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Theme session Report

Towards climate-informed ecosystem-based fisheries management

Conveners: Alan Baudron (UK), Kathy Mills (US), Kirstin Holsman (US)

Content

Climate change is having profound impacts on marine ecosystems and fisheries. Despite the clear need to mitigate climate-induced risks and to adapt to future climate change, accounting for climate impacts when developing fishery management plans and policies remains challenging. This session was developed to showcase how climate-informed ecosystem-based fisheries management can be implemented in practice and the actions needed to get there. Activities towards such climate-informed approaches can include accounting for climate impacts in fisheries scientific advice and management measures, integrating long-term strategic planning with short-term tactical management, and engaging stakeholders and diverse knowledge sources in management processes. The session provided an opportunity to share experiences and approaches from examples across the North Atlantic.

The Theme Session attracted a lot of contributions, with 24 oral presentations and 19 posters being presented. It also proved popular, and it was well attended not only by physical participants, but also by 75 online viewers, making it the Theme Session most viewed online.

The contributions received fell loosely into three topical categories: (i) spatial dimension, distribution change and Marine Protected Areas (MPAs); (ii) stock assessments and productivity; and (iii) management advice and resilience. The oral presentations were therefore grouped and presented during three consecutive sub-sessions covering these topics.

Contributions to the Theme Session highlighted diverse approaches and examples of climate considerations being integrated into fishery management processes. Incorporation of climate and ecosystem information in fisheries management is occurring through several pathways, including stock assessments, harvest control rules, risk policies, and management strategy evaluation.

Changes in spatial distribution are being observed, analyzed, and modeled in many regions of the North Atlantic, and species distribution shifts are being considered at multiple points of fishery management processes. Examples include adjusting survey abundance indices to account for temperature-related catchability before using them as inputs to stock assessments, revising quota allocations to nations or states based on the current distribution of the managed stock, developing near-real-time forecasts to reduce bycatch, conducting scenario planning, and developing climate resilience plans that account for shifts in the availability of certain species. Distribution shifts will also affect the stability of essential fish habitat areas and effectiveness of marine protected areas; presentations on these topics demonstrated approaches for evaluating these effects, but the approaches were not integrated into decision-making pipelines yet.

Multiple approaches to consider climate impacts in stock assessments were presented in the session. These efforts often focused on identifying relevant climate and ecosystem covariates that relate to population processes such as growth and recruitment. Research track stock assessments, particularly as conducted in the Northeast US, provide avenues for identifying climate and ecosystem covariates and then either using these covariates to interpret stock dynamics or, in some cases, incorporating covariates into stock assessment models. While it has been challenging to include ecosystem covariates in stock assessments, new integrated assessment models provide more flexibility for

incorporating them, and the current research track stock assessment process enables covariates to come in after an initial assessment model is adopted—allowing time for careful testing and evaluation of potential covariates. Additional approaches are also being used to account for productivity changes in fisheries management. Management strategy evaluation is being used to evaluate the robustness of multiple management measures and harvest control rules under climate change scenarios. Risk policies also provide pathways for considering climate conditions in determining acceptable levels of risk to a managed fish stock, as well as to social and economic outcomes.

Contributions on management advice and resilience to climate change highlighted the fact that a lot of effort has been put towards improving our scientific understanding of the impact of climate change on fish resources and fisheries management, yet these efforts still have not translated into advice being delivered. Our current governance system lacks flexibility, and we need to develop mitigation and adaptation measures towards actionable management strategies. There is an array of tools we can employ now to apply, or at least facilitate, near-term actions. Several possible tools that could be used to improve existing advice were presented in this Theme Session. Modeling tools included individual based models simulating climate impacts on life history traits to test management measures under future climate change, and Management Strategy Evaluations using ensemble models to assess the impact of rising temperature on recruitment and evaluate future catch potential under climate change. Other tools presented included a framework to incorporate ecosystem and socioeconomic information into stock assessment models in order to make them climate-ready. This is particularly relevant since stock assessment model outputs are currently primarily used to formulate advice. Another framework identified, based on 18 real-world fishery case studies, two possible pathways to resilience: (i) building ecological assets and strengthening communities, and (ii) building economic assets and improving effective governance. Another tool presented in this session is the co-management of fisheries where collaborative networks and stakeholder-driven solutions contribute to more resilient and adaptive fisheries management. Lastly, a useful tool towards achieving climate-resilient fisheries is facilitating scientists and managers' access to data at spatial and temporal scales suitable for short-term tactical advice. Such data can then be applied in risk-based advice. However, while our data collection abilities have increased, we are limited by the advances in computing power and high-performance modeling. Cross-disciplinary collaborations between fisheries scientists, data scientists, and computer scientists towards the development of new tools such as AI, machine learning and network analysis will enhance the capability to deliver climate-informed ecosystem-based fisheries management.

A number of presentations and posters focused on relevant research that is underway related to climate change in fisheries and ocean management, yet many examples have not been actively integrated into management and decision-making processes to date. These presentations generally either (1) documented changes in living marine resource populations in relation to climate and ecosystem conditions or (2) demonstrated approaches that could be applied to better consider climate change in management efforts. Many contributions documented changes in population abundance, growth, distribution, phenology, life history, predator-prey interactions, fish community traits, and fleet composition. Most studies explored drivers of the changes, identifying climate and ecosystem features as well as human pressures (e.g., fishing pressure) that may be associated with population or community dynamics. These studies applied a variety of approaches for tracking ecosystem change (e.g., community traits as indicators); considering multi-species dynamics (e.g., food web modeling); assessing the effectiveness of marine protected areas; and projecting population features, biodiversity, and fleet composition under future climate scenarios. While many examples shared during the session have not yet been adopted in management arenas, they demonstrate promising approaches for future applications.

Conclusions

The contributions to this session demonstrated that climate information is being incorporated into fisheries management processes in a variety of ways in certain fisheries. However, research efforts are outpacing management uptake: as Mark Dickey-Collas emphasized in his presentation, scientists are providing relevant information related to climate impacts on marine ecosystems and fisheries, but governance systems are not always ready to receive and act on this advice. While the prominence of contributions that are delivering research results relevant to climate-informed fisheries management demonstrates a lag in information uptake, multiple presentations demonstrated that this information is being used in management processes (and not just through stock assessments), provided decision rules for determining when management actions may need to consider climate effects, and outlined climate resilience assessment and planning approaches. Adoption of these approaches, coupled with modernization of existing fishery data management systems and high performance modeling capacities, will all enhance capacities for delivering climate-informed EBFM across a broader array of fishery systems.

Feedback

The topic of the session seemed to have widespread appeal and interest for the ICES audience. The session included 24 oral presentations and 19 posters–a strong showing of presentations despite the fact that we had a number of withdrawals after the abstract selection process. There was good attendance throughout the session at the meeting, and it was the most watched theme session with 75 online virtual attendees. We are convening a parallel workshop at PICES in late October, after which we will synthesize insights from the North Pacific with those shared in the ICES session. Given the interest in this topic, we hope that ICES continues to support climate-focused theme sessions and workshops–whether convened by SICCME or others–as part of the mix of topics represented at future ASCs.

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CM 28: Evidence for spatiotemporal shift in demersal fishery management priority areas in the western Mediterranean

Iosu Paradinas*, Joan Giménez, David Conesa, Antonio López-Quílez, and Maria Grazia Pennino

Marine protected areas (MPAs) are generally established as permanent closures, but marine systems are dynamic, which has generated debate in favour of more dynamic designs. The identification of priority areas should therefore assess their persistence in space and time. We developed a step-by-step approach to assess the spatiotemporal dynamics of fishery management priority areas using standard fishery-independent survey data. We fitted Bayesian species distribution models over different demersal fish species and used the resulting maps to fit different spatial prioritisation configurations. We then compare these results to assess the level of persistence of identified priority areas. We illustrated the method in a western Mediterranean case study based on six commercially important species and a 17-year temporal window. We identified two fishery priority area patterns in the study area, each predominant during a different time period of the study, asserting the importance of regularly reassessing MPA designs.

Keywords: conservation planning, marine protected area design, marine spatial planning, spatial prioritization, spatiotemporal prioritization

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CM 45: Implications for the global tuna fishing industry of climate change-driven alterations in productivity and body sizes

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Tunas and billfishes are the main large pelagic commercial fish species. Tunas comprised around 5.5 million t and USD 40 billion in 2018. Climate change studies and projections estimate that overall, global fisheries productivity will decrease due to climate change. However, there are seldom projections of the climate-driven productivity of the higher trophic levels where tunas and billfishes belong. In this work, we use a mechanistic model to evaluate the effects of climate change and fishing for globally distributed and commercially exploited seven tuna species and swordfish which are divided into 30 stocks for management purposes, under a range of climate change (RCP 2.6 and 8.5) and fishing scenarios (from no fishing to 1.5 times the fishing mortality (F) at the Maximum Sustainable Yield, F_{MSY}) from two Earth System Models (IPSL and MEDUSA). The results suggest that high trophic level species will be more impacted by climate change than by fishing pressure under the assumption that they remain nearby their MSY levels. However, no-fishing scenarios project much higher biomass. The overall productivity of the target species will decrease by 36% and only the Pacific bluefin showing a slight increase in the future. Five species; Atlantic and Southern bluefins, swordfish, bigeye, and albacore are estimated to decrease in biomass and size at different rates. These species represent almost a third of the landings in the Atlantic Ocean and 10% in the Pacific Ocean being the bluefins, the highest-valued tuna species. On average, the body size is expected to decrease up to 15% by 2050. Fish price and demand are partially driven by body size and therefore, revenues can be reduced even in stocks with an increase in productivity. The fishing industry can adapt to the changing climate by increasing the value of fish through sustainability certifications and reducing fuel consumption and time at sea with higher digitalization. Reducing fuel consumption would also be an additional mitigation measure to climate change since it would reduce CO_2 emissions.

