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Report of the ICES/ PICES Workshop on Political, Economic, Social, Technological, Legal and Environmental scenarios used in climate projection modelling (WKPESTLE)

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International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Executive summary

ICES/ PICES Workshop on Political, Economic, Social, Technological, Legal and Environmental scenarios used in climate projection modelling (WKPESTLE), held in Washington D.C., USA, 9 June 2018, was attended by 20 participants from 9 countries. The workshop directly followed the 4th International Symposium on the Effects of Climate Change on the World's Oceans (ECCWO) and hence benefitted from enhanced participation.

As ICES strives to provide improved scientific advice within the context of a changing environment, it is essential to consider how different futures of physical climate as well as societal development are together impacting marine ecosystems and maritime activities. Short-, medium- and long-term developments in governance, social, technological and economic drivers may be just as important to the future development of fisheries and aquaculture as climate-driven changes in habitats and species abundances and distributions.

WKPESTLE aimed to investigate how and where scenarios are being developed around the world to explore the impacts of anthropogenic drivers on marine systems?

WKPESTLE brought together a diverse group of researchers from the ICES and PICES communities who are active in the development of social and economic storylines and connecting them to integrated marine climate modelling approaches. One of the workshop co-chairs, John Pinnegar, is a co-chair of the ICES/ PICES Strategic Initiative on Climate Change Impacts on Marine Ecosystems (SICCME) and two of the co-chairs, Jörn Schmidt and Alan Haynie, are co-chairs of the ICES Strategic Initiative on the Human Dimension (SIHD). Tyler Eddy, the fourth co-chair, is coordinator for regional models and the co-coordinator of the scenarios working group within the global FishMIP initiative.

The meeting provided an opportunity for the leading researchers to exchange ideas and to update each other on current work. A number of related publications are in preparation by meeting attendees and a global synthesis paper remains in discussion. The meeting was valuable for all participants as a means to understand the different approaches to scenario-building employed across different projects. The workshop led directly to a successful proposal for an 'oceans' theme session at the first 'Scenarios Forum' in Denver in March 2019.

A range of different projects was presented during the WKPESTLE workshop (and subsequently in Denver) and the geographic and thematic focus of each was compared, contrasted and discussed. Conclusions from the work included:

- Comparison across projects is valuable, although the diversity of purposes makes direct comparisons challenging.
- Projects have adopted a wide variety of approaches, some involving stakeholder engagement and elicitation, others drawing heavily on previous published studies.
- Shared Socioeconomic Pathways (e.g., O'Neill 2015) provide some general direction for how society may address climate adaptation and mitigation challenges. Many projects are working to balance the value of standardization with these frameworks with the specific needs of their project and geographic scope.

1 Details and aims of the meeting

Short-, medium- and long-term developments in governance, social, technological and economic drivers may be just as important to the future development of fisheries and aquaculture as climate-driven changes in habitats and species distributions. This workshop provided an opportunity for the leading researchers in the field of scenarios development to meet following the ECCWO conference to discuss approaches and to agree a common way forward. A number of related publications are being completed or are in preparation by meeting attendees as a result of this workshop and a synthesis paper remains a key aspiration.

The key purposes of the workshop were to:

a) Compile and compare future scenarios currently used by different research groups projecting the socio-ecological consequences of climate change on fisheries and aquaculture in the future;

b) Discuss the rationale and data sources employed to establish elements of "PESTLE" scenarios for bio-economic projection;

c) Where possible, agree on a common set of scenarios and outputs to facilitate region-region and region-global comparison of social-ecological impacts of climate change on fisheries and/or aquaculture.

The PESTLE approach stems from the business world and is frequently used to assess the political, legal or environment climate that a particular business or company is operating in (see figure 1). This tool is especially useful when starting a new business or entering a foreign market. PESTLE is a mnemonic which in its expanded form denotes P for **Political**, E for **Economic**, S for **Social**, T for **Technological**, L for **Legal** and E for **Environmental**. In participating in this workshop, attendees were encouraged to make use of the 'PESTLE' framework to think about how the future might unravel according to this framework, for their particular scenario typology.

Key Questions include:

- What is the political situation of the country (e.g. trade, fiscal and taxation policies) and how can it affect the industry in each scenario?
- What are the prevalent economic factors in each scenario (e.g. interest rates, employment or unemployment rates, raw material costs and foreign exchange rates, etc.)?
- How much importance does culture and societal issues have (e.g. changing family demographics, education levels, cultural trends, attitude changes and changes in lifestyles)?
- What technological innovations are likely to occur and affect the development pathway of the particular industry?
- Is there current legislation that regulate the industry or will there be any change in legislation for the industry in the future?
- What are the environmental concerns of the industry?

Figure 1. The six components that make up a PESTLE analysis.

The workshop was organized so that different approaches could be presented and discussed before the workshop participants proposed a generic framework to summarise the different scenario development approaches and to outline how scenarios are being used in each case (see agenda in Annex 2).

The different approaches are briefly described in Section 3 of this report, which provides an overview of each presentation from the workshop. In addition, the different approaches mentioned are listed in Section 4 (Table 1), showing the focus of the respective study (plus other studies not covered in the presentations), both in terms of geographic focus as well as considered elements and goals of the particular analysis.

As recognised by the United Nations Environment Programme (UNEP 2002), 'scenarios do not have to be developed from scratch', they can be borrowed or adopted from the literature. Many of the scenario exercises described by participants were built upon an earlier 'architecture', notably the four Special Report on Emissions Scenarios (SRES) socio-political storylines developed by the Intergovernmental Panel on Climate Change (IPCC) or the more recent Shared Socioeconomic Pathways (SSPs).

The SRES was published by the IPCC in 2000 (Nakićenović *et al.* 2000). Greenhouse gas emission scenarios described in this report were subsequently used to make projections of future climate change impacts, but these were themselves based on a set of underlying socio-political development storylines that yielded projections of carbon outputs. The SRES scenarios (both the emissions and the socio-political storylines), were used in the Third Assessment Report (TAR) of the IPCC, published in 2001, and in the Fourth Assessment Report (AR4), published in 2007 as well as forming the basis of the UN - Millennium Ecosystem Assessment published in 2005.

