WORKSHOP ON PATHWAYS TO CLIMATE-AWARE ADVICE (WKCLIMAD)

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Contents

i Executive summary

The Workshop on pathways to climate-aware advice (WKCLIMAD) met in the autumn of 2021 to develop a proposal for an advisory framework that accounts for the influences of climate change on aquaculture, fisheries, and ecosystems. The workshop worked through online sessions with over 40 participants.

Climate-informed advice should be provided through a risk-based framework that considers magnitude and likelihood of impacts, effectiveness and feasibility of measures. A wealth of data, tools and methods exists to on-ramp the advice. However, it is important to consider how these are utilised. To provide robust climate-informed advice, there is a need to identify and rank climate impacts and the associated risks, and match adaptation measures with public policy objectives. There must be a balance between actionable advice and reporting of uncertainty.

The next steps for ICES should be to evaluate these three recommended additions to the advice framework/principles:

- Development of a framework for spatial knowledge and advice, that includes definitions of temporal and spatial scale of management challenges.
- Proactive solicitation of experts and stakeholders in relevant fields. Co-production of knowledge with iterative feedback, accounting for the plurality of knowledge and participation mechanisms.
- Formulation of a plan for outputs, and communication, from the start of process, including allocation of sufficient resources to deliver advice.

Greater emphasis needs to be placed on the communication and co-creation of advice.

Climate-informed advice should include an assessment of current conditions in relation to the desired state. This requires not just an evaluation of the current state of the system, but the likely and/or desired future state of the fisheries/aquaculture system. This will also require greater effort on scoping of future scenarios of ecosystem state, and potential management measures for adaptation, and some mitigation. Advice should document the expected effects of specific management actions, giving attention to the potential distribution of management costs and benefits. Advice should be produced in response to requests but also be proactively produced by ICES. WKCLIMAD provides ICES with definitions, language and terminology that align with, and build on, those of the IPCC and calls on ICES to consistently use this terminology. The workshop also provides example lists of drivers, impacts, measures and potential actions.

ICES needs to attract expertise from beyond its traditional areas of ecosystem and population dynamics and oceanography. Engagement with the plurality of the knowledge base is required, as a mean to refine goals, explore trade-offs between management objectives, as well as to build a common understanding and build knowledge about the system and efficient pathways of action to governance. WKCLIMAD considered that to provide credible climate-informed advice, the evidence base needs to be strengthened in the following scientific fields:

- future scenarios of management options and ecosystem state
- risk, vulnerability and resilience analysis of species, ecosystems, and human communities
- spatial planning information and models
- trade-offs among potential actions, and incentives for best practice sharing including technological developments
- carbon accounting across the system
- monitoring and early-warning systems

ii Expert group information

Expert group name	Workshop on pathways to climate-related advice (WKCLIMAD)
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chair(s)	Kirstin Holsman, USA
	Mike Rust, USA
	Mark Dickey-Collas, Denmark
Meeting venue(s) and dates	21 June 2021, online
	2930 September 2021, online
	1820 October 2021, online

1 Introduction

1.1 Context of Workshop on pathways to climate-aware advice (WKCLIMAD)

The overall aim of WKCLIMAD is to develop a broad framework for climate-related advice that can be applied to different management and policy needs. Managers, decision makers, and other stakeholders are increasingly aware that they need to consider climate impacts in their decision making, but they often are not clear on how this can be effectively achieved. As outcomes of climate change become more pervasive, there is a need and expectation for ICES to evaluate and implement its plans for providing climate-related advice. This implementation should be consistent with other global and regional initiatives. Climate-enabled tools and predictive tools are increasingly available and deployed to improve management, and various frameworks have been proposed to integrate climate information into advice, yet an overarching synthesis is needed to categorize and summarize this wealth of information. WKCLIMAD occurs in an arena filled with much information and tools, and the challenge to ICES is to incorporate critically and transparently this evidence in order to provide clear, reliable and relevant advice to managers along with some insight about the trade-offs associated with different courses of action and potential implementation barriers.

WKCLIMAD was formed around three components:

1. Building a common understanding of best available evidence and expert opinion on climate change and its influence on fisheries and aquaculture.
2. Constructing actionable strategies and approaches that are appropriate for advice to managers of fisheries and aquaculture.
3. Bringing together the evidence and strategies in a proposed advice framework.

Identification of climate change impacts should include consideration of the temporal scales (short, medium and long-term) and spatial scales relevant to ICES ecoregions (including regional aspects such as environmental and ecological hotspots that are particularly vulnerable to climate impacts). Climate change forcing includes sudden climate events (marine heatwaves, low oxygen events, changes in circulation, altered oceanographic conditions) as well as more unprecedented rates of change over time (warmer waters declining pH) resulting in long-lasting impacts (e.g. shifting distributions or declines in productivity, changes in marine HABs and pathogen distributions/impacts, etc.). Climate change impacts also have social and economic consequences for people (e.g. job loss or gain in fisheries and aquaculture, altered access to nutritional resources and habitats, increased warmer water pathogens or increased spread of disease in aquaculture species, cascading impacts on human health and well-being, food security, dietary routines).

The review of the evidence base related to identified impacts ideally includes identification of key risks to ecological and social systems, associated with estimations of confidence (qualitative or quantitative) in terms of attribution, severity, and probability of occurrence. In this context, it is critical to communicate on best practices for testing, selecting, and implementing climate advice tools that can help estimate risk or opportunities, including tools to facilitate the assessment of variability and uncertainty.

Climate-related advice should include an assessment of the feasibility and effectiveness of mitigation and adaptation measures, providing managers a toolbox of actions that can enable fisheries and aquaculture systems to become more resilient to climate change.

1.2 Approach used

WKCLIMAD was an open workshop, advertised to ICES communications networks, message boards, news, and social media, with high interest from scientists and stakeholders. The final 44 participants came from National Research Institutes, Universities, and NGOs, with geographical distribution ranging within Europe, USA and Canada. The skillset and interests of the group were dominated by fisheries ecologists followed by aquaculture science experts, and included experts in climate change science, Ecosystem Based Fisheries Management (EBFM), bioeconomic models, phytoplankton ecology, socio-ecological adaptation, marine ecosystem resilience, fisheries economics, climate risk assessments, marine chemistry, and stakeholder interactions. WKCLIMAD participants were experienced in working and leading national and international projects on the effects of climate change in marine ecosystems and in developing operational strategies for climate aware fisheries and aquaculture management. During the online workshop participants actively worked in subgroups facilitated by a variety of experts.

As WKCLIMAD met during the global COVID-19 pandemic, all work was carried out through remote meetings and online exercises. Surveys, online meetings, and virtual whiteboards were used. A kick off meeting was followed by inter-sessional work leading to the two main workshop meetings (Figure 1.2.1). To fulfil its terms of reference, WKCLIMAD considered the drivers, risk of impacts, evaluation of measures and actionable e strategies (Figure 1.2.2).

A key component of WKCLIMAD was the use of a modified Delphi approach to populate risk/opportunity models for fisheries and aquaculture, and to assess the potential for management measures. Delphi asks experts to privately and individually rank issues related to a specific question, then brings the experts together to discuss the rankings, followed by a second round of private individual rankings of the same information. The result is an average of the rankings of all the experts (± a measure of variability, where n = the number of experts). Only the data from the second rankings is used for analysis. WKCLIMAD used the Delphi method to calculate average rankings based on opinions from groups of ICES experts on: likelihood and magnitude of climate forced hazards (risks) and/or beneficial impacts (opportunities); value of potential mitigation options (reduces climate change directly); and value of adaptation options (allows the activity to proceed in the face of climate change) for both seafood producing sectors. Rankings were developed for different temporal scales and management intensities.

An online brainstorming exercise and a literature review to identify climate drivers and potential impacts frontloaded the discussion at the main workshops (Figure 1.2.1). Once impacts to each sector where identified from the brainstorming exercise and literature review, a second online tool (Delphi 1.1) was used to ask experts to work as individuals to rank the magnitude and likelihood for each climate driven impact. The first workshop (day 1 and 2) was used to discuss the information from the rankings, and, in accordance with the ICES guiding principles, to develop a proposed format to consistently include climate information into ICES advice.

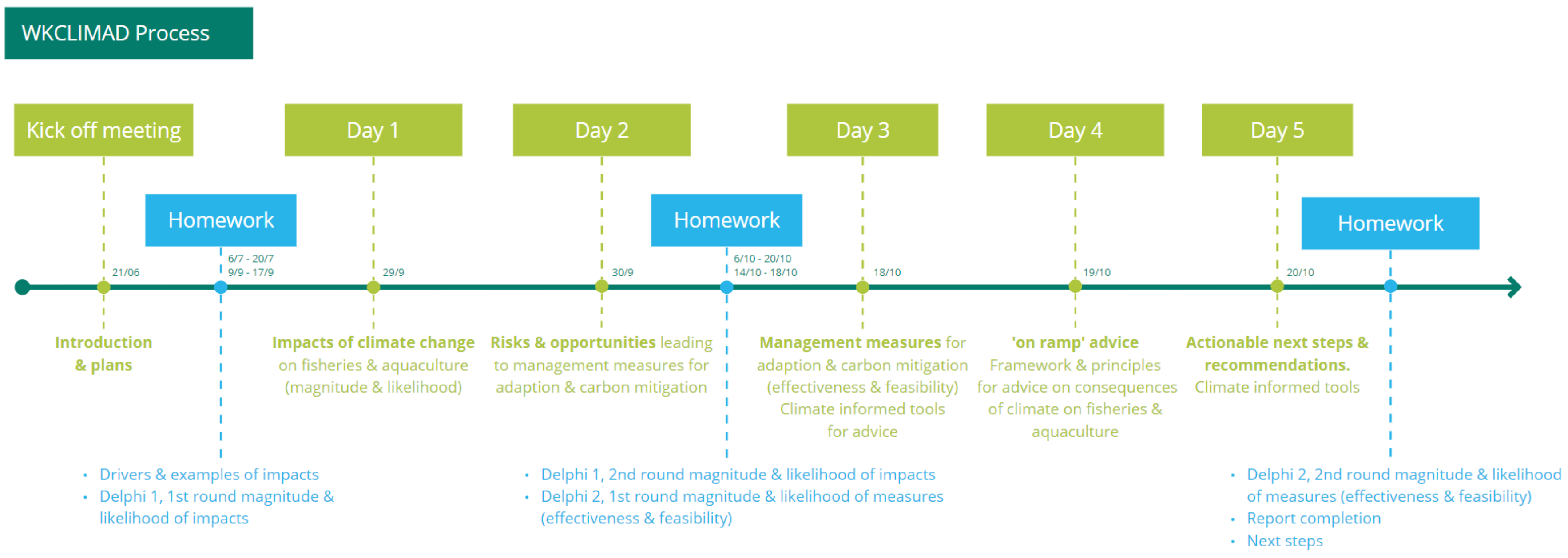

Figure 1.2.1. The timeline of WKCLIMAD process. Green boxes denote inter-sessional work.

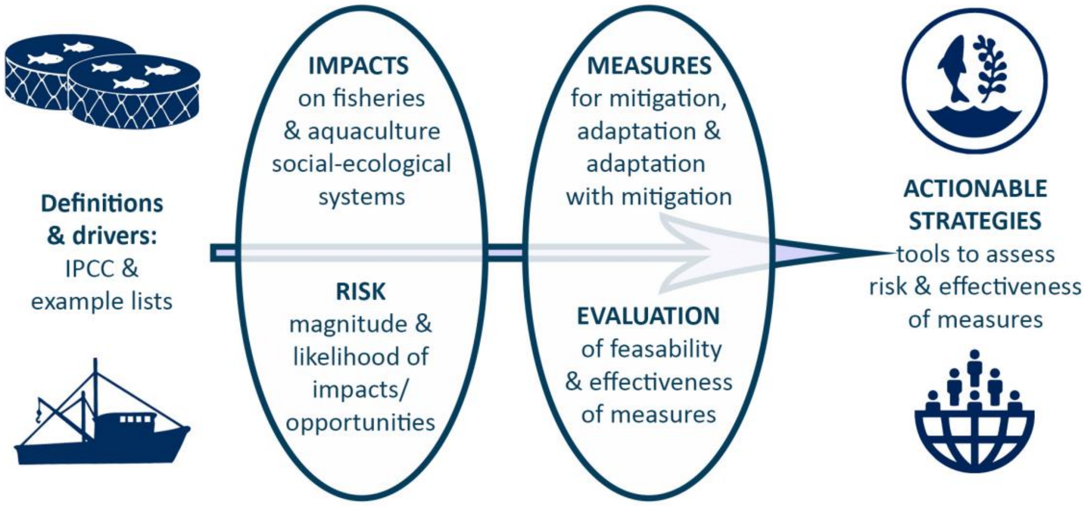

Figure 1.2.2. Schematic of the approach used by WKCLIMAD to deliver the terms of reference.

1.3 Background to ICES science and climate change

ICES has examined the impact of climate change on fish and fish populations for decades. Examples include the 1992 steering group on cod and climate, the partnership with the project GLOBEC in the 1990s and 2000s through the cod and climate change working group (WGCCC), the strategic initiative on climate change (SSICC) which ended in 2010, the ICES/PICES Working Group on Forecasting Climate Change WGFCCIFS which ended in 2011, and the current ICES/PICES Strategic Initiative on Climate Change Impacts on Marine Ecosystems (SICCME) which was established in 2011. This examination has been supplemented by the series of symposia on decadal variability of the North Atlantic (covering 40 years of observed change) and the four ICES/PICES/IOC/FAO symposia on the effects of climate change on the world's oceans.

The **Strategic Initiative on Climate Change Impacts on Marine Ecosystems (SICCME)** coordinates more than 20+ northern hemisphere efforts to understand, estimate and predict the impacts of climate change on marine ecosystems and dependent human communities. The objectives include advancing the scientific capacity by engaging the PICES and ICES scientific community in work targeting key uncertainties and technical barriers that impact the predictive skill of ocean models used to project the impacts of climate change, sharing and coordination around integrated modelling and coupled climate-ecological-social economic models, and innovation through collaboration with social and economic working groups to advance assessment of climate change impacts, risk, and adaptation effectiveness. The ICES-PICES SICCME recognizes that the timeline for projections (5-100 years) requires the development of (1) coupled biophysical models to mechanistically examine potential future climate scenarios, (2) behavioural models that include anticipated changes in marine resource use in response to both changing climate and changing marine policies aimed at mitigating climate impacts, (3) scenarios for expected changes in anthropogenic trends in marine resource use following trends in marine policy. Interdisciplinary research teams aim to develop climate-informed advice for decision makers, and the aim is for the ICES-PICES SICCME to identify approaches and operational practices that will facilitate and encourage the development of integrated scenarios of climate impacts on marine systems by engaging scientists from diverse backgrounds.

The **Workshop on Fish Distribution Shifts (WKFISHDISH)** found that 16 out of 21 commercially fished species show changes in their distributions across the northeast Atlantic since 1985, with hake (*Merluccius merluccius*) and mackerel (*Scombrus scombrus*) shifting the most (published in Baudron *et al* 2020). Of the species, eight exhibited distribution changes that crossed quota management and allocation boundaries. Environmental conditions such as sea temperature, in addition to changes in the distribution and intensity of fishing effort, were found to be strong drivers for these patterns of change.

The second **Workshop on Fish Distribution (WKFISHDISH2)** worked on producing a standardised and open-source way of routinely using trawl survey data to produce distribution maps which can be easily updated for fish, cephalopods, and crustaceans. Distribution maps produced during the workshop and the associated script are available at the ICES SharePoint.

The **ICES Integrated Ecosystem Assessments Steering Group** and **Aquaculture Steering Group** are incorporating Climate Change impact in the ICES Ecosystem Overviews and the Aquaculture Overviews advisory products. This work includes using the IPCC Regional Concentration Scenarios to outline the historical reference period of temperature in the various ecoregions and present evidence of observed climate change impacts on relevant environmental variables, ecosystem state components, and/or human activities based on past and present observations.

The ICES/PICES Workshop on Regional climate change vulnerability assessment for the large marine ecosystems of the northern hemisphere (WKSICCME-CVA) compared Climate Vulnerability Assessments (CVA's) on fish and shellfish and the human communities dependent on these resources in Large Marine Ecosystems. Most of these CVA's were conducted for regions of North America, Europe, and Australia, but global-scale as well as local/regional efforts in lower-income nations were also included. Findings of WKSICCME-CVA focus on the next generation of CVAs requiring a highly interdisciplinary and spatial approach, recognizing the unequivocal connections between marine systems and the prosperity of human communities. The integration of physically-driven natural science indicators with community-driven social science indicators will be necessary to advance CVAs. When linked across natural and social indicators, and when considering adaptive capacity, CVAs can be powerful tools for communicating and prioritizing risk from climate variability and change and planning adaptation.

The **ICES Working Group on Seasonal-to-Decadal Prediction of Marine Ecosystems (WGS2D)** studied ocean predictions on timescales from seasons to decades in order to support marine resource management. The main goals of the group were to develop and operationalize forecasts of marine ecological properties, such as distribution, recruitment, phenology. WGS2D's first forecast product was for the spawning habitat of blue whiting (*Micromesistius poutassou*) and it has been verified as effective.

The **ICES/ PICES Workshop on Political, Economic, Social, Technological, Legal and Environmental scenarios used in climate projection modelling (WKPESTLE)** focused on different futures of physical climate as well as societal development impact marine ecosystems and maritime activities. Short-, medium- and long-term developments in governance, social, technological and economic drivers will likely be just as important to the future development of fisheries and aquaculture as climate-driven changes in habitats and species abundances and distributions. WKPESTLE showed the scenarios being developed around the world to explore the impacts of anthropogenic drivers on marine systems.

The recently formed **ICES/PICES Working Group on Impacts of Warming on Growth Rates and Fisheries Yields (WGGRAFY)** brings together scientific expertise to assess the impact of warming on fish growth, and the implications for fisheries yield, on a global scale. The expert group develops statistical models to investigate growth patterns in commercial fish populations experiencing a variety of thermal conditions, ranging from cold upwelling regions (non-warming) to shallow regional seas experiencing strong warming. This comprehensive worldwide analysis will enable the group to build robust predictive models for forecasting the effect of temperature on future growth rates and fisheries yield. The group will also assemble a global database of fish length-at-age data accessible the scientific community.

Relevant ICES cooperative research reports include:

- Werner *et al*. 1999. Report of the Workshop on Ocean Climate of the NW Atlantic during the 1960s and 1970s and consequences for gadoid populations. ICES Cooperative Research Report No. 234. 85 pp https://doi.org/10.17895/ices.pub.5365
- Rijnsdorp *et al*. 2010. Resolving climate impacts on fish stocks. ICES Cooperative Research Report No. 301. 371 pp. https://doi.org/10.17895/ices.pub.541
- Reid and Valdés 2011. ICES status report on climate change in the North Atlantic. ICES Cooperative Research Report No. 310. 262 pp. https://doi.org/10.17895/ices.pub.5404
- The annually produced ICES reports on ocean climate.

1.4 Methods used

1.4.1 Brainstorming of potential impacts

An Excel worksheet was circulated to all of the participants. The purpose of the worksheet was to collect the range of climate change drivers that will impact fisheries and aquaculture (see initial list of candidate drivers in section 1.4.3). Participants were asked to consider this list of candidate drivers and adapt and revise as appropriate to their experience and understanding of the fisheries and aquaculture systems. They were asked to select a number of key drivers that impact fisheries and aquaculture and then consider the chain of impacts that these selected drivers will have on fisheries or aquaculture. Participants were also asked to consider direct and indirect impacts of their selected drivers and provide examples (with references) to support their selected drivers.

The worksheet asked the following:

Participant name and email address

Climate Impact driver (see candidate list in section 1.4.3)

Direct impact of the driver (negative or positive), whether this has been observed (past) or potential (future), the time period (years) and associated climate scenario

Indirect impact (can be negative or positive) whether this has been observed (past) or potential (future), the time period (years) and associated climate scenario

Adaptation response whether this has been observed (past) or potential (future).

Suggestions for adaptation improvement (including tools, approaches and policies that would have / will aid adaptation)?

References

1.4.2 Risk Model, Delphi method and definitions

Based on the responses from the brainstorming exercise, WKCLIMAD investigated using a Delphi method to populated risk models for fisheries and aquaculture as a starting point to communicating climate-aware advice. We were also interested in the opposite of risk for positive impacts from climate-driven processes. We termed these as "opportunities" and called the agnostic to positive or negative condition as simply "impacts". Conceptually the models are the same with the only difference being that mitigation and adaptation seeks to decrease the likelihood and severity of risks, but increase opportunities (Figure 1.4.1).

Specific definitions are as follows:

Climate Change Driver - Climate change induced environmental change that directly or indirectly impacts fisheries or aquaculture

Impact - Impacts are broadly defined and can affect physical, biological, economic or social parts of the ecosystem. Impacts can spur further impacts, i.e. akin to a chain of events, and can therefore be direct or indirect. They can also be positive or negative. In a classic risk assessment focused on negative impacts, the term "hazard" is often used for this concept however we are adopting the term "Impact" because we understand them as positive and negative, and to include the potential for a chain of impacts (indirect impacts).

Risk / Opportunity - The integrated negative (risk) or positive (opportunity) outcome of exposure, sensitivity, and response to climate change drivers and other impacts, and is influenced by inherent values, objectives, and priorities associated with different systems or individuals (and of those assessing risk or opportunities).

Confidence / certainty - The quality of evidence supporting estimates of risk, opportunity, and impacts and, effectiveness and feasibility of mitigation and adaptation

Mitigation - Short for "climate change mitigation" and refers to activities or policies that limit or reduce emissions of greenhouse gases or remove and sequester atmospheric carbon and therefore reduce the strength of climate change drivers in projection scenarios.

Adaptation - Active or passive responses, actions, policies, and planning to adjust to or reduce the impacts of current or future climate change (e.g., through reduction in the exposure, sensitivity, or other effects of climate change). Ranges from incremental and passive responses at local and regional level to large scale planning and transformation of social and ecological processes. Some adaptation measures have co-benefits for mitigation.

Strategic on-ramp tools: tools that will lead to the fulfilment of a broader strategic objective.

Tactical on-ramp tools: tools to be used for immediate action.

Information from the brainstorming exercise and from a review of the literature was used to inform the design of Delphi method and scope further focus on the impacts on fisheries and aquaculture (positive or negative), strength of the impact (severity, magnitude), probability of the impact (likelihood, exposure), potential adaptation and mitigation measures (feasibility and effectiveness) across different time frames. The brainstorming provided 119 responses for fisheries and 29 for aquaculture (see Annex 4).

The Delphi method is a well-established means of gathering expert input and quantitative information when objective data are unattainable, experimental research is unrealistic or unethical, or when heterogeneity of the participants must be preserved to assure the validity of the results (Hallowei and Gambatese 2010). Delphi has been used within ecology and biodiversity conservation for collating global expert opinion on the most important research questions and topics, (Pittman *et al*. 2021, Sutherland *et al*. 2013, Yates *et al*. 2018, Dey *et al*. 2020). Given the varied and fast changing state of best available science and uncertainty regarding future climate impacts on fisheries and aquaculture, a Delphi approach was deemed most appropriate for gathering information quickly and consistently about which impacts are the most concerning to a group of experts and for obtaining suggestions about how best to adapt to and mitigate the potential impacts identified. Delphi is complimentary to and influenced by the experimental data and model driven research that ICES (and others) has sponsored to date (see Section 1.3). It provides a systematic approach to collection of experts' subjective but informed opinions at a given point in time, presents data as an average opinion (ranking) and can be repeated relatively easily to track changes in the communities' perceptions, and/or to provide a consistent set of data that can be widely applied across topics, geographies, and industries which could be important for consistent advice.

There are known criticisms in using the Delphi method especially related to desirability biases during the ranking of the different impacts. Some issues that may have been present in our application of the method include:

- The 'Primacy Effect' i.e. whether or not climate outcomes that were always ranked first were afforded more weight with regard to likelihood/magnitude of effects and measures. To minimize this effect, the data collection tool was set to randomize the order of the issues to be ranked.
- Previous experience or highly read papers dealing with any of the climate drivers listed and their impacts may also lead to a higher ranking. This can be minimized by including a wide diversity of many experts (larger n) working on different parts of a single issue.
- Conversely, the strength of using a Delphi is to determine group homogeneity of thought on a specific issue based on common expertise (finfish, shellfish, seaweed and/or biologists/grower/restaurant owner, and/or natural scientist, economists, social scientist, manager etc.). For this reason, too much diversity can also reduce confidence.
- The expertise of participants relative to the research question needs to be matched. Industry-related outcomes may be rated as less likely to happen and less important due to mostly natural science panel members being more uncertain or unfamiliar with this area. The level of concern for and uncertainty around biological outcomes vs. those related to infrastructure or businesses may be higher for biologists than for fishers.
- The Von Restorff Effect where the outlier in a group is easier to focus on than a group of similar items.

To determine the level of desirability bias, Ecken *et al*. 2011 suggest asking Delphi panellists for their desirability of each projection along with their probability estimates and then to adapt/attenuate responses by these post hoc responses. In our case we could ask follow-up questions or provide instructions to such questions as:

- What do you consider as your level of expertise for each area and what was your confidence in the answers you provided based on?
    - We did ask this question as a part of the ranking tool, but it was hard to know what to do with low confidence responses.
- Were you more confident in your answers when the group appeared to agree?
- What are your assumptions when answering/ranking?
    - Did you assume technological innovation would emerge to address growing climate change challenges to aquaculture and fisheries, or did they assume status quo?
    - Did you consider the relative likelihood and magnitude of factors individually, or relative to one another?

As much as the organizers tried to anticipate and consider these questions and provide clear unambiguous instructions up front, dealing effectively with bias may only come with experience using the Delphi method. For this workshop we used a modified Delphi approach. The initial brainstorming survey and literature review identified climate impacts which were subsequently ranked by likelihood and magnitude using a ranking tool (Delphi x.1), followed by a Miro board exercise (Annex 3) and a repeat of the multi-part ranking tool (Delphi x.2). The Miro exercise offered a robust platform for conducting the discussion phase of the Delphi as it provided a unique opportunity for participants to interactively discuss and adjust the generated climate data in breakout sessions of 4-8 participants, split between fisheries and aquaculture. This approach was also valuable for the discussion of developing consistent advice, since the functionality of the Miro board allowed for highly participatory sessions where all users were expected to simultaneously add and edit content, and an intention to reduce the influence of the more vocal individuals of the groups.

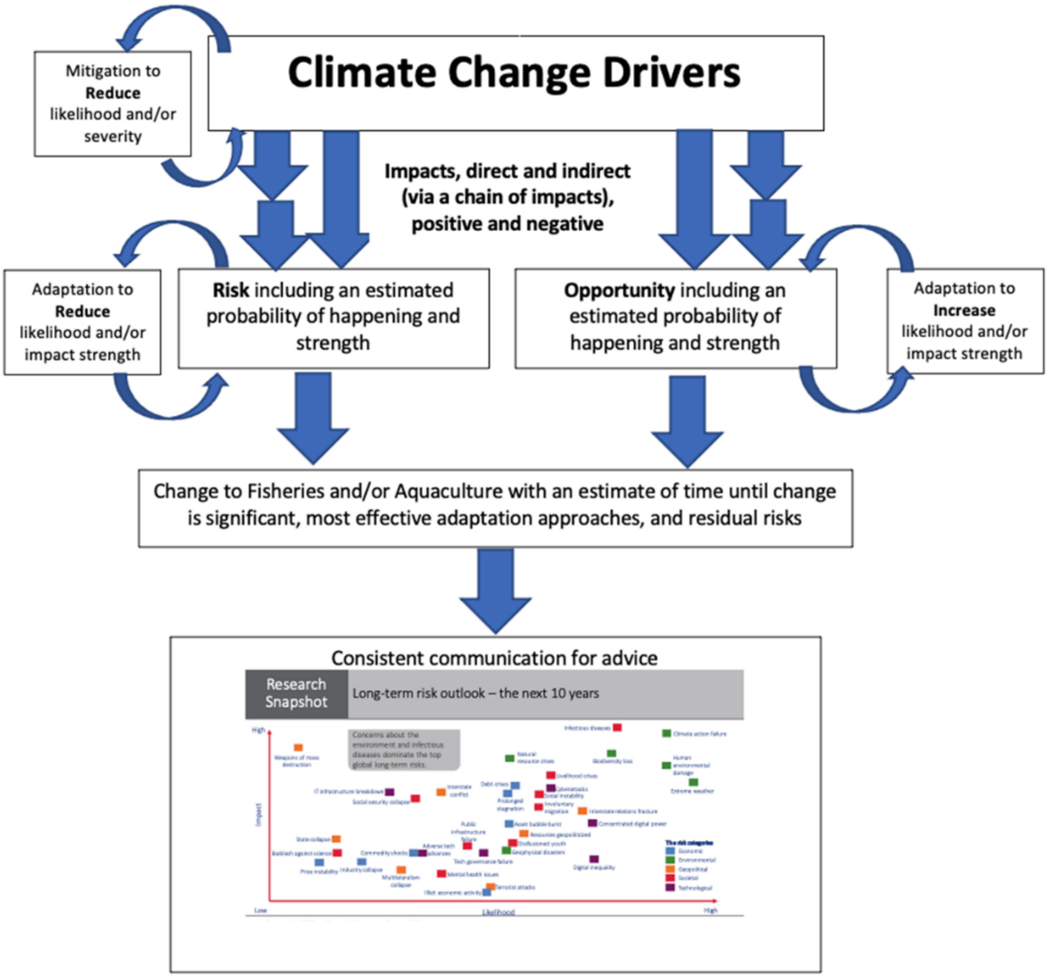

Figure 1.4.1. Risk and Opportunity models used by WKCLIMAD

1.4.3 List of candidate climate-related drivers of change

List of candidate climate drivers used to build common understanding, based on IPCC (Ranasinghe *et al*. 2021):

Climate Driver	
Ocean warming	Changes to frost
Marine heatwave	Changes to precipitation
Changes in ocean pH	Changes to river flood
Changes to salinity or mixed layer	Pluvial flood
Changes to dissolved oxygen	Landslides
Change to ocean circulation, current, and eddies	Aridity
Freshwater warming	Drought
Changes to phytoplankton bloom timing/location	Changes to wind speed/direction
Sea level rise	Severe wind storms
Coastal erosion	Sand/dust storms
Coastal flood	Changes to snow/land ice
Changes to lake, river, and sea ice	Loss of permafrost
Warming (air)	Snow avalanche
Extreme heat (air)	Air pollution
Cold spell	Atmospheric CO2
Heavy snow and ice storm	Surface radiation
Hail	

1.4.4 Remote meeting methods

The 5 days of workshop meetings (4 hours each) followed a similar approach. The work was carried out using Microsoft Teams for the conferencing platform and Miro virtual white boards for the synthesis exercises. The participants met in plenary and then split into subgroups to carry out the exercises and joined plenary at the end of the meeting. An example of the workplan from Day 2 is shown in Figure 1.4.2.

