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Theme session Report

Advancing scientific support for evaluating trade-offs in ecosystem-based management

Conveners: Olivier Thébaud (France), Katell Hamon (Netherlands), David Goldsborough (Netherlands)

Session context and objectives

Making difficult and informed trade-offs among competing uses of marine resources is central to effective ecosystem-based management (EBM) and achieving the United Nations' Sustainable Development Goals. Trade-offs are equally central to the ICES Vision of "meeting societal needs for impartial evidence on the state and sustainable use of our seas…" and the ICES Mission of generating "advice for meeting conservation, management, and sustainability goals." More specifically the ecosystem approach to fisheries aims to provide advice to make management trade-offs. Similarly, the ICES Science Plan states that "understanding […] pressures and their impacts will provide evidence to advise on tradeoffs between benefits and risks."

While the need for managers to make trade-off decisions is clear and well-recognized, how do they actually do this effectively across diverse environmental, economic, and social objectives and risks? Different disciplines and management systems have different approaches to how they measure and evaluate trade-offs across alternative uses of scarce ocean resources.

The session aimed to identify methods and present diverse case studies on providing effective trade-off evaluations in complex management and allocation situations. Key considerations included:

1. What information do we need to help analyze and make the primary trade-offs that we face?
2. What modeling or other approaches are best suited to inform and help managers make effective trade-offs? How do we ensure that some modeling approaches that are effective at making economic trade-offs also include social values that are more difficult to measure?
3. Are there "win-win" approaches that simultaneously make things better for multiple stakeholders in some common management areas?
4. How do we think long-term about building scientific tools and capacity to help make better informed trade-offs?
5. How do stakeholders and managers perceive the diverse information that scientists present to them? Can scientists more effectively present information about trade-offs in management decisions?

Session structure and attendance

The session ran over five hours one afternoon, followed by an additional hour and a half the next day, with a combination of presentations (21 oral and 5 poster) and open discussions. Presentations were grouped in the following topics: (i) scene-setting presentations on general principles and institutional perspectives; (ii) presentations of methods and tools for applied trade-off analysis; (iii) and presentations with a specific focus on spatial management.

The session was well-attended (135 attendees, 53 online, according to the Whova app on day 1; 90 attendees, 30 online on day 2). A Whova poll of attendees showed that about a third (36%: 28/77) of respondents were involved with the analysis of trade-offs, while only 29% (16/54) were involved in

providing trade-off advice, and 25% (12/48) in policy decision-making involving trade-offs. 35% (17/49) of the poll respondents had not (yet) heard of the ICES working groups (WGs) on management objectives and economic and social dimensions (WGSOCIAL, WGECON, and WGBESEO). 72% (13/18) of the attendees were members of other expert groups that also address trade-off analysis and advice.

Selected key presentation and discussion points

The following paragraphs provide a summary of selected key presentation and discussion points of the session.

The importance of trade-off decision contexts

Scene-setting presentations highlighted the importance of better characterizing the context for trade-off advice. In particular, participants highlighted the need to assess the extent to which the information provided to inform trade-off decisions is considered objective and precise (as opposed to subjective/imprecise), as well as the degree to which policy goals are considered explicit and shared. These two dimensions determine the value and potential role of trade-off evaluations in both formal (institutionalized) and informal ("back-stage") decision-making settings. With the growing scope of the policy goals included in EBM, and the fact that many of these may not be shared among actors, formal governing structures taking care of trade-off decisions will need time to adapt, and scientific analysis and advice will likely need to operate at the interface of both formal and informal trade-off settings.

A particularly important role for social science in such processes is to contribute to avoiding biases in the information-basis for trade-off decisions, by providing an understanding of the positions of the different actors involved, and their motivations. Participants discussed the question of the means by which to avoid that dominating worldviews among actors do not also dominate the advice process, particularly in informal decision-making settings. The value of explicit tradeoff analyses was also seen to lie in helping actors of the decision-making process refine their evaluations of what the tradeoffs really are, as well as helping them familiarize themselves with multiple dimensions that could be considered in assessing the impacts of their decisions.