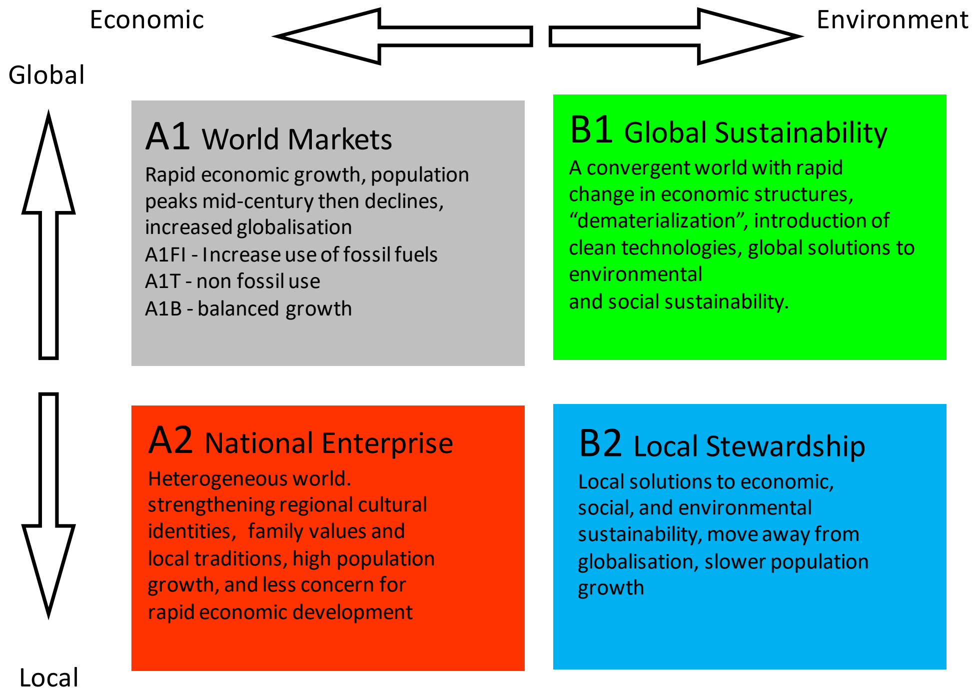

Figure 2. The four SRES socio-economic scenarios, as defined by two axes, local to global and economic to environment.

Within the context of marine and fisheries issues, this basic SRES architecture was adopted in the UK AFMEC project (Alternative Futures for Marine Ecosystems, Pinnegar *et al.* 2006), the EU ELME project (European Lifestyles and Marine Ecosystems, Langmead *et al.* 2007) and the EU VECTORS projects (Vectors of Change in Oceans and Seas Marine Life, Groeneveld *et al.* 2015).

Over the past few years, an international team of climate scientists, economists and energy systems modellers have built a range of new "pathways" that examine how global society, demographics and economics might change over the next century. They are collectively known as the "Shared Socioeconomic Pathways" (SSPs); (see O'Neill *et al.* 2014). These SSPs are currently being used as important inputs for the latest climate models, feeding into the Intergovernmental Panel on Climate Change (IPCC) sixth assessment report (AR6) due to be published in 2020–2021. They are also being used to explore how societal choices will affect greenhouse gas emissions and, therefore, how the climate goals of the Paris Agreement could be met.

The new SSPs offer five distinct pathways (figure 3) that the world might take in the future. Basic SSPs consist of a narrative outlining broad characteristics of the global future and country-level population, GDP, urbanization projections. Information about the scenario process and the SSP framework can be found in Moss *et al.* (2010), van Vuuren *et al.* (2014) and O'Neill *et al.* (2014) and Kriegler *et al.* (2014).

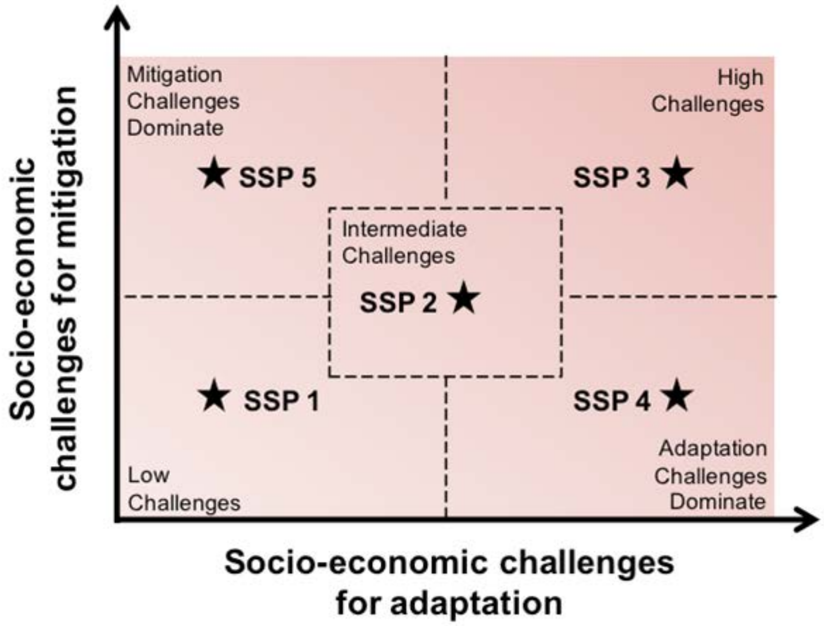

Figure 3. The five Shared Socioeconomic Pathways (SSPs) as defined by axes comprising socio-economic challenges to climate change adaptation and mitigation.

Several of the participants who attended the WKPESTLE workshop made explicit reference to the "Shared Socioeconomic Pathways" (SSPs), and have based their fisheries, aquaculture and maritime scenarios on this newer architecture.

Scenarios are imagined 'futures'. They do not come singly, as a forecast would, but in sets of alternatives. Scenarios are not necessarily "visions" or "plans", but they can help to guide strategy. They describe both optimistic and problematic futures. For scenarios to be a useful tool, they must be possible, plausible and credible. Plausibility is a necessary criterion, otherwise it simply becomes science-fiction.

Before discussing the details of the different approaches, participants at the workshop were asked to consider why scenarios are useful or necessary. Socio-political scenarios are needed because:

- There are literally 1000s of possible future states that could be evaluated (using models) – depending on different assumptions. It can be very difficult to constrain the number of permutations of climate vs economic vs political legislation scenarios without defining a small number of scenarios or pre-defined 'pathways' to cut-through this complexity.
- Humans matter. Governments manage people and their activities not the ecosystems themselves, therefore it is necessary to map- out how human societies might develop in the future as well as changing physical variables.
- Scenarios are needed for long term modelling, as issues such as fuel prices, fish prices, fish consumption and demand will all vary alongside fish availability in the environment and are needed for socio-economic modelling of the future.

- It is important that we are all speaking the same language and have a similar concept of how the future might unravel. Scenarios can be used to connect/unify seemingly disparate disciplines.
- Scenarios can be used to get people to talk together (explorative scenarios).
- Scenarios can be used to encourage the exchange of quantitative outputs within a common framework and to inform each other's modelling.
- Scenarios can be used to evaluate potential benefits and threats, to energise those who will be most impacted (if realistic/recognizable).
- Scenarios can be used to define the scope for adaptation and to characterise the behavioural response (e.g. of fishers) under each future world.
- Scenarios are needed so that we have a similar framework and starting point where regional differences in flavour and detail may exist (e.g. from the Arctic to Mediterranean, from the deep ocean to inland waters).

2 Overview discussion of Socioeconomic Scenarios in Marine Applications

The workshop built upon the ICES/PICES Workshop on Economic Modelling of the Effects of Climate Change on Fish and Fisheries (WKeconSICCME) held in June 2016 in Brest, France. That workshop was held primarily to address the following three goals: a) identify the socioeconomic data and features of a suite of representative future fishing and ecosystem scenarios that could be employed for use in evaluating climate change effects on fish and fisheries; b) identify how fisheries management policies will interact with climate change and identify how researchers can best evaluate what management tools are most likely to be resilient to climate change effects on fisheries; and c) identify suites of bio-economic and spatially explicit models of fishery behaviour that can be used to project the implications of different climate models on commercially important marine fish stocks in the northern hemisphere. Various further efforts have been undertaken to develop scenarios that capture developments of the human system in relation to marine and maritime activities (e.g., Alcamo 2008, Maury *et al.* 2017). Although a complete mapping of different activities was not possible in our one-day workshop, we did examine outputs from a wide range of groups and approaches globally.