Keywords: Tuna fishery, climate change, fishing pressure, future scenarios, Ecosystem-Based Model, Size Spectrum, Bioclimatic Envelope Model

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CM 46: Future projections of marine biodiversity in Natura 2000 network areas under climate change and fishing activities

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Fishing activity developed in the Canary Islands is configured as the main responsible for the changes that have occurred in the productivity, structure, and stability of marine ecosystems. Likewise, inadequate use of fishing gears, the lack of information, the oversizing of real fishing power, levels of fishing effort higher than the resilience of species, loss of ecosystems and water quality, together with the impacts derived from climate change, among others, could be responsible for the decline and depletion experimented by some of the main target species. In this context, and to address this problem from a more comprehensive point of view, the use of new management methodologies based on an ecosystem approach to fisheries is considered the most suitable option. Through temporal and spatial models defined in cooperation with fishermen and local action groups, exploitation patterns that guarantee the sustainability of resources in the future were established. The ecosystem model developed for the island of Gran Canaria has served to determine the structure, functioning and status of this marine ecosystem, quantifying the impact of fishing activity, both professional and recreational, combined with climate change. The results show the risk of continuing with the current fishing strategy, and the need to establish new management measures and increase protection in marine areas included in Natura 2000 Network.

Keywords: artisanal fishing, recreational fishing, Canary Islands, ecopath, climate change, Natura 2000 Network

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CM 52: Bottom temperature effect on growth of multiple demersal fish species in the Flemish Cap, Northwest Atlantic

Krerkkrai Songin*, Fran Saborido-Rey, Graham J. Pierce

An increase in initial growth and decrease in maximum size have been linked to warmer temperatures in fish due to the increase in metabolism. It is essential to understand the dynamics between environmental conditions and growth in order to forecast temperature impacts on fish growth and inform management decisions. This study aimed to determine growth responses to variation of sea bottom temperature in both sexes of seven demersal fish species of commercial interest commonly found in the Flemish Cap, Norwest Atlantic, and to compare the magnitude of growth changes among them. The species were *Gadus morhua*, *Hippoglossoides platessoides*, *Reinhardtius hippoglossoides*, *Macrourus berglax*, and three species of the genus *Sebastes*. The study used size-at-age data collected from bottom trawl EU surveys conducting in summer, typically July from 1993 to 2018 and bottom temperature (BT) data from the Copernicus Marine Service (CMEMS). The effect of BT and age on size was analysed using Generalised Additive Models (GAM). The best-fit models were selected using the Akaike Information Criterion (AIC). The best-fit GAMs for both sexes of all species included the variable BT and all explained over 80% of deviance. The interaction between effects of BT and age was significant for both sexes of *G. morhua* and *M. berglax*, male *R. hippoglossoides*, and male *S. norvegicus*. Based on the models, size-at-age predictions were made for 3, 4, and 5°C BT scenarios, which are within the typical temperature range in the area. The predictions were fitted with von Bertalanffy Growth Functions (VBGF). The GAMs predictions for all species, sexes and scenarios fit the VBGF well ($R^2 \geq 0.95$) and growth parameters were delivered. The most common response to increased BT was a decrease in L_∞, with some species also showing increased k. The estimated maximum sizes at maximum ages generally declined at higher temperatures, with the varying magnitudes among species and sexes. The greatest reductions in maximum size were seen in female *G. morhua* (8.1%) and male *M. berglax* (10.8%). Individuals becoming smaller could directly reduce the stock biomass and many studies suggest that smaller fish are less fecund which can lead to lower recruitment and productivity. These potential direct and indirect productivity impacts may raise concerns for fisheries. Integrating the impact of temperature on growth into ecological modelling, such as Objected-oriented Simulator of Marine Ecosystem (OSMOSE), could provide valuable insights for simulating fish responses to various temperature scenarios and inform managements.

Keywords: life-history, climate change, fish growth, deep-sea, cod, general additive models

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CM 55: What is climate informed-informed fisheries advice?

Mark Dickey-Collas

Over three billion people's livelihoods depend on marine and coastal resources, and the market value of these resources and related blue industries is estimated at US$3 trillion yearly, equivalent to around 5 % of the global gross domestic product (GDP). Plastics make up around 80% of the total waste discarded in the ocean, and each year, over 13 million metric tons of plastic enter the marine environment threatening biodiversity and affecting ecosystem services upon which the economy of coastal countries depends. In this sense, we investigate how plastic waste influences the provided ecosystem service by coastal and marine environments using the Millennium Ecosystem Assessment conceptual framework (known as Ma conceptual framework). The analysis provides us with basic data and information about the impact of plastic on marine ecosystem services and highlights the need to consider managing our plastic waste mainly because each ecosystem service feed into another.

Keywords: fisheries advice, climate change, governance

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CM 59: Annual spawners of common cuttlefish, *Sepia officinalis*: who are they and implications for fisheries management

Laptikhovsky V., Barrett, C.J., Barry, P., Firmin, C., Stott, S., Vieira, R.

Common cuttlefish, *Sepia officinalis* L. is the most important commercial cephalopod species in the European waters. Throughout the species range, its populations are represented by mixture of two cohorts maturing and spawning being 1 y.o. or 2 y.o. respectively. Cuttlefish spawning at the age of 2 years until recently represented more than 95% of the English Channel stock (Dunn 1999) and only recently annual spawners appeared in important numbers (Gras et al., 2016). Annual spawners are smaller and have fewer chambers in cuttlebones because these chambers are deposited periodically: each 3-8 days depending on temperature. Samples of mature cuttlefish collected from January to June 2020-2022 revealed presence of annual spawners only in the very end of the spawning season (June 2020 and 2022). Their size ranged between 122 mm and 169 mm mantle length (vs 153-228 mm in mature 2 y.o. cuttlefish collected in June) and the number of chambers varied from 74 to 92 (vs 119-133 in mature 2 y.o. cuttlefish collected in June). We hypothesize that 1 y.o. spawners are hatchlings from eggs laid early in the spawning season, so they are the oldest and largest among their annual cohort. As a result, some of them have enough of time to attain the size of maturity by the end of the next spawning season. For the rest of a cohort, it takes 2 years to attain maturity. The number of annual spawners is thought to increase in warmer years, thus impacting population dynamics and spawning success. Observed rates of septal deposition in 2020-2022 samples in the English Channel were very similar to those in 1980s in the Bay of Biscay (~80 septa in 1 y.o. spawners and ~120 septa in 2 y.o. spawners – Goff et al 1998). We recommend that varying population dynamics in response to climate changes could be considered to inform the development of robust stock assessment models.

Keywords: cuttlefish, spawning, *Sepia officinalis*, English Channel, stock structure, climate changes

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CM 74: Ocean-climate conditions and spawner biomass affect the survival of blue whiting early life history stages

Costanza Cappelli[1], A. Sofia A. Ferreira, Hjálmar Hátún, Jan Arge Jacobsen, André W. Visser, Brian R. MacKenzie

Blue whiting (*Micromesistius poutassou*) recruitment has shown wide variations since the start of available time series in the early 1980s, with some yearclasses being nearly 10-fold larger than others. Hitherto, no models can accurately quantify these past recruitment variations, potentially due to the lack of studies addressing blue whiting stock dynamics in relation to ocean-climate variability, constituting a major source of uncertainty for the management of this species. Here we focus on a large-scale oceanographic feature, the wind stress curl (WSC), which might affect recruitment through several mechanisms, including Ekman pumping/suction of deep nutrient-rich water to the surface, meridional transports, the positions of fronts, and through lagged effect on basin-scale oceanographic properties. In particular, the long-term mean location of the transition zone in the northeast Atlantic between ocean areas having positive and negative WSC (i. e., the WSC zero-line) coincides with the location of the largest known blue whiting spawning area in the Northeast Atlantic Ocean. Consequently, WSC fluctuations in this region could potentially affect blue whiting recruitment and population levels, possibly through changes in upwelling/downwelling intensities, vertical mixing, and lateral transport processes. We hypothesize that WSC variability affects the environmental conditions (i.e., temperature and salinity) and the drift patterns experienced by eggs and larvae in the spawning grounds, and ultimately regulates blue whiting survival and recruitment in the North Atlantic Ridge area.

We assess the relationship between WSC variability in the zero-line region and a blue whiting recruit survival index between 1980 and 2021. We found that coupling stock-recruitment relationships to local indices of WSC variability near the zero-line significantly increased explanatory power (up to ~50%), especially if the recruit index was lagged 1 year behind the WSC variations (i. e., WSC variations lead yearclass variations). The 1-year lag is consistent with a literature-reported ca. 1 year response time of ocean properties to WSC variations in this region. Using WSC as a main driver of blue whiting survival greatly improves the prediction abilities of blue whiting recruitment, increasing the forecast horizon one year ahead of spawning for identifying major recruitment variations and improving stock assessments. It also suggests new processes driving blue whiting survival which can be mechanistically investigated in the future and could potentially inform sustainable and ecosystem-based management practices for this important fishery resource.

Keywords: blue whiting, recruitment variability, survival index, ocean-climate impact, wind stress curl, EBFM

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CM 92: Marine species distribution shifts in the Northeast Atlantic

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Important amount of literature highlight effects of climate change on marine species, communities functioning and consequences for fisheries, which exploited them. It is essential to consider both climatic and anthropogenic influences to explore the underlying mechanisms of species responses, and especially to explore species distribution shift, one of the most commonly reported species response to global change. Our study explores the effect of global change on marine taxa spatial distribution in the temperate ecosystems of the Celtic sea and Bay of Biscay, two systems intensively harvested by European fishing fleets. The scientific EVHOE survey provides long-term fisheries independent and standardized data on species composition and abundance. Spatio-temporal changes in taxa distribution were analyzed using spatial indices that describe latitudinal, longitudinal and depth shifts of a given population as well as the expansion or the contraction of its distribution range. For the taxa presenting significant distribution shifts over time, we examined the links between their shifting distribution and the following predictive variables: fishing pressure, taxa abundance, and climate change through two long-term indices, the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO), and a regional index, the bottom temperature anomalies. Results show that the distribution of 53% of the taxa shifted significantly over the last 20 years. Southeastward and downward shifts were mainly achieved by Actinopteri class belonging to boreal and demersal guilds while northwestward and upward shifts were completed by Malacostraca and Cephalopoda class in the Bay of Biscay and both pelagic and benthic guilds. These shifts were mainly explained by taxa abundance and fishing pressure and in a minor extend by the regional index of climate change. The implication of both fishing pressure and global change in taxa distribution shift over time is significant and should be considered to improve regional fisheries management (e.g., definition of stock boundaries, change in fleet behaviour and target species, stock status).

