# ICES WKSICCME-CVA REPORT 2017

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# Report of the ICES/PICES Workshop on Regional climate change vulnerability assessment for the large marine ecosystems of the northern hemisphere (WKSICCME-CVA)

19–22 July 2017

ICES Headquarters, Copenhagen, Denmark

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## Executive summary

The ICES-PICES Strategic Initiative (Section) on Climate Change Impacts on Marine Ecosystems (SICCME) workshop on climate vulnerability assessment (WKSICCME-CVA) took place on 19–22 July 2017 at ICES Headquarters in Copenhagen, Denmark. The event was attended by 19 scientists from 8 nations as well as representatives from ICES and PICES. The workshop was chaired by Myron Peck (Germany, ICES SICCME), Elliott Hazen (USA, PICES (S-MBM, co-Chair SG-CERP)) and Kathy Mills (USA, ICES). The event was co-sponsored by the EU H2020 project CERES (Climate Change and European Aquatic Resources).

The workshop was convened to discuss and compare climate vulnerability assessments (CVA's) that have been (or are currently being) conducted on fish and shellfish and the human communities dependent on these resources in various Large Marine Ecosystems. Participants discussed CVA frameworks and how best to integrate vulnerability ranking stemming from natural science (changes in fish and shellfish resources) and social science (socio-economics of human communities). In total, 25 CVAs performed on fisheries or aquaculture were compared and discussed. These encompass a wide range of spatial scales and methods employed (from rapid literature-based assessments to local community engagement). Most of these CVA's were (are being) conducted for regions of North America, Europe and Australia but global-scale as well as local/regional efforts in developing nations were also included.

The next generation CVAs require a highly interdisciplinary and spatial approach that recognizes the unequivocal connections between marine systems and prosperity of human communities. The separate approaches taken within natural and social science CVAs have relied on indicators of estimated vulnerability of marine-related assets at varying scales quite independent of each other. For example, CVAs performed on fisheries targets are most often large, basin-scale analyses that limit the potential gains in knowledge that are relevant to human management systems and communities. The integration of physically-driven natural science indicators with community-driven social science indicators is necessary to advance CVAs. When linked across natural and social indicators, and when taking into account adaptive capacity, CVAs can be powerful tools for communicating and prioritizing risk from climate variability and change and planning adaptation.

When conducting a CVA, participatory processes are needed to contextualize risks to marine stakeholders and communities, to foster engagement, and to support science communication and transparency. CVAs based on systematic vulnerability ranking of marine assets or human communities can support important actions, including prioritizing research on the most vulnerable fish stocks or farmed species and identifying knowledge gaps that may affect planning for future change and sustainability of ecosystem and human communities. CVAs can also facilitate the integration of climate information into fish stock assessments and farm production models. Finally, CVAs can raise awareness of marine fisheries and aquaculture industries (to the risks and opportunities posed by climate change) and of policymakers (for climate adaptation strategies promoting sustainable resource use as well as the resilience of coastal communities).

Workshop participants also generated templates for describing the projected climate impacts within each of the ICES ecoregions. This text can be integrated by others (e.g. IEA working groups) within the ecosystem overviews produced by ICES.

## Opening of the meeting

The 2.5-day workshop was opened with a presentation by Myron Peck (Germany, ICES) that extended a warm welcome on behalf of SICCME, the other co-conveners and the EU project CERES to the 18 participants (see Annex 1). Each participant briefly introduced themselves and their expertise. The goals and terms-of-reference of the workshop were reviewed (see Annex 3) and the agenda (see Annex 2) was discussed and adopted. After a brief background section describing the evolution of CVAs, this report provides a syn-thesis of ideas and outputs in relation to the five Terms of Reference (ToRs).

## 1 Introduction to Climate Vulnerability Assessments

In 2001, the Intergovernmental Panel on Climate Change (IPCC) developed a generic model to assist in understanding the multiple facets of vulnerability as "a function of the *sensitivity* (S) of a system to changes in climate (the degree to which a system will re-spond to a given change in climate, including beneficial and harmful effects), *adaptive capacity* (AC, the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and the degree of *exposure* (E) of the system to climatic hazards" (IPCC, 2001); (Figure 1.1).

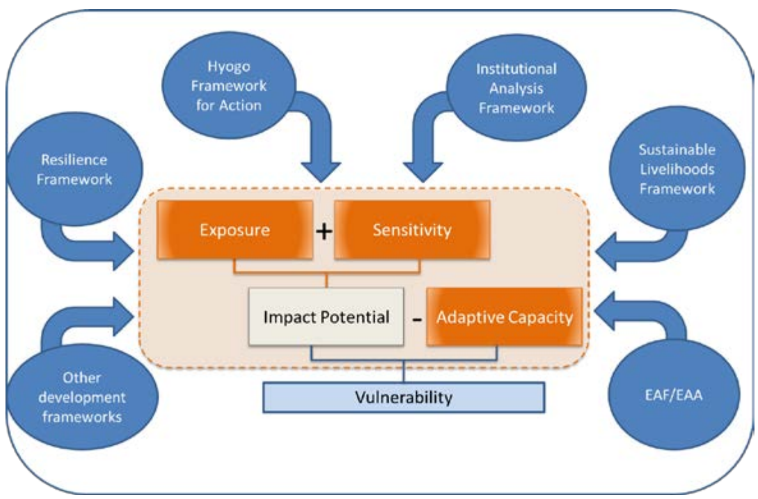


**Figure 1.1. The basic IPCC Vulnerability framework and other frameworks leading to its development such as the Hyogo Framework for Action building the resilience of nations and communities to natu-ral disasters, the British Department for International Development (DFID) Sustainable Livelihoods Framework combating poverty, and Ecosystem-based Approach to Fisheries (EAF) and Ecosystem-based Approach to Aquaculture (EAA).**

The use of Climate Vulnerability Assessment (CVA) has evolved as their application has grown and spread to encompass multiple scales, sectors, and purposes (Fussel and Klein, 2005; Cardona *et al.*, 2012). A vulnerability assessment was initially adopted by nations involved in the United Nations Framework Convention on Climate Change (UNFCCC) to negotiate the need for the appropriation of adaptation funds. These CVAs attempted to address the question, "where is climate change going to have the most impact on society?" The vulnerability of different nations was then compared to national emissions of greenhouse gasses, highlighting the disconnect between the nations emitting greenhouse gasses and those likely to be most impacted by the resultant effects of climate change. These assessments, thus, created global maps of national-level effects.

Some of the earliest sub-national CVAs were conducted in India and Southeast Asia. For instance, Adger (1999) conducted a CVA of coastal communities in northern Vietnam to extreme events. In that work, vulnerability was defined as the "exposure of individuals or collective groups to livelihood stress as a result of the impacts of such environmental change". In a somewhat later example, O'Brien *et al.* (2004) produced maps of vulnerability to the multiple pressures caused by climate change and globalization. Most of these seminal efforts framed the vulnerability of populations in terms of E, S, and AC (Fussel and Klein, 2005). When vulnerability assessments were applied at the level of individual communities, there was a need for additional planning for participation of stakeholders (human communities). For example, humanitarian agencies such as CARE, OXFAM and the International Red Cross included participatory methods within community-level vulnerability assessments.

In recent years, there has been a subtle shift in the terminology and framework of climate vulnerability assessment from the three dimensions of vulnerability (E, S, AC) to one that separated vulnerability from exposure so that vulnerability was defined as the inherent propensity/susceptibility of a population (or ecological system) to harm. This new framework was first presented in 2012 in the IPCC Special Report on Extreme Events (SREX); (Cardona *et al.*, 2012; Lavell *et al.*, 2012).

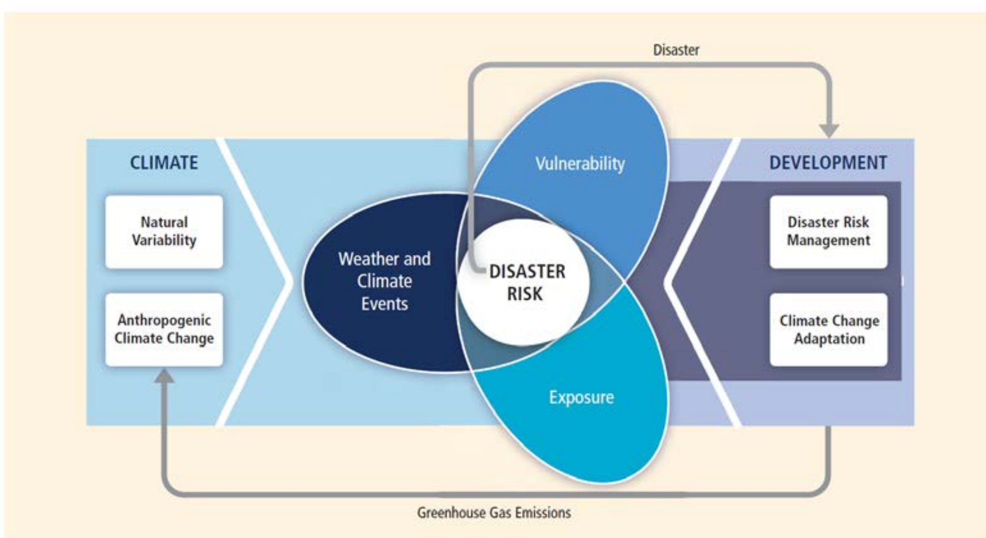


**Figure 1.2. Key concepts involved in disaster risk management and climate change adaptation, and the interaction of these with sustainable development as presented in by Lavell *et al.* (2012 pg 31).**

The specific vulnerability questions asked (i.e. vulnerability of whom/what to what changes and why) and the methodologies used to answer these questions will often be influenced by the historical background and disciplinary training of the assessor. That is, an assessment stemming from risk/hazard, resilience or political economy traditions may place different emphasis on the various elements underlying vulnerability, such as whether the hazard itself and its impacts are the main elements of concern or, perhaps, whether differentiating susceptibility to such change is important or whether there are tipping points to such susceptibility. In addition, different disciplines (i.e. natural or social sciences) within these traditions may also frame the vulnerability assessment in a different way. For example, one can focus on the vulnerability of the natural system, the human system, or whether underlying vulnerability to change determines the ability of either of these systems to adapt to a climate-related driver (focussing on the why of vulnerability) versus a more linear impacts assessment approach, and so on. Understanding the array of different perspectives and methodologies is needed to effectively plan and undertake a CVA or when one attempts to compare and contrast the results of different CVAs.

In developed nations such as Australia, Canada, Europe and the USA, there are various incentives for conducting a CVA on living aquatic resources important for aquaculture and fisheries as well as the human communities that depend on these resources. Due to the high costs of operation in these regions, European countries subsidize rural fishing communities as well as aquaculture farming so that these aspects of cultural heritage are not abandoned (Sumaila *et al.*, 2010). Climate change will influence these rural fishing and aquaculture activities. Moreover, these countries have large commercial fishing and aquaculture operations that will benefit from understanding the risks and opportunities posed by a future climate. A CVA helps identifying the stocks, species, areas, systems and communities were adaptation needs to be prioritized. Moreover, the majority of nations worldwide have agreed to achieve targets set forth in UN Sustainable Development Goals (SDGs). CVAs will be particularly useful for meeting SDG 13 (Climate Action) and SDG14 (Life Below Water), where sustainable, climate-ready national policies for fisheries and aquaculture will be required.

# 2 Comparison and contrasts of various vulnerability assessment approaches used for fisheries and aquaculture including their strengths and weaknesses (ToR A)

The fisheries and aquaculture sectors have gained considerable experience in applying CVAs using the IPCC framework as was noted in a 2013 bibliography of work conducted in these sectors (Barsley *et al.*, 2013). CVAs of fisheries or aquaculture have been conducted at a wide range of scales from local communities such as the joint ecological and socio-economic CVA of 10 coastal communities in Kenya by Cinner *et al.* (2013); (Figure 2.1) to regional-level CVAs conducted on tropical fisheries and aquaculture among island na-tions in the Pacific by Bell *et al.* (2011). Ekstrom *et al.* (2015) provide an example of nation-al-level CVA in their work on ocean acidification and aquaculture across coastal areas of the USA. At the global scale, Allison *et al.* (2009) performed a CVA of 132 national econ-omies to potential changes in capture fisheries.

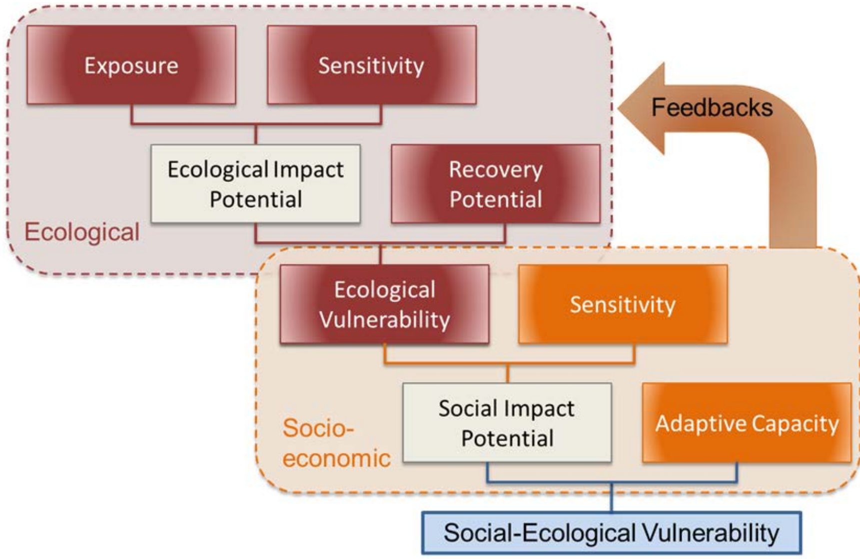


**Figure 2.1. Approach taken by Cinner *et al.* (2013) examining the socio-ecological impacts of coral bleaching to 10 coastal fishing communities in Kenya.**

Guides for the application of vulnerability assessments for fisheries and aquaculture have been developed (FAO, 2015) as well as "best practice" recommendations. For example, based on knowledge gained while performing CVAs on marine habitat conservation and on local and regional fisheries and aquaculture sectors in Australia, Johnson *et al.* (2016) recommended a 10-step, semi-quantitative assessment ('SQA') method. Finally, recent work by Monnereau *et al.* (2017) highlighted bias and corrected methods used to calculate socio-economic vulnerability, in this case of Small Island Developing States to climate change.

The participants of SICCME-CVA compared and contrasted various methods used to examine the vulnerability of fisheries or aquaculture targets (and their associated human communities) to climate change. The following describes previous and ongoing work in various nations and regions represented by workshop participants (the study numbers refer to Tables 1.1–1.6).

### Australian Waters (Table 1.1: Studies 1 & 2)

Australia's oceans are undergoing rapid change and changes in fish distribution, abundance and phenology have been widely reported. A considerable variety of research has been conducted in Australia to advance the use of climate CVAs for fisheries (e.g. Pecl *et al.*, 2014) and aquaculture species (e.g. Doubleday *et al.*, 2013) and the human communities that depend on those resources (Metcalf *et al.*, 2013). Pecl *et al.* (2014) described a three-step process of performing a rapid assessment of the sensitivity of key, commercially-important species to ongoing, climate-driven changes in southeast Australia waters. The first step was for resource managers in each of the four states of southeast Australia to create a list of key species for their region; this original list contained 36 species with many species appearing on lists of multiple jurisdictions. Based on their rank of importance in terms of equally weighted measures of economic (annual gross value of production), ecological (high, medium and low), and recreational (high, medium and low) importance, each jurisdiction then ranked the 10 most important species and 22 species or species-groups were ultimately selected for inclusion in the study. A second step was to create "Assessment Profiles" of each species using methods described by Pecl *et al.* (2011) in which a high-level literature screening identified physical and chemical parameters that may determine impacts and the life history stages likely to be impacted. That screening also highlighted critical data gaps relevant to future assessment and adaptation to climate change. 'Assessment profiles' for key species were conducted from literature reviews; the likely physical drivers of climate change stressors were identified for each species and the economic and social values of each fishery were assessed.

The third step was to estimate the sensitivity to climate change of each species. This component used a trait-based approach, extending an Ecological Risk Assessment for the Effects of Fishing (ERAEF) methodology that calculates a productivity score based on the combined, biological and life-cycle-specific attributes of species (Hobday *et al.*, 2007). Pecl *et al.*'s (2011) CVA considers three aspects of the biology of exploited species that are relevant to fishers and resource managers: changes in distribution, abundance and phenology. Changes in distribution could require fishers to change the location of their fishing efforts in order to continue to harvest the same species, while management regulations may need to be changed to cover the new regions. Likewise, changes in abundance and phenology mean that management may need to update the harvest levels or the timing of fishing seasons. Scoring of trait-based attributes in each category (distribution, abundance, phenology, 12 attributes altogether) was limited to a scale of 1–3, representing 'low', 'medium', and 'high' sensitivity, with significant consultation occurring in each of the broader project teams before, during and after the two sensitivity assessment workshops to develop both the attributes and the criteria for scoring the three categories. Following previous methods, the scores for each group of attributes were combined (averaged) to yield separate scores for abundance, distribution and phenology. These scores were then summed and used to produce a ranking of sensitivity across the selected fishery species. The final sensitivity scores ranged from 1 to 32 and could be placed within four categories (High, Medium-high, Medium, Medium-low). In most of those four categories, species were identified that would likely be at greater risk of either range extension or range contraction, i.e. species where there would be a likely gain or loss of range area in Australian waters, given further warming (Pecl *et al.*, 2014).

The species sensitivity assessment in southeast Australia was subsequently extended to Western Australia and northern Australia via separate studies that are now being collated into an Australia-wide synthesis (Fulton *et al.*, 2017). The fish sensitivity scores have been collated for 5 regions, covering the Australian seas from the three different projects: Region 1: south east Australia (Pecl *et al.*, 2011); Region 2: Western Australia (Caputi *et al.*, 2015); Regions 3, 4 and 5: north-western Australia, Gulf of Carpentaria and Queensland East coast (Welch *et al.*, 2014). This Australia-wide synthesis is conducting an analysis of sensitivity by species, region and gear type for approximately 100 species across the five regions. These results suggest that fisheries targeting invertebrates are the most sensitive to climate change, a consistent pattern across regions. The sensitivity to particular gears was not consistent across regions and, although the sample size was small, this suggested that taxa was a more sensible grouping than gear type. Sensitivity with regard to changes in phenology was scored higher than that for distribution, followed by abundance. These results can inform priorities for additional monitoring, data collection, research, and industry and management responses (Fulton *et al.*, 2018).

Another study extended the wild fisheries climate sensitivity assessments from Pecl *et al.* (2011), Caputi *et al.* (2015), and Welch *et al.* (2014) into the socioecological domain by linking ecological vulnerability to the socioeconomic subsystem (Figure 2.2, Metcalf *et al.*, 2013). Here, an analysis of the capital from five sustainable livelihoods were used to systematically estimate adaptive capacity of the human system and social-ecological vulnerability to climate change based on readily available Australian Census data.

