STORYLINES

# CERES

Climate change
and European aquatic RESources

**Impressum**

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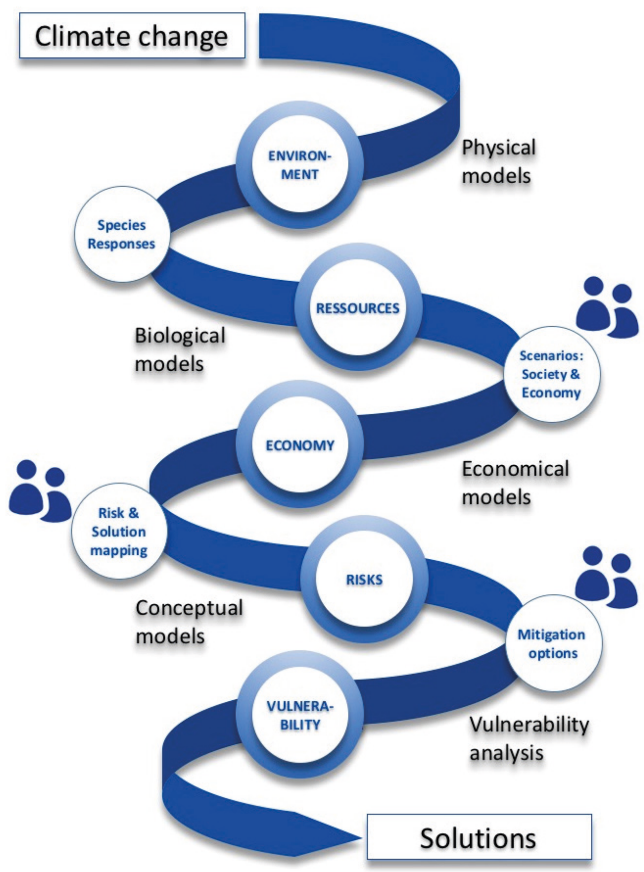
**Disclaimer**

## CERES for Blue Growth

CERES advances a cause-and-effect understanding of how climate change will influence Europe's most important fish and shellfish resources and the economic activities depending on them. It will provide tools and develop adaptive strategies allowing fisheries and aquaculture sectors and their governance to prepare for adverse changes or future benefits of climate change.

# CERES in a nutshell

The CERES project – named after the Roman goddess of agriculture and fertility – is devoted to the questions as to how climate change willl influence Europe´s fish and shellfish resources and how industry can adapt to and benefit from future change.




**environment**

CERES will project future changes in physical conditions of marine and inland waters relevant for fisheries and aquaculture industries.

**resources**

Biological models will scale up physiological and ecological responses of target species to estimate future changes in the productivity of fish and shellfish resources.

**economy**

Based on future social and economic scenarios, CERES will estimate consequences for the marine and inland fisheries and aquaculture industries.

**risks & vulnerability**

CERES will assess risks, adaptive capacity and vulnerability of European fisheries and aquaculture sectors using different conceptual models.

**solutions**

CERES will provide viable “bottom-up” (industry-driven) solutions to minimize the risks and maximize potential benefits of climate change. CERES will also provide “top-down (policy & management) solutions and highlight challenges where current governance structures may hinder future adaptation. ding on them. It will provide tools and develop adaptive strategies allowing fisheries and aquaculture sectors and their governance to prepare for adverse changes or future benefits of climate change.

# Storylines

*Aquaculture*



*Fisheries*

# Trout in the Eastern Mediterranean

**What do we expect under climate change?**

Trout is a diadromous cold-water fish species with high oxygen demand. Rainbow trout farming is generally carried out in land-based farms using cold spring water or in natural/artificial lakes using floating cages. Climate related changes such as rise in inland water temperatures, increased frequency of extreme events (e.g. storms, floods, drought) and water stress are expected to have direct or indirect negative impacts on rainbow trout farming both in land-based and cage farms. For instance, rising temperature in inland waters and decreasing dissolved oxygen concentrations will result in hypoxia and lower growth rates and poor feed conversion ratios (FCR). Droughts and water stress are likely to limit freshwater water availability and quality for trout farming. Rising water temperature will also increase incidents of diseases and parasites in trout farms resulting in higher mortalities and losses.

**How vulnerable is trout?**

Cold-water species like trout with high demand for dissolved oxygen are very vulnerable to rise in water temperature. Rising inland water temperature will directly lower dissolved oxygen concentrations. Trout is also very sensitive to high water temperatures. Water temperatures above 15-18 °C during grow-out period would limit trout feed intake due to lower dissolved oxygen levels and lower fish growth.

**What are the expected economic consequences?**

Climate related changes such as rise in inland water temperatures, increased frequency of extreme events (e.g. storms, floods, drought) as well as freshwater availability and quality are likely to have direct or indirect negative impacts on performance and productivity of rainbow trout farming both in land-based and cage farms in natural/dam lakes. This would not only mean an increase in production costs but would also lower harvest and income levels in rainbow trout farms.

**What are the challenges?**

One of the most important challenges for sustainability of inland aquaculture sector is to develop mitigation or adoption tools and strategies with respect to impact of climate change on farmed species and thus farming operations. To this end, projecting direct and indirect impacts of climate change on productivity and financial performance of rainbow trout farms is crucial for addressing climate change related challenges. In this respect the CERES trout-storyline is a proactive approach for projecting the impact of climate change on productivity and financial performance of inland aquaculture farms.

**What is the working program in CERES?**

A series of field studies will be conducted to collect environmental, bio-technical (e.g. growth rates, mortalities, FCR, stocking densities, diseases outbreaks), structural and financial data from Turkish rainbow trout farms (land-based and cage). The aim is to contribute to modeling the direct effects of climate change on farmed rainbow trout and further to construct theoretical farms for examining the impact of climate change on productivity and financial performance of rainbow trout farms.

Collected bio-technical, structural and financial data from rainbow trout farms will be used to construct virtual Turkish rainbow trout farm according to the "Typical Farm" approach (Lasner et. al., 2017). Based on findings on direct effects of climate change on rainbow trout, the impact of climate change on productivity and financial performance (e.g. production costs, profitability) of Turkish rainbow trout farms will be simulated on engineered virtual farm using the "Agri benchmark Simulation Model TIPI-CAL (Deblitz & Zimmer, 2005).

**Literature**

*Deblitz & Zimmer (2005) A standard operating procedure to define typical farms, http://literatur.thuenen.de/digbib_extern/dk038513.pdf*

*Lasner et al. (2017). Establishing a benchmarking for fish farming – Profitability, productivity and energy efficiency of German, Danish and Turkish rainbow trout grow-out systems. Aquaculture Research, doi:10.1111/are.13144*

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# Carp in North-East Europe

**Will carp be effected from climate change?**

Common carp (*Cyprinus carpio*) is a broadly reared species, specifically in Middle and Eastern Europe. The traditional production of carp is conducted in earthen ponds, which can be harvested every 2-3 years depending on thermal conditions. Fish of different market sizes from 600 g (Ukraine, part of Poland) to over 3 kg (Czech Republic, Bavaria) are produced, depending on local traditions and markets. As production takes place in naturally-occurring earthen ponds, and fish are predominantly fed with cereal feed, with a significant share of natural food, carp production is highly dependent on climatic conditions.

Carp grows well in water temperatures above 20 °C. However, further increase in water temperature (for commercial fish over 28 °C) leads to inhibit the growth of fish. Therefore, any climate change that are the results of the increase in average water temperatures affects the conditions of production.

Our aim in CERES is determine the potential impact of climate change on environmental condition and potencial of growth carp production in European countries.

**What will be the challenges for carp farming in the future?**

The traditional production of carp in the earthen ponds is well described and recognized. The practice developed from the Middle Ages where monks established the first large carp farms in eastern Europe. Today, after the recent significant innovations at the turn of the 19th and 20th centuries by Tomasz Dubisz, the European system of carp production in ponds has been established. However, depending on the development of the carp market, new challenges may emerge.

The most relevant barriers and challenges affecting the growth of this sector are:

- increased competition from other aquaculture species
- direct and indirect effects of climate change on the production (growth, new diseases)
- increased cost of water using
- disease management especially problems with viral diseases such as KHV (Cy-HV3)
- predators under government parasol (for example otter, beaver, cormorants)
- unregulated supply and demand causing imbalance in the market and reduced profitability
- predominance of big-scale farmers
- lack of co-operation amongst local/international pro-ducers & between government and industry on R&D
- lack of product differentiation and development – special traditional market with live fish versus processed fish
- lack of coordinated national strategic plan for aquaculture and poor industry administration
- lack of strategy of development new methods of production of carp (aquaponics systems etc.)

Carp production, FEAP report 2016

| PRODUCTION (tons) | | YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | COUNTRY | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
| Common Carp | POLAND | 15,698 | 17,150 | 18,300 | 15,400 | 14,400 | 16,500 | 17,700 | 18,000 | 18,000 |
| | CZECH REPUBLIC | 17,947 | 17,507 | 17,258 | 17,746 | 18,198 | 17,972 | 16,809 | 17,833 | 17,860 |
| | HUNGARY | 9,570 | 10,485 | 10,500 | 9,927 | 10,807 | 9,985 | 9,632 | 9,800 | 10,461 |
| | GERMANY | 10,500 | 10,500 | 9,000 | 9,783 | 5,082 | 5,521 | 5,700 | 5,285 | 4,916 |
| | FRANCE | 6,000 | 6,000 | 6,000 | 4,000 | 3,500 | 3,500 | 3,500 | 3,000 | 3,000 |
| | CROATIA | 1,503 | 1,546 | 2,058 | 1,816 | 2,891 | 2,484 | 2,100 | 2,100 | 2,100 |
| | ITALY | 750 | 750 | 750 | 700 | 750 | 750 | 700 | 700 | 700 |
| | AUSTRIA | 346 | 362 | 344 | 348 | 596 | 590 | 619 | 573 | 573 |
| Common Carp Total | | 62,314 | 64,300 | 64,210 | 59,720 | 56,224 | 57,302 | 56,760 | 57,291 | 57,610 |

**What is the economic value of this fishery?**

Most of carps are produced by aquaculture. The EU is very small producer worldwide (only 1,38 % of world production). The trade between the EU and third countries is very limited. Main producers in the EU are Poland, Czech and Hungary. Total production of carp was in 2014 only 57 291 ton compared to 4 159 117 ton (fao.org) in the World. Climate related change is expected to affect production yields. This change can provide two shorter cycle of production and moving production to north of Europe, but because of tradition not out of typical "carp countries".

**What are the challenges?**

Further development on carp aquaculture in Europe requires that knowledge gaps are covered in the future:

- Projecting the impact of climate change on carp production based on current data is expected to be accompanied with a great uncertainty, thus higher data collection is needed to assess the direct and indirect effects of climate changes on common carp.
- Overcoming the barrier of demand, intensive methods of breeding this species are needed. The prospect is to link RAS systems using agricultural post-production water (eg. Aquaponic).
- The traditional farming technology is limited by the lack of new places to build ponds. At present legal regulations are unfavorable for the development of traditional carp breading farm, and it largely corresponds to the so-called small water retention in significant areas of Eastern Europe.
- It is necessary to develop new innovative carp products that can increase the demand for this species.
- Significant threats to virological diseases in traditional breeding methods require the development of new, effective ways of combating viral diseases, eg. by introducing genetically resistant carp lines to specific viruses.

**What is the working program in CERES?**

The effect of temperature on growth, survival and stress biomarkers of farmed carp in different rearing conditions will be studied.

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# Mussels in the North Sea

**What do we expect under climate change?**

Blue mussel (*Mytilus edulis*) is a ubiquitous species present along the North Sea Coast in the intertidal and subtidal areas. The main physical factor influencing its distribution is temperature which affects both adult and larvae survivals. Other external pressures for mussel aquaculture development in the coastal zone include pollution, biotoxins, invasive species, water quality and competition with other activities. Along the North Sea Coast, mussels are both fished at a commercial size for food consumption and as juveniles (seeds) for bottom culture. Mussel seeds are also caught directly on spat collectors for both on-bottom and long-line cultures.

Blue mussel culture is currently dependent on natural recruitment and environmental factors such as food supply, temperature and salinity. Our goal in CERES is to determine and predict the changes in Blue mussel productivity (and resulting socio-economic effects) from direct and indirect climate-driven environmental factors on physical, biochemical and biological components. Climate change is expected to affect the health and growth performance of farmed mussels directly via physiological responses, immunobiological performance and acclimation to the new environmental conditions and indirectly via potential pressure from Harmful Algal Blooms (HABs), jellyfish outbreaks, invasive species and diseases. The expectation is that the southern boundary where *M. edulis* can be cultured may shift Northwards and conditions for the Mediterranean mussel (*Mytilus galloprovinciallis*), that already occurs in the North Sea area in low percentages, may become more favourable.