3 Summary of presentations from WKPESTLE

Workshop attendees gave the following presentations, each of which described their own efforts to generate socio-political storylines.

3.1 From Shared Socioeconomic Pathways (SSPs) to Oceanic System Pathways (OSPs): Building policy-relevant scenarios for global oceanic ecosystems & fisheries

Olivier Maury [IRD – UMR, France] described recent efforts to extend SSPs to encompass global oceanic fisheries (tuna and "tuna-like" species). The initiative was launched during a workshop organized in UNESCO-IOC under the auspices of the CLimate Impacts on Oceanic TOp Predators (CLIOTOP http://www.imber.info/Science/Regional-Programmes) and Euro-Marine (http://www.euromarinenetwork.eu) programmes during late 2013. This initial workshop laid foundations for a longer term CLIOTOP "Scenario Task Team" aiming at an in-depth multidisciplinary effort to develop model-based scenarios in marine systems. The CLIOTOP Scenario Task Team adopted the Story And Simulation (SAS) approach proposed by Alcamo (2008) as a guiding principle for its work. The SAS approach is a methodology for combining qualitative and quantitative approaches to developing scientifically sound scenarios.

The main methodological steps (described in detail in Maury *et al.* 2017) were:

1) Review existing global scenarios, initiatives and identify the relevant ones that will form the outline of the OSPs.

2) Define the boundaries of the oceanic social-ecological system that constitute the scope of the OSPs and identify the external driving factors.

3) Identify the major domains of the oceanic social system considered.

4) Identify the key drivers of oceanic social-ecological systems for each of the domains retained from (3), i.e. economy, management and governance.

5) Translate SSPs to the oceanic realm and design "Oceanic System Pathways" narratives for the drivers identified in (4).

6) Compare the five OSPs to identify relative positions, potential overlaps and gaps to sharpen the OSP storylines as a set.

The authors developed five contrasting Oceanic System Pathways (OSPs), based on the existing five archetypal worlds of Shared Socioeconomic Pathways (SSPs); (Maury *et al.* 2017). Two major driving forces of oceanic social-ecological systems were identified in each of three domains, viz., economy, management and governance.

- The two major driving economic forces chosen to structure the OSPs were: (1) the demand for oceanic living resources, (2) the costs of harvesting, processing, and transporting these resources and associated products.
- The two drivers of global marine fisheries governance chosen to structure the OSPs were: (1) inter-state relations and (2) the global reach of firms.
- The two major independent yet complementary forces that were driving the management domain of OSPs were: (1) the importance of sustainability in management objectives and (2) the degree of compliance with management by the different actors of the oceanic system.

The authors compared the different pathways of oceanic social-ecological systems by projecting them in the two-dimensional spaces defined by the driving forces, in each of the economy, management and governance domains. Ultimately, the goal is that these OSPs will be useful for factoring in long-term objectives into present day management, designing effective strategies to transition toward sustainability, building long-term visions to design policies in a participatory way or assessing alternative global governance strategies and management options (Maury *et al.* 2017). Eventually, RCPs and OSPs will be combined to drive coupled simulation models

3.2 Socio-economic pathways and global fisheries

Colette Wabnitz and William Cheung [University of British Columbia, Canada] described work within the CORU (Changing Ocean Research Unit) and NEREUS programmes, that included the development of future scenario frameworks for the assessment of fisheries worldwide under climate change. This work has been described in more detail in Cheung *et al.* (2019).

Firstly, the authors developed storylines of alternative tenable futures of fisheries governance – including different combinations of area and fishing effort-based interventions on the high seas – given a world with sharply contrasting political, socioeconomic, technological and environmental priorities (Cheung *et al.* 2019). Scenarios were developed using contributions provided by key experts during a two-day workshop in Vancouver in November 2018 using the shared socioeconomic pathways (SSP) framework (O'Neill *et al.* 2017).

Secondly, the project team translated the qualitative scenarios into key representative quantitative metrics and applied biological and economic simulation models to global fish stocks and fisheries in 'Areas beyond national jurisdiction' (ABNJ). The aim was to project the future of fisheries' ecological (mean species abundance or MSA) and economic (revenues, profits and catches) performance based on the scenarios. Two climate-change scenarios (Representative Concentration Pathway or RCP8.5 and RCP2.6) were tested to examine alternative futures of high seas fisheries under climate change. Out of a possible five SSP futures, the authors developed three contrasting scenarios of high seas fisheries determined by a range of interconnected biophysical, social and economic factors:

- The first future **(SSP1) – 'charting the blue course'** – is an ocean with relatively higher fish abundance and lower levels of impact from fishing and climate change than the other two scenarios, made possible by global cooperation centred on sustainable development. Across the three futures, in SSP1 the high seas contribute the least to income and livelihoods.
- In the second future **(SSP3) – 'rough seas ahead'** – national interests, particularly those of high-income countries, drive the intense exploitation of marine resources on the high seas. Impacts on marine biodiversity through fishing and climate change are high, while subsidies are responsible for maintaining the viability of high seas fisheries.
- The third future **(SSP5) – 'fossil-fuelled development'** – is characterised by intense exploitation of high seas fisheries resources to support rapid and broad-based economic development, particularly for lower-income countries. Fishing intensity and its impacts are the highest across the three futures, exacerbated by high fossil-fuel use and few environmental concerns.

Computer simulation models were used to project future changes in fish stock and fisheries on the high seas and in EEZs under different SSPs. A bioeconomic modelling approach was then used to link the results from a biological model and an economic model (Cheung *et al.* 2019). All countries known to have fishing vessels operating on the high seas were grouped into three major income groups: low-income countries (LIC), middle-income countries (MIC) and high-income countries (HIC), based on their Human Development

Index (HDI) ranking. For each income group and each of the three defined SSPs, fishing effort on the high seas was projected using the effort dynamic model.

The analysis suggests that, on average, high seas fisheries are not economically viable across the three ocean futures, although findings highlight variations across the different country income groups considered. Among the three ocean futures investigated, the relative importance of the main direct drivers is dependent on whether the focus is on ecological, social or economic perspectives as well as the timeframes considered (Cheung *et al.* 2019).

3.3 Climate change and European aquatic RESources (CERES) – Scenarios of multi-scale governance and socio-economic drivers

John Pinnegar [Cefas, United Kingdom] described recent efforts as part of the EU H2020 project CERES to extend SSPs to encompass the aquaculture and fisheries sectors in Europe (both freshwater and marine).