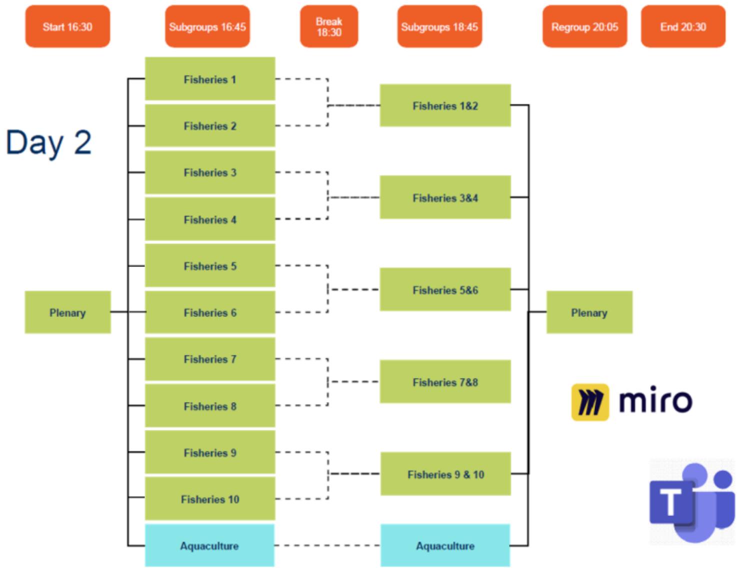

Figure 1.4.2. The workflow from day 2 of WKCLIMAD.

The work flows of the five days are provided in Annex 3.

1.5 References

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2 Exploring the evidence base on impacts, and mitigation and adaptation measures.

2.1 Impacts of climate change (mixture of direct and indirect impacts)

2.1.1 Listing of impacts

The participants of WKCLIMAD were requested to list impacts of climate change on fisheries and aquaculture, supported by examples and references. These impacts were reviewed by the Chairs of WKCLIMAD and the following lists of impacts were agreed by the workshop to be used as the basis for further discussions (Tables 2.1.1 and 2.1.2).

Table 2.1.1 Impacts of climate change on fisheries

Recruitment of fish	Range & Distribution
growth of fish	fecundity of fish
behaviour of fish	mortality of fish
phenology of fish life stages	spawning habitats
nursery habitats	connectivity of early life stages
migration routes	overall stock productivity
distribution of protected species	distribution of invasive species
distribution jellyfish and salps	harmful algal blooms (HABs)
disease & parasites	susceptibility to disease & pathogens
ecosystem 1° & 2° productivity	food web dynamics
pollutants	fishing opportunities
damage to fishing gear rate	fisheries management measures
seafood quality for human consumption	processing opportunities
markets & market access	interaction with other marine sectors

Table 2.1.2 Impacts of climate change on aquaculture

Distribution of Broodstock & Spawner Timing	Assimilation of Fish Waste
catastrophic effects (i.e. death) on cultured species	reproduction & growth
nutrient availability for seaweed (N, P, K)	availability of natural feed for filter feeders (phytoplankton)
availability of ocean-based feed ingredients (fish meal, fish oil)	distribution of wild broodstock
spawning timing	Growth
sublethal effects other than growth or disease susceptibility	pathogen & parasite presence
susceptibility to disease	pathogen/disease dynamics
wild seed production/juvenile availability	Survival
water chemistry/turbidity/salinity (e.g. from erosion/flooding)	water quality dynamics
dissolved Oxygen levels	normal phytoplankton bloom timing/location
frequency of damage to equipment/facilities	ability to access facility (days per year)
seafood quality pre harvest	seafood quality post-harvest
availability of terrestrial ingredients for fish feeds	habitat area suitable for aquaculture
location of shore-based processing facilities, docks, distribution centres	range of non-target species which impact aquaculture such as marine mammals, predators, protected species etc.
amount or toxicity of pollutants released into water/air.	target culture species range expansion/contraction
terrestrial crop production & impact on demand for aquaculture as food source	

2.1.2 Approach to impacts in terms of drivers

For fisheries, most of the impacts selected are bio/physically (ecologically) oriented and related to the fish themselves (life history, distribution and productivity impacts), but also included some industry-related impacts on processing, markets, etc. A course categorisation between ecological/biological impacts and those that relate more directly to human/management systems highlights the dominance of the former category. The impact of climate change via temperature on range and distribution is supported by the most robust evidence. For many other impacts and drivers, the effects are often indirect and robust evidence was harder to provide. The relevant time frames might also impact the ecological and human systems differently. In projections, drivers also differed in confidence as well. Given the input provided by the participants, there is insufficient confidence to distinguish and assess the relative contribution of individual drivers. As many of the climate drivers are strongly linked, individual/relative assessment may not be possible nor appropriate.

Impacts such as shocks were not selected, and respondents probably thought of continuous and long-term effects but not shocks. There is a bias in publishing, with fewer studies showing low magnitude impacts. This likely contributed to a desirability bias in our Delphi exercises as well.

It was likely that participants provided answers on the informal assumption that the impacts were sustained/consistent through time (especially since we were asked about their significance from short to long-term time frames) and not happening as a single extreme event. Similarly, the consideration of any impact was formulated without considering potential additive effects or the impact of new mitigation/adaptation measures.

It was clear that the participants of WKCLIMAD from the fisheries arena focused on the ecosystem and natural sciences elements of climate change impacts. The choice of IPCC scenario was not clearly specified. Less attention was given to emissions, governance, processing, markets and other socio-economic scenarios (including fisheries and marine governance). Given the primary expertise of most participants was in the biological sciences, this result is not unexpected. Participants may have made conservative assumptions about the behaviour of the system and its ability to adapt, based on the existing inertia of market and governance systems. The results would probably have been different if work had occurred on scenario building (about future states of the system), allowing consideration of threshold/breakpoint effects and non-linear behaviours in the system. Future workshops by ICES on climate informed advice would benefit from actively establishing a broader participant base.

The impacts identified from the aquaculture experts reflected the expertise of the participants. While there was relatively wide expertise on the production side (nutrition, disease, ecosystem interactions) and species group (shellfish, finfish, and seaweeds), there was a lack of expertise in economics and social sciences, nor were there representatives from industry or governance. In addition, due to the small total number of aquaculture participants, there was a lack of depth in each of the sub-disciplines, typically only one person with specific expertise represented an effect. Future exercises could be improved by having more sub-discipline experts first rank issues that are within their disciplines and then have the various groups come together for larger multi-disciplinary rankings. For example, first have aquatic disease experts (WGPDMO) focus on animal and plant health effects of climate using a Delphi focused on these impacts, have genetics experts (WGGAGFA) focus on genetic issues and so on for engineers (WGOOA), economists (WGSEDA), fish nutritionists (develop an adhoc group) and others, then bring them together to rank the rankings as a larger multi-disciplinary group.

2.2 Magnitude and likelihood of impacts

2.2.1 Comparison of first and second rounds of surveys in Delphi method

The discussion between the first and second Delphi rounds resulted in a change in perception of the magnitude and likelihood of climate impacts on aquaculture, whereas there appeared to be little change in the perception of climate impacts on fisheries (Figure 2.2.1). WKCLIMAD asked participants about their confidence in their rankings. Those that answered the fisheries surveys were more confident about their perceptions than those who answered the aquaculture surveys. In general, there was a positive correlation between likelihood, magnitude, and confidence across all time frames for all surveys. Contrastingly, there wasn't much differentiation of these patterns between the time frames themselves. In other words, both fisheries and aquaculture surveys (in the 1st and 2nd rounds) showed the property of a gradient from the lower left quartile to the upper right quartile of increasing confidence in their survey results. For aquaculture, the first Delphi round (1.1) lumped the aquaculture sectors whereas during the second (1.2), questions were separated into the different sectors of finfish, shellfish, and seaweeds. This may have contributed to the larger spread in responses for aquaculture during the second survey and for greater uncertainty in responses. Winkler and Moser (2016) concluded that confidence does not appear to be an indicator of accuracy. Rather, they find quantitative or argumentative feedback a more reliable indicator of accuracy. During the Miro exercises, participants were allowed to provide short text comments and justification regarding their suggestions to rate climate drivers higher or lower on the likelihood and magnitude scale. However, there was no opportunity for extensive feedback/justifications that may have had a stronger influence on the ratings prior to the final round of the Delphis.

As with all Delphi methods, the results reflect the strength of the available evidence and the expertise of the participants. The methodology and underlying respondent backgrounds (region, species, ...) mean that careful interpretation is needed when looking at the results.

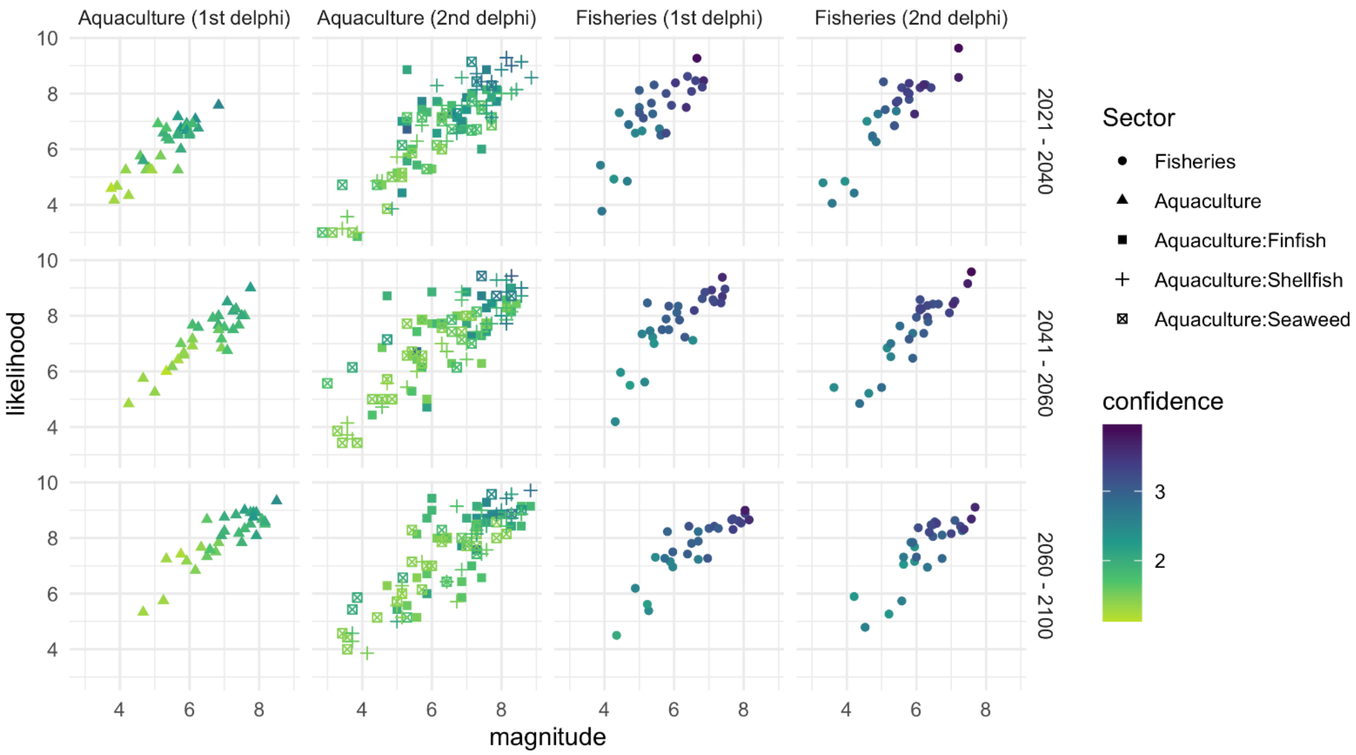


Figure 2.2.1 The changes in estimation of magnitude and likelihood of climate impacts on aquaculture and fisheries from 1st and 2nd rounds of the Delphi method.

Fisheries - magnitude and likelihood of impacts in short term

For fisheries and the short-term time period from 2021-2040, the climate-driven changes/impacts based on the likelihood of their occurrence and their anticipated magnitude of impact (+/-) are shown in figure 2.2.2. The rankings by magnitude, likelihood and combined magnitude and, likelihood are provided in tables 2.2.1 to 2.2.3.

For fisheries, changes in the following were rated as the most likely and of the highest impact due to short-term climate change: target species range and distribution, fishing opportunities, overall stock productivity, ecosystem 1˚ and 2˚ productivity, recruitment of fish, food web dynamics, fish growth, nursery habitats, phenology of fish life stages, and the distribution of invasive species. Resilience is a function of both the biology and the adaptive capacity of the species limited by its scope for adaptation (moving deeper or poleward), and this can mask climate impacts. Different systems have different natural variabilities, species richness and baseline functional redundancy. If species are living in a natural system with high natural variability then they may have a better adaptive capacity.

Should more shocks have been included in the list of impacts (with lower likelihood and high magnitude) they would have been placed in the lower right quadrant of figure 2.2.1.

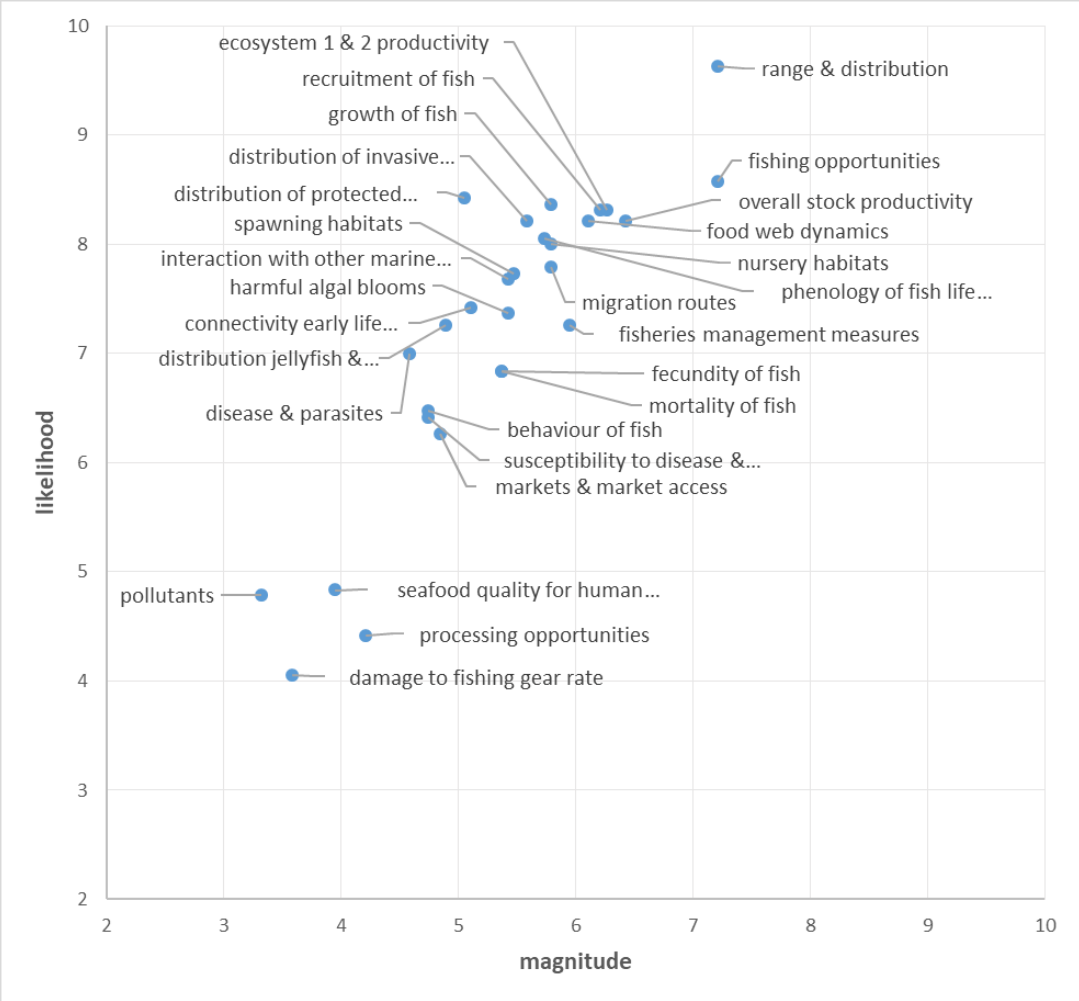


Figure 2.2.2 short-term time period from 2021-2040, the climate driven changes/impacts based on the likelihood of their occurrence and their anticipated magnitude of impact (+/-) Impacts (full description given in section 2.2.2)

Table 2.2.1. The top ranked climate driven changes/impacts for fisheries based on the likelihood of their occurrence

Rank	Top Ranked Likelihood scores Climate Driven Change and/or driver Fisheries
1	Changes in range and distribution
2	Change in fishing opportunities
3	Changes in growth of fish
3	Changes in distribution of protected species
4	Change in ecosystem 1˚ and 2˚ productivity
4	Changes in recruitment of fish

Top Ranked Likelihood scores	
Rank	**Climate Driven Change and/or driver**
	Fisheries
5	Changes in overall stock productivity
5	Change in food web dynamics
5	Changes in distribution of invasive species
6	Changes in phenology of fish life stages
7	Changes to nursery habitats
8	Changes in migration routes
9	Changes to spawning habitats
9	Change in interaction with other marine sectors
10	Change in harmful algal blooms (HABs)
10	Changes to connectivity of early life stages

***The top ten climate driven changes are highlighted for each sector**

Table 2.2.2 . The top ranked climate driven changes/impacts based on their anticipated magnitude of impact (+/-)

Top Ranked Magnitude scores	
Rank	**Climate Driven Change and/or driver**
	Fisheries
1	Changes in range and distribution
1	Change in fishing opportunities
2	Changes in overall stock productivity
3	Change in ecosystem 1˚ and 2˚ productivity
4	Changes in recruitment of fish
5	Change in food web dynamics
6	Change in fisheries management measures
7	Changes in growth of fish
7	Changes to nursery habitats
7	Changes in migration routes
8	Changes in phenology of fish life stages
9	Changes in distribution of invasive species

Top Ranked Magnitude scores	
Rank	**Climate Driven Change and/or driver**
	Fisheries
10	Changes to spawning habitats

***The top ten climate driven changes are highlighted for each sector**

Table 2.2.3. The top ranked climate driven changes/impacts based on their combined likelihood and magnitude scores

Top Ranked Magnitude and Likelihood combined scores	
Rank	**Climate Driven Change and/or driver**
	Fisheries
1	Changes in range and distribution
2	Change in fishing opportunities
3	Changes in overall stock productivity
3	Change in ecosystem 1˚ and 2˚ productivity
4	Changes in recruitment of fish
5	Change in food web dynamics
6	Changes in growth of fish
7	Changes to nursery
7	Changes in phenology of fish life stages
7	Changes in distribution of invasive species
8	Changes in migration routes
9	Changes in distribution of protected species
10	Change in fisheries management habitats measures
10	Changes to spawning habitats

***The top ten climate driven changes are highlighted for each sector**

Fisheriesmagnitude and likelihood of impacts over short, medium and long term

When comparing between the three periods (short, medium and long term, Figures 2.2.3 and 2.2.4), the rankings remain fairly stable (Table 2.2.4), as with few exceptions, the combined likelihood and magnitude scores were similar for short, medium, and long-term evaluation periods. The magnitude, likelihood and confidence was positively correlated (Figure 2.2.3). The small change between the periods represents mainly the magnitude rather than likelihood or confidence. The phenomena of higher confidence for long-term changes compared to shorter term reflects difficulty addressing short-term variability compared to longer term trends. It could be expected that more scatter (both in terms of confidence but also magnitude and likelihood scores) for the more distant time frames and higher confidence and tighter scattering of points for nearer term time horizons. Confidence (looking from the present) should be lower in the distant future as scenarios would diverge considerably in the distant future, whereas they cannot be differentiated in the short-term. Few studies explore the shorter term, so thus less confidence in the short term. Studies tend to compare two time frames, or scenarios, but generally not short term.

The list of drivers focused on impacts that were likely already occurring. Lower impact or negative results are not readily published, or don't have the same number of reads as those that show a big impact. Researchers are more likely to have more knowledge, and higher confidence, of the higher magnitude impact studies.

Choice of IPCC scenarios for the time periods was not discussed. The selection of which Representative Concentration Pathway (RCP) scenario you look at would determine whether things are likely or not and the magnitude.

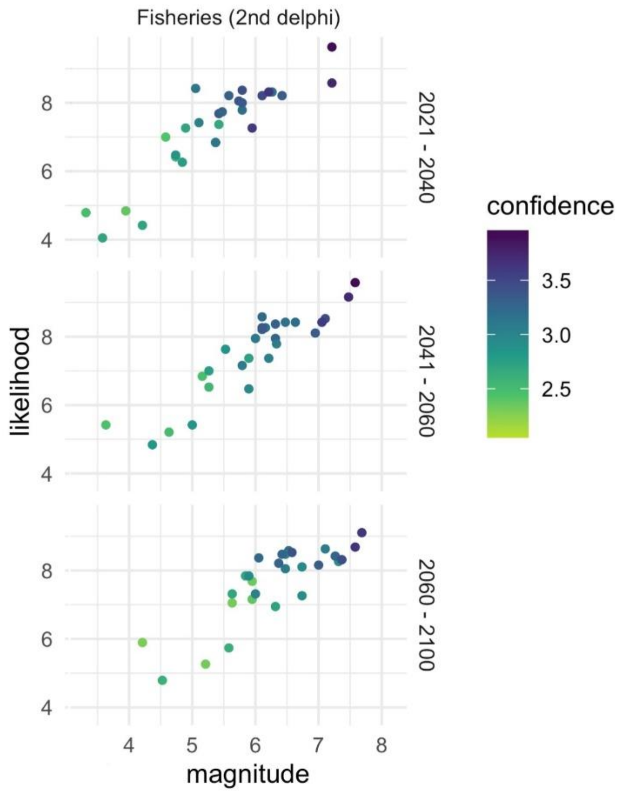


Figure 2.2.3. Short medium long term impacts for fisheries

Table 2.2.4. Top Ranked Likelihood and Magnitude scores for fisheries

Top Ranked Likelihood + Magnitude scores	
Category	**Temporal Scale**
Fisheries	
Changes in distribution of protected species	short, medium
Change in interaction with other marine sectors	medium, long
Change in ecosystem 1˚ and 2˚ productivity	short, medium, long
Change in fisheries management measures	short, medium, long
Change in fishing opportunities	short, medium, long
Change in food web dynamics	short, medium, long
Changes in distribution of invasive species	short, medium, long
Changes in growth of fish	short, medium, long
Changes in migration routes	short, medium, long
Changes in overall stock productivity	short, medium, long
Changes in phenology of fish life stages	short, medium, long
Changes in range and distribution	short, medium, long
Changes in recruitment of fish	short, medium, long
Changes to nursery habitats	short, medium, long
Changes to spawning habitats	short, medium, long

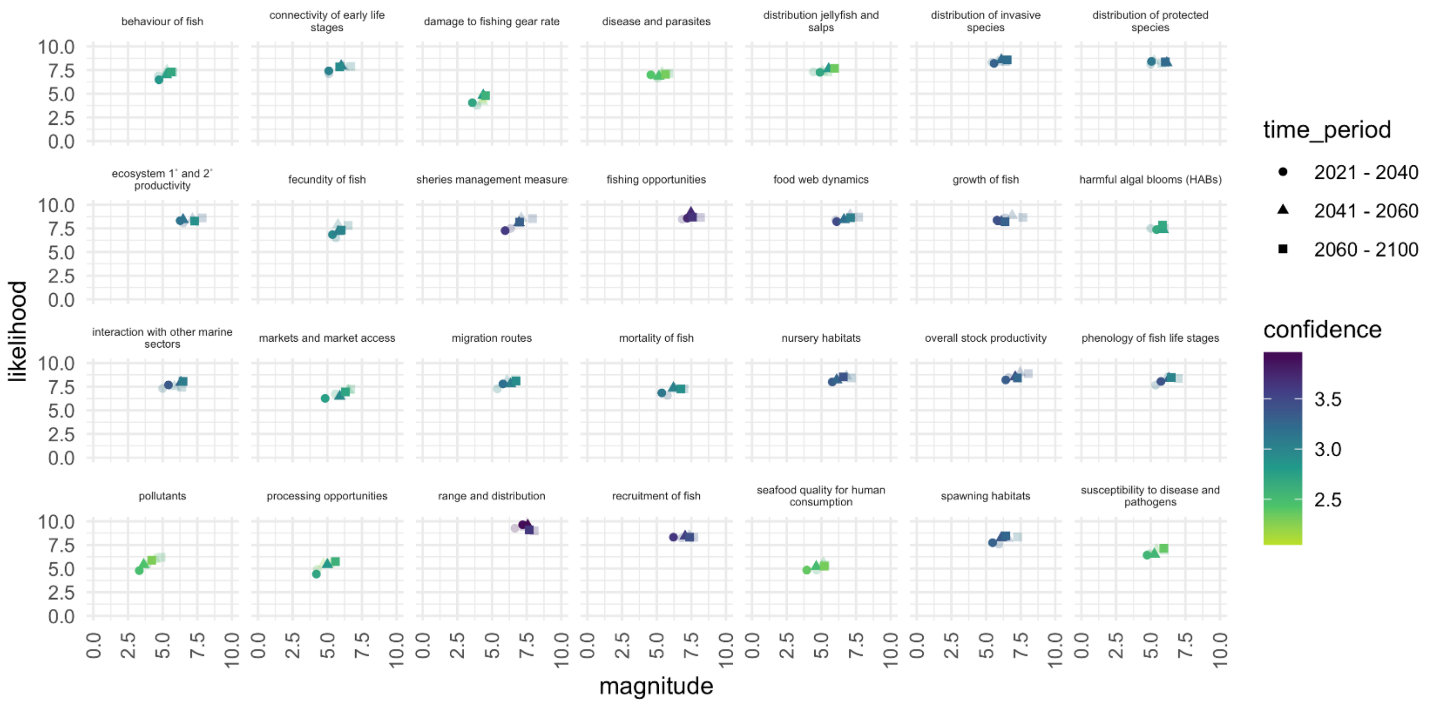


Figure 2.2.4 Each impact short, medium long for fisheries

Aquaculturemagnitude and likelihood of impacts in short term

For the short-term time period from 2021-2040, the top ranked climate driven changes and/or drivers for aquaculture based on the likelihood of their occurrence are listed in Table 2.2.5. Similarly, Table 2.2.6 includes the top ranked climate driven changes based on their anticipated magnitude of impact (+/-).

Both lists are similar as the likelihood and magnitude values were highly correlated. The top ranked climate driven changes and/or drivers based on their combined likelihood and magnitude scores are reported in Table 2.2.7. For aquaculture, this includes six changes and/or impacts that were rated as likely to highly affect all sectors (Table 2.2.8). These include changes in growth and survival of cultured species, changes in water chemistry, turbidity, and or salinity, and changes in the pathogen and parasite community, pathogen/parasite disease dynamics, and susceptibility of cultured species to disease. Anticipated changes in the distribution of wild broodstock and in the frequency of damage to equipment and/or facilities was rated high (based on likelihood and magnitude of impact) for finfish. Changes in normal phytoplankton bloom timing and location and changes to reproduction and growth were rated high for shellfish, and changes in dissolved oxygen and water quality dynamics were rated as being highly likely and impactful to seaweed culture over the next twenty years. Changes in harmful algal blooms, catastrophic effects on cultured species, and ocean acidification (OA) were rated high with respect to the likelihood and magnitude of impacts to finfish and shellfish, finfish and seaweed, and to shellfish and seaweed culture respectively.