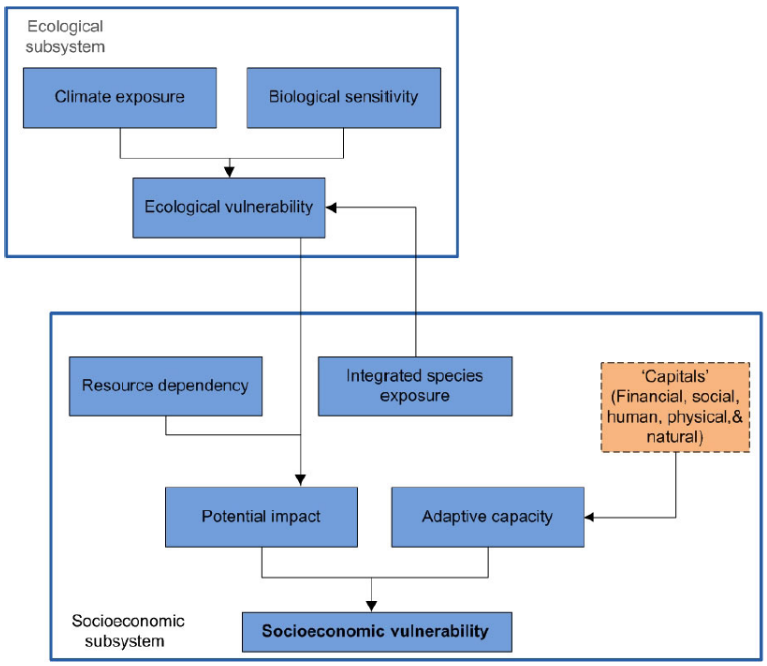


**Figure 2.2. Framework for the calculation of socioeconomic vulnerability (and adaptive capacity) undertaken for each of three case studies on coastal communities in Australia reported by Metcalf *et al.* (2013) as modified from Marshall *et al.* (2013). The 'biological sensitivity' components in the top box was taken from the three biological studies (see Pecl *et al.*, 2011; Welch *et al.*, 2014; Caputi *et al.*, 2015).**

Aquaculture is also an important component of Australia's seafood production (ABARE, 2009). In the southeast region alone, aquaculture contributes 55% of the total value of seafood production (excluding Commonwealth fisheries) and 74% of the total value of aquaculture production in Australia. To estimate the risks of southeast Australian aquaculture species to climate change, Doubleday *et al.* (2013) developed a two-stage screening-level assessment. In the first stage, detailed 'species profiles' were produced much like the Pecl *et al.* (2011) companion project on wild fisheries species, which describe the industry, life history stages, farming methods, likely climate change impacts, key physical drivers responsible for those impacts and data gaps. Subsequently, these species profiles were used in conjunction with an expert panel to inform the second stage, which produced qualitative ecological risk assessments for each species. These assessments established a relative risk level among the relevant aquaculture species. The risk assessment focused on the biology of the aquaculture species and the physical environment of the farms, and did not cover social or economic impacts.

The Doubleday *et al.* (2013) aquaculture risk assessment examined 11 categories of farming (species x method combinations). Using the species profiles together with the team's broader knowledge of marine climate change impacts, 'attributes' were selected which could be used to test the sensitivity of all aquaculture species and relevant farming processes to climate change. Attributes were designed around the basic farming, business, and life history stages, including broodstock conditioning, spawning, and larval and juvenile rearing, with the last five attributes focused solely on the grow-out or adult stage (see Table 2 in Doubleday *et al.*, 2013 ). Three risk categories or scores were assigned to each attribute, low (1), medium (2) and high (3), in relation to level of sensitivity to climate change. For example, a high score of 3 would indicate that the aquaculture activity in question has a relatively high sensitivity to climate change and thus at a higher risk of being impacted. The second step in the risk assessment involved providing a 'weighting' for each attribute based on the level of known or predicted impacts of climate change. Weightings were scored for each species and attribute as follows: strong negative impact (2), moderate negative impact or level of impact unknown (1) and mild negative impact, positive impact, or no impact anticipated (0). Again, the unweighted sensitivity scores and impact scores were based on information derived from the species profiles. To calculate the overall weighted score for each species, the unweighted score was multiplied with the impact score for each attribute; the scores from each of the nine attributes were then added together. The weighted scores indicated that the edible oyster industry in south-eastern Australia was the most sensitive aquaculture industry to climate change impacts, primarily due to summer or heatwave-related mortalities that are already an issue (Doubleday *et al.*, 2013).

**Table 1.1. Summary information for fisheries and/or aquaculture CVAs in Australia.**

| | **Study 1** | **Study 2** |
|---|---|---|
| **Location (Project)** | SE Australia | Gulf of Carpentaria, Australia |
| **Rationale / Purpose** | Provide a qualitative risk assessment of aquaculture to climate change | Assess implicatiuons of climate change on fisheries resources of Gulf of Carpentaria |
| **Targeted users** | scientists, resource managers and stakeholders | scientists, resource managers and stakeholders |
| **Finest scale (unit of analysis)** | four jurisdictions in SE Australia | |
| **Biological component** | Yes | Yes |
| **Species / habitat** focus | 11 "industries" (species of finfish and shellfish/farming method combinations) | 21 fisheries species |
| **Socio-ecological component**? | no | |

| | | |
|---|---|---|
| **Spatial Scale (exposure** | NA | region, fishery-scale |
| **Climate Scenario(s) tested** | NA | A1FI SRES |
| **Capturing uncertainty** | The level of uncertainty with regard to anticipated impacts was documented in 'species profiles'. | Sensitivity analysis of vulnerability ranking to different indicators (1) indicators most influencing overall ranking, and (2) indicators most influencing higher rankings (likely management actions targets). Bootstrapping examined effect of each input (indicator) on the output values |
| **Timeframe Covered** | NA. This assessment examined 'sensitivity' to climate change and 'impact' (on farming operations) of those changes, it was not timeframe dependent | 2030 |
| **Stage of completion?** | Published as Doubleday *et al.* 2013 | Published |
| **Key** resources needed | Detailed species profiles (3000–5000 words) based on consistent template and collated and synthesised existing data and expert opinion on the industry, production, the species' life history, farming process, current and potential climate change impacts, and critical data gaps. Two workshops held to score each species x farming method combination, and then outputs reviewed | |
| **What would** you do different if you repeated it?? | NP | The research team had strong differences of opinion on mixing socioecological and ecological adaptive capacity metrics - I would recommend keeping ecological and socioeconomic adaptive capacity separate. |
| **Application of CVA** | Guidance to scientists, resource managers and stakeholders on how CC is expected to alter the physiology, life cycles and environment of aquaculture species and, ultimately, the way they are farmed. Critical research gaps highlighted across a broad range of farming systems. Outcomes focused research attention but has had little industry uptake until recently. | Yes, has been used to modify target species, prioritise habitat protection and revise size and catch limits. |

| | | |
|---|---|---|
| **stakeholder engagement** | Yes, from both industry and resource managers, at the start. | Yes, highly participatory from start to finish - this is critical for work with small island states |
| **communication of results** | During and immediately after the project there was a series of presentations and a wide dissemination of the report. However, the main industry communication was through a steering committee for a broad research program (called the South East Australia Program) which was disbanded shortly after completion of this project. | Ongoing work with stakeholders |
| **Reference Info.** | http://www.int-res.com/articles/aei2013/3/q003p163.pdf | http://www.sciencedirect.com/science/article/pii/S0308597X16304626 |
| **Contact** | Gretta Pecl | Gretta Pecl |

### Canadian Atlantic and Pacific Waters (Table 1.2: Studies 3 – 6)

The goals of Canadian Aquatic Climate Change Adaptation Services program (ACCASP) are to assess how climate change will impact the delivery of Fisheries and Oceans Canada's programs and develop adaptation tools and strategies to enable the integration of climate change considerations into the delivery of those programs and policies. The ACCASP Risk/Vulnerability Assessment has completed the first of two, five-year phases (2011–2016). The goal of the first phase was to identify vulnerable marine species to two scenarios of ocean warming (mild and severe). The goal of the second phase (2017–2022) is to examine changing ocean chemistry (acidification, oxygen) and evaluate vulnerabilities of ecosystem/fisheries and infrastructure and to advance the capacity to make future projections as well as near-term (seasonal) forecasting.

In eastern Canadian maritime waters, sea-level rise is imminent. Seasonal changes in warming including extreme events have been observed and are expected to continue. Overfished species on the southern edge of their range are expected to be the most vulnerable to climate change and some areas / species are expected to benefit from climate-driven warming. Phase I efforts focused on the impacts of changes in water temperature. In offshore areas, warming is expected to have earlier impacts on species compared to other (interacting) climate drivers (e.g. ocean acidification, water currents). Moreover, projections of warming have been more thoroughly developed compared to those for other climate drivers. The typical "exposure" component is refined to be a function of gain/loss of thermal habitat of different life stages. This CVA builds on other efforts (e.g. Hare *et al.*, 2016) by producing scores for each species. A null distribution model is used and the most vulnerable species are identified through Monte Carlo simulations.

The vulnerability of 33 fish and invertebrate species was examined at the scale of the Scotian Shelf, Canada (see Shackell *et al.*, 2013 & 2014; Stortini *et al.*, 2015); (Study 3). A sub-set of species was examined at smaller spatial scales. Initial scores agree with expectations and suggest that populations in the warmer, southwest portion of the domain are more vulnerable to climate-driven warming than those in the northeast. Overall, 45% of the populations of species examined may be vulnerable under a severe (+3°C) warming scenario, including currently endangered, threatened, and commercial populations (e.g. southwestern Atlantic cod, smooth skate, snow crab), while only one species has a relatively high vulnerability score under the mild (+0.7°C) scenario (Moustache sculpin). Populations triaged by relative vulnerability to regional warming should help managers prioritize resources and identify knowledge gaps. The next steps include assessing fish vulnerability by economic zone, to combine with a parallel process that assesses adaptive capacity/vulnerability of maritime coastal communities to sea-level rise and storm surge (Study 4). This information will help guide the development of adaptation plans for economic zones identified as particularly vulnerable to climate-driven warming.

In western Canadian maritime waters, Hunter *et al.* (2014 & Submitted) conducted a climate vulnerability assessment on fisheries occurring in Pacific coastal waters (Study 5). The IPCC definition of vulnerability was employed to determine vulnerability: E x S x AC. Exposure (e.g. thermal risk) on fishing grounds was estimated by linking thermal thresholds of 16 commercially important species to regional dynamically downscaled hydrodynamic model outputs (Regional Ocean Model Systems; ROMS). The ROMS simulations included a hindcast validation (1995–2008; Masson and Fine, 2012) and projections to the 2060s (Foreman *et al.*, 2014). Thermal risk was determined by estimating the difference between ambient water temperature exploited by a species and its stage-specific (egg, juvenile, adult, spawning adult) upper thermal limits, and ranked in categories according to the proportion of its thermal window projected to be exceeded in a future climate. The frequency of threshold exceedance across fishing footprints was determined seasonally. Scores were merged with catch and analysed in a GIS to determine hotspots of thermal risk. Scores were aggregated at the spatial scale of fishery management areas as well as coast-wide. The Exposure assessment suggested that localized portions of historic fishing grounds for several important target species will be more impacted by projected thermal change, with southern and shallower sections of the BC coast exceeding species thermal limits with greater frequency. Sensitivity was estimated by completing a fish-focused, literature-based evaluation of species sensitivity to climate change using a logic model (modified from Stortini *et al.* (2015) and Morrison *et al.* (2015).

In this western Canada (Study 5) example, a third set of attributes was separately developed to assess climate change adaptation barriers in fisheries governance and this was applied as the adaptive capacity (AC) component of vulnerability. The AC was estimated using a ranking of the perceived ability of fisheries governance to design systems that manage for variability, extreme events and new trends to maintain resilience. This is a central challenge facing fisheries governance in light of climate change. For assessing AC in this manner, it is important to identify tools used by institutions that foster resilience and lower barriers to adaptation under climate change. To assess AC, 10 attributes of Canadian fisheries governance, nested within "pre-harvest", "active-harvest" and "post-harvest" categories, were ranked to determine the relative adaptive state of fisheries (Hunter, in review). A final vulnerability score was presented at three scales (fishery footprint, fishery management area, and coast-wide) by combining scores from the three defined components for each assessed fishery.

Additional broader CVAs in both the eastern (Study 4) and western (Study 6) Canadian maritime waters are ongoing. These CVAs will include vulnerability on infrastructure (harbors).

**Table 1.2. Summary information for fisheries and/or aquaculture CVAs in Canada.**

| | Study 3 | Study 4 | Study 5 | Study 6 |
|---|---|---|---|---|
| **Location (Project)** | Eastern Canada (ECanVA) | Eastern Canada Infrastructure Vulnerability Assessment | Canada Pacific and coastal waters | Pacific Canada Risk Assessment |
| **Rationale / Purpose** | Prioritize species for further analysis | Infrastructure vulnerablity ranking small craft harbour vulnerability | Assess ecological vulnerability of commercial fish species and fisheries governance adaptive capacity | Assess risks from climate change on DFO infrastructure and managed resources |
| **Targeted users** | DFO Sectors | DFO Sectors | DFO Fisheries Management | DFO Sectors (Fish management, Coast Guard, Small Craft Harbours etc.) |
| **Finest scale (unit of analysis)** | Atlantic Basin | Atlantic Basin | Fishery Footprint (4x4km) | Canadian Pacific Coast |
| **Biological component** | Yes | Not yet | Yes | Yes, high-level assessment |
| **Species /** habitat focus | All species caught in RV survey | Small craft harbours | Commercially harvested fish and invertebrates, Thermal habitat change focus | All biological resources (commercial, species at risk, AIS focus) |
| **Socio-ecological component?** | no | yes | yes, fisheries governance assessment | Yes, internal Pacific Coast assessment |
| **Spatial Scale (exposure** | basin | county | fishery-scale | Pacific coast scale |
| **Climate Scenario(s) tested** | 4.5 & 8.5 | 4.5 | 8.5 | 8.5 - applied qualitatively in conceptual assessment |
| **Capturing uncertainty** | bootstrapped scores; uncertainty | | Canadian climate model only, no measure of uncertainty in ROMS outputs | |
| **Timeframe Covered** | | | 1995–2008 vs. 2065–2078 | projections to 2065–78 |
| **Stage of completion?** | published | not yet published | Ongoing, MS on adaptive capacity component in review; MS on CVA in review by winter 2018 | Completed in 2013 |

| | | | | |
|---|---|---|---|---|
| **Key resources** needed | | plan to add fish vulnerability | ROMS outputs, FTE time; Spatial analyst | Staff time invested ~2FTE, 2 x 30 person workshops to review assessment and complete voting |
| **What would** you do different if you repeated it?? | would integrate socio-economic info from start and perform at NAFO region spatial scale/add sensitivity to seasonal changes | NP | Work with more social scientists to develop attributes using existing frameworks/link better to theory | Socio-economic and policy analysis was completed based on science outputs (natural science driven), Should have been more integrated from the start. |
| **Application of CVA** | Prioritization Management Strategy Evaluations, Inform national assessment | Inform Coastal Communities | Identify vulnerable zones within Pacific region, Prioritize research, provide management with spatially-explicit rankings for species of high commercial value | Assess risk to DFO mandate from climate change |
| **stakeholder engagement** | Yes | Yes | No, assuming stakeholders are defined as external to DFO | No, assuming stakeholders are defined as external to DFO |
| **communication of** results | Ongoing work with stakeholders | Ongoing work with stakeholders | Primary papers, Internal Species Profiles for Management, Possible Canadian Secretariat Science Advice Review | Canadian Science Advice Secretariat Review in 2013; Published as DFO Science Advice Report |
| **Reference Info.** | https://academic.oup.com/icesjms/article/72/6/1731/918246; http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0090662 | NP | http://www.dfo-mpo.gc.ca/science/rp-pr/accasp-psaccma/projects-projets/008-eng.html; | http://waves-vagues.dfo-mpo.gc.ca/Library/349895.pdf; http://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs97–4-3049-eng.pdf |
| **Contact** | Nancy Shackell | Nancy Shackell | Karen Hunter | Karen Hunter |

### European Regional Seas (Table 1.3: Studies 7 – 10)

Unlike other regions discussed in this report, Europe has had no formal, large-scale climate vulnerability assessments published on its fisheries or aquaculture resources and human-dependent communities. However, a number of activities are underway.

In the UK, the Climate Change Act of 2008 introduced a statutory framework aimed at enhancing adaptation to climate change. This Act specifically introduced a requirement for a UK-wide climate change risk assessment (CCRA) that must take place every five years and that a national adaptation programme (NAP) must be put in place every five years to address the most pressing climate change risks to England. That Act also mandated powers to direct "reporting authorities" (companies with functions of a public nature such as water and energy utilities) to prepare reports (Adaptation Reporting Powers (ARP)s) outlining how they are assessing and acting on the risks and opportunities from a changing climate (Study 7).

In 2016 the UK seafood industry authority (Seafish) teamed up with scientists from the Centre for Environment Fisheries and Aquaculture Science (Cefas) to prepare an ARP report for the wild-capture seafood sector in the United Kingdom. This study was conducted over a period of nine months and included four main tasks. These tasks were to (1) review of published literature, (2) group workshops and individual consultations with industry stakeholders; (3) identify potential impacts and a structured assessment of risks, threats and opportunities – using secondary and primary sources of evidence; (4) develop adaptation plans – together with indicative implementation, monitoring and evaluation components. It is important to note that a formalised Vulnerability Assessment (involving assessment of Exposure, Sensitivity, Adaptive Capacity and Vulnerability) was not carried out, although many of the activities undertaken were broadly comparable with those in a more conventional CVA, including a scoring of risks in accordance with 'Proximity' (time to consequence occurring); speed of response (urgency of action). Separate reports were drafted on: (a) the domestic wild capture seafood supply chain; and (b) the international wild capture seafood supply chain. Risks were elucidated for whitefish, pelagic fish and shellfish production, both offshore and onshore. A follow-up report is now being prepared (for publication in 2018) on 'responding to climate change in the UK aquaculture industry' in collaboration with the EU H2020 projects CERES (Climate Change and European Aquatic Resources) and ClimeFish (Co-creating a decision support framework to ensure sustainable fish production in Europe under climate change). A link to that effort is:

http://www.seafish.org/industry-support/seafood-horizons/climate-impact/climate-change-adaptation.