At the CERES 'kick-off' meeting in Mallorca (5–6 April 2016), a basic outline of the prototype CERES socio-political story-lines was provided, based on outputs from previous scenario-construction exercises (e.g. Pinnegar *et al.* 2006, Langmead *et al.* 2008, Groenveld *et al.* 2018). Personal visions (for 49 participants) of how the future might unfold under each of the four CERES prototype story-lines were gathered, specifically focussing on fisheries and aquaculture. At this initial workshop it was also suggested that it might be helpful if the developing CERES scenarios could be 'mapped' against the new Shared Socio-economic Pathways (SSPs) being developed by the IPCC, to ensure that CERES outputs could then be used directly in the next IPCC assessment scheduled for 2021. Following further reading, it was identified that van Vuuren & Carter (2014) provided a useful methodology for mapping SSPs against the previous generation of IPCC SRES socio-political scenarios and, hence, the prototype CERES scenarios considered at the March 2016 workshop.

The CERES socio-political scenarios represent a hybrid between the earlier SRES system of four scenarios and the newer SSPs. While developing the CERES scenarios, the narrative characteristics and evocative names of the original SRES scenarios (Figure 2) were adopted, but these were bolstered with additional quantitative information derived from the SSPs (and made available in 2016 by the International Institute for Applied Systems Analysis - IIASA). The four scenarios were titled: World Markets, National Enterprise, Global Sustainability and Local Stewardship.

It should be noted that <u>none of the CERES socio-political scenarios assume RCP2.6 or SSP4</u>. The main reason for this particular choice is that van Vuuren & Carter (2014) did not include this combination in their mapping of RCPs and SSPS against the previous generation of IPCC SRES scenarios.

The first CERES deliverable (D1.1) was a 'Glossy report card' (CERES 2016) aimed at stakeholders and project partners, communicating the CERES socio-political scenarios. This was delivered in the first 6 months so that all project partners could make use of this common architecture for subsequent tasks, irrespective of where they were working in Europe (from the Mediterranean to the Arctic) or whether they were working on fisheries or aquaculture. The draft CERES socio-political scenarios and the 'glossy report card' were presented at the ICES/PICES Workshop on 'Modelling Effects of Climate Change on Fish and Fisheries'

(WKSICCME1) on 24 September 2016 in Riga (Latvia) in a session co-chaired by the CERES Scientific coordinator and the CERES Task 1.2 leader. Furthermore, they were also presented at the PICES Annual Science Meeting, in San Diego (USA) on 4 October 2016 in a specially convened workshop on "Modelling effects of climate change on fish and fisheries".

Additional quantitative analysis was carried out using recent outputs from the IIASA SSP community. These included research papers outlining the logic behind each of the five SSPs as well as a series of overview papers that talk about human demographics, GDP and economic growth, urbanisation, land and energy use trajectories etc. Information at the individual European country level was extracted from the data portal https://tntcat.iiasa.ac.at/SspDb/.

The changing demand for fish and shellfish products within Europe is clearly influential in terms of governing how the fisheries and aquaculture industries will develop in the future. A considerable amount of previous modelling work has been undertaken to provide regional predictions of fish prices, fish production, per capita fish consumption, and the contribution of aquaculture (Failler *et al.* 2007; Delgado *et al.* 2003; World Bank 2013). Within CERES the team made use of these earlier scenario outputs for the fishery and aquaculture sectors but combine these with updated outputs based around the new Shared Socio-economic Pathways (SSPs). World population size is a key driver of seafood demand, as is the relative affluence of citizens. In 2007, Failler *et al.* published fish consumption, production (capture, aquaculture and commodities) and fish trade (exports and imports) estimates and projections for 28 European countries from 1989 to 2030. Within the CERES project, in order to estimate total demand for fish products out to 2100, the project team combined the national population estimates under each SSP with per-capita seafood consumption estimates reported from Failler *et al.* (2007).

Armed with the detailed contextual information (above) for each of the Shared Socioeconomic Pathways (SSPs), as well as the 'personal visions' of the CERES partners/internal stakeholders, it was possible to map out what marine fisheries might look like in each case, including thoughts about management drivers, technological innovation, environmental concerns etc. (see Figure 4). Similarly, Figure 5 (taken from the 'glossy report card') provides an overview of the CERES aquaculture scenarios for Europe.

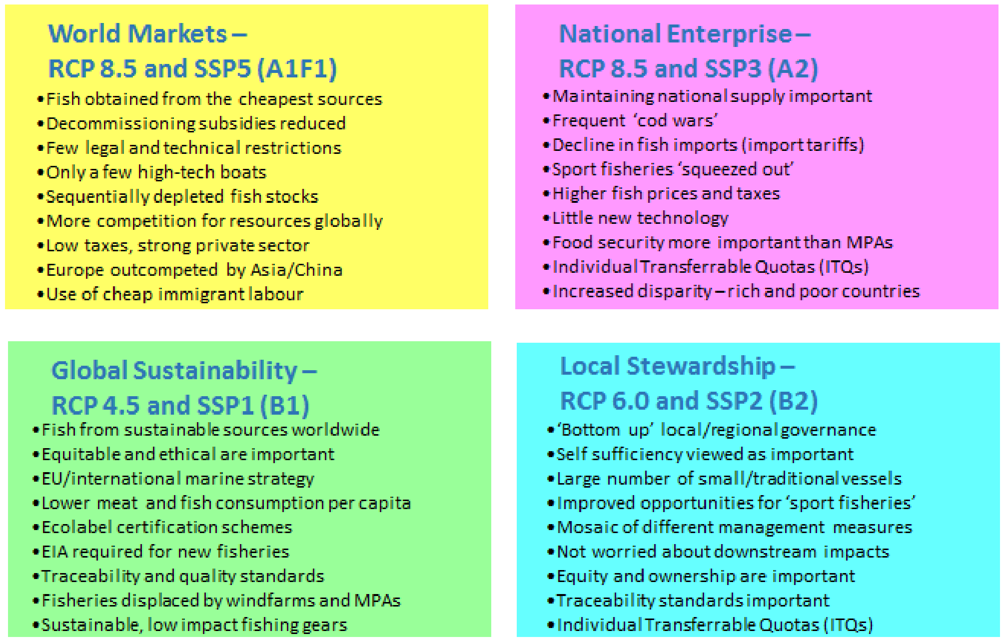

Figure 4. Draft socio-political scenarios elaborated for European fisheries by CERES partners and stakeholders.

