Case study

#23 Hake in the Aegean Sea and eastern Mediterranean

#24 Bluefin Tuna in the north-west Mediterranean

#1 Rainbow trout in north-west Europe

Species background and economics

European hake (*Merluccius merluccius*) is found throughout the Mediterranean Sea, and has been commercially exploited since historical times by demersal fisheries.

Mediterranean stocks of hake are declining and are over-exploited in some regions (GFCM 2017). During the 1980s, the spawning stock biomass (SSB) of western Mediterranean stocks drastically changed in parallel with changes in oceanographic conditions.

Size-selective fishing mortality has also eroded the age structure and, consequently, the stock displays marked recruitment variability driven by externally-forced environmental fluctuations.

The combined effects of fisheries, environment and internal dynamics have led to increased recruitment (year-class success) variability, a process which is largely climate driven.

For hake in the Aegean Sea, both fishing mortality (F) and SSB may be outside optimal levels (MINAGRIC, 2017).

In Greece, hake represents as much as 10% of total catch and 8.5% of total landings value, and is important to both small-scale fisheries and larger, industrial bottom trawlers.

Given the low profitability of the Aegean fleet and the inability to increase capital investment to enhance their competitiveness, efficiency and productivity, any negative impact of climate change on hake yields may pose a serious threat to the viability of the fishing sector.

Expected projections under climate change

In the Aegean Sea, sea surface temperature (SST), salinity (S) and primary production (PP) are projected to increase, while bottom water dissolved oxygen and pH are projected to decline (fig. 1).

The two scenarios (RCP 4.5 and 8.5) diverge significantly for SST and S after 2050 (fig.1).

In the business-as-usual (RCP8.5) scenario, a warming of approximately 4°C is projected from present day to the end of the century and this trend seems to be spatially homogeneous (fig.2).

Increases in PP are also projected; however, the western parts of both Greece and Turkey will be the most affected (fig.2).

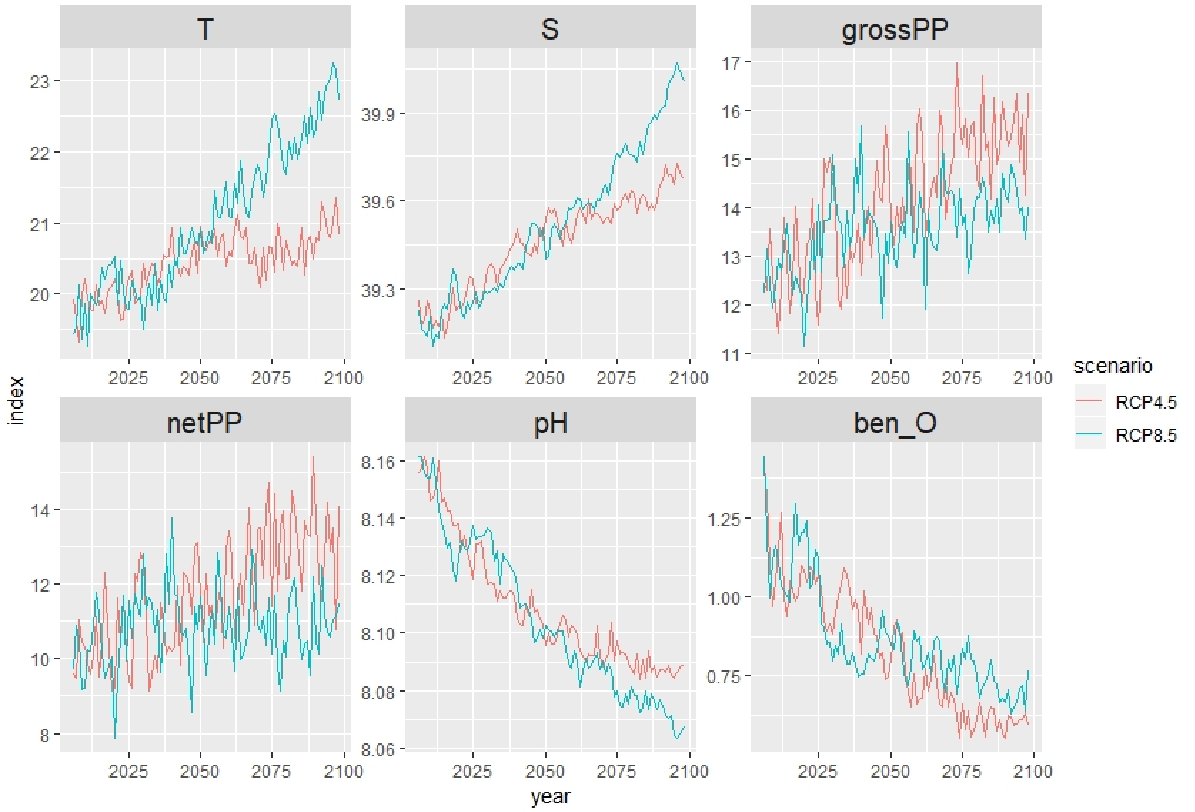


Figure 1 Trends of various environmental parameters in the Aegean Sea under RCP4.5 and RCP8.5 scenarios (2006-2098).

