security in price and access rights