**How vulnerable are mussles?**

Mussels are taking nutrients directly from the water column and do not require feeding, thus production is dependent on the environmental conditions. Bivalves are sensitive to climate change induced variabilities in temperature and salinity which affect behaviour, physiological rates and immune system. Recent Blue mussels mass mortalities in Europe potentially are linked to multi-factor stress and could jeopardize the mussel industry.

**What is the economic value of this species?**

Mussel, both blue mussel (*Mytilus edulis*) and Mediterranean mussel (*Mytilus galloprovinciallis*), is the first aquaculture species produced in the EU with around 470 thousand tons produced in 2014 for a value of around 372 million euros.

Within the North Sea area (Denmark, Germany, Netherlands, UK, Norway and Sweden) only *M. edulis* is produced. In 2013 production was 90 thousand tons. Although the production has declined since the 90s, new values have been added to the mussel market with the development of organic products and labeling. In 2012, blue mussels represented 8% of the weight and 4% of the value of the cultivated seafood in Europe .

**What are the challenges?**

Some parameter values and functional response curves for climate change driven environmental conditions (e.g. extreme temperature, low oxygen concentration) on blue mussel are not described adequately in the literature and require new experiments to improve production models under climate-driven changes. Other experiments regarding indirect factors such as toxic algae impact on mussel productivity and mortality are missing. Regarding indirect pressure from HABs, pathogens and jellyfish bloom, early warning techniques are not developed to take preventive actions to protect cultured mussels

**What is the working program in CERES?**

Multi-stressor laboratory experiments (e.g. temperature vs food concentration vs oxygen saturation) will be conducted on blue mussels as well as the impact of indirect effects of toxic algae on mussel productivity.

For modelling two approaches are used to predict the mussel productivity under various climate change scenarios.

- Direct effect of climate change - models for productivity and connectivity, including physiological models and population models at farm and local scale
- Indirect effects of climate change - models for mitigation and early warning (Harmful Algal Bloom occurrence)

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# Oysters in the North Sea

### What do we expect under climate change?

Two species of oysters are produced in the North Sea area; the Pacific oyster *Crassostrea gigas* and the European oyster *Ostrea edulis*. Main production techniques are fisheries (e.g. in Limfjord Denmark), bottom culture (SW Netherlands), off-bottom culture (bags on trestles in UK and Netherlands, cages on longlines in Netherlands) and ponds in Norway.

Oyster culture depends on either natural recruitment and environmental factors such as food supply, temperature and salinity, or hatchery production.

Our goal in CERES is to determine and predict the changes in oyster productivity (and resulting socio-economic effects) from direct and indirect climate-driven environmental factors on physical, biochemical and biological components. Climate change is expected to affect the health and growth performance of oysters directly via physiological responses, immunobiological performance and acclimation to the new environmental conditions and indirectly via potential pressure from Harmful Algal Blooms (HABs), jellyfish outbreaks, invasive species and diseases. The most important effects of climate change on oyster production concern more frequent occurrence of diseases and toxic algal blooms

### How vulnerable are oysters?

Direct effects on Pacific oysters are less likely since the species seem to withstand a wide range of temperatures and salinities. European oysters are sensitive to low salinities. Thus, extra inflow of fresh water as a result of rain may be a problem. Indirect effects such as toxic algae and diseases are expected to cause problems. Expansion of the distribution range of non-native species such as the Japanese oyster drill (*Ocenebra inornata*) can cause mortality among juveniles.

### What is the economic value of this species?

According to the FAO statistics, oyster production in the North Sea area was 2008 tonnes in 2015. Production was largest in the UK, followed by the Netherlands. Production in the Netherlands is most probably Pacific

Production and economic values of oyters (www.fao.org)

| Country | Species | Quantity (tonnes) | Value (1000 USD) |
|---|---|---|---|
| Germany | Pacific cupped oyster | 80 | 799 |
| Netherlands | European flat oyster | 350 | 1806 |
| Norway | European flat oyster | 10 | 72 |
| United Kingdom | European flat oyster | 28 | 287 |
| United Kingdom | Pacific cupped oyster | 1540 | 6200 |
| Total | | 2008 | 9163 |

and European oysters combined. The value of the total landings was over 9 million US dollars.

**What are the challenges?**

Differences between native European oyster and non-native Pacific oyster in adaptation to changed environmental conditions are important in determining potential competition between the two species.

**What is the working program in CERES?**

Multi-stressor laboratory experiments (e.g. temperature vs food concentration) will be conducted on oysters.

Two model approaches are used to predict the oyster productivity under various climate scenarios. After reviewing and collating the knowledges on climate-driven environmental factors affecting oyster productivity, and performing experiments to fill gaps, data will be used to improve process parameterization needed for projecting climate-driven changes in oyster production potential:

Direct effect of climate change: models for productivity and connectivity

- Physiological modelling: Net Energy Balance (NEB) and generic Dynamic Energy Budget (DEB) models will be calibrated using new experimental data to improve the prediction of climate change effects on individual oyster growth.
- Population models at farm and local scale, e.g. Farm Aquaculture Resource Management (FARM) model will be used to examine direct climate-driven responses on population growth, harvest, environmental effects of culture and production analysis, using a layout which reflects typical culture practices for oysters in Northern Europe.
- Collections of farms (farm areas) at the system scale outputs that for instance combine increased susceptibility to disease with connectivity patterns

Indirect effects of climate change: models for mitigation and early warning

- Development and application of theoretical & statistical early warning techniques long-time series of Harmful Algal Bloom (HAB) occurrence in European waters and dynamic linear programming techniques to model the prevalence of HABs in coastal waters
- Model of the spreading of diseases through aquaculture facilities as a result of climate change, providing unique risk assessments of the cumulative impacts on aquaculture productivity both on farm and large scale, as a result of climate change

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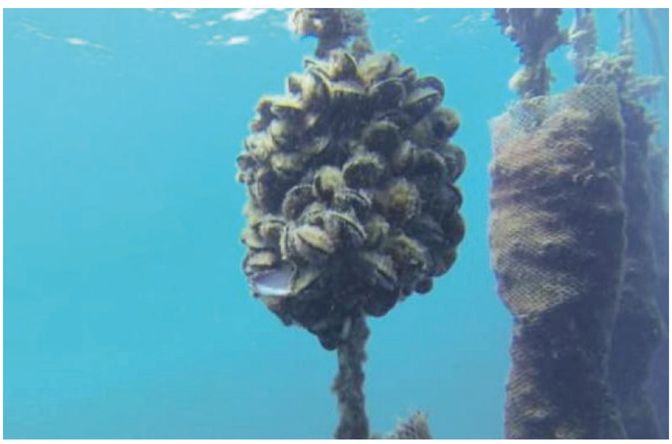
# Mussels at the South Atlantic coast

### What do we expect under climate change?

The Mediterranean mussel (*Mytilus galloprovincialis*) is a bivalve filter feeder that occurs naturally along the Portuguese coast. However in recent years, the development of aquaculture production areas on the coast has allowed the implementation of offshore companies for this species production, especially on the Algarve coast. The environmental background condition can define the production potential of a mussel offshore company, being determinant to scale the production according to environmental factors. In the SW coast of Algarve, the Mediterranean mussel is highly dependent on the natural occurrence of phytoplankton production as a result of upwelling events, as there is not significant runoff input from rivers into the coastal system. The spawning periods are also very dependent on the upwelling, where there is a typical spawning period from April to June during spring phytoplankton blooms, as well as a second smaller spawning period in mid to late autumn.

One main issue is the frequency of upwelling events that relates to food availability (phytoplankton) that affects mussel condition, reproduction and consequently settlement of mussel seed that naturally attaches to ropes. Other issue is the occurrence and intensity of Harmful Algal Blooms (HAB's). In the south Portuguese coast, Mediterranean mussel exhibits recurrently elevated concentrations of Okadaic Acid (OA) group toxins between spring and autumn due to the proliferation of HAB's. Our goal in CERES is to examine in laboratory whether changes on water temperature influence the depuration rates of OA-group toxins in mussels, with or without food supply.



### How sensitive and vulnerable are mussels?

The Mediterranean mussel is well-adapted to shifts of temperature as demonstrated in CERES experimental testing effects of different temperatures and two chlorophyll-a concentrations. Their vulnerability/ sensitivity as a species in the environment is not a major issue, but the capacity of being a suitable species to be farmed and of economic interest is highly sensitive to climate change, particularly warming. It is known that the occurrence of warm waters represents a reduction of phytoplankton abundances (reduced chlorophyll-a), followed by reduced mussel conditions, affecting the spawning performance and increased susceptibility to diseases. Another point is an indirect effect that is related with the intensification of the occurrence of Harmful Algal Blooms which conduce to large closure periods on harvesting. These vulnerabilities make the sustainability of offshore mussel aquaculture very difficult.

### What is the economic value of this species?

The global production in 2014 of aquaculture in Portugal, reached 10,791 tons, with a total value of 50.3 million Euro. Bivalves represented 45 % of total production, where mussel's production reached 1,547 t. The average price of fresh mussels in Portugal decreased 17.6 %, from 0.70 €/kg in 2014 to 0.58 €/kg in 2015 (INE, 2016).

Large volumes of mussels (20 tons) can be sold at 0.70 €/kg and direct sales to restaurants can reach 3.3 € to 4 €/kg, whereas at large supermarket chains the medium mussel size are regularly sold at 2.49 €/kg.

**What are the challenges?**

The knowledge of the reproductive performance of the Mediterranean mussel in the Algarve coast, behind the simple biological characterization, will be an essential help to increase farm productions and to develop better aquaculture management, adjusting and maximizing the placement timings of larval recruitment according to the market needs. The gonad development depends on the synergic effect of both internal and external factors. Specific endogenous rhythm is synchronized by external factors, such temperature, food availability, regulate reproductive cycles. Indeed, mussel's quality is assessed by consumers as a result of gonad development, with the fuller gonad attaining higher commercial value. The only available information is from a recent study developed by IPMA. Nonetheless, it is well known that climate changes, specially alteration on temperature and food availability can influence the reproductive cycle and condition of mussels with a great impact on mussel's recruitment, settlement and condition.

The high incidence of toxic phytoplankton blooms reported along the Algarve coast in the last years can affect mussel physiology, condition and reproductive cycle. As reported in previous studies, a reduction in soft body mass and gonad build-up was observed as a consequence of the reduction of filtering capacity in presence of toxic phytoplanktonic cells, apart of the longer closure periods of harvesting when mussels contain toxins above the regulatory limit. In general, 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.

**What is the working program in CERES?**

The experiments planned with mussels will be performed at IPMA. After the gap analysis carried out within CERES it was decided to examine whether changes on water temperature influence the depuration rates of OA-group toxins in mussels. This depuration procedure would enable the possibility to commercialize Mediterranean mussel with a good nutritional status in a much shorter period than in natural conditions, as observed for other species.

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# Oysters at the South Atlantic coast

**What do we expect under climate change?**

Until the 1970s, in Portugal and France the Portuguese oyster *C. 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. The conservation of *C. angulata* populations is important in the context of production diversification and biodiversity preservation, since in Europe, pure populations of C. angulata were observed only in the southern coasts of Portugal and Spain, namely in Rio Sado estuary, Rio Mira estuary and Rio Guadalquivir. Despite the effort made, climate changes may compromise the conservation of the genus Crassostrea populations in Portugal.

Given their global importance, coastal marine environments are a major focus of concern regarding the potential impacts of climate change, namely due to alterations in seawater salinity and temperature. Both factors are major issue impacting estuarine organisms, especially in cases of abrupt changes. Therefore, the occurrence of extreme climate events, especially extreme rain and drought periods, may severely impact bivalve's species, affecting immunological and physiological processes. The increased physiological stress frequently results in behavioral and physiological responses and in extreme cases may lead to mortality episodes.

Our goal in CERES is to determine the potential impact of climate change, namely the combined effect of salinity and temperature changes, not only on oyster survival, but also on behavior, immunology and biochemistry.