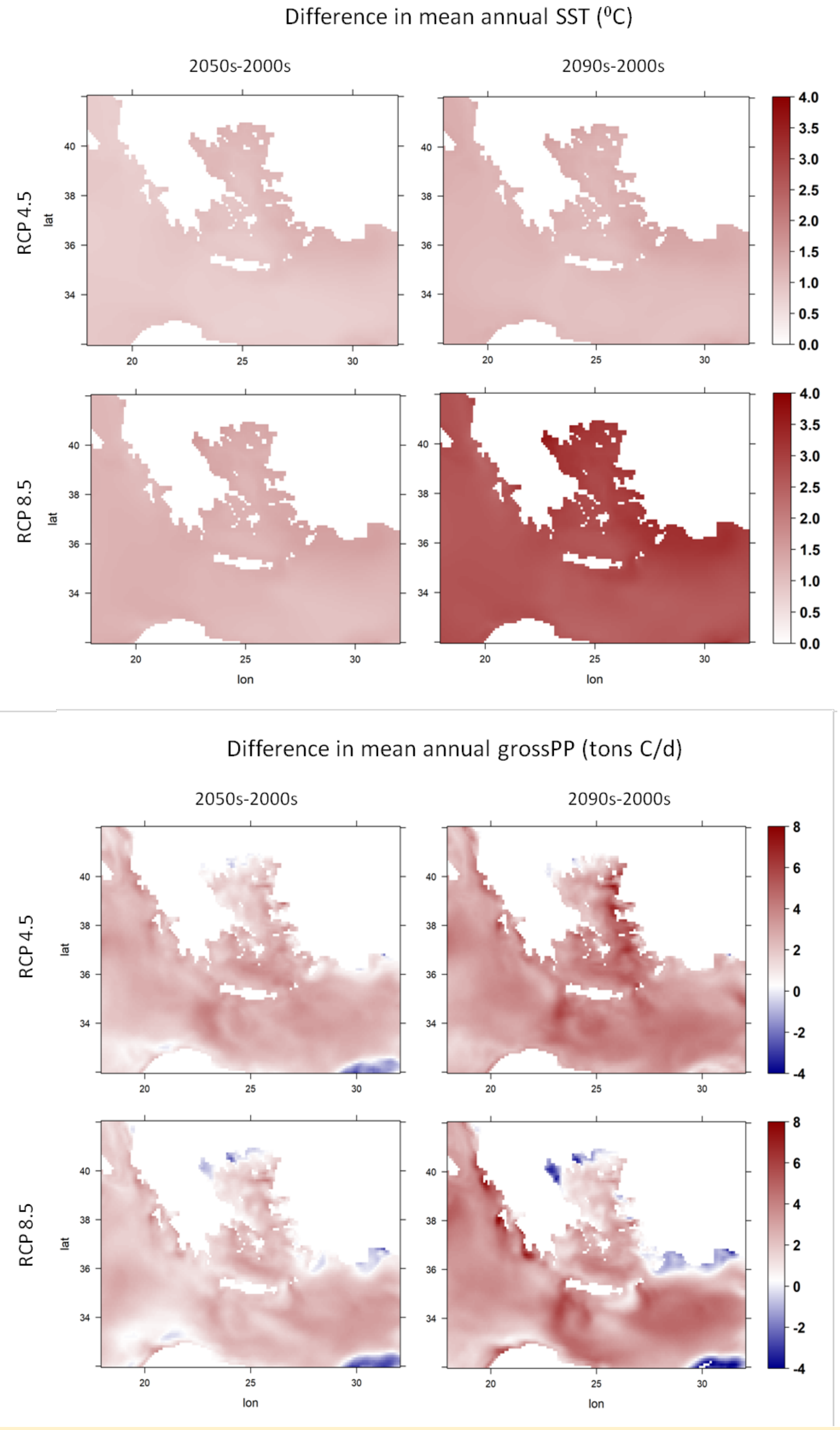


Figure 2 (left) Spatial trend for the average temperature and comparison between present and future temperature under both RCPs. (right) Spatial trend for the average primary production and comparison between present and future primary production under both RCPs.

