CERES – Climate change and European aquatic RESources

Participant no. (leadership role)	**Participant legal name**	**Country**	**Type**
1 (Coordinator, WP6, T6.2, WP7, T7.1, T.2)	University of Hamburg	Germany	RTD
2	Ayhan ALP Trout Farms	Turkey	SME
3	ANSA, SAU (Culmarex)	Spain	SME
4 (CS1, T1.2, T4.2)	CEFAS	UK	RTD
5	CONISMA	IT	RTD
6 (WP2, T2.1)	CSIC	Spain	RTD
7 (CS3)	DDNI	Romania	RTD
8 (WP3, T4.1, T6.1)	DLO	Netherlands	RTD
9 (T5.1)	DTU-Aqua	Denmark	RTD
10 (T2.2)	HCMR	Greece	RTD
11	Ińskie Centrum Rybackie (ICR)	Poland	SME
12 (CS2, T3.1)	IEO	Spain	RTD
13	IFREMER	France	RTD
14	IMR	Norway	RTD
15	IPMA	Portugal	RTD
16 (T3.3)	Longline Environment	UK	SME
17 (T3.2)	National University of Ireland Galway	Ireland	RTD
18	Pelagic Freeze Trawlers Association	Netherlands	SME
19 (WP1, T1.1, T2.3, T4.3)	PML	UK	SME
20	SMHI	Sweden	RTD
21 (WP4, T5.3)	TI-SF	Germany	RTD
22 (WP5, T5.2, T6.3)	University of Hull	UK	RTD
23	University of Mersin	Turkey	RTD
24	Vet-Aqua International	Ireland	SME
25	VisNed/CVO	Netherlands	SME
26	W. Pomeranian University of Technology	Poland	RTD

1. Excellence

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 anticipate and prepare for adverse changes or future benefits.

1.1 Objectives

CERES will provide the knowledge, tools and technologies needed to successfully adapt European fisheries and aquaculture sectors in marine and inland waters to anticipated climate change. We will identify and communicate risks, opportunities and uncertainties thereby enhancing the resilience and supporting the development of adaptive management and governance systems in these blue growth sectors. _CERES_ strongly supports important European policy goals including self-sufficiency of the domestic supply of fish and shellfish.

Global warming and climate change are likely to affect all biosphere components, including the functioning of aquatic ecosystems and their organisms. Given the significant **increase in human population (15% by 2024, 35% by 2050) and demand for secure, sufficient and safe food supplies, it is critical to predict and anticipate the nature and magnitude of potential impacts of climate change on food production**, to work with the industries concerned to develop innovative adaptation and mitigation strategies to enhance resilience to perceived threats, and to facilitate access to opportunities (the 'blue growth' agenda). Providing short-, medium- and long-term projections for aquatic ecosystems and the threats and opportunities for industries that rely on these is not an easy task, and requires our transdisciplinary team of oceanographers and hydrologists, modellers, ecologists, aquatic physiologists, social scientists, economists, fishers and fish/shellfish farmers working in conjunction with managers. Detailed mechanistic understanding and complex models must be employed to incorporate the workings of these industries as well as global sea-food markets and policy landscapes.

The EU now requires fishing to be environmentally friendly, economically viable and socially sustainable to provide long-term European food security given prevailing and future climatic conditions. EU Policies also intend to boost aquaculture and Strategic Guidelines have been published outlining common priorities and general objectives. Climate change will affect the capacity to achieve these ambitions and a greater understanding is urgently needed to ensure that management measures remain appropriate and achievable. To specifically address these challenges, *CERES* will involve and closely cooperate with industry and policy stakeholders to:

1. *Provide regionally relevant short-, medium- and long-term future projections of key environmental variables for European marine and freshwater ecosystems;*
2. *Integrate the resulting knowledge on changes in productivity, biology and ecology of wild and cultured animals (including key indirect/food web interactions), and 'scale up' to consequences for shellfish and fish populations, assemblages as well as their ecosystems and economic sectors;*
3. *Anticipate responses and assist in the adaptation of aquatic food production industries to underlying biophysical changes, including the development of early warning methods, new operating procedures, infrastructures, location choice and commercial markets;*
4. *Assess relative exposure, sensitivity, vulnerability and adaptive capacity within the European fisheries and aquaculture sectors;*
5. *Consider market-level responses to changes (both positive and negative) in commodity availability as a result of climate change;*
6. *Develop innovative risk-assessment methodologies that encompass drivers of change, threats to fishery and aquaculture resources, barriers to adaptation and likely consequences if mitigation measures are not put in place;*
7. *Formulate viable autonomous adaptation strategies within the industries to circumvent/prevent perceived risks or to access future opportunities;*
8. *Formulate policy guidelines and highlight management challenges where established governance structures may hinder successful adaptation to long-term climate change.*

The total budget for *CERES* will be €5 million and the project will run over 48 months (2016-2019).

1.2 Relation to the work programme

CERES addresses topic H2020-BG-2015-2 (BG-02-2015) **Forecasting and anticipating effects of climate change on fisheries and aquaculture,** part of the Call for Blue Growth: Unlocking the Potential of Seas and Oceans under societal challenge Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy. *CERES* considers that humans and the ecosystems on which we rely face two grand challenges over the twenty-first century: anthropogenic climate change and global population growth. We urgently need solutions to these challenges, especially increasing food production while maintaining our natural ecosystems in a long-term sustainable state in the context of a changing climate. *CERES* will start by estimating the impacts of **climate change on the functioning of aquatic ecosystems and their living organisms in European Seas and freshwater systems**. To achieve this, *CERES* combines IPCC AR5 emissions pathways, novel regional climate model data sets, and state-of-the-art physical-biogeochemical models to project physical and biological properties at high spatial and temporal resolution across European seas and river catchments. This will enable projections of how climate-driven atmospheric and ocean and hydrological processes impact the survival, growth, distribution and productivity of key wild and cultured fish and shellfish species using a combination of innovative, mechanistic and statistical models in hindcast, nowcast and forecast modes. *CERES* will reveal potential changes in fisheries productivity and catch in coming decades and the sensitivity of established and new aquaculture production systems to climate change. Implicit in this will be the role of non-indigenous and outbreak-forming species both to the contribution of system resources and disruption of natural processes. In addition to physical changes in key factors such as temperature, oxygen, salinity, freshwater flow and storminess, *CERES* will examine changes in sea level rise, ocean acidification, climate variability (e.g. the North Atlantic Oscillation) and hydrological processes, and provide early warning methods for indirect climate-driven factors (pathogens, HABs and jellyfish) particularly relevant to fisheries and aquaculture.