**How vulnerable are oysters?**

Climate change processes potentially threaten the bivalve mollusc aquaculture sector, which is economically relevant in several regions and countries. Detrimental effects on bivalve mollusc species might arise from the associated increase in sea surface temperature, pH reduction, higher frequency of extreme climatic events, extreme alteration in salinity, and possible synergies with other non-climatic stressors, such as harmful algal blooms and mollusc diseases. Simultaneous exposure to multiple stressors may lead to even stronger impacts on organisms, but such interacting effects remain poorly understood.

**What is the economic value of this species?**

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.

**What are the challenges?**

Several studies reported the effect of climate changes in bivalves. Most studies evaluated the effect of changes in an isolated environment factor and some evaluated the potential impact of the combined effects of changes in different environmental parameters in bivalves, such as temperature and pH. Other studies revealed that salinity by itself can affect significantly bivalves behavioral and physiological responses, and in extreme cases may lead to massive mortality episodes. However, no studies evaluated so far the combined effect of temperature and salinity in bivalves.

**What is the working program in CERES?**

Adults and juveniles of oyster *C. angulata* will be distributed in different aquaria to test the combination of different levels of temperature (5 to 35ºC) and salinities (0 to 40) exposures. For each condition, 3 replicates will be used, with 5 organisms per replicate (15 organisms per condition). Organisms will be exposed to each condition for 144 hours. Daily animals will be checked for mortality and behavior. Aquaria will be maintained at 12 light: 12 dark photoperiod and continuous aeration. Animals will be fed with the same diet, seawater will be renewed every day, and temperature and salinity levels re-established. Dead organisms will be removed when identified. After exposure, surviving organisms will be frozen for biochemical and physiological analysis.

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# Clams at the South Atlantic coast

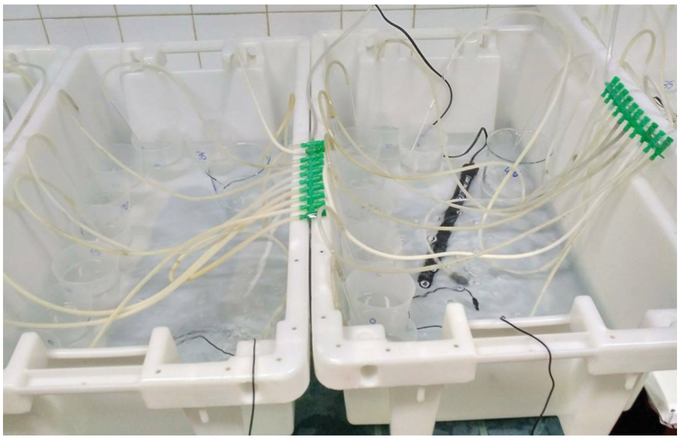
**What do we expect under climate change?**

The European clam Ruditapes decussatus is widely distributed along the coastal and estuarine areas of Europe and Northern Africa and represents an important resource income due to its high commercial value. *R. decussatus* is extensively produced and harvested in Portugal, where clam farming represents an important economic sector. The main production areas of this species are Ria de Aveiro (40°42'N; 08°W) and Ria Formosa Lagoon (37°01'N; 07°49'W). In these production areas, clams are reared in plots in the intertidal zone. Clam farming involves seeding juveniles, collected from natural beds, into plots maintained in tidal flats and harvesting commercial size animals. During the last two decades, the European clam production has suffered an important decrease due to several constraints, namely recruitment failures and excessive pressure on the capture of juveniles on natural banks and severe clam mortalities.

Given their global importance, coastal marine environments are a major focus of concern regarding the potential impacts of climate change, namely due to alterations in seawater salinity and temperature. These two factors are major issues impacting estuarine organisms, especially in cases of abrupt changes. Therefore, the occurrence of extreme climate events, especially extreme rainy events and drought periods, may severely impact bivalve's species, affecting immunological and physiological processes. The increased physiological stress frequently results in behavioral and physiological responses and in extreme cases may lead to massive mortality episodes. Our goal in CERES is to determine the potential impact of Climate Change, namely the combined effect of estuarine salinity and temperature changes, not only on clam survival, but also in behavior, immunology and biochemistry.

**How vulnerable are clams?**

Climate change processes potentially threaten the bivalve mollusc aquaculture sector, which is economically relevant to several regions and countries. Detrimental effects on bivalve mollusc species might arise from the associated increase in sea surface temperature, pH reduction, higher frequency of extreme climatic events, extreme alteration in salinity, and possible synergies with other non-climatic stressors, such as harmful algal blooms and mollusc diseases. Simultaneous exposure to multiple stressors may lead to even stronger impacts on organisms, but interacting effects remain poorly understood



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## What are the challenges?

Several studies reported the effect of climate changes in bivalves. Most studies evaluated the effect of changes in an isolated environmental factor and some evaluated the potential impact of the combined effects of changes in different environmental parameters in bivalves, such as temperature/pH. Other studies revealed that salinity by itself can significantly affect bivalve behavioral and physiological responses and in extreme cases may lead to mortality episodes. However, no studies evaluated so far the combined effect of temperature and salinity in bivalves.

## What is the working program in CERES?

Adults and juveniles of European clams *R. decussatus* will be distributed in different aquaria to test the combination of different levels of temperature (from 5 to 35°C) and salinities (0 to 40) exposures. For each condition, 3 replicates will be used, with 5 organisms per replicate (15 organisms per condition). Organisms will be exposed to each condition for 144 hours. During the experimental period animals will be checked for mortality and behavior factors, every day. Aquaria will be maintained at 12 light: 12 dark photoperiod and continuous aeration. Animals will be fed with the same diet, seawater will be renewed every day, and temperature and salinity levels re-established. Dead organisms will be removed when identified. After exposure, surviving organisms will be frozen for biochemical and physiological analysis.

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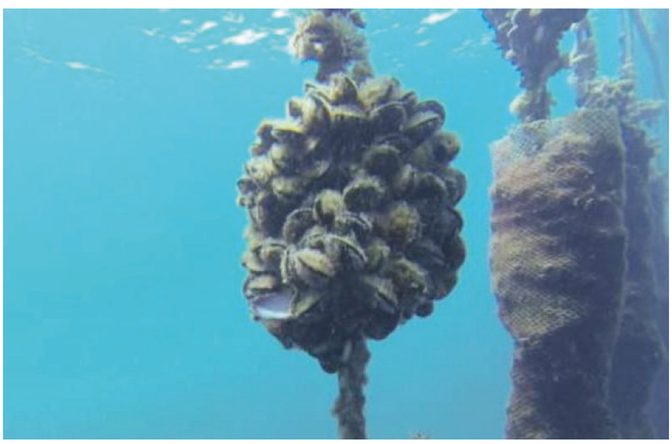
# Mussels in the Mediterranean

### What do we expect under climate change?

The Mediterranean Sea has been considered a "hotspot" for climate change. The following trends are expected in the Mediterranean basin during the 21st century: an increase in air temperatures between 2.2 and 5.1°C; a decrease in rainfall between 4 and 27%; longer periods of drought, related to an increased frequency of days with temperatures above 30°C; and sea level rise of around 35 cm. The Mediterranean is also becoming saltier and more acidic. Therefore, organisms inhabiting coastal and estuarine waters, i.e. bivalves, will be naturally exposed to greater environmental variations.. Considering the importance of bivalve aquaculture and artisanal fisheries in the Mediterranean region, a strong potential for significant socioeconomic impact of climate change is beyond doubt.

Bivalve culture on the Spanish Mediterranean coast is carried out mainly in the two Ebro Delta bays, Fangar and Alfacs. These semi-enclosed bays present distinctive characteristics, including a wide annual range of temperature (from 6°C to 31°C), salinity (between 13.22 and 37.40 psu) and total particulate matter between 2.70 mg $l^{-1}$ and 14.95 mg $l^{-1}$. Mussels (*Mytilus galloprovincialis*) are cultured in rafts that occupy a surface area of 1.8% and 6.5% of the total bay surface for Alfacs and Fangar, respectively. Mussel seed is collected using ropes hung from the culture rafts. These seed reaches adult commercial size within 18 months. However, persistence of high seawater temperatures for several consecutive days during some summers caused seed partial or total mortality, which must be then, imported from areas such Italy and France to continue the culture cycle.



### How vulnerable are mussels?

The first time that total mussel mortality was observed in Fangar Bay was in August 2003. All mussels cultivated in the bay perished due to high summer temperatures, which surpassed 28°C during a period of 2 weeks. Since then, several mortality episodes have been occurring in summer, affecting mainly the mussel seed.

A reduction of clearance, ingestion and absorption rates obtained in summer highlights the negative influence of high water temperatures upon the feeding and digestive processes of mussels.

### What is the economic value of this species?

Mollusc aquaculture represents the 65% of the total aquaculture production in Catalonia, being the mussel the 92% of the molluscan production of about 3000-4000 t $year^{-1}$.

### What are the challenges?

Environmental stressors can have simple (additive) or interactive (synergistic or antagonistic) effects on marine organisms and ecosystems. The biological impacts of ocean acidification have been largely considered in

isolation. Interactive effects with other climate change stressors, such as temperature or salinity, are still poorly understood. A study on combined effects of ocean acidification and warming on *Mytilus galloprovincialis* in a laboratory experiment and concluded that mussels were highly sensitive to warming, with 100% mortality observed under elevated temperature (25°C), although survival was not affected by a pH decrease of 0.3 units. It remains unclear whether the somatic and shell decreases in growth found after summer under low pH were a consequence pH levels or a consequence of a combined effect of acidification and warming. Another study found that the adverse effects of global warming were exacerbated when high temperatures coincided with acidification. Thus, bivalves' production in the Mediterranean is expected to be at risk because of this kind of interactions.

**What is the working program in CERES?**

Accordingly, in this proposal we plan to set up a series of experiments to investigate the effects of different levels and patterns of variability in pH and temperature on the physiology of *M. galloprovincialis.* Experimental laboratory conditions will be set to simulate natural conditions in the Ebro Delta bays, which is where the most important bivalve aquaculture in the Spanish Mediterranean coast are located. Regarding the experimental set up, we will follow the methods already in use at the ICM-CSIC for pH and temperature manipulation. Three levels of pH (8.1, 7.7 and 7.3), two temperatures (control following Ebro delta bays temperature, and control+3ºC), and one salinity (following the variable Ebro Delta bay salinity) will be tested. Regarding bivalve performance, several indicators will be followed and analyzed, both at cellular and organism level, including mortality counts of dead individuals, shell growth, buoyant weight, ash percentage, calcification (alkalinity anomaly in incubations), feeding behavior (i.e., clearance rate, ingestion rate, and absorption efficiency), reproductive activity, burrowing activity, histopathological lesions (foot, gills, digestive and gonads) and tolerance to desiccation to assess their resilience during low sea level events or during transportation to the market. Regarding feeding behavior, two filter feeding devices with 10 mini-flume tanks each (45×180×60 mm, length×width×height respectively) will be used. These devices have been designed for the purpose and successfully used in the field.

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# Salmon in the North-East Atlantic

**What do we expect under climate change?**
As Atlantic salmon are anadromous (adult fish live in the sea and migrate into fresh water to spawn), the production cycle has both fresh water (hatchery and nursery) and marine phases (on-growing to harvest). Salmon aquaculture production in Europe (including Norway, Iceland and the Faroe Islands) represents ~48% of total aquaculture production (1,331,955 tonnes in 2013). Therefore, in terms of quantity it is by far the most important aquaculture product in Europe. Within the EU-28, salmon aquaculture production has increased only marginally since 2010 while it has massively expanded in Norway.

**Direct effects of climate change:**

- Increased sea temperatures may lead to faster growth rates in certain areas. However, prolonged periods of warmer summer temperatures may cause thermal stress which reduces growth potential, and make fish more susceptible to disease.
- Increased sea temperatures may open up new areas for salmon aquaculture production further north (e.g. in Norway, Iceland), but equally may reduce production in more southern areas that are already on the temperature limits for this species. Thus, overall there may be a shift from current production areas to areas further north, and may drive production further offshore.
- Changes in the frequency and strength of storms may pose a risk to industry infrastructure, e.g. salmon pens may be dislodged from seabed.
- Adverse weather events may also temporarily limit production (e.g. by reduced feeding) and health management practices (i.e. removal of mortalities, health treatments). Increased strength of storms can lead to physical skin damage to the fish, which can then be prone to secondary bacterial infections.
- With climate change it is predicted that winds will increase in intensity and storminess, so harmful jellyfish species such as *Pelagia noctiluca* or *Muggiaea atlantica* may be swept into coastal waters of the North East Atlantic more frequently, which can cause fish health issues.