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

Economic Small scale fisheries are extremely sensitive to fish price changes, while industrial bottom trawlers are also dependent on fuel price volatility.

Management Under the current exploitation pattern, the economic viability of the fleets is threatened, particularly if fuel prices increase.

Additionally, the biological targets set for hake will not be met under the current management regime.

Projections indicate that the only management scenario under which both resource sustainability and economic viability of the fisheries are ensured is the decrease of fleet capacity in terms of vessel numbers.

In this case, however, measures to support the fisheries-dependent communities need to be implemented to prevent the collapse of local economies due to loss in employment.

Scenarios assuming selectivity improvements would be also beneficial for the stocks but they showed low economic performance and their application would threaten the viability of the fleets, particularly that of the trawlers.

Key research needs

Humans and the ecosystems on which we rely face two grand challenges in the near future: anthropogenic climate change and global population growth.

We urgently need to increase food production while maintaining our natural ecosystems in a long-term sustainable state.

It is anticipated that access to the hake resources will likely change due to spatial re-allocation of fish stocks and to the increase in fishing intensity and spatial footprint.

Similar to many other fish species, hake is influenced by environmental factors such as temperature, food availability and other features of the habitat that determine the timing and intensity of the spawning season and the development and survival of eggs and the survival, growth and development of larvae and juveniles.

Elevated seawater temperatures may affect spawning in ways currently unknown: e.g. changes in fecundity, reallocation of spawning and nursery areas.

CERES research

The aim of CERES is to investigate the effect of environmental conditions on commercially exploited stocks of hake (fig. 3) and to project how the stock will respond to climatic changes. Using a series of climatic scenarios, CERES reviewed biological knowledge, compiled new information and developed tools to project the biological and/ economic consequences of climate change scenarios on Aegean Sea hake using a participatory approach.

In detail, CERES work focused on:

- Conducting a systematic literature review, a GAP analysis and a meta-analysis to examine direct effects of climate change (warming, acidification, deoxygenation) on survival and growth physiology of European fish and shellfish.
- Compiling and analysing long-term environmental and fisheries (landings) data to examine how climate variability and/or fishing pressure may have influenced the historical development of hake in the Aegean.
- Developing a biological model and made medium- (2040-2060) and long- (2090-2100) projections of the impacts of two climate change scenarios on the productivity of the Aegean hake stock.
- Projecting the economic impacts of different, future scenarios of fishing and climate change scenarios on Aegean hake fisheries.
- Engaging stakeholders to gain their perspectives on the risks and opportunity of climate change to the fisheries sector in this region and to regionalise future socio-political scenarios used in climate change projection modelling.

Figure 3 European hake (*Merluccius merluccius*) caught in the Aegean Sea

Biological consequences

Research published on finfish in European seas

	Temperature	Oxygen	pH	Salinity	Temperature$^{x}O_2$	Temperature^{x}pH
Egg	72	3	11	11	0	3
Larvae	10	1	2	0	0	0
Juvenile	38	20	4	10	3	0
Adult	16	8	2	3	2	0

- Hake ranked 22 out of 28 European fish and shellfish genera reviewed here (2 studies).
- no studies were conducted in the Mediterranean
- Temperature was the only stressor analysed.

Hake preferences in the Aegean Sea, as inferred by analysing a series of historical experimental survey data, suggested that it occupies large part of the water column (20-600m depth), with higher abundance within the continental shelf (peak at 80m of depth).

Young-of-the-year hakes remain at shallow waters, while adult hakes can be found much deeper, following the 'smaller-shallower', 'larger-deeper' pattern.

The meta-analysis conducted in T2.1 suggests that, as a rule, an increase of temperature will have a positive effect on the growth of demersal fishes. Nevertheless, seasonality is more important and increased summer temperatures could exceed species tolerance leading to higher mortality rates.

The preferred temperature range of juvenile and adult hake in the Aegean Sea is in the range of 11.8-15^{o}C and 12-14^{o}C, respectively, while salinity range was between 37.0-40.0 psu. However, hake larvae occurred in a much higher temperature range (20.4–22.7^{o} C) and a lower salinity range (34.7-37.7 psu), indicating that spawning preferences may significantly differ from the 'overall' preferences identified earlier.

Since spawning success is significantly affected by environmental fluctuations, under a climate change scenario, hake spawning season may be shifted much earlier in the year.

A suite of methods (PCA, chronological clustering, TGAMs – figs.4-5) were used to investigate trends and relationships of historical hake landings (1960-2006) and environmental indices time series.

It has been identified that a significant change has occurred in the mid- late 80's. This is concurrent and correlated with the abrupt increase of hake landings since 1980.