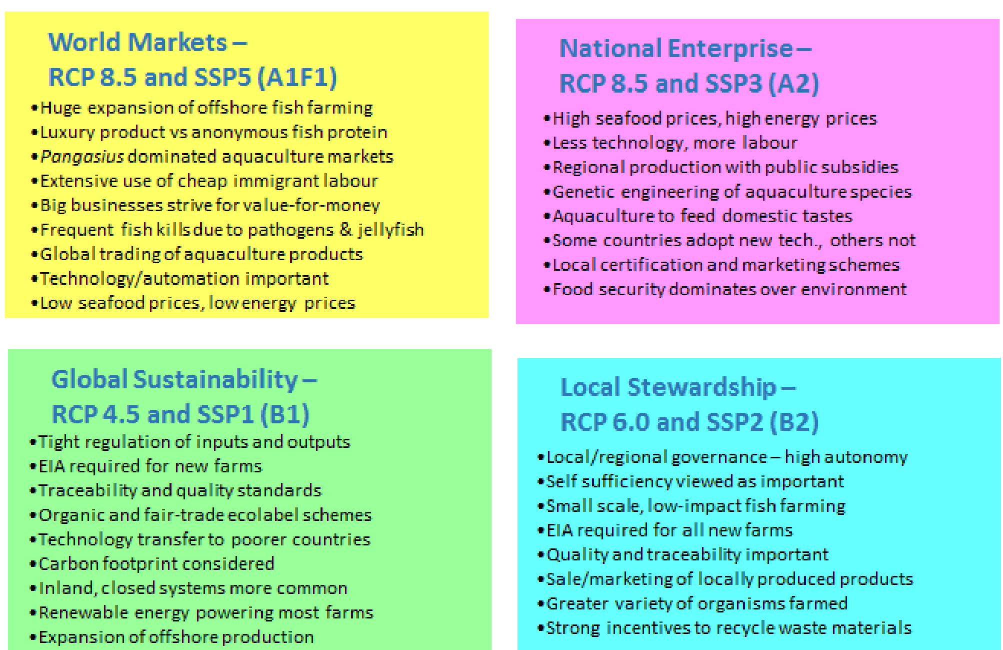

Figure 5. Draft socio-political scenarios elaborated for European aquaculture by CERES partners and stakeholders.

The primary objective of CERES is to "provide the knowledge and tools needed to successfully adapt European fisheries and aquaculture sectors in marine and inland waters to anticipated climate change". The socio-political scenarios described above have been used as this basis for long-term projections using bio-economic models, notably for fisheries simulations in the North Sea. This task was led by Katell Hamon (Wageningen Research, Netherlands) and involved further elaboration/quantification based on the generic storylines. Fuel and fish prices are influenced by prevailing socio-political conditions. For this reason, the modelling group within CERES decided to use the trends of fish and fuel prices from the MAGNET model which is a global general equilibrium model (Woltjer & Kuiper 2014). To implement projections of future fishing intensity, multipliers of Maximum Sustainable Yield (MSY) were specified in each case. In addition, spatial closures (MPAs, windfarms, oil and gas rigs etc.) were implemented based on maps contained within Matthijsen *et al.* (2018) who used a similar scenario architecture to the SSP and SRES framework.

3.4 Human scenarios in the Alaska Climate Integrated Modelling (ACLIM) project

Alan Haynie [Alaska Fisheries Science Center, USA] described scenario construction work under the auspices of the Alaska Climate Integrated Modeling (ACLIM) project. ACLIM is a multidisciplinary effort to examine how different climate scenarios are likely to impact the Bering Sea ecosystem – and to ensure that the management system is ready for these potential changes. ACLIM integrates climate scenarios with a suite of biological models which include different levels of ecosystem complexity and sources of uncertainty. This presentation focussed on coupling the project's bio-physical models with models of fisher behaviour and management. The authors identified groups of economic and management factors that are the core drivers of fisheries. Three Types of Economic Elements considered, included:

- **Pressures** – demographic, cultural, and macro-economic drivers of price and cost changes
- **Behaviors –** how fishing fleets and processors respond to econ, management, and environment
- **Results –** indicators / measures of success.

For management, there are many possible future policy choices, such as changes in target and bycatch species allocations or expanded spatial protective measures that can reduce the vulnerability of different stakeholders. Building on shared socioeconomic pathways (SSPs), the ACLIM team have defined the primary measures that have been shown to impact past fisher behaviour and define a range of future economic changes and policy interventions under which it is possible predict future integrated modelling outcomes. A set of seven ACLIM fishery scenarios were initially tested, these included:

- No fishing
- Status quo ecosystem-based-management
- MSY (no 2 million MT Ecosystem cap)
- Max. Economic Yield (MEY)
- Bycatch changes
- Price & cost changes

- Extreme events (e.g., stock collapse)

The team have demonstrated how different policy tools can have a large impact on how effectively fishers can adapt to environmental change and variation. The approach has since been compared with approaches of several other large integrated modelling projects (such as CERES and FISHMIP), to determine the potential utility of adopting a similar approach to explore long-term change in the Bering Sea ecosystem.

3.5 Spatial and sectoral extensions of the SSPs for coastal impact assessment

Lena Reimann [Kiel University, Germany] described efforts to extend the SSP (Shared Socioeconomic Pathways) framework in order to conduct a spatial analysis of socioeconomic vulnerability to sea level rise and storm floods in coastal locations of the Mediterranean (see Reimann *et al.* 2018). The ultimate aim of this work was to answer the question "How many [Mediterranean] people will be exposed to coastal hazards over the course of the 21st century?"

To enhance the basic SSPs, the authors made use of coastal SSP narratives developed by Merkens *et al.* (2016). To develop assumptions regarding the characteristics of each coastal SSP element, Merkens *et al.* (2016) considered a number elements originally proposed by O'Neill *et al.* (2017) that differentiate the various SSPs, such as urbanization, economic growth, inequality, international trade, globalization, consumption and diet, international cooperation, and technology.

For the gridded population projections, Reimann *et al.* (2018) followed the methodology employed in Merkens *et al.* (2016). Based on the assumption that future population patterns in coastal areas are determined by historical growth patterns. The authors divided each country into four zones: coastal urban (CU), coastal rural (CR), inland urban (IU), and inland rural (IR). Based on the established population growth rates, the authors calculated the observed urban and rural growth differences of each country. To differentiate between geographical regions and SSPs, the authors modified the observed growth differences by using pre-defined modification factors. In particular, the national-level urbanization (Jiang and O'Neill 2017) and population projections (KC and Lutz 2017) of the basic SSPs available in the SSP database (IIASA 2016) were used.

Based on these projections, Reimann *et al.* (2018) split the total national population into urban and rural population for each SSP and projection year. To differentiate between coastal and inland population, the authors applied the adjusted growth differences to the urban and rural population totals. Based on the total population in each zone (CU, CR, UI, IR), they calculated the growth rate of each zone and applied it to the GPWv4 dataset (observed current population density) in 5-year steps from 2010 to 2100. The analysis carried out by Reimann *et al.* (2018) resulted in the coastal population distributions illustrated in figure 6, and five named SSPs, characterised as:

- **SSP1—Green Coast** - Coastal ecosystem protection and decreasing importance of fisheries lead to declining population growth in coastal rural areas. Restrictive policies inhibit migration to coastal urban areas.
- **SSP2—No Wind of Change -** This pathway is characterized by continuing historical patterns. Therefore, population growth patterns in the coastal zone continue like before as well.

- **SSP3—Troubled Waters** - This pathway is characterized by regional rivalry, which decreases coastal attractiveness for human settlement. As living standards decrease, this pathway is characterized by little mobility of the population and thus little coastal migration.
- **SSP4 -Fragmented Coast** - This pathway is characterized by high inequalities across and within countries, with a wealthy elite which comprises a small share of the population and a poorer population group which makes up the rest of the population. Coastal population growth increases compared to inland population growth in the whole region.
- **SSP5—Coast Rush** - In this highly globalized world, the coastal zone is extremely attractive, leading to higher population growth in the coastal zone compared to inland locations in all Mediterranean countries. In coastal rural areas, tourism and second homes are the main drivers of population growth.