As a key prerequisite for **projecting and anticipating potential consequences of climate change on aquatic production methods and systems,** *CERES* will develop socio-economic scenarios of utilization, trade and governance; the latter including policies, politics, administration and legislation. This will be followed by quantification of the economic consequences of climate change in fisheries and aquaculture production, assessing the sensitivity of these production systems to changes in productivity and distribution and analyzing how climate change and technology (advances in fishing gear or aquaculture techniques) will interact to alter the reliance of some aquaculture production on fisheries resources. To ensure there is **sufficient preparedness and rapid adaptation potential of the European marine and freshwater fisheries and aquaculture sectors to potential threats and opportunities due to climate change,** *CERES* will assess, quantify and simulate the current and future likely climate-driven changes to marine and freshwater fisheries and aquaculture, quantify the social, policy and regulatory repercussions of this, and develop risk management tools and adaptation strategies for each sector, selected keystone species, and production methods. *CERES* will employ joint problem framing with stakeholders for scenario development, assessment of governance and industry repercussions and adaptation and mitigation options. This approach will be **imperative for the long-term sustainability of the fisheries and aquaculture sectors and helping guarantee food security for European consumers and society.** In the context of increasing global population and demand for sufficient and safe food supplies, the overall objective is **to predict, anticipate, accommodate and capitalise on the effects of climate change on food production systems.**

1.3 Concept and approach

1.3.1 Policy relevance

The policy relevance of *CERES* will be addressed at several levels including the governance of i) natural resource/ capital, ii) aquatic space use, and iii) the overarching environmental policy pillar. All have direct implications for long-term sustainable fisheries and aquaculture. If natural resources and the available locations for exploitation of those resources change because of climate modification then society and industry will also have to change and adapt in response. This may involve occupying new

fishing areas or aquaculture sites or targeting and exploiting novel species. Similarly, governance structures will need to be 'adaptive' with fishery effort (and quota) allocations, closed-area boundaries and spatial planning regimes all responsive to emerging conditions. The EU is a pre-eminent player in the field of sustainable regional development, and more than 200 directives, regulations and many other forms of legislation and amendments have been adopted in the area of environmental policy with direct repercussions for aquatic resource development[(1)].

The multifaceted nature of the relationship between human society and European marine environments and ecosystems has necessitated development of the EU **Integrated Maritime Policy**. The revised **Common Fisheries Policy (CFP**), a pillar of this strategy, aims to ensure that fishing practices are environmentally, economically and socially sustainable, and that they provide a sufficient source of healthy food for citizens throughout Europe in the long-term. In the reformed CFP, aquaculture plays a much more prominent role than in the past, recognising the need to streamline and integrate these two aquatic-based food production sectors and the impacts of their spatial footprint and resources, as well as their interactions in providing resources. This approach is consistent with the objective of *CERES* to predict, anticipate and provide tools to respond to the nature and magnitude of impacts of climate change on aquatic food production systems.

The environmental pillar of the Integrated Marine Policy is the **Marine Strategy Framework Directive (MSFD)** which aims to more effectively protect the marine environment, and to implement an 'ecosystem approach' to the management of all human activities in the sea with the goal to enable the sustainable use of living marine resources and to ensure the marine environment is safeguarded for future use. Together, the CFP and MSFD provide a comprehensive framework to ensure the protection and sustainable production of European seas and, in combination with the **EU Water Framework Directive (WFD**), for catchments to deliver the ecosystem services on which we rely.

Inland fisheries are regulated through national legislation, and in the context of the WFD (which encapsulates the articles of the **Freshwater Fish Directive**) and EU Regulations, such as the Eel Regulation. These policies support Member States to introduce integrated management of catchments and direct management of fisheries to restore inland fish stocks to the sustainable levels approaching those without human impacts. This is an increasingly challenging target given changes in precipitation, water temperature, and river discharge (magnitude and regime). *CERES* will contribute significantly by using state-of-the-art models of river flows and precipitation levels crucial to determine the evolving carrying capacity of European lakes and rivers under climate change.

The EU Shellfish Waters Directive (now subsumed into the WFD) was adopted to protect and, where necessary, improve the quality of waters where shellfish grow and to contribute to production of high quality, edible shellfish products. *CERES* will examine changes in sources (coastal and river discharge) of nutrients and pathogens, given that these are crucial to the continued safe and sustainable farming of shellfish such as mussels, oysters, and clams. *CERES* will create early warning methods, advance and apply well-tested tools, and provides advice to best implement the **Strategic Guidelines for the Sustainable Development of EU Aquaculture (EU COM(2013) 229**).

The above policy directives are linked to the European Blue Growth and the Blue Economy strategies, which aim to capitalise on and maximise the capacity of aquatic systems to support economic activity by safeguarding the ability of those habitats to produce needed resources. *CERES* will be central to the Blue Economy, enabling sustainable fisheries and aquaculture and thus ensuring food security against a background of a changing natural and social environment. ***CERES* will provide quantitative estimates of how climate change may impact the success of European fisheries and aquaculture and the information required for these sectors to successfully adapt to increase competitiveness, skills and employment.**

Furthermore, European education/research/training policies require an increasingly skilled workforce which is adaptable to cope with changing environments, resources, methods and markets. This requires knowledge-transfer both across disciplines and Europe. *CERES* will accomplish knowledge-transfer through close involvement with stakeholders and a clear and effective dissemination structure. Finally, various Directives (Birds and Habitats, Marine Spatial Planning, Strategic Environmental Assessment and, for individual activity sites, Environmental Impact Assessment) are

relevant to *CERES*. **Each of these Directives requires managing activities and determining, preventing and accommodating change against accepted societal targets and objectives**. Climate change will shift baselines and alter these targets, thus requiring adaptation of policies and responses. This set of policies is central to the assessment and management of risk and vulnerability of fisheries and aquaculture to climate change, and is the main thread linking our different workpackages and sectoral case studies**.** The ***CERES* project itself is named after the Roman goddess of agriculture and fertility, emblematic of the EU's 'blue growth' agenda.**

1.3.2 Basic approach: Key species / groups and areas

Using representative commercially fished and cultivated species and assemblages, *CERES* will create an **integrated framework quantifying exposure, sensitivity, adaptive capacity and vulnerability** to allow risk management of fisheries and aquaculture which fully accounts for the diversity of European marine and inland waters. While all species cannot be examined**, *CERES* thoroughly investigates representatives of the main ecological and industry examples to give necessary and valuable information relevant to all European fishery and aquaculture species.**

This approach requires a strong interaction with industry representatives, policy makers, water and resource managers, and other stakeholders, at both regional and European levels. At the outset of the project, this stakeholder interaction will be used to confirm the *CERES* vision of the perceived climate-driven risks and opportunities expected to occur for fisheries and aquaculture in the short (3-5 yr), medium (10-15 yr) and long term (25-50 yr). Stakeholders are engaged throughout the project, thus ensuring that *CERES* is fully anchored in the practical nature and application of its outcomes including current plans with respect to adaptive management and mitigation.

CERES will conduct **integrative research (from physics to fish/shellfish to markets/sectors) on key species/groups in 3 Sectoral Case Studies. Species/groups are selected using a multi-criteria analysis** including (i) production volume/abundance, ii) production and catch value, and iii) local and regional relevance in terms of economy, employment, and cultural and traditional values.