The CERES and ClimeFish projects will produce Europe-wide, national-level climate vulnerability assessments for both fisheries and aquaculture. The CVA for fisheries in CERES (Study 8) will identify stocks, species, fishing fleets, regions and nations that are the most exposed and sensitive to marine climate change. The approach employed is intended to be as simple and broad-brush as possible, with a focus on minimizing the amount of resources required. The vulnerability of each species will be derived using the standard FAO model. Exposure of a species will be defined in terms of the amount of warming that it is expected to experience throughout its range, based on projections of sea-surface temperature from global climate models for the period 2040–2060 in RCP 4.5

and 8.5. Sensitivity of species will be based on a suite of traits (e.g. maximum length, fecundity, egg size, life span, trophic level and degree of parental care of the offspring) which define three archetypical life-history strategies. One life history strategy ("opportunistic species") is considered to be the most tolerant to highly variable environments (i.e. the most insensitive to climate variability and change). The initial estimates rank swordfish, Atlantic halibut and salmon as being amongst the most vulnerable species. The sensitivity and exposure of each species will be integrated create national-level sensitivity by weighting the individual values for each species by the proportion of the economic value of the landings for each country. Initial rankings indicate a clear north-south gradient within Europe, with the most northern nations fishing on the most vulnerable species. Future work will refine this analysis to focus on the finer details of the analysis, including improvements to the definition of exposure, moving from a species-based to a stock-based approach, focusing on regions rather than nations as the unit of geographical analysis, and incorporating socio-economic aspects into the analysis.

The CERES aquaculture vulnerability (Study 9) will examine Europe's most valuable farmed finfish (Atlantic salmon, trout, seabass, seabream and carp) and shellfish (blue mussel, oysters and clams). Exposure will be based on regionally downscaled projections of physical and biogeochemical changes. Sensitivity will be based on a thorough literature review of physiological traits along with expert rankings of species x method combinations, incorporating elements of the model utilized by Doubleday *et al.* (2013). Finally, these broad-scale CVAs for fisheries and aquaculture performed in CERES will be accompanied by bioeconomic model projections conducted in specific regions on specific fleets and aquaculture farming types to provide additional, regional-specific information on risks and opportunities posed by climate change.

Within the ClimeFish project (Study 10), the vulnerability of fisheries and aquaculture to climate change is being analyzed at both European and regional scales, for the three main production sectors, marine fisheries, freshwaters (lakes and ponds) and marine aquaculture. Each sector is represented by several specific Case Studies (CS). The project investigates the impact of climate change on aquatic food production by first identifying the effect(s) of climate change on the biological properties of both fish stocks and aquaculture species. Second, ClimeFish is developing novel forecasting tools which include the biological parameters (spawning, recruitment, growth, migration and trophic interactions) that determine the productivity of the species studied by ClimeFish in order to perform forward simulations and assess the likely future impact of climate change under climate scenarios RCP 4.5 and RCP 8.5. Vulnerability is defined as a function of exposure, sensitivity and adaptive capacity following the framework used by the IPCC and described by Allison *et al.* (2009). Exposure is defined as 'warming', sea surface temperature model predictions are more suited to the marine sector while land temperature model predictions are more suited for inland fisheries (Allison *et al.*, 2009; Blasiak *et al.*, 2017). Sensitivity is defined using two metrics characterizing the species harvested: an index of their biological sensitivity (BS); (Cheung *et al.*, 2005) and the maximum temperature (Tmax) that they are currently experiencing (see Cheung *et al.*, 2013). Each species temperature range, defined as the interquartile range of its distribution, was used as a proxy for the adaptive capacity. To explore each country's vulnerability to warming by sector, ClimeFish weighted the above presented indices by the production volume by sector and country according to the FAO database. The preliminary results of the sensitivity analysis show that the marine sectors are more vulnerable to warming than the freshwater sector. Production vulnerability in the marine sector increases with latitude due to the temperature sensitivity of the landed species and their high production volume. No such gradient was predicted for the freshwater sector because most of the production is based on two species with opposite temperature and biological sensitivities. The predictions resulting from the case study biological modelling in 2050 fits reasonably well with the vulnerability assessment. A combination of the generalist and qualitative vulnerability assessment, based on a common methodology for all sectors, cases and countries, together with the case study-specific and quantitative biological numerical modelling approach appears to be a powerful tool to examine the expected response of European freshwater and marine fisheries and aquaculture to climate change.

**Table 1.3. Summary information for aquaculture and/or fisheries CVAs in Europe.**

| | **Study 7** | **Study 8** | **Study 9** | **Study 10** |
|---|---|---|---|---|
| **Location (**Project) | UK Seafish ARP Assessment | European Regional Seas Fisheries (CERES) | European Marine and Freshwater Aquaculture (CERES) | European Waters (ClimeFish) |
| **Rationale / Purpose** | Understand climate change risks to the UK wild capture seafood sector | Highlight relative risks and opportunites posed by climate change on fisheries | Highlight relative risks and opportunites posed by climate change on aquaculture | Co-create a decision support framework for sustainability of three seafood production sectors (marine fisheries, marine aquaculture and freshwater aquaculture) in light of climate cchange |
| **Targeted users** | Industry, policy makers, regulators, scientists, consumers | Industry | industry and policymakers | Industry, policy makers, regulators, scientists, consumers |
| **Finest scale (unit of analysis**) | UK Domestic and International seafood sectors | Country | regional-level | Regional Case Studies: 8 European Marine Areas and several inland waters (Lakes and Ponds) |
| **Biological component** | Yes, high level assessment | Yes | Yes | Yes |
| **Species / habitat** focus | Seperate assessments for whitefish, pelagic fish and shellfish | Pelagic & Demersal & Aquaculture | Salmon, trout, carp, seabream, seabass, mussels, oysters, | Pelagic, demersal, fresh water and marine aquaculture north and south |

| | | | | |
|---|---|---|---|---|
| | | | clams | (Salmon, seabass, mussels) |
| **Socio-ecological** component? | Yes | Yes | not envisioned | yes |
| **Spatial Scale (exposure** | national and international seafood sectors | | European Regional Seas | regional, national and European |
| **Climate Scenario(s) tested** | NA | 4.5 & 8.5 | RCP 4.5 & 8,5 | RCP 4.5 & 8.5 |
| **Capturing uncertainty** | Largely a conceptual (qualitative) assessment, although did consider level of consensus and proximity (in time) of impacts | | Will explore sensitivity of ranks to individual expert ranks and species / farming traits using bootstrapping. Some regional seas have ensemble climate projections | Largely qualititative and when possible quantitative |
| **Timeframe Covered** | Largely conceptual/qualitative (but mostly 2050) | | 2015–2050 | 2015–2055 |
| **Stage of completion?** | Completed in 2016, will be followed by aquaculture sector in 2018 | Year 1 | Year1 | Year 1 |
| **Key resources needed** | Stakeholder workshops | | Experts from science and industry, two dedicated workshops | Biological forecasting, socio-economic data, stakeholder involvement through workshops |
| **What would** you do different if you repeated it?? | Employ a more conventional, semi-quantitative CVA approach | NA | NA | NA |

| | | | | |
|---|---|---|---|---|
| **Application of CVA** | Risk assessment for the seafood sector - comply with statatory reporting requirements under the UK Climate Change Act | Inform, support and actively involve industry stakeholders and decision makers in their management process including na climate adaptation policies (national level) and CFP | Inform, support and actively involve industry stakeholders and decision makers in their management process (MSFD, WFD, UN Strategic Development Goals, national climate adaptation plans) | Inform, support and actively involve industry stakeholders and decision makers in their management process |
| **stakeholder engagement** | Yes | | Yes, industry for adaptive capacity | Yes |
| **communication of** results | Short summary document widely circulated and made available online as well as longer technical report. Presentation at Seafish Common Language Group meetings. | | To be published and presented at various policy (EC Commission), science (Aquaculture conferences) and industry (EATIP) meetings | DSS and various dissemination |
| **Reference Info.** | http://www.seafish.org/industry-support/seafood-horizons/climate-impact/climate-change-adaptation | http://ceresproject.eu | http://ceresproject.eu | http://climefish.eu/ |
| **Contact** | John Pinnegar | Mark Payne | Myron Peck | Juliana Arias-Hansen |

### United States Atlantic and Pacific Waters (Tables 1.4a&b, Studies 11 – 18)

The US National Marine Fisheries Service (NMFS) is approaching CVAs based on the National Climate Science Strategy and Regional Action Plans (https://www.st.nmfs.noaa.gov/ecosystems/climate/national-climate-strategy). Specifically, the initial goal is to develop a common approach towards expert-based CVAs for federally managed fisheries and protected species. The northeast US (northwest Atlantic) was chosen as the pilot, and fished species and fishery-dependent human communities were examined in tandem (Hare *et al.*, 2016; Colburn *et al.*, 2016). Specifically, 82 federally managed fish and invertebrate species were assessed using an expert panel for both sensitivity and exposure (Study 11) and about half of the species were found to be high or very high in terms of vulnerability (Hare *et al.*, 2016). Colburn *et al.* (2016) took the results from the fish species assessment to populate the risk axis of fisheries and communities (Study 12, discussed in more detail in Section 4 of this report). This combined approach is viewed as the template (Figure 2.3) that will be conducted in future Large Marine Ecosystems. Currently, there are CVAs underway in the California Current (Study 16) and Bering Sea (Study 18).

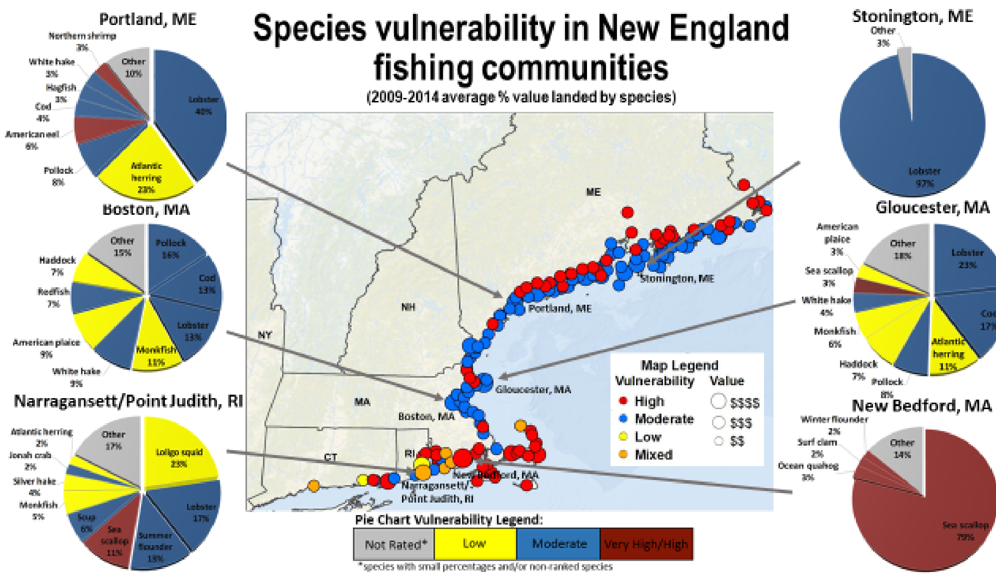


**Figure 2.3. Community dependence on climate vulnerable species in New England fishing communities. The six highest grossing ports in terms of value landed are highlighted. The catch composition of each port is expressed as the percent contribution of value landed and climate vulnerability ranking (low=yellow, blue=moderate and red=high) for each species landed in that port.**

Uncertainty in climate modelling is important to address, particularly when conveying advice to ecosystem managers and policymakers (e.g. Littell *et al.*, 2011). The ongoing CVA in the Eastern Bering Sea which explores 36 stocks of fish and invertebrates (Study 18) provided an excellent example of how uncertainty can be taken into account within various steps of the analysis. In this ongoing work, three downscaled GCMs are used (e.g. Hermann *et al.*, 2013 & 2015) to help account for structural uncertainty in downscaled projections of physical climate impacts. Second, the quality of biological data for each stock is scored (from 0 (poor) to 3 (high). Finally, bootstrapping is used here (and in all of the NMFS CVAs) to randomly resample the scores for each of the exposure factors and sensitivity attributes and re-calculate vulnerability. This process is repeated 1000 times to create a distribution of bootstrap scores.

Additional CVAs are underway by NMFS focusing on specific species groupings (salmonids and forage fish – Studies 16 & 17) and exploration of more automated approaches towards identifying vulnerable species. Specifically, as new model output or new fisheries or community data become available, it will require additional expert input using Hare *et al.* (2016) and Colburn *et al.* (2016) approaches. Efforts are underway at NMFS to calculate automated risk and exposure metrics based on historical variability and predicted future changes for forage fish species (Study 17).

The Northeast USA COCA project (Study 13) provides an example of coupled social-ecological vulnerability assessment of fishing communities. This work is being conducted along the Northeast U. S. Shelf and will provide information to communities, fishing industry stakeholders, and managers about relative vulnerability of over 150 fishing communities. It provides a framework for evaluating how the adoption of specific adaptation strategies will alter vulnerability levels. The program utilizes ecological data such as projected climate-driven changes in species vulnerability (Hare *et al.*, 2016) and distribution as well as socio-economic data on community landings composition, community fishing locations, and social resilience (Jepson and Colburn, 2013). More detailed work will occur within four focus communities to understand effective adaptation strategies for buffering climate impacts and capitalizing on new opportunities. Economic models, stakeholder focus groups, and fishing industry surveys will be used to identify adaptation strategies of interest, evaluate the ability to buffer climate impacts and reduce community vulnerability, and assess factors that facilitate or hinder the implementation of specific adaptation measures.

**Table 1.4. Summary information for fisheries and/or aquaculture CVAs in USA (Atlantic waters and nation-wide OA).**

| | **Study 11** | **Study 12** | **Study 13** | **Study 14** |
|---|---|---|---|---|
| **Location (Project)** | USA Northeast Shelf species vulnerability assessment | USA (24 coastal states) fishing community vulnerability and resililence | USA Northeast Shelf Integrated social-ecological vulnerability assessment | USA Coastal Waters, Shellfisheries OA vulnerability |
| **Rationale / Purpose** | Relative vulnerability of fish species to climate change | Social impact assessments, climate change assessments, integrated ecosystem assessments | Relative vulnerability of fishing communities to climate change | |
| **Targeted users** | Management Bodies | Management Bodies / Industry / Public Awareness | Management Bodies and Industry | |
| **Finest scale (unit of analysis)** | Northeast US Shelf LME | Community | fishing communities (fishing footprints) | TNC's ecoregions |
| **Biological component** | Yes | No | Yes | Yes |
| **Species / habitat** focus | 82 commercial, forage, and protected species | Sea level rise | 60 commercial species from Hare *et al.* (2016) | shelled mollusks |
| **Socio-ecological** component? | No | yes | Yes | Yes |

| | | | | |
|---|---|---|---|---|
| **Spatial Scale (exposure** | regional | community | fishing communities (fishing footprint) | regional to national |
| **Climate Scenario(s) tested** | RCP 8.5 | | RCP 8.5 | |
| **Capturing uncertainty** | Logic rules allow for sharing of 5 votes among bins to identify expert confidence. | NA | Climate scenario median, 5%, and 95% results; mean and prediction interval for p(presence) from species distribution models | NA |
| **Timeframe Covered** | 2005–2055 | 2005 to 2015 | 2015–2055 | |
| **Stage of completion?** | Published | Published 2012 and 2013 (updated annually) | Shelfwide assessment completed in 2017; evaluation of adaptation strategies and outcomes for communities within 2 years | published 2015 |
| **Key resources needed** | NP | US census and nmfs fisheries data | Species vulnerability (Hare *et al.*), social resilience indicators (Colburn & Jepson), fishery-dependent data (landings composition & value by port, fishing locations by vessel traceable to landing port), climate model ensemble outputs, species distribution models, ~1.5 year technician - acquire data, build models, integrate data sets) | NP |
| **What would** you do different if you repeated it?? | Integrate species and social | Stakeholder engagement from the beginning | | represented tourism and coral; gotten higher resolution human data |
| **Application of CVA** | Inform stakeholders (industry, communities, managers and others) | Sea level rise vulnerability | inform industry stakeholders, coastal communities, managers; use framework to evaluate adaptation strategies | garnered attention? |

| | | | | |
|---|---|---|---|---|
| **stakeholder engagement** | yes | Groundtruthed results in communities with primary data collection. | Limited in initial model development process; extensive for defining adaptation scenarios to run subsequently using the model | No |
| **communicatio n of** results | To various stakeholders (industry, communities , managers and others including congressional audiences) | NOAA | shelf-wide paper, presentation to communities and management bodies, community-specific reports for four focus communities | NP |
| **Reference Info.** | http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0146756 | https://www.nefsc.noaa.gov/read/socialsci/pdf/Coastal_Management_Colburn_SocialIndicators.pdf | NP | http://www.nature.com/nclimate/journal/v5/n3/abs/nclimate2508.html |
| **Contact** | Lisa Colburn | Lisa Colburn | Kathy Mills | Julie Ekstrom |

**Table 1.4b. CVAs conducted in the USA (Pacific waters and Bering Sea).**

| | **Study 15** | **Study 16** | **Study 17** | **Study 18** | **Study 19** |
|---|---|---|---|---|---|
| **Location (Project)** | USA NE Pacific (California Current CVA) | USA NE Pacific (salmon) | USA NE Pacific (forage fish automated CCCVA) | USA Eastern Bering Sea CVA | USA Alaska Fisheries OA vulnerability |
| **Rationale / Purpose** | Obtain relative information on biological vulnerabilty | Obtain relative information on biological vulnerabilty for Salmon ESUs | Quantitatively determine risk for fish and fishers (in an automated fashion) | Determine which stocks are most vulnerable and identify data gaps & research priorities | scientific exercise, awareness building |
| **Targeted users** | Managemen t Bodies | | Management Bodies | | Management Bodies / Public Awareness |
| **Finest scale (unit of analysis)** | LME | Ecologically Significant Units | LME | local to regional | census place/town |
| **Biological component** | Yes | Yes | Yes | Yes | Yes |

| | | | | | |
|---|---|---|---|---|---|
| **Species / habitat** focus | 65 federally managed pelagic and demersal species | 33 Salmon runs | 10 forage species | 36 stocks (25 finfish, 4 elasmobranchs, 4 crabs, 3 cephalopods) | mollusks, crustaceans, some finfish |
| **Socio-ecological** component? | Not yet, to come | Not yet, to come | Yes | No | Yes |
| **Spatial Scale (exposure** | regional, fishery-scale | | sub-regional, fishery vessel-scale | regional, fishery-scale | community (census areas) to regional |
| **Climate Scenario(s) tested** | RCP 8.5 | RCP 8.5 | RCP 8.5 | RCP 4.5, SRES A1B, RCP 8.5 | RCP 8.5 |
| **Capturing uncertainty** | Logic rules allow for sharing of 5 votes among bins to identify expert confidence. | Logic rules allow for sharing of 5 votes among bins to identify expert confidence. | none right now | 3 downscaled GCMs used, Data quality scored. Bootstrap analyses of scores for each exposure factor and sensitivity attribute are randomly sampled. Repeated 1000 times with replacement, create distribution of bootstrap scores. | NA |
| **Timeframe Covered** | 2005–2100 | 2005–2100 | 2005–2100 | 2003–12 vs 2030–39 | present (2003–12) vs end of century (2090–99) |
| **Stage of completion?** | Working on biological publication | Working on biological publication | Working on coupled ses publication | Initial results obtained, publication underway | published |
| **Key resources** needed | GCM output, expert group, FTE time | GCM output, expert group, FTE time | FTE time, undergraduate support, physical data processing | Large number of assessment scientists and external experts for workshops, works builds on long history of survey data and downscaled regional hydrographic modelling | US census, NMFS fisheries data, state data |

| | | | | | |
|---|---|---|---|---|---|
| **What would** you do different if you repeated it?? | Integrated with socio-economic from the start, re-assess Hare *et al.* logic thresholds, and others! | Integrated with socio-economic from the start, re-assess Hare *et al.* logic thresholds, and others! | Use better species distribition models for sensitivity calculations. Split by life histories (currently adult only) | | reduced confusing overlap in language in indicators |
| **Application of CVA** | Prioritizatio n Managemen t Strategy Evaluations, Inform national assessment | Prioritization Management Strategy Evaluations, Inform national assessment | Exploration of "automated framework" for sensitivity and exposure | NA | garnered attention? |
| **stakeholder engagement** | will be done post-hoc | will be done post-hoc | No | Will be done post-hoc | No |
| **communicati on of results** | Presentation to council, publication, presentation throughout NOAA. | Presentation to council, publication, presentation throughout NOAA. | Integrated Ecosystem Assessment, publication | Part of the NOAA Alaska Fisheries Science Center (draft) Regional Action Plan for southeastern Bering Sea Climate Science | NOAA |
| **Reference Info.** | NA | NA | NA | https://www.afsc.noaa.gov/news/pdfs/NMFSClimateScienceStrategySoutheasternBeringSea%20Feb%202016.pdf | http://www.sciencedirect.com/science/article/pii/S0079661114001141 |
| **Contact** | Elliott Hazen | Elliott Hazen | Elliott Hazen | Paul Spencer | Julie Ekstrom |

### Other Regions (Table 1.5: Studies 20 – 22)

Workshop participants had projects underway in a variety of locations including in western Africa (Study 20), the Arabian Gulf (Study 21) and Caribbean Waters (Study 22). These studies provide important contrasts to the CVAs performed by scientists charged with resource management in first-world (highly industrialized) nations. Ongoing work within the Arabian Sea and in West African coastal communities has a strong social science component with emphasis on engagement with local / regional fishing communities (surveys, workshops, interviews). The ongoing work on Caribbean coral reefs is an example of a socio-ecological CVA with socio-economic metrics of sensitivity and adaptive capacity. The work in the Arabian Gulf included considerable data mining to create baseline estimates of fish species / biodiversity of the region and fisheries catch by nation.