Aquaculturemagnitude and likelihood of impacts over short, medium and long term

With few exceptions, the combined likelihood and magnitude scores were similar for short, medium, and long-term evaluation periods (Table 2.2.9)

Table 2.2.5. The top ranked climate driven changes/impacts and/or drivers for aquaculture based on the likelihood of their occurrence

	Top Ranked Likelihood scores
Rank	**Climate Driven Change and/or driver**
	Seaweed Aquaculture
1	Changes in Ocean Acidification
2	Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)
3	Changes in water quality dynamics
4	Changes in growth
5	Changes in pathogen and parasite presence
6	Changes in survival
7	Changes in dissolved O2 levels
7	Changes in the habitat area suitable for aquaculture
8	Changes in the range of non-target species which impact aquaculture
8	Changes in the distribution of wild broodstock
8	Changes In other sublethal effects other than growth or disease susceptibility
8	Changes in the susceptibility to disease
9	Changes in the frequency of damage to equipment/facilities
10	Changes in pathogen disease dynamics
	Shellfish Aquaculture
1	Changes in Ocean Acidification
2	Changes in growth
3	Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)
4	Changes in reproduction and growth
5	Changes in normal phytoplankton bloom timing/location
6	Changes in survival
6	Changes in wild seed production/juvenile availability
7	Changes in water quality dynamics
7	Changes in the range of non-target species which impact aquaculture
7	Changes in HABs
8	Changes in the distribution of wild broodstock

Top Ranked Likelihood scores	
Rank	**Climate Driven Change and/or driver**
	Seaweed Aquaculture
9	Changes in susceptibility to disease
9	Changes in the availability of natural feed for filter feeders (phytoplankton)
10	Changes in pathogen disease dynamics
10	Changes in pathogen and parasite presence
	Finfish Aquaculture
1	Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)
1	Changes in the distribution of wild broodstock
2	Changes in growth
2	Changes in pathogen disease dynamics
3	Changes in pathogen and parasite presence
4	Changes in the susceptibility to disease
4	Changes in HABs
5	Changes in survival
5	Changes in Target culture species range expansion/contraction
5	Changes in the distribution of broodstock and spawner timing
6	Changes in the frequency of damage to equipment/facilities
7	Changes in catastrophic effects (i.e. death) on cultured species
7	Changes in wild seed production/juvenile availability
8	Changes in water quality dynamics
8	Other sublethal effects other than growth or disease susceptibility
9	Changes in dissolved O2 levels
9	Changes in the normal phytoplankton bloom timing/location
10	Changes in reproduction and Growth
10	Changes in spawning timing
10	Changes in the availability of ocean-based feed ingredients (fish meal, fish oil)

***The top ten climate driven changes are highlighted for each sector**

Table 2.2.6. The top ranked climate driven changes/impacts based on their anticipated magnitude of impact (+/-) for aquaculture

	Top Ranked Magnitude scores
Rank	**Climate Driven Change and/or driver**
	Seaweed Aquaculture
1	Changes in water quality dynamics
1	Changes in the susceptibility to disease
1	Changes in pathogen disease dynamics
2	Changes in pathogen and parasite presence
2	Changes in survival
3	Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)
3	Changes is catastrophic effects (i.e. death) on cultured species
4	Changes in Ocean Acidification
4	Changes in growth
4	Changes in nutrient availability for seaweed (N, P, K)
5	Changes in dissolved O2 levels
6	Changes in reproduction and Growth
7	Changes in the habitat area suitable for aquaculture
8	Changes in the range of non-target species which impact aquaculture
8	Changes in the frequency of damage to equipment/facilities
8	Changes in spawning timing
8	Changes in the amount or toxicity of pollutants released into water/air
9	Changes in the target culture species range expansion/contraction
10	Changes in the distribution of broodstock and spawner timing
10	Changes in wild seed production/juvenile availability
	Shellfish Aquaculture
1	Changes in survival
2	Changes in growth
3	Changes in the susceptibility to disease
4	Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)
4	Changes in the pathogen disease dynamics
5	Changes in Ocean Acidification

Top Ranked Magnitude scores	
Rank	**Climate Driven Change and/or driver**
	Seaweed Aquaculture
6	Changes in reproduction and Growth
6	Changes in pathogen and parasite presence
7	Changes in HABs
7	Changes in dissolved O2 levels
8	Changes in spawning timing
8	Changes in catastrophic effects (i.e. death) on cultured species
9	Changes in water quality dynamics
10	Changes in normal phytoplankton bloom timing/location
10	Changes in the availability of natural feed for filter feeders (phytoplankton)
10	Changes in the habitat area suitable for aquaculture
	Finfish Aquaculture
1	Changes in growth
1	Changes in survival
2	Changes in the susceptibility to disease
3	Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)
3	Changes in pathogen disease dynamics
4	Changes in the availability of terrestrial ingredients for fish feeds
5	Changes in pathogen and parasite presence
6	Changes in HABs
6	Changes in catastrophic effects (i.e. death) on cultured species
7	Changes in Reproduction and Growth
7	Changes in the habitat area suitable for aquaculture
8	Changes in dissolved O2 levels
9	Changes in the frequency of damage to equipment/facilities
9	Changes in water quality dynamics
10	Changes in normal phytoplankton bloom timing/location

The top ten climate driven changes are highlighted for each sector

Table 2.2.7. The top ranked climate driven changes and/or drivers based on their combined likelihood and magnitude scores for aquaculture

	Top Ranked Magnitude and Likelihood combined scores
Rank	**Climate Driven Change and/or driver**
	Seaweed Aquaculture
1	Changes in Ocean Acidification
2	Changes in water quality dynamics
3	Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)
4	Changes in pathogen and parasite presence
5	Changes in survival
5	Changes in the susceptibility to disease
5	Changes in growth
6	Changes in Pathogen disease dynamics
7	Changes in the catastrophic effects (i.e. death) on cultured species
7	Changes in dissolved O2 levels
8	Changes in nutrient availability for seaweed (N, P, K)
9	Changes in habitat area suitable for aquaculture
10	Changes in the range of non-target species which impact aquaculture
	Shellfish Aquaculture
1	Changes in growth
2	Ocean Acidification
2	Changes in survival
3	Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)
4	Changes in reproduction and growth
5	Changes in susceptibility to disease
6	Changes in pathogen disease dynamics
7	Changes in HABs
8	Changes in the normal phytoplankton bloom timing/location
8	Changes in pathogen and parasite presence
9	Changes in water quality dynamics
10	Changes in the availability of natural feed for filter feeders (phytoplankton)

Top Ranked Magnitude and Likelihood combined scores	
Rank	**Climate Driven Change and/or driver**
	Seaweed Aquaculture
1	Changes in wild seed production/juvenile availability
	Finfish Aquaculture
1	Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)
2	Changes in growth
3	Changes in pathogen disease dynamics
4	Changes in survival
4	Changes in the susceptibility to disease
5	Changes in pathogen and parasite presence
6	Changes in HABs
7	Catastrophic effects (i.e. death) on cultured species
8	Changes in the distribution of wild broodstock
8	Changes in the frequency of damage to equipment/facilities
9	Changes in reproduction and growth
9	Changes in dissolved O2 levels
9	Changes in water quality dynamics
9	Changes in Target culture species range expansion/contraction
10	Changes in the habitat area suitable for aquaculture

***The top ten climate driven changes are highlighted for each sector**

Table 2.2.8 D. changes/impacts and/or impacts that were rated as likely to highly affect all sectors in aquaculture

Top 10 Likelihood and Magnitude scores for aquaculture	
Category	**aquaculture sector**
Changes in the distribution of wild broodstock	Finfish
Changes in the frequency of damage to equipment/facilities	Finfish
Changes in the normal phytoplankton bloom timing/location	Shellfish
Changes in reproduction and growth	Shellfish
Changes in the dissolved O2 levels	Seaweed
Changes in water quality dynamics	Seaweed

Top 10 Likelihood and Magnitude scores for aquaculture	
Category	**aquaculture sector**
Changes in HABs	finfish, shellfish
Catastrophic effects (i.e. death) on cultured species	finfish, seaweed
Ocean Acidification	shellfish, seaweed
Changes in growth	finfish, shellfish, seaweed
Changes in pathogen and parasite presence	finfish, shellfish, seaweed
Changes in pathogen disease dynamics	finfish, shellfish, seaweed
Changes in survival	finfish, shellfish, seaweed
Changes in the susceptibility to disease	finfish, shellfish, seaweed
Changes in water chemistry/turbidity/salinity (e.g. from erosion/flooding)	finfish, shellfish, seaweed

Table 2.2.9 Top raked likelihood and magnitude scores for aquaculture

Top Ranked Likelihood + Magnitude scores	
Category	**Temporal_scale**
Finfish	
Changes in the range of non-target species which impact aquaculture	Medium
Changes in other sublethal effects other than growth or disease susceptibility	Long
Changes in Catastrophic effects (i.e. death) on cultured species	short, medium
Changes in Distribution of broodstock and spawner timing	short, medium
Changes in Distribution of wild broodstock and spawner timing	short, medium
Changes in Frequency of damage to equipment/facilities	short, medium
Changes in Habitat area suitable for aquaculture	short, medium
Changes in Dissolved O2 levels	short, long
Changes in Growth	short, medium, long
Changes in HABs	short, medium, long
Changes in Pathogen and parasite presence	short, medium, long
Changes in Pathogen disease dynamics	short, medium, long
Changes in Reproduction and Growth	short, medium, long
Changes in Survival	short, medium, long
Changes in Susceptibility to disease	short, medium, long

Top Ranked Likelihood + Magnitude scores	
Category	**Temporal_scale**
Finfish	
Changes in Target culture species range expansion/contraction	short, medium, long
Changes in Water chemistry/turbidity/salinity (e.g. from erosion/flooding)	short, medium, long
Changes in Water quality dynamics	short, medium, long
Shellfish	
Changes in the availability of natural feed for filter feeders (phytoplankton)	Short
Changes in Wild seed production/juvenile availability	Short
Changes in Distribution of wild broodstock	Long
Changes in Range of non-target species which impact aquaculture	Long
Changes in Water quality dynamics	short, long
Changes in Dissolved O2 levels	medium, long
Changes in Target culture species range expansion/contraction	medium, long
Changes in Growth	short, medium, long
Changes in HABs	short, medium, long
Changes in normal phytoplankton bloom timing/location	short, medium, long
Changes in Ocean Acidification	short, medium, long
Changes in Pathogen and parasite presence	short, medium, long
Changes in Pathogen disease dynamics	short, medium, long
Changes in Reproduction and Growth	short, medium, long
Changes in Survival	short, medium, long
Changes in Susceptibility to disease	short, medium, long
Changes in Water chemistry/turbidity/salinity (e.g. from erosion/flooding)	short, medium, long
Seaweed	
Changes in Target culture species range expansion/contraction	Long
Changes in Dissolved O2 levels	short, medium
Changes in Growth	short, medium
Changes in Nutrient availability for seaweed (N, P, K)	short, medium
Changes in Habitat area suitable for aquaculture	short, long

Top Ranked Likelihood + Magnitude scores	
Category	**Temporal_scale**
Finfish	
Changes in Range of non-target species which impact aquaculture	short, long
Changes in Catastrophic effects (i.e. death) on cultured species	short, medium, long
Changes in Catastrophic effects (i.e. death) on cultured species	short, medium, long
Changes in Ocean Acidification	short, medium, long
Changes in Pathogen and parasite presence	short, medium, long
Changes in Pathogen disease dynamics	short, medium, long
Changes in Survival	short, medium, long
Changes in Susceptibility to disease	short, medium, long
Changes in Water chemistry/turbidity/salinity (e.g. from erosion/flooding)	short, medium, long
Changes in Water quality dynamics	short, medium, long
Changes in Water quality dynamics	short, medium, long

Of note is that during the first Delphi (1.1) survey, the aquaculture sectors were lumped whereas during the second (1.2), the aquaculture questions were separated by the different sectors of finfish, shellfish, and seaweeds. This may have contributed to the larger spread in responses for aquaculture during the second survey and for greater uncertainty in responses.

There is potential that a positive feedback loop / reinforcement was at play with various factors that have been more heavily researched being positively correlated with high likelihood/impact compared to those that are more obscure at this point in time. A good example of this is ocean acidification, which was identified as a high likelihood/high impact factor, but is also heavily researched compared to some of the other climate drivers. This leads one to question whether or not the patterns observed in the Delphi reflect reality, or are they skewed based upon factors that are more frequently researched? If ICES develops more routine use of Delphi, this known form of bias may need to be explicitly managed.

There also appears to be an association between confidence and likelihood/impact whereby there was greater confidence in factors that participants believed to have higher likelihood/higher impact. In other words, 'we don't know what we don't know? There was also a tight correlation between likelihood and magnitude with very little spread. Is this reality, or an artefact of the difficulty in mentally disentangling the two when scoring? Identifying the potential for "Black Swan" events could be made explicit in the methods.

The issues above are likely compounded by the relatively small number of experts participating in the aquaculture teams. The sample size decreased from the first round of the Delphi to the second for aquaculture. During the second round, participants were asked to rate each of the various climate drivers based on the three separate aquaculture sectors of finfish, shellfish, and seaweeds. This added to the complexity and length of the survey. According to Halloweii and Gambatese (2010), the complexity and length of a particular survey will determine participation rate with simpler and more accessible surveys promoting a higher rate of participation. It is likely that the time commitment for the second Delphi survey became too much.

Desirability bias occurs when participants systematically estimate the probability of occurrence for desirable (or undesirable) future projections higher than that of neutral desirability. Consequently, rating things more likely if there is some benefit to themselves if they occur. This may have been at play during the exercise. The participants were mostly researchers who may have unconsciously rated topics related to their own line of work (or to work they are interested in) as being more likely to occur and of higher impact.

Finally, the bandwagon effect whereby participants tend to go along with group think, may have applied to our study because were asking for participants to evaluate the anticipated effects of climate drivers in three time points in the future. As such, the risk (in the present) of being wrong about the future was not pressing and participants may have been more likely to agree during the Miro exercises about where the various climate drivers were placed on the likelihood and magnitude axes just to get along or because confidence decreases with distance in time.

Conclusion on magnitude and likelihood of impacts

- Based on magnitude and likelihood, key impacts for fisheries and aquaculture have been recognised.
- However, no high magnitude, low likelihood impacts were highlighted (e.g. heat shocks).
- All elements are regionally and species/fishery/farm specific so further analysis is needed when considering operational advice.
- The assessment is based on expertise and focal areas of the WKCLIMAD participants
- There is a need to distinguish between "Management impacted by" versus "management responding to or planning for impacts", in other words reactive vs anticipatory management
- Complexity of focal impact influences the confidence, and confidence is higher for those with more likelihood & magnitude of change
- Confidence and magnitude is inherently intertwined with adaptive scope and system resilience with an interdependency of multiple compounding pressures and impacts
- There is general increase in magnitude and likelihood with time, possibly because of increasing strength of climate change drivers, distinctive from variability of the system

2.3 Measures for carbon mitigation, adaptation, and adaptation with mitigation benefits.

The participants were asked to consider the risks and opportunities from the impacts and also to who these matter? Can management measures attenuate or adapt to an impact? Also, what are potential mitigation measures? The following lists provide the mitigation, adaptation and adaptation with mitigation measures.

Fisheries -carbon mitigation

- regulate to avoid carbon emissions due to ineffective policies (e.g. poorly implemented discard bans)
- increase offshore wind power to reduce emissions
- locate wind farms in no-fishing areas
- maintain higher fish stock biomass to increase efficiency of fishing

- shift to low emission fishing methods
- develop electric, hydrogen power and/or wind powered fishing boats
- increase incentives to use more fuel-efficient vessels
- reduce global trade & shipping of fish/fish products
- regulate bottom impact gear with reference to blue carbon trade-offs
- reduce fishing
- develop fixed-place fishing with clean energy needs provided at fishing site
- protect, restore or increase blue carbon nursery habitats
- implement carbon taxing
- conduct carbon audits to evaluate shore-based versus at sea processors
- enhance nearshore/small scale fisheries:
- improve fishery management to make industry more efficient
- shift to aquaculture to increase income diversity & reduce carbon

Aquaculturecarbon mitigation

- use electric or hydrogen powered boats that recharge from wave energy or wind energy at the farm
- locate seafood processing plants near farms to decrease transport emissions
- use carbon fibre in materials to take carbon out of circulation
- change aquaculture feeds to low carbon ingredients (Low Emission Formulation)
- promote local consumption rather than exporting seafood
- improve forecasting technologies to improve the industry carbon use efficiency
- build renewable energy powered seaweed drying facilities
- use aquaculture to replace high energy or water intensive agriculture-create virtual water, energy etc
- explore more efficiency across the board for all types of aquaculture
- use ecosystem approach to develop maximum benefits of the whole system
- co-locate aquaculture farms with marine based renewable energy installations to power farms
- Use seaweeds for supplement feed to cows to reduce GHG from cows
- farm seaweed for biofuels to keep oil in the ground
- develop low cost low impact production systems from low carbon materials
- promote aquaculture products that have low carbon footprint over other high carbon sources
- farm/harvest seaweed with the purpose of carbon sequestration
- decarbonize transportation, processing, & distribution of products from aquaculture
- design & use renewable energy on farm sites for farm needs
- consider carbon emissions from all systems in the design phase

Fisheriesadaptation

Structural reform of governance system:

- Reform system to be more resilient to pre-empted impacts (risk-based evidence)
- Reform system to be more resilient to infrequent but high magnitude impacts
- Improve planning for emergency responses
- Reform system to be more responsive to monitoring information (adaptive)
- Reform of high-level cross-jurisdiction governance and agreements (e.g. UN Fish stocks agreement)
- Reform using local solutions cross-jurisdiction governance issues

- Improve equity/agency in management and decision making

Targeted investments (by public or private sector):

- Invest in making changes to ports/shipping facilities
- Invest in making changes to processing facilities
- Plan for changes in markets and consumer preference
- Plan for changes of fishing opportunities
- Invest in gear development
- Improve tools for fisheries management including ecological forecasts, climate-informed assessments and targets, long-term projections

Capacity building/capacity reduction:

- Increase public awareness of need for adaptation
- Increase fishing industry awareness of need for adaptation
- Increase decision-makers awareness of need for adaptation
- Increase scientists' awareness of need for adaptation
- Improve livelihood diversification of coastal communities
- Increase vessel decommissioning or repurposing

Approaches to fisheries management

- Increase real-time fisheries management
- Increase adaptive management
- Increase results-based management
- Adjust management targets/objectives for management (e.g. reduce yields, reduce acceptable risk, increase precautionary buffers)
- Diversify opportunities to fish
- Improve integrated and cross-sectoral considerations in ecosystem-based fisheries management (EBFM)
- Implement ecosystem-based management (integrated and cross sectoral)
- Increase use of spatial-temporal management measures

Aquacultureadaptation

The strategies identified for adapting to climate change impacts by aquaculture sector are described below. These adaptation measure fell into the following subcategories with the number of times each was cited in parentheses: farm practice(40), research(30), genetics(26), gear(18), site suitability and spatial planning(17), event forecasting(15), monitoring(14), insurance(13), species selection(12), therapeutics(12), biosecurity(12), hatcheries(10), health(9), nutrition(8), stronger regulations(7), relocate (5), IMTA(5), RAS(3), business models(3), upland management (2), sanctuaries(1), better communication within industry sectors(1), and public outreach(1).

Feeds (finfish)

- push water smart agriculture
- develop alternatives from seaweed
- improve feed formulation
- improve small scale feeds for poorer regions
- look for innovative ocean-based feedstuffs (e.g. wastes, seaweeds, underused)
- encourage low environmental impact agriculture
- develop insects for feeds
- innovate to develop new sources of marine unique (n-3's) nutrients and feeds
- define nutritional requirements of culture organisms
- use seaweeds and other sources that avoid freshwater use

- find alternatives from shellfish
- ensure seafood nutritional value with alternative feeds
- improve feed manufacturing technology
- innovation in agriculture to keep feed sustainable
- improve basic fish nutrition
- look to plant species overlooked, e.g. sunflower, hemp, etc.
- develop land-based microalgae for n-3's
- move into circular economy models for feeds

Harmful algal blooms (HABS) (finfish, shellfish)

- threat prediction models
- crop insurance
- HABs forecasting, early detection, real time monitoring
- development of mitigation /husbandry measures by industry to negate HABs impacts
- include climate projections to inform planning
- better nutrient x HABs understanding (timing and ratios) to develop management measures
- genetic selection for resistant cultivars
- monitoring strategies for disease impacting humans
- hatchery based seed
- ability to protect local environment
- improved husbandry methods
- insure farms do not increase epiphytic HAB species
- develop seafood handling/safety measures
- biotoxin monitoring
- better background information on likelihood of HABs before farm location
- depuration of products prior to sale
- move to unaffected areas

Oxygen and general water chemistry (finfish and shellfish)

- spatial planning overlain with climatic data to develop 'future' map for suitable new locations
- site suitability mapping in general that looks at all potential stressors in advance of licensing activity
- decrease land-based pollution
- use ecosystem approach to balance aquaculture in an area
- support transition to water column farming/IMTA
- species choice
- more sites/habitats available for stocking/rotation
- better husbandry practices
- reliable and monitoring activities in place/real time measurements
- monitoring systems and methods
- develop aeration systems
- improved upland management
- better early warning/forecasting of low DO events (environmental forecasting)
- genetic improvement
- look and solve upstream nutrient additions
- move to areas with better water quality
- bioenergetic models

Ocean acidification (shellfish and seaweeds)

- develop alternative culture methods other than hatcheries for vulnerable life stages

- improve predictions
- relocated to areas where OA not such a problem
- make seaweed products more cost effective
- culture more resilient species
- develop adaptation strategies
- genetic selection for resilience
- technology/ability to alter local pH other than co-culture with seaweeds
- better monitoring systems
- hatcheries to by-pass vulnerable stages
- co-culture of shellfish and seaweeds
- restore/protect sea grass beds
- culture species that thrive in acidic conditions

Nutrient and plankton availability (seaweeds and shellfish)

- change consumer preference for size and other qualities
- develop nutrient supplementation strategy
- technology to alter local conditions temporarily to make more favourable
- develop methods to balance nutrient ratio for beneficial plankton and not HABs
- manage increasing agriculture run off
- locate to avoid issues
- monitor N in seaweed blades
- model nutrient dynamics to determine balance for seaweeds/animals and wild
- better reporting of good environmental status for habitats
- develop method to upwell nutrients when needed
- better understanding of plankton's role in nutrient and energy transfer
- improved knowledge of impacts during planning
- optimize location
- genetic selection for resilience
- locate in high nutrient areas
- change growth and harvest timing
- ecosystem approach to put the right type of aquaculture in the right place to use/balance nutrients
- balance nutrients with IMTA
- stricter environmental management targets
- monitor plankton phenology
- better models and validation of nutrient/plankton flow
- post-harvest holding/finishing
- model nutrients to balance for farms and wild-use an ecosystem approach
- better monitoring and early warning
- integrated multi-trophic culture methods

Seafood safety and quality (any species group)

- develop low cost depuration systems
- move farms away from the source of the hazard
- need to develop monitoring programs to protect human health
- develop added value products
- improved forecasting to improve management
- better management actions/thresholds
- develop post-harvest storage so harvest can be timed to safe/high quality periods
- better dialogue between farmers and processors to mitigate impacts from closures e.g. not requiring harvesting on specific dates
- public outreach/education

- stock checks prior to harvest

Changes in growth and survival (any species group)

- develop diversity in businesses
- new farming tech to move to locations with better environment for farming (offshore?)
- proactive siting/planning to identify resilient farm sites
- develop head start programs
- use of therapeutics (good and bad) to maintain good health
- develop hatcheries
- spatial planning to select optimal sites to max growth and survival
- adopt and ecosystem approach to management including adaptive management
- crop insurance programs
- genetic selection for better performance
- improve genetic risk x selection understanding
- change species to something more appropriate for new conditions - look south for species in north

Changes in range of culture species (any species group)

- target species development with adaptation in mind
- develop genetic breeding programs if possible
- create a historical record of activities lost to climate change
- proactive siting/planning to identify resilient farm sites
- reduce other stressors to provide scope for climate change stress; improve husbandry
- government support for relocation of farms and time to make other adaptive changes
- reduce other stressors to provide scope for climate change stress; improve health management
- choose new species
- sterile cultured species to avoid range expansion of feral pops
- reduce other stressors to provide scope for climate change stress; improve nutrition
- spatial planning for change in species range
- regular assessment of ecosystem approach to aquaculture management
- determine heritability of culture species
- reassess use of area for other species
- develop hatcheries

Changes predators, pathogens, parasites and diseases (any species group)

- reduce other stressors to provide scope for climate change stress; improve husbandry
- threat forecasting for when diseases might be impactful
- increase number of aquatic veterinarians
- select resistant species
- removal of non-native species
- advanced biosecurity
- develop new treatments
- improved husbandry methods
- insurance
- certification label from known entity, to ensure consumer confidence
- use of probiotics
- environmentally sound anti-foulants
- breed disease resistant species
- reduce other stressors to provide scope for climate change stress; improve nutrition
- move to land-based farms
- drug approval studies/better therapeutics & public education

- faster growth so they can be harvested before they die
- develop monitoring protocols to catch early signs of disease
- ensure seed from hatchery is pathogen free
- develop the field of "ocean epidemiology" to understand which pathogens will be significant and which will fade away
- identify and encourage adjacent wild species which benefit aquaculture
- increase research on pathogens of aquatic organisms (animal and plant)
- develop a market for the grazers/predators and harvest

Catastrophic events (any species group)

- invest in ocean engineering/science, technology, engineering, and mathematics (STEM)
- disaster relief support
- use genetic risk models to choose low risk species when they escape
- ability to harvest early
- genetically select for ability to survival events
- choose robust species for ability to survival events
- design near shore farms to protect shoreline development
- better gear
- timing of production to seasonal events
- realistic scenarios and climate proof planning
- remote operation of farms (including feeding of fish and tending of crops)
- harden shore-based infrastructure
- required mitigation plans for events, structural requirements, a robust marine spatial planning (MSP) needs to be in place
- event forecasting/prediction
- design to collect energy for own use
- develop low cost-effective ways to make stock un reproductive for when they escape
- sanctuaries/land-based hatcheries for moving/holding fish in short term
- make available systems and infrastructure for moving/storing gear
- insurance
- co-locate with offshore wind farms or Marine energy farms to share risks
- remote farm monitoring
- move, harden or adapt production practices or timing
- husbandry practices to ensure stock are not impacted
- designs to mitigate other impacts

Distribution of wild broodstock and natural spawn timing (any species group):

- sterilization of cultured organisms
- develop hatcheries to smooth out production over year
- monitoring research on changing distribution and timing
- focus on a few species that can have enough critical mass to support scientific research
- monitor phenology
- genetic breeding programs to change spawn timing
- use genetic risk models to choose low risk species

Changes in habitat suitability (any species group):

- social and economic programs for losses in production areas
- strong husbandry, cost-effective practices
- land based aquaculture
- exploratory cultures of new species (warm/introduced species)
- spatial planning for easier permit processes with potential legal challenges
- industry conflict mitigation

- aquaculture planned with an ecosystem approach can be designed to improve habitat for wild species of interest
- grow something else
- need to develop species that are tolerant to wide ranging conditions
- spatial planning for long-term suitability
- develop integrated multi-trophic aquaculture (IMTA) and all-inclusive permits for species together
- improve genetic ability for existing species to grow in old habitat

2.4 Feasibility and effectiveness of measures for carbon mitigation, adaptation, and adaptation with mitigation benefits.

Fisheries - effectiveness and feasibility of mitigation measures

The top five mitigation measures in terms of effectiveness and feasibility were further development of offshore wind energy production, placing wind production in no-fishing areas, incentives for the use of fuel effective vessels, carbon taxing and protecting and restoring blue carbon in nursery habitats (Figure 2.4.1). The results of the Delphi method should be further reconciled with the overarching objectives of national and regional, climate and environmental policies.

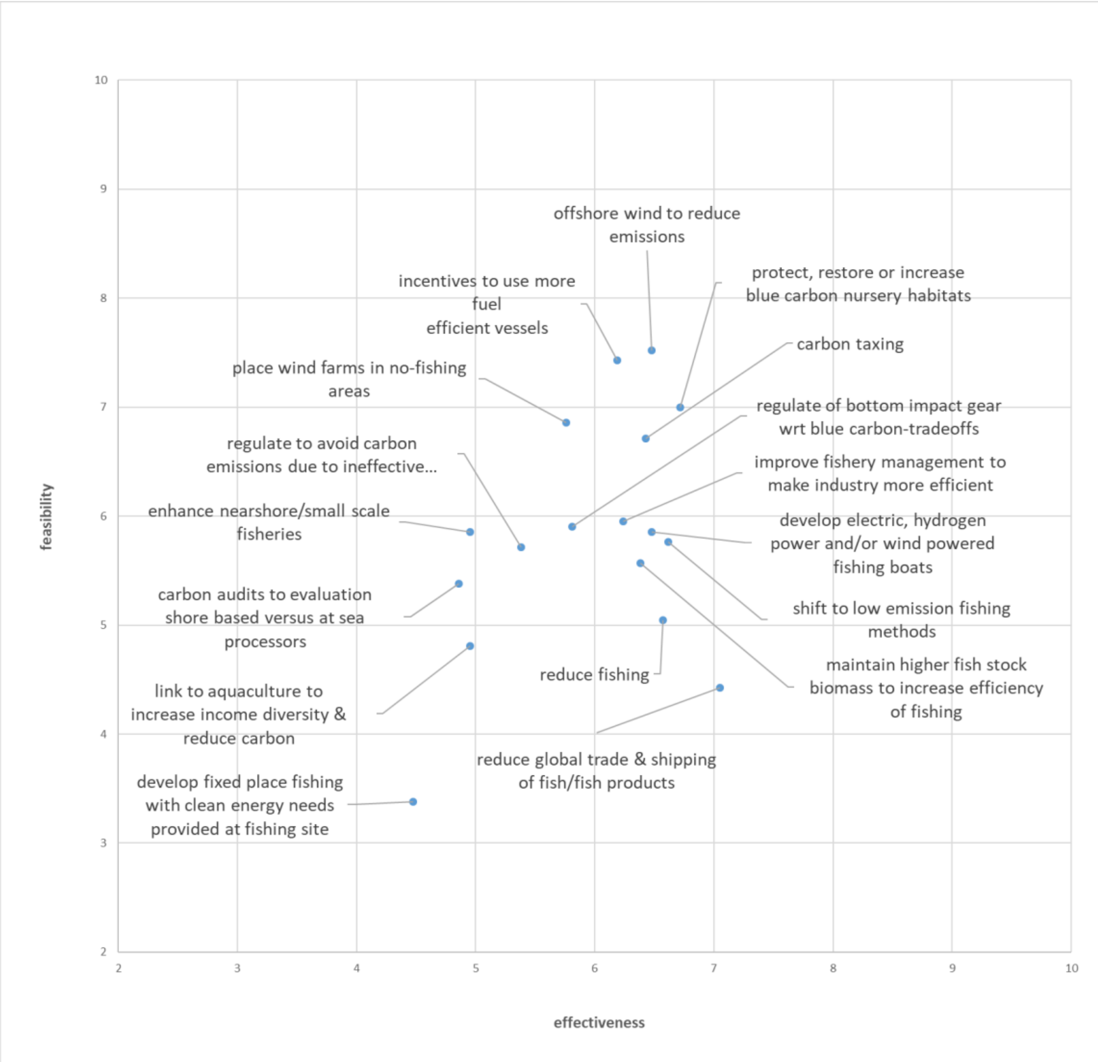


Figure 2.4.1 Fisheries effectiveness and feasibility of mitigation measures

Fisheries – effectiveness and feasibility of adaptation measures

The top six adaptation measures in terms of effectiveness and feasibility were increase the awareness for adaptation of decision makers and the general public, adjust management objectives to account for climate objectives, improve tools for fisheries management to include climate-informed advice, plan for change in fishing opportunities advice, and increase use of spatial-temporal management measures (Figure 2.4.2).