Table 1) *CERES* Sectoral Case Studies and species/groups (modified after stakeholder engagement).

MARINE FISHERIES SPECIES/GROUPS (SECTOR CASE STUDY 1)
Flatfish – regional relevance (Baltic, North Sea), catch, economy, employment, cultural *plaice, sole*
Demersal roundfish – regional relevance, (Baltic, North, Barents, Med. Seas), economy *Atlantic cod, haddock, hake, saithe*
Small to mid-sized pelagic – Europe-wide, catch, economy, employment, cultural *anchovy, Atlantic herring , blue whiting,dolphinfish,mackerel(s) , sardine(s)*
Large pelagic *tuna(s)*
Invertebrates – regional relevance, catch, economy, cultural *squid (Loligosp), cuttlefish, octopus, shrimps*
MARINE AQUACULTURE (SECTOR CASE STUDY 2)
Salmonids: Northern Europe, production, value, export *Atlantic salmon*
Shellfish – local to Europe-wide, tradition, conservation, non-native, economy *mussels, oysters, clams, scallops*
Warm-water perciforms – Regional, pond production, employment, food security *meagre (emerging), sea bream and sea bass (established)*
INLAND FISHERIES AND AQUACULTURE (SECTOR CASE STUDY 3)
European Fisheries: Regional (east, south), cultural *cyprinids, whitefishes, perch, pikeperch*
Species of Conservation Concern – Europe-wide, niche and export markets *Atlantic salmon, European eel, sturgeon (Acipenser spp .) shads,*
Culture species – Regional concern, employment, cultural, value export *common carp* , rainbow *trout* , Chinese carps

The selection and analysis will fully account for stakeholder perspectives of key emergent species, the ramifications of changes in policies and markets as well as industry innovation such as new fishing gears (e.g. electric pulse beam trawling), cultivation techniques (e.g. greater control of both inputs and outputs using recirc-ulating aquaculture systems).

Relative to the species in the top 70% (by value), ***CERES* species or groups represent >50% of high-value fisheries (mixed demersal, mixed pelagic) and >90% high value aquaculture targets in European marine and inland waters.** Emphasis is also placed on identifying emerging species/groups (the winners from climate change).

1.3.3 Consortium

To secure a successful outcome and achieve **highest return on public investment**, the *CERES* consortium has been carefully constructed for its expertise and **wide geographic coverage across all key European marine and inland waters** (Fig 1). It involves **large multidisciplinary aquatic research institutes** expert in focusing on synergies between scientific disciplines that elsewhere work in isolation including climate modelling, oceanography/hydrology, physiology, fisheries and aquaculture science, ecology, bio-economics, and risk and policy analysis. The other partners, including universities, SMEs and stakeholders, bring additional knowledge and skills. All partners have been chosen to have a hinterland of national and international contacts and influence to ensure a two-way flow of information and the most up to date science and policy relevance. Eight complementary SMEs are full partners in *CERES*, and will provide significant **guidance and knowledge into both fisheries and aquaculture production sectors**. SMEs comprise fish-producer and processor organisations (pelagic and demersal wild-capture fisheries) and operators of large and small-scale aquaculture facilities, aquaculture farmer organizations, and consultancies. The SME and RTD partners are well placed to engage stakeholders throughout the project (staring on day 1) and in every workpackage (WP). SMEs play various leadership roles within this project (see section 1.4).

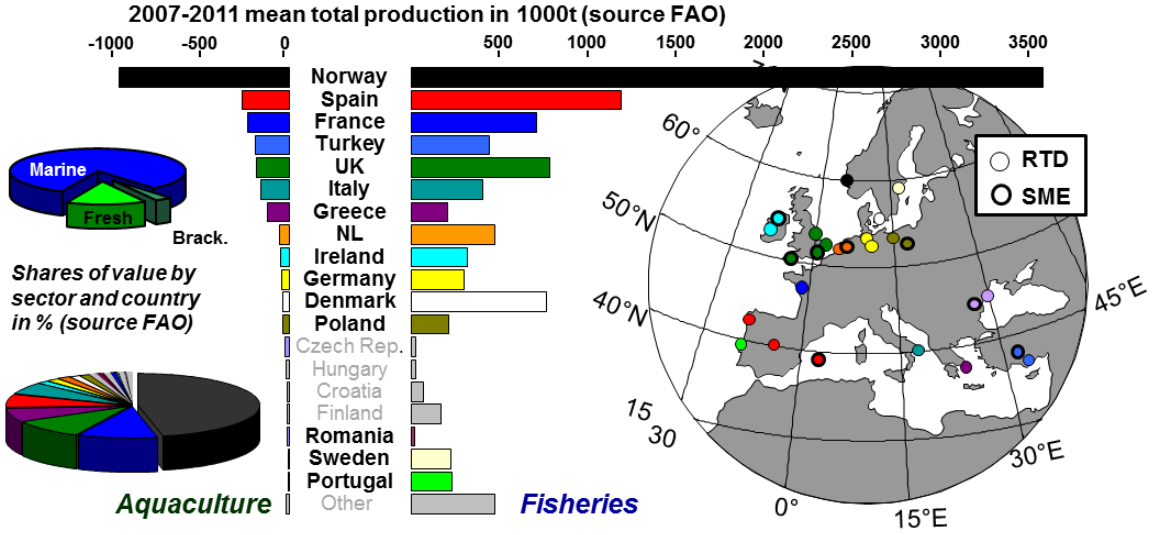

Fig 1) CERES partner locations and importance of the 15 countries (colors) to European aquaculture and fisheries production.

A Reference User Group (RUG) will be formed of experts tasked with ensuring that the project provides **outputs directly understandable, accepted, useful and relevant to industry and policy makers**. Many stakeholders have been consulted from the earliest elaboration phase of this project, at local (processing and seafood companies), national (administrations, national fisheries associations), regional (Regional Advisory Councils), and European/international (Federation of European Aquaculture Producers and European Association of Fish Producers Organisations, International Council for the Exploration of the Sea, UN Food and Agriculture Organisation) levels, to create an industry and policy-relevant project.

A Research Advisory Board (RAB) will be formed to directly engage world-leading experts such as coordinators of global initiatives on climate change and aquatic living resources (e.g. the Fish Model Intercomparison Project - Fish-MIP via a joint *CERES* Fish-MIP workshop in year 1 to coordinate activities / test scenarios) and the international *Sea Around Us Project* at UBC, Canada (William Cheung) to provide guidance on forward projections of fish distributions and fishery yields. RAB members have strong ties to the European Aquaculture Society, and policy and governance organizations (EU JRC, FAO, ICES) and provide global perspectives on climate research regarding fisheries and aquaculture (US NOAA NMFS, CA DFO, AU CSIRO). Gender balance is an important goal of CERES and women coordinate 2 of 7 WPs and 12 of 19 tasks. Moreover, all partners have

proactive gender-balance policies. The composition of the RAB and RUG will also reflect this goal towards gender balance.