Historical changes in climate include an increase in sea surface temperature and gross primary production.

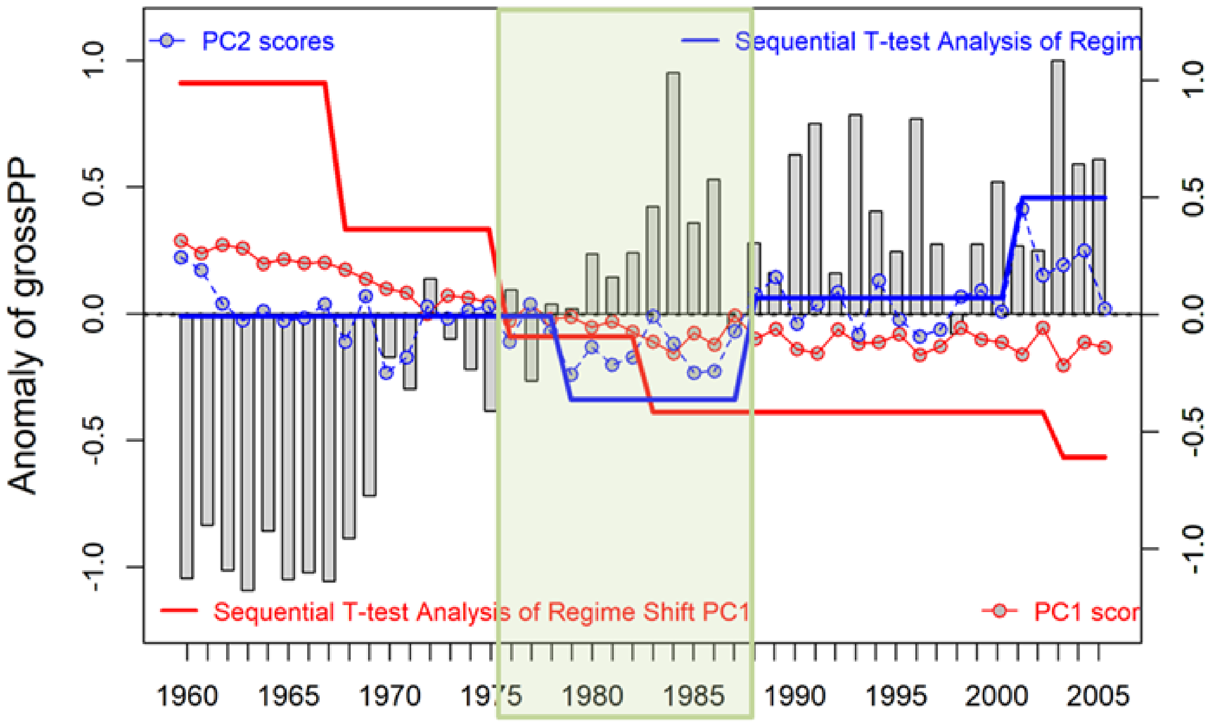


Figure 4 Sequential Regime Shift Detector Analysis

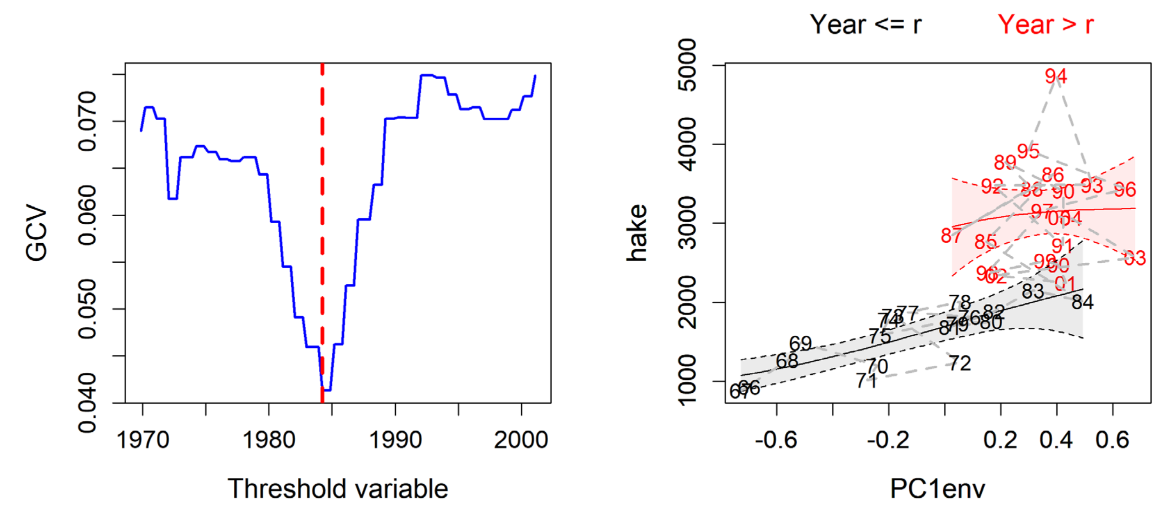


Figure 5 Threshold GAM for hake against the first principal component of the environmental system (PC1env). (left) GCV as function of the threshold variable (year), (left) fitted models and data points (hake landings) for year <=1984 (gray),and year>1984 (red).