**Indirect effects of climate change:**

- Outbreaks of diseases may increase or decrease depending on changing conditions.
- Increased temperatures may increase the geographic range of some diseases (northern spread) and increase the occurrence of as yet unknown or emerging diseases.
- Sea lice and amoebic gill disease (AGD) are some of the main challenges for the industry in sea water. The life cycle of these parasites is directly related to sea water temperatures and therefore it is possible that the impact of sea lice and AGD will increases with warming seas .
- White spot (caused by the protozoan parasite *Ichthyophthirius multifiliis*) is an important disease for freshwater Atlantic salmon stages, and the parasite life cycle is also directly associated with water temperature, which may increase as temperatures increase.
- Increased incidence of AGD and sea lice may lead to an increase in the number of disease treatments. Bath treatments used for AGD, and sea lice, include enclosing cages in tarpaulins (baths) and adding freshwater or hydrogen peroxide. Higher water temperatures may increase risk of fish losses during bath treatments due the higher oxygen requirements during treatment, fish stress and increased toxicity (i.e. hydrogen peroxide). Hydrogen peroxide treatment is not recommended above 13.5°C and higher sea temperature may limit this treatment as an option. Periods of low rainfall may also limit access to freshwater.
- Lumpfish are used as a biological control for sea lice in Atlantic salmon aquaculture. These fish eat sea lice to lower the concentrations. However, Lumpfish are cold water species and increasing sea temperatures may lead to thermal stress, which may reduce efficacy and result in lower efficiency for this treatment option.
- Jellyfish fish kills may become more prevalent in some areas. For example, if the prevalence and widespread occurrence of *Pelagia noctiluca* increases it will have a detrimental impact on the

aquaculture industry. Currently there is anecdotal evidence that they are increasing but limited scientific evidence. Even if jellyfish do not increase, an increase in the salmon aquaculture footprint will increase the likelihood of future fish kills.

- Gill health is one of the main health challenges for the industry, and gill disease can be caused by infectious and non-infectious agents. Increasing temperatures, leading to increased pathogen load, and increasing phyto and zooplankton blooms may increase impact and prevalence of complex gill disease cases.
- The biofouling hydroid Ectopleura larynx is the predominant fouling organism on salmon nets in the North Atlantic. Increased abundances of this species (either through increased growth rates, or a prolonged season for growth) will result in added production costs due to increased frequency of cleaning or changing of nets. The costs associated with such biofouling are substantial and the blasting of such hydroids into the water can directly sting and injury the salmon.
- Some other potential impacts, not be related to climate change specifically but relevant in the overall context, relate to management of the industry. The current inflexibility to implement adaptive changes to sites, technology and management practices, without the need long and complex license changes, hinders adaptive change. Also, if certain locations can no longer support salmon production due to climate change, scaling up production in other areas to offset the loss of business and reduced supply is not a simple or short task, and thus food security may become an issue.

**What are the challenges?**

There is a large uncertainty surrounding many of the above potential impacts on salmon aquaculture. This is largely a result of limited long term datasets to examine trends or limited data on new and emerging diseases. For example, there are few jellyfish time series to examine whether Pelagia noctiluca is increasing in the North Atlantic and limited research to show the effectiveness of proposed mitigation measures (e.g. bubble curtains).

AGD has emerged to become one of the most significant health challenges in marine salmon in Northern Europe and despite the identification of risk factors such as high water temperature and high salinity with AGD here remains a dearth of knowledge on the factors that have led to this dramatic increase in prevalence and impact. There are also very limited studies on the interaction of changing biofouling cleaning methods, parasites, environment (in particular temperature and salinity) with marine aquaculture finfish species and these gaps in our knowledge require to be addressed.

**What is the working program in CERES?**

We wil

- examine the effectiveness of a bubble curtain to keep jellyfish out of salmon aquaculture cages.
- conduct experiment challenge trials to examine whether a fish feed supplement could protect salmon from the toxic effects of jellyfish venom.
- use a growth model and the Farm Aquaculture Resource Model (FARM) to assess individual and site level population changes to fish production in sea cages, based on climate predictions.
- develop a new product called WATER, a model that predicts, based on environmental conditions, locations where "Aquaculture can Thrive in EuRope", which will enable users to look at the physical locations where salmon aquaculture will and will not be possible under a changed climate. This will assist policy makers, investors and other stakeholders to improve spatial planning for salmon aquaculture depending on how the climate changes in the future.

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# Meagre at the South Atlantic coast

**What do we expect under climate change?**

Meagre (*Argyrosomus regius*) is an important resource, both for fisheries and aquaculture. This species is distributed along the Atlantic Northeast, Atlantic Eastern Central and Mediterranean Sea. It is a fast growing species, with high fecundity and may attain over 180 cm in total length and 50 kg in weight, reaching over 200€ per specimen.

These characteristics, make meagre particularly valuable for small-scale commercial and recreational fishers, as well as to the processing industry due to the diversity of products that can be developed (e.g. fillets, slices). Therefore, its production for aquaculture has been heavily promoted. Meagre is produced in several Mediterranean countries (France, Italy, Spain, Egypt, Greece, Turkey, Malta and Portugal), mainly in cages but also in earth ponds.

Europe produces around 10,000 Tons of meagre. Its commercial size is above 1.5kg that can be reached in only 15 months depending on temperature (sea bream required the same time to produce a 400 g specimen). Growth is heavily depressed when water temperature decreases below 17°C, and is optimal at 24ºC. Therefore, this species might be a good solution for Mediteterranean and South Atlantic aquaculture, considering global warming scenarios.

Our goal in CERES is to determine the potential impact of Climate Change on meagre, both for aquaculture and fisheries, by assessing growth, survival at different development stages and infer on how climate change may affect recruitment.

**How vulnerable is meagre?**

The meagre farming industries are still expanding in South Europe, with research still needed to achieve a sustainable and efficient production system. The most relevant barriers and challenges affecting the growth of this species are:

- availability of efficient protein sources and feed prices
- increased requirements for sustainability in farming practices
- diseases management
- transfer of diseases and parasites between farmed and wild fish
- farmed fish escapes
- predominance of small-scale farmers
- lack of product differentiation and development
- lack of co-ordinated national strategic plan for aquaculture and poor industry administration
- competition from an emerging range of other farmed species
- consumer's growing interest for safe and healthy food

**What is the economic value of this species?**

Meagre distribution and commercialization is growing and the market demand for this species is growing exponentially. Yet, several constrains still affect the growth of this species production, mainly related with the harvesting seasons that are identical to other fish species already established, like sea bream and seabass, and the availability of wild meagre in the market. The total production of meagre in Europe attained 4100 Tons in 2015, and a market average value of 5.8 €/kg, thus representing a market value of 23 780 K€. Climate related changes are expected to affect production yields posing threat and opportunities to the viability of this species aquaculture.

**What are the challenges?**

The knowledge on meagre aquaculture is still scarce when compared to salmon, sea bass and sea bream. Several aspects related with different stages of meagre development still require the development of protocols for a sustainable production of this species, namely on breeding programs for selection traits, bioenergetics, physiology, nutrition, disease prevention, optimization of technology adapted to meagre behavior, among others.

**What is the working program in CERES?**

- Evaluation of sudden environmental changes on survival and growth of larvae and post-larvae
- Effect of temperature on growth rate, survival and feed efficiency of juveniles

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# Sea bream and seabass in the S Atlantic and W Mediterranean

**What do we know about about these species?**

Gilthead sea bream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*) are the main species currently farmed on a large scale in South Europe. They are common throughout the Mediterranean and are also found along the Eastern Atlantic coasts, from the United Kingdom to the Canary Islands (*sea bream*) or from Norway to Senegal (*seabass*). Traditionally, sea bream and seabass have been farmed extensively in coastal lagoons and brackish ponds of northern Italy and in southern Spain and Portugal. In the 1980s it was successfully reproduced in captivity and intensive rearing systems (especially sea cages or land-based tanks) were developed. Since then sea bream and seabass have become two of the main products of South European aquaculture. In coastal lagoons, sea bream are generally reared with mullet, seabass, bream and eels. On average, sea bream reach commercial size after one and a half years, whereas seabass is generally harvested when they weigh 300 g to 500 g, which takes from 1.5 years to 2 years, depending on water temperature.

Our goal in CERES is to determine the potential impact of climate change, not only on sea bream and seabass production, but also on growth, recruitment, and natural mortality. Of particular interest is to identify which environmental factor was the key driver behind this change.

**How vulnerable are sea bream and seabass?**

The sea bream and seabass industries are sectors already entering its mature phase, but still needing more efficient production systems and new technologies. The most relevant barriers and challenges affecting the growth of this sector are:

- increased competition for space in coastal areas
- availability of protein sources and feed prices
- climate change direct and indirect effect on the production
- increased requirements for sustainability in farming practices
- diseases management
- transfer of diseases and parasites between farmed and wild fish
- farmed fish escapes
- unregulated supply and demand causing imbalance in the market and reduced profitability
- predominance of small-scale farmers
- lack of co-operation amongst local and international producers, and between government and industry on R&D
- lack of product differentiation and development
- lack of co-ordinated national strategic plan for aquaculture and poor industry administration
- competition from an emerging range of other farmed species.
- industry rationalisation and scope for development of efficient production systems
- need to develop quality schemes, branding strategies and better promotional tactics
- consumer’s growing interest for safe and healthy food

**What is the economic value of this species?**

Most sea bream and seabass are produced by aquaculture. The EU is by far the biggest producer worldwide (67% for sea bream and 80% for seabass), followed by Turkey (sea bream) and Egypt (seabass). Within the EU, Greece is the largest sea bream and seabass producer, followed by Spain. Trade between the EU and third countries is very limited, while the intra-EU trade is substantial. The annual sea bream production reaches around 370 million euros in the EU (i.e. 73k tons), whereas the seabass production reaches around 370 million euros in the EU (i.e. 68k tons) (data from 2011). Climate related change is expected to affect production yields may pose a serious threat to the viability of this aquaculture sector.

**What are the challenges?**

Further development on sea bream and seabass aquaculture requires that knowledge gaps are covered in the future:

» Cost-efficient production and high efficiency of operations are the most important challenges currently experienced. These may be met by intensification, automation and up scaling of the production. This requires well developed operational routines, accurate measuring real time systems for monitoring of the enclosed biomass and contaminants, and reliable control mechanisms.

» The growing awareness for seafood safety, ethics and welfare pushes forward the need for production systems that safeguard animal optimal condition and that take sufficiently care about the preservation of the surrounding environment. In intensive mariculture, good water quality, responsible handling routines and minimisation of escapes are important objectives towards a sustainable production. This may be achieved by improved containment systems.

» Technology to advance the safety on aquaculture platforms and a further automation of high-risk operations may contribute to make the profession more appealing.

» The gradual movement of production units towards more exposed areas has been initiated through the search for locations with more stable environmental conditions and less conflict with other coastal activities. New challenges in comparison to mariculture in sheltered areas are the development of more robust equipment as well as a larger degree of automation for operations such as feeding and maintenance.

» Projecting the impact of climate change on production based on current available and disperse data is expected to be accompanied by a great deal of uncertainty, thus higher data collection is needed to assess the direct and indirect effects of climate changes on these species, integrating with real-time environmental monitoring tools.

» Finding sustainable and efficient alternatives to reduce dependency on wild stock for farmed fish feed production.

**What is the working program in CERES?**

- Experiments about acidification and jellyfish exposure impact on sea bream and seabass
- Impact of toxic algal exposure on farmed sea bream under warming and acidification
- Impact of vibriosis on farmed sea bream under warming and acidification
- Combined effect of temperature and food on growth, survival and stress biomarkers of farmed sea bream juveniles.
- Sampling & data collection strategy for farm economic datasets using the „typical farm approach". Farm surveys and data collection from seabass / seabream farms will be used to reflect the prevailing production system with common technology, capital input, labour resources and typical production volume within W Mediterranean/S Atlantic areas.

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# Sea bream and seabass in the Eastern Mediterranean

### What do we expect under climate change?

Sea bass and sea bream farming in the Mediterranean is generally carried out in off-shore cages or semi-offshore cages. Climate related changes such as changes in sea surface water temperature, sea level rise, increased frequency of extreme events (e.g. storms, floods, drought) and other oceanographic variables (wind velocity, currents and waves) would have a negative impact on marine aquaculture in cages. Stress due to increased water temperature and oxygen demand, eutrophication and toxic events e.g. harmful algal blooms, increased incidents of diseases and parasites and large waves and storms are some of the climate change related challenges for marine aquaculture sector.