A transdisciplinary team is essential to address the complex and multi-faceted issues highlighted in the call, for the freshwater and marine fisheries and aquaculture sectors. Many of the senior individuals in the *CERES* team are **high-level scientific advisors in national and international fora**. They have excellent scientific and managerial reputations, broad networks and daily contact with their fishing, aquaculture and seafood industries and policy sectors. They will be the natural ambassadors of the project to stakeholders and to society and will be given roles as champions of the outputs to a wider audience. All *CERES* partners have a **substantial track record** of participation and leadership (coordination) in relevant national and international research both as institutes and as individual scientists in large-scale EU projects examining climate (CLAMER, RECLAIM), fisheries (EFI+, MYFISH, MINNOUW-H2020), jellyfish (ECOJEL), aquaculture (AquaSpace-H2020, ECASA, MedAquaMarket, SUCCESS-H2020, EFIMAS), seafood and environmental safety (ECsafeSEAFOOD, SECUREFISH, IMPASSE) and the dynamics and management of marine (COEXIST, DEVOTES, ELME, ODEMM, SOCIOEC, VECTORS) and/or freshwater (FORECASTER, GMfish, REFORM) habitats including the brackish Baltic and Black Seas (BIO-C3, CREAM, INSPIRE, MARLISCO, PERSEUS) and Arctic (Belmont Forum). Specific tools include state-of-the-art projection modelling (e.g. ASIMUTH, MEECE, REPRODUCE) as well effective communication and engagement strategies with stakeholders (GAP2, JAKFISH). *CERES* partners have an intimate knowledge of and involvement in many recent or current national/regional projects on climate change adaptation and mitigation. Working on a global to local scale, *CERES* **builds on state-of-the-art knowledge and tools and mobilises and uses these from Day 1**.

1.3.4 Project Structure

CERES is organized into 6 scientific workpackages (WPs), each addressing specific objectives. Another WP (WP7) is specifically focused on project coordination, management and dissemination. **Research activities focus on Environment (WP1-2-3), Economics (WP1-WP4) and Industry Sectors (WP1-4-5)**. Approximately equal shares of funding will be provided to these three components. Project integration and synthesis occur in WP6, where stakeholder engagement is organized and final recommendations will be defined and delivered. Strong interdependencies exist among all WPs (see Fig 2). The 6 research WPs are conducted in each of the three sectoral Case Studies (CS) taking into account natural differences between fisheries and aquaculture sectors as well as between climate impacts on marine and inland waters. Each CS has well-defined SME involvement to bring practical links to industry:

- CS1) Marine Fisheries - demersal (VisNed) and pelagic (PFA) fisheries.
- CS2) Marine Aquaculture - salmon pathogens (Vet-Aqua), farms in western and eastern Mediterranean (ANSA, ALP) and aquaculture consultancy with worldwide activities (Longline)
- CS3) Inland Aquaculture and Fisheries – regional carp and trout farms (ICR, ALP).

Activities within the three sectoral Case Studies occur across a wide geographical distribution (see Fig. 1 for locations of *CERES* SMEs and RTD partners) ensuring that a diversity of fisheries and aquaculture industries and practices are included. For example, all Case Studies will contrast effects at high and low latitudes in Western and Eastern Europe (e.g. the NE. Atlantic/Barents Seas vs. NW Mediterranean vs. Canary Islands; the Baltic Sea vs. the Black Sea and their river catchments) Europe. In many instances, the same species/groups will be examined across broadly different climate zones, often at the edges of latitudinal distribution (e.g. salmon grown in Ireland) where climate-driven responses and impacts are projected to be most dramatic (e.g. decreased productivity of Irish Sea and North Sea cod versus large increases in the productivity of Barents Sea cod).

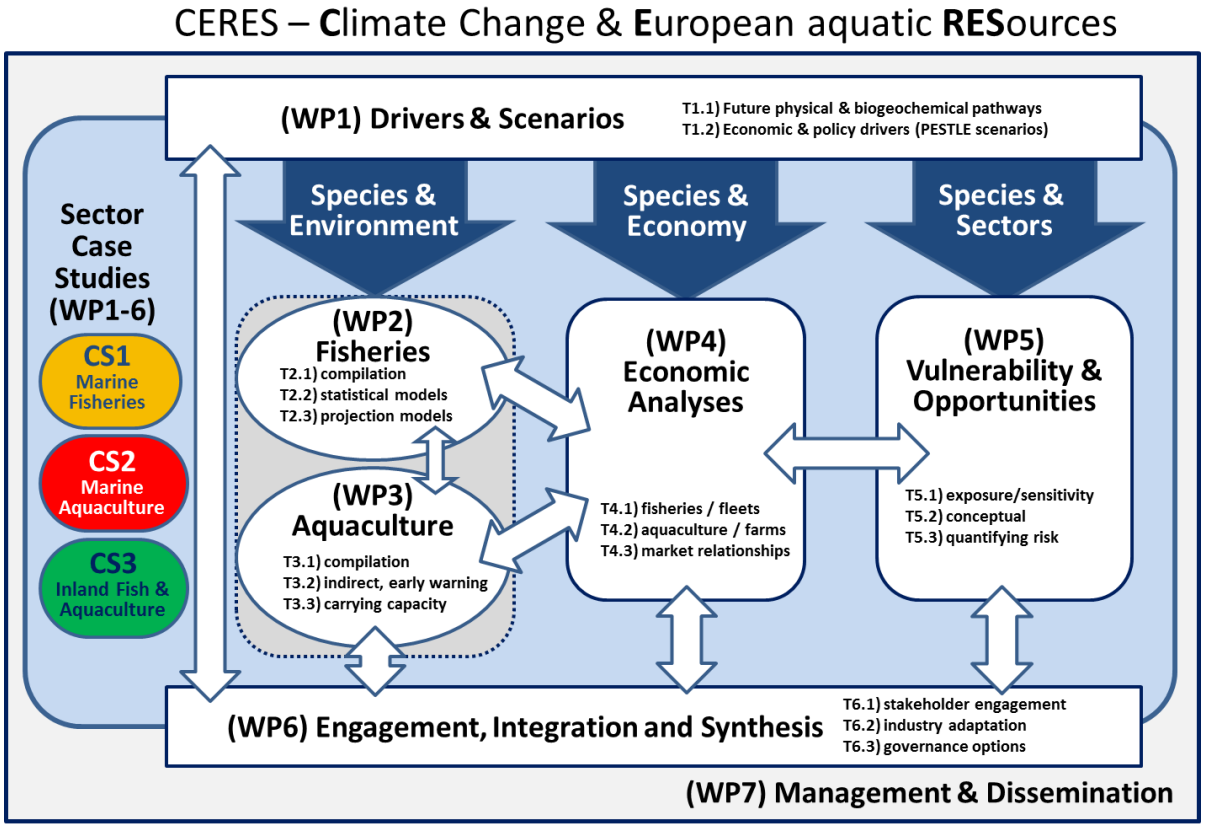

Fig 2) The project structure of *CERES* showing seven WPs and three Sector CSs.