Keywords: climate change, marine species, spatial indices, distribution shift, northeast Atlantic, Celtic-Biscay Shelf, fisheries management

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CM 97: Sustainable ecosystem-based solutions for collapsed fisheries under climate change

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Climate change is continuing to affect the productivity of fish stocks with important implications for the design of sustainable harvesting strategies. Finding management solutions for an ecosystem-based fisheries management under climate change is especially important for collapsed fisheries that require rebuilding to sustainable resource bases. A contemporary case for the need of such solutions are the fisheries on Western Baltic cod (*Gadus morhua*) and herring (*Clupea harengus*). Both fish stocks are historically important for local communities at Danish and German coasts but recently collapsed to unsustainable stock sizes through overfishing and climate effects. We here present a management strategy evaluation study based on an interacting ensemble of two single-species population models, a multi-species coupled ecological-economic model and an Ecopath with Ecosim (EwE) ecosystem model. Our model ensemble is forced by temperature projections according to locally downscaled CMIP5 RCP4.5 and 8.5 scenarios in stock-recruitment relationships for cod and herring. The goal of our study is to evaluate catch potentials of Western Baltic cod and herring under climate change as a basis for developing sustainable futures for these fisheries. Individual ensemble models interact by exchanging fishing mortality (F) time-series that are optimized for the present F_{MSY} management approach applied or for management strategies that alternatively account for optimal societal welfare or protection scenarios of marine mammal populations. Comparing resulting management strategies elucidates trade-offs between fisheries-focused, societal, and ecosystem objectives for future sustainable catches of cod and herring in the Western Baltic Sea. Overall, our study demonstrates how low productivity of these collapsed fish stocks in combination with detrimental effects of warming on recruitment will likely lead to catch potentials that are severely reduced in comparison to historical yields.

Keywords: Baltic Sea, climate change, cod, ensemble modelling, herring, projections, sustainable solutions

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CM 111: Future projections of suitable habitat for 49 commercial fish species: how will quota allocation and fisheries access be affected?

John K. Pinnegar[1], Bryony Townhill[1], Elena Couce[1], Jonathan Tinker[2], Susan Kay[3]

Climate change is anticipated to result in shifts to distributions of marine organisms, including commercial fish. We describe projections from models, showing the future suitable habitat for 49 commercially valuable fish in the Exclusive Economic Zone (EEZ) of the United Kingdom. We employed an ensemble of species distribution models together with downscaled climate projections assuming three different climate change scenarios (RCP4.5, RCP8.5 and A1B). Habitat suitability and latitudinal shifts were quantified in the recent past (1997-2016) and for two futures (2030-2050; 2050-2070). Of the species examined, around half were predicted to have consistently more suitable habitat in the future within the UK Exclusive Economic Zone (EEZ), including black seabream, seabass, sardine, surmullet (red mullet), anchovy and pouting (bib). Conversely, it is suggested that the seas will become significantly less suitable for other species including saithe, Atlantic wolffish, starry ray, halibut, ling, megrim and lemon sole. Commercial fisheries will need to adapt to these changes by: (1) changing the location where fleets operate, (2) changing the gear used and/or species targeted, and (3) modifying fishing patterns on a seasonal basis. There may be financial or regulatory barriers to successful adaptation and these will need to be overcome if the UK fishing industry is to remain profitable and sustainable in the years to come. The implications of anticipated future distribution change on 'zonal attachment' and 'quota sharing' agreements will be discussed.

Keywords: distribution, climate change, fisheries management, zonal attachment

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CM 129: Finishing the puzzle: A spatio-temporal approach for understanding past structural and functional changes in the Baltic Sea induced by climate change

Frane Madiraca[1], Christian Möllmann[1], Saskia A. Otto[1]

Climate change is becoming the dominant force driving state changes in the Baltic Sea ecosystem and, together with overfishing and pollution, has already shaped its spatio-temporal dynamics in the past decades. At the same time, this large brackish system is essential for the provision of marine ecosystem services and the region's socio-economic dynamics. Achieving sustainable management of the Baltic Sea is thus a highly important task that is unlikely to be successful without properly understanding how climate change affects it at both temporal and spatial scales. Traditionally, time series of structural indicators related to organism density, diversity and size are used in state assessments. Concurrently with the development of ecosystem assessment tools during the past decades, functional trait analyses started to grasp the attention of marine scientists to better understand ecosystem processes and functioning. Unfortunately, indicators developed using trait-based analyses are still seldomly employed for this purpose and, thus, important ecological information is likely lost. In the work presented here, we combine these approaches and investigate the degree to which climate change has affected the spatio-temporal structure and functioning of the Baltic Sea. Using spatially high-resolved data covering more than two decades we model the responses of both structural and functional indicators based on the highly advanced Integrated Nested Laplace Approximation approach. In addition to setting a baseline on understanding past structural and functional dynamics in space and time, this study will further be used as a starting point for forecasting long-term changes of the Baltic Sea ecosystem state and spatial shifts in diversity hotspots that are likely to occur under future climate change and eutrophication scenarios. These endeavours could prove highly valuable for achieving the goals of ecosystem-based management in the Baltic Sea and safe-guarding the ecosystem services that are provided by it.

Keywords: Baltic Sea, climate change, ecosystem state assessment, ecological indicator, ecosystem function, spatio-temporal dynamics

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CM 144: Data solutions to develop climate conditioned tactical and strategic fisheries advice

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Climate and ecosystem changes are not just strategic considerations for sustainable fisheries advice but also now for short term tactical advice. These changes are impacting fish stock production within the time scale of updating benchmark processes thus creating a mismatch between biological production process and sustainable fishing strategies. One of the key hindrances to rectifying this mismatch is the availability of environmental and ecological data sets at appropriate scales which can be used to tune advice to bring it into alignment with the present biological realities. We have developed an "ecosystem matrix" which brings together a wide variety of environmental and ecological and pressure indicator data with a regular update cycle such that assessors can have access to the most recent data to help tune or condition advice in the near term to the actual conditions. In addition, downscaled atmospheric and oceanographic climate projections for different RCP scenarios are provided for strategic advice development. This matrix has been bundled into a R package that is freely available in seconds to anyone via github/gitlab. Its availability as an R package means it integrates seamlessly into the analyses of assessors, most of whom use R, with a simple library call. The utility of this matrix is demonstrated with two case studies where risk-based advice has been climate conditioned for shrimp and Greenland halibut stocks in the Gulf of St. Lawrence, Canada: a rapidly warming marine ecosystem.

Keywords: ecosystem data, climate change, ecosystem approach, r package

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CM 183: Integrating climatic variables and fishing impacts to assess cumulative effects through a food-web modelling approach in the Northern Ionian Sea (Central Mediterranean Sea)

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A multitude of synergistically and antagonistically interacting factors (environmental drivers, anthropogenic pressures) play a role in the structure and functioning of marine ecosystems, making challenging to guide the management of marine resources and biodiversity conservation towards sustainability. Fishery is a strong impacting stressor for individual species and ecosystems. In the framework of ecosystem-based fisheries management, accounting for different ecological roles in the food web, ecological processes, as well as the pressing climate change has become pivotal. A food-web modelling approach is useful to integrate these necessities, thanks to the model's capacity to encompass the physical and human drivers of change in the entire ecosystem, from plankton to top predators. The Northern Ionian Sea (NIS, Central Mediterranean Sea) represents a very complex environmental context in the Mediterranean basin, characterized by several critical habitats, a hot-spot of cetaceans biodiversity, an important fishing activity and several anthropogenic pressures. A calibrated time-dynamic model (Ecopath with Ecosim) of the NIS food web described by 51 functional groups - including four odontocetes (striped dolphin, common bottlenose dolphin, Risso's dolphin and sperm whale) and 5 fishing metier - was developed to investigate its functioning and to assess the cetacean-fishery competition in the area. Also, the modelling approach allows the investigation of cumulative impacts of multiple factors, such as climate and fishery, addressing a comprehensive evaluation of the entangled cause-effect relationships of these factors and these top-predators. A total of 6 scenarios were tested to estimate odontocetes biomasses and their main preys in the mid-term future (2036-2040), simulating the cumulative effects of changes in effort for the bottom trawl, which result the most important métier in the area (FE, as increase, reduction, and ban), and the increase in primary production (PPN, as a proxy for climate change). Fishery changes showed negligible effects on all odontocetes and similarly, the bottom-up effect due to increased PPN tends to be diluted towards the top of the food web. In this study, the interactive effects were assessed for the FE reduction and PPN increase, according to realistic indications provided by Multiannual Fishery management plan (Common Fishery Policy, 2013) and projection of RCP_8.5. The cumulative effects were assessed through an Interaction Effect Index, which showed slightly antagonistic effects on the predicted biomass of the odontocetes in the future. This indicates that fishing regulations may lose some of their effectiveness due to climatic effects combined to the trophic interaction pattern within the food web.