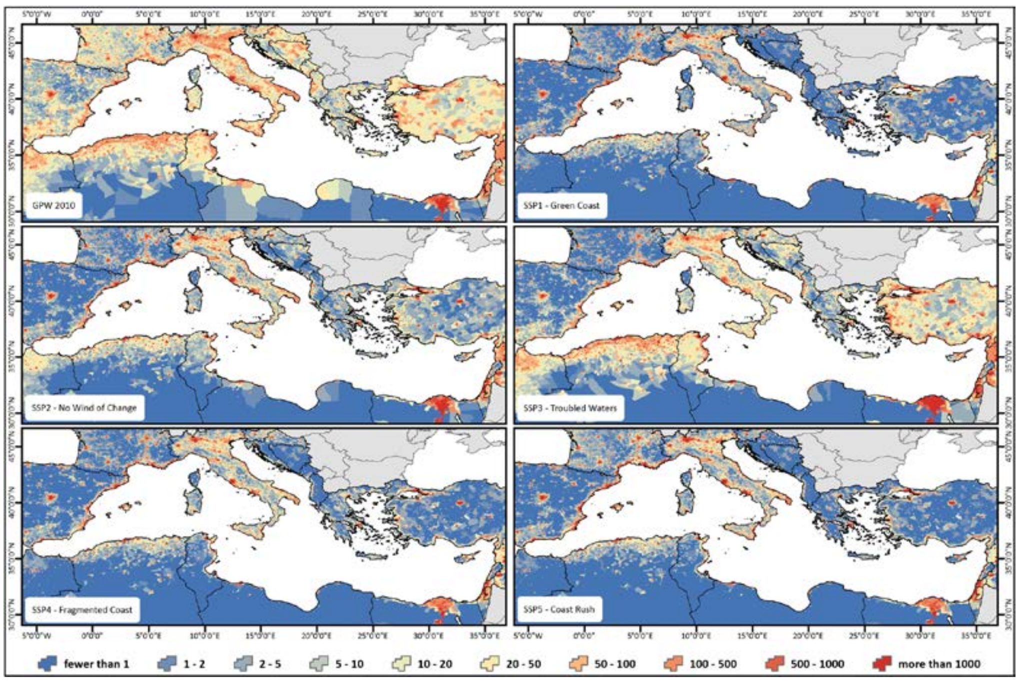

Figure 6. Population per grid cell for the base year 2010 and each SSP in 2100. Pixel size = 30 arcsec (from Reimann *et al.* 2018).

3.6 A participatory scenario method to explore the future of marine social-ecological systems

Benjamin Planque [Institute of Marine Research, Norway] described a participatory, first-principles approach to scenario development for Marine Social-Ecological Systems (MSES), based on experiences in the Barents Sea. The work was funded through the Euromarine+ program and the Institute of Marine Research in Norway. The primary objective was to allow different actors to jointly develop scenarios which contain their multiple visions of the future (see Planque *et al.* 2019). The method involved three major steps: (a) identify current state and recent trends in each perspective, (b) project contrasted futures according to each perspective (single-perspective scenarios), and then (c) build a set of comprehensive future scenarios by integrating projections (multiple-perspective scenarios). A similar participatory approach was taken in the EU FEUFAR (The Future of EUropean Fisheries and Aquaculture Research, 2007–2008) project, which yielded five distinct future scenarios for the European seafood industry (FEUFAR 2008).

According to Planque *et al.* (2019), during the first step, participants describe the current state and trends in the MSES from each individual perspective (i.e. ecosystem, fisheries management, ocean and climate, or global governance). These descriptions express the current understanding of the MSES functioning and its recent history. During the second step, participants produced multiple narratives about the possible futures of the MSES, separately for each individual perspective. These are elaborated following a few contrasted storylines, typically "baseline," "positive," and "negative." This allows for the exploration of a wide range of futures while limiting the number of single-perspective scenarios developed. The third step was dedicated to integration, when actors are ready to explore complex and multi-faceted futures and bring together their views about the current status, trends and futures of the system.

The Barents Sea was used as a case study to illustrate the multiple-perspective scenario method (Planque *et al.* 2019). The development of the scenario method and its application to the Barents Sea MSES were conducted during a workshop hosted in Sommarøy, Tromsø, Norway in June 2016. The participants in this workshop were diverse: representatives of the fishing industry, of fisheries policy, NGOs, and research in several disciplines. Workshop participants first synthesized current state and trends of the Barents Sea according to the four identified perspectives. They then elaborated 12 single-perspective scenarios: one for each perspective (fisheries management, ecosystem, climate and global governance) and for each trend (baseline, positive, negative). From the full combination of single-perspective scenarios, workshop participants jointly selected and developed three contrasting storylines:

A. all baselines (Figure 7);
B. degraded fisheries management, healthy ecosystem, cold future and declining governance (Figure 8); and
C. improved fisheries management, unhealthy ecosystem, baseline ocean climate and baseline governance (Figure 9).

Figure 7. Scenario A: (a) A small number of fishing companies own more and more powerful fishing vessels while local fishing communities get a significant part of their income from tourism and recreational fishing; (b) Sea water temperature is rising and ice cover is decreasing, the biomass of most exploited stocks stabilized, with a low natural variability; (c) An international context of persistent economic globalization (illustration: Juliette Planque).

Figure 8. Scenario B: (a) While the production of fisheries resources did not significantly change, the economic value of these resources did; (b) The return of colder and icier conditions favoured growing populations of species that were earlier considered to be endangered or in strong decline such as charismatic ice-dependent megafauna; (c) Communication and trust between scientists, fishing firms and managers has slowly declined. A situation of management laissez-faire has emerged, in which ecological and societal concerns receive little attention (illustration: Juliette Planque).

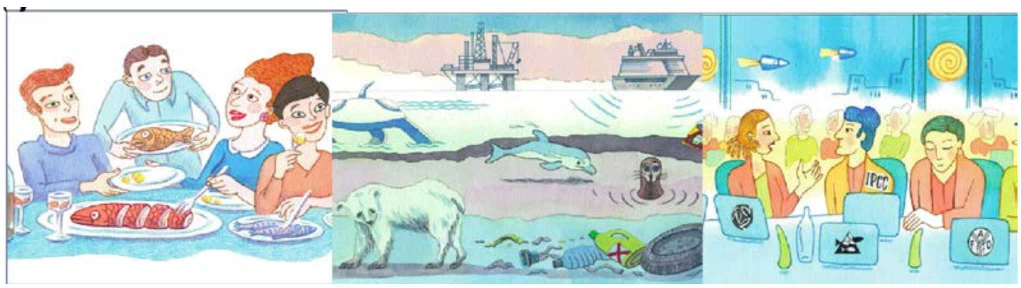

Figure 9. Scenario C: (a) The international demand for seafood is growing; (b) Development of shipping, Arctic tourism and oil exploitation has led to an increase in noise pollution. Monitoring programs of water and sediment have revealed increasing trends in persistent organic pollutants, heavy metals, microplastics and oil residues; (c) Stakeholder participation, transparency, and accountability play essential roles in the new marine resource management (illustration: Juliette Planque).