1.4 Ambition

The following briefly outlines the *CERES* ambition with regard to the 6 research WPs and 17 tasks.

WP1 – Drivers and scenarios of European fisheries and aquaculture (PML, Manuel Barange)

Ambition: Provide highly spatially and temporally resolved estimates of climate-driven changes in key physical and biogeochemical factors projected from the most recent IPCC scenario pathways plus regional climate models. Engage stakeholders for joint problem framing of economic, social, and policy scenarios to be examined in CERES. This work is conducted across all 3 Case Studies.

T1.1) Physical and biogeochemical short-, medium- and long-term scenarios. (PML, Susan Kay)

CERES will employ existing POLCOMS-ERSEM and other regionally downscaled (e.g. Baltic) models to provide future projections of changes in ocean physical properties, biogeochemistry and the planktonic part of the ecosystem, for all European marine areas except the Black Sea. Available outputs include temperature, pH, salinity, water velocities, dissolved oxygen, nitrate and phosphate concentration, plankton biomass and net primary and community production at monthly and annual frequency up to 2100 based on up to three IPCC AR5 relative concentration pathways. Estimates of relevance to inland fisheries and aquaculture stem from 11 AR5 runs of E-HYPE, a pan-European hydrological model including projected river flows for all regions accounting for anthropogenic (e.g.

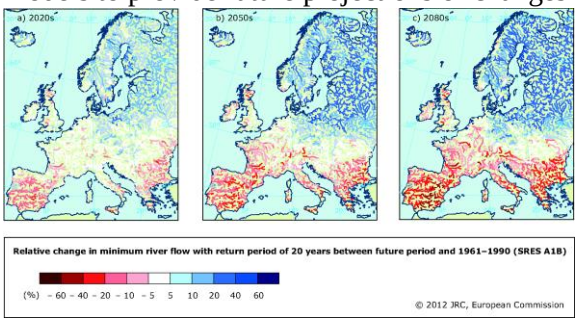

Fig 3) Relative change in minimum river flow for (a) 2020s, (b) 2050s and (c) 2080s compared to 1961-1990 for SRES A1B[(2)].

irrigation, hydropower) impacts. Regionally downscaled climate models will be applied in selected habitats such as the Baltic Sea. Currently, the IPCC states low confidence in projections of waves and storminess over coming decades. However, assessments of changes in global wave climate are available for RCP8.5 and RCP4.5[3]. Within *CERES* T1.1, outputs from relevant studies will be collated to inform analyses of direct threats (exposure) to the fishing and aquaculture infrastructure under WP2-4.

T1.2) Impacts of multi-scale governance and economic drivers of change (CEFAS, John Pinnegar)

Short-, medium- and long-term developments in governance, social, technological and economic drivers may be just as important to fisheries and aquaculture and sectors as climate-driven changes in habitats and species. Given the backdrop of environmental changes projected in T1.1, Task 1.2 uses stakeholder engagement to complete the PESTLE approach (Political, Economic, Social, Technological, Legal and Environmental) to create future scenarios examined in *CERES*. Stakeholders and *CERES* team members will discuss and agree on plausible changes in a diverse array of parameters needed for species/group (WP2-3), bioeconomic (WP4) and ecological risk assessment (WP5) modelling, and adaptation strategies (WP6). Topics include potential future fuel and fishing costs, assumed domestic and global demand for fisheries/aquaculture products, technological developments and changes in European policy and management. In addition, climate change impacts need to be framed with respect to activities in other sectors (notably renewable energy due to inland water diversion / marine spatial closures). Engagement of fishers and aquaculture business owners is particularly important in order to gain information on social factors / constraints. Discussions will benefit from previous projections made by CERES partners, notably on future demand for fish resources in Europe. A coherent and consistent set of assumptions and development trajectories will be established and used in subsequent WPs.

WP2 – Effects of climate change on fisheries target species (finfish and shellfish) (CSIC, Ignacio Catalan)

Ambition: Deliver an unparalleled, cause-and-effect understanding of how climate change will alter key aspects of species targeted by fisheries using both statistical analysis of long-term data and models integrating direct (abiotic / physiological) and indirect (trophodynamic / ecosystem) factors.

T2.1) Direct and indirect climate impacts on life stages of fisheries species (CSIC, Beatriz Morales-Nin)

CERES will collate existing information from laboratory studies and field observations on environmental preference, phenology (e.g. timing of spawning), growth rates and spatial distribution of economically important fishery species. Previously compiled, extensive data sets on the physiological limits of species to multiple stressors (EU COST FA1004) and spatiotemporal field abundance (CEFAS archives, ICES) will be expanded using desktop reviews during the first six months of *CERES*. Important knowledge gaps exist and additional experiments are planned to improve mechanistic understanding of how multiple factors (e.g. temperature and salinity, low oxygen or pH) interact to influence vulnerable life stages[4]. Data generated from previous and new experiments will be used to 'scale up' impacts of key factors to populations and communities. Application CS1 and CS3 (data mining all species / groups; Marine Exps. = anchovy, dolphinfish, herring, tuna spp., Inland Exps. = eel, pikeperch, shads).

T2.2) Statistical analysis of historical changes in fish stock distribution and productivity (HCMR, Christos Maravelias)

Extensive spatiotemporal data series will be analyzed to determine the impacts of climate change and variability on historical distribution, fecundity, growth, maturity, recruitment, and natural mortality. Statistical models (generalized additive/linear models, etc.) will characterize responses of communities, populations and individuals to changes in physical variables. Statistical models will help provide baselines and hypotheses to be tested using forward-projecting models and will be particularly valuable for estimating responses in species where detailed knowledge is lacking. Particular attention will be paid to disentangling the confounding impacts of fishing pressure and climate variability (in marine and inland waters), identifying frequency-dependent variability, and

separating climate signals from short –term 'noise' and natural variability. Application-CS1 (Baltic, Barents, Bay of Biscay, Mediterranean, North Seas, Northeast Atl.), CS3 (Szczecin Lagoon, eastern European lakes, large EU rivers, e.g. Elbe, Danube)

T2.3 Projection modelling of changes in distribution and productivity of commercial fish populations (PML: Jose Fernandes)

The future distribution and productivity of key commercial fish stocks will be projected using state-of-the-art modeling tools. Species distribution models will be used in marine and inland waters (e.g. SS-DBEM) to make direct use of climate model outputs, historical species distributions and habitat preferences, plus ecological and physiological model parameters. Temporal (annual) and spatial (0.5x0.5◦) changes in biomass and (in some cases) fishery catches will be projected to 2100. Existing individual-based physiological life cycle models will be applied, where necessary, to create spatial data-layers of relative fish abundance needed to determine fishery and economic consequences and key metrics (spawning stock biomass, maximum sustainable yield) including confidence limits. Existing mixed-fishery, multispecies and end-to-end (North Sea ATLANTIS) models will examine climate-driven changes to indirect factors (predator-prey overlap, expanding jellyfish populations) to not only characterize trade-offs between species, but also to determine where mixed-fishery, technical interactions may arise. Application: CS1 (40-50 marine fishes), CS3 (cyprinids, eel, shads, sturgeon)

WP3 – Effects of climate change on aquaculture species (DLO, Pauline Kamermans)

Ambition: Project climate-driven changes on the productivity of aquaculture species/groups due to climate-driven effects on both direct (abiotic / physiological) and indirect (pathogens, HABs, jellyfish)) factors and advance and apply early warning tools for the industry.