The expected future changes in productivity and distribution of Aegean Sea hake stock were investigated under the climatic scenarios RCP4.5 and RCP8.5.

To predict the future productivity of hake, a series of GAM models were built which link hake's annual biomass estimates from stock assessments with annual means of environmental variables.

The best model identified by model selection (AIC criterion) was used to projects hake's biomass to the future under the two scenarios.

Hake's biomass is expected to remain more or less stable around 10000 tons under RCP4.5 and decrease dramatically below 5000 tons under RCP8.5 (fig. 6).

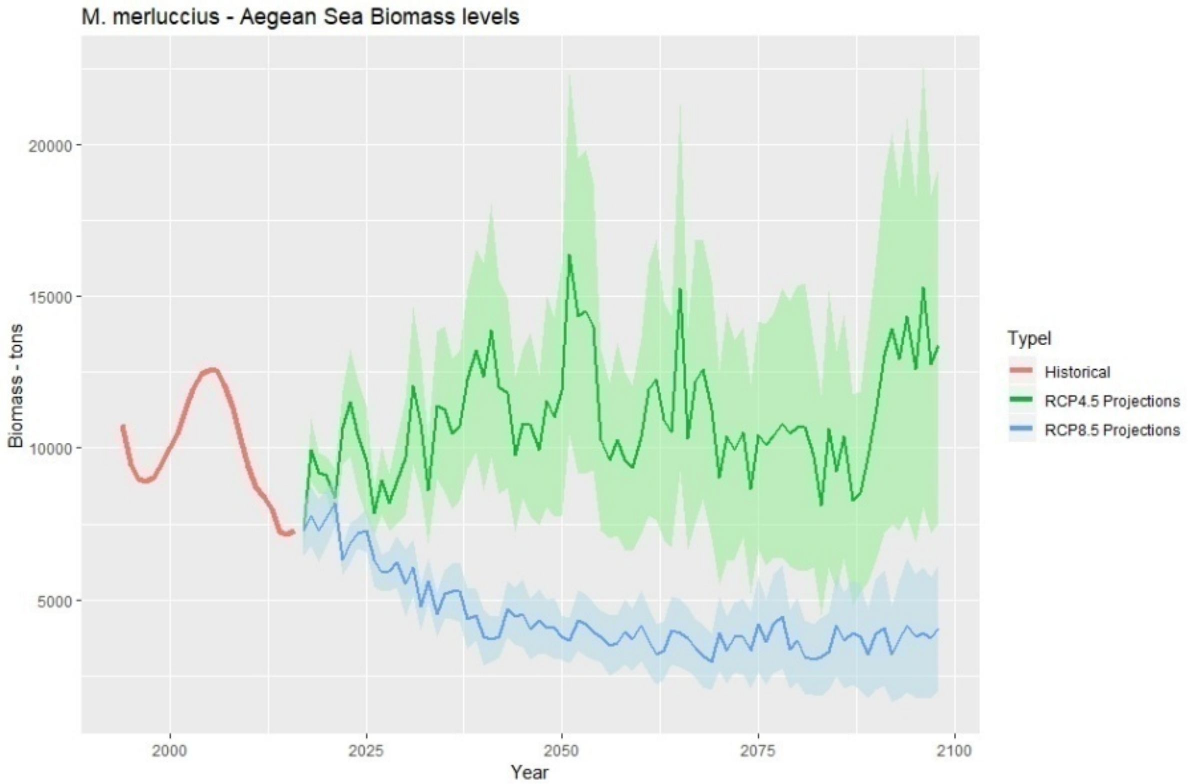


Figure 6 Historical and projected biomass of hake in the Aegean Sea under RCP4.5 and RCP8.5 scenarios (1990-2100).

To investigate changes in distribution, a maximum entropy spatial model was parameterised using MaxEnt software. Hake occurrence data from MEDITS trawl survey were used to fit the model. An increase of suitable habitat is predicted under both scenarios, which would allow the species to expand its range in the Aegean Sea (fig.7).