4 Catalogue of Scenario Projects

Workshop attendees have been active in a wide range of projects. Some of these are regionally or nationally focused while others have been global in scale.

Table 1. Summary of scenario exercises specifically focussed on fisheries, aquaculture or the marine environment.

Project	Scope of Project	Goals of Human Scenarios	Based on SSPs or SRES?	Number of scenarios tested	Scope of management advice	References / links
ACLIM	Regional (Bering Sea)	To frame human actions in integrated models; demand, markets, sector trade-offs	SSPs	4	Fish + Marine mammals	
AFMEC	National (UK)	Horizon scanning - all maritime activities in the United Kingdom EEZ	SRES	4	All maritime activities	Pinnegar *et al.* (2006)
CERES	Regional (Europe)	To frame human actions in integrated models	SSPs & SRES	4	Fisheries & Aquaculture	CERES (2016)
CLIOTOP (OSPs)	Global	Contribute to understanding tuna supply chain	SSPs	5	Fisheries	Mullon *et al.* (2016)
CORU - UBC vulnerability assessment	Global	Assess vulnerability focusing on fisheries	SSPs	3	Fisheries	Cheung *et al.* 2019
ELME	Regional (European seas)	Horizon scanning - To explore consequences of future alternative development scenarios on marine ecosystems (contrast differences between European seas).	SRES	4	All maritime activities	Langmead *et al.* 2007
FAO - Fish to 2030	Global	Production, demand and per capita consumption of fish and shellfish	No	4	Fisheries & Aquaculture	World Bank 2013
FEUFAR	Regional (Europe)	To define long-term fisheries and aquaculture research needs in the EU	No	5	Fisheries & Aquaculture	FEUFAR (2008)

FishMIP	Global and regional	To frame human actions (mainly fisheries) in integrated models	No (not yet)	3	Fisheries	Tittensor *et al.* (2018); Lotze *et al.* (2019)
GAUFRE	National (Belgium)	Contribute to marine spatial planning in the Belgian EEZ	No	6	All maritime activities	GAUFRE (2009)
Norway Barents-RISK	Regional (Barents Sea)	Horizon scanning - all maritime activities in the Barents Sea	No	3	All maritime activities	Planque *et al.* (2019)
PBL Netherlands	Regional (North Sea)	Contribute to marine spatial planning in the Netherlands EEZ	SRES	4	All maritime activities	Matthijsen *et al.* (2018)
Prib-BKC	Local (Japan)	Scope adaptive measures to recover single spp (blue king crab) under climate change	No		Fisheries	
RISES-AM	Regional (Mediterranean)	Regionalize SSPs for the Mediterranean coasts	SSPs	5	All maritime activities (human population)	Reimann *et al.* (2018)
Shiretoko	Local (Japan)	Horizon scanning - fisheries, food supply, industry & economy, local & community support	No		Fisheries	Makino and Sakurai (2012)
UBC IAM	Global	Determine fisheries future & integrate into fisheries effort dynamic model and trade dynamic model	SRES	4	Fisheries	Alder *et al.* (2007)
VECTORS	Regional (Europe)	Horizon scanning - To explore consequences of future alternative development scenarios on marine ecosystems (contrast differences between European seas).	SRES	4	All maritime activities	Groeneveld *et al.* (2018)

5 Discussion and Conclusions

This workshop provided attendees with a follow-up opportunity to the longer ICES/PICES workshop held in 2016 in Brest, France. Exciting progress continues to be made across a variety of different regional and global projects, using a variety of both deliberative and highly participative approaches. It was concluded that a comparative synthesis paper would be an excellent contribution to the field, but participants also felt that finishing current project-specific activities was a higher priority.

The follow-up marine workshop held at the Scenarios Forum in Denver in March 2019 provided further opportunity to discuss and compare social and economic scenarios for the marine environment. The Scenarios Forum was interesting in that it highlighted how SSPs (Shared Socioeconomic Pathways) have emerged as a dominant 'architecture' and is being used across a wide variety of terrestrial and aquatic applications, from land use to urban and military planning. In many cases, researchers are wrestling with how to balance the desire to have standardized, all-encompassing scenarios framework with one that is specific and addresses the needs of local applications. We expect that this conflict (specifically mentioned by Planque *et al.* 2019) will continue to be a problem in the future, but we will learn from cross-project and international comparisons such as WKPESTLE, and hopefully contribute significantly to major international reports such as the IPCC 6th Assessment (in 2021) or the 1st Assessment of IPBES (in 2019).

One major point considered at the WKPESTLE workshop was how to further develop this work to be helpful and usable by different ICES working groups, especially ICES Integrated Ecosystem Assessment (IEA) groups. The products of this workshop are of immediate and direct relevance for modelling groups that aim to examine the efficacy of long-term management actions under different climate and socio-political scenarios. However, the question arises; how to harmonize regional scenarios for the different ecoregions to ensure consistency among groups. Usually global scenarios lack the degree of detail to be useful in a local context, but locally-derived scenarios have little transferability beyond the immediate system. It was concluded that scenarios should ideally be 'nested' to ensure that outputs from numerical models have wide-scale relevance in the global context. Through its two Strategic Initiatives SICCME and SIHD, ICES can take a lead in this field, developing global, regional and local storylines that have wider resonance and utility elsewhere.

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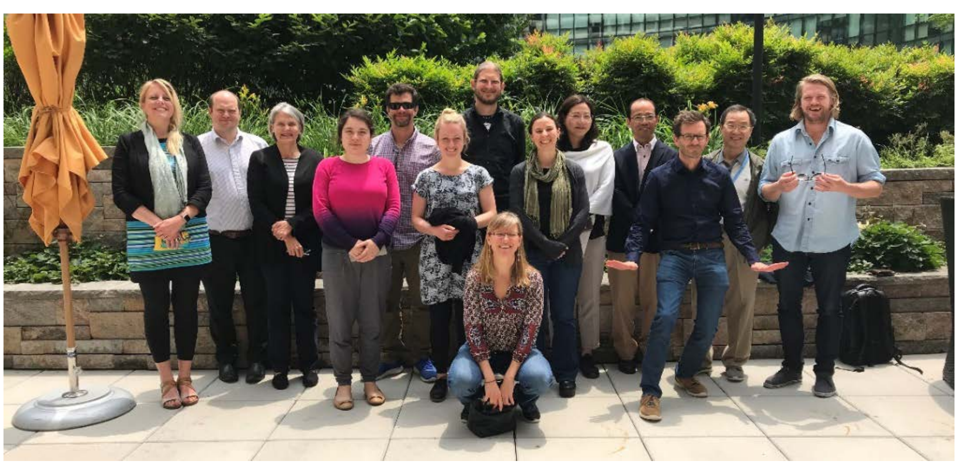
Annex 1: List of participants