Keywords: Ecopath with Ecosim, fishing effort, food-web modelling, interaction effects, primary production

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CM 200: Revisiting post-settlement dynamics and mechanisms for a depleted American lobster stock

Conor McManus

Understanding the processes influencing survivorship across marine species life stages is critical for proper resource management. The causal mechanisms for inducing variability or incoherence in these relationships is often the product of environmental conditions or harvest; however, elucidating the contribution of individual mechanisms is challenging. Describing the functional relationships between life stages that incorporate the mechanisms are desirable for identifying important factors influencing survivorship and improving population predictions under projected conditions. Additionally, these relationships must be consistently evaluated, as they can breakdown over time when the driving mechanisms change. As such, continuous reevaluation of these models is warranted to ensure our inference of these processes for population assessments. Understanding the stock-recruit relationship for American lobster (*Homarus americanus*) has consistently been challenging. The Southern New England (SNE) U.S. lobster stock is currently considered depleted and experiencing recruitment failure, largely believed to be from a myriad of direct and indirect climate stressors hypothesized to adversely affect the stock. Identifying which factors have been most important for post-settlement survival can help determine rebuilding plans' efficacy. Previous work has examined the relationship between young-of-year (hereafter "settlers") and pre-recruit American lobsters from the SNE stock to explain the drivers in post-settlement survivorship, a critical phase between the spawning stock and future recruitment. Previous research identified the interaction between cumulative shell disease from settlement through pre-recruit stages and settler densities to best explain the variability in the settler – pre-recruit relationship. With continued climate and ecosystem change, it is unclear whether this factor remains significant in predicting pre-recruit lobsters from settlers. Here, the relationship between settlers and pre-recruit American lobsters is revisited to determine if our perception on this post-settlement relationship has changed. Analyses were focused within a central location of the SNE stock range (Rhode Island, U.S.) that has often been used to represent the larger SNE stock dynamics. The inclusion of additional, recent years' data provided insight on how the functional relationship between settlers and pre-recruit lobsters has shifted from an exponential to linear function. New and retested climate and ecosystem drivers in the post-settlement relationship are presented to provide insight on the climate and ecosystem drivers on survivorship during these life stages. This renewed analysis supports the notion of reevaluating environmentally-explicit models over time and further researching post-settlement processes toward improving climate-informed ecosystem-based fisheries management for American lobster.

Keywords: lobster, settlers, pre-recruits, southern New England

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CM 202: Understanding effects of long-term environmental changes for contaminant concentrations in herring from the Baltic Sea

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Herring in the Baltic Sea contain elevated concentrations of dioxins, other organic contaminants, and mercury due to historical pollution loading into, and long residence time of Baltic Sea water. In addition, herring, a marine species, grow slowly in the low salinity Baltic. Of relevance for the latter is that improvement in fish growth from changing environmental conditions would reduce the concentrations of POPs in fish and decrease human exposure. More knowledge on the feeding ecology of herring is needed for forecasting dioxin exposure to humans in the future. In this study, partial least squares-based structural equation modelling (PLS-SEM) was applied to examine how temperature, salinity, altered production base of phytoplankton and availability of benthic food items contribute in explaining contaminant concentrations in herring from the two major basins in the Baltic Sea during the last three-four decades. Although organic contaminants and heavy metals showed an overall decreasing trend in herring in the overall timeseries, the trends are variable on a yearly basis indicating ecosystem process may alter the levels of acquired contaminants. In fish of known size and age analyzed for dioxins within the Swedish contaminant monitoring program, retrospective analyses of stable isotopes of carbon and nitrogen including amino acid specific analyses of nitrogen were performed. These analyses allow tracing ultimate diet sources (i.e., N-fixing cyanobacteria which has increased in the Baltic has a district traceable signal in source amino acids) and calculating diet proxies (trophic niche size and position) in fish. Oceanographic data including phytoplankton biomass and surface cover of cyanobacterial blooms as well as abundance of benthic fauna from other monitoring programs were linked to the annual contaminant concentrations. Our analyses demonstrate the importance of considering biological variables for understanding year-year variability in contaminant trends but also to predict long term contaminant trends in fish in the rapidly changing Baltic Sea ecosystem.

Keywords: climate change, eutrophication, mercury, PCB, dioxin, bioaccumulation, *Clupea harengus,* Baltic Sea, stable isotopes, time trends

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CM 241: Climate-informed stock assessment of yellowtail flounder off New England

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Yellowtail flounder (*Pleuronectes ferruginea*) inhabit the continental shelf of the northwest Atlantic and historically have supported target fisheries off New England. However, the Georges Bank and southern New England/ Mid-Atlantic stocks have declined in recent decades and have not recovered despite restricting fisheries. In the northwest Atlantic, ocean waters are warming four times faster than the global average and decreased yellowtail flounder productivity has been associated with ocean warming in the region. US stock assessments of yellowtail flounder have exhibited retrospective patterns, which are a major source of uncertainty for determining stock status and informing rebuilding plans. These patterns may result from model assumptions that do not account for environmental effects on population or fishery dynamics. In the face of climate change, there is increasing exploration of climate impacts on stock dynamics in the context of stock assessments. However, incorrectly integrating climate information can lead to model misspecification and thus, it is important that relationships are identified before using them in assessments. The research presented here highlights the need for accounting for climate information and explores the steps that can be taken to identify pertinent environmental data for implementation in stock assessments. We reviewed the available information on environmental drivers impacting US stocks of yellowtail flounder from literature and harvesters' ecological knowledge, tested relationships between environmental indices and components of productivity (i.e., recruitment, growth, …), and are developing stock assessment models that account for environmental effects. Generalized additive models were employed to explore relationships between the identified environmental variables and stock dynamics to determine what data should be incorporated into the yellowtail flounder stock assessment models. Several potential climate impacts were identified. Yellowtail flounder off New England have shifted to deeper waters, which may affect capture efficiency of the fishery and survey trawls. Recruitment of yellowtail flounder off southern New England appears to be related to the Mid-Atlantic Bight Cold Pool, with lower recruitment associated with a warmer, less persistent, and smaller Cold Pool. Recruitment of yellowtail flounder on Georges Bank is correlated with water temperature, as well as the North Atlantic Oscillation index, wind, and shelf water volume. Recruitment in all three US stocks appears to be related to the abundance of zooplankton communities. Preliminary results suggest weight-at-length is lower when ocean waters are warmer. Integrated state-space stock assessment models such as the Woods Hole Assessment Model allow direct incorporation of environmental data. This research serves as a model for how analyses can be conducted to identify appropriate ecosystem drivers for use in integrated stock assessment models.

Keywords: climate change, temperature, integrated model, environmental covariates, generalized additive models

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CM 278: Biodiversity exposure to projected climate change may compromise future marine protected areas resilience under business-as-usual scenario

Milica Predragovic, Jorge Assis, Christopher Cvitanovic, Rashid Sumaila, Barbara Horta e Costa

Ecosystem-based management (EBM) is a comprehensive approach to fisheries management that recognizes the interconnectedness of marine ecosystems and the complex relationships among the species within them. Marine protected areas (MPAs) are a crucial tool in EBM, as they provide safe havens for marine species and habitats. However, the effectiveness of MPAs can be compromised by climate change impacts, such as changes in temperature, acidity, and productivity, which can alter the distribution and abundance of marine species. Climate change impacts are often neglected during the design and implementation of MPAs, raisng questions about their long-term effectiveness.

Our study aimed to evaluate the vulnerability of species targeted by fisheries in European MPAs to climate change. We assessed their exposure to novel climates using climate dissimilarity based on four environmental variables: temperature, oxygen, pH, and primary productivity, coupled with projected species distributions from present-day conditions to the end of the 21st century, under two contrasting Shared Socioeconomic Pathways (SSP) scenarios (SSP1-1.9 and SSP5-8.5). Our findings revealed that 6% of the species within European MPAs will be exposed to novel climates under SSP1-1.9, and 76% under the business-as-usual scenario (SSP5-8.5). The most vulnerable areas under future climate change projections appear to be enclosed and semi-enclosed basins, such as the Baltic Sea and the Black Sea, both in terms of the number of fisheries species exposed to novel climates and in number of MPAs with the highest degree of novel climatic conditions.

The results of our study highlight the urgent need for action to mitigate climate change and protect marine species and habitats. The post-2020 Convention on Biological Diversity framework aims to expand global MPA coverage to 30% by 2030, but this goal can only be achieved if effective measures are put in place to protect marine ecosystems from the risks of climate change-induced irreversibility. Incorporating climate change projections into management plans, identifying and protecting climate refugia, and promoting adaptive management strategies are key elements of EBM that can boost the resilience of MPAs and contribute to the conservation of marine fisheries.

Keywords: climate change, marine protected areas, fisheries management

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CM 279: Building ecosystem resilience and prosperous sustainable fisheries with a Whole Site Approach to marine protection

Emma V. Sheehan, Martin J. Attrill, Jean-Luc Solandt, Sian E. Rees

With effective, strategic management and comprehensive monitoring European Marine Protected Areas have the potential to deliver resilient, productive and prosperous seas resulting in benefits for conservation and fisheries.

In Lyme Bay, southwest UK, a mosaic of rocky reef and inter-reef sediment habitats were protected from bottom-towed fishing in 2008, adopting the Whole Site Approach. The Lyme Bay Marine Protected Area (MPA), 206km2, was the first and largest of its kind in the UK as most other MPAs are managed following the Feature Based Approach whereby destructive trawling and dredging is permitted on sediment habitats within the majority of UK MPAs.

Consistent management throughout the MPA across rocky reef features and inter-reef sediment areas has offered a unique opportunity for research on the effectiveness of whole site marine management, something that had never been tested before in the UK. In the following 13 years, interdisciplinary research has developed a unique and critically important dataset that has significantly changed reef management in the UK. The whole site approach to managing this site increased functional reef habitat, built resilience and site integrity against extreme climatic events, and increased the abundance and diversity of species of conservation and commercial importance.

This research has led to greater protection of the marine environment; new and ambitious marine policy; economic and well-being benefits for fishermen; and a strengthened interdisciplinary evidence base for fisheries management and habitat conservation.

Novel approaches to assess optimum static fishing gear density and the value and connectivity of MPAs for mobile species using acoustic telemetry as part of an Interreg Channel project (FISH INTEL) will also be presented.

This research models a flagship for the application of a successful network of marine protected areas across Europe. We will discuss how existing EU legislation (the habitats directive) offers the opportunity for other countries to adequately protect productive and prosperous marine habitats. Our findings also highlight the critical need for strictly protected reference sites, allied to integrated socio-ecological monitoring and engagement to promote compliance.