Using models for trade-off evaluations, and the value of looking back

Many presentations illustrated the role of models in evaluating trade-offs. Among the discussion points, session participants highlighted the fact that EBM has complex effects in socio-ecological systems, and that overly simple models may produce unreliable projections, so model results should always be confronted with observations. The value of mobilizing expert knowledge from stakeholders to increase model validity was also highlighted, although some participants stressed the fact that this may also lead to biased understanding of key processes and highlighted the importance of using empirical data as much as possible, where these are available.

Presentations also highlighted the value of "looking back" with an integrated ecological-economic perspective. In addition to revealing the actual trade-offs made, this may also provide information on system responses that will be useful to current and future decisions. For example, analyses of harvesting policy choices in fisheries and their outcomes given estimated catch potentials may help better elicit the trade-offs between foregone returns from the use of marine resources and the risks associated with the selection of less stringent precautionary buffers in defining harvesting strategies.

A difficulty stressed by participants lies in the fact that future projections based on models calibrated on past observations may not be able to predict unobserved behavior. This is for example a possible limitation of statistical models explaining past spatial behavior of fishers, where certain areas that may become attractive were never included in past fishing choice sets. Given the sense that marine social-ecological systems will be moving outside known boundaries in the future, participants stressed a

need to combine such statistical models with mechanistic approaches that allow exploring unchartered futures. While such explorations can strongly benefit from stakeholder consultations, these analyses also offer an opportunity to explore what some stakeholders might consider as too extreme scenarios.

Integrating across multiple dimensions of trade-off evaluations

Another key question relates to the ways in which existing information can be incorporated in concrete advice products, when the number of management objectives, hence evaluation dimensions, is large. Aggregating across these multiple dimensions into evaluations that seem tractable is of prime relevance for operational decision support, yet this raises the question of the methods by which to achieve such aggregation and communicate its meaning to stakeholders engaged in policy decision-making.

In many cases, the multi-dimensional nature of trade-off decisions associated with EBM leads to the use of multi-criteria decision-support approaches. A central question to address in these approaches regards the weightings implicitly or explicitly associated with the aggregated presentation of evaluations across trade-off criteria. This has been a core debate in the cost-benefit analysis literature, where the aim is to assess all dimensions in a single monetary unit, raising the question of the prices used to carry this out. Participants highlighted that a lesson learned from this and other related debates is that whatever the approach, studies should endeavor to explicit what the weightings are, how they have been obtained, and how much their modification would affect aggregate evaluation results (via sensitivity analysis). In addition, analyses should aim to account for equity concerns.

In developing such analyses, participants stressed that working with stakeholders is key to help establish clearer definitions of operational objectives, and assessment of their perceived importance. This applies also to the ways in which risks are defined in trade-offs evaluations, as any notion of risk at least implicitly implies a value attached to the current and future status of a particular component of a social-ecological system. Such stakeholder engagement requires a good understanding of the existing institutional settings that structure decision-making processes, and a clear identification of the roles in which stakeholders are involved.

Dealing with uncertainties

Participants also highlighted the need to improve the understanding of uncertainties in tradeoff assessments and the ways of communicating these to stakeholders, while also demonstrating the value of these assessments to guide decision-making (avoiding the risk that uncertainty be used as a justification for inaction). The tradeoffs between developing complex models and the use of faster-to-run light-weight models enabling more rapid feedback to decision-makers was discussed, as was the growing use of ensemble modelling approaches, to identify robust evaluations of trade-offs likely to carry more weight in supporting decisions. In addition, participants highlighted the value of evaluations that, without providing precise evaluations to support decisions (e.g., in relation to compensation requirements across stakeholder groups) may still provide good indications of the expected directions of consequences associated with EBM decisions.

Data needs

Another important point discussed related to the need to improve availability and access to data relating to the social and economic dimensions of EBM tradeoffs, at scales appropriate to connect these with our understanding of ecosystem dynamics and including all the key components of marine social-ecological systems (including, e.g., energy use, or markets for marine products). This is thought be helped by the on-going digital revolution, and growing efforts to include social and economic information in platforms such as the Digital Twin of the Ocean. A particular challenge given the

diversity of methods, models and data structures required is the need to establish processes that will help establish standards in this domain, as has been done in other fields of ICES advice such as stock assessment. This includes the specific challenge of accommodating quantitative data, qualitative understanding of social-ecological systems and expert knowledge.

