ICES input to the UN ICSP17 on "Sustainable fisheries management in the face of climate change."

Understanding the impacts of climate change on fisheries

ICES and an intergovernmental marine science organization focused on the north Atlantic 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.

Currently the ICES network is actively tackling climate change impacts on sustainable fisheries in several ways; through its strategic initiatives, integration into the Advice and building scientific understanding through the many ICES expert groups.

Strategic Initiatives

The *Strategic Initiative on Climate Change Impacts on Marine Ecosystems (SICCME)* was set up by ICES and PICES in order to coordinate northern hemisphere efforts to understand, estimate and predict the impacts of climate change on marine ecosystems. Objectives include advancing the scientific capacity on these three main challenges 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. The ICES-PICES SICCME recognizes that the timeline for projections (20-100 years) requires the development of mechanistic scenarios of future bio-physical couplings, as well as scenarios for expected changes in anthropogenic trends in marine resource use following trends in marine policy. Interdisciplinary research teams will be required in order to develop science-based advice to 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.

ICES Advice

Answering an advice request from the European Commission, experts of the *Workshop on Fish Distribution Shifts (WKFISHDISH)* found that 16 out of 21 species examined have shown changes in their distributions across the northeast Atlantic since 1985, with hake and mackerel shifting the most. Of these, eight species 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 ICES Integrated Ecosystem Assessment Groups (IEAs) work on incorporating Climate Change impacts in the ICES Ecosystem Overviews (EOs) advisory product. 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. Climate change is incorporated in the ecosystem overviews as a distinct pressure/driver which is not manageable at the ecoregional scale (and as such not included in the top five pressures). Climate change affects the environmental context and may operate across all human activities and ecosystem state components.

The Workshop on pathways to climate-aware advice (WKCLIMAD) met in the autumn of 2021 to develop a proposed advisory framework that accounts for the influences of climate change on aquaculture, fisheries, and ecosystems. 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 workshop also provides example lists of drivers, impacts, measures and potential actions.
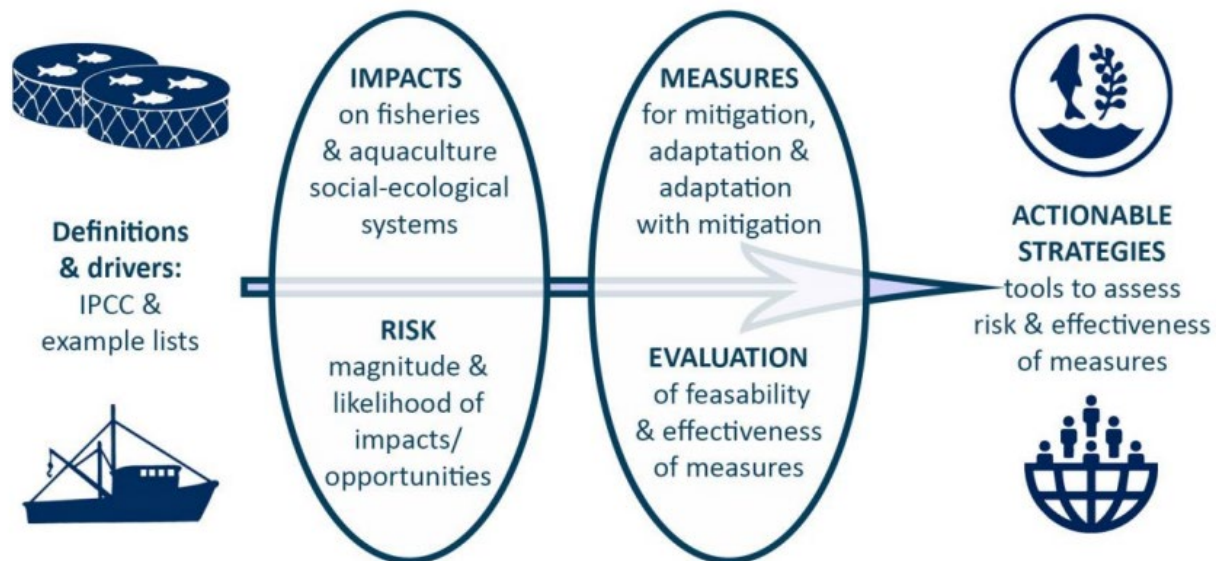
ICES regularly updates the IROC report on ocean climate this highlights trends in Essential Oceanographic Variables (EOVs) driven by climate change throughout the North Atlantic. Various ICES expert groups, such as Working Group on Operational oceanographic products for fisheries and environment (WGOOFE) have been exploring how to routinely integrate climate change drivers into operational fisheries management. Benchmark process such as WKIRISH have led to some progress such as the F_{ECO} concept (Bentley et. Al 2021) where fishing mortality targets are adjusted to integrate ecosystem drivers including climate.