### How vulnerable are seabass and sea bream?

Off-shore cage operations are extremely open to changes in oceanographic variables e.g. wind velocity, currents and waves. Along with rise in sea water temperatures changes in oceanographic variables would have physiological impact on farmed species and create operational challenges for fish farmers.

### What are the economic consequences?

Physiological impact of climate related changes on sea bass and sea bream and emerging operational problems at off-shore farming sites would not only mean an increase in capital investment for more sophisticated off-shore facilities and production costs but could also lead to lower profitability levels in marine cage farms. What are the challenges?

### What are the challenges?

One of the most important challenges for sustainability of marine aquaculture sector is to develop mitigation or adoption tools and strategies with respect to impact of climate change on farmed species and thus farming operations. To this end, projecting direct and indirect impacts of climate change on productivity and financial performance of sea bass and sea bream farms is crucial for addressing climate change related challenges. In this respect CERES sea bass/sea bream-storyline is a proactive approach for projecting the impact of climate change on productivity and financial performance of marine aquaculture farms.

**What is the working program in CERES?**

A series of field studies will be conducted to collect environmental, bio-technical (e.g. growth rates, mortalities, FCR, stocking densities, diseases outbreaks), structural and financial data from Turkish sea bass/sea bream farms.

The aim is to contribute to modeling the direct effects of climate change on farmed sea bass and sea bream and further to construct theoretical farms for examining the impact of climate change on productivity and financial performance of marine cage farms.

Collected bio-technical, structural and financial data from marine cage farms will be used to construct virtual Turkish sea bass/sea bream farm according to "Typical Farm" approach (Lasner et. al., 2016).

Based on project findings regarding the direct effects of climate change on sea bass and sea bream, the impact of climate change on productivity and financial performance (e.g. production costs, profitability) of Turkish sea bass/sea bream farms will be simulated on engineered virtual farm using the "Agri benchmark Simulation Model TIPI-CAL (Deblitz & Zimmer, 2005).

**Literature**

*Deblitz & Zimmer (2005) A standard operating procedure to define typical farms, http://literatur.thuenen.de/digbib_extern/dk038513.pdf*

*Lasner et al. (2017). Establishing a benchmarking for fish farming – Profitability, productivity and energy efficiency of German, Danish and Turkish rainbow trout grow-out systems. Aquaculture Research, doi:10.1111/are.13144*

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# Sardine and anchovy in the Bay of Biscay

**Will small pelagisc be effected from climate change?**

Spatial distribution at different life stages may change depending on climate scenarios. Changes in the adult distribution may be conveyed by a change in the growth pattern or some habitats becoming physiological unsuitable (low food, high temperature). Changes in larval dispersal are expected to depend on changes in the seasonality of currents and spawning windows depending on climate scenarios. Changes in stock productivity with climate change scenarios could be mediated by the scaling at population-level of changes in individual growth, fecundity and larval survival.

**How vulnerable are small pelagics to climate change?**

The spatial organization of the life cycle may change depending on climate scenarios affecting larval dispersal, individual growth and timing of reproduction.

Stock productivity may increase with spatial displacement.

The capacity of fishers to adapt their strategies, vessels or gears will determine the viability of the pelagic fishery.

**What is the economic value of this fishery?**

For sardine there ist no total allowance of catch (TAC) or management plan. The resource in the Bay of in Biscay is in the order of 400-500 000 tons but a larger spatial extend of stock is probable. The annual international catch is 30-40 000 tons in recent years. Fish price is in the order of 1-2 € per kg varying with fishing gear, season, location, markets.

For anchovy a management plan was evaluated as precautionary. TAC ranges between a minimum of 7000 tons and a maximum of 33000 tons set depending on the spawning stock biomass being higher/lower than reference points. The annual international catch is 20-30 000 tons in recent years. Fish price is in the order of 2-3 € per kg varying with fishing gear, season, location, markets.

**What are the challenges?**

There are several knowledge gaps for these species:

- mortality (predation) in the ecosystem
- larval connectivity.
- translation of individual vital rates into population level behavior and productivity.
- behavioral adaptation of fishers to changing conditions (biology, management and markets)
- relationship between food quality changes and composition of the (changing?) phyto- and zoo plankton communities

**What is the working program in CERES?**

- Outputs of the model run for currents, hydrology and zooplankton will be the input for individual based models (IBM).
- Full-life cycle IBM-dynamic energy budget (DEB) models of anchovy and sardine: The IBMs will be run in population mode in 0-d to assess how individual vital rates (growth, reproduction, survival) translate into population-level productivity (recruitment, demography) and fecundity depending on climate scenarios.
- Larval IBM-DEB models for anchovy and sardine: The IBMs will be run to assess change in larval dispersal depending on climate scenarios and reproductive windows.
- Spatially explicit pelagic fishery model: The model will be run to assess the effect of change in spatial distributions on the economic viability of fishing strategies using different metrics.
- Statistical modelling of spatial distributions and their links to demographic and climate drivers: The models will be run to predict distributions at different life stages under different scenarios.

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# Sardine and anchovy in the Mediterranean

**Will small pelagisc be effected from climate change?**

During the last 3 decades landings of small pelagics fisheries in the North Western Mediterranean have decreased significantly, due to environmental changes as well as to excessive fishing pressure in the early 1990s. Fisheries-independent abundance estimates of sardine (Sardina pilchardus) and anchovy (Engraulis encrasicolus) mirror the decrease in fisheries landings. Additionally, scientific surveys of early stages (eggs and larvae) show increased abundance of the round sardinella (Sardinella aurita), a previously rare species in the area spreading from the south. All these lines of evidence suggest profound changes in pelagic ecosystems.

**How vulnerable are small pelagics to climate change?**

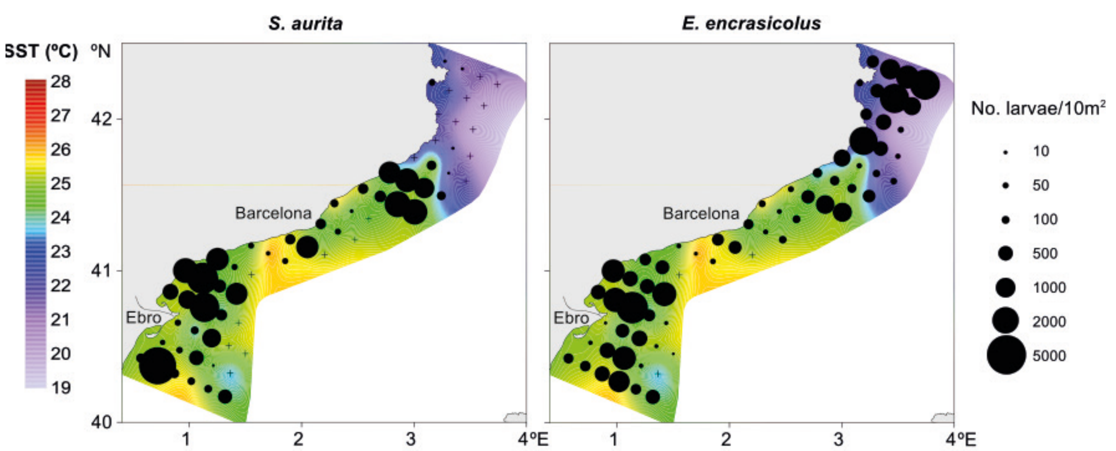
The decrease in the abundance of the traditional target species of small pelagic fisheries, sardine and anchovy, is having important effect on fisheries productivity. The purse seine fleet exploiting the resource in Spanish coasts, as well as the midwater trawl fleet operating in the French coasts, have suffered important reduction in the number of fishing units to half of the former fleet size and the economic viability of the fisheries are uncertain. The increase in abundance of the round sardinella cannot mitigate the economic impact of productivity loss, as this species has very low commercial value.

**What is the economic value of this fishery?**

The combined landings of sardine and anchovy in the early 1990s in Catalonia were ca. 50 000 t, for a total value of 100 M € approximately. In recent years, the combined landings are ca. 10 000 t with a value of 25 M€. The fleet size has likewise decreased in the 1993-2016 period, from 163 units to 82.

**What are the challenges?**

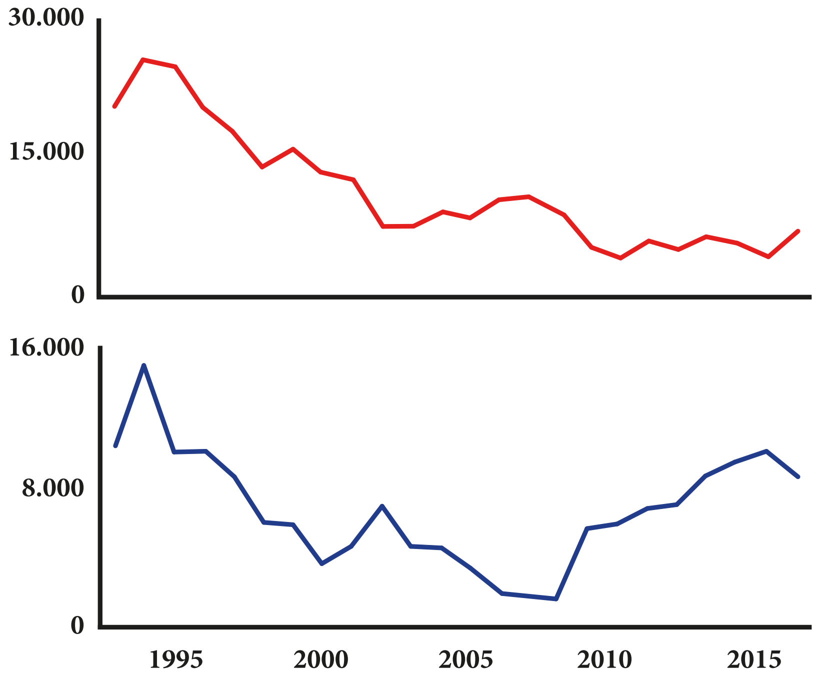
Current research shows that the productivity of these small pelagic fish stocks is negatively affected by increased temperatures, that reduce reproductive




Larvae of round sardinella, *Sardinella aurita*, and anchovy, *Engraulis encrasicolus*, along the Catalan coast in summer success in the winter spawning sardine. The summer spawning anchovy can be affected also by extreme temperatures, such as the anomalous hot summers of 2003 and 2006. Further climate related impacts are suspected to be driving slow growth in sardine and anchovy, likely due to changes in the ocean's biological productivity.

**What is the working program in CERES?**

Statistical models will be used to determine the effect of climate changes on the early life stages of sardine, anchovy and round sardinella, as well as to relate these changes to decreasing fisheries productivity.




Landings of sardine (t) *Sardina pilchardus* by the purse seine fleet of Catalonia (1993-2016)

Landings of anchovy (t) *Engraulis encrasicolus* by the purse seine fleet of Catalonia (1993-2016)

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# European hake in the Mediterranean

**Will European hake be effected from climate change?**

European hake (*Merluccius merluccius*) is found throughout the Mediterranean Sea, and is a common catch in all commercial demersal fisheries. Exploited since historical times, it has been concluded by the General Fisheries Commission for the Mediterranean that stocks are declining and are over-exploited in some regions.

For the Aegean Sea hake, a recent study suggested that both fishing mortality (F) and spawning stock biomass (SSB) may be outside optimal levels. As a result, a national multi-annual management plan targeting fisheries exploiting the hake stock has been put in place since 2014. Our goal in CERES is to determine the potential impact of climate change, not only on hake historical production but also distribution, fecundity, growth, maturity, recruitment, and natural mortality. Of particular interest is to identify the exact point in time when this climatic driven regime shift may have occurred and which environmental factor was the key driver behind this change.

**How vulnerable is hake to climate change?**

It has been documented that during the 80's West Mediterranean hake stocks have undergone drastic changes, consistent with hydroclimatic variability. It is now suggested that the combined effect of fisheries, environment and stock internal dynamics can increase the dependency of the hake populations on the recruitment variability, which is largely climate driven.

**What is the economic value of this fishery?**

Hake is an important commercial species in the small scale fisheries sector, as well as the industrial bottom trawl fleet, reaching as much as 10% of total catches. Given the low profitability of the Greek Aegean fleet and the inability for an increase in capital investment to become more competitive, efficient and productive, any climate related change that will affect hake yields may pose a serious threat to the viability of the fishing sector.