Stakeholder engagement was important to this process by providing much-needed local knowledge of fisheries resources. Responses of fisheries resources to climate change were extremely negative with local losses of species richness as much as 35% of the initial values projected under RCP 8.5. Exposure was related to changes in temperature and salinity and projections of change were made using three different species distribution models (AGEDI, 2015). Results were used to highlight gaps in knowledge (e.g. the need for monitoring programs) and make policy recommendations (strengthening the network of marine protected areas in light of climate-driven shifts in distribution).

**Table 1.5. Summary information for CVAs conducted in developing regions.**

| | **Study 20** | **Study 21** | **Study 22** |
|---|---|---|---|
| **Location (Project)** | Africa (Senegal, Cape Verde, Nigeria) AWA/PREFACE | Arabian Gulf (AGEDI) | Caribbean Island States |
| **Rationale / Purpose** | Understanding vulnerability of coastal fishing communities to environmental change | Assess the vulnerability of marine biodiversity and fisheries to climate change | assess socio-ecological vulnerability to climate change impacts in coral reefs |
| **Targeted users** | local communities, local governments | | Management bodies |
| **Finest scale (unit of analysis)** | individual fishing community | EEZ of the Arabian Gulf countries | country |
| **Biological component** | yes | Yes | Yes |
| **Species / habitat** focus | all, but focus on small pelagics | Exploited fishes and invertebrates, charismatic mega-fauna e.g., turtles, durgoon, coral, seagrass | coral reefs (algae, fish, etc.) |
| **Socio-ecological** component? | yes | Yes | Yes |
| **Spatial Scale (exposure** | community | national | national |
| **Climate Scenario(s) tested** | all | RCP 2.6 & 8.5 | NA (time series) |
| **Capturing uncertainty** | uncertainty and bias from climate ocean models | Three different species distribution models as exposure | NA |
| **Timeframe Covered** | likely 2030/2050/2100 | 2050s and 2100s | |

| | | | |
|---|---|---|---|
| **Stage of completion?** | work started | Reported completed, manuscript in review | not yet published |
| **Key resources needed** | data from questionnaires, national statistic data, stock data, regional climate-ocean model output, functional effect on fish distribution and productivity | Downscaled ocean model outputs, expert group, species distribution modelling, socio-economic data | spatial analysis |
| **Lessons Learned** | not yet clear, but for the questionnaire the focus on one CVA framwork would have helped | Incorporate future scenarios for socio-economic attributes | surveys and community based analysis, stakeholder engagement |
| **Application of CVA** | Inform Coastal Communities, local and national governments and regional management body | Identify vulnerable regions in the Arabian Gulf | priorization of countries, inform international community |
| **stakeholder engagement** | Yes, different level, scoping process, questionnaire and finally community workshops to reflect the results | yes | No |
| **communication of results** | to communities, local and national government and regional fisheries management body | A conference (with other vulnerability assessment groups), a lay-person booklet, a web-portal | not planed yet |
| **Reference Info.** | NA | https://agedi.org/climate-change-inspectors-toolkits-now-online/ | NA |
| **Contact** | Jörn Schmidt | William Cheung | Elena Ojea |

### Global-scale Assessments (Studies 23 – 25)

A number of the workshop participants were experienced in conducting global-level analyses which ranked nations in terms of their risks and vulnerability of fisheries or aquaculture sectors to climate change. This work included the seminal activities of Allison *et al.* (2009) who used an indicator approach to rank the vulnerability of 132 national economies to climate-driven changes in fisheries (Study 24). Similar to other studies, that work used the FAO model (E x S x AC = V). Exposure was air temperature at 1.5 m projected from two, contrasting SRES (B2 and A1F1) scenarios by a global climate model.

Sensitivity was a composite index (from 0 to 1) of the employment and economic dependence on the fisheries sector (number of fishers, percentage of total employment, expert value of catch, etc.) as well as the percentage of the total, daily protein intake stemming from fish. Adaptive Capacity was also an index (from 0 to 1) which took into account the ability of nations to commit resources to climate adaptation. In this context, AC was a composite index of health, education, governance and size of the economy. The work highlighted important data gaps in terms of fishery data in countries heavily reliant on fish for their protein intake. This study also highlighted how high vulnerability can stem from different combinations of E, S and AC as well as the disconnection between nations emitting greenhouse gasses and those vulnerable to the downstream climate impacts on their fisheries resources.

A second, global-scale study which also applied a small number of indicators was by Pendleton *et al.* (2016); (Study 23). Pendleton *et al.* (2016) examined the country-level de-pendence on ecosystem services provided by coral reefs and future $CO_2$-related threats (e.g. ocean acidification and thermal stress).

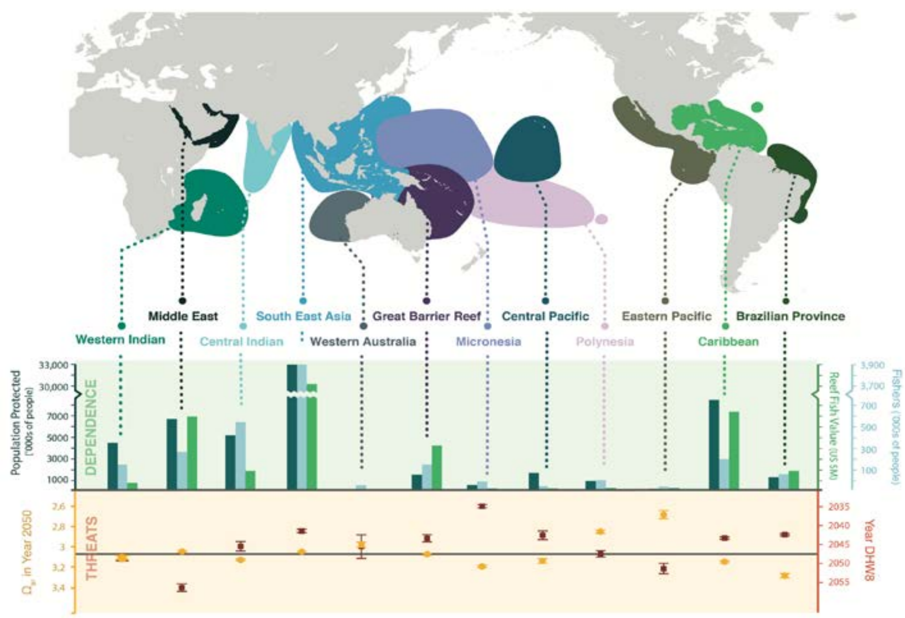


**Figure 2.3. Regional dependence of 12 ocean provinces on ecosystem services provided by coral reefs and average $CO_2$-related threats (from Pendleton *et al.* 2016, their Figure 6). Threats include ocean acidification, measured as projected omega aragonite levels in 2050, and elevated sea surface temperature, measured as the year when 8 degree heating weeks (DHWs) are projected to occur annually. A DHW is a standard measure of heat accumulation over the previous twelve weeks and represents the number of weeks an area has experienced temperatures in excess of 1 degree Celsius above the highest mean summer time temperature). Coral bleaching is associated with 6 DHWs. The horizontal line in the threats panel represents the mean threat for all regions (scores above this line indicate above average severity of threat).**

As explained by Pendleton *et al.* (2016), indicators can provide information in the absence of a complete set of observations needed to create more complex (e.g. quantitative) models of processes affecting the ecology of regions and the responses of people to changes in the ecosystem. That study employed four indicators of the social-ecological system. Two indicators represented human dependence on coral reefs at the national level; (i) people benefitting from shoreline protection offered by coral reefs and ii) people benefitting from reef-related fisheries. Two regional-level indicators provided spatial projections of the severity of exposure to warming and ocean acidification based on RCP 8.5 (see Figure 2.3). It is important to follow the best methodological choices that allow for comparative studies. In fisheries CVAs addressing social adaptive capacity. A recent study by Monnereau *et al.* (2017) reported that not scaling indicators to population sizes, having a small number of indicators, and not taking into account redundancy lead to inaccurate results in the past. They recommend this analysis as a framework for policymakers to target geographical areas where new data collection and science will have high social relevance. They also underscore that additional knowledge on the human responses to coral reef change is needed.

**Table 1.6. Summary information for global-level CVAs conducted on aquaculture and/or fisheries.**

| | **Study 23** | **Study 24** | **Study 25** |
|---|---|---|---|
| **Location (Project)** | Global (coral reefs) warming and OA | Global (fisheries & 132 national economies) | Global (Nereus Program) |
| **Rationale / Purpose** | Create an attribute-based approach to pinpoint geographical areas and nations most at risk to warming and OA. Awareness building of international coral community | Riase awareness of most vulnerable nations to climate change | Assess of vulnerability and risk of impacts of climate change (including ocean acidification) for global exploited marine fishes and invertebrates |
| **Targeted users** | International coral community, policymakers and management bodies | International organization, NGOs, national and regional government and researchers | International organization, NGOs, national and regional government and researchers |
| **Finest scale (unit of analysis)** | Regional-level exposure of reefs (0.5 lat x 0.5 lon grid of the world oceans), national dependence of human communities | National-level analysis | |
| **Biological component** | Yes | Yes | Yes |
| **Species / habitat** focus | Areas with coral reefs between the equator and 32°N and S. | Global | Pelagic & Demersal fishes and invertebrates |
| **Socio-ecological** component? | Yes, two national-level indicators: i) poeple within low lying areas near coastal reefs, ii) number of people in reef-dependent fisheries | Yes (composite indicator of fisheries importance to economy) | No |

| | | | |
|---|---|---|---|
| **Spatial Scale (exposure** | regional | national (Global Climate Model HadCM3) | NA |
| **Climate Scenario(s) tested** | RCP 8.5 | A1F1 and B2 | RCP 8.5 |
| **Capturing uncertainty** | Indicator approach used to pinpoint areas most vulnerable where data gaps are also high (uncertainty is high) | NA | Fuzzy logic and the associated max/min ranges and membership to vulnerability categories. |
| **Timeframe Covered** | projections of omega aragonite to 2050 suing CMIP 5 ensemble | to 2050 | Exposure indices based on projections for 2050s |
| **Stage of completion?** | Published in 2016 | Published in 2009 | In review |
| **Key resources** needed | Number of Jobs and value of reef-dependent fisheries (2005 estimate, Sea Around Us project). Low elevation coastal zone: Urban-rural population and land area estimates (Center for International Earth Science Information Network, Columbia University) | | Open acccess R code and dataset will be available to calculate vulnerability of >1,000 exploited marine fishes and invertebrates in the world |
| **What would** you do different if you repeated it?? | | | Incorporate species distribution models projections as exposure index, which we have got the data for all the species |
| **Application of CVA** | Raise awareness of policymakers on spatial allocation of research funds | Raise awareness of policymakers on spatial allocation of research funds | Prioritization of species and regions (LME/EEZ/sub-regional scale) for climate concerns. |
| **Stakeholder engagement** | No | No | No |
| **Communication of results** | | high-profile publication with media coverage | Plan to have the vulnerability index for each species on FishBase and SeaLifeBase |
| **Reference Info.** | http://www.nature.com/nclimate/journal/v5/n3/abs/nclimate2508.html | http://www.uba.ar/cambioclimatico/download/Allison%20et%20al%202009.pdf | N/A |

| **Contact** | Julie Ekstrom | Ed Allison | William Cheung |
|---|---|---|---|

William Cheung also presented a modelling approach to synthesize data on species-specific estimates of exposure, and ecological and biological traits to undertake an assessment of vulnerability and risk of impacts of climate change (including ocean acidification) for global marine fishes and invertebrates (see Jones and Cheung, 2017). The approach used fuzzy logic to accommodate the variability in data availability and uncertainties associated with inferring vulnerability levels from climate projections and species' traits. The study employed the climate vulnerability and risk assessment framework used by the IPCC 5th Assessment Report (IPCC, 2014). Sensitivity of a species was the degree to which it was susceptible to impacts from climate change. The sensitivity of a species may be moderated by specific biological traits including their adaptive capacity or the ability to adapt and thus cope with, or avoid, the impacts of climate change. As the unit of assessment is an individual species, we consider a species' ability to shift in distribution to avoid or minimize negative impacts from changing habitat conditions on its viability as an adaptive response to climate change. This study focused specifically on characteristics that determine a species ability to show this response, within its current distribution. Thus, the spatial response of a distribution shift may, itself, be influenced by adaptive characteristics included here. The combination of a species' sensitivity and (lack of) adaptive capacity determines its vulnerability to climate change. Ultimately, the risk of impacts of climate change on the species is determined by its vulnerability as well as the potential occurrence of climate-related ocean changes and the degree of exposure (warming, ocean acidification, deoxygenation).

Under the RCP 8.5 'business-as-usual' greenhouse gas emission scenario, this approach indicated that the mean (±SD) vulnerability and risk of impacts to 1074 exploited marine species globally, was 52(19) and 66(11), respectively, where vulnerability and risk scale from 1 (lowest) to 100 (highest). There were 157 highly vulnerable species while 294 species were at high risk of impacts. The most vulnerable species tended to be large-bodied endemic species. Furthermore, when the same fuzzy logic approach was applied to the vulnerability from fishing, about a third of the assessed species had a high risk of impacts due to both fishing and climate change. The vulnerability and risk of impacts of each species was mapped on a 0.5° latitude x 0.5° longitude grid of the world oceans, and calculated the average risk of impacts across the assessed fishes and invertebrates by countries' Exclusive Economic Zones (EEZs). The EEZs that have high risk to climate change were concentrated in tropical regions and semi-enclosed seas, while those that at risk from fishing are more widespread, particularly in temperate and high latitude regions. A few regions display a high risk to the impacts of fishing and climate. As discussed by Jones and Cheung (2017), this fuzzy logical framework could be applied at regional scales to examine climate change vulnerability and risk of impacts using publicly and readily available information. It could be adapted to incorporate additional rules and attributes for additional specific taxonomic groups and areas, and linked to social-economic vulnerability assessment.

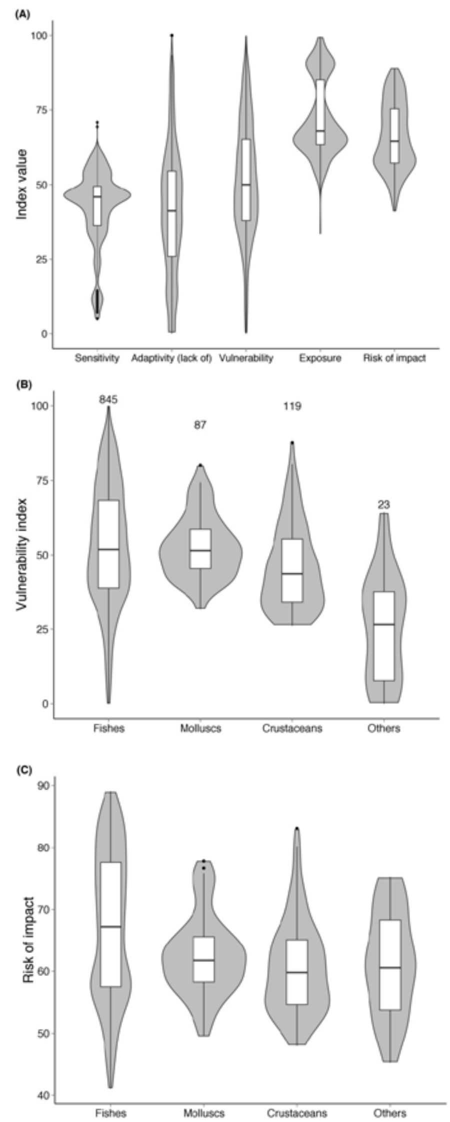


**Figure 2.4. Predicted indices of sensitivity, adaptive capacity (lack of), vulnerability exposure to climate hazards, and risk of impacts for the 1074 exploited marine species using the fuzzy logic expert system developed in this study: (A) distribution of each index across all species, (B) vulnerability and (C) risk of impacts subdivided by major taxonomic groups. The boxplot represents the median (thick black line in the middle of each box), 25th and 75th quartiles (lower and upper boundary of each boxy) and the minimum and maximum values (the lower and upper ends of the vertical lines). The shaded area represent the frequency distribution (in proportion). The number on top of each box in (B) indicates the number of species.**

# 3 Opportunities for comparative studies looking at the relative vulnerability of species in different LMEs (ToR B)

Recent efforts to implement vulnerability assessments for marine fisheries have resulted in the adoption of a variety of frameworks, methodologies, and processes across a range of marine ecosystems. As the end goal of a CVA may differ, there is a high diversity in approach yet, as previously discussed, many have evolved from a common framework (Marshall *et al.*, 2013; Cinner *et al.*, 2013). These efforts provide opportunities for comparative studies of the structure and results across regions and against past experiences in this disciplinary field.