T3.1) Direct effects of climate change on species (IEO, Virginia Martin)

Climate-driven changes in physical factors will have direct effects on productivity via physiology. *CERES* has experienced researchers who have/are generating considerable data from multi-stressor (temperature x pH x O_2) experiments on fish and shellfish in aquaculture. Results from laboratory experiments previously conducted on key species in marine and inland waters will be compiled and combined with those from ongoing and new experiments. The latter will fill gaps in knowledge (e.g. better understand adaptive capacity, collect data on emerging, poorly studied species, link genetic to organismal response) and provide parameter values needed for projecting climate-driven changes in production potential (T3.3) and sensitivity analyses (T5.1) to quantify vulnerability (T5.3). Application C2 & C3 (Review of all current and potential future aquaculture fin- and shellfish; Exps on cyprinids, pikeperch, sea bream, sea bass, tuna (larvae), shellfish spp.)

T3.2) Impact and early warning of climate-driven indirect factors on cultured species (NUI Galway, Tom Doyle)

Climate change will alter risks associated with harmful algal blooms (HABs), harmful jellyfish blooms (Fig 4), the spread and virulence of pathogens as well as the strength of interactions with (non-indigenous) species. Two activities will be performed here to better understand these indirect threats. First, CERES will promote development and application of statistical early warning techniques allowing aquaculture facilities to take preventive action (e.g. quarantining or employment of bubble curtains to protect net pens). Second, experiments will be conducted examining changes in the productivity, mortality, and disease resistance of key European aquaculture species (shellfish to finfish) to indirect factors. Both methods will supply information to other WPs. Application: CS 2 (HAB impacts on shellfish spp., jellyfish impact on sea bream, tuna (eggs), sea bass and salmon cages, pathogen spread across salmon farms), CS3 (water availability/quality impacts on carp / trout farms).

Fig 4) Caged-raised salmon damaged by jellyfish (T. Doyle, NUI Galway).

T3.3 Modelling cumulative impacts on the productivity of aquaculture species (LEnv, Joao Ferreira)

Well-tested models such as EcoWin.NET [5] and FARM [6] will be employed to simulate direct and indirect effects of climate change on aquaculture species. Based on environmental drivers and scenarios (T1.1), climate-driven changes in production will be estimated by: (i) spatial models examining coastal habitat loss; (ii) local, farm-scale, physiological-based models examining productivity including stochastic functions for incidence of pathogens, HAB and jellyfish; (ii) ecosystem-scale (bay, fjord, transitional water) models examining connectivity-related changes (e.g. pathogen transmission among sites as influenced by changes in the aquaculture footprint). The three groups of models will provide essential data on biological production functions for economic models (T4.2) and sensitivity (see T5.1) risk assessment (see T5.3). Application: CS2 (meagre seabream, salmon, shellfish spp. in northern and southern Europe), CS3 (carps, trout in northern and southern Europe).

WP4 – Economic impacts on fisheries and aquaculture sectors (TI-SF, Ralf Döring)

Ambition: Provide a step change in the ability to project economic opportunities and challenges of climate change to fisheries and aquaculture by applying state-of-the-art tools integrating biological responses of target species, future economic trajectories, social/behavioural responses of fishers and farmers accounting for regional specificities.

T4.1 Spatially-explicit bioeconomic estimates of climate-driven changes in fishery access, resources, and effort (DLO-LEI, Katell Hamon)

Bio-economic models with a proven track record (FISHRENT[7], DISPLACE[8], MEFISTO[9], BEMTOOL[10] and FLR[11]) and an end-to-end model (ATLANTIS[12]) will be applied. The economic consequences of climate adaptation scenarios including impact of mitigation measures (e.g. tackling CO_2 emissions largely responsible for climate change), and effects of adaptation strategies (e.g. gear changes, promoting energy efficient/environmentally friendly practices) will be examined by fleet. Emphasis is on climate-driven changes in fishery access (e.g. closed areas, wind farms), resources (shifts in distribution / productivity, WP2) and effort (fisher behavior). The expected results will be changes in distribution of effort, catch composition, costs, gross value added and profit useful for both strategic and tactical advice. These tools provide both long-term (strategic – what to do) as well as short-term (tactical – how to do it) management advice. Application: CS1 (demersal mixed fisheries, North Sea, Baltic Sea, Mediterranean and Aegean; pelagic mixed fisheries, North Atlantic, Baltic, Eastern Mediterranean; tuna fisheries).

T4.2 Effects of climate change on farm-level productivity and profitability (CEFAS, Birgit Oidtmann)

The profitability and productivity of aquaculture will be examined at the farm level focusing on the effects of climate change on specific production systems in specific regions given future physical, ecological and economic (e.g. costs for space, feed, wages, energy, changes to stocking density and environmental externalities) trajectories of change. *CERES* will apply a well-established method from agricultural economics (typical farm) to build theoretical farms based on production systems, regional statistics, detailed (anonymous) data from multiple farms and interviews with experts, consultants and scientists familiar with specific local / regional characteristics. Application: CS2 (sea bream, sea bass, salmon, shellfish) and CS3 (carp, trout) – across Europe. A separate end product is a simple web-based analysis tool to examine profits given the likelihood of different climate scenarios.

T4.3 Fisheries-aquaculture interaction and aquatic sector relevance to national economies (PML, Eleni Papathanasopoulou)

The potential climate-driven changes to interaction between fisheries and aquaculture production systems as well as other national economic sectors will be examined. A global fishmeal trade model[13] will be updated and applied to investigate the impacts of changes in European fisheries on the availability of fishmeal from and to Europe and the impacts on global trade. In a second step, a multi-regional input-output (MRIO) model[14] will be applied to highlight the potential economic impacts of changes in the fisheries and aquaculture sectors, with inputs from WP2-3 and outputs to WP5 and WP6 in the context of proposed scenarios. Application CS2 & CS3 (all relevant species).

WP5 – Risks and vulnerability of fisheries and aquaculture sectors in relation to climate change (UHULL, Mike Elliott)

Ambition: Examine risks presented by climate change to fisheries and aquaculture using both conceptual and (semi-) quantitative approaches including Bayesian networks as decision support tools to a wide range of end users (farmers, fishers, policy makers) incorporating both data rich and data poor approaches and expert opinion.