Keywords: plastic, pollution, ecosystem service, economy, environment, sustainability

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CM 288: Using individual-based models to test alternative management measures under multiple climate regimes

Cameron Hodgdon, Yong Chen

The application of individual-based modeling frameworks has greatly expanded over the last few decades, but their use is still comparatively limited in global fisheries management practices. These probabilistic models are incredibly flexible and allow simulation of complex species' life history and fishery-dependent processes to occur. This research sees the advancement and implementation of an individual-based modelling framework known as the IBLS to simulate American lobster (*Homarus americanus*) stocks in the Gulf of Maine and Southern New England stock regions of the Northeastern US. American lobster in this region are fished for by relatively small owner-operator vessels using bottom-set traps and fishers are regulated in the number of traps they can set, the size of lobsters they can keep, and other conservation measures such as gear requirements or not being able to keep females with eggs. With these measures explicitly considered, the IBLS simulates individual lobsters from birth to death and seasonally subjects them to random Bernoulli trials representative of life history and fishery-dependent probabilities before stock-wide statistics are calculated at the terminal year. Many of these life history probabilities in the IBLS, including aspects of mortality, recruitment, growth, and maturity, are dominated by climate change and the rapidly warming waters of the Northeastern US. The immense flexibility of the IBLS allows for alteration of these life history probabilities that would occur under different warming scenarios. Simulations under static management approaches to these life history changes were forecasted out fifty years. We then tested alternative management measures on these simulated projections to determine appropriate management actions that could be used to safely and effectively account for these future changes to lobster life history. For both the Gulf of Maine and Southern New England stocks, we found management actions such as changes to legal size limits and number of traps to be more effective than others, such as gear modifications or conservation of females with eggs. We also discovered that fishery performance was tightly linked with future recruitment dynamics. Future work will continue to explore combinations of lobster life history changes and management actions. This framework has the ability to be adapted for many crustacean and finfish stocks and can be used to determine the most appropriate future management actions to stabilize catches and population levels under dynamic life histories impacted by climate change. This model can additionally act as a first step towards development of management strategy evaluation frameworks.

Keywords: individual-based modelling, management strategy evaluation, climate change

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CM 395: Designing a large-scale marine protected area network in a warming Mediterranean Sea

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Climate change can have decisive effects on the effectiveness of Marine Protected Areas (MPAs) due to induced changes in species composition, spatial distribution of species, physiology and demography. Identified as a biodiversity hotspot, the Mediterranean Sea is also one of the fastest warming ocean regions. In the context of a required increase in the extent of protected areas in the Mediterranean Sea in line with international objectives (30% of protected areas by 2030 of which 10% under high protection), this study aims to evaluate the impacts of climate change on the ecological efficiency of different large-scale MPA networks scenarios. Using an integrated modelling chain including a high-resolution regional climate model, a regional biogeochemistry model and a food web model (OSMOSE), we quantified the cascade of impacts of climate-induced changes in the spatial distribution of fish and primary production under a high emission scenario (RCP8.5) for the periods 2022-2050 and 2071-2100. Future projections on species biomass and fisheries catches under climate change were compared with present biomass and catches and according to different MPA network configurations, either randomly drawn or suggested from the scientific literature. By undertaking a systematic comparison between the outcomes of a diversity of MPA scenarios and expliciting fish population dynamics under climate change, our study brings some insights on large-scale spatial planning in a warming Mediterranean Sea.

Keywords: marine protected areas, Mediterranean Sea, climate change, food web model

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CM 397: Fishing influences sensitivity of fish growth to warming

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The effects of climate change and fishing pressure on fish populations are of great concern. Understanding how these effects interact is important to advance towards sustainable and climate-informed fisheries management. In this study, we investigated how fishing affects the thermal response of fish growth, an important driver of population dynamics and fishery productivity. We used a large archive of otoliths collected from Belgian, Dutch and French fisheries to develop a multidecadal growth biochronology (1957-2020) of three populations of sole (*Solea solea*) in the North Sea, the Irish Sea, and the Bay of Biscay. These regions represent the optimal thermal distribution range of sole and have experienced variable temperature and fishing pressure. We applied a hierarchical mixed-effects modelling framework to examine the intrinsic (age, age at capture) and extrinsic (temperature, fishing pressure) drivers of growth and the interaction of temperature and fishing pressure. Increasing temperature stimulates juvenile growth (20.3% in age 1) but reduces adult growth (40.2% in age 10). In contrast, increasing population density reduces juvenile growth (44.5% in age 1) but increases adult growth (76.6% in age 10). Fishing, through reducing population density, weakens the overall growth repose to temperature and alters the response direction in certain age groups. This interaction of fishing and temperature occurs at both population and individual levels. Our results highlight the complex relationship between climatic and fishing conditions and fish growth, which should be considered in fisheries management.

Keywords: sole, growth, otolith, climate change, fishing

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CM 433: Proposed Business Rules to Incorporate Climate-induced Changes in Fisheries Management

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Changing oceanic conditions are having impacts on living marine resources (LMR) and their management, often in ways beyond what we have ever seen before. This is largely manifested as changes in production or location of these LMRs. The challenge has been not only to disentangle the possible causes of these changes to LMR stocks, but then even if clear changes are detected, it has been unclear what we can actually do about them. Here we propose a set of recommended actions or "business rules" to better address climate-induced changes to LMR production and location. These emphasize a series of diagnostics which can be used to demarcate significance of whether action is necessary, and then if action is deemed necessary, we propose a set of insertion points or "on-ramps" to address the nuances of locational or production changes at every step in the science to management process. These proposed "business rules" for dealing with climate-induced changes to fisheries can always be debated, can always be updated with new information, and can always be adjusted under a given set of circumstances. But we also assert that it would be wise to start acting on them, as a proposed set of options, given the urgency and exigency of the situation.

Keywords: climate change, living marine resources, science to management process, on-ramps, business rules, distribution shifts, productivity

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CM 446: Modelling fish stock dynamics considering environmental variability: a case study of European hake (*Merluccius merluccius*)

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Increasing demand for food resources in conjunction with climate-related alterations in marine ecosystems and declining trends in fishing catches worldwide, suggests little room for fisheries expansion and a greater need for efficient approaches to fisheries management. To reach this goal, it is really important to understand how the effects of climate change could affect the different species and consequently what the socio-economic impacts would be. Different approaches are needed to determine which of the processes underlying the stock dynamics are the most affected by those environmental drivers. Considering the case-study of the southern stock of the European hake (*Merluccius merluccius*), a commercially important resource in the European waters, and specifically its southern stock in the International Council of the Exploration of the Sea (ICES), the aim of this work is to analyze and quantify the impact of climate change on the future development of this species. For this purpose, a preliminary study is carried out to determine the correlation between these environmental drivers and the maturity process which is one of the crucial biological processes affecting population dynamics. Then, according to the Representative Concentration Pathway (RCP) scenarios defined by the Intergovernmental Panel on Climate Change (IPCC), the population dynamics is projected considering how these future environmental scenarios affect the maturity process and, therefore, the natural mortality and growth. The effects over the fish population are analyzed through medium and long term projections deriving indicators on its sustainability, performance and stability. This framework could be extended to other fish species and areas and will allow a deeper understanding of how climate change could affect the fish population dynamics.

Keywords: climate change, population dynamics, stock assessment

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CM 480: Satellite-derived marine environmental indices and their relations to higher trophic levels in the bay of Biscay

Baptiste Ozanam, Marine Dorand, Antoine Huguet, Mathieu Doray, Pierre Petitgas[1]

Operational oceanography provides for 20 years satellite-derived daily sea surface maps of temperature and chlorophyll-a. In meteorology, similar data exist as atmospheric pressure fields. Their space-time analysis has allowed them to identify characteristic and recurrent situations (spatial patterns) and provide amplitude indices for these patterns. The North Atlantic Oscillation index is a well known index resulting from such analysis. We present here a similar approach for analysing the series of satellite-derived monthly sea surface maps of temperature and chlorophyll-a, over the bay of Biscay (43°N - 48°N, 0°W - 5°W) from 1999 to 2021. Empirical Orthogonal Functions were applied by month to the series of maps to extract spatial eigen vectors consistent in time and the time series of their amplitudes. The eigen vectors were further classified to identify consistent spatial patterns over years and months. An index by month and year for each spatial pattern is proposed. The analysis shows that sea surface temperature has increased from 1999 to 2021, emerging from seasonal variability in coastal waters in winter and in the bay's south-east waters in seasonal transition periods. Chlorophyll-a has decreased, especially in coastal waters and in autumn. The analysis agrees with other works on Chlorophyll-a satellite images using time series analysis by pixel. The spatial patterns are discussed in light of meteorological situations and environmental variables (river plumes, wind, nutrients). The series of indices correspond to new environmental time series that have been correlated to variations in higher trophic levels' abundance, condition or habitats (small pelagic fish, marine mammals).

Keywords: Satellite, EOF, SST, Chlorophyll a, Climate Change, Biscay, High Trophic Levels

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CM 510: Title : When isotopes reveal boreal species niche contraction in favor of lusitanian species

Morgane Amelot [1], Marianne Robert [2], Maud Mouchet [1], Dorothée Kopp [2]

Marine species are impacted by climate change in various manners, depending on their exposure and sensibility to environmental and human induced variations. These differences in species' responses to climate change, particularly in their migration and resource acquisition patterns, could lead to new community and network structures and functioning. Changes in ecosystem structure, including trophic structure, will conditioned future ecosystems' species composition and abundance, and might be early indicators of community shifts. Structural variations might be exacerbated in areas that gathered species with diverse thermal preferendum and are likely to have adverse reactions to global warming.

The aim of this study was to explore the evolution of the isotopic niches of ten fish species in the Celtic Sea. The hypothesis was made that trophic niches have varied in response to climate change depending on community and species thermal affinities. Boreal ("cold-affinity") community niche size would have decreased while lusitanian ("warm-affinity") community niche size would have increased due to recent environmental variations impacting prey availability and/or species spatial distribution. Trophic niche widths and overlap of ten commercial demersal fish species either boreal or lusitanian were compared, between 2014-2016 period and 2021, based on their $\delta^{13}C$ and $\delta^{15}N$ isotopic signatures.