Conclusions

Work presented and discussed in the session demonstrated strong advances in the science of trade-off analysis, which today offers a wide range of approaches, methods and tools to help inform EBM decision-making. The challenge remains to further integrate this science into actual decision-making processes. An important step in advancing trade-off analyses in ICES would be ensuring that approaches are transdisciplinary, and that they are included in requests to ICES from decision-making organizations. Support from the ICES secretariat, and the recently established Human Dimensions steering group will certainly be key in progressing this area of ICES work.

Results of our session attendee poll also highlight the importance of better inventorying and sharing experiences on the ongoing work of ICES WGs in the area of trade-off analysis, particularly of the relatively new groups focusing on the human dimensions, across the ICES community. Such coordination should help make the best use of the available expertise in ICES, to develop the information-basis for EBM trade-off decisions.

Contents

CM 38: Dynamic marine spatial planning for conservation and fisheries benefits

Vigo M.[1], Hermoso V.[2], Navarro J.[1], Sala-Coromina J.[1,3], Company J.B.[1], Giakoumi S.[4]

Marine Protected Areas (MPAs) such as no-take reserves are usually permanent, static closures that can benefit conservation and fisheries management. However, in addition to the difficulty in managing fisheries' impacts on ecosystems, social and ecological reasons have driven interest in dynamic ocean management. A dynamic management strategy addressing temporal shifts may be able to better adapt to changing habitat patterns or species behaviours over time, but also minimise opportunity costs of conservation on local fisheries' benefits. In this study, we compare the outputs of a static management approach with four scenarios applying a dynamic management, which differ in both spatial and temporal priorities over seasons. The dynamic scenarios combined the selection of typical no-take reserves as permanent closures with temporal closures addressed as Other Effective Conservation Measures. The network of MPAs design in this study focuses on restoring the Norway lobster (*Nephrops norvegicus*), the second most important European fishing crustacean that has experienced a critical decline in recent years, as well as other important target species highly exploited, such as the European hake (*Merluccius merluccius*), that can be benefited from MPAs. To do this, we used the spatial planning tool Marxan based on the spatial distribution of the biomass of 13 species (conservation features), and the total profits (€) derived from all fisheries (multispecies trawlers) conducted in the study area (opportunity cost). Scenarios presented different trade-offs concerning the total area selected, which entailed a higher opportunity cost and a greater biomass gain. All dynamic scenarios showed better solutions in terms of minimizing the cost and achieving higher biomasses than the static scenario. The scenarios in this study can be used as different methodologies by decision makers interested in dynamic management.

Keywords: dynamic ocean management, systematic conservation planning, Marine Protected Area, Marxan, spatiotemporal, fisheries management

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CM 47: Ecosystem trade-offs assessment of a potential mesopelagic fishery in the Bay of Biscay

Raúl Prellezo[1], Xavier Corrales, Eider Andonegi, Carlos Bald, Jose A. Fernandes-Salvador, Bruno Iñarra, Xabier Irigoien, Adrian Martin, Arantza Murillas, Deniz Tasdemir.

The mesopelagic or ocean twilight zone (OTZ) in the ocean contains huge numbers of fish in a relatively pristine environment and so may attract interest as a commercial fishery. In this study we evaluate in economic terms, the likely trade-offs between the different services provided by the mesopelagic layer in the Bay of Biscay and the societal benefits of its commercial exploitation. Benefits arise mainly from the likely use of this group of species as raw material for producing fishmeal and fish oil. Costs are derived from the loss in climate regulation and cultural, services, but also from the loss in the provisioning service of other commercial species. To do so we compare the current non-exploited status with a situation in where mesopelagic fishes are harvested at levels capable of producing the Maximum Sustainable Yield.