Name	Affiliation	Country	Email
John Pinnegar	CEFAS, SICCME Co-Chair	UK	john.pinnegar@cefas.co.uk
Jörn Schmidt	Kiel University, SIHD Co-Chair	Germany	jschmidt@economics.uni-kiel.de
Alan Haynie	NOAA AFSC, SIHD Co-Chair	USA	Alan.Haynie@noaa.gov
Tyler Eddy	University of British Columbia	Canada	t.eddy@oceans.ubc.ca
Myron Peck	Uni HH	Germany	myron.peck@uni-hamburg.de
Lena Reimann	Kiel University	Germany	reimann@geographie.uni-kiel.de
Olivier Maury	IRD	France	olivier.maury@ird.fr
Benjamin Planque	IMR	Norway	benjamin.planque@hi.no
William Cheung	University of British Columbia	Canada	w.cheung@oceans.ubc.ca
Anne Hollowed	NOAA AFSC	USA	anne.hollowed@noaa.gov
Kirstin Holsman	NOAA AFSC	USA	Kirstin.Holsman@noaa.gov
Amanda Faig	UW / NOAA AFSC	USA	Amanda.Faig@noaa.gov
Shin-ichi Ito	University of Tokyo, SICCME Co-Chair	Japan	goito@aori.u-tokyo.ac.jp
Colette Wabnitz	University of British Columbia	Canada	c.wabnitz@oceans.ubc.ca
Robin Brown	PICES	Canada	robin.brown@pices.int
Kim Jungjin	National Institute of Fisheries Science (NIFS)	Korea	king.jungjin@korea.kr
Sukyung Kang	Korea SICCME member	Korea	kangsk@nfrdi.go.kr,
Suam Kim	Korea, SICCME	Korea	suamkim@pknu.ac.kr
Phoebe Woodsworth-Jefcoats	NOAA PIFSC	USA	phoebe.woodworth-jefcoats@noaa.gov



Annex 2: Agenda

9:30 Scoping questions for Talks

1. What's the nature of the project?
2. What's the purpose of the human scenarios?
3. What human scenarios have you developed?
4. What results do you have?
5. How will you use them?
6. How will you evaluate them?
7. Next steps

10:00 Intro talk 1 (narratives and contextualizing SSPs, Lena Reimann)

10:15 Intro talk 2 (William Cheung, fuzzy logic approach to SSPs, presented by Colette Wabnitz)

10.30 COFFEE

10:45 Intro talk 3 (John Pinnegar, CERES)

11:00 Intro talk 4 (Slides from Olivier Maury (OSPs) presented by Tyler Eddy)

11:15 Intro talk 5 (ACLIM, Alan Haynie)

11:30 Intro talk 6 (Benjamin Planque)

11:45 Discussion on approaches for developing harmonized procedures to allow inter-comparison; what are the elements in the models? How do they deal with different PESTLE variables and discuss structure for the paper

12:30 Lunch

13:30 Session - discuss next steps and come up with a plan

15:00 Health Break

16:00 Final Discussion, Wrap up, distribution of tasks

17:00 Closing

Annex 3: WKPESTLE terms of reference

An **ICES-PICES Workshop on Political, Economic, Social, Technological, Legal and Environmental scenarios used in climate projection modelling (WKPESTLE)**, chaired by John Pinnegar, UK; Jörn Schmidt, Germany; Alan Haynie, USA; and Tyler Eddy, Canada, will meet in Washington D.C., USA, on 9 June 2018 (directly proceeding the 4th International Symposium on the Effects of Climate Change on the World's Oceans) to:

a) Compile and compare future scenarios currently used by different research groups projecting the socio-ecological consequences of climate change on fisheries and aquaculture;
b) Discuss the rationale and data sources employed to establish elements of "PESTLE" scenarios for bio-economic projection;
c) Where possible, agree on a common set of scenarios and outputs to facilitate region-region and region-global comparison of social-ecological impacts of climate change on fisheries and/or aquaculture.

WKPESTLE will report by 31 July 2018 (via EPGSG) for the attention of ACOM and SCICOM.

Supporting Information

Priority	This workshop is a joint activity of the ICES-PICES Strategic Initiative on Climate Change Impacts on Marine Ecosystems (SICCME) and the ICES Strategic Initiative on the Human Dimension (SIHD). It will contribute towards the ICES thematic areas: Understanding Ecosystem Processes and Dynamics (EPDSG), Ecosystem Pressures and Impacts (EPISG) and Integrated Ecosystem Assessments (IEASG). Our focus will be on comparing, contrasting and, where possible, aligning future scenarios used in social-ecological projecting modelling of climate impacts on fisheries and aquaculture. This comparison is timely as separate groups are moving forward with projection modelling and SICCME and SIHD can help align activities to more easily compare model results across regions / spatial scales. Consequently, the activities of WKPESLTLE are considered to have a very high priority to ICES.
Scientific justification	For the past 15 years, the Intergovernmental Panel on Climate Change (IPCC) has utilized scenarios of future greenhouse gas emmissions. Specifically, the IPCC published a Special Report on Emissions Scenarios (SRES) in 2000. These SRES scenarios were used in the Third Assessment Report (TAR - 2001) and formed the basis of the Regional Concentration Pathways (RCPs) used in the Fourth Assessment Report (AR4 - 2007). The IPCC is now using Shared Socio-economic Pathways (SSPs) for their next assessment report (AR6) scheduled for 2021. Short-, medium- and long-term developments in governance, social, technological and economic drivers may be just as important to the future development of fisheries and aquaculture as climate-driven changes in habitats and species distributions from greenhouse gas emmisions. Separate modelliing groups are building plausable future trajectories of change in some or all of the elements of the "PESTLE" approach (Political, Economic, Social, Technological, Legal and Environmental) needed to project bioeconomic consequences of climate change on fisheries and/or aquaculture. This workshop is a forum for discussion and comparison of future scenarios developed by different groups. Aligning PESTLE scenarios

	among modelling groups will facilitate region-to-region or region-to-global comparisons of model results.
Resource requirements:	The workshop is planned to take place directly after the 4th International Symposium on the Effects of Climate Change on the World's Oceans in Washington, D.C., USA and some logical support from conference organizers will be needed.
Participants:	Researchers involved in previous or ongoing projecting modelling of climate impacts on coupled human-ecological systems in ICES and PICES nations including representatives from international (FAO, UNEP-WCMC) policy groups charged with fisheries and aquaculture advice and management.
Secretariat facilities:	There are no special requests of the secretariat.
Financial:	No funding is requested from ICES. Funds dedicated to SICCME will be used for meeting room rental (if necessary).
Linkages to advisory committees:	ACOM
Linkages to other committees or groups:	This workshop contributes to the Ecosystem Processes and Dynamics Steering Group (EPDSG) , the Ecosystem Pressures and Impacts Steering Group (EPISG) and the Integrated Ecosystem Assessment Steering Group (IEASG).
Linkages to other organizations:	PICES , FAO, UNEP-WCMC, WTO, NOAA, IMBER, ESSAS
Publication of proceedings	A workshop report will be generated and it is envisioned that this will form a submission to a high-profile, peer-reviewed journal (e.g. Marine Policy, Nature Climate Change).

Annex 4: Recommendations

Recommendation	Addressed to
1.Meet in conjunction with the ICES ASC to update other researchers	Workshop participants; SIHD and SICCME Members
2.Complete a synthesis manuscript about current work across projects.	Workshop participants; SIHD and SICCME Members
3.Organize a scenario development workshop for IEA groups	Workshop participants; SIHD, in collaboration with IEASG