T5.1. Climate-driven exposure and sensitivity of fisheries and aquaculture (DTUAqua, Mark Payne)

Metrics of exposure and sensitivity, two critical components of vulnerability[15], will be quantified for fisheries and aquaculture sectors under CERES climate scenarios. Exposure will be based on outputs of T1.1 (severity and direction of change in physical factors including rainfall and altered hydrological patterns, warming, extreme events, frequency of hypoxia, reduced pH, changes in ocean currents, etc.). Sensitivity will be assessed as a quantitative (sum) of the scores (3 point scales) of an amalgam of biological and economic categories. Biological categories include physiological traits (optimal, sub-optimal, and critical ranges in temperature as influenced by pH or hypoxia), climate-driven responses in historical time series data, and ecological traits (e.g. life history characteristics such as reproduction mode, migration, growth, lifespan, degree of habitat specificity) from WP2 and WP3. Economic categories include results for specific fisheries and aquaculture farms/production sites targeting those species/groups (WP4) including adaptation options. Thus, scores for exposure and sensitivity will be species-/group- and region-/site-specific (data required for T5.3). Furthermore, this task will identify the most influential and most uncertain parameters affecting vulnerability, and hence the economic performance of fisheries / farm type. Application: Exposure, sensitivity and adaptive capacity will be compared across regions (CC may benefit and be detrimental to the same species in different regions) in all Case Studies.

T5.2. Conceptual Framework for risk assessment and management (UHULL: Katie Smyth)

A conceptual model for risk assessment and management will be created using a well-established industry compliant tool (Bow-Tie Analysis [16]. The analysis focuses on the hazard (climate change) and its influence on a set of main events (e.g. losses to wild fisheries and aquaculture). The framework will produce conceptual models which list i) threats causing the main events as well as ii) prevention measures limiting the severity of the main event, and identifies iii) the consequences of the main event occurring and, iv) mitigation measures aimed at minimizing those consequences. These conceptual models will be created at the start of *CERES* in dialogue with stakeholders and will be used as basis for quantitative risk assessment (*T5.3)* parameterizing the most important links between threats, events and consequences. This rigorous conceptual analysis of risk management will help determine suitable adaptation actions as well as the current and future legislation directions and interactions of global, European and national legislation and will examine the ability to consider these against cumulative and in-combination effects. Application: CS1, CS2, CS3.

T5.3. Quantifying vulnerability for fisheries & aquaculture segments (TI-SF, Vanessa Stelzenmüller)

CERES will provide quantitative, probabilistic measures of risk to different fisheries and aquaculture sectors using an environmental risk assessment (ERA) framework. ERAs have been used to examine cumulative pressures on a variety of aquatic habitats, species and/or sectors and can integrate expert knowledge in the assignment of exposure and sensitivity[17]. A series of ERAs will be conducted on the cumulative effect of climate change and other (multiple) stressors. ERAs will link spatially explicit information on the vulnerability of key fish and shellfish as well as their dependent fisheries or aquaculture industries with the occurrence and magnitude of climate-driven direct and indirect pressures identified in T5.2. Bayesian belief network models or similar tools will consider the consequences of CERES scenarios including process-based model estimates of climate-driven changes in key direct and indirect factors and their implications for future economic and policy settings (defined in WP1). Application: *CS1, CS2, CS3.*

WP6 – Engagement, integration and synthesis (UHAM, Myron Peck and all project partners)

Ambition: Engage industry and policy stakeholders throughout the project to use CERES outputs to create meaningful adaptive options for fishers and aquaculture companies and the

governance of these blue growth sectors in light of short-, medium- and long-term climate change scenarios. Activities occur across all Case Studies.

T6.1. Stakeholder Consultation and Engagement (DLO, Birgit de Vos + all partners)

Stakeholder engagement is a core activity of *CERES* and stakeholder/WP integration in the three CSs is critical to realizing operational climate change mitigation and adaptation solutions. Stakeholders (together with 8 industry/SME partners) are engaged early and throughout the project to i) define common PESTLE scenarios, ii) provide data for analysis and modelling, and provide iterative feedback on iii) project results, iv) their perceived policy and management options, and iv) likely responses to policy and management options derived by *CERES*. A broad range of tools will be used from round-table discussions to semi-structured interviews of various groups (contrasting Member States, stakeholders from industry, European Commission and regulators plus NGOs and consumers). These activities allow joint problem framing, critical to the success of stakeholder engagement (see GAP2 project). Information from *CERES* will be combined with a wealth of information obtained from previous projects of *CERES* partners (both EU and regional) and from their wide advisory capacities at national and regional levels.

T6.2. Adaptation, mitigation and compensation strategies (UHAM + all partners)

Industry-specific adaptation, mitigation and compensation strategies will be developed from the ERAs (T5.3) and potential reactions to those threats/opportunities by fisheries and aquaculture sectors (revealed by SME and stakeholder engagement). Mitigation strategies will include recommendations on policy reform as well as technological advances and economic instruments; compensation strategies will be advocated for the resource, the habitat and/or the users of the resource. This will include built in autonomous adaptation and planned adaptation and responses of both markets and users.

T6.3. Governance Recommendations for Blue Growth (UHULL, Sue Boyes + all partners)

Activities in this task will synthesize and communicate the governance repercussions of the predicted climate-driven changes, assessing prevention measures, management measures, mitigation options and adaptive strategies in enabling fisheries and aquaculture sectors to not only cope but also reap the potential benefits of climate change in the short-, medium- and long-term. It is envisioned that policy recommendations will affect a broad array of governance tools (see section 1.3.1) including but not limited to the CFP, MSPD, MSFD, WFD and national aquaculture legislation including zoning.

A seventh WP addresses project **management and dissemination** led by the coordinator (UHAM, Ines Mügler, Ute Kreis). It includes *T7.1, day-to-day project management and internal communication,* and *T7.2 External project communication*. Details of WP7 are provided at proposal Stage 2.

2.0 Impact

Europe currently imports 64% of the finfish it consumes[(18)] valued above 16 billion € y^{-1} and increasing whereas exports have remained relatively constant at about 3 billion € y^{-1}, hence Europe suffers an annual trade deficit of 13 billion € y^{-1} [(19)]. CERES addresses the Europe 2020 strategy by recognizing that increased aquatic production is required for future food security, given the expected increase (~30 Million t y^{-1}) in global demand and the current dependence of Europe on imports. ***CERES* will provide solutions for sustainable growth of the European aquatic food production sector in the context of climate change.**

Deliverables of CERES will have Technology Readiness Levels (TRL) ranging from 'new knowledge' (TRL1, WP1,2&3), 'new advice and standards' (TRL3, WPs 4,5&6), 'business models' (TRL8, WP4) and 'public information' (TRL9, WP7). The ability to harness the best available, pre-existing data sets and tools will allow ***CERES*** to **answer important, practical, and inter-related questions for European fisheries and aquaculture sectors** including:

1) How will the key physical and biogeochemical features (including habitat loss) of marine and inland waters change in a future climate and what forecasting methods can most reduce the uncertainty in those estimates?