Results suggest that if mesopelagic fishes are harvested, a mean value of 1.2 million Euro loss in a year will be created in the Bay of Biscay, although in a range between 42 million Euro loss and 48 Euro million benefits. This uncertainty comes, mainly, from the existing knowledge of the mesopelagic fishes' biomass and from the evolution of the prices and values applied to the economic monetarization. The range indicates that a better understanding of the mesopelagic ecosystem is needed, however, results also show that the support and regulation services provided by the OTZ could be more valuable than the fishmeal and fish oil yield that could be obtained from extracting fishes from this sea layer.

Keywords: Mesopelagics, economics, valuation, fishing, ecosystem services, uncertainty

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CM 58: Rock and a hard place: trade-offs in international fora

Mark Dickey-Collas[1], Marta Ballesteros

Most international organisations that engage with ICES place the ecosystem approach central to their activities and EBM is proposed as a solution to the complex management challenges facing the multi-use marine social-ecological system. EBM offers a way to reconcile diverse management challenges across transboundary/basin wide issues/ABNJ arenas. There is a clear gap, namely the capability to explore trade-offs and reconcile objectives in these international organisations. Many are constrained by their institutional design; this includes their decision-making processes, use of implicit objectives, limited scope of responsibilities and their ability to work with stakeholders. This talk will use examples to illustrate the challenges and propose recommendations for marine EBM at the scale of international organisations and/or basin wide systems.

Keywords: RMFO, RSC, transboundary, ABNJ, BBNJ

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CM 87: Evaluating trade-offs in ecosystem-based management with artificial intelligence

Jose A. Fernandes-Salvador[1], Gotzon Mandiola, Igor Granado, Izaro Goienetxea, Arantza Murillas, Ibon Galparsoro, Raul Prellezo

Decision support tools (DST) are software-based simulative and analytical tools that provide in a systematic and objective manner, support in an evidence-based decision-making process for alternative management plan development. DSTs based on Bayesian networks are presented that allows exploring management measures trade-offs under fishing and climate change scenarios. Bayesian networks have the advantage of being easier to interpret and extract knowledge from than other artificial intelligence approaches, due to their graphical representation and their probabilistic foundations in domains of high uncertainty. The DSTs can be used to inform about interactions between different ecosystem components and human activities. The approach not only allows considering environmental and biological uncertainties but also economic valuation uncertainty. Two examples of DSTs are presented. Firstly, a nonspatial DST to inform management decisions on the ecosystem services trade-offs that arise if the exploitation of mesopelagic resources begins in the Bay of Biscay. The tool is used to explore fishing scenarios of mesopelagic species in provisioning, cultural and regulating services. The high uncertainty on regulating services valuation is a key driver of changes in the total value of the ecosystem in the region. The model also allows the exploration of the trade-offs of other decisions beyond mesopelagic fishing. For example, the preservation and maximization of the value of two key food provisioning species with a long tradition in the Basque area (anchovy and tuna). Increasing the exploitation of the marine mammal's tourism value reduces the chances of lower values in the provisioning and cultural ecosystem services. However, there are trade-offs (e.g., small vs large pelagic fish) affecting the chances of the highest total and ecosystem services value. The second is a spatially explicit DST example applied to inform restoration and conservation measures under climate change and restoration scenarios in a Basque estuary. This example follows the DPSIR approach to build the conceptual model whereas the implementation is based on the combination of empirical data, literature review and expert knowledge. Both are examples of DSTs that respond to the needs for ecosystem-based management, including the ecosystem services approach and the implementation of nature-based solutions.

Keywords: Decision support systems, Bayesian networks, big data integration, ecosystem services, nature-based solutions

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CM 91: The role of social constructions in the implementation of ecosystem-based management in EU marine policies