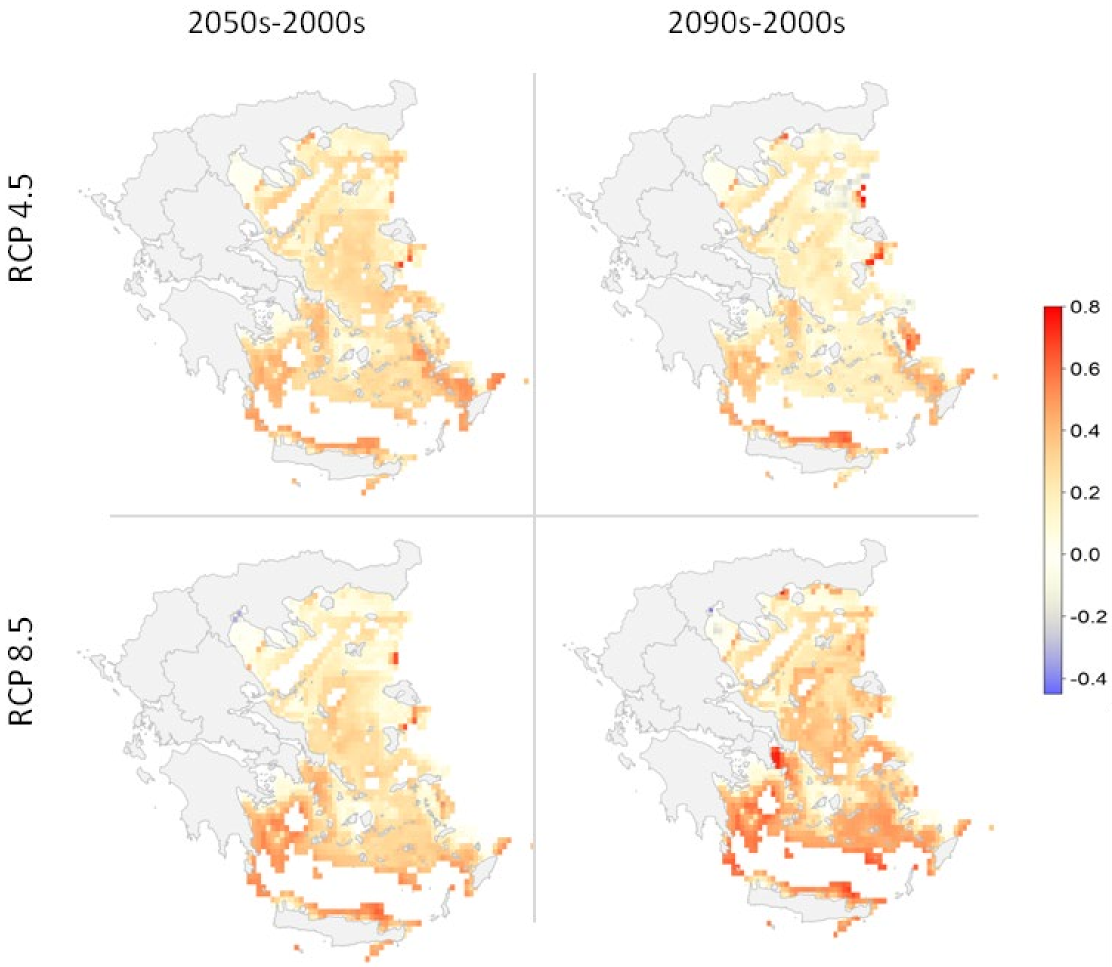


Figure 7 Expected difference in habitat suitability for Aegean hake between mid-term (2050s) or long-term (2090s) future and present (2000s) under RCP 4.5 and RCP 8.5 scenarios.

Economic consequences

Hake population was projected to the future under both environmental and economic development scenarios:

World Markets: RCP8.5-SSP5

National Enterprise: RCP8.5-SSP3

Local Stewardship: RCP4.5-SSP1

Global Sustainability: RCP4.5-SSP2

(See Fig.8)

Each economic scenario was associated with a given fishing scenario for trawler and coastal fleet segments.

World Markets and Global Sustainability scenarios, although having very different objectives, foresee similar outcomes, which are the reduction of fishing effort, increase of total fishery profit, reduction of total landings and sustainable exploitation of hake.

On the contrary, under Local Stewardship and National Enterprise scenarios, the increase of fishing effort will lead to the overfishing of hake (fig. 8).