During this short time period, both boreal and lusitanian trophic niche widths and positions changed. Boreal species niche contracted while lusitanian niche expanded. Moreover, niche overlap variations demonstrated that the competitive pressure exerted by the lusitanian community on the boreal community increased, while the competitive pressure exerted by the boreal community on the lusitanian community released.

The trophic niche size variations observed in the Celtic Sea were associated to communities and species thermal preferendum, which strongly support the hypothesis of a climate-influenced structural change of the ecosystem. The speed and magnitudes of the changes observed were unexpected. This finding suggests that ecosystems composed of various biographic affinities, seems to be particularly sensitive to trophic structure variations. In the Celtic Sea those variations are mainly related to negative effects on the boreal community, and are likely to result in important network re-organisation that will induce major consequences on the local fisheries in short to medium term.

Keywords: climate change, Isotopic niche, competition

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CM 514: Disentangling the environmental forcing of the European Hake stocks (*Merluccius merluccius*) (Linnaeus, 1758) in the Western Mediterranean

Eduardo Ramirez-Romero, Cristina González-Andrés, Diego M Macias, Enric Massutí, Martha B. Dunbar, Gabriel Navarro, Beatriz Guijarro

Ecosystem Based Fisheries Management requires a massive amount of environmental information to explain key mechanisms and drivers of fish population dynamics. Several programmes, such as the European Union's Copernicus Marine Service greatly improve data availability and promote the use of several products to support Blue Economy activities, such as fisheries.

In this study we assessed the environmental link between the NW Mediterranean dynamics and a key population process, i.e., recruitment, of a highly valuable demersal resource for the local fishing sector, the European hake. Two hake stocks were analyzed comprising the Geographical Subareas (GSA) 5 and 6 defined by the General Fisheries Commission for the Mediterranean. These areas present contrasting oceanographic features representing oligotrophic waters (GSA5) and more productive waters with riverine influence (GSA6). Deep water formation during winter in the Gulf of Lion is also a key phenomenon explaining the response of the hydrology and production in the NW Western Mediterranean.

In order to assess the environmental-population link, several Copernicus Marine Service products were used, mainly from satellite observations (Sea Surface Temperature and chlorophyll-a) and physical modelling reanalysis, both specific to the Mediterranean. Using Generalized Additive Models to compute the relationships with the environment and with the Spawning Stock Biomass (SSB), we show that recruitment in GSA5 could be captured by winter SST and SSB (% explained deviance=52). In GSA6, recruitment can be modeled using yearly averaged SST, chorophyll-a, water column salinity and SSB (% explained deviance=79).

In the face of climate change this information is crucial for projecting stock scenarios using climate modeling and stock exploitation intensity with the ultimate goal of reaching sustainable levels of the stocks in question.

Keywords: European hake, Copernicus Marine Service, environmental forcing, EBFM

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CM 525: Comparing performance of management alternatives for the US summer flounder recreational fishery given climate-driven shifts in availability

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Ecosystem approaches to fisheries management recognize people as part of a socio-ecological system and consider links among environmental, economic, and societal goals for sustainability. Fisheries systems are challenged by change due to the climate crisis, increasing human use of the oceans, and regulatory complexity, which coupled with geographic variation in human populations and economies means impacts of policy choices will continue to be felt differentially across coastal communities. This may be particularly the case for recreational fisheries, where anglers are confronted by climate-change driven shifts in resource availability within management units. In 2022, as part of their Ecosystem Approach to Fisheries Management structured decision process, the Mid-Atlantic Fishery Management Council completed a Management Strategy Evaluation to compare options designed to reduce discarding in the recreational summer flounder fishery, with a goal of increasing both harvest and recreational opportunities. Reducing regulatory discards within the recreational sector of the summer flounder fishery has been challenging: 90% of the recreational catch is released and 1 out of every 10 fish released ends up dying. Through a collaborative, stakeholder-driven, and science-based process, a modeling framework was developed that integrates a full summer flounder population dynamics model with an angler behavioral model to understand how the recreational sector at the state level responds to changing regulations and summer flounder availability as a result of a climate-driven shift in geographic distribution. Seven management procedures were tested, and the benefits of each management procedure were assessed using a suite of biological, social, and economic performance metrics across four management objectives.

Results showed there are management procedures that outperform status quo management at reducing discards and converting those discards into harvest while limiting risk to the summer flounder population and increasing angler satisfaction. However, coastwide performance of most management procedures degraded with a simulated summer flounder distribution shift. Further, the relative performance of a management procedure was highly variable at the state or regional level, with adverse angler satisfaction outcomes for some states compared to status quo even when coastwide outcomes improved. These models and results can be used to directly inform recreational management and provide both strategic and tactical advice to develop climate-ready fisheries. The ability to compute likely outcomes of management options at the state or regional level provides a pathway for explicitly considering the distribution of benefits from proposed management strategies in a changing ocean.

Keywords: ecosystem approach to fisheries management, climate-ready fisheries, angler satisfaction, management strategy evaluation

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CM 538: Bathymetrical variations of fish indicators in Atlantic and Mediterranean waters

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One of the consequences of global change, especially on climate, is the modification of the distribution of certain marine species that shift their range towards more favourable areas. These changes have been latitudinal and longitudinal but vertical changes have also been recorded, as some species move to colder and deeper waters. In this study we will examine the spatiotemporal evolution of indicators with depth for the fish community. Focusing on the North Atlantic (considering the North Sea, Barents Sea, and Svalbard as separate regions) and western Mediterranean area, we calculate a set of indicators representative of different aspects of the ecology of the group using data from the Mediterranean International Trawl Survey (MEDITS) and the Fishglob database. These metrics are related to biodiversity (i.e., species richness and beta diversity), trophic ecology and biomass (i.e., total biomass, mean size, and relative biomass of predator taxa). Using Generalized Additive Models (GAM) we unravel the patterns of variation between the considered areas as well as within, the trends of the different indicators and the influence of depth. We have detected the 200–400-meter range as the threshold where the maximum values of some indicators (such as biomass and richness) occur in all four regions. Despite this, differences in response can be seen on indicators such as mean size (where responses in the western Mediterranean and the Barents Sea are negatively correlated with depth, while on the North Sea and Svalbvard increases) or the mean trophic level (negatively correlated with depth except on Svalbard where it increases up to 500 meter). Differences between the relationship of indicators and time were also seen with a general temporal decrease in relative biomass of predators and trophic level in all regions except the North Sea. Our findings show the existence of the variation of the indicators by regions as well as the significant effect of both the bathymetric component and the temporal evolution of the fish populations of the different communities.

Keywords: biodiversity, fishes, ecological indicators, bathymetry, climate change

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CM 540: Spatio-temporal variations and influence of environmental parameters in the biomass of long-finned squid (*Loligo spp*) in the English Channel

Anna Marcout[1], Eric Foucher[2], Jean-Paul Robin[1]

Long-finned squids (*Loligo forbesii* and *Loligo vulgaris*) are among the valuable resources exploited by English Channel demersal fisheries. They are set apart from other commercially exploited species due to several biological and ecological characteristics including short lifespan, semelparous reproduction, rapid growth, high natural mortality and sensitivity to environmental conditions. As a result, they show significant seasonal and inter-annual fluctuations in biomass and subsequent landings.

The two *Loligo* species are not distinguished by fishers and are characterized by a difference in the timing of their life cycle. In the English Channel, recruitment peak is observed in July for *L. forbesii* whereas *L. vulgaris* recruitment peak appears in October.

In this study, we computed *Loligo* spp biomass indices using 22 years of commercial fishery data (2000-2021) and examined relationship between recruitment biomass indices (July and October) and hydro-climatic parameters in the English Channel in the pre-recruitment period such as bottom temperature, salinity, current velocity, primary production, nitrate, phosphate and chlorophyll concentrations.

Two different models were obtained to forecast *L. vulgaris* and *L. forbesii* biomass indices during the recruitment. These models explain a high percentage of variation in biomass indices and can be used to forecast the abundance (in terms of biomass) and spatial distribution of the resource. Such forecasts are potentially useful tools to guide fishery managers although models fitted at the beginning of cohort exploitation will require season management procedures.

Keywords: squid, Loligo forbesii, Loligo vulgaris, English Channel, fisheries, biomass indices, predictive model, hydro-climatic variables

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CM 549: Adapting the ecosystem and socioeconomic profile framework to include climate readiness for informing next generation stock assessments

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Ecosystem-based science is a forefront component of effective marine conservation and resource management; however, a gap remains between ecosystem research and integration with stock assessments. Primary obstacles are a lack of a consistent approach to deciding when and how to incorporate ecosystem and socioeconomic information into a stock assessment and how to test the reliability of this information within a changing climate. Over the past several years we have developed a standardized framework called the Ecosystem and Socioeconomic Profile (ESP) for operationalizing the integration of ecosystem and socioeconomic factors within NOAA Fisheries' stock assessment system. The ESP uses data collected from a variety of sources in a four-step process to generate a set of standardized products that culminate in a focused, succinct, and meaningful communication of potential drivers on a given stock. ESPs are produced operationally for several Alaska stock assessments including sablefish, pollock, Pacific cod, and crab and are currently being incorporated into Northeast United States stock assessments as well. The ESPs also inform conversations regarding the use of climate science in fisheries management decisions. The North Pacific Fisheries Management Council's Scientific and Statistical Committee recently recommended focusing climate change modifications on short-term responses to climate change effects for tactical management and that the ESPs in particular can be used or adapted to achieve our climate ready goals. We describe the success of the ESP framework for informing management decisions using the Alaska sablefish and Pacific cod stocks as case studies and identify avenues for including climate information within the ESP four step process. The adaptability and responsiveness of the ESP framework allows for timely and streamlined products that will increase the readiness of our stock assessment enterprise as we respond to a rapidly changing climate.