Indirectly, climate change related changes in productivity metrics such as weight-at-age and changes in recruitment are used to forecast short term catches. In addition, when defining reference points regime shifts have been considered for some stocks in the ICES area. Predicting climate change related changes in productivity in fisheries is complex but there has been some progress (Payne et. Al, 2017). There is increasing evidence of non-stationarity in stock and recruitment relationships which in turn impacts on reference points and sustainable harvest strategies (Silvar-Viladomiu, et al 2022 and Zhang, et al 2021).

Other work in the ICES network

The ICES/PICES *Workshop on Regional climate change vulnerability assessment for the large marine ecosystems of the northern hemisphere (WKSICCME-CVA)* worked on comparing Climate Vulnerability Assessments (CVA's) that have been conducted 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 developing nations were also included. Findings of WKSICCME-CVA focus on the next generation of CVAs that will require 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 taking into account adaptive capacity, CVAs can be powerful tools for communicating and prioritizing risk from climate variability and change and planning adaptation. In order to conduct a successful CVA, the use of participatory processes is needed in order to contextualize risks to marine stakeholders and communities, foster engagement, and support science communication and transparency. CVAs based on systematic vulnerability ranking of marine assets or human communities can support important actions, including prioritizing research on the most vulnerable fish stocks or farmed species and identifying knowledge gaps that may affect planning for future change and sustainability of ecosystem and human communities. CVAs can also facilitate the integration of climate information into fish stock assessments and farm production models, as well as raise awareness of marine fisheries and aquaculture industries (to the risks and opportunities posed by climate change) and of policymakers (for climate adaptation strategies promoting sustainable resource use as well as the resilience of coastal communities).

The *ICES Working Group on Seasonal-to-Decadal Prediction of Marine Ecosystems ([WGS2D](#))* studies ocean predictions on timescales from seasons to decades in order to support marine resource management. The main goals of the group are to develop and operationalize forecasts of marine ecological properties, such as distribution, recruitment, phenology. WGS2D's first forecast product, for the spawning habitat of Blue whiting, has now been through one full cycle of making a forecast and then verifying the result. A new forecast product, for the feeding habitat of Bluefin tuna was produced and is now being delivered operationally.

The ICES Workshop of Fisheries Management Reference Points in a Changing Environment ([WKRPChange](#)) reviewed the robustness of the current ICES procedures relating to changes in stock productivity arising from environmental conditions. Their key recommendation was that a scoping exercise should be undertaken for each stock to identify any key drivers. Where there is good evidence for ecosystem-driven changes in stock productivity that process should be accounted for in setting reference points. Reference points have a finite lifespan, generally related to the benchmark cycle, and the estimation of the reference point should predominantly take into account processes likely to be important over that lifespan. Many ICES stocks are managed by Harvest Controls which are evaluated through a MSE process. In this case there is considerable scope for including such environmentally driven processes in the Operating Model.

The *ICES/ PICES Workshop on Political, Economic, Social, Technological, Legal and Environ-mental scenarios used in climate projection modelling ([WKPESTLE](#))* focused on how different futures of physical climate as well as societal development are together impacting marine ecosystems and maritime activities. Short-, medium- and long-term developments in governance, social, technological and economic drivers may be just as important to the future development of fisheries and aquaculture as climate-driven changes in habitats and species abundances and distributions. WKPESTLE looked at which scenarios are being developed around the world in order to explore the impacts of anthropogenic drivers on marine systems.

The 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 to the scientific community.

Future directions

Where climate change related environmental drivers have some predictive power there are now ways to integrate into stock assessment models and forecast (e.g. Stock and Miller 2021). This could lead to improved assessments and forecasts of short-term tactical advice. Taking account of productivity changes and regime shifts in definition of

reference points and biological limits can be either integrated into assessments or tested though climate-enhanced management strategy evaluations to elucidate the potential benefits and costs of changing management targets (Szuwalski and Hollowed, 2016).

Another key area is around Species Distribution Modelling (SDMs). Shifting species distributions has already been observed in the ICES area has the potential to cause both stock assessment issues (e.g. bias, catchability changes, sampling coverage issues etc.) and management dilemmas (e.g. stock area-management area mismatches, quota sharing challenges, impaired stock rebuilding etc.). For some species new data form tagging can be used to better inform or parameterize SDMs which in turn can be used to improve assessments and management.