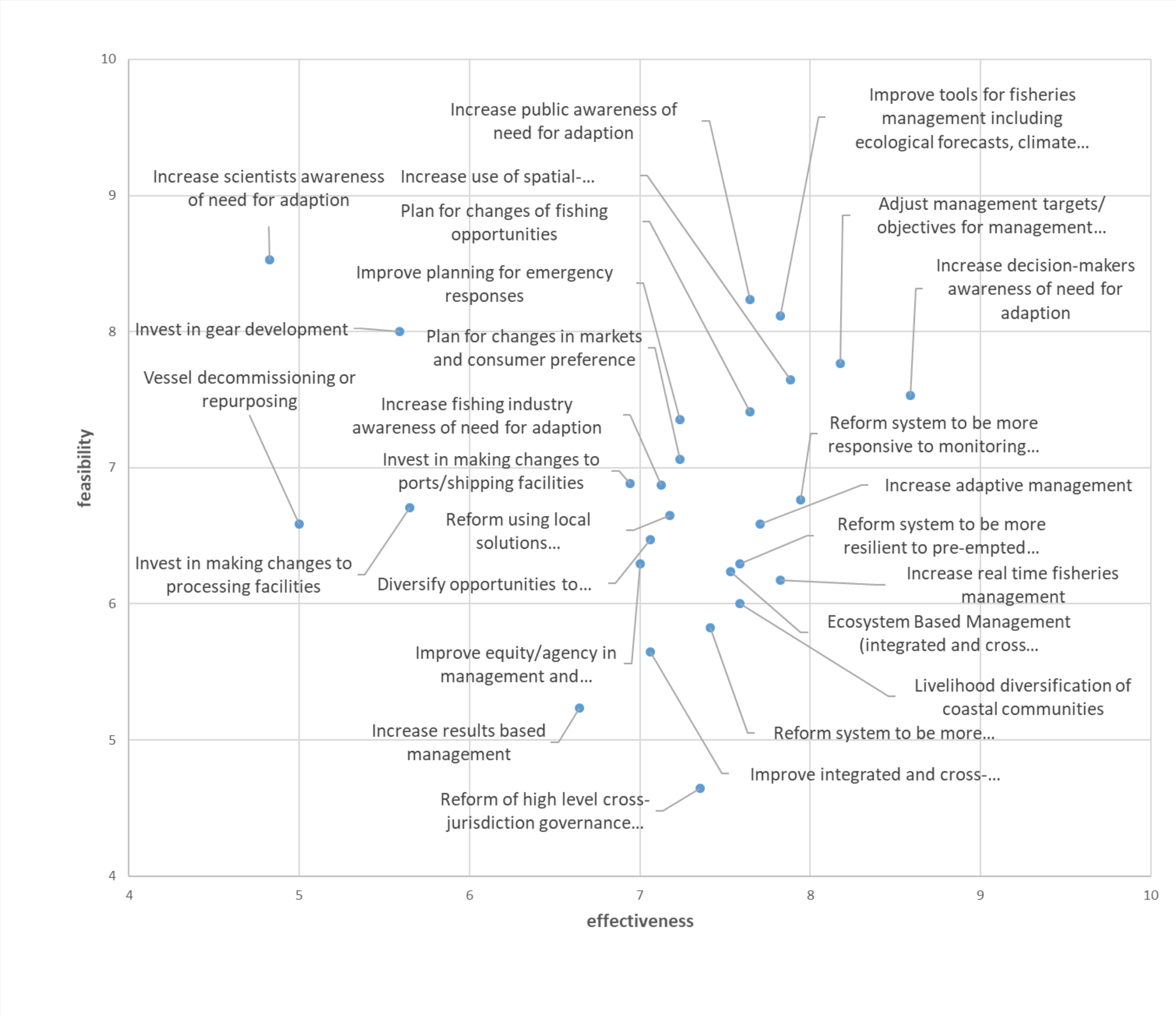


Figure 2.4.2. Fisheries effectiveness and feasibility of adaptation measures

There was considerable commonality in results, and there were some interesting differences that emerged. Measures should be proactive, adaptive and ecosystem-informed e.g., changes in protected areas, changes in gear, changes in surveys. There are opportunities and threats from the impacts and the adaptive measures suggested. Hence, distributional aspects of management costs and benefits should receive attention.

The time frame for action and implementation of measures (before social-ecological system tipping points) has not been considered in the analysis. The nature of responsiveness and timing of measures must be considered in the advice. Responsiveness and time frame need to be further explored. Especially when adaptation is immediately required for impacts and can be implemented over time for others, or negative impacts precede management benefits.

Suggesting that robust mechanistic understanding and attribution between impacts and measures before action can be taken, conflicts with the precautionary approach and hinders likely action. In providing immediate, medium- and long-term advice for management practice, the urgency to act means that are slow to implement (impacts already are present) and could delay action, so risk-based frameworks that assess risk to achieving fishery objectives should also be considered. The language and terminology of risk are useful, but risk is a complex and challenging term; and advice needs to be explicit.

Researchers need to increase their understanding of the governance, and management decision making. The linkages between local, regional and international arenas needs to be better understood by researchers, and how any measures for mitigation and adaptation can be implemented. Cost effectiveness and social acceptability of candidate measures as well as social beliefs and motivations might be also considered.

Aquacultureeffectiveness and feasibility of adaptation measures

Aquaculture adaptation measures that were rated as having both likelihood and magnitude scores greater than or equal to five are depicted in the table below. Clearly there is too much information to display in a simple plot as was done for fisheries. Complicating is that we have broken out aquaculture into three sectors; fish, shellfish and seaweeds. In order to allow for data exploration, we present a screen shot and the link to a series of Sankey Diagrams. One for each sector. The diagrams at the links allow for interactive highlighting of specific connections between drivers, effects, and adaptation measures.

Looking at the table and the diagrams several impacts stand out. Growth, reproduction, health and physical infrastructure key among them. Likewise, adaptation measures which allow greater human control over the production process such as hatcheries, genetic selection, aquatic organism health management, nutrition (feeds), engineering (gear) and general improvements to husbandry were highlighted as adaptation measures that could address multiple effects at the farm level. Improvements in site selection, permitting, insurance, monitoring and forecasting were also seen as areas that governments or industry lead efforts could contribute to improved adaptive ability for aquaculture.

Suggested Adaptation Measures (Likelihood >5 Magnitude >5)				
Drivers	**Impacts**	**Aquaculture Sector**	**Adaptation Measures**	**Subcategory**
Changes to phytoplankton bloom timing/location, increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & increase frequency of landslides	Catastrophic effects (i.e. death) on cultured species	finfish, shellfish, seaweed	event forecasting/prediction	event forecasting
			ability to harvest early	farm practice
			husbandry practices to ensure stock are not impacted	farm practice
			move, harden or adapt production practices or timing	farm practice
			remote operation of farms (including feeding of fish and tending of crops)	farm practice
			timing of production to seasonal events	farm practice
			better gear	gear
			design near shore farms to protect shoreline development	gear
			designs to mitigate other impacts	gear
			harden shore-based infrastructure	gear
			make available systems and infrastructure for moving/storing gear	gear
			required mitigation plans for events, structural requirements, a robust MSP needs to be in place	gear
			invest in ocean engineering/STEM	gear
			Use genetic selection for ability to survival events	genetics
			use genetic risk models to choose low risk species when they escape	genetics
			insurance	insurance
			disaster relief support	insurance
			remote farm monitoring	monitoring
			develop low cost-effective ways to make stock un reproductive for when they escape	research
			sanctuaries/land-based hatcheries for moving/holding fish in short term	sanctuaries
			realistic scenarios and climate proof planning	site suitability_spatial planning
			choose robust species for ability to survival events	species selection

Suggested Adaptation Measures (Likelihood >5 Magnitude >5)				
Drivers	**Impacts**	**Aquaculture Sector**	**Adaptation Measures**	**Subcategory**
Changes in ocean salinity, changes in pH, changes in dissolved oxygen, & changing ocean temperature	Changes in Growth	finfish, shellfish, seaweed	new farming tech to move to locations with better environment for farming (offshore?)	farm practice
			develop diversity in businesses	gear
			genetic selection for better performance	genetics
			improve genetic risk x selection understanding	genetics
			develop head start programs	hatcheries
			develop Hatcheries	hatcheries
			crop insurance programs	insurance
			proactive siting/planning to identify resilient farm sites	site suitability spatial planning
			spatial planning to select optimal sites to max growth and survival	site suitability spatial planning
			change species to something more appropriate for new conditions - look south for species in north	species selection
			use of therapeutics (good and bad) to maintain good health	therapeutics
Changes in ocean salinity, changing ocean temperature, changes in dissolved oxygen, & changes in pH	Changes in pathogen and parasite presence	finfish, shellfish, seaweed	certification label from known entity, to ensure consumer confidence	biosecurity
			advanced biosecurity	biosecurity
			develop the field of "ocean epidemiology" to understand which pathogens will be significant and which will fade away	biosecurity
			ensure seed from hatchery is pathogen free	biosecurity
			threat forecasting for when diseases might be impactful	event forecasting
			improved husbandry methods	farm practice
			reduce other stressors to provide scope for Climate change stress; improve husbandry	farm practice
			Breed disease resistant species	genetics
			Select resistant species	genetics
			increase number of aquatic Vets	health
			increase research on pathogens of aquatic organisms (animal and plant)	health
			Insurance	insurance
			develop monitoring protocols to catch early signs of disease	monitoring
			reduce other stressors to provide scope for CC stress; improve nutrition	nutrition
			use of probiotics	nutrition
			move to land-based farms	RAS
			faster growth so they can be harvested before they die	species selection
			develop new treatments	therapeutics
			drug approval studies/better therapeutics & public education	therapeutics
			environmentally sound anti-foulants	therapeutics

Suggested Adaptation Measures (Likelihood >5 Magnitude >5)				
Drivers	**Impacts**	**Aquaculture Sector**	**Adaptation Measures**	**Subcategory**
Changes in freshwater temperature, changes in ocean salinity, changing ocean temperature, changes in dissolved oxygen, & changes in pH	Changes in pathogen disease dynamics	finfish, shellfish, seaweed	develop the field of "ocean epidemiology" to understand which pathogens will be significant and which will fade away	biosecurity
			certification label from known entity, to ensure consumer confidence	biosecurity
			advanced biosecurity	biosecurity
			ensure seed from hatchery is pathogen free	biosecurity
			threat forecasting for when diseases might be impactful	event forecasting
			improved husbandry methods	farm practice
			faster growth so they can be harvested before they die	farm practice
			reduce other stressors to provide scope for CC stress; improve husbandry	farm practice
			breed disease resistant species	genetics
			select resistant species	genetics
			increase number of aquatic Vets	health
			increase research on pathogens of aquatic organisms (animal and plant)	health
			Insurance	insurance
			develop monitoring protocols to catch early signs of disease	monitoring
			reduce other stressors to provide scope for CC stress; improve nutrition	nutrition
			use of probiotics	nutrition
			move to land-based farms	RAS
			develop new treatments	therapeutics
			drug approval studies/better therapeutics & public education	therapeutics
			environmentally sound anti-foulants	therapeutics
Changes in ocean salinity, changes in pH, changes in dissolved oxygen, & changing ocean temperature	Changes in reproduction and growth	finfish, shellfish, seaweed	develop diversity in businesses	better biz models
			new farming tech to move to locations with better environment for farming (offshore?)	farm practice
			genetic selection for better performance	genetics
			improve genetic risk x selection understanding	genetics
			develop Hatcheries	hatcheries
			develop head start programs	hatcheries
			crop insurance programs	insurance
			proactive siting/planning to identify resilient farm sites	site suitability spatial planning
			spatial planning to select optimal sites to max growth and survival	site suitability spatial planning
			change species to something more appropriate for new conditions - look south for species in north	species selection
			use of therapeutics (good and bad) to maintain good health	therapeutics

Suggested Adaptation Measures (Likelihood >5 Magnitude >5)				
Drivers	**Impacts**	**Aquaculture Sector**	**Adaptation Measures**	**Subcategory**
Changes in ocean salinity, changes in pH, increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes tropical storms, dust storms), changes in dissolved oxygen, & changing ocean temperature	Changes in survival	finfish, shellfish, seaweed	develop diversity in businesses	better biz models
			new farming tech to move to locations with better environment for farming (offshore?)	farm practice or site suitability
			genetic selection for better performance	genetics
			improve genetic risk x selection understanding	genetics
			develop Hatcheries	hatcheries
			develop head start programs	hatcheries
			crop insurance programs	insurance
			proactive siting/planning to identify resilient farm sites	site suitability spatial planning
			spatial planning to select optimal sites to max growth and survival	site suitability spatial planning
			change species to something more appropriate for new conditions - look south for species in north	species selection
			use of therapeutics (good and bad) to maintain good health	therapeutics
Changes in ocean salinity, changing ocean temperature, changes in dissolved oxygen, & changes in pH	Changes in suscepti bility to disease	finfish, shellfish, seaweed	certification label from known entity, to ensure consumer confidence	biosecurity
			advanced biosecurity	biosecurity
			develop the field of "ocean epidemiology" to understand which pathogens will be significant and which will fade away	biosecurity
			ensure seed from hatchery is pathogen free	biosecurity
			threat forecasting for when diseases might be impactful	event forecasting
			improved husbandry methods	farm practice
			faster growth so they can be harvested before they die	farm practice
			reduce other stressors to provide scope for CC stress; improve husbandry	farm practice
			breed disease resistant species	genetics
			select resistant species	genetics
			increase number of aquatic Vets	health
			increase research on pathogens of aquatic organisms (animal and plant)	health
			insurance	insurance
			develop monitoring protocols to catch early signs of disease	monitoring
			reduce other stressors to provide scope for CC stress; improve nutrition	nutrition
			use of probiotics	nutrition
			move to land-based farms	RAS
			develop new treatments	therapeutics
			drug approval studies/better therapeutics & public education	therapeutics
			environmentally sound anti-foulants	therapeutics

Suggested Adaptation Measures (Likelihood >5 Magnitude >5)				
Drivers	**Impacts**	**Aquaculture Sector**	**Adaptation Measures**	**Subcategory**
Changing ocean temperature, & changes in dissolved oxygen	Changes in the distribution of wild broodstock	finfish, shellfish, seaweed	genetic breeding programs to change spawn timing	genetics
Changing ocean temperature, & changes in dissolved oxygen	Changes in the distribution of wild broodstock	finfish, shellfish, seaweed	use genetic risk models to choose low risk species	genetics
Changing ocean temperature, & changes in dissolved oxygen	Changes in the distribution of wild broodstock	finfish, shellfish, seaweed	develop hatcheries to smooth out production over year	hatcheries
Changing ocean temperature, & changes in dissolved oxygen	Changes in the distribution of wild broodstock	finfish, shellfish, seaweed	monitoring research on changing distribution and timing	research
Changing ocean temperature, & changes in dissolved oxygen	Changes in the distribution of wild broodstock	finfish, shellfish, seaweed	sterilization of cultured organisms	research
Changing ocean temperature, & changes in dissolved oxygen	Changes in the distribution of wild broodstock	finfish, shellfish, seaweed	focus on a few species that can have enough critical mass to support the science	species selection
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	event forecasting/prediction	event forecasting
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	husbandry practices to ensure stock are not impacted	farm practice
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	ability to harvest early	farm practice
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	timing of production to seasonal events	farm practice
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	harden shore-based infrastructure	gear
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	better gear	gear
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	design near shore farms to protect shoreline development	gear
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	designs to mitigate other impacts	gear
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	invest in ocean engineering/STEM	gear
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	make available systems and infrastructure for moving/storing gear	gear
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	move, harden or adapt production practices or timing	gear
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	required mitigation plans for events, structural requirements, a robust MSP needs to be in place	gear
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	sanctuaries/land-based hatcheries for moving/holding fish in short term	gear
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	use genetic risk models to choose low risk species when they escape	genetics
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	disaster relief support	insurance
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	insurance	insurance
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	remote farm monitoring	monitoring
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	develop low cost-effective ways to make stock un reproductive for when they escape	genetics
Increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricanes and tropical storms, dust storms), & sea level rise	Changes in the frequency of equipment/facilities damage	finfish, shellfish, seaweed	realistic scenarios and climate proof planning	site suitability spatial planning

Suggested Adaptation Measures (Likelihood >5 Magnitude >5)				
Drivers	**Impacts**	**Aquaculture Sector**	**Adaptation Measures**	**Subcategory**
Changes in ocean salinity, changes in pH, changes in dissolved oxygen, & changing ocean temperature	Changes in the target culture species range expansion/contraction	finfish, shellfish, seaweed	regular assessment of ecosystem approach to aquaculture management	better biz models
			reduce other stressors to provide scope for CC stress; improve husbandry	farm practice
			determine heritability of culture species	genetics
			develop genetic breeding programs if possible	genetics
			target species development with adaptation in mind	genetics
			develop hatcheries	hatcheries
			reduce other stressors to provide scope for CC stress; improve health management	health
			government support for relocation of farms and time to make other adaptive changes	insurance
			reduce other stressors to provide scope for CC stress; improve nutrition	nutrition
			sterile cultured species to avoid range expansion of feral pops	genetics
			create a historical record of activities lost to climate change	site suitability spatial planning
			proactive siting/planning to identify resilient farm sites	site suitability spatial planning
			reassess use of area for other species	site suitability spatial planning
			spatial planning for change in species range	site suitability spatial planning
			choose new species	species selection
Sea level rise, changes to snow/ice; including loss of permafrost, changes in salinity, changes in pH, & changes to wind speed/direction, ocean circulation (currents and eddies)	Habitat area suitable for aquaculture	finfish, shellfish, seaweed	aquaculture planned with an ecosystem approach can be designed to improve habitat for wild species of interest	farm practice
			strong husbandry, cost-effective practices	farm practice
			improve genetic ability for existing species to grow in old habitat	genetics
			need to develop species that are tolerant to wide ranging conditions	genetics
			develop IMTA and all-inclusive permits for species together	IMTA
			social and economic programs for losses in production areas	insurance
			spatial planning for easier permit processes with potential legal challenges	site suitability spatial planning
			spatial planning for long term suitability	site suitability_ spatial planning
			exploratory cultures of new species (warm/introduced species)	species selection
			grow something else	species selection

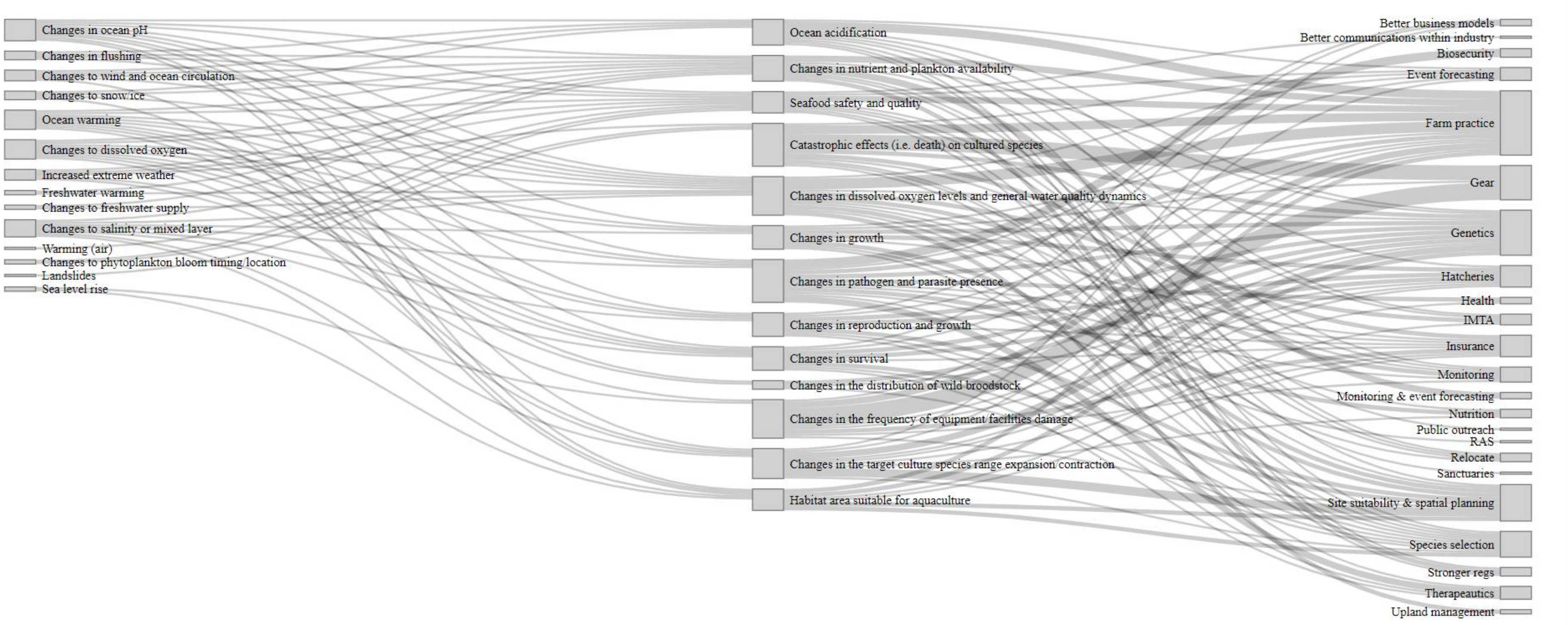
Suggested Adaptation Measures (Likelihood >5 Magnitude >5)				
Drivers	**Impacts**	**Aquaculture Sector**	**Adaptation Measures**	**Subcategory**
Increased frequency of extreme weather events, changing ocean temperature, changes in pH, changes in dissolved oxygen, changes in ocean salinity, changes in flushing patterns at offshore farms, changes to wind speed/direction, ocean circulation (currents/eddies), changes in air temperature, & Changes to phytoplankton bloom timing/location creating toxic areas (i.e. HABs)	Seafood safety and quality	finfish, shellfish, seaweed	better dialogue between farmers and processors to mitigate impacts from closures e.g. not requiring harvesting on specific dates	better communication within industry sectors
			improved forecasting to improve management	event forecasting
			develop low cost depuration systems	farm practice
			develop post-harvest storage so harvest can be timed to safe/high quality periods	farm practice
			stock checks prior to harvest	farm practice
			need to develop monitoring programs to protect human health	monitoring
			public outreach/education	public outreach
			move farms away from the source of the hazard	relocate
			develop added value products	species selection
			better management actions/thresholds	stronger regs
Changing ocean temperature, changes in dissolved oxygen, changes in flushing patterns at offshore farms, changes to wind speed/direction, ocean circulation (currents and eddies), changes to snow/ice; including loss of permafrost, changes in pH, changes in ocean salinity, changes in freshwater supply due to changes in precipitation, changes in freshwater temperature	Changes in Dissolved O2 levels and general water quality dynamics	finfish & shellfish	better early warning/forecasting of low DO events (environmental forecasting)	event forecasting
			better husbandry practices	farm practice
			decrease land-based pollution	farm practice
			develop aeration systems	farm practice
			more sites/habitats available for stocking/rotation	farm practice
			use ecosystem approach to balance aquaculture in an area	farm practice
			genetic improvement	genetics
			co-culture of shellfish and seaweeds	IMTA
			support transition to water column farming/IMTA	IMTA
			monitoring systems and methods	monitoring
			reliable and monitoring activities in place/real time measurements	monitoring
			bioenergetic models	nutrition
			move to areas with better water quality	relocate
			site suitability mapping in general that looks at all potential stressors in advance of licensing activity	site suitability spatial planning
			spatial planning overlain with climatic data to develop 'future' map for suitable new locations	site suitability spatial planning
			species choice	species selection
			improved upland management	upland management

Suggested Adaptation Measures (Likelihood >5 Magnitude >5)				
Drivers	**Impacts**	**Aquaculture Sector**	**Adaptation Measures**	**Subcategory**
			look and solve upstream nutrient additions	upland management
Changes in flushing patterns at offshore farms, changing ocean temperature, increased frequency of extreme weather events (e.g. marine heatwave, heat dome, hurricane and tropical storms, dust storms), changes in freshwater supply due to changes in precipitation, & changes in wind speed/direction, ocean circulation (currents and eddies)	Changes in frequency/location of HABs	finfish & shellfish	better background information on likelihood of HABs before farm location	event forecasting
			HABs forecasting, early detection, real time monitoring	event forecasting
			include climate projections to inform planning	event forecasting
			threat prediction models	event forecasting
			improved husbandry methods	farm practice
			development of mitigation /husbandry measures by industry to negate HABs impacts	farm practice
			ability to protect local environment	gear
			genetic selection for resistant cultivars	genetics
			hatchery based seed	hatcheries
			depuration of products prior to sale	health
			develop seafood handling/safety measures	health
			crop insurance	insurance
			biotoxin monitoring	monitoring
			monitoring strategies for disease impacting humans	monitoring
			move to unaffected areas	relocate
			better nutrient x HABs understanding (timing and ratios) to develop management measures	forecasting
Increased frequency of extreme weather events, changing ocean temperature, changes in pH, changes in dissolved oxygen, changes in ocean salinity, changes in flushing patterns at offshore farms, changes to wind speed/direction, ocean circulation (currents/eddies), changes in air temperature, & Changes to phytoplankton bloom timing/location creating toxic areas (i.e. HABs)	Issues dealing with Feed	finfish	alternatives from seaweed	research
			alternatives from shellfish	research
			define nutritional requirements of culture organisms	research
			develop insects for feeds	research
			develop land-based microalgae for n-3's	research
			improve feed formulation	research
			improve feed manufacturing technology	research
			improve small scale feeds for poorer regions	research
			Innovate to develop new sources of marine unique (n-3's) nutrients and feeds	research
			innovation in ag to keep feed sustainable	research
			look for innovative ocean-based feedstuffs (e.g. wastes, seaweeds, underused)	research
			look to plant species overlooked, e.g. sunflower, hemp, etc	research
			move into circular economy models for feeds	research
			seaweeds and other sources that avoid freshwater use	farm practice
			encourage low environmental impact ag	stronger regs
			ensure seafood nutritional value with alternative feeds	stronger regs
			push water smart agriculture	stronger regs

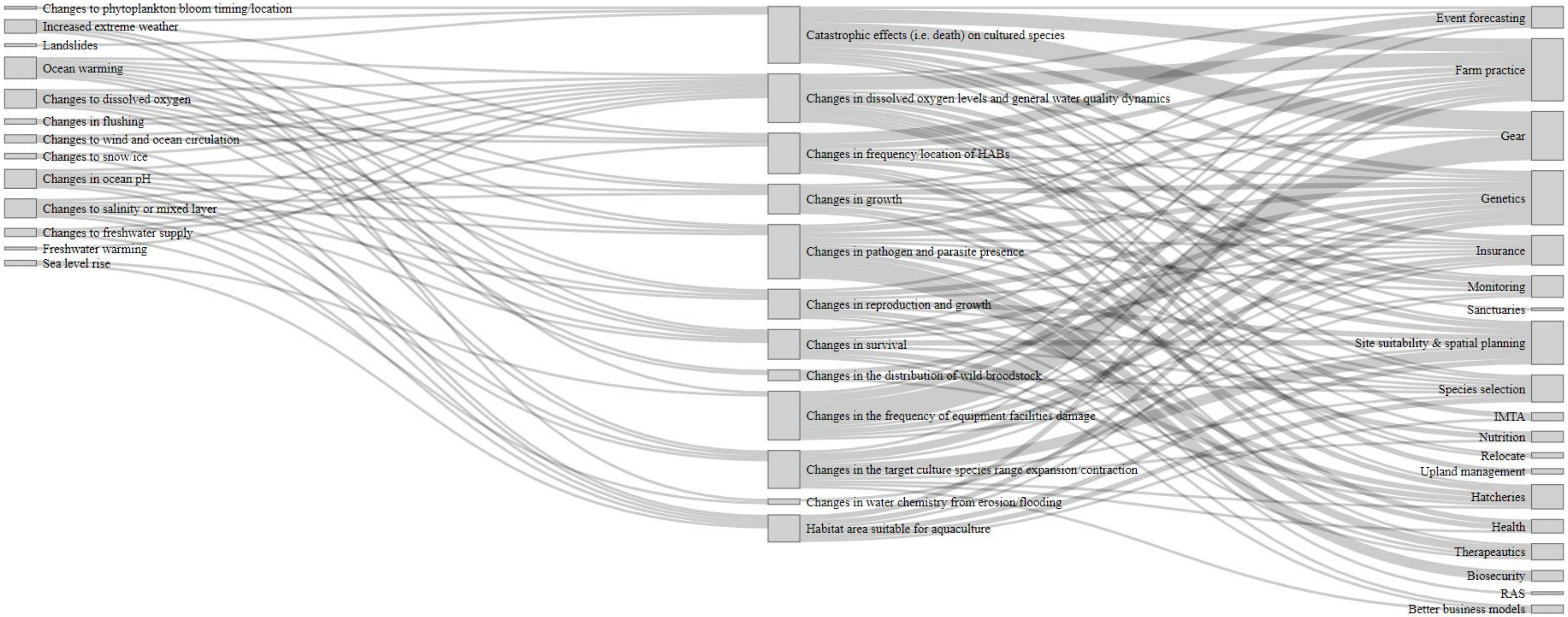
Suggested Adaptation Measures (Likelihood >5 Magnitude >5)				
Drivers	**Impacts**	**Aquaculture Sector**	**Adaptation Measures**	**Subcategory**
Changes in pH, changes in flushing patterns at offshore farms, changes to wind speed/direction, ocean circulation (currents/eddies), & changes to snow/ice	Ocean acidification	shellfish & seaweeds	improve predictions	event forecasting
			make seaweed products more cost effective	farm practice
			genetic selection for resilience	genetics
			hatcheries to by-pass vulnerable stages	hatcheries
			co-culture of shellfish and seaweeds	IMTA
			better monitoring systems	monitoring
			relocated to areas where OA not such a problem	relocate
			develop adaptation strategies	research & farm practice
			technology/ability to alter local pH other than co-culture with seaweeds	research & farm practice
			develop alternative culture methods other than hatcheries for vulnerable life stages	research & farm practice
			culture species that thrive in acidic conditions	research & species selection
			restore/protect sea grass beds	stronger regs
Changing ocean temperature, changes in pH, changes in dissolved oxygen, changes in flushing patterns at offshore farms, changes to wind speed/direction, ocean circulation (currents/eddies), changes to snow/ice; Increased frequency of extreme weather events, changes in freshwater temperatures, & Changes in freshwater supply	Changes in nutrient and plankton availability	seaweeds and shellfish	better reporting of good environmental status for habitats	monitoring & event forecasting
			better models and validation of nutrient/plankton flow	monitoring & event forecasting
			better monitoring and early warning	monitoring & event forecasting
			post-harvest holding/finishing	farm practice
			change growth and harvest timing	farm practice
			genetic selection for resilience	genetics
			integrated multi-trophic culture methods	IMTA
			locate in high nutrient areas	relocate
			better understanding of plankton's role in nutrient and energy transfer	research
			improved knowledge of impacts during planning	research
			develop methods to balance nutrient ratio for beneficial plankton and not HABs	research
			model nutrient dynamics to determine balance for seaweeds/animals and wild	research
			develop method to upwell nutrients when needed	research
			model nutrients to balance for farms and wild-use an ecosystem approach	research
			develop nutrient supplementation strategy	research & farm practice
			ecosystem approach to put the right type of aquaculture in the right place to use/balance nutrients	site suitability spatial planning
			stricter environmental management targets	stronger regs
			manage increasing agricultural run off	stronger regs

To visually present the connections of impacts and driver with measures, the aquaculture data was displayed in a series of Sankey plots. Three plots where developed one each for seaweeds, shellfish and finfish (Figures 2.4.3). Presented in the figure is a screen shot of the interactive plots that are available at the links provided. The interactive plots allow a way to explore connections quickly and visually. Impacts were driven by more than one driver, and responses in many cases addressed more than one impact.