**What are the challenges?**

Hake related information is associated with significant knowledge gaps, being no exception from the rule governing Greek fisheries. The lack of sufficient time series of stock related data, due to the discontinuous implementation of the Fisheries Data Collection Programme, hindered any efforts to analytically assess the status of the stocks. Valuable descriptors


of population status such as age structure, biomass levels, spawning stock biomass, fishing mortality, recruitment variability, spatio-temporal distribution, fecundity, growth and maturity are either partial or lacking completely. The only available long-term datasets are the official landings provided by national statistics which date back to the 60's. Inferring on these data was deemed the only option within reach. However, projecting the impact of climate change on hake production based on these data is expected to be accompanied by a great deal of uncertainty.

**What is the working program in CERES?**

The modeling approach will go along the following steps:

- Review the physiological limits of the species to multiple stressors.
- Investigate trends and relationships of landings and environmental indices time series
- Select which environmental indices to include (check for multi-colinearity)
- Identify if and when changes have occurred in the 'system' (Aegean demersal marine biota - e.g. hake stock) through application of:
  - » Principal Component Analysis (PCA)
  - » Chronological Clustering (CC)
  - » Sequential Regime Shift Detector (STARS)
  - » Non-linear Threshold Generalized Additive Models
- The aforementioned models, will be applied in parallel, with the intention to confirm in more than one ways if a climatic driven regime shift has occurred and which environmental factor was the key driver behind this change.
- Project future changes in distribution and productivity under various climate scenarios, through life cycle and mechanistic models.
- Provide spatially-explicit bio-economic estimates of climate-driven changes in the fishery and the resources (bio-economic model).

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# Bluefin tuna in the Mediterranean

**What do we expect under climate change?**

Atlantic bluefin tuna is a large migratory apex predator that migrates in May–June to the Mediterranean Sea to reproduce, and then return to their foraging grounds in the North Atlantic during July–August. The confined spawning window and the specific location of their spawning grounds make this species very sensitive to climate change. We expect climate-driven consequences in the offspring fitness and the selection of reproductive habitats.

**How vulnerable is the bluefin tuna to climate change?**

Atlantic bluefin tuna is categorized as an endangered species according to the IUCN Red List Criteria (IUCN 2016) though in 2009 there was even a proposal to list bluefin tuna under Appendix I of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora). It is considered one of the most vulnerable species to climate change and harvesting among tuna and billfish species.

Atlantic bluefin tuna is managed in two stock units, the western and eastern Atlantic stocks, by the International Commission for the Conservation of Atlantic Tuna (ICCAT). The eastern stock reproduces in the Mediterranean Sea. The western stock reproduces in the Gulf of Mexico and the Slope Sea. It has been demonstrated that their reproductive habitats are sensitive to climate change, particularly warming, in the western stock. No studies have yet addressed the plausible effects of climate change on the reproductive habitats in the eastern stock.

**What is the economic value of this species??**

The two stocks are subjected to important restrictions and harvesting controls. A recommendation by International Commission for the Conservation of Atlantic Tuna established a 15 year recovery plan for the eastern Atlantic and Mediterranean bluefin tuna stock starting in 2007 to ensure the sustainability of the fishery by 2022. The TAC was reduced to 13,500 tonnes in 2010 in agreement with the scientific advice. There are closed fishing seasons for pelagic longline vessels, purse seiners, baitboats and pelagic trawlers. There is prohibition to use airplanes and helicopters to search bluefin tuna and there is a 30 kg minimum size catch except in the Adriatic Sea where the minimum size is established at 8 kg. TACs for 2015, 2016, and 2017 were established at 16,142 t, 19,296 t, and 23,155 t, respectively. A new assessment will be conducted in 2017 for the next years.

**What are the challenges?**

Since bluefin tuna is an environmental driven spawners, that is, selects spawning grounds based on specific environmental characteristics, we expect and important impact of environmental changes in the reproductive traits of the species. The biggest gaps are to estimate possible changes in reproductive timing and habitat use induced by global change based on a solid ecological knowledge and forecast economical consequences in the future.

**What is the working program in CERES?**

1. The experiments planned include egg and larvae sensitivity measured, as growth, developmental time and survival, to different ranges of temperature, salinity and pH
2. Long-time series of field data of different life stages (egg, larvae, juvenile, adults) from fisheries and fisheries-independent data, data from annual icthyoplankton surveys, oceanographic data, operational oceanographic models, data from satellite, knowledge of the fleets, economical data.
3. Statistical models, bio-physics models (coupled circulation and individual based models parameterized for the species), bio-economic models (Flbeia). The different models will be combined with the aim of making environment-tuna relationships useful for population projection models and bio-economical models in different scenarios of climate change.

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# Dolphinfish in the Mediterranean

**What do we expect under climate change?**

The dolphinfish *Coryphaena hippurus* ("llampuga", "dorado" or "mahi-mahi") is a world-wide distributed tropical and subtropical large migratory species of commercial intrest. In Europe, the Mediterranean is part of its northern distribution limit. There, dolphinfish lives fast and dies young (max age of 3 years), dwelling surface waters that uses only for reproducing and growing until juvenile stage. After that, adults move (supposedly) to the Atlantic. Only juveniles (age 0) are targeted by a seasonal and intense fishery based on FADS.

Due to its thermal requirements for spawning and growing (above 19°C), it is expected that climate change will affect the

- change in spawning season and area of spawning
- presence of the species in the Mediterranean
- accumulated growth until the fishery is open (always at a fixed time)

The consequences for the fishery can include

- changes size/abundance at the onset of the fishery
- change in presence of the species through the year
- change in market behavior depending on the latter two points

This can lead to the adoption of adaptive management measures, including changing the timing of seasonal closure, plans to incentive/discourage the consumption etc..

**How vulnerable is the dolphinfish?**

This species meets several requirement of sensitivity to climate change.

1. The studied fishery is located at its northern distribution limit, hence the probability that environmental changes affects distribution/ phenology is higher.
2. In tropical areas, the species is present all year round and spawn throughout the year. In the Mediterranean, the thermal window enabling the lively fishery constraints the species to spawn (may-june) and grow until juvenile stage (around 60 cm).
3. The growth of this species is extremely high, attaining up to 70 cm in 6 months, the fishery targets only age-0 individuals and its vertical distribution is mostly confined to the first tens of meters . Therefore, even heat waves will affect the whole fishery in a particular year.

We anticipate that increasing warming can affect the length of the spawning season and the growth of the fish. Therefore, it is not unlikely that this species increases its presence through the year, and that the landed sizes and total catches vary in the coming decades.

**What is the economic value of this species??**

This species is exploited in the NW Mediterranean by the small-scale fleet in the Balearic Islands, Malta, Italy and Tunisia and supports a major fishery for three months at the end of summer/autumn. In the case of the Balearic islands, for example, It is the most important fish in terms of weight for the small-scale fleet (345 boats in 2010). With less than 10% of effort (boat-days) devoted to this fishery, it generates 26% in weight of all landed fish and 13% of the gains (data for 2004-2016, Palmer et al., in press). Fishing boats are small, around 7m, and catches tend not to exceed 80 kg per trip, although the fishery has established a self-regulated maximum of 200 kg per boat in order to control the prices. Maximum gains are around 45 000 euros/month during the fishing season. The fishery employs most fishermen of the small-scale fleet for three months. The fishery is based on purse-seine around fixed FADs whose number and location are strictly regulated, and assigned to individual boats. As an appreciated fish of the season since ancient time, it has profound cultural value in these places.

**What are the challenges?**

The main knowledge gaps that will try to be solved within CERES are:

- Environmental constraints for spawning and growth (physiological limits, ranges of preference)
- Historical series of abundance, or proxies for it
- Species ontogenetic and seasonal movement
- Robustness of the fishing fleet in front of climate change (adaptability, shift in species)
- Relationship between fishery regulations, biological data and the formation of market price

**What is the working program in CERES?**

1. New data are being extracted from existing otolith collections in order to relate the individual growth variability to changes in environmental conditions. For that, a cooperation with other countries (Tunisia, Italy, Malta) has been established within the frame of CERES and FAO, and otoliths have been provided to CSIC in order to conduct such analyses.
2. In cooperation with the Spanish Institute of Oceanography, all spatially-explicit data from longline catches of adult dolphinfish are being analyzed to delineate the environmental constraints for spawning.
3. In cooperation with the strong industry of sports fishing in the Balearic Islands, a citizen science-based field study has been launched, by which catches of dolphinfish spawners are positioned through GPS and sent to CSIC.
4. Growth: a dynamic energy budget (DEB) model is being explored as a tool to relate temperature-related growth to observations.
5. Spawning constraints. A spatial statistical model based on multiple data sources is being built. Further, we will explore the outcomes of the climate envelope modelling approach for this species, implemented by PML.
6. Abundance index. As no abundance index exists for the species (but it is known that its fishery is based on recruits and it is environmentally-driven), we will apply a Depletion model based on catches that has been recently and effectively used for this species in the Pacific Ocean.
7. Environmental data (productivity, temperature, stratification and eddy kinetic energy) are being explored by comparing the outcome of several existing coupled physical/biogeochemical models (e.g. Copernicus). This process will enable the selection of relevant environmental data that can be projected, and relevant data to be used in shorter-term exercises.
8. We will modify the MEFISTO bioeconomical model (V.4.0) for the species. In particular, we will analyze the effects on:
   - within-season availability to fishermen
   - mean initial size at the onset of fishery (price?)
   - size-progression within the season (will that affect the market?)
9. With all that data, we will work on adaptation strategies of the fishing sector, including the effects of possible adaptation strategies by the artisanal fleets. We will also include an analysis of robustness of the artisanal fleet based on FADs with respect to climate change, and the potential effects of management measures on the flexibility of the fisheries sector to adapt to climate driven changes.

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# Demersal fishery in the North Sea

**What do we expect under climate change?**

The storyline focuses on the mixed demersal fisheries in the North Sea where complex biological and technical interactions occur. For these fisheries the important target species such as cod, haddock, saithe and hake are taken into account. Potential consequences of current and changing (e.g. through Brexit) management principles and measures of the Common Fisheries Policy (CFP) comprising the Maximum Sustainable Yield (MSY) objective, the ecosystem approach including the landing obligation as well as Marine Protected Areas (MPAs) and Real Time Closures (RTCs) on fleet and fish stock dynamics will be addressed in this storyline.

In particular, fisheries management based on the MSY concept is a complex task in the North Sea and there are ongoing discussions among stakeholders what objective might be most suitable: MSY or Maximum Economic Yield (MEY). There might be trade-offs between economic optimization and biological and social benefits (e.g. employment) that have to be taken into account by managers. In this context, mixed fisheries interactions further complicate the situation in the North Sea.

For instance, there is a need for management to address the recovery of the North Sea cod stock while still allowing fishing on more productive stocks caught in the same fisheries. Therefore, technical interactions may prevent reaching MSY for all stocks at the same time, since the FMSY for the different stocks correspond to different levels of fishing effort. Conceptually, this implies that the fleets may be constrained by the stock with the smallest relative quota, the "choke stock". This choke stock can be the least productive stock (e.g. cod) or the stock with quota imbalance compared to historical right allocations (e.g. hake). Under the landing obligation the fleets may not be able to fully exploit the more productive ones, which negatively affects their economic returns.

The magnitude of this problem will further increase due to climate change (e.g. changing stock productivities, changing species distribution patterns and increased spatial overlap of highly and little productive stocks), and is, therefore, regarded as a serious problem for the actual distribution key of fishing opportunities as well as relative stability in general. Ultimately, fleet profitability will be affected by both increasing costs and reducing revenues.

Research on the technical interactions is needed to identify trade-offs and their consequences and to define alternative options for balancing conflicting objects. Scientific advice that accounts for technical interactions between fleets and species as well as ecological effects is needed to improve assessments of the impact of alternative fishing strategies on yield and value as well as the state of fish stocks.

Therefore, this storyline will investigate the potential of current and alternative management measures for the mixed demersal fisheries in the North Sea, including the impact of climate change on fish stocks (e.g. recruitment failures, changed distribution patterns, changed body sizes etc.), fleet behavior (e.g. tactical strategies to avoid discards), and fleet economics (e.g. fish prices, fuel costs, profits, employment).

**How vulnerable are demersals to climate change?**

The fact that key species of the food web exist at either their high or low latitudinal extreme makes the species composition in the North Sea highly variable with seasonal dynamics and more importantly it makes it very sensitive to climate change. Furthermore, the high diversity of habitats, the high population density and the large number of active sectors (e.g. shipping, fishing, windfarms and tourism) makes the North Sea one of the most complex "hot spots" of anthropogenic effects worldwide.