2) Which current or emerging species will be the most profitable and environmentally sustainable to culture in light of climate change, considering the wide range of farming structures and systems (e.g. freshwater ponds in Eastern Europe, sea cages in Norway, Scotland, Eastern Mediterranean (etc.), suspended and bottom culture of bivalves in many EU countries)?
3) In a warming climate, when and how far (to the north and/or to greater depths) will European marine fish stocks shift and how can/should their dependent fisheries respond at different time and geographical scales and in different regions?
4) What are the implications for fish stocks and their fisheries of climate-driven changes in ecosystem-level multi-species interactions and productivity?
5) What are the likely changes in fisher behaviour given the above changes and how will interacting policy measures (e.g., discard ban, closed seasons and areas) influence fleet activities?
6) Biologically and economically, who stands to gain and lose in the light of climate change and how can aquaculture and fisheries reap the benefits of those emerging players?
7) Which early warning techniques can protect against climate-driven increases in the frequency of events such as harmful algal blooms or jellyfish outbreaks, the spread of pathogens or episodes of coastal hypoxia which negatively impact on fisheries and aquaculture sectors?
8) What practical policy changes can increase the scope and enhance the profits of fisheries and aquaculture in the short-, medium- and long-term while still safeguarding the health and productivity of marine and inland habitats in a future climate?

Our answers to these questions will address the outcomes expected from projects in this call:

i) Support fisheries management and aquaculture development by reducing uncertainties and risk, while optimising scientific advice, policy implementation and production planning.

CERES acknowledges that, although statistical correlations of ecological time series data may be necessary to provide answers to historical questions (what and when), mechanistic, process-based understanding is ultimately desired (in a multi-stressor context) to answer the most important questions (why, how and what if) for policy and industry to most effectively manage European aquatic living resources in a future climate. As noted by the (re)insurance industry, a paradigm shift is needed in the way we advise policy and industry from historic to predictive risk assessment methods. This strategy is embraced by the partners in this consortium. *CERES* also acknowledges that there are limits in the ability to predict climate and the responses of fish, shellfish, and their markets in the future and that uncertainty (from scenario (T1.1, 1.2), sampling (T2.1, 3.1), to model structure (WP2-4)) must be carefully and thoroughly communicated to stakeholders and policy makers (WP6) to adequately develop risk management.

CERES will reduce uncertainty in estimates of impacts of climate change on habitats by using state-of-the-art physical and biogeochemical models (WP1) and by being closely aligned with additional regional and global modelling efforts conducted alongside *CERES* by our partners and their collaborators. Defining realistic scenarios is an important, initial task within this project which relies on the combined inputs from partner projects (SMEs) and stakeholders (industry and policy makers). Climate scenario definitions are underway world-wide and *CERES* will be central to this effort. Uncertainty in estimates is also reduced by the considerable expertise of project partners in the ecophysiology and population dynamics of fish and shellfish resources (and ecosystem dynamics) used to estimate impacts (on growth, reproduction and mortality, habitat association and migration, as well as species interactions) based on first principles (mechanistic / process-oriented and not merely correlative models).

CERES will quantify risks (WP5) and provide clear options to fisheries and aquaculture sectors based on well-defined short-, medium- and long-term combined climate/economic/governance scenarios (WP6). These three time horizons allow adaptation strategies to include current policies and industry practices (short-term) as well as medium- and long-range planning which may require more substantial changes to infrastructure (e.g., in terms of the composition of fishing fleets, gears, the types of species/sites chosen selected, farming system for aquaculture). This approach offers a logical framework for production planning by both fisheries and aquaculture sectors. Both conceptual and quantitative (Bayesian) risk assessment and management tools are a key culmination of *CERES*.

ii) Allow regulators, fisherman and aquaculture operators to anticipate, prepare and adapt to different scenarios driven by climate change, while minimizing economic losses and social consequences.

A suite of regionally-specific adaptation strategies for fisheries and aquaculture (WP6) will be a main output of the combined efforts of scientists and industry in *CERES* WPs 1-5. Climate change and variability has been explicitly blamed for several recent events critical to European fisheries and aquaculture sectors (e.g. shift and expansion of mackerel to Icelandic waters; increasing impacts of jellyfish and/or more rapid transmission of disease in species cultured in coastal waters). Early warning methodologies for extrinsic climate-driven factors (e.g. HABs, jellyfish, disease) are advanced in this project (T3.2). *CERES* will provide tools and a list of options for fishing fleets and aquaculture production systems based on climate-driven bioeconomic drivers (T4.1, T4.2) and will deliver information needed to support decision-making by licensing authorities, producers, and investors with respect to i) target species, ii) spatial management and site selection, and iii) capacity of different production methods.

The expected outcomes of this call cannot be accomplished unless a broad base of stakeholders from industry and policy are engaged throughout the project; hence *CERES* has partner SMEs in fisheries and aquaculture that will provide 'hands-on', 'real-world' road testing of *CERES* science and recommendations. The consortium contains partners with vast experience in the fisheries and aquaculture industries as well as European and global advice and governance systems. The importance of industry and stakeholders to the formulation of the scenarios to be tested cannot be understated and is one of the highest priorities in this project. A second important element of *CERES* research will be a strong foundation of industry representation via project SMEs and other stakeholder groups. Long-standing relationships of *CERES* partners to umbrella science and policy organizations (European Aquaculture Society, Association of the European Fisheries and Aquaculture Research Organisations (EFARO), European Aquaculture Technology and Innovation Platform (EATIP), European Fisheries Technology Platform (EFTP) and the involvement of stakeholders organizations (e.g., European, Regional Advisory Councils, NGOs) will ensure that *CERES* is guided by practical concerns, anchored in solid science, in order to achieve maximum societal impact.

iii) *Identify opportunities that might occur under the different scenarios and prepare to reap the potential benefits for the European fisheries, aquaculture and seafood sectors and consumers.*

Climate change will create new opportunities for commercial exploitation in terms of the availability of new species to fisheries (range shifts) and conditions more suitable to the growth of new farmed products (e.g., warm water fishes and shellfish in temperate coastal and offshore areas). Examples include the potential expansion of European anchovy, red mullet and seabass for fisheries in the North Sea or sites relevant for Pacific oyster or sea bass culture in northern European waters. The European Commission DG-MARE and EU Member-States are now working together to develop coherent national support programmes for projected growth and sectorial allocation of European aquaculture and fisheries for the period 2014-2020 under the European Maritime and Fisheries Fund (EMFF). *CERES* will support member states and the EU Commission in implementing their operational programmes, and the consequential decisions by producers by providing an analytical framework and quantitative estimates needed for adapting the sector in the light of climate change.

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