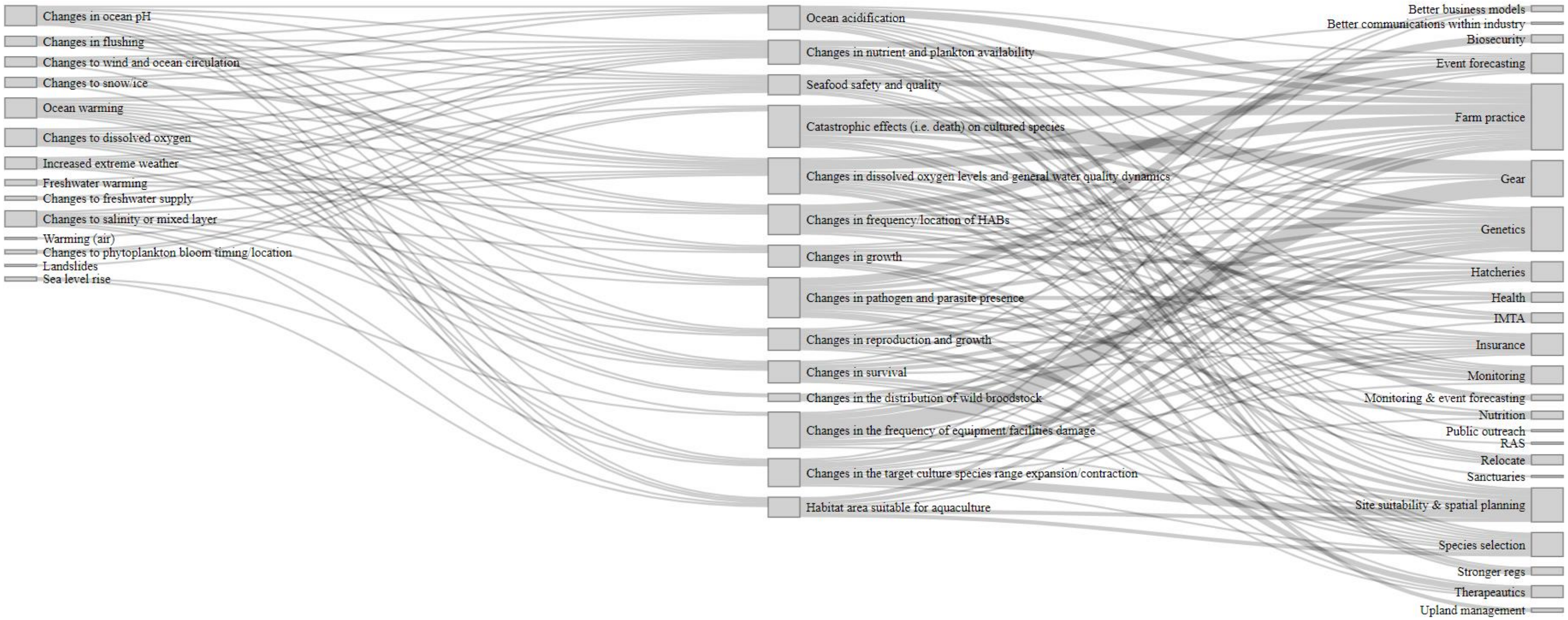
While this list of responses was focused on being climate impacts, the list may also vary in terms of cost effectiveness and social acceptability. Even so, the exercise does provide a good start for further exploration and prioritization. Funders may also want to look at the plots to determine which responses fit with their missions.



A. Seaweed. Aquaculture. For the Interactive version the file needs to be downloaded from: http://doi.org/10.17895/ices.pub.22196560



B. Finfish. Aquaculture. For the Interactive version the file needs to be downloaded from: http://doi.org/10.17895/ices.pub.22196560



C. Shellfish. Aquaculture. For the Interactive version the file needs to be downloaded from: http://doi.org/10.17895/ices.pub.22196560

Figure 2.4.3. Connections among climate drivers, impacts to the aquaculture industry and potential responses (counter measures) for (A) seaweed, (B) finfish and (C) shellfish.

There is an opportunity to drill down into feasibility and effectiveness through empirical study, modelling and data exploration. Further analysis of cost effectiveness and social acceptability for each response may help refine feasibility estimates based on expert opinion, for example. Likewise, testing the effectiveness of responses with empirical data will inform future expert opinions. Connecting drivers to impacts to responses in the Sankey plots can also guide empirical data collection, which again can inform future expert opinion. It is an iterative process where each type analysis has advantages and can inform and guide the other. Empirical data driven studies tend to be expensive and focused, while expert opinion exercises such as Delphi tend to be integrative and relatively inexpensive. Neither approach alone may be sufficient to providing quality climate-informed advice, however the plots from WKCLIMAD do provide a transparent means of communication. Beyond managers, research funders and industry may look at the plots to determine which responses fit with their missions and may be further developed. These plots do identify and rank climate impacts, consider and match adaptation measures. Advice can link this information with public policy objectives.

3 Actionable strategies and on-ramp tools for climate-informed advice.

Climate-informed advice is needed to help individuals, industry, communities, and managers plan, prepare and respond to climate change impacts on marine resources and industries. Climate-informed advice will provide tools for fisheries management and "on-ramps" of such advice to decision making including near-term tactical, near-term strategic, and longer-term (years to decades) strategic decision making.

3.1 Tools and supportive elements for climate-informed advice

WKCLIMAD considered various potential on-ramps for climate-informed advice and associated on-ramps to management (table 3.1.1).

3.1.1 Overarching fisheries and aquaculture

- Climate-informed risk in the advice
- Visual tools/storytelling/cartoons/infographics and media-oriented visualization of advice, including web portals
- Climate-informed executive summaries and policy briefs, including regional climate-change effect summary sheets
- Co-production of knowledge and advice, with increased participatory processes
- Management strategy evaluation (MSE) of climate scenarios with climate-informed processes

3.1.2 Fisheries

The top considered **near-term tactical** on-ramp tools were:

- Categorising climate-related vulnerability of single stocks in fishing opportunities advice
- Comments in the advice on risk that could be used for emergency financing, relief, insurance, insurance or weighted extra quota for harvesters using more CO_2-friendly gears
- Workshops on climate-informed advice for scientists, industry, and a combination of the two
- Climate-informed stock assessments, habitat models, and catch forecasts, which would include a re-evaluation of precautionary buffers that address vulnerability to climate change
- Models of spatial dynamics (now-casts and climate-informed future SDMs)

The top considered **near-term strategic** on-ramp tools were:

- Maps and forecasts of anticipated changes per species/stock
- Advice that can inform incentives for technology and gear development to improve mitigation and adaptation to climate change
- Workshops on climate-informed advice with scientists, industry

- Future scenarios and science/stakeholder groups on coastal zone management
- Climate-informed minimum biomass thresholds (i.e. that adjust based on marine heatwaves (MHW) forecasts for the next 1-2 years
- Current and climate-informed predicted trends at key variables and pressures and advice that incorporates broader objectives from across fisheries, climate and environmental policies
- Fleet-based advice

The top considered **medium to long-term strategic** on-ramp tools were:

- Maps and forecasts of anticipated changes per species/stock and species/habitat (specifically blue carbon habitats) distribution maps and projections
- Interactive information to evaluate CO_2, catch potential, and other outcomes of different gear choices
- Websites for education/awareness purposes
- Collaborative models (co-produced), scenario exploration and serious games
- Fore-sighting exercises, including shared Socio-economic Pathways (SSPs)
- Scenario building around percentage of restoration of stocks and habitats under climate change
- Counterfactual/retrospective analyses to test policy options (what if in the past we had done..)

3.1.3 Aquaculture

The top considered **near-term tactical** on-ramp tools were:

- Regular expert assessment of risk (such as Delphi) and co-development scenario planning (e.g., fore sighting exercises, shared socioeconomic pathways).
- Scientific publications (e.g. primary literature, systematic reviews, and meta-analyses).
- Genomic data collection for use in selection and prediction of performance under climate change.
- Carrying capacity estimation under climate change.
- Development and use of early warning systems; disaster plan guidance and development.
- Feed innovation for small-scale aquaculture.
- Proactive aquaculture spatial planning.

The top considered **near-term strategic** on-ramp tools were:

- Vulnerability or risk assessments, using an indicator-based approach.
- Training and workshop with industry to co-produce knowledge, including a focus on integrated coastal zone management (e.g., management strategy evaluation), scenario planning and collaborative model development.
- Improved marine spatial planning and modelling, to include clear objectives, targets, and reference points, and an emphasis on a changing marine environment (e.g., forecasting environmental conditions, mapping changes in marine traffic).
- Targeting key species for genetic selection, including genomic data collection for use in selection and prediction of performance under climate change.
- Enhanced seafood handling and safety measures, and farm-scale environmental monitoring.

The top considered **medium to long-term strategic** on-ramp tools were:

- Climate-informed risk advice, retrospective analysis to explore past impacts, and adaptation strategy assessments.
- Proactive spatial planning and disease modelling around climate scenarios, considering future interactions and forecasting.
- Scenario planning and gaming, including qualitative network modelling to explore change scenarios and their consequences. Promotion of seaweed farming for multiple benefits, including potential as a coastal erosion mitigation tool, OA buffering, and benefits from co-culture of shellfish and seaweed.
- Evidence for emergency financing, relief and various insurances.
- Evidence for financial incentives for technology and gear development (e.g., loans, grants) and emission reductions.
- Development of a range of technologies and tools to support adaptation, such as: a pre-competitive database of feed including carbon footprint and sustainability; low cost depuration; post-harvest storage for safe/high quality harvest; feed innovation to improve resource efficiency and nutrition; hatcheries.

Table 3.1.1 Potential tools for climate-informed advice for fisheries and aquaculture (shading for fisheries represents total mentions across 5 breakout groups for each time-frame, since there was only one aquaculture group the coloured boxes indicate mentions)

	Near-term (e.g., annual) tactical	Near-term (e.g., annual) strategic	Med-Long -erm (e.g., multi-year to decadal) strategic	Near-term (e.g., annual) tactical	Near-term (e.g., annual) strategic	Med-Long-term (e.g., multi-year to decadal) strategic
Climate impacts, vulnerability, and risk assessments	**Fisheries**			**Aquaculture**		
Section in single stock advice which categorizes climate related vulnerability of stock	4	1	0	0	0	0
Climate-informed risk advice	3	2	1	0	0	1
Maps of anticipated changes per species	1	5	5	1	0	0
Management strategy evaluation (MSE)	1	3	3	0	0	0
Delphi to continually assess expert opinions about risks	0	0	0	1	0	0
Information about markets	0	0	0	1	0	0
Vulnerability / risk assessments (indicator-based approach)	0	2	2	0	1	0
Retrospective analysis for exploring past impacts	0	2	1	0	0	1
Fisheries Adaptation Status Evaluation (science tool to operationalize climate risk)	0	1	3	0	0	0
Retrospective analysis for exploring past impacts (and dynamics)	0	1	0	0	0	0
Section in advice which highlights/categorizes climate related considerations	0	0	0	0	1	0
Investment in collection of long-term data sets	0	0	1	0	0	0
Promote seaweed farming as a coastal erosion mitigation tool	0	0	0	0	0	1
Communication & knowledge sharing	**Fisheries**			**Aquaculture**		
Media & Visualizations	4	4	4	0	1	0
Executive summaries	4	3	3	0	1	0

	Near-term (e.g., annual) tactical	Near-term (e.g., annual) strategic	Med-Long -erm (e.g., multi-year to decadal) strategic	Near-term (e.g., annual) tactical	Near-term (e.g., annual) strategic	Med-Long-term (e.g., multi-year to decadal) strategic
Climate impacts, vulnerability, and risk assessments	**Fisheries**			**Aquaculture**		
Infographics and maps to help visualise the concepts and uncertainties	3	3	2	1	0	0
Policy briefs or report cards	3	3	2	0	1	0
Visual tools/storytelling/cartoons	2	4	3	1	0	0
Web-type portal for displaying evidence, sharing data	2	3	2	1	0	0
Social media (use of twitter etc for knowledge transfer)	1	3	1	1	0	0
Secondary/primary school educational workshops	1	2	3	0	0	1
Regional climate-change effect summary sheets; based on stock assessments (past), species information, and/or projections	1	2	1	0	1	0
Websites for education/awareness purposes	1	1	3	0	1	0
Training	1	1	1	0	0	0
Visual tools/storytelling/cartoons/info-graphics	1	1	1	0	0	0
Interactive information tool to enable users to evaluate CO2, catch potential, and other outcomes of different gear choices	0	2	3	1	0	0
Scientific publications (primary literature, systematic reviews, meta-analyses)	0	0	0	1	1	0
Develop communication tools for public, policy makers about aquaculture and climate change	0	0	0	1	0	0
Improved education on how upland management affects downward systems	0	0	0	1	0	0
Prioritize transparent communication	0	0	0	1	0	0
Summary reports of impacts of climate change on aquaculture and how it can meditate impacts	0	0	0	1	0	0
Develop a database of the carbon sequestration capacity of aquaculture species to demonstrate contribution to Blue carbon/blue growth potential	0	0	0	0	1	0
Workshops with industry	0	0	0	0	1	0
Incentives & finance	**Fisheries**			**Aquaculture**		
Emergency financing, relief, insurance, crop insurance	3	1	0	0	0	1
Weighted extra quota for harvesters using more CO2 friendly gears	3	1	0	0	0	0
Financial incentives for technology and gear development (e.g., loans, grants)	1	3	2	0	0	1
Certification, scoring, carbon labelling, Eco labelling	1	2	2	0	1	0
Incentive through lower CO2 taxation	1	2	2	0	0	1
Need a more transparent process for ranking/scoring certification and labelling	1	1	2	0	1	0
Credits/incentives for ecosystem services (nutrient removal, carbon)	0	0	0	0	1	0
Incentives for aquaculture using more CO2 friendly practices	0	0	0	0	1	0
Incorporate climate change criteria in certification	0	0	0	0	1	0

	Near-term (e.g., annual) tactical	Near-term (e.g., annual) strategic	Med-Long -erm (e.g., multi-year to decadal) strategic	Near-term (e.g., annual) tactical	Near-term (e.g., annual) strategic	Med-Long-term (e.g., multi-year to decadal) strategic
Climate impacts, vulnerability, and risk assessments	**Fisheries**			**Aquaculture**		
standards						
Review supply chain CSR CC commitments and advocate to include aquaculture	0	0	0	0	1	0
Uptake by finance & underwriting/insurance sector and addition of suitable caveats on advice (e.g. sea level rise & "not for insurance purposes")	0	0	1	0	0	0
Evaluate emissions along supply chain and opportunities/incentives to reduce	0	0	0	0	0	1
Process for climate-informed advice	**Fisheries**			**Aquaculture**		
Science workshops	3	3	3	1	0	0
Workshops with industry	3	3	2	1	0	0
Co-production of knowledge (field, gear, etc)	2	3	3	0	1	0
Participatory and co-development scenario planning	1	3	3	1	0	0
Stakeholder group on integrated coastal zone management	1	4	2	0	1	0
"Companion modelling"/serious game/workshop	1	3	2	0	1	0
Serious games (something that stakeholders and others can "play" with - table top and also computer)	1	2	4	0	1	1
Gaming / scenario exploration	1	2	3	0	1	0
Presentations with industry (as observers only)	1	0	0	0	0	0
Fore sighting exercises	0	0	4	1	0	0
Shared Socio-economic Pathways (SSPs)	0	0	4	1	0	0
Collaborative model development and scenario exploration	0	2	2	0	1	0
Qualitative network modelling to explore change scenarios and their consequences (+ or -)	0	1	4	0	0	1
Develop seafood handling/safety measures	0	0	0	0	1	0
Marine Spatial Planning (MSP) /Siting	0	0	0	0	1	0
Workshops with fishermen	0	0	1	0	0	0
Co-culture of shellfish and seaweeds	0	0	0	0	0	1
Proactive spatial planning around climate-scenarios, considering future interactions	0	0	0	0	0	1
Stock, habitat, and ecosystem assessments/Structural and technological	**Fisheries**			**Aquaculture**		
Dynamic management closure areas based on now-casts of climate-SDMs and bycatch risk	5	1	1	0	0	0
Summary information by species of biological changes included into traditional advice sheets	4	0	0	1	0	0
Precautionary buffers	4	2	0	0	0	0
Climate-informed stock assessments and forecasts	4	1	0	0	0	0
Stock assessment or habitat models with climate covariates	4	0	0	0	0	0

Climate impacts, vulnerability, and risk assessments	Fisheries: Near-term (e.g., annual) tactical	Fisheries: Near-term (e.g., annual) strategic	Fisheries: Med-Long -erm (e.g., multi-year to decadal) strategic	Aquaculture: Near-term (e.g., annual) tactical	Aquaculture: Near-term (e.g., annual) strategic	Aquaculture: Med-Long-term (e.g., multi-year to decadal) strategic
Assessment models that explores a scaled Fenv.	3	1	0	0	1	0
Adoption of clear objectives, targets and reference points in fisheries and other sectors	2	3	0	0	1	0
Tracking of increasing marine transport and new routes	2	1	2	0	1	0
Satellite tracking of ice coverage	2	1	1	0	0	0
Fleet assessments	1	3	2	0	0	0
Use temperature projections to adjust area & season closures for upcoming 5 years	1	1	4	0	0	0
Ecological forecasts and projections	1	1	2	0	0	0
Integrate targets (e.g. IPCC and IPBES) into models and forecasting (e.g. stock assessments, MSEs)	1	0	3	0	1	0
Fishery dependence tool	1	0	2	0	0	0
Forecasts of recent climate-influenced species distributions (e.g. for climate-informed catchability terms)	1	0	0	0	0	0
Hindcasts of recent climate-influenced species distributions	1	0	0	0	0	0
Minimum biomass thresholds that adjust based on MHW forecasts for the next 1-2 years (e.g., 20%B0)	0	5	0	1	0	0
Current and predicted trends at key variables and pressures	0	4	0	1	0	0
Species/habitat (specifically blue carbon habitats) distribution maps and projections	0	2	3	1	0	0
Set of scenarios around percentage of restoration under climate change	0	1	3	1	0	0
Genomic data collection for use in selection and prediction of performance under climate change	0	0	0	1	1	0
Carrying capacity estimates under climate change	0	0	0	1	0	0
Development/ implementation of early warning systems	0	0	0	1	0	0
Disaster plans-i.e. for equipment damage/escapees/HABs events	0	0	0	1	0	0
Feed technology development for small scale	0	0	0	1	0	0
Proactive site planning as part of wider marine spatial planning	0	0	0	1	0	0
Simulation modelling: blob occurrence and intensity (based on available data)	0	2	2	0	1	0
Management Strategy Evaluation	0	2	0	0	1	0
Adaptation strategy assessments	0	2	2	0	0	1
Counterfactual / retrospective analyses to test policy options (what if in the past we had done...)	0	1	3	0	0	0
Better open access data (UN decade)	0	0	0	0	1	0
Farm-scale environmental monitoring	0	0	0	0	1	0
Science to evaluate carbon benefits of seaweed	0	0	0	0	1	0
Target key species for genetic selection	0	0	0	0	1	0

Climate impacts, vulnerability, and risk assessments	Fisheries: Near-term (e.g., annual) tactical	Fisheries: Near-term (e.g., annual) strategic	Fisheries: Med-Long -erm (e.g., multi-year to decadal) strategic	Aquaculture: Near-term (e.g., annual) tactical	Aquaculture: Near-term (e.g., annual) strategic	Aquaculture: Med-Long-term (e.g., multi-year to decadal) strategic
Ecological projections	0	0	1	0	0	0
Integrated Ecosystem Assessments	0	0	1	0	0	0
Review and update reference levels (limits and targets) used for providing advice	0	0	1	0	0	0
Develop a pre-competitive database of feed including carbon footprint and sustainability	0	0	0	0	0	1
Develop low cost depuration system(s)	0	0	0	0	0	1
Develop post-harvest storage so harvest can by timed to safe/high quality periods	0	0	0	0	0	1
Disease assessment models with climate covariates	0	0	0	0	0	1
Feed technology (improve resource efficiency + nutrition)	0	0	0	0	0	1
Hatcheries	0	0	0	0	0	1
OA buffering via seagrass planting and seaweed farming	0	0	0	0	0	1
Regular assessment of ecosystem approach to aquaculture management	0	0	0	0	0	1
Seaweed farming for multiple benefits	0	0	0	0	0	1
Selected resilient organisms	0	0	0	0	0	1
Threat forecasting and monitoring	0	0	0	0	0	1

3.2 Supportive elements for climate-informed tools

The workshop explored further a few of the above-mentioned tools in order to identify common outputs and supportive elements for each tool. Emergent themes were around sub-components (e.g., data collection, steps, workshops, and models) and supportive elements (species distribution maps, communication tools, industry and stakeholder engagement processes) that could feed into management tools underpinning climate smart decision making and adaptation.

The workshop examined in more detail the following climate-informed tools:

For fisheries: climate-informed risk advice (including climate-informed buffers on quotas), indicator-based vulnerability/risk assessments, ecological forecasts and projections, integrating IPCC targets into ecosystem models and forecasts, maps and projections of species and habitats, stock assessment models with climate covariates, exploring and scoping future scenarios, incorporating 'F_{env}' into F_{msy} ranges, MPA networks, and fisheries carbon footprint assessment and certification.

For aquaculture: engagement with stakeholders, MSP, and threat forecasting.

Examples from both fisheries and aquaculture are shown in figure 3.2.1.

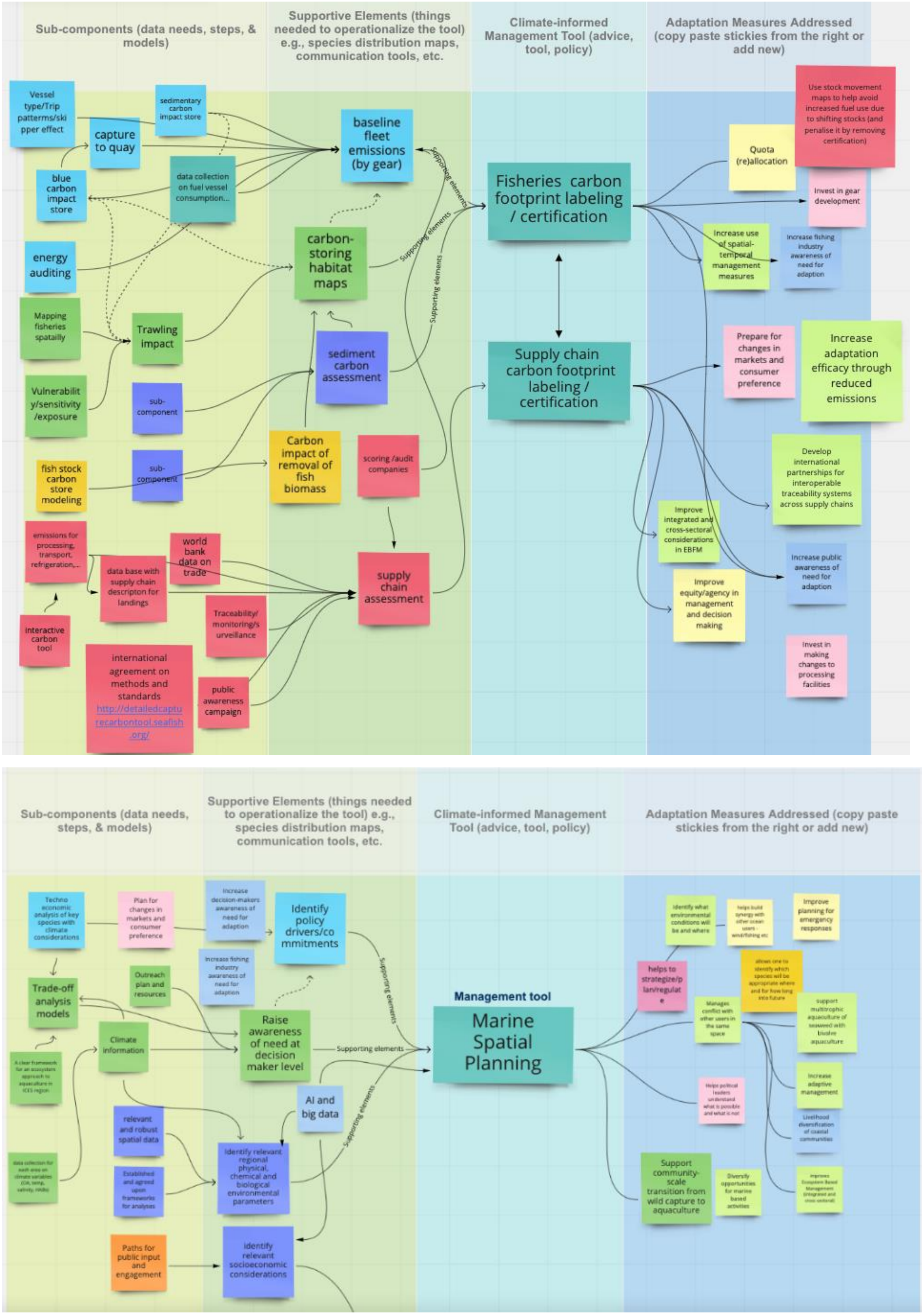


Figure 3.2.1. Example figures of tools and supportive elements fisheries (top) and aquaculture (bottom).

The outputs from those sessions can be explored through an interactive tool (shiny app) https://kkh2022.shinyapps.io/WKCLIMAD/

The key elements that were discussed during the exploration of climate-informed advice tools are summarised in figure 3.2.2, a tree plot of the top used elements in this exercise.

The top ten key elements across fisheries and aquaculture were

- Communication of need for adaptation,
- Stakeholder & public engagement,
- Ecosystem-Based Management,
- Plan for change in fishing opportunities,
- Risk & vulnerability assessment,
- Adaptive management,
- Adjust management targets/objectives,
- Systemic reform for high magnitude impact,
- Climate-informed advice,
- Climate projections.

It is notable that WKCLIMAD emphasised communication, engagement, and management measures as tools as much as the more traditional elements such as risk assessments, projections, and other methods for climate-informed advice.

WKCLIMAD found that suites of interlinked information types (supportive elements) were required to address these elements (Figures 3.2.3, and 3.2.4). For fisheries climate-informed stock assessment models, data and maps on species distribution (current and forecast), climate projections, risk and vulnerability assessments were considered important to inform communication, engagement and management advice (Figure 3.2.3). For aquaculture the use of marine spatial planning, conflict resolution and AI (and big data) were considered as similar important supportive elements as threat forecasting, and climate information etc.