Sašo Gorjanc

The EU has some of the widest and, arguably, best marine environmental policy portfolios on the planet, with its main policies explicitly subscribing to and invoking the ecosystem-based management (EBM) approach. Despite the robust policy framework, the overarching framework and planning directives, and very ambitious policy objectives, the competing anthropogenic uses, environmental and conservation objectives have yet not been integrated successfully and the environmental status of the EU seas is still continuing to degrade. The approach of passing existing legislation and improving the data supporting the policy decisions has not led to coherent and coordinated implementation of ecosystem-based management in the EU seas. This study aims to widen the scope and consider the significance of socio-psychological influences on the ways in which key actors across different EU governance levels perceive, interpret, and, ultimately, implement EBM policies. Despite rich literature in the fields of psychology and sociology, as well as policy and science and technology studies, there remains a lack of understanding of cognitive elements in the functioning of science-policy interfaces. This study employed Q methodology to identify different social constructions linked to implementation of EU marine conservation and environmental policies. The social constructions identified were then further discussed in a series of Living Q focus groups, with key actors from all four EU Regional Seas. The results reveal the existence of six distinct social constructions, rooted in individuals' knowledge and expertise, as well as their values, worldviews, and norms. While all participants are supportive of EBM, their interpretation of it was divergent and their interpretation of data conforms to their existing social constructions and policy priorities. Despite decades of work invested into making the implementation of EBM policies coherent, coordinated, and evidence-based, the key actors still hold divergent views, with some supporting very strong and expansive conservation actions with exclusions of people from sections of the marine environment, whereas others strongly support sustainable use of the seas. All the social constructions identified here are aligned with some EU policy objectives and founded on solid scientific data. Therefore, more attention should be accorded to the framings and social elements that define the interpretation of both data and policies. Particularly, since the various framings result in differing implementation of EBM policies.

Keywords: social constructions, EU, policies, EBM, Q methodology

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CM 108: Small-scale fishery mobilities across the West African borderlands in a changing climate

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Climate change challenges coupled human- and natural systems such as fisheries socio-ecological systems (SESs). Understanding the capacity of an SES to adapt to changing ecological or socio-economic conditions is complex and entails a clear differentiation between the system´s properties such as resilience, vulnerability and adaptive capacity. We quantified autonomous adaptation strategies of the German mixed demersal fishery in the southern North Sea SES to environmental and socio-economic change at regional and local scales over the last two decades. Deploying the modified Ostrom framework for institutional analysis and development allowed us to analyse spatio-temporal dynamics of SES attributes and their linkages. SES actors have shown autonomous adaptations to environmental and socio-economic change which entailed a shift of target species, fishing strategies, as well as a distinct decrease of the number of actors over the past two decades. We found that the ability of the SES to adapt decreased with time, with the SES being now on the brink to weather future to environmental and socio-economic change. Our results showed that the key barriers to adaptation for the fisheries SES related to fishing cultures, economic structures, a complicated political setting and pressures from other marine sectors potentially undermining fishing activities in relevant areas. Hence, an in-depth understanding of the SES components and linkages of SES attributes is a key requirement to develop future management approaches to enhance SES adaptive capacity to global change. Tailored and context specific co-management approaches are required for all decision-making processes to which the SES are exposed.

Keywords: adaptive capacity, fishing métiers, marine spatial planning, network analysis, stakeholder interviews, North Sea, tipping point

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CM 149: Identifying hotspots of adaptive capacity in a fisheries social-ecological system through Bayesian Belief Network analysis

Maren Kruse[1], Jonas Letschert[1], Kira Gee[2], Andreas Kannen[2], Jürgen Schaper[2], Roland Cormier[2], Christian Möllmann[3], Henrike Rambo[4], and Vanessa Stelzenmüller[1]

The southern North Sea is a notably busy marine area, where viable fisheries are becoming increasingly difficult to sustain. Social-ecological systems (SES) centered around these fisheries face multiple threats, including climate change, the rapid expansion of offshore renewables, and marine conservation efforts. To support these SES and foster their capacity to adapt to future challenges, there is an urgent need for tools that are both transparent and spatially explicit in describing their key components, dependencies, and spatio-temporal dynamics.

To address this need, we developed a Bayesian Belief Network that goes beyond ecological and economic considerations to also incorporate the socio-cultural subsystem of the SES describing the German plaice-related fisheries in the southern North Sea. Our goal was to identify critical marine areas for the SES's capacity to adapt to the increasing pressures and to evaluate potential management strategies to strengthen the system.

Our analysis of different future scenarios revealed that the loss of space due to the installation of wind farms or marine protected areas is the most significant factor affecting the fishery SES's spatio-temporal dynamics, outweighing the effects of climate change and economic fluctuations in the near future. With its ability to provide high-resolution maps of profitability and adaptive capacity, our Bayesian Network offers a promising tool to assist in effective marine spatial planning and to help mitigate spatial use conflicts among different sectors.