For North Sea species progress has been made in investigating the causes of the variability of growth and productivity over time, especially when trends are observed beyond the annual fluctuations. In particular, the role of increasing temperature has often been emphasized, as this can affect many biological processes. Six out of eight commercial species in the North Sea underwent concomitant growth reductions, and this coincided with a 1-2 °C increase in water temperature. Smaller body sizes decreased the yield-per-recruit of these stocks by an average of 23%. The recruitment success of North Sea cod may also have decreased because of reduced plankton availability for the early life stages in warming waters. Moreover, spatial distributions of fish stocks are shifting, and this has been attributed to recent climate change.

**What is the economic value of this species?**

In 2014 eleven Member State fleets operated in the North Sea having a high economic dependency on this region. The fleets fishing in the North Sea landed around 1500 thousand tons of seafood corresponding to a value of 1.56 billion euros in 2014. The revenue generated in the North Sea fisheries was estimated to be at around 1.6 billion euros and a gross value added of 884 million euros in 2014.

**What is the working program in CERES?**

For the mixed demersal fisheries in the North Sea including cod, haddock, saithe and hake the FishRent model (http://fishrent.thuenen.de/) will be applied. FishRent is an integrative bio-economic optimization and simulation model that helps to understand how fishers may respond to management options and natural variations such as climate change. The model includes the economics of multiple fleet segments, the impact of fishing on stock development and the spatio-temporal interplay of fleet segments and fish stocks. In contrast to many other models, it not only considers a possible effort redistribution, it does account for the fact that ecologic conditions (e.g. recruitment failure, distribution changes) and economic conditions (e.g. revenues and fishing costs) will determine fishing effort and that management regulation itself will alter profitability and hence subsequent effort decisions by fleet segments, which in turn will impact the commercial fish stock.


The three CERES scenarios (World Markets, National Enterprise and Global Sustainability) will be analyzed with FishRent. These scenarios will differ in their

1. policy framework in terms of management objectives (e.g. MSY, MEX, national maximum profits vs. global maximum profits), policy instruments (e.g. LO, effort restrictions, MPAs, RTCs, TACs) and quota trading (quota swaps between species, countries and years),
2. economic framework regarding prices elasticities, fuel and other costs,
3. and their ecological framework including recruits (e.g. stochastic stock-recruitment relationships), species movement (e.g. seasonal migration of stocks and dispersal to adjacent areas), spatial distribution patterns (e.g. shifting patterns caused by climate change) and species life parameters (e.g. body-size, natural mortality and maturity).

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# Pelagics in the North East Atlantic

**What do we expect under climate change?**

This storyline will focus on the pelagic fisheries in the Northeast Atlantic (NEA), with important target species being Atlantic mackerel (*Scomber scombrus*), herring (*Clupea harengus*) and horse mackerel (*Trachurus trachurus*).

**Atlantic mackerel**

- highly migratory species with wide distribution from Marocco up to northern Norway, incl. North, Baltic and Black Seas as well as the Mediterranean
- stock sizes and migration patterns of different spawning stocks/components changed over time, also the international fishery and management with several nations beeing involved
- in 2014, the EU, Norway and the Faroe Islands (but not Iceland) agreed on a management strategy for 2015-2020: the total declared quotas for 2015/16 exceeded the TAC advice of ICES

**Atlantic herring**

- most commercially important pelagic fish species in the NEA, several coastal stocks typically aggregated in large and dense shoals, several fleets target for NEA herring
- varying spawning and migration pattern (e.g. autumn vs. spring spawner) increase the complexity of stock separation and distribution
- due to recovery plans and harvest control rules North Sea herring is considered to be harvested on a sustainable level and over the last years, a profitable herring roe fishery developed during the spawning season

**Horse mackerel**

- distributed from South Africa to Norway, including Mediterranean and Black Sea, the Atlanto-Iberian stock consists of the North Sea, the southern (Iberian) and the northwestern population
- tend to form large schools and migrate to specific spawning, feeding and over-wintering areas
- increasing commercial importance, specifically of the larger NW stock, European market still relatively small and large amounts are exported

Climate change will have significant effects on

- on the distribution of those highly migratory target species and hence key fishing opportunities
- increasing spatial overlaps and hence also inter- and intraspecific competition.
- changes in stock productivities: e.g. NEA herring population fluctuations have been already known to be a response to both natural environmental variations and exploitation by humans. In addition, the apparent decreases in weight at age for mackerel and herring are thought to be influenced by stock size and lack of sufficient food.

An additional issue for these pelagic fisheries will be the consequences of Brexit on fishing opportunities and quota availabilities for the remaining eight EU member states, also causing new trade barriers and disruption of the market.

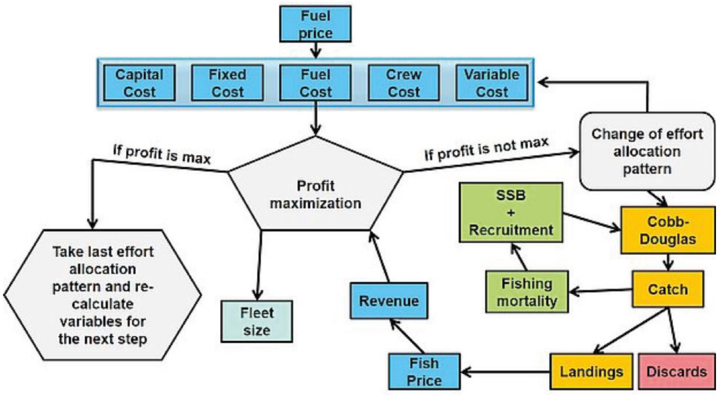
**Are there first signs of climate related changes?**

**Atlantic mackerel**

- distribution shifts to deeper regions and higher latitudes (since mid 1990s), stock size increase in whole catch area (in last decade) as well as good recruitement (in last 3 years) observed by industry

**Norwegian spring-spawning herring**

- the stocks' more westerly deeper distribution in recent years might be due to better feeding competition with mackerel, but at the same time accounting for a reduced spatial overlap of herring and mackerel in the Norwegian Sea and adjacent waters since 2014.




Conceptual model design with arrows that explain the interaction between submodules. In the maximization procedure, the effort allocation pattern is changed until profit of the entire fleet is maximized. When profit is maximized, the last effort allocation pattern is used to calculate catch, which in turn is used to calculate fishing mortality and SSB for the next step.

**Horse mackerel**

- distribution and spawning season is thought to be affected strongly by changes in temperature: at higher latitudes, a decrease in mean length-at-age were attributed to an increase in water temperature from 1977 to 2007
- the status of the North Sea stock is unknown and difficult to assess

**What is the economic value of this species??**

Landings:

- Atlantic mackerel represents by far the most landed species in the NEA (286 thousand tonnes, €300 million) and the North Sea (255 500 tonnes, €221 million)
- Atlantic herring and horse mackerel landings both accounted for approximately 50 thousand tonnes., with decreasing prices per kg in the last years
- In general, the EU NEA fleet accounted for 1.5 million tonnes of landed seafood with a value of €2.4 billion.

Fleets (in 2014):

- ten fleets operated in the NEA, of which half showed limited fishing activities (<30% of landing shares and effort)
- eleven fleets operated in the North Sea and landed 1 500 thousand tonnes of seafood with a value of €1.56 billion.

Total Allowable Catch (TAC)

- The TAC's of the main pelagic species have remained fairly stable over time, especially for mackerel (around 50 thousand tonnes). The TAC's of sprat and herring have both increased from approximately 200 thousand tonnes to nearly 450 thousand tonnes for herring and 350 thousand tonnes for sprat. Due to disputes between the EU, Norway, Iceland and the Faroe Islands, the improvement of the MSC certification on Atlantic mackerel was not granted and negatively affected the prices.

**What is the working program in CERES?**

This storyline will investigate the potential of current and alternative management measures for the named NEA pelagic fisheries, including the impact of climate change on fish stocks (e.g. recruitment failures, changed distribution patterns, changed body sizes etc.), fleet behaviour and fleet economics (e.g. fish prices, fuel costs, profits, employment).

For pelagic fishery in the NEA the FishRent model (http://fishrent.thuenen.de/) will be applied. FishRent is an integrative bio-economic optimization and simulation model that helps to understand how fisher may respond to management options and natural variations such as climate change. The model includes the economics of multiple fleet segments, the impact of fishing on stock development and the spatio-temporal interplay of fleet segments and fish stocks. It not only considers a possible effort redistribution, but it also accounts for the fact that ecological and economical conditions as well as management regulations will determine fishing effort.

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# Pelagics and demersals in the Baltic Sea

**What do we expect under climate change?**

For the Baltic Sea, we expect changes in hydrographical and hydrodynamic conditions such as water temperature, salinity, oxygen concentration and turbidity. Also, we expect changes in nutrient loads, i.e. eutrophication levels of nutrients like nitrate and phosphate. The changed climate and eutrophication scenarios will result in changed production and biomass levels of Baltic cod, sprat and herring and accordingly changed fishery resource availability. Finally, we expect socio-economic changes resulting in changed fishing costs, e.g. fuel prices, and fish prices which will also affect fishing conditions and viability.

**How will cod, sprat and herring be affected by climate change in the Baltic Sea?**

The different climate scenario projections predict changed **salinity levels** in the water layers of the Baltic Sea. This may affect the survival of Baltic cod eggs and larvae in certain Baltic Sea Basins where cod spawns. Reduced salinity will reduce the cod spawning volumem which is determined by water density (floating eggs in deep haline waters) and oxygen levels (oxygen deficiency layers due to reduced inflow from oxygen rich water from the North Sea).

The changed **sea surface temperatures** resulting from the climate scenario projections may potentially affect Baltic sprat recruitment in relation to sprat egg survival. Increasing temperature in sea surface layers (where sprat eggs are ditributed) may increase sprat fry survival and accordingly increase the sprat recruitment.

Changes in **water turbidity** (e.g. due to potential change in frequency, intensity and duration of storms) as projected by climate models may change survival conditions for herring eggs and accordingly impact Baltic herring recruitment. The survival of herring eggs are dependent on their attachment to certain flora and seabed substrates which may be altered by changed variability and intensity in water currents and turbidity.

Changed horizontal and vertical spatial and seasonal extension of **oxygen depletion areas**, which are projected in different climate and eutrophication scenarios, may result in changed food availability to and survival of Baltic cod. The change in oxygenated zones may result in changing survival and biomass levels of invertebrate benthic and pelagic food organisms for especially juvenile cod, but also for larger cod. Potential limitations in adequate food supply and availability due to oxygen depletion in certain areas, water layers, and seasons may result in changed survival of cod, especially juveniles.

In general, the changed climate and eutrophication scenarios may change different primary and secondary production patterns and biomass levels of certain

plankton groups that are essential prey organisms for fish fry of Baltic cod, sprat and herring, as well as for adult sprat and herring. The above adverse effects and impacts may likely result in changed biological interactions between Baltic gadoids and clupeoids (predation and consumption patterns) as integrated indirect effects. This may be associated with changed fish growth levels (temperature dependent). Together with the more direct effects described above the changed biological interactions will also influence the fish species productivity and overall biomass levels, as well as their distribution and abundance patterns.

**What is the economic value of cod, herring and sprat?**

The Baltic cod, sprat and herring stocks are subject to extensive international demersal and pelagic mixed and target fisheries conducted with mainly trawls and gillnets. The yearly landings values of these species in the total international eastern and western Baltic fisheries amounted in 2014 a value of 45 Mio Euro for cod, 72 Mio Euro for herring, and 52 Mio Euro for sprat, and the landings values for other species in those fisheries amounted in 2014 a value of 49 Mio Euro, all in all resulting in a total landing value of 218 Mio Euro for these fisheries.

**What is the working program in CERES?**

Global climate scenarios are downscaled to the Baltic Sea region to derive projections of climate change and eutrophication level. The applied model (RCO-SCOBI) provides information on sea conditions such as temperature and salinity, nitrate and phosphate nutrient concentrations, dissolved oxygen concentrations, ice conditions, water velocities and mixed layer depth, water quality and sedimentation of organic matter, as well as fractioned plankton biomass and net primary and community production. Those parameters will be affected by scenarios of climate change and change in eutrophication levels. The projections are then used in the model ATLANTIS to derive ecosystem responses on the changed climate and eutrophication parameters, e.g. in the production and biomass levels for important fish stocks such as cod, herring and sprat, as well as recruitment, growth, consumption, spatial distribution and biological interactions. Different scenarios (based on different future carbon emissions and socio-political developments) will be evaluated. according to effects on commercial fishery of the changed fish resource availability, as well as in relation to different levels of fishing costs and fish prices.