Figure 3.2.2. Tree plot of terms used by WKCLIMAD when considering tools for climate-informed advice. https://kkh2022.shinyapps.io/WKCLIMAD/ This is a combined plot for fisheries and aquaculture

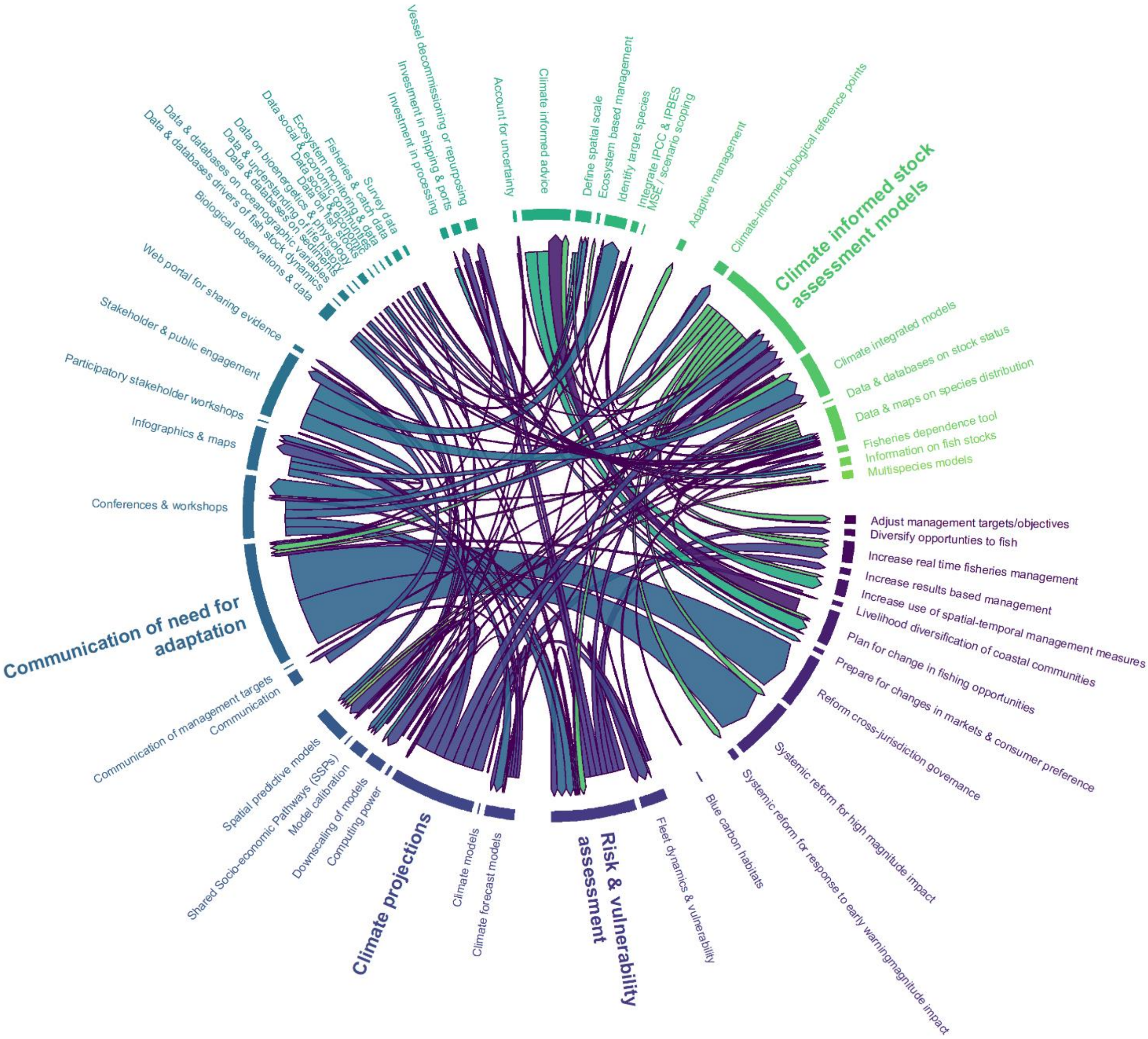


Figure 3.2.3. Chord plot of Fisheries climate-informed tools linking to supportive data elements. For the Interactive version the file needs to be downloaded from:
http://doi.org/10.17895/ices.pub.22196560

Figure 3.2.4. Chord plot of aquaculture climate-informed tools linking to supportive data elements. For the Interactive version the file needs to be downloaded from:

http://doi.org/10.17895/ices.pub.22196560

4 Integrity and production of climate-informed advice

4.1 Existing framework for ICES advice

ICES bases its advice on ten principles (Figure 4.1.1). The framework of the advice is described and annually reviewed in the document "1.1 Guide to ICES advisory framework and principles" (https://doi.org/10.17895/ices.advice.7648).

Figure 4.1.1. The ten principles that underpin ICES advice. The terms 'Request, Production, Release' are described in figure 4.1.2.

The advice is produced in response to requests for advice from predominantly ICES member countries and intergovernmental organisations (Figure 4.1.2). A request is developed through an iterative process between ICES and the requesters. The final request formulation has clarified the requester's needs and expectations, the internal ICES process, the likely resource implications, timelines, the format of advice, and the roles and responsibilities of the engaged parties. Where possible, existing policy goals, objectives, and the level of acceptable risk relevant to the advice request are identified. Where the management objectives and descriptions of risk are unclear, ICES identifies these in the advice, and, where possible, provide options for management action and the consequences of the options and their trade-offs. The advice is produced using the best-available science and quality-assured data. ICES selects and applies the relevant methods for any analysis, including the development of new methods. The methods are peer-reviewed by independent experts and clearly and openly documented. The data used should conform to the ICES data policy (https://doi.org/10.17895) and ICES aspires to follow the FAIR data principles, where data are findable, attributable, researchable, reusable.

Advice from ICES should be comprehensive, unambiguous, and consistent with the synthesized knowledge, while taking the peer review of data and methods into account. All advice should follow existing advice frameworks and any deviation from the frameworks or related, previous advice is identified and justified.

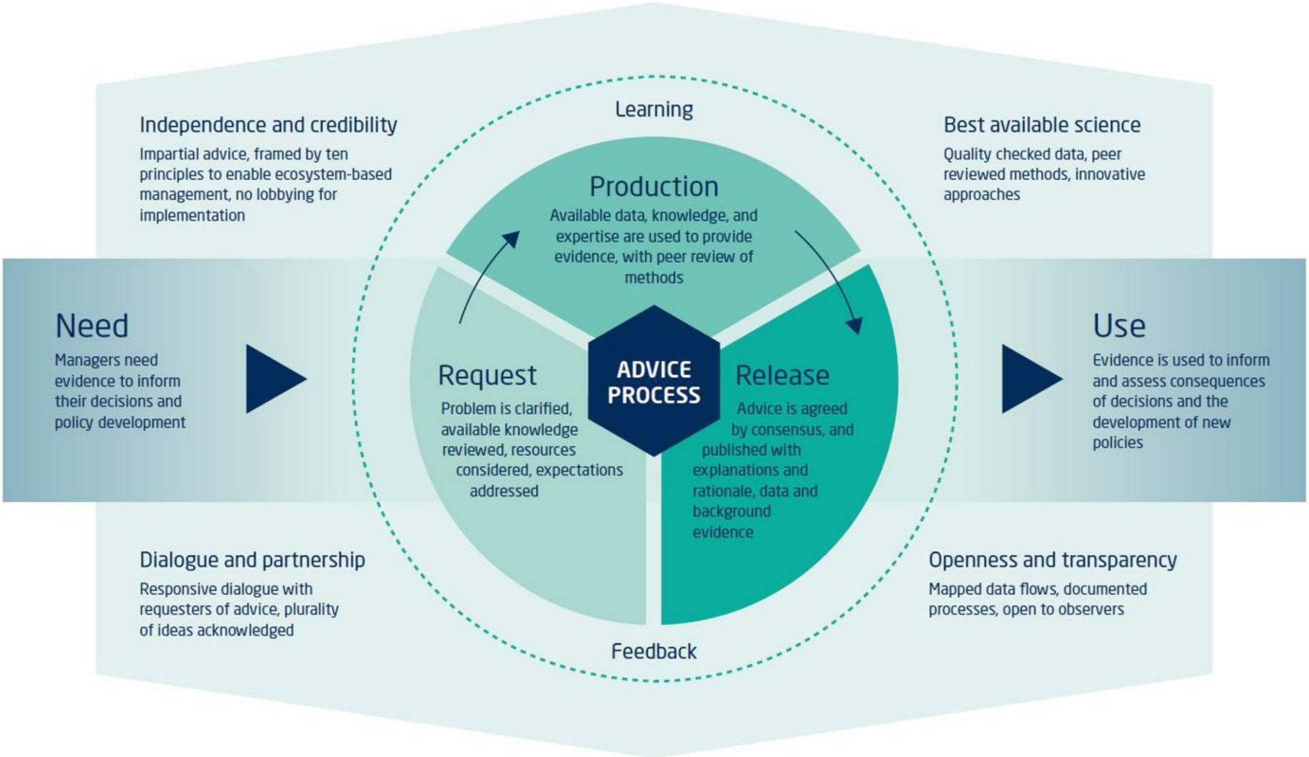


Figure 4.1.2. Conceptual diagram of the ICES advice production process.

4.2 Relevance of framework to advice on climate

WKCLIMAD found the existing advice framework to be helpful when developing a framework for advice on impact, adaptation, and mitigation in fisheries and aquaculture. WKCLIMAD considered that three key areas needed further development of specific issues: (1) advice on climate change impacting fisheries and aquaculture, (2) better incorporation of risk and uncertainty, and (3) further development of processes around the production of advice with partners (managers, industry, NGOs, and wider society) to better inform decision- and policy-makers.

4.2.1 Providing advice on climate issues

A key need for ICES is to align, where appropriate, its terminology, concepts, and scenarios with IPCC. ICES cannot re-invent the wheel and should consider best practice developed through consensual processes in other fora.

Early warning monitoring systems of ecosystems (including fisheries and aquaculture) are required, combined with a new decision-making process to enable appropriate action when impactful change is detected. The risks of potential change should also be evaluated. These all likely require further capacity-building of expertise and tools.

Medium- and long-term climate change projections should be incorporated into evaluations of fisheries and the planning of new aquaculture species and activities. To more clearly understand the consequences of these projections, social scientists and economists should be engaged in these processes.

An approach is needed to identify and rank climate impacts, and consider and match adaptation measures with public policy objectives. Decision-makers are not always able to fully articulate priority objectives, so effort needs to be put into iterative scenario-building to refine goals, to help understand assumptions, and transparently evaluate trade-offs.

Advice should be practical and tiered based on desired outcome with best-worst case with recommended strategies and risks, with time frames associated with each as well as uncertainties and strategies.

4.2.2 Incorporating risk and addressing uncertainty

ICES has a long way to go to create a robust risk-based approach to its provision of advice. The development of a climate advice framework offers ICES an opportunity to incorporate risk approaches into an element of the advice framework from the start. Additionally, ICES needs to consider how opportunities as defined in this document are presented, if at all.

Risk-based approaches (including biological/ecological/social/cultural/economic limits and targets) have properties/characteristics (flexibility, scenario-based, transdisciplinary, amenable to all evidence base/knowledge types) that can support and facilitate pro-active, adaptive, and transparent management decision-making.

Advice should clearly present the risk associated with achieving management objectives with the understanding of how decisions can impact the stability of the system, the impact of anthropogenic pressures, and the derived consequences for adaptation and mitigation to climate change for fisheries and aquaculture.

Many in the ICES network and beyond still conflate risk and uncertainty. This has been noted by IPCC. The framework needs to clarify these two issues and address how to clearly communicate the distinction to requesters of advice, and those impacted by the advice. Uncertainty should be seen as a property of advice, not a problem.

4.2.3 Production and partnership

The plurality of knowledge and the need for local solutions means that ICES should offer advice that is implementable and opens doors for solutions, rather than advice that limits opportunities and innovation. The process of providing advice also needs to be more human, in that it focuses on building collaboration and clear communication between scientists and the audience.

WKCLIMAD considered that ICES has not developed a science process to match the need of the advisory process for climate change. SCICOM and ACOM need to work in partnership. It is a challenge to give a clear message in advice, especially in the context of providing integrated advice, and adding layers of complexity could blur any narrative - but often caveats and nuance must still be included. ICES also needs to include advice on the risks of inaction, and accounts for appropriate time-scales. ICES should strive to be more proactive, and avoid remaining in a reactive positions.

The advice must be tuned to the target recipient/audience and their information needs. The value and uptake of advice products can be increased if it is accessible and transparent for other users. These include multiple stakeholders, such as industry, academics, managers, NGOs and wider society.

ICES would also benefit from drawing upon lessons learned from drafting process for the IPCC reports Summary for Policymakers section (Barkemeyer *et al*. 2016) and aligning their communication about uncertainty with similar language to that used by the IPCC scientific community (Molina and Abadal 2021).

4.3 Concept of "best available"

The concept of "best available" science or advice is written into a host of convention and international treaties (Table 4.3.1). Very few of these define what is meant by this, with the OSPAR and HELCOM conventions being notable exceptions, defining best available techniques/technology as "*the latest stage of development (state of the art) of processes, of facilities or of methods of operation*." NOAA fisheries service have described expectations for best scientific information available (BSIA) in relation to stock status determinations and catch specifications. WKCLIMAD explored further how the concept of best available is relevant to ICES advice. The term "best available" is also written into the Memoranda of Understanding and grant agreements between requesters of advice and ICES.

Table 4.3.1. The occurrence of best available in relevant conventions and legislation

Terminology	Convention/legislation	
best scientific evidence available	UN 1995, Fish stocks agreement articles 5, 6, 10, 16 FAO code of conduct for responsible fisheries, 2011	
best available scientific information	FAO COFI declaration 2021	https://doi.org/10.4060/cb3767en
best scientific information available	USA Magnuson-Stevens Fishery Conservation and Management Act (amended 2007)	https://www.federalregister.gov/documents/2013/07/19/2013-17422/magnuson-stevens-act-provisions-national-standard-2-scientific-information
best available scientific advice	EU CFP 2014 UK fisheries Act 2020	
best available science	EU MSFD, Commission decision 2017	
best available techniques	OSPAR convention 2007	
best available technology	HELCOM convention 1992	

4.3.1 Conceptual definition of "best available" in the context of ICES advice

There are a number of issues around the phrase "best available". The phrase needs to be considered as "to who" and "for what" is the best available science, information, or advice? Also, who decides that it is the "best available"? Best available science is being provided to ACOM for that committee to produce best available advice to requesters, i.e., the best available to address any specific request. In the instance of ICES advice, the decision on whether this is best available is based on methods being peer reviewed, data audited, and a dialogue between ICES, the requesters, and those impacted by the advice. The reputation, transparency, and trust in ICES as an independent provider of scientific advice is the foundation of the credibility of ICES advice.

ICES aims to produce advice that is based on the best available science, characterized by quality assurance, developed in a transparent process, unbiased, independent, and is recognized by all relevant parties as applicable to management (ICES, 2021).

WKCLIMAD also considered that "best available" should be the most useful/relevant science/advice that acknowledges the plurality and uncertainty of various kinds of knowledge, and accounts for potential cognitive bias of those providing that advice. There are two dimensions to "best available", the process of creating the science as much as the findings of the science.

"Best available" is science that evolves and adapts. It should be responsive to applied problems, implement innovations that are considered robust and develop and apply the information and knowledge base, through socially acceptable means.

4.3.2 Properties of best available science

WKCLIMAD considered that the following properties were key to the provision of best available science:

- Information and approaches are credible and relevant for societal decision making
- Up to date data, methods and knowledge
- Evolving and adaptable
- Regionally relevant
- Science that enables action and informs decisions
- Appropriate temporal and spatial scale used in analysis
- Objective and independent, while alert to cognitive bias of those contributing
- Multiple knowledge sources and knowledge providers respected and acknowledged
- Reconciling assumptions and complexity
- Documented, reproducible, available and transparent methods, assumptions and decision
- Uncertainty acknowledged and appropriately explained.

4.3.3 Operational qualities

WKCLIMAD explored the concept of operational best available science. In the context of climate-informed advice, best available science uses standardised and widely accepted scenario assumptions (RCPs & Shared Socioeconomic Pathways, SSPs). The science must be reproducible and attributable. Documented consideration must be given on accuracy, reliability, relevancy, and application of FAIR data principles.

The methods used must be credible, and accepted as robust. Application must be peer-reviewed. The data should be quality-controlled and the methods be quality-assured. The application of a variety of tools to incorporate various types of knowledge is preferable, thus one approach informs the other. The science should strive to be inclusive and participatory.

The methods, data and application of the results must adhere to the Arhus Convention which requires transparency in the evidence base for environmental decision making. Outputs must be documented and publicly available. The science must be challengeable. The system should welcome critique and have mechanisms that allow for a plurality of understanding and reanalysis. It should be possible to critically examine the evidence base, and formerly question the science and ask for further explanations.

4.3.4 Standards for data provision

By maximizing the availability of data to the community at large, ICES promotes the use of these data, thereby ensuring that their maximum value can be realized and thus contribute to an increased understanding of the marine environment. ICES has a data policy (https://doi.org/10.17895/ices.pub.8883) to ensure standards of accessibility, quality control, citation and general adherence to FAIR data principles (Findable, Accessible, Interoperable, and Reusable). ICES has developed the 'data profiling tool' to ensure that new data, such as that which would be in climate-informed advice is consistent with the ICES data policy, and the 10 principles of ICES advice.

Data Profiling Tool (DPT; available at https://www.ices.dk/data/tools/Pages/Data-profiler.aspx) was developed in response to growing need to triage/document/organise information relating to the use of data, data products and services that are not part of the ICES data management offering. The DPT is designed as a document to track data flows, verify the data sources and to know who the owner of the data is. The tool is important for transparency and credibility of the ICES advice. The purpose is the template to fit/meet needs of all advice products.

The tool aids in evaluating the completeness of supporting information for a dataflow or data product. It is designed as a checklist primarily feeding scientific and/or advice outputs through ICES working groups. The aim is to both document the dataflow or product, but also use the answers to evaluate completeness of the dataflow, and document ICES efforts to quality assure all aspects of its advice production. The checklist comprises questions on: i) data sharing, ii) data categorisation, iii) storage and access, iv) data quality; and v) data format.

ICES Data Centre and DIG will continue improving the tool as new datasets and services are registered. Continued work on the DPT is carried out by DIG, including to develop the implementation of the process, and review incoming cases.

4.3.5 Standards for web products (including shiny apps)

Web visualization applications (such as ShinyApp) are created under the auspices of an ICES Expert Group or process that are then publicly available. ICES has in its strategy a clear aim to enable support for, and transparency of, science and advice work in ICES through the use of data visualisations. The challenge is that these applications may not be fit for purpose in providing traceable contextual information to the underlying science and data. For example, if the application is related to a formal ICES advice, this should follow FAIR principles for data provision that underpins the visualization (Findable, Accessible, Interoperable, and Reusable). There is an implication for the integrity of ICES, as a trusted provider of science-based advice, that ICES have to ensure a review and onboarding publication process that meets an agreed standard, and that ShinyApps used in an ICES context are documented and stored appropriately. Therefore, ICES is currently developing ShinyApp publication guidance which should aim to ensure 'best available' web visualisation of data and products.

4.4 Properties of advice

WKCLIMAD agreed that ICES has not as yet designed the science process to match the need of the climate-informed advice. ICES is a boundary organisation (Cvitanovic *et al*, 2021) and its climate-informed advice should have the following properties: be a clear message; based on societal chosen management objectives and clarified acceptable risk; incorporating a diversity and plurality of science approaches; incorporating risk; delivered through the most appropriate formats and mechanisms; providing mechanisms for ad hoc and early warning advice; considering long-term needs of the ICES network.

Plurality of truth and the need for local solutions to regional or global challenges means that ICES should provide advice that is implementable and opens doors for solutions, through innovation recommendation for instance. The process of providing advice should become more human; building collaboration in the communication between scientists and the audience; shared acceptability of uncertainty, and understanding.

Be a clear messenger

It is a challenge to give a clear message, especially in the context of providing integrated advice, and adding layers of complexity could blur the message. ICES needs to ensure that science-based advice does not get lost in translation or obscured in the final delivery by the complexities and nuances of the science. Communicate the active nature of the scientific insights; find balance between actionable advice and uncertainty. Uncertainty and risk should aid the messaging of the advice, not make it more obscure to the end user.

Advice processes should include and execute a communications plan.

Based on management objectives and clarified acceptable risk

Decision-makers are not always able to (or willing to) fully articulate priority objectives, so effort needs to be put into iterative scenario-building to refine goals, clarify assumptions, and transparently evaluate trade-offs within and beyond sectoral policies. It is important to work with policy-makers to also articulate the relevant questions. Explicit and implicit management objectives need to be explored with managers to ensure that the advice is socially relevant. If management guidance is not forthcoming, this needs to be stated in the advice.

ICES should work to ensure that the advice explicitly incorporates the acceptable risk thresholds of the managers.

Incorporating a diversity and plurality of science approaches

Engage multiple stakeholders, using a variety of engagement techniques, (industry, academics, and scientist) to capture local monitoring and data that can be used for near-term and long-term projections. Incorporate short-medium-long-term climate change projections into planning when management measures or new maritime activities/aquaculture species are being considered. Once potential measures are identified, consult stakeholders and investigate feasibility. Engage social scientist and economists in this process and make sure to capture uncertainties.

Accept that there is a plurality of understanding and strive to co-create a shared knowledge base building on a diversity of disciplines. Advice will likely have consequences for social equity. Appreciate that effort is required to create common language, definitions and understanding.

Also note however that consistency is important and that climate-informed advice should use terminology that aligns with IPCC terminology and scenarios. Identify and rank climate impacts, consider and match adaptation measures with public policy objectives.

Delivered through the most appropriate formats and mechanisms

Risk-based approaches (including biological/ecological/social/cultural/economic limits and targets) have a lot of the properties/characteristics (flexibility, scenario-based, transdisciplinary, amenable to all evidence base/knowledge types) that can support and facilitate pro-active, adaptive, and transparent management decision-making. Advice should consider the highest probability of impact and resulting in change.

Advice should clearly present to all participants the best understanding of risks associated with achieving management objectives, including an understanding of how decisions can impact the system overall and available information on how far we are from the desired state. Also, accounting for the costs of inaction. Ideally, advice would further articulate change in risk associated with the different management measures/options available and under different assumptions about the state of the environment/climate/ecosystem.

Delivered through the most appropriate formats and mechanisms

Advice needs to be transparent and must stand up to scrutiny. ICES should be able to justify the choices, assumptions, and data in the science that is incorporated into the advice. Advice product impact can be increased if advice is accessible and transparent for other users, considers appropriate time-scales to avoid being only reactive, and takes into account the risk of doing nothing during that timeframe. ICES should ensure advice developed is examinable/accessible for other future/parallel needs. An example of such a framework the recent National Academies report that evaluated the knowledge base, and the efficacy, scalability, viability and barriers.

Advice should be practical and tiered based on desired outcome with best-worst case with recommended strategies and risks, including cost and benefits and time frames associated with each as well as uncertainties and strategies.

Providing mechanisms for ad hoc and early warning advice

Early warning monitoring systems may require a new decision-making process in place to do something when a change is detected (e.g., change in fishing thresholds that accounts for predator needs, coral reef watch in the USA).

Considering long-term needs of the ICES network

The process of providing advice should also address the long-term needs of ICES as a boundary organisation as well as the build capacity in the ICES community whilst ensuring equity and inclusivity as it develops the community of knowledge brokers. This building of capacity should involve shared expertise and development of skills.

4.5 References

Barkemeyer, R., Dessai, S., Monge-Sanz, B. *et al*. Linguistic analysis of IPCC summaries for policymakers and associated coverage. Nature Clim Change 6, 311–316 (2016). https://doi.org/10.1038/nclimate2824

Cvitanovic C., *et al*. 2021. Strategies for building and managing 'trust' to enable knowledge exchange at the interface of environmental science and policy. Environmental Science and Policy 123: 179 – 189. https://doi.org/10.1016/j.envsci.2021.05.020

Molina, T.; Abadal, E. The Evolution of Communicating the Uncertainty of Climate Change to Policymakers: A Study of IPCC Synthesis Reports. Sustainability 2021, 13, 2466. https://doi.org/10.3390/su13052466

National Academies of Sciences, Engineering, and Medicine. 2022. A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration. Washington, DC: The National Academies Press. https://doi.org/10.17226/26278

5 Conclusions and “on-ramp" climate information and tools to ICES management advice.

5.1 Summary of main findings

Climate-informed advice should be in a risk-based framework that considers magnitude and likelihood of impacts, as well as the effectiveness and feasibility of measures. Plenty of on-ramp tools already exist (examples shown section 3 of this report). A suite of the existing monitoring, analysis and evaluation tools and data flows support the on-ramp tools. The next steps for ICES are to evaluate the three recommended additions to the advice framework/principles (Fig. 5.1), and further develop science-to-advice mechanisms that are risk-based. To maintain advice based on best available science, ICES needs to draw from and synthesise research in six fields and attract further expertise from beyond its core/traditional competencies. Greater emphasis needs to be placed on the communication and co-creation of advice – and advice itself should be implementable and engaging, and allow for solutions and innovation, rather than limit opportunities.

To provide robust climate-informed advice, there is a need to identify and rank climate impacts and the associated risks, and match adaptation measures with public policy objectives. There must also be a balance between actionable advice and reporting of uncertainty. When providing advice to requesters, while the requester may ask for advice for a specific impact or measure, ICES will need to understand the context of that impact or measure in relation to the suite of impacts and measures in the marine ecosystem and the exploited resource.

Climate-informed advice should include an assessment of current conditions in relation to the desired state. This requires not just an evaluation of the state of the system now, but the likely and/or desired future state of the fisheries/aquaculture system. Advice should document the expected effects of specific management actions. Advice should be produced in response to requests and also be proactively produced by ICES. This will also require greater effort on scoping of future scenarios of ecosystem state, and potential management measures for adaptation, and some mitigation.

Capacity building is required in expertise, monitoring as well as in data acquisition and management. ICES needs to attract expertise from beyond its traditional areas of ecosystem and population dynamics and oceanography. Effort is required to further develop iterative scenario-building, evaluating innovation in technology, gear, feeds and the use of genetic resources, and the dynamics of the ecosystem, and its components, in future scenarios. Engagement with the plurality of the knowledge base is required, as a means to refine goals, explore trade-off between management objectives, as well as to build a common understanding about the system.

WKCLIMAD provides ICES with definitions, language and terminology that align with, and build on, those of the IPCC and calls on ICES to consistently use this terminology. The workshop also provides example lists of drivers, impacts, measures & actions. WKCLIMAD acknowledges the utility of the 10 ICES advice principles, and recommends that to improve climate-relevant advice, system should further include,

- Development of a framework for spatial knowledge and advice, that includes definitions of temporal and spatial scale of management challenges.
- Proactive solicitation of experts and stakeholders in relevant fields. Co-production of knowledge with iterative feedback, accounting for the plurality of knowledge and participation mechanisms.

- Formulation of a plan for outputs, and communication, from the start of process, including allocation of sufficient resources to deliver advice.

WKCLIMAD considered that to provide credible climate-informed advice, the evidence base needs to be strengthened in the following scientific fields:

- future scenarios of management options and ecosystem state
- vulnerability and threat analysis of species, ecosystems, and human communities
- spatial planning information and models
- trade-offs, and incentives for technological developments
- carbon accounting across the system
- monitoring & systems for early warning

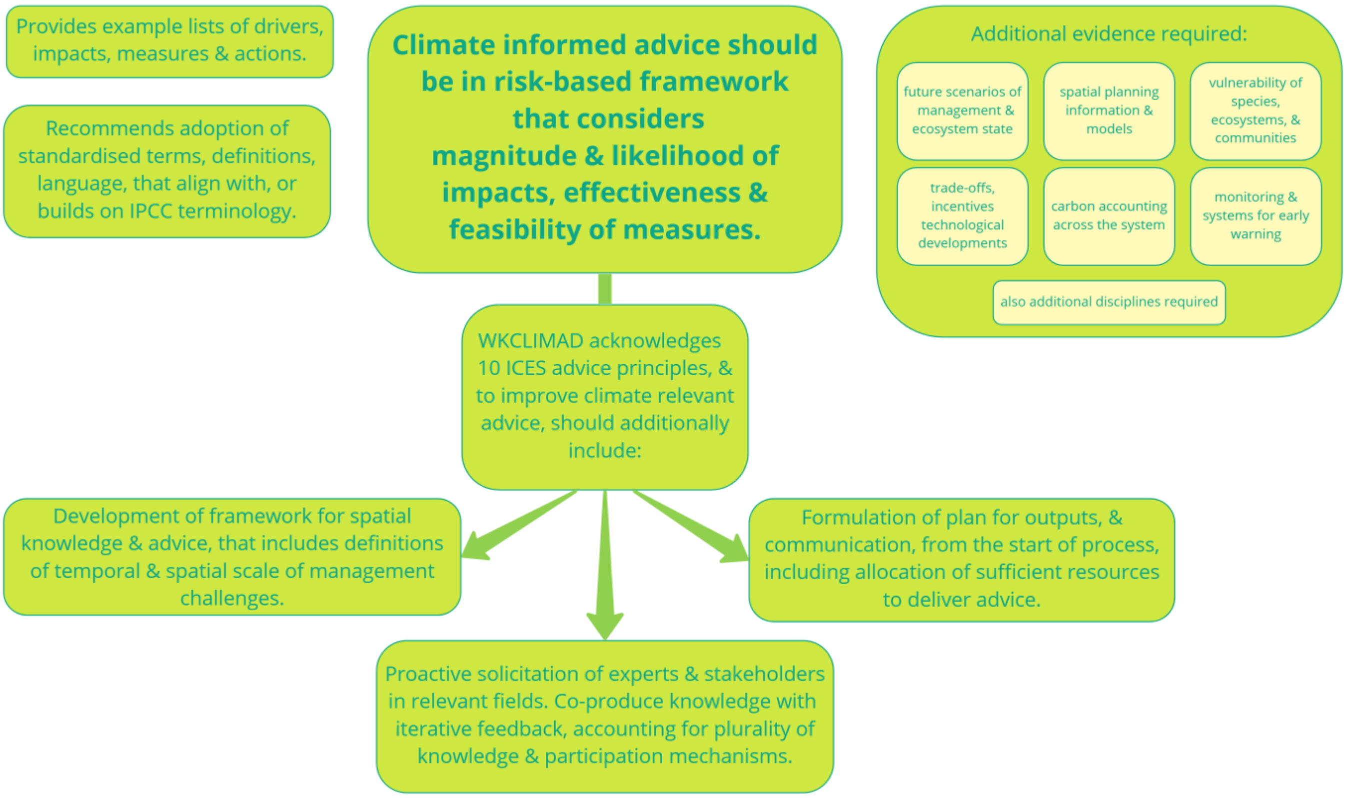


Figure 5.1. Graphical summary of key conclusions of WKCLIMAD (source: Miro board of WKCLIMAD https://miro.com/app/board/uXjVPeJFnu8=/?share_link_id=797996104149)

5.2 Take-home messages for climate-informed fisheries advice

5.2.1 Key elements of climate communication

Providing advice on climate change issues is a challenge as it can be difficult to give a clear and effective message (Corner *et al.*2018, Neal *et al.* 2021). This is especially true in the context of providing integrated advice which includes many layers of complexity, as well as issues around uncertainty and risk (Sterman 2011). It is important that the advice is tailored to the audience**.** A key issue is the terminology that is used that could be a source of ambiguity if not used pertinently or consistently. ICES should avoid jargon, to ensure that science-based advice is not lost in translation. Where scientific or official wording is used ICES should make sure to use it consistent and aligned across documents and relevant external arenas. Clear advice uses consistent language and terminology aligned with existing guidance and is consistent in the concepts included. Communication of advice also needs to expand beyond convention into infographics and interactive visualizations to simplify complicated messages and facilitate exploration of the future. **In order to communicate the active nature of this field, it is important to find balance between actionable advice and uncertainty.** To enable this, there is a need to identify and rank climate impacts, consider and match adaptation measures with public policy objectives. As well as to suggest tailored adaptation measures, relating them where appropriate with existing public policy objectives.