World Markets

Management	-30% trawls, 0% coastal	
Profit	↗	(128%)
Revenue	↗	(42%)
Landings	↘	(12.8%)
Stock status	sustainable	

National Enterprise

Management	0% trawls, +30%coastal	
Profit	↗	(29%)
Revenue	↗	(53%)
Landings	↘	(0.5%)
Stock status	hake overfished	

Global Sustainability

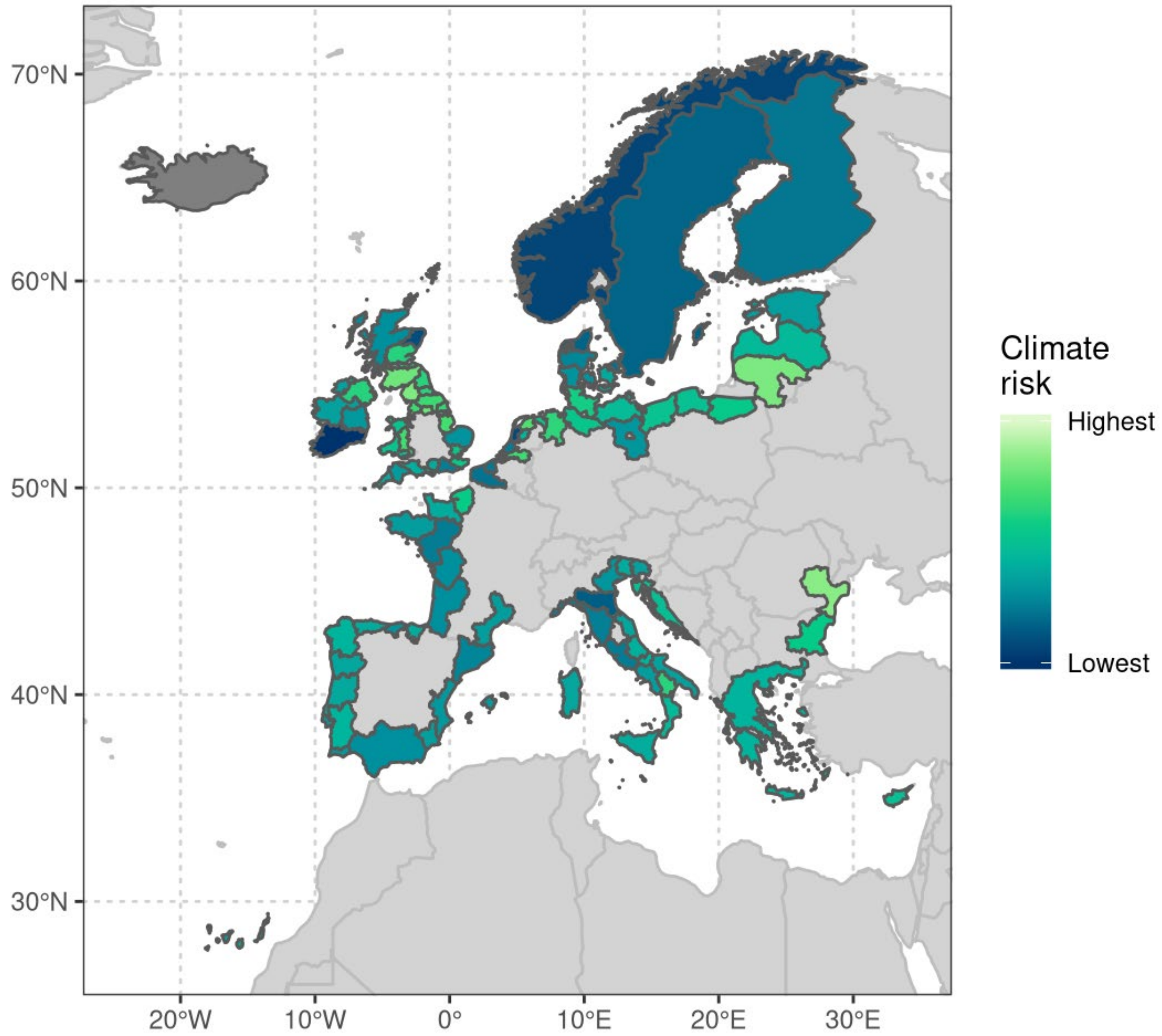
Management	-10% trawls, -5%coastal	
Profit	↗	(116%)
Revenue	↗	(40%)
Landings	↘	(0.1%)
Stock status	sustainable	

Local Stewardship

Management	+2% trawls, +10%coastal	
Profit	↗	(97%)
Revenue	↗	(58%)
Landings	↗	(10.1%)
Stock status	hake overfished	

Figure 8 Outputs of the four socio-political scenarios investigated

Climate-ready solutions



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 high climate risk.

Poor profitability (high vulnerability) combines with the moderate-high hazard of the stocks to give a high climate risks.