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# Fisheries in the Barents and Norwegian Seas

**What do we expect under climate change?**

*Herring* - There has no clear effect of climate change on Norwegian spring spawning herring at this stage. However, there has been a correlation between spawning stock biomass and the climatic condition (water temperature), although the mechanisms are not fully understood. Two issues are potentially affected by climate changes; recruitment success and feeding areas. Spawning is taking place along the Norwegian coast in February-March and larvae drift northwards and into the Barents Sea during the spring and early summer. Winds affecting the strength of the northward flowing currents have been shown to influence the recruitment success of herring. The feeding areas for adult fish are in the Norwegian and Icelandic Sea. The geographic distribution of herring feeding in the spring and summer has shifted westward during the last two decades. Warmer waters may have had an impact, but cannot be the main driver for the change directly. Reduced production of prey or higher predation pressure in the traditional feeding areas are more likely reasons for the observed changes in feeding areas.

*Cod* - Feeding distribution over the Barents Sea expected to change (expand) as sea ice cover shrinks, but the details are likely to be variable and uncertain. Freedom to move northwards to feed may partially offset warming waters, so not easy to predict ambient temperature effects on the cod. Impacts on the ecosystem may change food availability - but cod are generalist feeders so not clear how they will be affected. Current increase of snow crabs in the Barents Sea is being reflected in increase in the diet, suggesting they may be resilient to changes in food availability. Warming is occuring at a period of increasing age structure due to moderate fishing pressure, difficult to seperate these effects.

*Capelin* - More open water and less sea ice due to warming of the Barents Sea has facilitated increased plankton production in northern areas and made a northern extension of the capelin feeding area possible. However, the capelin stock size is fluctuating and only when the stock is large the need to utilize this larger feeding area is realized. Spawning areas are less flexible since capelin are spawning at the sea floor, and need specific substratum (gravel/sand) for the eggs to develop. It is uncertain what will happen if the water temperatures on the present spawning grounds becomes too high.

**How vulnerable are demersals to climate change?**

*Herring* - Adult herring are not directly sensitive to climate changes in the range anticipated for the next century. Warmer waters will lead to a larger potential feeding area. However, climate changes can potentially affect prey organisms and thereby indirectly have an impact on growth and survival. Further, climate changes leading to changes in the ocean currents can impact the advection of larvae drifting northwards, and thereby affect the recruitment success.

*Cod* - Species are at the northern extreme of their range, and therefore clearly shows effect of climate variation over the past 100 years. Recent warming has been positive for NEA cod, by extending feeding grounds, this is likely to continue in the medium term. Historical data suggests NEA cod do well during warm periods. Being at the north end of their range, NEA cod unlikely to suffer directly from warming temperatures in the medium term, but ecosystem level changes to food supply will likely have unpredictable effects (both negative and positive)

*Capelin* - Northern expansion of the feeding areas will imply a longer migration route and increased energy expenditure as long as the spawnig areas are unchanged. There are limits to how how far from the spawning areas the capelin may feed. For capelin to feed beyond that limit, the spawning areas will have to be moved northwards as well, but it is highly uncertain where suitable spawning areas may be found

**What is the economic value of this species?**

*Herring* - Landing has the last 20 years been in the range 328 000 – 1 687 000 tonnes. The fishery is important for several countries, but especially for Norway. The fishery is a key pillar in several smaller communities as vessels of all size groups participate in the fishery.

*Cod* - Landings have been c. 700,000 - 1,000,000 tonnes in recent years (2011-2016), making this the largest and most valuable cod stock in the world. Discarding is largely banned, fishing is controlled by a sustainable HCR.

*Capelin* - Highly variable. The stock swings from less than 1/2 million tonnes to 7 million tonnes in cycles, and the catches have varied between 0 and 650 thousand tonnes during the last twenty years. The harvest strategy is an escapement strategy where the first priority is to leave enought capelin in the sea to feed the cod and to let a certain amount spawn.

**What are the challenges?**

*Herring* - It is not known if climate change will affect the recruitment success in the future. The geographic distribution during feeding may change, affecting the relative allocation in national economic zones.

*Cod* - It is unclear how cod wil respond to continued climate change, unclear how maturity at age will develop under continued moderate fishing pressure (i.e. if there have in fact been fisheries induced evolutionary changes or not)

*Capelin* - It is unknown what will happen if higher sea temperature drives capelin from their normal spawning areas along the northern Norwegian and Russian coasts. It is also unknown whether climate change may cause shifts in prey availability in the Barents Sea. So far, the rise in temperatures and loss of sea ice have seemingly been favourable for capelin recruitment and feeding.

**What is the working program in CERES?**

Models applied

- Altantis ecosystem model
- Gadget multispecies model
- Stockobar Model
- 2-species (cod-capelin) assessment model (Bifrost/CapTool)

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# Inland fisheries

**Will inland fishery be effected from climate change?**

Over the past 40 years biodiversity has declined faster in inland waters than in marine or terrestrial ecosystems. This is caused by multiple anthropogenic pressures such as agriculture, damming, channelisation, deforestation, navigation, wetland reclamation, urbanisation, hydropower generation, water abstraction and transfer, and waste disposal. For inland waters these pressures are exacerbated by climate change impacts, which are elicited as changes in water temperature and rainfall patterns that modify the volume of water entering rivers or lakes and will therefore affect the hydrological and limnological regimes. Collectively, anthropogenic pressures and climate change have resulted in a shift in the ecological status of inland fisheries and a general decline in productivity and ultimately yield.

In Europe, commercial inland fisheries exploit a wide range of species and most fish are supplied to regional or national markets through local dealers and wholesalers. There are considerable differences in the fish species caught by commercial (or professional) fishers across Europe.

| Fish | commercially used in |
|---|---|
| salmonids | northern western countries |
| eel (*Anguilla angulla*) | all countries |
| whitefish (coregonids ) | Baltic & Scandinavian countries, Austria, France, Germany and Poland |
| carp *Cyprinus carpio* | Eastern European countries and Germany, |
| cyprinids e.g. : | all countries except for Sweden and UK |
| pike *Esox luscious* | Austria, the Netherlands, Sweden, most Eastern European countries |
| perch *Perca fluviatis* | |
| zander *Sander lucioperca* | |

Therefore it is important to understand the impacts of climate change on commercial fisheries and tease out them out from other anthropogenic stressors. Inland waters are also heavily exploited by recreational fisheries, and target a wide variety of freshwater fish species, from salmonids to cyprinids. Tourism within the fishing industry is a large driver of income and can put a high value on species such as salmon and sturgeon. It is important that climate change does not result in a reduction in these species.

**How vulnerable is inland fishery to climate change?**

Temperature, flow and lunar cycle are controlling factors in the distribution of organisms and timing of spawning. It is likely that climate change will disrupt the spawning regime of fish and encourage them to spawn earlier in the year subsequently allowing juveniles a longer growth period before winter or causing premature hatching and low survival.

Furthermore, higher temperatures will result in higher productivity and therefore increase fish growth and over-winter survival. Inhabitants of large temperate lakes that are intolerant to high temperatures, such as whitefish, will be particularly vulnerable if temperatures were to increase as their "thermal refuge" will be reduced. Longer warming periods and higher temperatures are likely to increase the stratification of lakes thus reducing the amount of oxygen exchange to the hypolimnion from the oxygen rich epilimnion.

Cold water stenotherms such as the Artic charr, Salvelinus alpinus L., use the hypolimnion (deep stable 4°C layers of a lake) as a thermal refuge and the species composition could therefore be negatively affected by rise in water temperature.

Overall, on a local scale lacustrian species may be forced in to deeper water by rising temperatures while riverine species may have to migrate to higher, cooler stretches of river. On a larger scale, species may be entirely eradicated from a river or lake system, possibly contracting the species' range to a few isolated high altitude pockets, e.g. arctic char in the Cumbrian lakes.

Furthermore, an increase in parasite survival is an indirect effect of climate change and is likely to increase the virulence of certain fish pathogens and the transmission of some parasites. Higher winter temperatures may increase parasite survival resulting in year round infection and multiple generations of parasites in a single year. In addition, non-native species that have higher tolerances to warmer more stressful conditions will likely proliferate and displace endemic fish species homogenise fish communities.

Several studies have shown that drought and flooding have a noticeable effect on community composition, diversity, size structure of populations, spawning and recruitment of inland fish. Droughts may disconnect fish from floodplains and reduce the availably of habitat for spawning, feeding and refuge. Whilst unpredictable flooding due to climate change will change the regularity, amplitude, frequency and duration of annual flooding and could therefore cause changes in fish productivity. For example, migratory fish such as Atlantic salmon, *Salmo salar* L., are especially affected by high and low flows to complete their migration upstream to spawn. Low flows will make barriers difficult to pass, whilst high flows may allow migratory fish to pass barriers and enable wider access to spawning and nursery habitat.

**What is the economic value of this fishery?**

In Europe, most inland waters support commercial and recreational fisheries and therefore climate change has the potential to affect the societies and their economies that rely on them by altering fish production and potential yields. Commercially, fish are produced for sale to consumers or managers of recreational fisheries for stocking. For example, in the UK, brown trout *Salmo trutta* L., farming industry produces several hundred million pounds of marketable product annually and supports other livelihood activities related to the recreational fishing industry.

Recreational fishing in fresh waters produces far more revenue in the industrialised world than commercial capture industries. It is difficult to attach a true monetary value to the recreational fisheries of the world because participation is voluntary and not regulated. However, the money spent by recreational anglers on fishing equipment is quantifiable and indicates that the activity is a multibillion dollar industry and an integral component of local economies. Recreational fisheries is estimated to be 555 million EUR, of which 121 million EUR is spent by out-of-state anglers. When indirect impacts are factored in then the overall economic impact is estimated to be approximately 750 million EUR. Furthermore, they estimate that recreational angling can support 10,000 job. The most prized fish to anglers are generally cold water fish species such as salmonids and centrachids. These are the species that are most at risk from warming as their thermal habitat will be reduced. Subsequently, the recreational fisheries dependant on such species will decline, decreasing their contribution to the economy. The economic problems associated with a decrease in fish yields include a reduction in employment in the fish capture and fish culture sectors and a reduction in income from these activities.

Furthermore, loss of biodiversity is a major social issue as it is considered part of our heritage that must be available for future generations to enjoy and utilise. A species may have a direct use value, an indirect use value, an ecological value and/or a cultural and spiritual value . Atlantic salmon, for example are valuable in many as they are an important and desirable source of food and they have an important ecological value. If a flagship species such as this were to be extirpatedt, obligations to preserve biodiversity foregone. Many countries (e.g. Denmark, the Netherlands) also consider that the most valuable fishes in commercial fisheries are in decline, and, with increasing costs, their exploitation becomes less and less profitable, especially due to imports of cheap fish from Eastern European (post-Soviet Union) countries. Nevertheless, the productivity of some fresh waters is expected to increase as a result of climate change resulting in potentially greater yields and economic benefits. Pedictions indicate that the production of zander will increase in northern Europe through a strengthening of year classes and an enhancement of growth due to climate warming.

**What are the challenges?**

Climate change could cause a loss of, or reduction in abundance of inland waters species affecting both recreational and commercial fisheries. The challenge is to identify the risk and uncertainty associated with climate change, its effect on freshwater species and how this will consequently affect inland fisheries and the resilience of communities to respond to these changes. This will lead to the development of guidance and tools for suitable mitigation (e.g. catch limits, closed periods, legal size limits and type of gear) options to alleviate any negative effects of climate change, or adaptation strategies to the alleviate the problems encountered. It is also important to identify possible opportunities to overcome uncertainty for inland fisheries, both commercial and recreational, so they become resilient to climate change and develop adaptive management and governance techniques to support sustainability. For this it will be useful to not only produce an up-to-date literature review, but to also cross compare the socio-economic importance of fisheries, between inland and the marine sector.

**What is the working program in CERES?**

- Time series of precipitation (for meteorological droughts), river flows (for average flows), extreme high and low flows (for floods and droughts, respectively), and river and lake temperatures (for water quality), fisheries data. These time series can be observed or simulated for historical time periods and can be projected for future time windows, taking into account climate change and potentially also other drivers of change, such as land use changes.
- Identify if a climatic driven regime shift has occurs and which environmental factor was the driver through application of:
  - » Principle component analysis (PCA)
  - » Chronological clustering (CC)
  - » Sequential Regime Shift Detector (STARS)
  - » Non-linear Threshold Generalized additive Models

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