Keywords: ecosystem based fisheries management, ecosystem and socioeconomic profile, climate readiness

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CM 555: Thermally-driven changes in fish biodiversity in a temperate-boreal regional sea (Kattegat and Belt Sea)

Karoline Minna Bryndum[1], Asbjørn Christensen, Marie Storr-Paulsen, Brian R. MacKenzie

Climate-hydrographic properties and exploitation affect abundances and occurrences of fish species and can induce changes in the temporal and spatial distribution of species. Such changes can affect the effectiveness of fishery management plans, the availability of fishing opportunities and the functioning of ecosystems via changes in trophic interactions (e. g., predator-prey dynamics and competition). The Kattegat-Belt Sea region, which is located between the North and Baltic Seas, is an important area for fisheries and a hydrographic (salinity) transition area between these two seas.

In this study, we investigated how fish biodiversity (species richness), measured in spring and fall demersal surveys, has changed during 1994-2021 and whether such changes co-varied with fluctuations in regional temperature, salinity and oxygen concentrations. We also investigated how the thermal affinity of the fish community and the probability of occurrence of individual species changed over time and whether these responses co-varied with temperature.

Species richness, i.e., total number of species per year, increased on average at a rate of 0.44 species/year (spring) and 0.66 species/year (fall). During the same period, sea bottom temperature (SBT) increased significantly by on average 0.037 °C/year and 0.092 °C/year in spring and fall surveys respectively. Sea bottom temperature and total number of species co-varied significantly, with richness increasing between 2-4 species/°C. The analyses of changes in thermal affinity of the community showed a significant trend towards a more warm-adapted composition in both spring and fall surveys. This pattern suggests that the survey area is receiving new fish species with a southern affinity, which is supported by a strong association between the community thermal affinity metric and sea bottom temperature. Similarly, the probability of occurrence of two warm-adapted species, anchovy and red mullet, increased significantly during the survey period from 0-40%.

This study demonstrates that local temperatures have increased significantly and are driving shifts in species richness, including the immigration of formerly rare warm-adapted species. These changes could accentuate (or counteract) impacts due to other human pressures such as exploitation and eutrophication. As an example, efforts to recover biomasses of colder-adapted species in the region, such as cod, will likely be delayed with warmer temperatures. As climate change progresses, fishery management will be challenged, highlighting the need for an adaptive, ecosystem-based management.

Keywords: fish species richness, sea bottom temperature, climate change, latitudinal affinity, exploitation

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CM 557: Climate effects on swordfish early-life habitats: the western Mediterranean open-ocean observatory

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The Balearic Sea, in the western Mediterranean, is a remarkable reproductive area for many marine species, among which large oceanic migrants stand out. This region presents unique oceanic features with fronts and eddies, favouring the early-life stages of these species. We take advantage of already existing biological and oceanographic data and know how to advance in the understanding of the open-ocean pelagic ecosystem. We purpose indicators to monitor the environmental variability of the pelagic habitat, such as temperature anomalies that affect the survival of tuna larvae. The indicators are designed to inform climate aspects of the ecosystem approach to fisheries management for tunas and other related species in the framework of the International Commission for the Conservation of Atlantic Tuna, the organisation in charge of the fisheries management of these species. We take swordfish (*Xiphias gladius*) as a case study. Swordfish is a highly migratory species that, in the Mediterranean, reproduces at several locations and has the Balearic Islands as one of the main breeding areas. We investigate if climate change has already affected the suitability of this potential spawning ground. For that, we analyse how the variability of ocean characteristics and features affects the presence of swordfish larvae collected in ichthyoplanktonic surveys and identify their preferential habitat. Results of this work show that, during reproductive season and early developmental time of this species, significant heatwaves impact the pelagic realm in the Balearic Sea, a prominent hydrodynamic retention area of the western Mediterranean, with direct effects on the distribution of the swordfish larval habitat.

Keywords: ecosystem indicators, preferential habitat, environmental variability, climate change

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CM 562: Increasing resilience and adaptive capacity in Maine's co-managed shellfish fishery

Marissa McMahan[1], Emily Farr

Maine's wild harvest shellfish fishery has existed for over 10,000 years. It is an incredibly important part of Wabanaki culture, and supports 1500 harvester livelihoods along the coast of Maine. It is also Maine's second most valuable fishery, valued at over $25M in 2021. This fishery is collaboratively managed, or co-managed, between municipalities and the state, with 78 individual municipalities currently managing their shellfish resources. There are a host of intensifying environmental and social threats to the shellfish fishery, including the loss of coastal access, increased predation, sea level rise, harmful algal blooms, habitat degradation/loss, and newly emerging species. While the co-management system provides an infrastructure and space to foster adaptive capacities, there is also an increasing need for coordinated action across scale. This presentation will focus on recent efforts to build collaborative networks, advance stakeholder-driven solutions, and respond to the needs of managers, harvesters, and coastal communities to build a more resilient and adaptive shellfish co-management system.

Keywords: shellfish, co-management, small-scale fisheries, adaptive management

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CM 570: Patterns and trends in fish trait composition in the Baltic Sea: underlying causes and potential implications for management

Karoline Minna Bryndum, Esther D. Beukhof, Brian R. MacKenzie, Martin Lindegren

The diversity of marine organisms play an important role in maintaining the structure and functioning of our oceans and ecosystem, as well as provisioning key services vital for human well-being. It is therefore important to better understand the key drivers and processes impacting fish community diversity and composition, especially during climate change. Using a trait-based approach allows for a more mechanistic understanding of community dynamics, as the traits that species carry are important determinants of the individual, population and community response to environmental drivers and human pressures.

In this study, we investigated if and how climate variability and commercial fishing has influenced the spatio-temporal dynamics of fish community traits in the Kattegat and the western Baltic Sea. We used high resolution trawl survey data on fish community composition and biomass from 2001-2021, combined with environmental data (i.e., sea bottom temperature, salinity, oxygen concentration and chlorophyll α) and commercial fish landings, as well as available information on fish species traits, including size, trophic level, life history and reproduction.

We calculated the community-weighted mean (CWM) of traits in the fish community and used Principal Component Analysis to identify the main temporal trends and spatial patterns characterizing the overall trait composition in the survey area. Subsequently, we modelled the temporal CWMs and used a Redundancy Analysis for the spatial CWMs to investigate the key environmental drivers affecting both the temporal and spatial trait dynamics. We also investigated the lagged effects of the environmental variables and the effects of fishing pressure.

Our preliminary results demonstrate a pronounced change in the trait composition over time, though these trends differ between the Kattegat area and the Baltic area. Furthermore, our results demonstrate a marked spatial variation in trait composition across the survey area. Additionally, and similar to other studies in the area, we expect to find that trait composition will be strongly linked to the environment, particularly salinity.

This study underlines how analyses of traits contain valuable information on fish communities. This key knowledge can be useful to refine and formulate predictive models allowing managers and decision makers to evaluate scenarios of different management actions under the influence of climate variability. Additionally, our results demonstrate how traits can give a better simple mechanistic understanding of complex ecosystem functions and processes, and how the community responds to environmental and anthropogenic stressors.

Keywords: fish traits, trait-based approach, fish community composition, the Baltic Sea, sea temperature, climate change, exploitation

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CM 575: Overlap of pollock and northern fur seals in the Eastern Bering Sea

Ivonne Ortiz[1], Kirstin Holsman, Elizabeth McHuron, Jeremy Sterling, Nicholas Bond, Kerim Aydin

Understanding the differences between local spatial and temporal dynamics versus those of fish stocks as a whole, provides insights into the effects of environmental conditions and how ecosystem based management of northern fur seals (NFS) and pollock may address issues such as changes in feeding interactions and shifting distributions. We evaluated shifts in distribution of walleye pollock and quantified the changes in their availability as prey within the foraging ranges of NFS lactating females in the Pribilof Islands. Bering Sea pollock supports one of the largest fisheries in the world, is a key prey in the ecosystem, and is one of the main prey of NFS. We used 1982-2019 data from annual summer bottom trawl surveys to assess the availability of pollock within the five known NFS lactating female foraging ranges and estimated their overlap. Foraging ranges reflect satellite tracked adult female NFS departing rookeries grouped by unique diet clusters. We compared bottom-trawl time-series estimates of pollock within NFS foraging ranges to that of the corresponding stock assessment and overall survey estimate to highlight differences between the stock population dynamics which occupies the entire shelf and what is available to lactating females as central predators. The interannual variability of the fish distribution is largely influenced by the extent of the cold pool (a layer of cold bottom water that is 2°C or less), which has exhibited substantial fluctuations in recent decades. A large cold pool aggregates fish towards the shelf edge and south, whereas a small one allows fish to move into the middle shelf, shifting the center of distribution of the fish stocks with respect to the fixed foraging ranges. Results show area overlap of lactating female NFS with large pollock (>30cm) remained mostly stable while overlap with small pollock (<30 cm) was more variable. The overall trend in the pollock population as measured either by the stock assessment or the survey-based estimate did not reflect what was available within the different foraging ranges. Pollock biomass shows larger variability and distinct patterns within the foraging ranges which fall either mostly south, northeast, or northwest of the Pribilof Islands. Our results provide an example of tactical climate-informed advice for EBM decision making in the Eastern Bering Sea.

Keywords: northern fur seal, pollock, species overlap, ecosystem-based management, predator-prey

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CM 581: Near-term climate-ready fisheries actions for managers

Michael Drexler[1], Elizabeth Cerny-Chipman, Megan Williams, Meredith Moore

There has been substantial effort dedicated to developing the scientific information and tools needed to inform climate-ready fisheries, yet implementation of climate-ready approaches has been limited. Meanwhile, climate impacts on our fisheries are already occurring, and near-term action is critical even without the full complement of information and tools in hand. Climate change will require managers to improve the long-term resilience of our fisheries while concurrently improving the short-term responsiveness of our management systems to prevailing ecological conditions while avoiding unintended harm to stocks in a highly uncertain system. The nature of the climate challenge necessitates utilizing a range of approaches, including taking a holistic view of opportunities to address climate change in every facet of fishery management from data collection through management decisions.