The variety of approaches being used for climate vulnerability assessments across different marine ecosystems provides opportunities for comparison of purposes, frameworks, methodologies, and processes. This type of comparative study could be motivated by multiple interests, such as how the scientific understanding and data richness in a region shapes the assessment structure, how biological and social components of the assessment are conducted and integrated, how uncertainty is propagated and communicated, how stakeholders and potential users are involved in the assessment process, and how results are communicated and used. Insights gained from this type of comparison should provide valuable lessons learned for future development of vulnerability assessments for marine ecosystems and fisheries.

*Biological hypotheses to be tested via CVAs.* While the species of fish and invertebrates can vary among ocean and eco-regions, there are commonalities in ecological function and life history traits that would make comparisons more valuable. Thermal physiology of many commercially important fish has been well studied (e.g. Pörtner and Peck, 2010) and the realized thermal niche of species, as developed from statistical analyses of geographical distribution (e.g. Gerick *et al.*, 2014; Shackell *et al.*, 2014), is an example of an integrated trait that could be compared across systems. The ability to compare these common traits and common functions across ecosystems would allow us to see how different physical regimes buffer or amplify vulnerability to climate change. For example, Eastern Boundary Upwelling Systems (EBUS) are likely to have buffers to warming from climate change potentially with greater variance or extremes yet changes in phenology may still have significant effects on sensitive species. In contrast, western boundary systems may face more secular warming resulting in a greater change to the mean. As a result, identifying a few similar diadromous species, a few highly migratory pelagic species, and a few long-lived demersal species may offer valuable approaches to understanding the potential diversity of responses.

While ecological relationships can be considered in CVAs, they are often simplified into broad life history traits such as a specialist or generalist predator. An archetype analysis presented by Mark Payne (unpublished data) reduced multiple traits down to a single metric suitable for use as an indicator of sensitivity to climate change (Figure 3.1). This type of archetype analysis may hold promise for comparing traits of particularly vulnerable species across various LMEs.

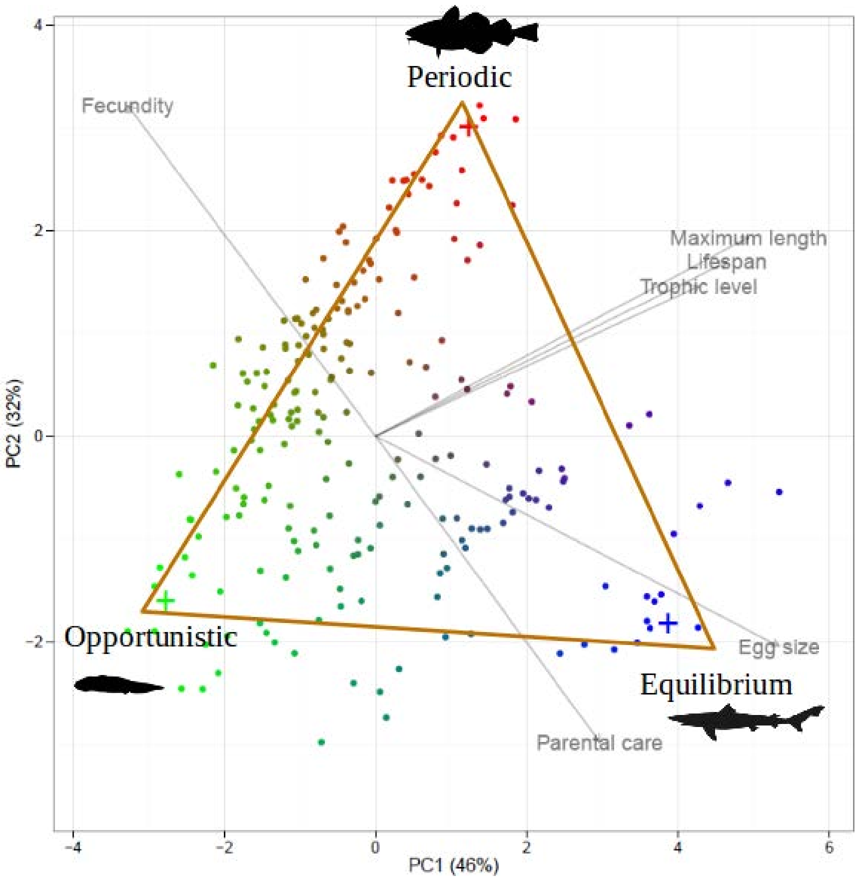


**Figure 3.1. An archetype analysis reducing multiple traits of species (e.g., Pecuchet *et al.*, 2017) down to a single metric suitable for use as an indicator of sensitivity to climate change The first and second principal components (PC1 and PC2) from a principal component analysis are used as axes. Each species used in the study is represented by a dot. The three extreme points (archetypes) that encompass the trait-space are represented by crosses, corresponding to equilibrium (blue, e.g. school shark (*Galeorhinus galeus*), opportunistic (green, e.g., sand goby (*Pomatoschistus minutus))* and periodic (red, e.g. cod (*Gadus morhua*)) strategies, respectively.**

Although all of the CVAs discussed in this report used the standard FAO model, it is important to note that the exposure and sensitivity (as well as adaptive capacity) terms varied widely among the various approaches. The exposure and sensitivity terms depended on the degree of biological (process) knowledge of target species and the spatial scale of the CVA. Most of the studies included biological attributes of fish and shellfish with regard to their potential exposure and sensitivity to climate change but the traits used to define sensitivity depending on the richness of understanding of life history strategies, essential habitats and potential bottlenecks for persistence of local stocks / populations. Extensive and unique lists of exposure terms and sensitivity traits were employed in CVAs performed on fisheries resources at regional spatial scales (relevant for stock management) when high-resolution, downscaled physical model outputs were available (e.g. Studies 3, 12 and 19). In contrast, data poor areas or CVAs conducted at much larger (e.g. global) scales normally employ a short list of more general indicators (e.g. sea surface temperature and fish length); (Figure 3.2).

| Exposure Terms (9 studies) | Biological Sensitivity (8 studies) |
|---|---|
| (7) Sea Surface Temperature | (5) Maximum Length |
| (4) Precipitation | (5) Fecundity (absolute or specific) |
| (4) Currents | (5) Trophic Level |
| (4) Subsurface Oxygen | (4) Parental Care |
| (3) Water Column Salinity | (4) Life Span |
| (3) Ocean Acidification (pH) | (4) Egg Size |
| (3) Sea Surface Salinity | (4) Habitat Specificity |
| (2) Air Temperature | (4) Prey Specificity |
| (2) Phenology of upwelling | (4) Sensitivity to Ocean Acidification |
| (2) Sea Level Rise | (4) Sensitivity to Temperature |
| (2) Bottom Temperature | (4) Stock Size/Status |
| (1) Midwater Temperature | (4) Other Stressors |
| (1) Wind | (4) Adult Mobility |
| (1) Adult Thermal Habitat Loss | (3) Spawning Cycle |
| (1) Loss of Larval Thermal Window | (3) Complexity in Reproductive Strategy |
| (1) Loss of Spawner Thermal Window | (3) ELH Survival / Settlement Requirements |
| (1) Chl-a (Proxy for Productivity) | (3) Population Growth Rate |
| (1) SST Anomalies | (2) Dispersal of Early Life Stages |
| (1) Total Suspended Matter | (1) Historical range of SST values |
| (1) Tidal Ranges | (1) Historical range of Chl values |
| (1) Ultraviolet Radiation | (1) Habitat richness and cover |
| | (1) Species richness and cover |

**Figure 3.2. Lists of exposure and sensitivity terms employed within some of the studies summarized in this report. The number of studies using a term is shown in parentheses.**

There remains a need for comparison among methods, particularly qualitative vs. quantitative approaches for systems where data are available to see which biological traits contribute most to methodological differences. These comparisons can aid the future iterations of CVAs conducted on living marine resources (fish and invertebrates). Furthermore, there are additional ecosystem components likely to be affected by climate change that can have direct as well as indirect effects on fished or farmed species. For example, the loss of key nursery habitats such as seagrass beds may exacerbate climate-driven declines in fish stocks and this indirect feature may not be captured in most CVA approaches. Commercially important species exists within food webs and the components of those food webs may be differentially impacted (positively or negatively) by climate change leading to altered predator-prey dynamics. For example, unfished species such as seabirds and marine mammals may offer significant predatory pressure on fished species such as forage fish (Peck *et al.*, 2014) and the effects of climate change on the strength of trophodynamic interactions will be challenging to project. For example, recent population growth in California sea lions has likely introduced competition and predation to a number of fished species, yet we will need additional approaches to incorporate these factors within ongoing vulnerability assessments.

# 4 Discuss best practices for extending vulnerability assessments of marine fish and invertebrates to vulnerability of coastal communities and identify a suite of representative concentration pathways for use in vulnerability assessments in the northern hemisphere (ToR C)

Social scientists have a longer history of employing CVAs than do natural scientists, with much of the seminal work performed on human communities (see Section 1). Extending CVAs to marine resources such as fish and shellfish and industries such as fisheries and aquaculture is a more recent phenomenon. Moreover, it is also noteworthy that a review of the vulnerability of fish and fisheries to climate change published in 2009 already urged researchers to use metrics in CVAs that extend "across economic, social, and biological attributes of fisheries" (Johnson and Welch, 2009 - pg 114). Therefore, a consensus from workshop participants was that the wording of this ToR was awkward and that the ToR could be more aptly written "Discuss best practices for merging biological, economic and social aspects of climate vulnerability" as this remains an important and currently debated topic.

Many coastal communities evolved through dependency on marine resources to satisfy social, cultural and economic needs. Close proximity to the sea can intensify the direct and indirect risks and potential benefits of climate change. Direct impacts include damage or disruption of activities due to storms and threats of loss due to sea level rise. Indirect impacts of climate change on fishing-dependent communities include changes in availability of fish stocks as a result ocean warming and acidification (IPCC, 2014; Ekstrom *et al.*, 2015; Colburn *et al.*, 2016). In order to thoroughly assess the direct and indirect impacts of changing climate conditions on these coastal communities, viable measures of social-ecological well-being and sustainability as well as measures of vulnerability, resilience and adaptive capacity are needed. An ongoing challenge for the application of the ecosystem approach for managing living marine resources is to find practical methods linking assessments of human and natural systems, and researchers performing CVAs are confronted with this same challenge.

Over the history of development and application of CVAs, methods and approaches have shifted from assessing the physical, ecological and socio-economic impacts of climate change at long temporal and large spatial scales to more thorough considerations of the adaptive capacity of social systems needed at shorter time and smaller (local/regional) spatial scales (Fussel and Klein, 2006). Different methods are best suited to perform CVAs at these different temporal and spatial scales. At large scales, top-down approaches have commonly employed global climate model projections of changes in ocean biogeochemistry and their potential impacts on resources utilized by local communities (e.g. Cinner *et al.*, 2013; Metcalf *et al.*, 2015). On the other hand, community-focused CVAs have employed bottom-up approaches drawing on historical and current local experiences to identify ways in which a community may be vulnerable under future conditions (Cinner *et al.*, 2013; Ekstrom *et al.*, 2015).

There are notable examples of CVAs which bridge both ecological impacts on living marine resources and the human communities that depend on them. Ekstrom *et al.* (2015)

examined the vulnerability of shellfish to projected changes in aragonite saturation of coastal waters due to ongoing ocean acidification as well as other, more manageable pressures such as eutrophication (Study 15). In that study, vulnerability took into account not only physiological impacts of aragonite saturation level on shellfish but also attributes of local fishing communities. These attributes included their economic dependence on the resource (value of catch, number of jobs, % total revenue from shellfish) as well as their adaptive capacity (alternative job options, preparedness of state legislation, research money available to advance knowledge of climate change impacts). Results highlighted US regions most vulnerable to ocean acidification (and why), important knowledge and information gaps, and opportunities to adapt through local actions. The research illustrated the benefits of integrating natural and social sciences to identify actions and other opportunities while policy, stakeholders and scientists are still in relatively early stages of developing research plans and responses to ocean acidification.

Most of the examples of community-focused vulnerability assessment discussed in this workshop employed the top-down approach where species vulnerability to projections of global change were linked to community patterns of resource dependence to evaluate coupled social-ecological vulnerability (e.g. Cinner *et al.*, 2013, Figure 2.1). This framework captures future climate impacts that will accrue through the ecosystem, typically represented as an aggregate vulnerability of the species targeted by fisheries in the community. The examples in the workshop, however, did not account for direct climate impacts on the social system. Moreover, few examples proposed scenarios of how the socio-economic system itself may evolve in the future and how those changes will feedback to affect climate vulnerability. Two projects represented at the workshop (CERES and NEUS COCA); (Studies 8 & 13) include scenarios of social change. CERES has established scenarios of socio-economic futures for European fisheries and aquaculture sectors (CERES, 2016) that are defined through Shared Socioeconomic Pathways (SSPs). These SSPs were designed by the IPCC to be used alongside Representative Concentration Pathways (RCPs) to analyze feedbacks between climate change and socioeconomic factors (see van Vuuren and Carter, 2014). The NEUS COCA project will evaluate how implementation of climate adaptation strategies may buffer climate impacts in selected coastal fishing communities in the northeastern seaboard of the USA.

One approach presented in the workshop described a bottom-up community vulnerability assessment. Ongoing work in West Africa (Study 20) is collecting basic data on fishing activities and perceived changes in those activities along with information on household economics, fishery management strategies, and perceptions of environmental change as an initial step towards a vulnerability assessment. Key differences between this bottom-up approach and the top-down assessments include the use community-derived metrics of vulnerability and a more holistic representation of climate impacts that extends beyond impacts transmitted through species vulnerability in the ecosystem.

The types of metrics used to gauge the vulnerability of human communities to climate-driven changes in fish and shellfish resources included the: i) proportional value of fisheries and/ aquaculture activities, ii) proportion of the community that directly (or indirectly) engages in either fishing or aquaculture, iii) the diversity of species caught or grown, iv) the level of poverty and/or education, and v) the existence of governance systems with flexibility to cope with climate-driven changes in resources. Similar metrics were used across a wide range of socio-economic conditions including industrialized fishing fleets and fishing communities (ports) on the east coast of the USA to artisanal fishing communities on coral reefs in the Caribbean (Study 22). It is important to follow the best methodological choices that allow for comparative studies. In fisheries CVAs addressing social adaptive capacity, a recent study by Monnereau *et al.* (2017) reported that not scaling indicators to population sizes, having a small number of indicators and not taking into account redundancy lead to inaccurate results in the past.

### Future advances needed in community vulnerability assessments

This workshop was designed to compare and discuss CVAs relevant to the fisheries and aquaculture sectors. The goal of many of these CVAs was (s) to inform science-based advice needed for resource management and policymakers. Most of the assessments (see Table 1.1 – 1.6) focused on the exposure and sensitivity of commercially important species to climate change. This focus poses several important limitations, and workshop participants identified advances needed to provide more holistic assessments of the vulnerability of fisheries- and aquaculture-dependent human communities to climate change. Importantly, no studies had examined the exposure of the socioeconomic dimension to direct climate change impacts in CVAs. Fishers and fishing communities can be directly exposed to climate change impacts (i.e. risk at sea or damaged infrastructure –see Badjeck *et al.*, 2010). In one key example discussed during the workshop, Colburn *et al.* (2016) examined the potential for sea level rise to impact on shore-side infrastructure and businesses that support commercial and recreational fishing industries (Study 12). Similar work is underway in Canada (Studies 4 & 6). Importantly, climate-driven sea level rise, increased storm surge, and more frequent flooding will also impact businesses affiliated with fishing activities such as gear storage areas, marinas, bait and tackle shops, processing plants, transportation networks connecting local ports to regional and distant markets.

The potential socio-economic impacts of climate change on fisheries operations and markets was reviewed in a recent climate change assessment report published for the North Sea region (Pinnegar *et al.*, 2016). A total of 11 potential impacts on fishing operations and 8 potential impacts on fish markets and commodity chains was listed. The former included those related to increased storminess (e.g. vessel safety and stability, damage to fixed gears, ports, harbours and land-based processing facilities, disruption of transport routes to market). The latter included whether or not future markets were available for novel species and the added cost of increased fuel usage to follow shifting resources. An important element will be the extent to which fisheries management and policy become "climate-ready" such as revisiting i) national share of the total allowable catch set in 1985, ii) the timing and location of protective measures to effectively safeguard spawning and nursery areas, and iii) regulations restricting the by-catch of 'choke species' that constrain fishing operations (Pinnegar *et al.*, 2016). The summary provided by Pinnegar *et al.* (2016) highlights the potential complexity of the vulnerability of coastal communities to climate change. Examples from Australia (not included in the workshop comparisons) demonstrates how vulnerabilities in the supply chain can be identified and evaluated using complementary methodologies, such as the supply chain analysis (Plaganyi *et al.*, 2014), or economic resilience (van Putten *et al.*, 2013).

Finally, the workshop offered the opportunity to discuss whether or not the vulnerability metrics derived for ecosystem and social systems should be consolidated to produce one metric similar to the Ocean Health Index (Halpern *et al.* 2012) and, if so, how to accomplish this. In one example, a vulnerability assessment provided contrasting vulnerabilities of two New England, USA coastal fishing communities based on natural science (resource) and social science (economic, cultural); (Figure 4.1). Merging these various vulnerabilities into a single metric may lose information relevant for policymakers.

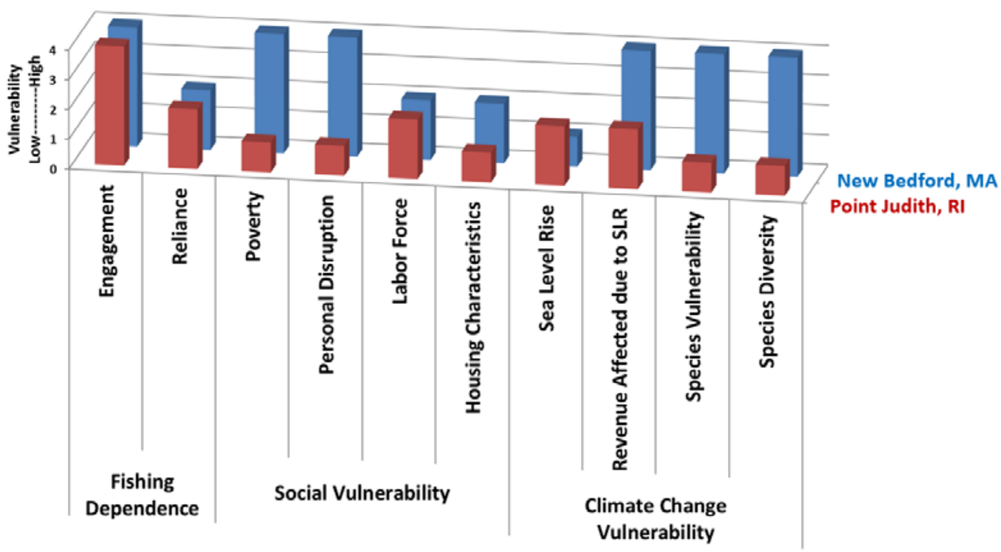


**Figure 4.1. Social-ecological climate vulnerability of two fishing communities in southern New England, USA (New Bedford, Massachusetts and Point Judith, Rhode Island) illustrating the various attributes that may offset or intensify climate vulnerability. This is research presented at the workshop by Lisa Colburn and colleagues at NOAA Northeast Fisheries Science Center.**

In this regard, it is important to recognize that, even if metrics are not combined, the ability to 'cross walk' between ecosystem and social information is essential. For example, ecosystem metrics need to have location information allowing one to incorporate them into socio-economic analyses. Moreover, the extent to which these "biological" metrics can be localized will influence the scale at which social vulnerability analyses can be conducted (i.e. whether analyses are conducted at the community, regional or national level).