5.2.2 Advice should clearly present the risks and benefits associated with fully achieving management objectives (or not)

Climate-informed management advice should include an assessment of how far we are from a desired state, reflect the expected effects of specific management actions, highlight trade-offs between potentially conflicting objectives, and present how actions can address objectives in terms of magnitude and time-horizon. **Risk-based approaches**, informed by qualitative, semi-quantitative and fully quantitative indicators**, will improve** the evidence base for **adaptive decision making. ICES risk terminology should align with that already used in other arenas, in particular the IPCC**. This applies to the expression of **certainties** of events and how these are associated with estimates of **likelihood** ("virtually certain", <-> 99-100%). It also applies to the description of climate **scenarios (e.g., SSP585).** A new class of scenarios that are useful to ICES advice will also require clear definitions (e.g. fisheries scenarios, ecological scenarios, stock scenarios). Developing advice should create space for collateral impacts of following the advice. This includes trade-offs, the risk of doing nothing during the defined time-frame, and the risk of hyper-reactivity or data-poor decision making.

5.2.3 Communicate uncertainty using ensemble projections

Developing climate-informed management advice for fisheries will require effectively communicating uncertainty. Using ensembles of climate model outputs generated under multiple future scenarios should reflect the range of potential future conditions and their influence on fish populations and fisheries. Operational, routinely-maintained systems for accessing climate model outputs and driving fish population and marine ecosystem models will be foundational for supporting ongoing, routine climate-informed fisheries advice.

5.2.4 ICES management advice should be inclusive of different viewpoints and allow for local solutions

Co-production of climate-aware solutions are essential for generating advice. ICES advice should include local situations, diverse disciplines, equity and co-creation of action. Stakeholder diversity in geographical distribution and expertise will ensure that local barriers and solutions can be identified and analysed holistically. **Advice should be implementable and engaging, and allow for solutions** and innovation, rather than limit opportunities. **The highest probability of impact may be reached when a broad spectrum of stakeholders are engaged** and involved in developing solutions, improving the scientific basis for decision-making and the reliability of policy-relevant science. This implies **room for differences of opinion and alternative solutions**, so that advice is applicable to all stakeholders. This co-production of knowledge approach can also draw on the breadth of understanding, integrate various data and knowledge types, and serve to effectively communicate the change in risk associated with different management options.

5.2.5 A collaborative approach is needed to identify objectives and targets under climate change

Currently, the science process is evolving to match the needs of the advisory process especially for climate change, although it remains nascent, and decision-makers are not always able to (or willing to) explicitly articulate prioritized policy objectives under climate change. Effort needs to be put into iterative scenario-building and engagement, as a means to refine goals, explore trade-off, as well as to build a common understanding and share knowledge about the system. An iterative and collaborative process helps evaluate and review management strategies, if it proceeds. Hence, it helps to adapt operational frameworks during the process and builds trust in the science-to-advice process.

5.2.6 Increase relevancy in advice

Enhanced transparency, accessibility and relevance with regards to management time-frames and available knowledge will increase the legitimacy, credibility and impact of science advice. Useful advice should consider and be clear about the appropriate time-scales underpinning that advice - i.e. whether it is immediate and tactical, or longer term and strategic. Impactful advice also needs to be justified and credible (supported by evidence), reproducible, and open to scrutiny. Relevance can also be enhanced if the advice is proactive as often as reactive. Advice should work to encourage policymakers to ask relevant questions, and ideally the advice request should be developed interactively between the providers and the clients.

5.2.7 Prioritize adaptation options based on their feasibility and effectiveness

Actions to address climate change will inevitably include compromises - e.g. among objectives as well as among community needs and values. Therefore, it is critical to prioritize and assess adaptation options, based on their feasibility and potential success given the diversity and interaction of many co-occurring impacts of climate change (let alone their interactions with other influences, e.g. fishing). This includes identifying interdependencies and ranking climate impacts when possible, and considering and matching adaptation measures as they affect the achievability of policy objectives. We recognize this is challenging and not always possible, but should be attempted. Options for climate adaptation need to consider short-medium-long-term projections and take into account how management outcomes will differ across space, time, and communities. Adaptation options should facilitate the transition to more sustainable paradigms.

5.2.8 Build capacity for adaptation through innovation

Climate-informed management will require increased capacity in multiple arenas and novel and rapid information needs require approaches that can draw on broad knowledge sources. Gear innovation to support climate adaptation and mitigation in the fishing sector will be needed. ICES experts are well placed to support this, but it will also require levers (e.g. financial incentives) to ensure adoption of new gears by the sector. The inclusion of social dimensions in the adoption of new fishing gears can contribute to our knowledge on how technological transitions in fisheries can be managed. (Haasnoot *et al.* 2016) Incentive systems, such as labelling of low carbon fishing, carbon taxes can provide the right levers, but require more established methods and authoritative frameworks of estimation of different aspects of carbon footprints and new data streams (e.g. monitoring the fuel use on-board fishing vessels, impact of fuel use of fleets). There is a need for scientific and data capacity for accounting for supply chain aspects. Those solutions that leverage markets also need to involve supply chain data collection, not just harvesters, and thus require processes and regulations to engage with these sectors.

Climate change (its impacts, adaptation and reduction of greenhouse gasses) will have winners and losers in the "blue economy". Actors across research, advice, practice and management will need to be suitably engaged. Inclusive engagement of multiple stakeholders (industry, academics, and scientist) can help leverage local monitoring, local knowledge, and climate data that can be used for rapid observations, now-casts, near-term and long-term projections. Innovation requires co-creation, consultation, public information campaigns to ensure they get buy-in (and avoid good ideas are thrown out due to few loud voices).

5.2.9 Build on and expand fundamentals

Current proven methods and tools have their role to play in the context of climate change related advice and can build on the fundamentals of good management (e.g., precautionary approach, EBM) but expand them to support climate adaptation. Continued development of scientific capacity to integrate climate information into stock assessments and other models on which fishery management is based is necessary. Moreover, efforts are needed to expand and standardize processes for communicating climate-informed scientific information to stakeholders and applying it routinely in management advice. Real-time monitoring and forecasting systems may be necessary to support rapid management responses to changing ecosystem and fishery conditions. Integrated marine spatial planning will require difficult conversations that require all stakeholders to be included in the process and sufficient support for a Just Transition for the sectors is achieved. Participatory methods and stakeholder engagement will be needed to support buy-in and implementation of management tools like precautionary buffers and carbon audits.

Both advisory and management processes should be reviewed to ensure that advice can take a pro-active pathway when sudden/extreme events occur and that subsequent management action can be taken.

The advisory process needs to be supported with sustained efforts to drive research outputs into operational capacity to inform EBM. The advisory process may need to change, e.g. revising assessments more often to take into account more frequent or unusual events. Proactive proposals on scientific climate-related advice by ICES can only be effective if the management system can make use of the information

5.3 Take-home messages for climate-informed aquaculture advice

5.3.1 Support a climate-smart aquaculture future and climate resilient present

Incorporate short-medium-long-term climate change projections into planning and management, including cumulative effects when new aquaculture industries for a particular area are being considered (e.g. species, sites, gear, technologies). Working with key stakeholders to identify potential suitable directions, and investigate marketability/feasibility, uncertainties, to identify knowledge gaps and prioritize actions to fill these gaps.

ICES needs to communicate the active nature of this field and continue to develop aquaculture focused advice that balances between actionable advice and uncertainty. In general, the results of this workshop show that the development of science and technology that will improve industries resilience to climate impacts tended to favour those that increased human management options and decreased reliance on wild ecosystems. For example, using hatcheries over wild recruitment, man-made feeds over reliance on wild feed, selective breeding for resilience over using wild brood stocks. Likewise, having choices in crops to grow be they different species or different strains of the same species, choices in biosecurity approaches, choices in feed ingredients and so on, add resilience.

5.3.2 Use a sub-disciplinary and a multidisciplinary approach to planning and advice generation

Aquaculture results from WKCLIMAD suffered from only having a small number of experts participate. This limited the diversity of expertise present and the depth within any sub-discipline important to aquaculture. The diversity of experts needed to develop sustainable aquaculture mirrors agriculture. Pathologists, veterinarians, nutritionists, physiologists, ecologists, geneticists, engineers, modelers, economists and social scientists among others all have unique points of view that were minimally or not represented at WKCLIMAD's aquaculture workshops. Likewise, the three sub-industries of shellfish, seaweeds and finfish exacerbated the spotty expertise. Further, without guidance from some unrepresented disciplines, group confidence in rankings suffered. Most of the bias introduced by this situation, and the low confidence could be addressed by first holding a series of more focused Delphi exercises with sub-discipline groups of experts to develop and rank impacts and responses specific to the sub-discipline and industry segment. Once a sufficient number of these groups presented their rankings, hold a second Delphi with multiple representatives from each sub-discipline together to rank across specific impacts and responses broadly. This two-step process may improve engagement of more relevant scientific expertise, including social scientists and economists in this process.

Finally develop and execute a communications plan that presents outcomes from all Delphi exercises in a consistent easy to understand format. The plots shown in this report could serve as templates. ICES may want to consider if a workgroup should be set up to coordinate a Delphi with other workgroups to carry this out.

Advice should be practical and tiered based on desired outcome with best-worst case with recommended strategies and risks, including cost/benefits and time frames associated with each as well as uncertainties and strategies.

It should identify and rank climate impacts, consider and match adaptation measures with public policy objectives. The stakeholders include policy makers, regulators, academia, industry, public, NGOs, community groups.

5.3.3 Support transparent decision making and data sharing

Advice and the data underpinning it should to be impartial, transferable, transparent, and publicly available.

5.4 Next steps: topics & disciplines for future workshops

WKCLIMAD suggested and ranked topics that warrant workshops to further develop climate-informed science and advice (Figure 5.4.1). The top ranked specifically climate-oriented suggestions are given below. There was also interest in workshops that explored equity, ethics, and just decision making, informal engagement with stakeholders, and expansion of expertise (e.g., decision makers, social scientists, stakeholders, lawyers, market experts, arts and humanities).

- Knowledge gaps: explore what scientific evidence that is missing and identify what is needed to be able to give climate-informed advice; investigate local/regional efforts
- Social and cultural aspects of climate-informed advice
- Accounting for, and communication of uncertainty in climate-informed advice
- Location/ecoregion specific workshops
- Evaluation of existing tools/models for climate-informed advice
- Joint workshop with IPCC
- Ecological trade-offs driven by climate change

WKCLIMAD considered that to provide credible climate-informed advice, the evidence base needs to be strengthened in the following scientific fields:

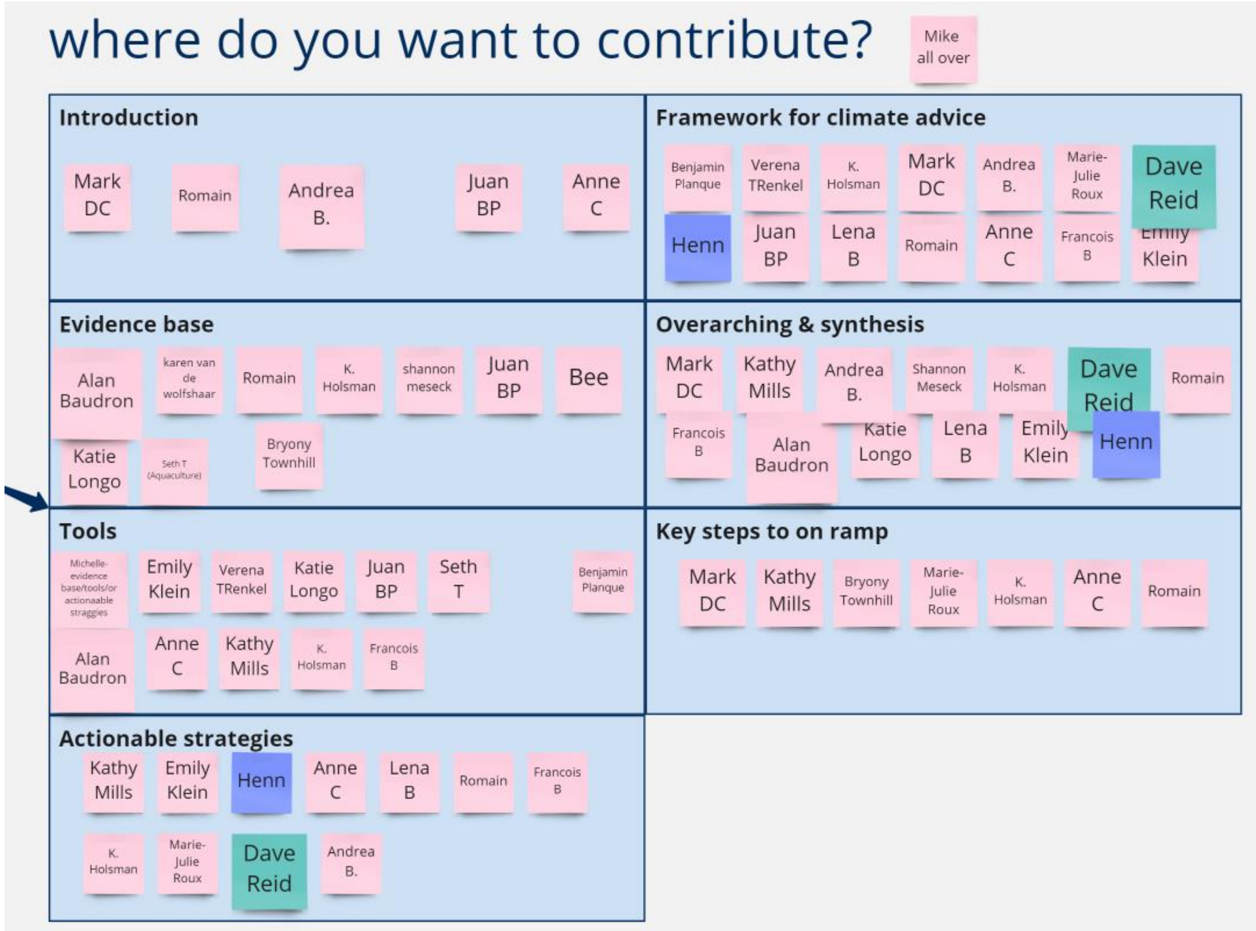
- future scenarios of management options and ecosystem state
- risk, vulnerability and resilience analysis of species, ecosystems, and human communities
- spatial planning information and models
- trade-offs among potential actions, and incentives for best practice sharing including technological developments
- carbon accounting across the system
- monitoring and early-warning systems

WKCLIMAD recognised that it lacked expertise, and experience in several disciplines and understanding. WKCLIMAD emphasised that the following knowledge holders should be proactively sought to engage with ICES as it develops climate-informed advice:

- Social scientists (including economists and governance experts)
- Industry representative (fishing and aquaculture)
- Indigenous and local knowledge holders
- Managers, decision makers
- Experts in evaluating risk (including specialists in insurance)
- Experts in evaluating markets and production systems
- Experts in ecosystem services.

Figure 5.4.1. The suggestion and votes of WKCLIMAD for further workshops to aid the development of climate-informed advice.

Contribution from participants


where do you want to contribute?
Mike all over
Introduction
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Romain
Andrea B.
Juan BP
Anne C
Framework for climate advice
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Verena TRenkel
K. Holsman
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Romain
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Bee
Katie Longo
Bryony Townhill
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Shannon Meseck
K. Holsman
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Romain
Francois B
Alan Baudron
Katie Longo
Lena B
Emily Klein
Henn
Tools
Emily Klein
Verena TRenkel
Katie Longo
Juan BP
Seth T
Benjamin Planque
Alan Baudron
Anne C
Kathy Mills
K. Holsman
Francois B
Key steps to on ramp
Mark DC
Kathy Mills
Bryony Townhill
Marie-Julie Roux
K. Holsman
Anne C
Romain
Actionable strategies
Kathy Mills
Emily Klein
Henn
Anne C
Lena B
Romain
Francois B
K. Holsman
Marie-Julie Roux
Dave Reid
Andrea B.

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Annex 2: Resolutions

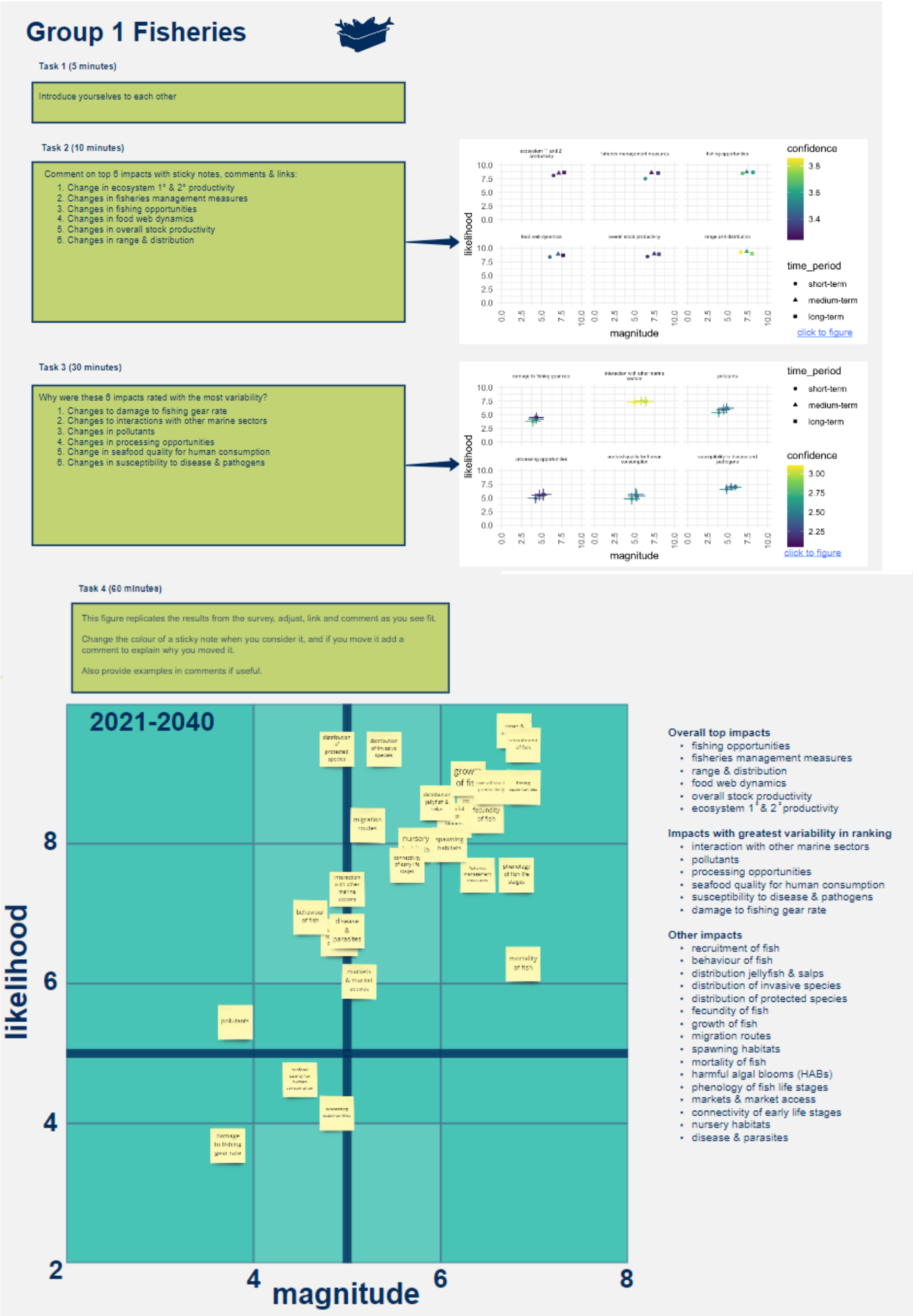
2020/WK/IEASG 05 The **Workshop on pathways to climate-aware advice (WKCLIMAD),** chaired by Kirstin Holsman, USA, Michael Rust, USA and Mark Dickey -Collas, ACOM, will be established on 15 June 2021 to start intersessional work and will meet online, 29–30 September 2021 and 18-20 October 2021 to develop a proposal for an advisory framework that accounts for the influences of climate change on aquaculture, fisheries, and ecosystems. The framework should address the short, medium and long-term influence of climate. The workshop will do this by:

a) Work intersessionally (via correspondence prior to and between meetings) to review the evidence base of recent and emergent analyses of key climate hazards to aquaculture, fisheries, and ecosystems. The review should include the probability of risk and the severity of the key climate hazards, the assessment of variability and uncertainty, identifying best practice for the consequences of both temporal and spatial scales (Science Plan codes: 1.3, 2.5).
b) Outline actionable strategies and approaches (including socio-ecological adaptation and mitigation) to promote resiliency in aquaculture, fisheries, and ecosystems; frame and identify the key steps to “on-ramp" climate information and tools to management advice. (Science Plan codes: 6.6).
c) Scope the next steps for an operational approach, expanding the relevant aspects of climate change that impact management decisions in aquaculture, fisheries, and ecosystems (Science Plan codes: 6.6).

WKCLIMAD will report by 15 November 2021 for the attention of IEASG.

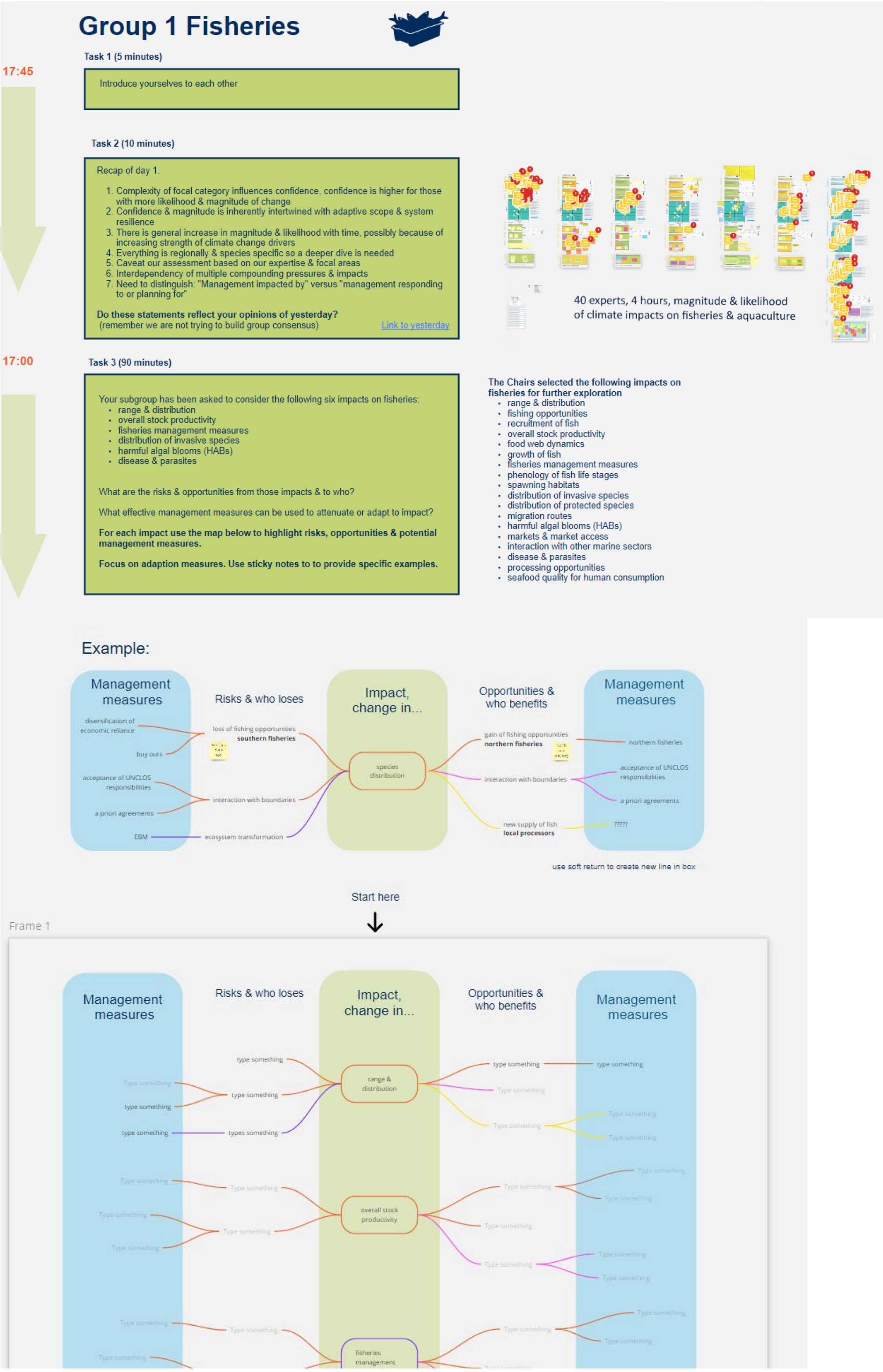
Annex 3: Work flows of virtual whiteboard activities (days 1 to 5).