Keywords: operationalized social-ecological system, adaptive capacity, Bayesian Belief Network, plaice-related fisheries, southern North Sea, marine spatial planning, offshore renewables, fisheries management

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CM 211: Accounting for trade-offs in risk assessments: the Western Baltic Sea as case study

Helene M. Gutte[1], Susa Niiranen[2], Christian Möllmann[1], Saskia A. Otto[1]

Marine ecosystems are increasingly threatened by a multitude of anthropogenic pressures and their cumulative impacts. Ecosystem-based management (EBM) is a holistic approach that recognizes the complex nature of these interactions within the socio-ecological system. In recent years, risk assessments have emerged as valuable tool for EBM to better understand and prioritize threats marine ecosystems are facing in the future. Traditionally, risk assessments have focused on the evaluation of direct impacts of a single stressor on species or habitats as state indicators. However, in the context of ecosystem-wide assessments, indicators are often aggregated over entire guilds or trophic levels so that responses to pressures are blurred and difficult to quantify. Another major challenge in risk assessments are trophic interactions as these may influence indicator responses and create trade-offs between management objectives, which constrain achievable target levels for indicators or affect evaluations of management. Using the Western Baltic Sea as a case study, we here present a modular semiquantitative risk assessment framework and its implementation in the R package ecorisk that moves beyond the simple one indicator – one pressure assessments to the ecosystem level and can be applied in both data-rich and data-limited situations. To assess trade-offs caused by interactions we include a network analysis module based on the Bayesian Belief Network (BBN) approach. BBNs are an emerging modelling approach that aim to provide a decision-support framework for problems involving uncertainty, complexity and probabilistic reasoning. BBNs can also be used to evaluate the outcome of different management scenarios by manipulating the input variables. The Western Baltic Sea is a highly dynamic system that has been greatly affected by overfishing, pollution and climate change making it a suitable case study. Using a set of state indicators and two different climate change scenarios (RCP 4.5, RCP 8.5) combined with status quo and mitigation eutrophication and fisheries scenarios we demonstrate how this framework can be used to improve our understanding of potential ecosystem risks for EBM.

Keywords: risk assessments, Bayesian Belief Networks, management evaluations, R package *ecorisk*

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CM 224: Modelling the economic viability of a case-specific mesopelagic fishery under ecological uncertainty

Berthe M. J. Vastenhoud[1], Francois Bastardie, J. Rasmus Nielsen

Motivated by the global rise in demand for marine products, there is increased interest in exploitation of the mesopelagic zone. Despite the growing interest, the feasibility of such fishery remains uncertain. This is partly due to limited biological data and knowledge on the ecosystem sustainability of exploitation, but also to questions related to the economic viability, including fish prices and fishing costs. Consequently, there is a demand for increased insights into these factors and dynamics before commencement of a fishery to avoid unsustainable practices and negative returns for the fishing industry.

In this study we use the DISPLACE individual-vessel based bio-economic model to evaluate economic and biological trade-offs related to the potential exploitation of *Maurolicus muelleri* and *Benthosema glaciale,* the main potential target species in the mesopelagic zone of the Northeast Atlantic. With the Danish large-vessel pelagic fleet as a test case, we identify ecological and economic thresholds for switching from current fishing activities to a mesopelagic fishery and evaluate candidate management strategies. Through simulation of different scenarios, we highlight the primary ecological and economic drivers and information gaps to inform decision-making regarding the management of mesopelagic fisheries if exploitation were to take place.