# 5 Opportunities for operationalizing vulnerability assessment methods to enable updates (e.g., release of CMIP6 scenarios) and automating exposure assessments (ToR D)

An inevitable feature of any analysis that involves a substantial input of human effort is that they become dated over time. In the context of CVAs, two issues are particularly relevant. First, the IPCC assessment cycle leads to projections of climate change impacts on the earth system that are updated every five-to-ten years via the Coupled Model Intercomparison Project (CMIP). Second, our understanding of the marine biological system, and how it relates to both the physical and human systems, is improving constantly. In both cases, it is desirable to incorporate this new knowledge into climate vulnerability analyses. However, given the substantial investment of human expertise and resources that CVAs can require, it is relevant to ask which, if any, parts of the assessment process can be streamlined to incorporate updates, or whether assessment updates could be fully automated. We examine this question here by examining the various components of a CVA, particularly in the hypothetical context of updating a CVA between IPCC assessment cycles (e.g. from AR5 and CMIP5 to AR6 and CMIP6).

The first and perhaps most important part of any CVA is scoping, i.e. identification of the parts of the system that should be included in the analysis. In many cases, the 5-year period between subsequent IPCC updates is long enough that the system being examined, or at least parts of it, may have changed appreciably since the previous assessment. For example, fisheries can easily evolve within a five-year period and species that were not considered previously relevant may now support significant fisheries that need to be included (e.g. the recent development of the fisheries for boarfish in Europe). Similarly, technological developments may mean that new indicator variables become available that could not previously be considered (e.g. if reliable zooplankton modelling and projection products were to be developed). The performance of climate models is improving and models are changing (e.g. finer resolution) as are the climate scenarios being tested (e.g. from SRES to RCPs to SSPs). However, as scoping is highly dependent on human inputs, the need to incorporate new developments presents the first hurdle to possible automation.

Updating the inputs into CVAs regarding physical systems (i.e. climate model outputs) could potentially be automated. Outputs from the CMIP project are stored in standardized formats following well-established conventions and, therefore, updated data could, in principle, be coupled to existing processing scripts. However, some CVAs also employ downscaled projections derived from high-resolution regional models forced by global climate models: in this case updated climate model outputs would also need to be run through these downscaling systems. Given that the time lag between updates to global climate models can be up to a decade, regional ocean models are also likely to evolve. Thus, downscaling systems from previous assessments may not be appropriate as advances in both the modelling code base and particularly the available computational power (and therefore the complexity of the downscaling system) mean that it will be highly desirable to update the downscaling system between CVAs. The use of downscaled variables in CVAs therefore introduces a bottleneck in any potential automation scheme. On the other hand, downscaling is seldom done solely for the purposes of

CVAs, and a common motivation for downscaling is that global climate models may be too course-scale and imprecise to make meaningful inferences in some regions. Ongoing methodological developments in downscaling global climate models that occur in parallel with the CVA may mean that, in the future, downscaled projections will become more readily available to be incorporated.

Once the physical data are available, the subsequent calculation of exposure indicators is a process that can readily be automated. In particular, the generation of maps (e.g. of projected warming anomalies or "z-scores") for use by the experts performing the CVA can easily be automated. Species distribution maps can potentially be reused directly from previous assessments, although there may be a desire to update them to reflect both new knowledge / data and any potential distribution shifts that may have occurred between CVAs. The calculation of exposure metrics directly from the combination of species distribution and exposure maps could be done automatically via running the appropriate scripts. This type of automatization, however, has not been previously attempted and the level of resources required to achieve this may be high.

Updating biological sensitivity and adaptive capacity metrics is another step that may require some human input. In principle, these parameters should be time-invariant, as they (often) reflect the innate biological characteristics of the organisms in question. However, ecological processes such as acclimatization, adaptation and phenotypical plasticity can modulate the sensitivity of an organism to the environment over time. Few CVAs, however, take these processes into account due to uncertainty in this biological response (a form of adaptive capacity of the resource). ). Additionally, our knowledge of parameters now considered to be time-invariant can improve, particularly for stocks initially characterized as data-poor. Some CVAs that consider the current stock status as a measure of sensitivity, and these metrics would need to be updated as new stock assessments are available, a process that could be automated. The most important issue in updating these biological metrics though would be the desire to incorporate new knowledge and information. In cases where expert panels are used, this could potentially require the panel to be reconvened, introducing a second important bottleneck.

The socio-economic aspects of CVAs that are built on census data may in some regards be easier to update than the biological aspects. Socio-economic sensitivity and adaptive capacity are generally defined in quantitative terms based on metrics derived from public statistical databases: updating the CVA to incorporate the most recent values of these statistics is a process that could readily be automated. Data-rich societies and communities, where there is open and transparent access to public data, are particularly well suited to this type of updating. However, in cases where socio-economic metrics are generated based on interviews with stakeholders, for example, a high-degree of human input can be required to update the assessment, although it may be possible to circumvent this aspect to some degree by integrating the collection of CVA-relevant socio-economic data into other routine activities e.g. household surveys.

In conclusion, the automated updating of CVAs may be possible as both CVA methodology and data archiving evolve. However, there are bottlenecks, including the use of downscaled data and reliance on both expert panels (to assess biological sensitivity/ adaptive capacity) as well as interviews with stakeholders (to assess socio-economic sensitivity / adaptive capacity). Ultimately, the question of whether a specific CVA can be updated automatically depends on the specifics of that analysis. On the other hand, the fact that these bottlenecks can be recognized and, in many cases, avoided, suggests that it is possible to design assessments that can be updated automatically when that is a priority. Based on the implementation of CVA results, the necessity for updating a CVA on a regular basis should therefore be considered from the very start of the exercise and, if desirable, explicitly incorporated into the design of the assessment.

# 6 Short statements on climate change impacts and vulnerability for regional ecosystem overviews produced at ICES and potentially other organizations (ToR E)

The majority of participants of the workshop were associated with organisations that are mandated to provide and/or aggregate evidence on the exploitation and conservation of the marine environment in the North Atlantic. The provision of this evidence is evolving not only in terms of its substance but also in how that evidence is created (ICES, 2016; Marskak *et al.*, 2017). There is a shift to providing knowledge for the exploration of scenarios/trade-offs for application of the ecosystem approach for marine management (Cormier *et al.*, 2017). In the climate context, this would inform options for adaptation.

There is a necessity to reconcile local priorities with regional objectives (Harvey *et al.*, 2017). European countries subsidise rural fishing communities to maintain their fishing industries. This illustrates the importance of community cohesion as an objective within the CFP. Ultimately, it is likely that climate change will shift species distribution and impact these communities. These CVA's serve a slightly different role within developed as opposed to developing nations. In the context of the North Atlantic, CVA's can inform science-based advice on the management of specific stocks regarding the potential effects of climate change. Climate vulnerability assessment could also offer guidance on the allocation of fishing rights amid ongoing and projected shifts in distribution and abundance. CVAs can also contribute advice in relation to policy initiatives designed to maintain productive fisheries and aquaculture industries in remote regions and adapting to the challenges and opportunities brought by climate change.

Many organisations in developed nations charged with the stewardship of living marine resources are developing status of the ecosystem products within their suite of outputs (Table 6.1). These status reports generally provide information on the current state of the system and on recent trends in state and pressures. They are increasingly looking forward toward future management challenges or exploring future scenarios. The audience for these assessments is usually managers of the activities of maritime sectors and as well as the individuals in the general public who may be interested or knowledgeable in this field. Climate vulnerability assessments can play a key role in prioritising and highlighting upcoming threats, associated risks and exploring opportunities for adaptation. Thus, to stay relevant and credible in a time of changing climate, these status reports could include the latest projections of CVAs.

**Table 6.1. Recent examples of ecosystem status reports from across the North Atlantic.**

| Jurisdiction | Assessment Name | Web site |
|---|---|---|
| USA | Ecosystem Status Reports | https://www.nefsc.noaa.gov/ecosys/ecosystem-status-report/. |
| | New version Mid-Atlantic | http://www.mafmc.org/s/Tab02_2017–04_State-of-the-Ecosystem-and-EAFM.pdf |
| | New version – New England | http://s3.amazonaws.com/nefmc.org/2_2016-State-of-the-Ecosystem-Report.pdf |
| Canada | State of the Oceans Report (SOTO) | http://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2012/intro-eng.html |
| EU | Marine Strategy Framework Directive (MSFD) | http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm |
| OSPAR | Quality Status report | https://qsr2010.ospar.org/en/index.html |
| | Intermediate assessment 2017 | https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/ |
| Arctic (CAFF) | Arctic Marine Biodiversity Report | https://www.caff.is/assessments |
| HELCOM | Initial Holistic Assessment of Ecosystem Health of the Baltic Sea (HOLAS) | http://www.helcom.fi/Lists/Publications/BSEP122.pdf |
| | HOLAS II | http://www.helcom.fi/helcom-at-work/projects/holas-ii |
| ICES | Ecosystem Overviews | http://www.ices.dk/community/advisory-process/Pages/Ecosystem-overviews.aspx |
| | Fisheries Overviews | http://www.ices.dk/community/advisory-process/Pages/fisheries-overviews.aspx |

## Examples of status reports

### ICES ecosystem overviews

The ICES ecosystem overviews are one of the three main product types for ICES advice (Figure 6.1). http://www.ices.dk/news-and-events/news-archive/news/Pages/Explaining-ICES-approach-to-ecosystem-based-management.aspx. The overviews set the boundaries and the management context for each ecoregion and they describe the main trends in the ecology and exploitation of living resources. They also list the ICES assessment of the top anthropogenic pressures on the system (and the activities that cause that pressure). This assessment is aimed to be cross-sectorial. The overviews finish with brief descriptions of ecosystem state.

Climate change was not included in the first iterations of the overviews, as they focused on activities that are regional managed. However, they will include input on climate change in the next iteration. To remain relevant to regional managers, the overviews will need inputs from CVA to highlight the priority issues for action and the potential risks and opportunities to ongoing activities in each regions.

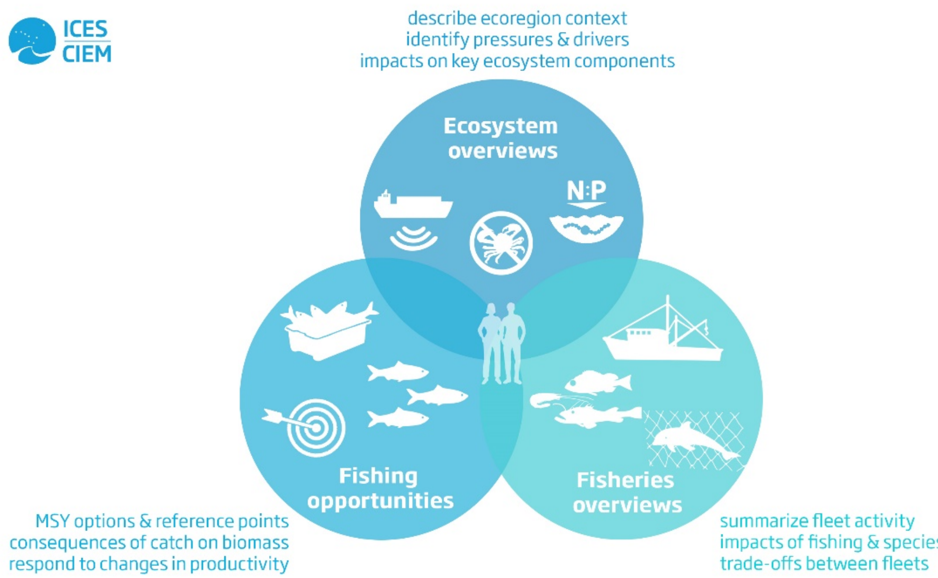


**Figure 6.1. The main advice products from ICES.**

#### NOAA NMFS Status of Ecosystem Reports

These reports are targeted at the regional Fisheries Management Councils. The NMFS CVAs are also targeted at the Councils, although some have been carried out to explore research prioritisation. Few of the status of the ecosystem reports contain inputs from CVA, although the recent New England and Mid-Atlantic reports incorporated social and cultural indicators from CVA, but the status reports across the USA do not as yet look forward to include potential risks and opportunities, thus highlighting to managers areas for development and action.

#### Canadian ecosystem overviews

Canada has had an evolving programme on ecosystem overviews beginning with descriptions of biogeographic regions and several regions now have regular updates on ecosystem trends. Climate change is not included as a separate section because in most ecosystem overviews, it is part of the changing seascape (e.g. http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/publications-eng.html;

http://dfo-mpo.gc.ca/oceans/publications/soto-rceo/2015/index-eng.html).

This basic monitoring information can be used in CVAs.

### Adding information on projected climate impacts to ICES ecosystem overviews

There are seven ecoregions, each of which has (or will soon have) an ecosystem overview (Table 6.2).

**Table 6.2. ICES Ecosystem Overviews – existing or forthcoming. These overviews provide a description of the ecosystems, identify the main human pressures (excluding climate change), and explain how these affect key ecosystem components.**

| Ecoregion | Date Produced |
|---|---|
| **Barents Sea** | *Published 04 March 2016; Version 2; 13 May 2016* |
| **Bay of Biscay & Iberian Coast** | *Published 04 March 2016; Version 2; 13 May 2016* |
| **Celtic Seas** | *Published 04 March 2016; Version 2, 13 May 2016* |
| **Greater North Sea** | *Published 04 March 2016; Version 2; 13 May 2016* |
| **Icelandic Waters** | *Published 10 April 2017* |
| **Baltic Sea** | *Forthcoming* |
| **Azores** | *Forthcoming* |

We advocate generating standardized outputs for each ICES Ecoregion using the NOAA Ocean Portal, that serves up ensemble outputs from the phase 5 of the Coupled Model Intercomparison Project (CMIP5) for anywhere in the world:

https://www.esrl.noaa.gov/psd/ipcc/ocn/ .

There are a number of potential maps and plots that can be generated for each region but, to keep this climate change section of the ecosystem overviews succinct, two plots (historical sea surface temperature (SST) and the difference between future and historical sea surface temperature) were chosen. Other parameters (e.g. salinity and pH) are available and could be included in specific areas where these other parameters are considered useful. For example, the same NOAA portal was used to create a multi-panel figure for the NE USA including 3 parameters and 3 future periods (Figure 6.2). In this example, a regional spatial planning body, this report agreed to use 3 parameters and 2 future time periods. These particular managers put low priority on displaying the standard deviation (SD) or uncertainty maps. Fishery managers, however, might find the SD more valuable. Finally, the portal can also plot the time course of warming which shows the variability among ensemble members (Figure 6.3).

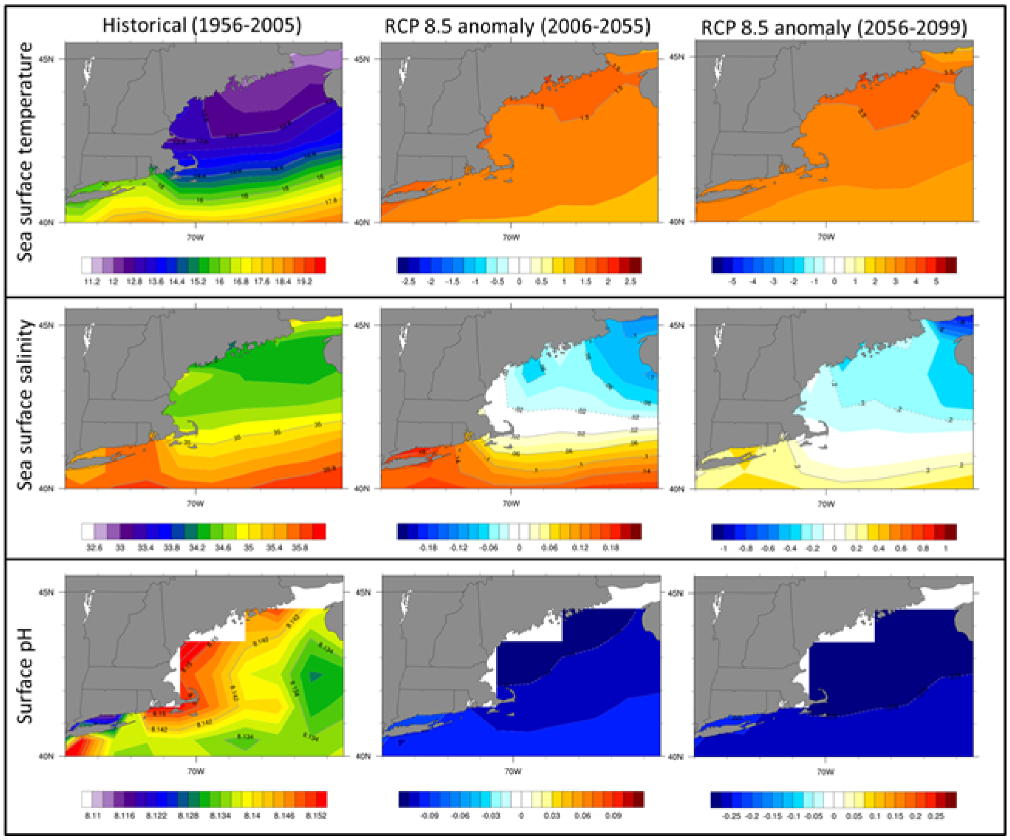


**Figure 6.2. Outputs from the NOAA portal used for a NE USA regional spatial planning body.**

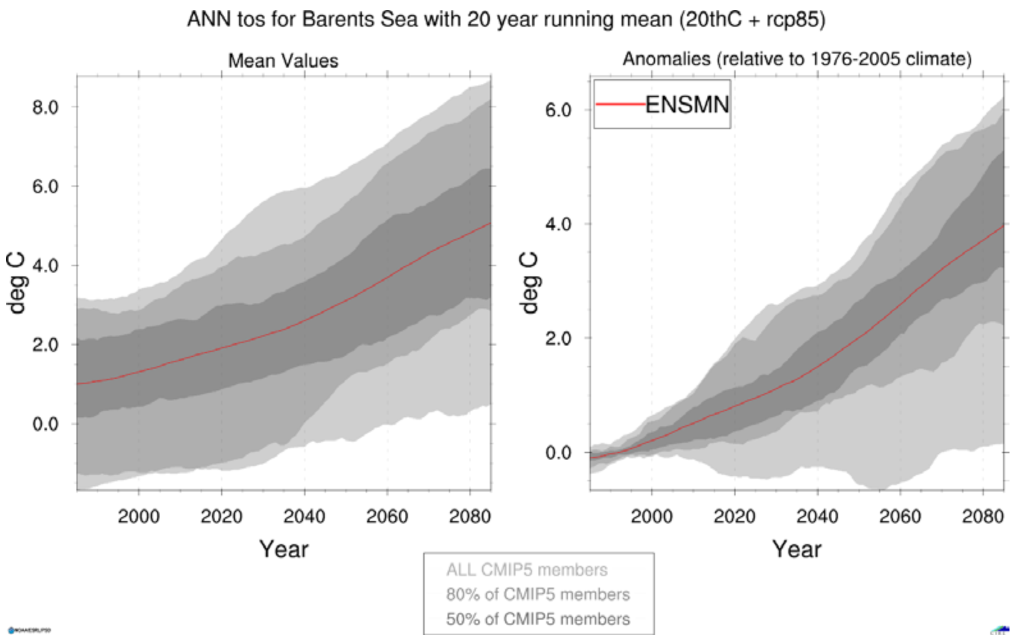


**Figure 6.3. Example of time series of yearly, mean SST for the 1976–2099 period for the Barents Sea. The simulations are forced using historical emission (1976 to 2005) and future projection (2006 to 2099) is under the RCP8.5 emission scenario. A 20-year running mean is applied. Figures show, the ensemble mean (ENSMN), in light grey, the spread of all the CMIP5 models, and in medium grey, and dark grey, 80% and 50% the spread of all the CMIP5 members, respectively. Left panel show the mean values and right panel shows the anomalies relative to the 1976–2005 climatology.**

As a first step towards including information on various pressures (other than fishing) within the ecosystem overviews, the following text and figures were created as a template to be filled in by experts working within a region. The yellow text should be completed by experts from each ecoregion. Regarding the figure(s), the NOAA portal provides the SST (historical and projected) within each of the six ecoregions and temperature data can be downloaded so that these graphs can be re-formatted.