One of the main conclusions of WKCLIMAD was that a greater emphasis needs to be placed on the communication and co-creation of advice in the context of climate change. 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.

References

Bentley, J. W., Lundy, M. G., Howell, D., Beggs, S. E., Bundy, A., De Castro, F., et al. (2021). Refining fisheries advice with stock-specific ecosystem information. Front. Mar. Sci. 8:346. doi: 10.3389/fmars.2021.602072

2016/2/ACOMSCICOM03 The ICES Strategic Initiative on the Human Dimension in Integrated Ecosystem Assessments https://www.ices.dk/community/groups/Pages/SICCME.aspx

ICES Strategic Plan

Fan Zhang, Paul M Regular, Laura Wheeland, Rick M Rideout, M Joanne Morgan, Accounting for non-stationary stock–recruitment relationships in the development of MSY-based reference points, ICES Journal of Marine Science, Volume 78, Issue 6, September 2021, Pages 2233–2243, https://doi.org/10.1093/icesjms/fsaa176

ICES. 2017a. Report of the Working Group on Fish Distribution Shifts (WKFISHDISH), 22–25 November 2016, ICES HQ, Copenhagen, Denmark. ICES CM 2016/ACOM: 55.197 pp.

ICES. 2017b. Report of the ICES/PICES Workshop on Regional climate change vulnerability assessment for the large marine ecosystems of the northern hemisphere (WKSICCME-CVA), 19–22 July 2017, ICES Headquarters, Copenhagen, Denmark. ICES CM 2017/SSGEPD:23. 67 pp

ICES. 2017c. EU request on distributional shifts in fish stocks. In Report of the ICES Advisory Committee, 2017

ICES. 2018a. Interim Report of the Working Group on Seasonal to Decadal Prediction of Marine Ecosystems (WGS2D), 27–31 August 2018, ICES Headquarters, Copenhagen, Denmark. ICES CM 2018/EPDSG:22. 42 pp.

ICES. 2023. ICES Ecosystem Overviews Technical Guidelines. Version 4. ICES Guidelines and Policies - Advice Technical Guidelines. 24 pp. https://doi.org/10.17895/ices.pub.22059803

ICES. 2021. Workshop of Fisheries Management Reference Points in a Changing Environment (WKRPChange, outputs from 2020 meeting). ICES Scientific Reports. 3:6. 39 pp. https://doi.org/10.17895/ices.pub.7660

ICES. 2022. Advice on ecosystem services and effects. In Report of the ICES Advisory Committee, 2022. ICES Advice 2022, section 1.1.2. https://doi.org/10.17895/ices.advice.19551433

ICES. 2019a. Report of the ICES/ PICES Workshop on Political, Economic, Social, Technological, Legal and Environmental scenarios used in climate projection modelling (WKPESTLE), 9 June 2018, Washington D.C., USA. ICES CM 2018/EPDSG:18. 27 pp

ICES. 2019b. Workshop on the design and scope of the 3rd generation of ICES Ecosystem Overviews (WKEO3). ICES Scientific Reports. 1:40. 46 pp. http://doi.org/10.17895/ices.pub.5445

ICES. 2023. Workshop on pathways to climate-aware advice (WKCLIMAD). ICES Scientific Reports. 5:25. 99 pp. http://doi.org/10.17895/ices.pub.22196560

Paula Silvar-Viladomiu, Cóilín Minto, Deirdre Brophy, David G Reid, Peterman's productivity method for estimating dynamic reference points in changing ecosystems, ICES Journal of Marine Science, Volume 79, Issue 4, May 2022, Pages 1034–1047, https://doi.org/10.1093/icesjms/fsac035

Payne MR, Hobday AJ, MacKenzie BR, Tommasi D, Dempsey DP, Fässler SMM, Haynie AC, Ji R, Liu G, Lynch PD, Matei D, Miesner AK, Mills KE, Strand KO and Villarino E (2017) Lessons from the First Generation of Marine Ecological Forecast Products. Front. Mar. Sci. 4:289. doi: 10.3389/fmars.2017.00289

Stock, B. C., and Miller, T. J. 2021. The Woods Hole Assessment Model (WHAM): A general state-space assessment framework that incorporates time- and age-varying processes via random effects and links to environmental covariates. Fisheries Research, 240: 105967. doi: https://doi.org/10.1016/j.fishres.2021.105967

Szuwalski C. S., and Hollowed A.B. 2016. Climate change and non-stationary population processes in fisheries management, ICES Journal of Marine Science, Volume 73, Issue 5, May/June 2016, Pages 1297–1305, https://doi.org/10.1093/icesjms/fsv229