Many of the leading solutions also face unexpected challenges. For example, incorporating environmental drivers into a stock assessment requires detailed understanding of the mechanistic linkages between life history and the environment. However, these relationships can only be tested in information rich stocks and may add only marginal improvements to already well-informed stock assessments in the near term. Further, revising fishery management targets to reflect prevailing ecological conditions poses a significant risk by potentially expediting population declines or limiting the potential for future population recovery. While more data-intensive solutions are being further resolved, there are additional tools that can, at minimum, be used as interim climate-ready adaptation options.

Given these challenges and an urgency for action, we performed a systematic review of climate-ready fishery solutions proposed in the literature and by managers. We refine those recommendations to a set near-term actions managers can take *now* to improve the long-term resilience and short-term adaptability of our fisheries while further links between the environment and fisheries are identified. Generally, we find that small improvements to existing harvest control rules, maintaining long term fishing and biomass targets, and increasing the availability of environmental information can have real benefits for climate preparedness. We develop a framework to demonstrate where these solutions integrate into management processes, what climate impacts they address, and examples of implementation of the proposed solutions.

Keywords: climate-ready fisheries, management, fisheries, climate change

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CM 611: Biomass and distribution of cnidarians and ctenophores in Icelandic waters during the summertime in relation to environmental variables and lumpfish distributions

Tyler E. Sharpton[1], James Kennedy[2], Teresa Silva[2]

In the past two decades, the research interest in jellyfish (cnidarians and ctenophores) has increased worldwide as they are essential in pelagic ecosystems and have been hypothesized to benefit from climate-change-induced warming waters. This study presents novel research on jellyfish biomass in Icelandic waters during the summer months from 2013 to 2022, where patterns or fluctuations in jellyfish biomass were assessed, and possible drivers, such as temperature, salinity, and lumpfish distributions. Lumpfish stomach samples were also analyzed to evaluate any prey-predator interactions. Data for this study was collected during the Icelandic Marine and Freshwater Research Institute's summer survey from 2013 to 2022. Exploratory analysis and the running of generalized additive models were conducted to understand the drivers of jellyfish biomass. Results show that jellyfish biomass had no significant trends in most water masses around Iceland from 2013 to 2022, except in western waters, where a significant increasing trend was seen in jellyfish biomass with an increase in lumpfish biomass. Location was found to be the highest explanatory variable of jellyfish biomass presence, and environmental variables' influences on jellyfish biomass seem region-specific. Lumpfish was an important predictor of jellyfish presence, explaining 4.94% of the deviance and within their stomach samples in 2022, jellyfish, crustaceans, and chaetognaths, were present the lumpfish diet. This research provides new insights into the ecology and distribution of jellyfish in Icelandic waters which has not previously been explored at this scale, and its potential implications for the management of jellyfish or jellyfish specialist predators in Icelandic waters and the jellyfish's influences on lumpfish distributions.

Keywords: Cnidarians, ctenophores, jellyfish, lumpfish, Iceland, North Atlantic, biomass estimates, stomach content analysis

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CM 622: Fishery management challenges and strategies for species distribution shifts: case studies from the Northwest Atlantic

Katherine E. Mills[1], Andrew Allyn, Lisa Kerr, Nancy Shackell

Species distribution shifts are one of the most widely documented biological consequences of climate-driven warming across marine ecosystems, yet many contemporary fishery management practices were designed under assumptions of stationarity in species distributions and population dynamics. As such, shifts in the distribution of fish and invertebrate species are creating a variety of challenges for fishery management processes and affecting achievement of management objectives. Species shifts across regional and national jurisdictions alter alignment with management authorities responsible for relevant fisheries, requiring increased coordination among multiple institutions to effectively monitor species and manage fisheries. At more local scales, species may shift across stock boundaries, influencing perceptions of population abundance in different stock areas in ways that may affect stock assessment processes and results. In addition, species distribution shifts can affect fishery operations and interactions, particularly if they alter encounter or catch rates of bycatch, choke, or protected species. Finally, changes in species distributions also challenge quota allocation arrangements, which are often tied to historical catch records. If species shift while fishing rights or access do not, fisheries have limited ability to adapt in ways that support economic, social, and equity objectives. In this presentation, we will draw examples from the Northwest Atlantic (i.e., Northeast U.S. Shelf and Scotian Shelf) to demonstrate ways in which species distribution shifts are challenging fishery management processes, fishing operations, and fishery objectives. For each example, we will highlight ways in which fisheries and management approaches are adapting to or incorporating considerations of species distribution shifts, and we will discuss how adaptation measures are buffering impacts to fisheries. Such measures include the use of near-real time information, seasonal forecasts, and state-based models to support operational and management decisions. In addition, climate-scale projections of species distributions can support strategic planning for fisheries, including providing insights into additional ways in which species distribution shifts may need to be incorporated into fishery management and adaptation planning efforts moving forward.

Keywords: climate change, species distribution shifts, fishery management, Northeast U.S., Maritimes Canada

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CM 626: A climate resilience assessment and planning tool for marine fisheries

Katherine E. Mills[1], Jacob Eurich, Meghan Fletcher, Kristin Kleisner, Patrick Sullivan, Peter Taylor, Alice Thomas-Smyth, Lily Zhao

In marine fisheries across the world, climate change is altering the productivity and distribution of fish stocks, challenging fishery management efforts, and changing the flows of benefits from fisheries. The nature of these impacts and ability of fishery stakeholders to respond to them are mediated by the ecological, socio-economic, and governance context within which fisheries operate. A Science for Nature and People Partnership (SNAPP) working group on Climate Resilient Fisheries has developed a framework and toolkit to support integrated assessments and planning for climate resilience in marine fisheries. This framework helps identify climate risks to a fishery; evaluate ecological, socioeconomic, and governance attributes that influence resilience; and prioritize actions to enhance climate resilience. By considering fisheries as coupled social-ecological systems, this framework can help identify approaches to operationalize climate resilience across ecological, socioeconomic, and governance dimensions of fishery systems. It can also be used to highlight strengths and limitations within dimensions that may influence climate resilience of the fishery. Applications to resilience assessment and planning will be demonstrated through case examples drawn from a variety of fisheries around the world. In these cases, multifaceted strategies have supported climate resilience, including measures to enhance stock and ecosystem health, reinforce social strengths, expand economic opportunities, and enhance governance responsiveness and effectiveness. We conclude by demonstrating how such information can be incorporated into structured fishery management systems familiar to many ICES participants.

Keywords: climate change, climate resilience, resilience assessment, decision support tool, resilience attributes, resilience strategies

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CM 632: Diverse pathways for climate resilience in marine fisheries systems

Kristin M. Kleisner[1], Jacob G. Eurich, Whitney R. Friedman, Lily Zhao, Kathy Mills

Both the ecological and social dimensions of fisheries are being affected by climate change. As a result, policymakers, managers, scientists, and fishing communities are seeking guidance on how best to holistically build resilience to climate change. Numerous theoretical and empirical studies have highlighted key attributes of resilience in fisheries, yet concrete examples that explicitly link these attributes to social-ecological outcomes in fishery systems are lacking. To better understand climate resilience, we assembled 18 case studies spanning ecological, governance, socio-economic, and geographic contexts. Using a novel framework for evaluating 38 resilience attributes, the case studies were systematically assessed to understand how attributes enable or inhibit resilience to a given climate stressor. We found population abundance, responsive governance, and learning capacity were the most important attributes for conferring resilience, with ecosystem connectivity, accountable governance, and place attachment scoring the strongest across the climate-resilient fisheries. We used these responses to develop an attribute typology that describes robust sources of resilience, actionable priority attributes, and attributes that are case-specific or in need of further research. We identify five fishery archetypes to guide practitioners and communities as they set long-term goals and prioritize actions to improve resilience. Lastly, we find evidence for two pathways to resilience through either building ecological assets and strengthening communities, which we observed in case studies of rural and small-scale fisheries, or through building economic assets and improving effective governance, which was demonstrated in urban and wealthy fisheries in our suite of cases. Our synthesis presents a novel framework that can be directly applied to identify approaches, pathways, and actionable levers for improving climate resilience in fishery systems.

Keywords: climate change, climate resilience, resilience strategies, social-ecological system

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CM 657: Next steps in climate-informed fisheries management: the use of computer and data science in the co-design of next generation models

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In recent years, significant strides have been made in advancing climate-ready fisheries approaches in the management of our marine resources. Building climate-ready fisheries requires information and tools to prepare for and respond to the impacts of climate change on targeted fisheries and help build resilience in communities that depend on healthy and sustainable fisheries (see the ACLIM project https://www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project).

Without a doubt, projects such as ACLIM have provided a step forward in our science-to-management-advice capabilities. At the same time, the continued rates of change in our environment and the urgency of our responses require continued increases in our ability for timely delivery of skillful predictions of future change. Simply, we need more realistic representations of diverse processes—from physical to socioeconomic—at all scales (and their interactions) within an Earth System framework. And while on the one hand the rapid increase of data collection capabilities will help bridge these needs, expected advances in high performance computing by itself is tempered by the limits (in processor and microchip capabilities) that are imposed on of the 'laws' of Dennard and Moore. As a result, we will need to rethink the way in which we approach Earth-system modeling and high-performance computing (e.g., see Bauer et al., 2021. Nature Computational Science, https://doi.org/10.1038/s43588-021-00023-0). We will need interdisciplinary approaches to co-design new algorithms, port computing intensive code parts to novel architectures, and we will need new data-driven methodologies such as network analysis and machine learning. In this presentation we will discuss anticipated needs to be able to continue to make progress in climate-informed ecosystem-based fisheries management, including needed closer inter- and transdisciplinary links between earth and fisheries science with computer and data science. We posit that these cross-disciplinary links will be essential to increasing the efficiency and effectiveness of how we advance our capabilities in climate-informed decision-making. The advancements in computer and data science in the last two decades have transformed how we extract knowledge from data, evolved our traditional approaches to modeling, and provided novel applications of artificial intelligence. Issues in the climate domain present new research challenges in computer science, requiring advancements to support these complex knowledge domains and machine learning models capable of integrating predictions of the future. An eventual goal is to build transdisciplinary, scientifically sound, and scale-explicit Earth system (e.g., resource/fisheries management) models that are to be codesigned by multidisciplinary communities.

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