## Barents Sea

- Climate change is expected to have important consequences for living marine resources. Some commercially important species targeted by fisheries are expected to be highly sensitive to climate-driven changes in hydrographic and/or chemical factors. Some areas are considered "hot spots" of change.
- At the global level, current greenhouse gas emissions are most closely tracking IPCC Regional Concentration Pathway (RCP) 8.5. Within the Barents Sea ecoregion, this scenario projects a 2.0 to 4.5 °C warming above mean conditions for years 2050–2099. There is, however, considerable spatial variability in projected warming (see Figure 6.4).
- Beyond anticipated changes in temperature, fisheries resources are expected to be affected by reductions in pH (ocean acidification), decreases in dissolved oxygen (hypoxia) and changes in salinity. In this particular region, shifts in X may have additional consequences on species Y…
- Distributional shifts are likely for most commercially targeted species which will promote losses and gains to current and future fisheries. In region X, shifts are expected to increase X and decrease Y.
- Forecasting the consequences of climate change for recruitment and overall productivity of commercially targeted fish stocks remains challenging and quantitative estimates are likely to remain highly speculative.
- Thus far there have been no detailed assessments of the effects of climate change on fleets and fishery-dependent communities in this region.

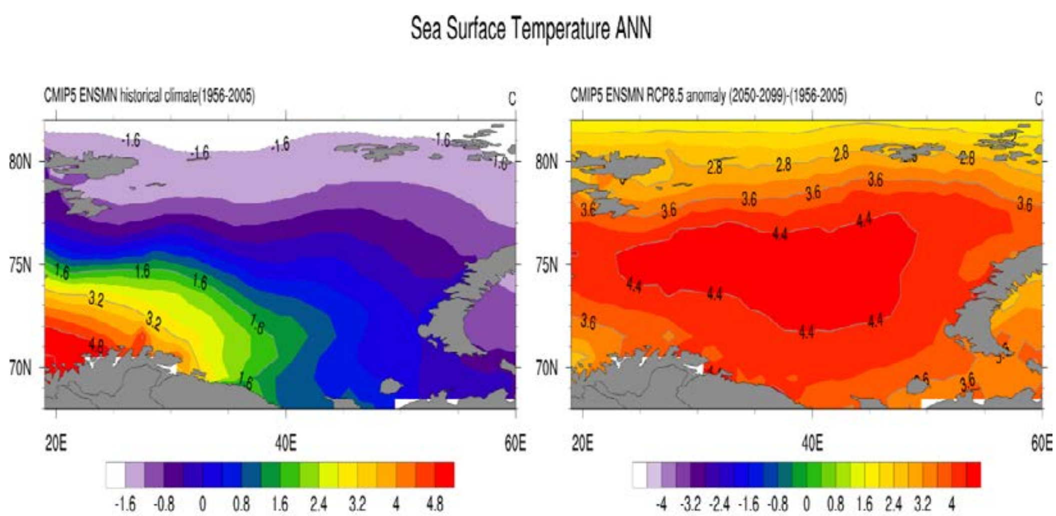


**Figure 6.4. Ensemble mean Sea Surface Temperature from the 5th Coupled Model Intercomparison Project (CMIP5) interpolated on a 1x1 grid for the entire year in the Barents Sea ecoregion. (Left) historical SST for the 1956–2005. (Right) difference in the mean climate in the future time period (RCP8.5: 2050–2099) compared to the historical reference period.**

## Bay of Biscay and Iberian Coast

- Climate change is expected to have important consequences for living marine resources. Some commercially important species targeted by fisheries are expected to be highly sensitive to climate-driven changes in hydrographic and/or chemical factors. Some areas are considered "hot spots" of change.
- At the global level, current greenhouse gas emissions are most closely tracking IPCC Regional Concentration Pathway (RCP) 8.5. Within the Bay of Biscay and Iberian Coast ecoregion, this scenario projects a 1.5 to 3.0 °C warming above mean conditions for years 2050–2099. There is, however, considerable spatial variability in projected warming (see Figure 6.5).
- Beyond anticipated changes in temperature, fisheries resources are expected to be affected by reductions in pH (ocean acidification), decreases in dissolved oxygen (hypoxia) and changes in salinity. In this particular region, shifts in X may have additional consequences on species Y…
- Distributional shifts are likely for most commercially targeted species which will promote losses and gains to current and future fisheries. In region X, shifts are expected to increase X and decrease Y.
- Forecasting the consequences of climate change for recruitment and overall productivity of commercially targeted fish stocks remains challenging and quantitative estimates are likely to remain highly speculative.
- Thus far there have been no detailed assessments of the effects of climate change on fleets and fishery-dependent communities in this region.

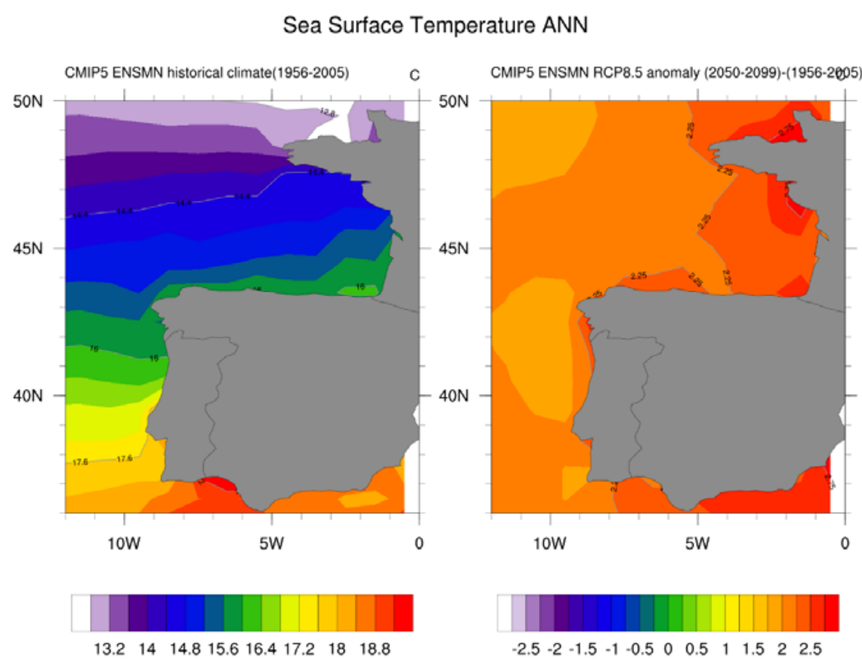


**Figure 6.5. Ensemble mean Sea Surface Temperature from the 5th Coupled Model Intercomparison Project (CMIP5) interpolated on a 1x1 grid for the entire year in the Bay of Biscay and Iberian Coast ecoregion. (Left) historical SST for the 1956–2005. (Right) difference in the mean climate in the future time period (RCP8.5: 2050–2099) compared to the historical reference period.**

## Celtic Seas

- Climate change is expected to have important consequences for living marine resources. Some commercially important species targeted by fisheries are expected to be highly sensitive to climate-driven changes in hydrographic and/or chemical factors. Some areas are considered "hot spots" of change.
- At the global level, current greenhouse gas emissions are most closely tracking IPCC Regional Concentration Pathway (RCP) 8.5. Within the Celtic Seas ecoregion, this scenario projects a 1.5 to 2.5 °C warming above mean conditions for years 2050–2099. There is, however, considerable spatial variability in projected warming (see Figure 6.6).
- Beyond anticipated changes in temperature, fisheries resources are expected to be affected by reductions in pH (ocean acidification), decreases in dissolved oxygen (hypoxia) and changes in salinity. In this particular region, shifts in X may have additional consequences on species Y…
- Distributional shifts are likely for most commercially targeted species which will promote losses and gains to current and future fisheries. In region X, shifts are expected to increase X and decrease Y.
- Forecasting the consequences of climate change for recruitment and overall productivity of commercially targeted fish stocks remains challenging and quantitative estimates are likely to remain highly speculative.
- Thus far there have been no detailed assessments of the effects of climate change on fleets and fishery-dependent communities in this region.

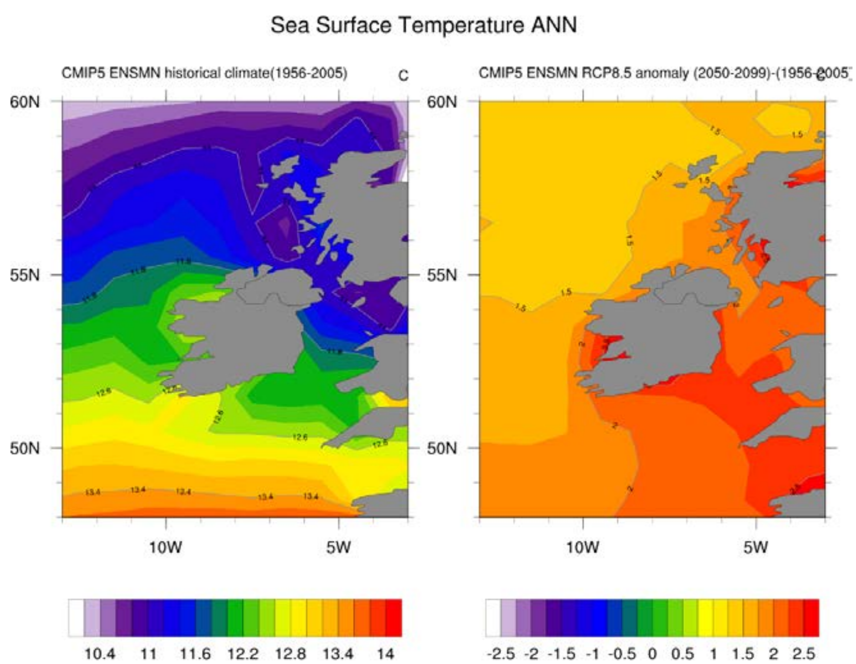


**Figure 6.6. Ensemble mean Sea Surface Temperature from the 5th Coupled Model Intercomparison Project (CMIP5) interpolated on a 1x1 grid for the entire year in the Celtic Seas ecoregion. (Left) historical SST for the 1956–2005. (Right) difference in the mean climate in the future time period (RCP8.5: 2050–2099) compared to the historical reference period.**

## Greater North Sea

- Climate change is expected to have important consequences for living marine resources. Some commercially important species targeted by fisheries are expected to be highly sensitive to climate-driven changes in hydrographic and/or chemical factors. Some areas are considered "hot spots" of change.
- At the global level, current greenhouse gas emissions are most closely tracking IPCC Regional Concentration Pathway (RCP) 8.5. Within the Greater North Sea ecoregion, this scenario projects a 1.5 to 3.0 °C warming above mean conditions for years 2050–2099. There is, however, considerable spatial variability in projected warming (see Figure 6.7).
- Beyond anticipated changes in temperature, fisheries resources are expected to be affected by reductions in pH (ocean acidification), decreases in dissolved oxygen (hypoxia) and changes in salinity. In this particular region, shifts in X may have additional consequences on species Y…
- Distributional shifts are likely for most commercially targeted species which will promote losses and gains to current and future fisheries. In region X, shifts are expected to increase X and decrease Y.
- Forecasting the consequences of climate change for recruitment and overall productivity of commercially targeted fish stocks remains challenging and quantitative estimates are likely to remain highly speculative.
- Thus far there have been no detailed assessments of the effects of climate change on fleets and fishery-dependent communities in this region.

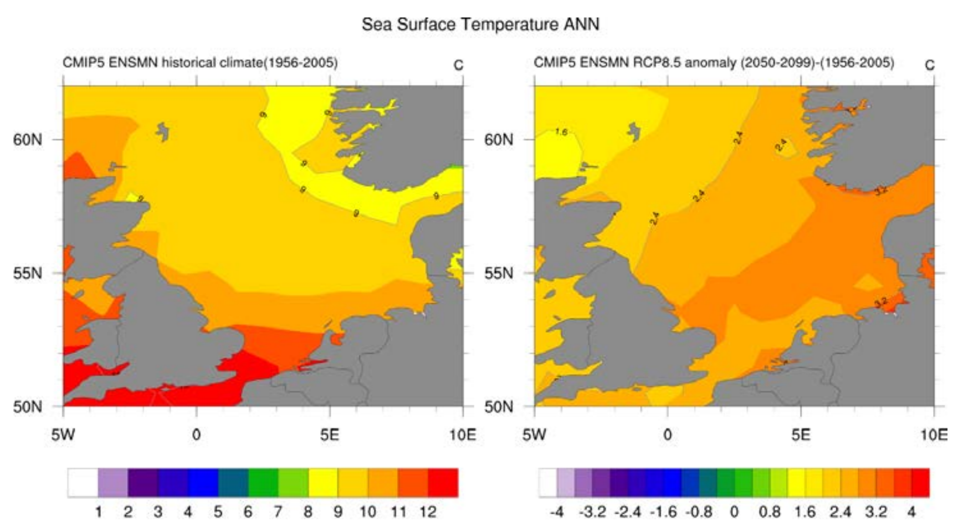


**Figure 6.7. Ensemble mean Sea Surface Temperature from the 5th Coupled Model Intercomparison Project (CMIP5) interpolated on a 1x1 grid for the entire year in the Azores ecoregion. (Left) historical SST for the 1956–2005. (Right) difference in the mean climate in the future time period (RCP8.5: 2050–2099) compared to the historical reference period.**

## Icelandic Waters

- Climate change is expected to have important consequences for living marine resources. Some commercially important species targeted by fisheries are expected to be highly sensitive to climate-driven changes in hydrographic and/or chemical factors. Some areas are considered "hot spots" of change.
- At the global level, current greenhouse gas emissions are most closely tracking IPCC Regional Concentration Pathway (RCP) 8.5. Within the Icelandic Waters eco-region, this scenario projects a 1.5 to 2.5 °C warming above mean conditions for years 2050–2099. There is, however, considerable spatial variability in projected warming (see Figure 6.8).
- Beyond anticipated changes in temperature, fisheries resources are expected to be affected by reductions in pH (ocean acidification), decreases in dissolved oxygen (hypoxia) and changes in salinity. In this particular region, shifts in X may have additional consequences on species Y…
- Distributional shifts are likely for most commercially targeted species which will promote losses and gains to current and future fisheries. In region X, shifts are expected to increase X and decrease Y.
- Forecasting the consequences of climate change for recruitment and overall productivity of commercially targeted fish stocks remains challenging and quantitative estimates are likely to remain highly speculative.
- Thus far there have been no detailed assessments of the effects of climate change on fleets and fishery-dependent communities in this region.

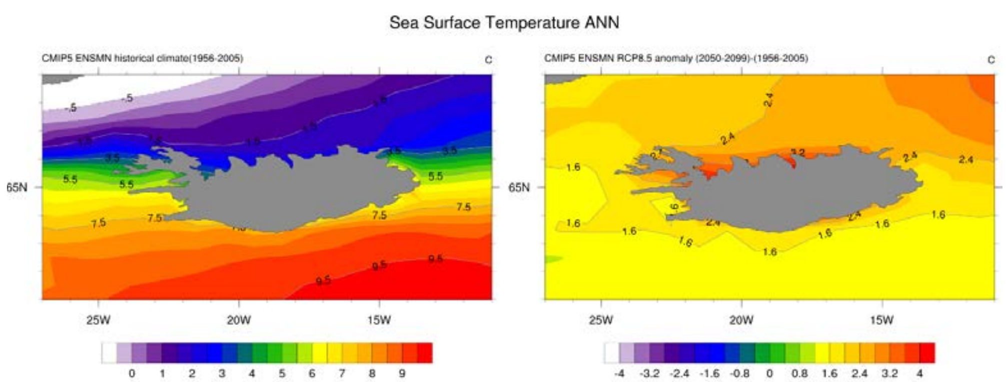


**Figure 6.8. Ensemble mean Sea Surface Temperature from the 5th Coupled Model Intercomparison Project (CMIP5) interpolated on a 1x1 grid for the entire year in the Icelandic Waters ecoregion. (Left) historical SST for the 1956–2005, (Right) difference in the mean climate in the future time period (RCP8.5: 2050–2099) compared to the historical reference period.**

## Norwegian Sea

- Climate change is expected to have important consequences for living marine resources. Some commercially important species targeted by fisheries are expected to be highly sensitive to climate-driven changes in hydrographic and/or chemical factors. Some areas are considered "hot spots" of change.
- At the global level, current greenhouse gas emissions are most closely tracking IPCC Regional Concentration Pathway (RCP) 8.5. Within the Norwegian Sea eco-region, this scenario projects a 1.5 to 4.0 °C warming above mean conditions for years 2050–2099. There is, however, considerable spatial variability in projected warming (see Figure 6.9).
- Beyond anticipated changes in temperature, fisheries resources are expected to be affected by reductions in pH (ocean acidification), decreases in dissolved oxygen (hypoxia) and changes in salinity. In this particular region, shifts in X may have additional consequences on species Y…
- Distributional shifts are likely for most commercially targeted species which will promote losses and gains to current and future fisheries. In region X, shifts are expected to increase X and decrease Y.
- Forecasting the consequences of climate change for recruitment and overall productivity of commercially targeted fish stocks remains challenging and quantitative estimates are likely to remain highly speculative.
- Thus far there have been no detailed assessments of the effects of climate change on fleets and fishery-dependent communities in this region.