Keywords: Mesopelagic zone, ecological sustainability, economic viability, economic and biological trade-offs, DISPLACE bio-economic model, individual vessel-based simulations, Danish large-vessel pelagic fleet, Northeast Atlantic Ocean, *Maurolicus muelleri*, *Benthosema glaciale*

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CM 271: Socio-political and ecological drivers of fish community catch across productive shelf regions

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Under ecosystem-based fisheries management, there is a need to inform managers about the links and trade-offs between conservation, socio-political and economic objectives. Here we present a novel assessment of the Political, Economic, Social, Technological, Environmental and Legal (PESTEL) aspects of fisheries in Alaska, northeast America and northwest Europe. We choose these three regions as all have high levels of fisheries productivity and data availability, as well as clear differences in fisheries governance and level of cooperation between countries. We show that current ecosystem management in the three regions differs in the choice of acceptable level of fishing exploitation and thus in the balance between sustainable human use and conservation. Furthermore, most parameters examined within the PESTEL framework differ among regions, with Alaska having the lowest fishing effort, ex-vessel price, community exploitation rate and discards, and the highest fish community biomass. We find that regions have equal fisheries productive capacities, that is, catch per unit of effort, stock productivity and potential catch per unit of net primary production. These results indicate that rather than biological productivity, socio-political factors are the drivers of the observed variation. These findings highlight the importance of explicitly varying the exploitation rate in forward-looking climate scenarios such as the Shared Socioeconomic Pathways.

Keywords: ecosystem productivity, demersal, fisheries catch, fishing fleet, pelagic, sustainability

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CM 277: Fishing the carbon pump: environmental cost-benefit analysis of mesopelagic fisheries

Rolf A. Groeneveld, Andries Richter, Suphi Sen

Exploitation of mesopelagic fish populations, particularly lanternfish and pearlsides, has so far been limited, largely because doing so is exceptionally expensive and requires highly advanced fishing gear and onboard preservation facilities. Throughout the last few decades, however, the commercial potential of a mesopelagic fishery has repeatedly been assessed because of the demand for fishmeal, fish oil, and nutraceuticals. Despite the economic potential, such exploitation also carries substantial environmental risks. These risks include impacts on the wider marine food web, notably large marine animals such as tuna, and the role of mesopelagic fish populations in the global climate system as they transport oceanic carbon to deeper layers through diurnal vertical migration. Earlier studies in economics have explored the economic viability of mesopelagic fisheries and its potential impact on the wider food web, but so far the potential implications on the climate have not been considered. In this article we include climate impacts in an environmental cost-benefit analysis of mesopelagic fisheries in four EU pelagic trawling fleets. We assess the economic viability of mesopelagic fishing for these fleets from a private economic perspective, focusing on the costs and revenues accruing to a single company; and from a public economic perspective, considering impacts on society at large, notably the climate. We assess the private and public costs and benefits for a small, emerging fishery, which allows us to gain quantitative insight into these issues while retaining analytical tractability. This analysis suggests that a mesopelagic fishery operated with current excess capacity in the four fleets considered is profitable from a private perspective, but its impact on vertically migrating populations and the subsequent consequences for oceanic carbon sequestration potentially outweigh the private economic benefits. These results suggest that although mesopelagic fisheries might be commercially viable, especially when excess capacity is utilised, their operation reduces economic welfare from a societal perspective. We extend the analysis to explore potential ecosystem and market impacts at larger scales.

Keywords: fisheries, economics, climate, mesopelagic, reduction fisheries

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CM 282: Big-picture modelling to help inform marine management trade-offs in the North Sea

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Resolving and quantifying trade-offs between competing marine stakeholders requires a fusion of spatial marine socio-economics and ecology. This is a long-standing vision but a difficult task because the disciplines have different supporting theories and systems of measurement. Conceptual and statistical models can only take us so far in identifying the trade-offs emerging from implementation of e.g., marine protected areas or offshore renewable energy systems, because they struggle to adequately incorporate feedbacks. However, the traditional bottom-up approach of building models from process understanding risks creating unwieldy behemoths. The present need may be for more big-picture, but still essentially process-based, models to stimulate trans-disciplinary discussion and debate. We should be able to identify the major ecological and human structural elements of the system in such models, but the detailed 'nuts and bolts' can be represented by aggregated parameterisations.