For bottom-up - mitigation measures

Stakeholder engagement pointed out that:

(i) the most conspicuous signs of CC identified were extreme weather conditions and water temperature change (increase)

(ii) '*National enterprise with regional cultural identities and less concern for sustainable development'* scenario will prevail and

(iii) there is no apparent strategy or plan to tackle CC impacts.

(iv) government policies will continue to limit growth of the sector and that conservation and the environment will not become a priority

All interviewees informed of lacking local strategy or plan to tackle climate change impacts. Suggestions for managing climate change impacts in future included the following strategies:

• Reducing pollutants and better management of pesticides

• Using more gears if climate change affects fishing effort; finding other occupation if catches fall.

• Subsidise modification of vessels or pay-outs for scrapping them

Policy recommendations

Suggestions for 'adaptive solutions in close collaboration with policy makers' (fig. 9) included:

• Ensuring stricter measures

• Establishing fishing reserves

• Encouraging better enforcement of minimum landing sizes and introduction of larger mesh sizes

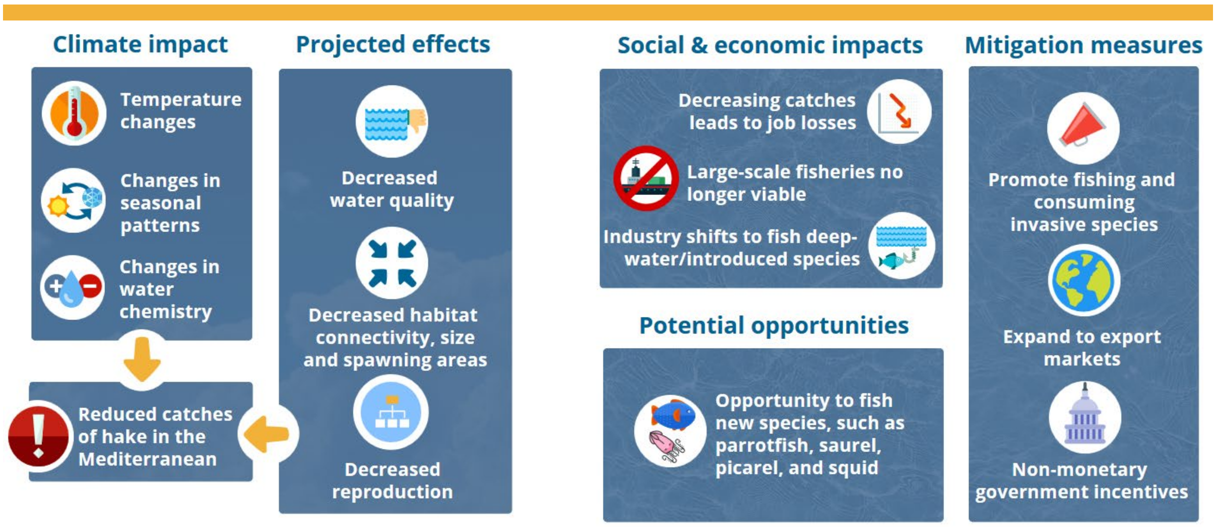


Figure 9 BowTie analysis based on stakeholder feedback. All full BowTies available http://bit.ly/CERESbowties2020 *Image: Katy Smyth*

Further reading

CERES publications

Reports and Online sources

- Project press release (Greek) at the national on-line journal "Alieutika Nea" (trans. Fishing News) 26/5/2016
- Participation in the 12th HCMR Symposium of Oceanography & Fisheries with a presentation: "Evidence of a climatic driven regime shift in the Aegean Sea demersal resources" https://www.symposia.gr/ 30/5/2018-3/6/2018

References

GFCM, 2017. Scientific Advisory Committee on Fisheries (SAC) Working Group on Stock Assessment of Demersal Species (WGSAD) FAO headquarters, Rome, Italy, 13–18 November 2017 FINAL REPORT. 70pp. Available at: https://gfcm.sharepoint.com/EG/Report%20v2/Forms/AllItems.aspx?id=%2FEG%2FReport%20v2%2F2017%2FWGSAD%2FGFCM_WGSAD_2017_Report%2Epdf&parent=%2FEG%2FReport%20v2%2F2017%2FWGSAD&p=true&slrid=297f879e-6092-6000-fc27-1861456ee254

MINAGRIC, 2017. Annual report of the Greek Fleet activities (2017). Ministry of Agricultural Development and Food, Directorate General for Sustainable Fisheries. Available at: http://www.alieia.minagric.gr/sites/default/files/basicPageFiles/Annual%20Fleet%20Report%202017.pdf