Day 1

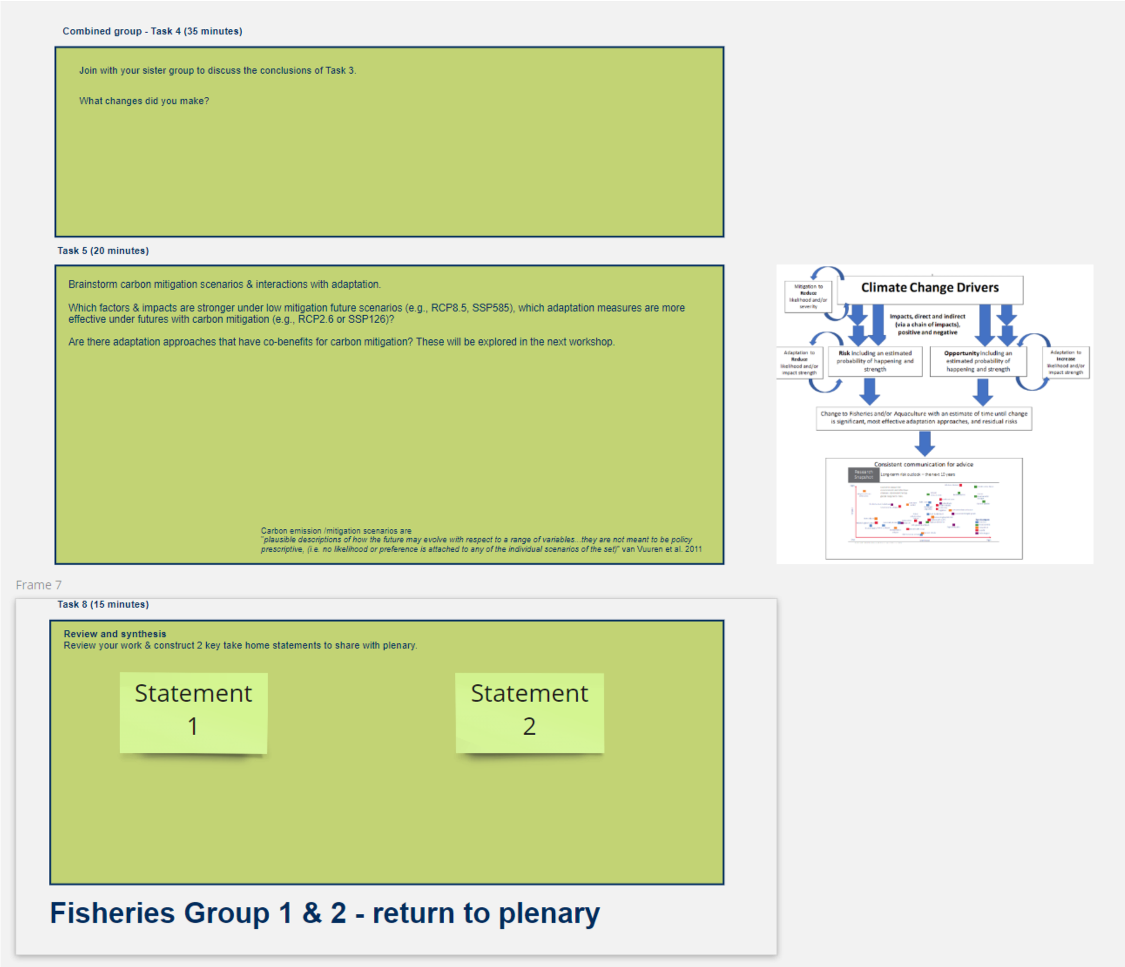



Task 5 (15 minutes)
Timeframe
Consider the differences between the short, medium & long term from the survey.
What phenomena & properties are apparent?
short-term
medium-term
long-term
likelihood
magnitude
fisheries
confidence
3.5
3.0
2.5
click to figure
Task 6 (15 minutes)
Confidence
Consider why does the confidence in the ratings increase from lower left quadrant to upper right quadrant?
Task 7 (30 minutes)
Drivers
The mechanisms & drivers for the impacts include & are combinations of temperature, salinity, O2, acidification, ice cover, floods, storms, other extreme events and ocean circulation patterns.
Do we have a robust evidence base to distinguish & assess the relative contribution for the top 5 impacts?
click for list of drivers
Task 8 (15 minutes)
Review and synthesis
Review your work & construct 2 key take home statements to share with plenary.
Statement 1
Statement 2
Fisheries Group 1 - return to plenary

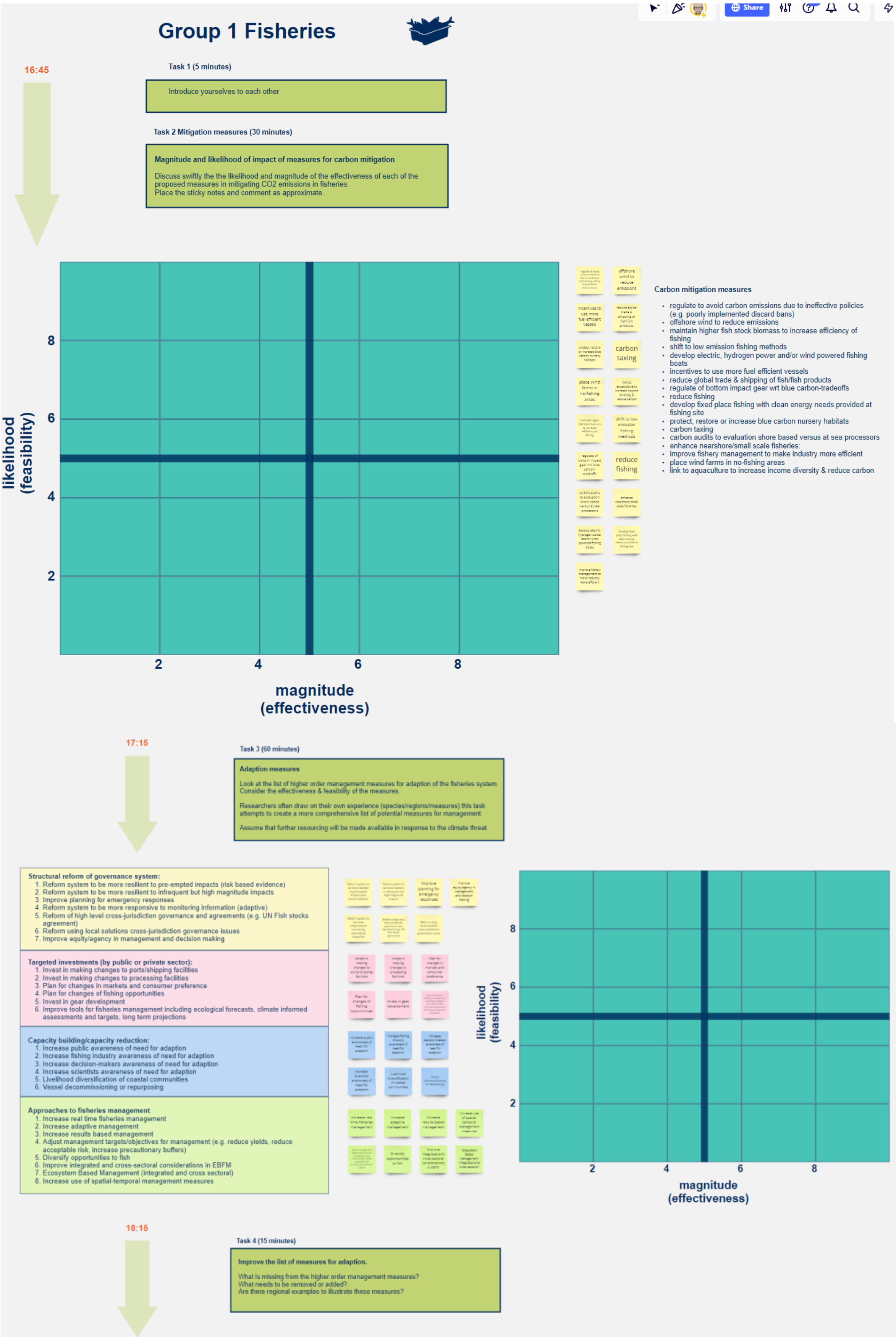
Day 2


Group 1 Fisheries
Task 1 (5 minutes)
17:45
Introduce yourselves to each other
Task 2 (10 minutes)
Recap of day 1.
1. Complexity of focal category influences confidence, confidence is higher for those with more likelihood & magnitude of change
2. Confidence & magnitude is inherently intertwined with adaptive scope & system resilience
3. There is general increase in magnitude & likelihood with time, possibly because of increasing strength of climate change drivers
4. Everything is regionally & species specific so a deeper dive is needed
5. Caveat our assessment based on our expertise & focal areas
6. Interdependency of multiple compounding pressures & impacts
7. Need to distinguish: "Management impacted by" versus "management responding to or planning for"
Do these statements reflect your opinions of yesterday?
(remember we are not trying to build group consensus)
Link to yesterday
40 experts, 4 hours, magnitude & likelihood of climate impacts on fisheries & aquaculture
17:00
Task 3 (90 minutes)
Your subgroup has been asked to consider the following six impacts on fisheries:
• range & distribution
• overall stock productivity
• fisheries management measures
• distribution of invasive species
• harmful algal blooms (HABs)
• disease & parasites
What are the risks & opportunities from those impacts & to who?
What effective management measures can be used to attenuate or adapt to impact?
For each impact use the map below to highlight risks, opportunities & potential management measures.
Focus on adaption measures. Use sticky notes to to provide specific examples.
The Chairs selected the following impacts on fisheries for further exploration
• range & distribution
• fishing opportunities
• recruitment of fish
• overall stock productivity
• food web dynamics
• growth of fish
• fisheries management measures
• phenology of fish life stages
• spawning habitats
• distribution of invasive species
• distribution of protected species
• migration routes
• harmful algal blooms (HABs)
• markets & market access
• interaction with other marine sectors
• disease & parasites
• processing opportunities
• seafood quality for human consumption
Example:
Management measures
Risks & who loses
Impact, change in...
Opportunities & who benefits
Management measures
diversification of economic reliance
buy outs
acceptance of UNCLOS responsibilities
a priori agreements
EBM
loss of fishing opportunities southern fisheries
interaction with boundaries
ecosystem transformation
species distribution
gain of fishing opportunities northern fisheries
interaction with boundaries
new supply of fish local processors
northern fisheries
acceptance of UNCLOS responsibilities
a priori agreements
?????
use soft return to create new line in box
Start here
Frame 1
Management measures
Risks & who loses
Impact, change in...
Opportunities & who benefits
Management measures
range & distribution
overall stock productivity
fisheries management

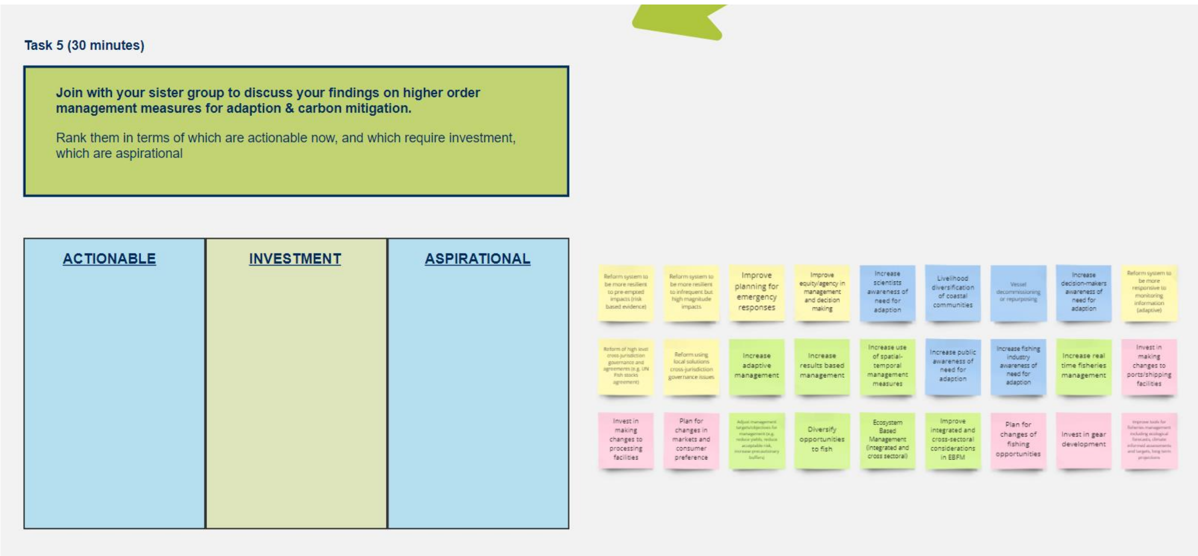
Then two subgroups join to consider:

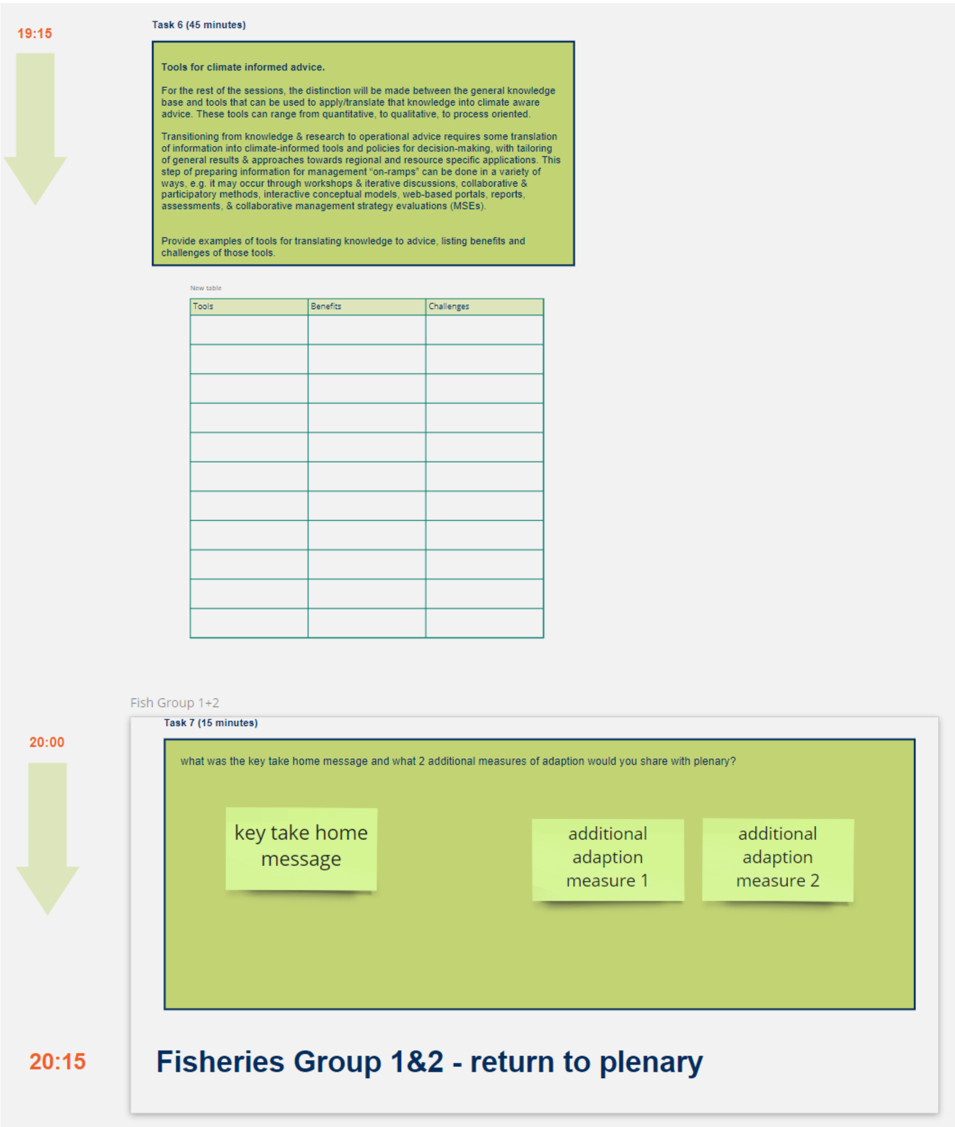


Day 3


Group 1 Fisheries
16:45
Task 1 (5 minutes)
Introduce yourselves to each other
Task 2 Mitigation measures (30 minutes)
Magnitude and likelihood of impact of measures for carbon mitigation
Discuss swiftly the the likelihood and magnitude of the effectiveness of each of the proposed measures in mitigating CO2 emissions in fisheries.
Place the sticky notes and comment as approximate.
likelihood (feasibility)
magnitude (effectiveness)
offshore wind to reduce emissions
carbon taxing
reduce fishing
Carbon mitigation measures
regulate to avoid carbon emissions due to ineffective policies (e.g. poorly implemented discard bans)
offshore wind to reduce emissions
maintain higher fish stock biomass to increase efficiency of fishing
shift to low emission fishing methods
develop electric, hydrogen power and/or wind powered fishing boats
incentives to use more fuel efficient vessels
reduce global trade & shipping of fish/fish products
regulate of bottom impact gear wrt blue carbon-tradeoffs
reduce fishing
develop fixed place fishing with clean energy needs provided at fishing site
protect, restore or increase blue carbon nursery habitats
carbon taxing
carbon audits to evaluation shore based versus at sea processors
enhance nearshore/small scale fisheries:
improve fishery management to make industry more efficient
place wind farms in no-fishing areas
link to aquaculture to increase income diversity & reduce carbon
17:15
Task 3 (60 minutes)
Adaption measures
Look at the list of higher order management measures for adaption of the fisheries system. Consider the effectiveness & feasibility of the measures.
Researchers often draw on their own experience (species/regions/measures) this task attempts to create a more comprehensive list of potential measures for management.
Assume that further resourcing will be made available in response to the climate threat.
Structural reform of governance system:
1. Reform system to be more resilient to pre-empted impacts (risk based evidence)
2. Reform system to be more resilient to infrequent but high magnitude impacts
3. Improve planning for emergency responses
4. Reform system to be more responsive to monitoring information (adaptive)
5. Reform of high level cross-jurisdiction governance and agreements (e.g. UN Fish stocks agreement)
6. Reform using local solutions cross-jurisdiction governance issues
7. Improve equity/agency in management and decision making
Targeted investments (by public or private sector):
1. Invest in making changes to ports/shipping facilities
2. Invest in making changes to processing facilities
3. Plan for changes in markets and consumer preference
4. Plan for changes of fishing opportunities
5. Invest in gear development
6. Improve tools for fisheries management including ecological forecasts, climate informed assessments and targets, long term projections
Capacity building/capacity reduction:
1. Increase public awareness of need for adaption
2. Increase fishing industry awareness of need for adaption
3. Increase decision-makers awareness of need for adaption
4. Increase scientists awareness of need for adaption
5. Livelihood diversification of coastal communities
6. Vessel decommissioning or repurposing
Approaches to fisheries management
1. Increase real time fisheries management
2. Increase adaptive management
3. Increase results based management
4. Adjust management targets/objectives for management (e.g. reduce yields, reduce acceptable risk, increase precautionary buffers)
5. Diversify opportunities to fish
6. Improve integrated and cross-sectoral considerations in EBFM
7. Ecosystem Based Management (integrated and cross sectoral)
8. Increase use of spatial-temporal management measures
likelihood (feasibility)
magnitude (effectiveness)
18:15
Task 4 (15 minutes)
Improve the list of measures for adaption.
What is missing from the higher order management measures?
What needs to be removed or added?
Are there regional examples to illustrate these measures?

Then two subgroups join to consider:





Day 4

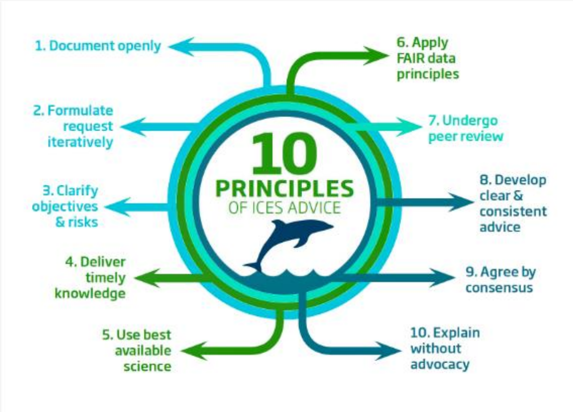
ICES CIEM WKCLIMAD Day 4
Subgroups Start 16:45

4

Frameworks & Principles
ICES uses frameworks & principles to create its advice. This provides transparency to the advice process & reduces the likelihood of imposing normative values & influence from individual interpretations.

An example can be found in our guides:

- Guide to ICES advisory framework & principles
- Advice on fishing opportunities
- Advice on ecosystem services & effects



Today, we will carryout two exercises to lay the foundations for the developing ICES approach to advice on climate change. We will 'on ramp' ideas.

1. Split into subgroups to develop scientific advice for examples. This will be based on described hypothetical case studies.
2. Brainstorm in subgroups to list issues that should be considered when providing advice in climate context, these could include likelihood, local/regional experience verse global, risk based approaches, responses to warning signals, adapting monitoring, science & evidence can only go so far, adaption can only go so far without mitigation etc

Then subgroups will merge to discuss their texts and brainstorming.
So head to your groups:

Group 1 Fisheries

16:45

Task 1 (5 minutes)

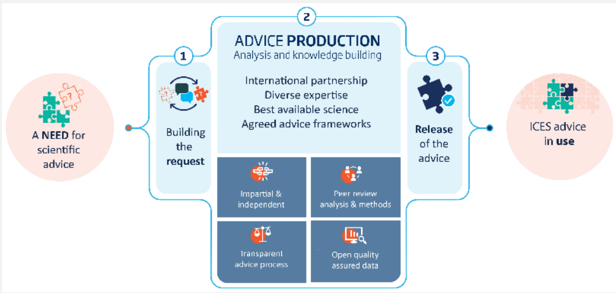
Introduce yourselves to each other

Task 2 (10 minutes)

ICES advice
We generate scientific advice to support ecosystem-based management of human activities in our seas and oceans.

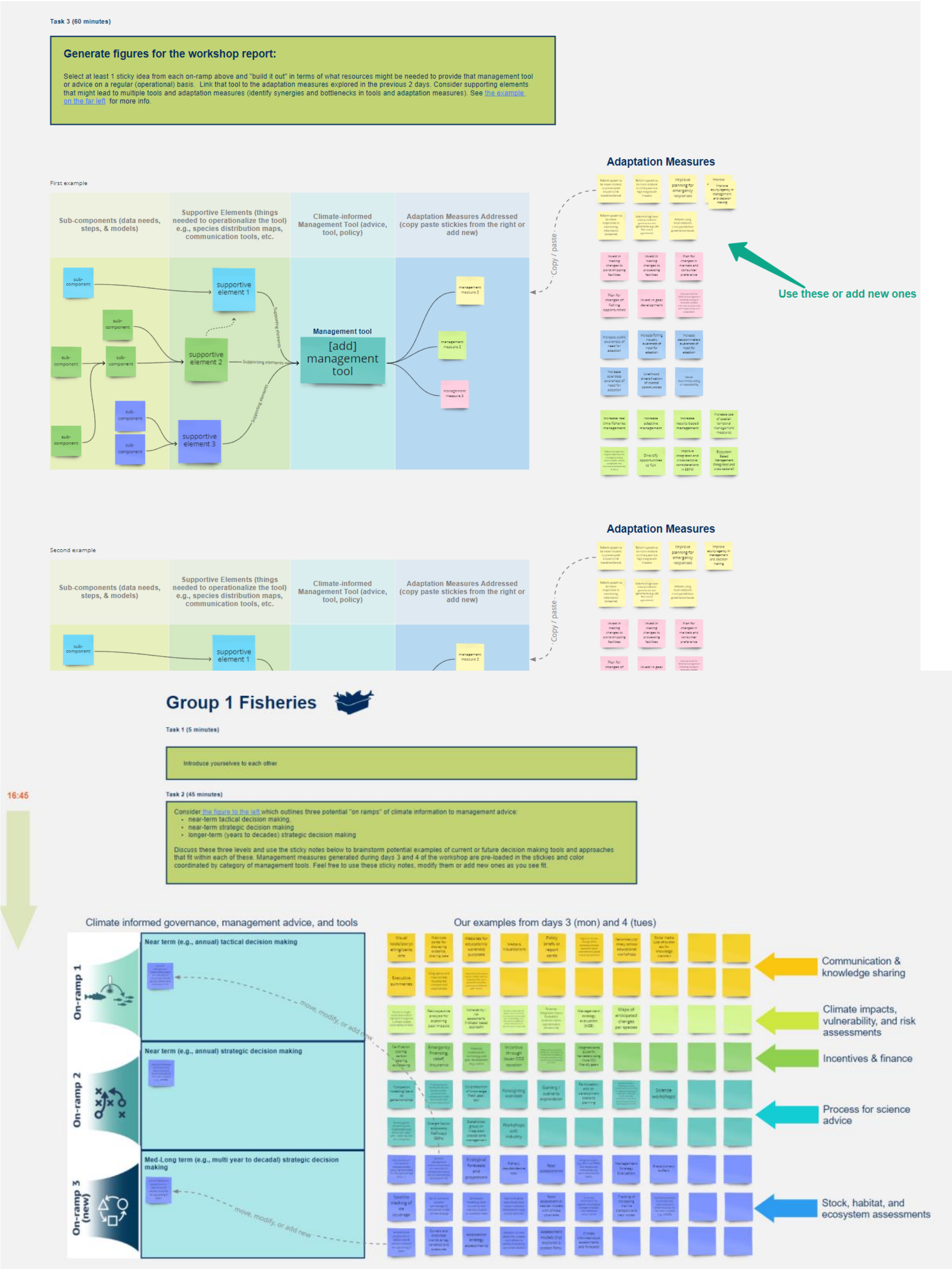
Our advice contributes towards the effective application of an ecosystem approach, which seeks to maintain the health of marine ecosystems, alongside appropriate human use, for the benefit of current & future generations.

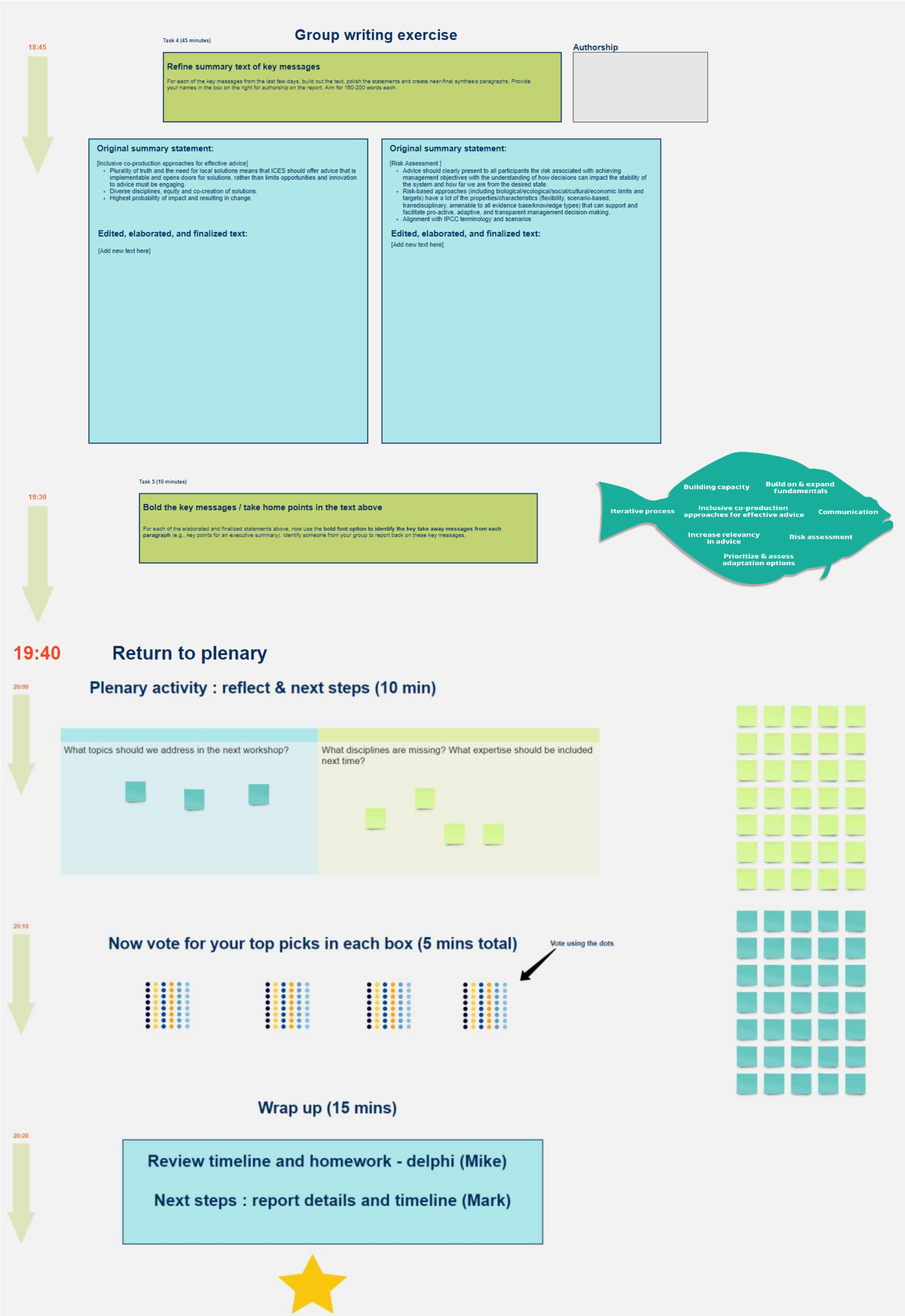
Provide adjectives on sticky notes that describe required properties of advice into the science to policy interface e.g. transparent, timely, relevant...




Frame 1
Case 1.
Advice:
Likely knowledge gaps:
On ramp tools:
Recommendations to improve:
Case 2.
Advice:
Likely knowledge gaps:
On ramp tools:
Recommendations to improve:
18:15
Task 4 (15 minutes)
Advice for society
Find and post an image (drag & drop, or use upload from left hand bar) that best represents the challenges of providing advice for societal decision making.
18:45
Task 5 (45 minutes)
Properties of Advice
Brainstorm in subgroups the properties & characteristics of advice in the context of climate change. These could include communicating risk & uncertainty, role of monitoring, local/regional experience vs global, ensuring best available science, building in precautionarity, risk based approaches, ensuring credibility, salience & legitimacy of advice.
Take home message on properties of advice
XXXXX
19:30
Task 6 (30 minutes)
Best available science?
International agreements commit ICES to provide advice on best available science.
From your experience, and perhaps with the help of google too, Describe what you understand as "best available science"

Day 5


Task 3 (60 minutes)
Generate figures for the workshop report:
Select at least 1 sticky idea from each on-ramp above and "build it out" in terms of what resources might be needed to provide that management tool or advice on a regular (operational) basis. Link that tool to the adaptation measures explored in the previous 2 days. Consider supporting elements that might lead to multiple tools and adaptation measures (identify synergies and bottlenecks in tools and adaptation measures). See the example on the far left for more info.
First example
Sub-components (data needs, steps, & models)
Supportive Elements (things needed to operationalize the tool) e.g., species distribution maps, communication tools, etc.
Climate-informed Management Tool (advice, tool, policy)
Adaptation Measures Addressed (copy paste stickies from the right or add new)
Management tool
[add] management tool
Adaptation Measures
Copy / paste
Use these or add new ones
Second example
Group 1 Fisheries
Task 1 (5 minutes)
Introduce yourselves to each other
Task 2 (45 minutes)
16:45
Climate informed governance, management advice, and tools
Our examples from days 3 (mon) and 4 (tues)
Near term (e.g., annual) tactical decision making
Near term (e.g., annual) strategic decision making
Med-Long term (e.g., multi year to decadal) strategic decision making
On-ramp 1
On-ramp 2
On-ramp 3 (new)
move, modify, or add new
Communication & knowledge sharing
Climate impacts, vulnerability, and risk assessments
Incentives & finance
Process for science advice
Stock, habitat, and ecosystem assessments


18:45
Task 4 (45 minutes)
Group writing exercise
Refine summary text of key messages
For each of the key messages from the last few days, build out the text, polish the statements and create near-final synthesis paragraphs. Provide your names in the box on the right for authorship on the report. Aim for 150-200 words each.
Authorship
Original summary statement:
[Inclusive co-production approaches for effective advice]
• Plurality of truth and the need for local solutions means that ICES should offer advice that is implementable and opens doors for solutions, rather than limits opportunities and innovation to advice must be engaging.
• Diverse disciplines, equity and co-creation of solutions.
• Highest probability of impact and resulting in change.
Edited, elaborated, and finalized text:
[Add new text here]
Original summary statement:
[Risk Assessment]
• Advice should clearly present to all participants the risk associated with achieving management objectives with the understanding of how decisions can impact the stability of the system and how far we are from the desired state.
• Risk-based approaches (including biological/ecological/social/cultural/economic limits and targets) have a lot of the properties/characteristics (flexibility, scenario-based, transdisciplinary, amenable to all evidence base/knowledge types) that can support and facilitate pro-active, adaptive, and transparent management decision-making.
• Alignment with IPCC terminology and scenarios
Edited, elaborated, and finalized text:
[Add new text here]
19:30
Task 5 (10 minutes)
Bold the key messages / take home points in the text above
For each of the elaborated and finalized statements above, now use the bold font option to identify the key take away messages from each paragraph (e.g., key points for an executive summary). Identify someone from your group to report back on these key messages.
Building capacity
Build on & expand fundamentals
Iterative process
Inclusive co-production approaches for effective advice
Communication
Increase relevancy in advice
Risk assessment
Prioritize & assess adaptation options
19:40
Return to plenary
20:00
Plenary activity : reflect & next steps (10 min)
What topics should we address in the next workshop?
What disciplines are missing? What expertise should be included next time?
20:10
Now vote for your top picks in each box (5 mins total)
Vote using the dots
Wrap up (15 mins)
20:20
Review timeline and homework - delphi (Mike)
Next steps : report details and timeline (Mark)