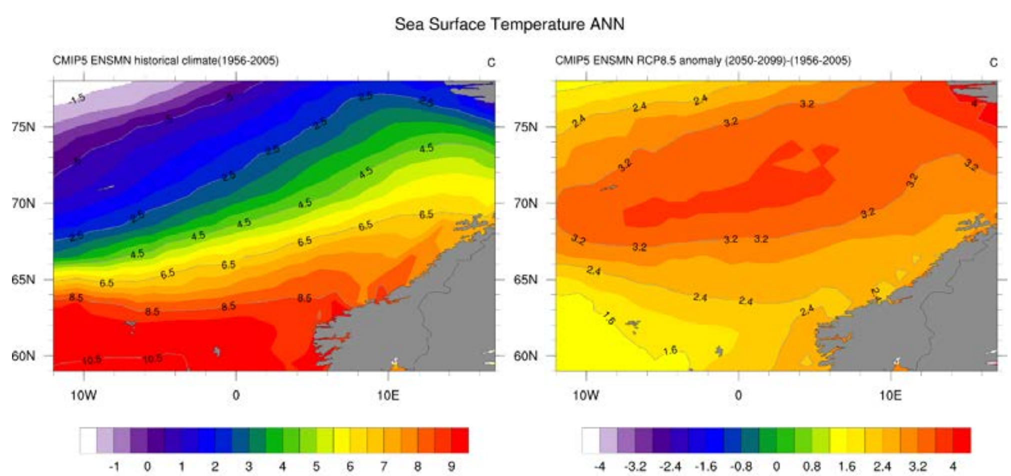


**Figure 6.9. Ensemble mean Sea Surface Temperature from the 5th Coupled Model Intercomparison Project (CMIP5) interpolated on a 1x1 grid for the entire year in the Norwegian Sea ecoregion. (Left) historical SST for the 1956–2005, (Right) difference in the mean climate in the future time period (RCP8.5: 2050–2099) compared to the historical reference period.**

## Baltic Sea

- Climate change is expected to have important consequences for living marine resources. Some commercially important species targeted by fisheries are expected to be highly sensitive to climate-driven changes in hydrographic and/or chemical factors. Some areas are considered "hot spots" of change.
- At the global level, current greenhouse gas emissions are most closely tracking IPCC Regional Concentration Pathway (RCP) 8.5. Within the Baltic Sea eco-region, this scenario projects a 2.5 to 4.0 °C warming above mean conditions for years 2050–2099. There is, however, considerable spatial variability in projected warming (see Figure 6.10).
- Beyond anticipated changes in temperature, fisheries resources are expected to be affected by reductions in pH (ocean acidification), decreases in dissolved oxygen (hypoxia) and changes in salinity. In this particular region, shifts in X may have additional consequences on species Y…
- Distributional shifts are likely for most commercially targeted species which will promote losses and gains to current and future fisheries. In region X, shifts are expected to increase X and decrease Y.
- Forecasting the consequences of climate change for recruitment and overall productivity of commercially targeted fish stocks remains challenging and quantitative estimates are likely to remain highly speculative.

Thus far there have been no detailed assessments of the effects of climate change on fleets and fishery-dependent communities in this region.

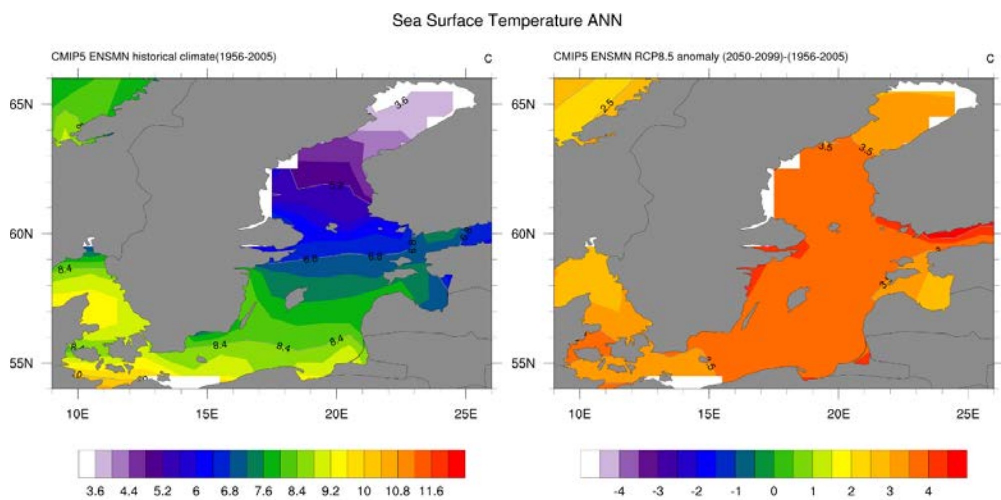


**Figure 6.10. Ensemble mean Sea Surface Temperature from the 5th Coupled Model Intercomparison Project (CMIP5) interpolated on a 1x1 grid for the entire year in the Baltic Sea ecoregion. (Left) historical SST for the 1956–2005, (Right) difference in the mean climate in the future time period (RCP8.5: 2050–2099) compared to the historical reference period.**

## Azores Ecoregion

- Climate change is expected to have important consequences for living marine resources. Some commercially important species targeted by fisheries are expected to be highly sensitive to climate-driven changes in hydrographic and/or chemical factors. Some areas are considered "hot spots" of change.
- At the global level, current greenhouse gas emissions are most closely tracking IPCC Regional Concentration Pathway (RCP) 8.5. Within the Azores eco-region, this scenario projects a 2.5 °C warming above mean conditions for years 2050–2099. There is little spatial variability in projected warming across this relatively small ICES ecoregion (see Figure 6.11).
- Beyond anticipated changes in temperature, fisheries resources are expected to be affected by reductions in pH (ocean acidification), decreases in dissolved oxygen (hypoxia) and changes in salinity. In this particular region, shifts in X may have additional consequences on species Y…
- Distributional shifts are likely for most commercially targeted species which will promote losses and gains to current and future fisheries. In region X, shifts are expected to increase X and decrease Y.
- Forecasting the consequences of climate change for recruitment and overall productivity of commercially targeted fish stocks remains challenging and quantitative estimates are likely to remain highly speculative.

Thus far there have been no detailed assessments of the effects of climate change on fleets and fishery-dependent communities in this region.

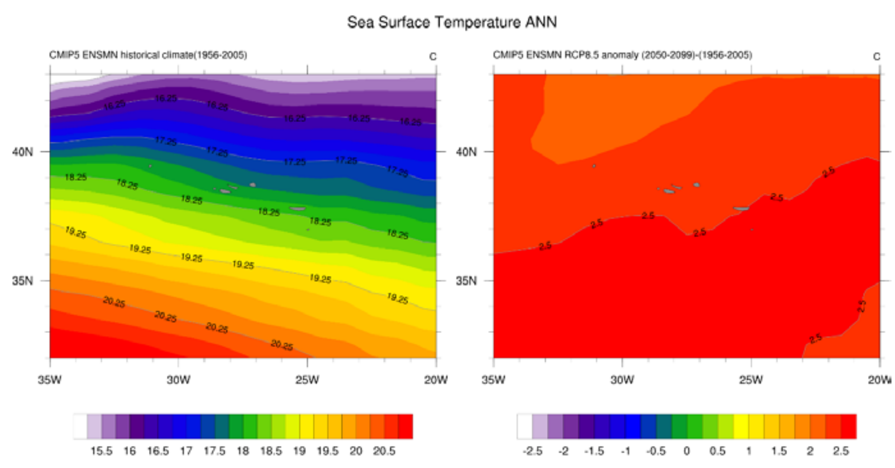


**Figure 6.11. Ensemble mean Sea Surface Temperature from the 5th Coupled Model Intercomparison Project (CMIP5) interpolated on a 1x1 grid for the entire year in the Azores ecoregion. (Left) historical SST for the 1956–2005, (Right) difference in the mean climate in the future time period (RCP8.5: 2050–2099) compared to the historical reference period.**

# 7 Concluding Remarks, Lessons Learned, Next Steps for CVAs of Fisheries and Aquaculture Species and Sectors

There are many purposes and levels of end-users of CVAs and CVAs can be tailored for the needs at hand. The advice and detailed guidance to perform CVAs is, therefore, specific to each individual application. CVAs have a longer history in many sectors and regions than they do in marine fisheries and aquaculture, and recommendations of best practices for vulnerability assessments have emerged from these experiences (FAO, 2015). Evaluating how approaches currently being applied in marine fisheries or aquaculture adhere to best practice recommendations from the vulnerability assessment field more broadly would help identify areas in which alternative approaches might be considered for improving the next generation of marine vulnerability assessments.

A list of generic "good practices" for conducting climate vulnerability assessment includes:

1. Conceptual/design lessons learnt for vulnerability assessments
    a. Define focus, context, purpose and specific question to address with the vulnerability assessment
    b. Select the framework and define the terminology
    c. Define scope of the assessment: spatial (community, region, country) and temporal scales (climate and socioeconomic projections)
    d. CVA should inform on the needs and priorities for adaptation in the systems and not encourage emigration to a different system (e.g. exiting the fishery), which is more of a policy decision.

One needs to be clear regarding the purpose of the CVA because the purpose will guide the methods and indicators used, the analysis conducted, and ultimately how the CVA is used to shape future research or management. Hinkel (2011) states 5 primary goals: i) Identify or justify mitigation targets, ii) Identify particularly vulnerable people and communities, iii) Raise awareness about the hazard and impacts, iv) Allocate adaptation funds to vulnerable regions, people or sectors, or v) Monitor the performance of adaption policy.

Lessons learned also include engaging stakeholders at multiple phases of the assessments from initial study design, participation in the CVA process, presentation of analyses, and communication of results. Clarity in the definition of exposure during presentation of the results will ensure that all parties involved are on the same page, as exposure can focus on physical exposure, biological exposure, or socioeconomic exposure (Badjeck *et al.*, 2010). Currently, most CVAs performed or underway are treating biophysical exposure and social exposure in two separate steps thus development of more integrated methods would help ensure results are defensible for both parts of the SES. Direction of impact is also often addressed separate from the CVA framework, for example in the US example directional affects were assessed after the bio-physical impacts. Adaptive capacity also can be considered capacity as an ecological adaptive capacity and/or social adaptive capacity, but some studies focus only on ecological vulnerability and methods for including social vulnerability varies. Developing methods for both uncertainty assessment and a framework for regular updating at the onset could improve longevity of CVA relevance. As CVAs are expanding around the globe, ensuring normalized results that allow for intra-regional comparisons would build upon regional assessments and could be useful for global level prioritization such as UN SDG-14.

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# Annex 1: List of participants

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**Figure A1. Group photo of participants of the ICES-PICES SICCME-CVA. Members of the group are (front, left to right) Elliott Hazen, Myron Peck, Kathy Mills, Nancy Shackell; (middle, left to right) Elena Ojea, Karen Hunter, Mark Dickey-Collas, Julie Ekstron, Juliana Arias-Hansen, Gretta Pecl, Lisa Colburn, Guillem Chust - (back, left to right), Mark Payne, Ignacio Catalan, John Pinnegar , Paul Spencer, Eddie Allison. Not pictured: William Cheung, Jörn Schmidt**

## Annex 2: Agenda

**Wednesday, 19 July (Day 1)**

| | |
|---|---|
| 9:00–9:10 | Welcome / housekeeping / introductions |
| 9:10- 9:20 | Discuss ToRs and discuss, modify and adopt the workshop agenda |
| 9:20–16:45 | Previous / Ongoing Climate Vulnerability Assessments - Workshop participants will briefly describe previous / ongoing activities on climate vulnerability assessment to provide a state-of-the-art background. |
| 9:20–11:00 | Regional presentations<br>9:20 Gretta Pecl<br>9:35 John Pinnegar<br>9:50 Myron Peck<br>10:05 Mark Payne<br>10:20 Juliana Arias-Hanse<br>10:35 Elena Ojea<br>10:50 Discussion / clarification |
| 11:00–11:20 | (break / coffee) |
| 11:20–12:30 | Regional presentations<br>11:20 Guillem Chust<br>11:35 Mark Dickey-Collas<br>11:50 Lisa Colburn<br>12:05 Kathy Mills<br>12:20 Discussion / clarification |
| 12:30–13:45 | (lunch) |
| 13:45–15:30 | Regional presentations<br>13:45 Elliott Hazen<br>14:00 Paul Spencer<br>14:15 Julia Ekstrom<br>14:30 Nancy Shackell<br>14:45 Karen Hunter<br>15:00 William Cheung<br>15:15 Ed Allison |
| 15:30–15:50 | (break / coffee) |
| 15:50–16:00 | Discussion of talks, particularly those in preceding time block |
| 16:00–16:30 | Small group brainstorm of ToR topics participants want to discuss |
| 16:30–17:30 | Comparisons and Contrasts (ToR A)<br>**ToR A: Compare and contrast various vulnerability assessment approaches used for fisheries and aquaculture including their strengths and weaknesses – develop a list of approaches and a matrix for comparison of pros and cons**.<br>Goal: Identify different approaches and set up matrix for comparison |
| 18:00 | Dinner—Pizza at ICES |

**Thursday, 20 July (Day 2)**

| | |
|---|---|
| 9:00 | Summary of discussions from Wednesday – open questions / issues |
| 9:10–10:00 | Vulnerability of Coastal Communities (ToR C)<br>**ToR C: Discuss best practices for extending vulnerability assessments of marine fish and invertebrates to vulnerability of coastal communities and identify a suite of representative concentration pathways for use in vulnerability assessments in the northern hemisphere**<br>Goal: Identify different approaches and set up a matrix for comparison |
| 10:00–10:45 | Small groups: populate comparison matrices for ToR A and ToR C, identify best practices for species and community vulnerability assessments |
| 10:45–11:00 | Share small group progress |
| 11:00–11:20 | (break / coffee) |
| 11:20–12:30 | Comparative Studies<br>**ToR B: Discuss opportunities for comparative studies looking at the relative vulnerability of species in different Large Marine Ecosystems (LMEs);**<br>Goal: Identify potential comparative study topics related to species and community vulnerability assessments |
| 12:30–13:45 | (lunch) |
| 13:45–14:45 | Operationalizing Climate Vulnerability Assessments (ToR D)<br>**ToR D: Identify opportunities for operationalizing vulnerability assessment methods to enable updates (e.g., release of CMIP6 scenarios) and automating exposure assessments** |
| 14:45–15:30 | Revisit remaining questions and topics of interest to the group |
| 15:30–15:50 | (break / coffee) |
| 15:50–17:30+ | Discuss potential format of review paper |
| 18:00 | (Group dinner, Höst) |

**Friday, 21 July (Day 3)**

| | |
|---|---|
| 9:00–9:15 | Review Thursday's accomplishments and remaining / open questions |
| 9:15–11:00 | Statements of Climate Vulnerability – Large Marine Ecosystems (ToR E)<br>**ToR E: Draft short statements on climate change impacts and vulnerability for regional ecosystem overviews produced at ICES and potentially other organizations).** Discuss potential inclusion in discussion section of review paper |
| 11:00–11:15 | (break / coffee) |
| 11:15–12:00 | Continue drafting |
| 12:00–12:30 | Meeting summary, next steps, final remarks and adjourn. |

## Annex 3: WKSICCME-CVA terms of reference for the workshop

**2016/2/SSGEPD07** A **Workshop on Regional climate change vulnerability assessment for the large marine ecosystems of the northern hemisphere (WKSICCME-CVA)**, chaired by Myron Peck* (Germany, ICES SICCME), Elliott Hazen* (USA, PICES: (S-MBM, co-Chair SG-CERP)) and Kathy Mills* (USA, ICES) will meet at the ICES Secretariat, Copenhagen, Denmark, 19–21 July 2017 to:

a ) Compare and contrast various vulnerability assessment approaches used for fisheries and aquaculture including their strengths and weaknesses;

b ) Discuss opportunities for comparative studies looking at the relative vulnerability of species in different LMEs;

c ) Discuss best practices for extending vulnerability assessments of marine fish and invertebrates to vulnerability of coastal communities and identify a suite of representative concentration pathways for use in vulnerability assessments in the northern hemisphere;

d ) Identify opportunities for operationalizing vulnerability assessment methods to enable updates (e.g., release of CMIP6 scenarios) and automating exposure assessments;

e ) Draft short statements on climate change impacts and vulnerability for regional ecosystem overviews produced at ICES and potentially other organizations.

**WKSICCME-CVA** will report by 10 September 2017 (via SSGEPD) for the attention of ACOM and SCICOM.

### Supporting Information

| | |
|---|---|
| Priority: | This workshop will contribute towards the ICES thematic areas: Understanding Ecosystem Processes and Dynamics (SSGEPD) and Ecosystem Pressures and Impacts (SSGEPI). Our focus will be on comparing previous (or ongoing) vulnerability assessments examining the exposure, sensitivity and adaptive capacity of living marine resources (fish and shellfish) and their dependent communities to climate change. This comparison is timely as separate groups have now established frameworks and SICCME can help coordinate future activities. Consequently, the activities of WKSICCME-CVA are considered to have a very high priority to ICES. |
| Scientific justification: | Climate change and ocean acidification pose significant risks to some marine species and the communities that depend on those species. Rapid assessment methods have been developed to assess these risks to marine life and humans based on qualitative ranking of risks based on a synthesis of data derived existing climate change projections and expert knowledge of the sensitivity of species or human communities to changing environmental conditions. These rapid vulnerability assessments typically involve an evaluation of the relative exposure and sensitivity of an organism to climate change. They are used to identify key gaps in on-going research and to identify potential risks to marine life and coastal communities. Task teams have been or are in the process of being formed to conduct vulnerability assessments in most of the ICES and PICES member nations. This workshop seeks to bring together scientists working on vulnerability assessments to discuss methods and analytical challenges. |

| | |
|---|---|
| Resource requirements: | The workshop is planned to take place at the ICES Secretariat. Meeting rooms and video conference facilities are required. Members of the ICES Secretariat are requested to help coordinate local (meeting) arrangements. |
| Participants: | Researchers involved in previous or ongoing vulnerability assessments in ICES and PICES nations including representatives from regional (e.g. OSPAR, HELCOM, GFCM) and international (FAO, UNEP-WCMC) policy groups charged with fisheries and aquaculture advice and management. |
| Secretariat facilities: | The workshop is to be held at the ICES Secretariate. Meeting rooms and video conference facilities will be required. |
| Financial: | No funding is requested from ICES. |
| Linkages to advisory committees: | ACOM/SCICOM Steering Group on Integrated Ecosystem Observation and Monitoring (SSGIEOM) |
| Linkages to other committees or groups: | This workshop contributes to the SCICOM Steering Group on Ecosystem Processes and Dynamics (SSGEPD) and to the SCICOM Steering Group on Ecosystem Pressures and Impacts (SSGEPI) |
| Linkages to other organizations: | FAO, OSPAR, HELCOM, UNEP-WCMC |
| 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. Nature Climate Change, Global Change Biology). |