Here we present a fusion of the existing StrathE2E big-picture model of marine ecological dynamics (https://doi.org/10.1111/2041-210X.13510), with a new big-picture model of the dynamics of fishing activity and distributions. The drivers for the fishing model are management conditions (e.g. allowable fishing mortality rates) and economic variables – ex-vessel prices of catches and variable and fixed cost items depending on fishing patterns including social constraints. Outputs, which are a dynamic balance between the functioning of the ecology and the economically viability of fishing activities and distributions, include natural ecology indicators, revenue flows and profitability measures, employment, pay rates, and CO2 emissions. The combined system takes only seconds to run, enabling extensive scenario analyses. We illustrate the model with an exploration of the system-wide consequences of expanding the space occupied by marine reserves and offshore wind infrastructure in the North Sea, relative to a 2003-2013 baseline.

Keywords: Modelling, ecology, economics, social, trade-offs, MPA, offshore wind, North Sea

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CM 283: Integrating economics into fisheries science and advice: progress, needs and future opportunities

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While the science supporting fisheries management has generally been dominated by the natural sciences, there has been a growing recognition that managing fisheries essentially means managing economic systems. Indeed, over the past seven decades, economic ideas and insights have increasingly come to play a role in fisheries management and policy. As an illustration of this, the International Council for the Exploration of the Sea (ICES) has been actively seeking to expand the scope of its scientific expertise beyond natural sciences. In particular, the recently created ICES Working Group on Economics set out to review current work and key future needs relating to economic research and management advice on marine capture fisheries. This article presents the results of this review and addresses how economic research can be incorporated into the science of ICES, to provide integrated perspectives on fisheries systems that can contribute to the provision of advice in support of policy development and management decision-making for sustainable uses of living marine resources.

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Keywords: Applied fisheries economics, Interdisciplinary fisheries science, Policy advice, Management decision support

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CM 328: Reducing the environmental impact of North Sea demersal fisheries, Alaskan style

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Sustainable ecosystem-based fisheries management aims to minimize long-term negative effects on ecosystem components while providing food and seeking long-term economic and social viability of the fisheries and the coastal communities depending on them. Managements may differ in how they balance the trade-offs between those different and often competing objectives. This study examines two alternative strategies that differ in their balance between sustainable human use and conservation.

Both the North Sea and Alaska's waters are famous groundfish fishing grounds, and both support high fishing catch. However, compared with the North Sea, groundfish fisheries in Alaska are characterized by low fishing mortality on target species, low community exploitation level, low seafloor disturbance and high compliance with existing conservation and management measures. This raises the question – how would an Alaskan style management strategy shift the ecological, economic and social environment of the North Sea?

We translate Alaska's fisheries management to the North Sea fisheries using three management principles from Alaska that clearly diverge from the current North Sea management. Those three principles are 1) switching from bottom trawling to alternative fishing gears that limit seafloor disturbance, 2) using Fmsy as a limit for single stock quota as opposed to a management target and 3) establishing of a maximum ecosystem catch at a lower level than the sum of the single species quota. Using publicly available data from the EU fisheries (Annual economic report data and Fisheries Dependent Information from JRC), we investigate the resulting fishing pressure, and identify the fleets that would be the most affected by a shift to an Alaskan style management of fisheries in the North Sea.

Keywords: Trade off, ecosystem based fisheries management, bottom trawling, North Sea

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CM 355: Small-scale fishery mobilities across the West African borderlands in a changing climate

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Ecosystem based management requires the study of both species interactions as well as the study of how marine species are harvested together (metiers). Fishers are to some extent flexible in the areas in which they fish, and some boats use multiple gears. However, they may have limited control over the species that target and avoid. In the case of management interventions in such a complex system, unforeseen spill-over effects can occur. For this reason, it is both important to study fisheries connectivity and fisher behaviour (e.g., metier usage). Fishers may want to fish in certain areas because of the expected abundance of target species, but external factors (i.e., boat size, fuel cost, and weather) can limit accessibility. Here we combine two major questions (how are species and catches connected? what drives fishers metier usage?) and seek to answer them with a detailed dataset of logbook records in an arctic and sub-arctic industrial fishery in Icelandic waters. We employ a multinomial model based on machine learning methods to find what are important drivers of fishers choosing certain metiers. We find that habitat related variables (temperature, weather, primary productivity) and economic drivers (available quota, vessel length etc.) have the greatest effect. Beyond traditional bio-economic variables, we additionally included social variables that have previously been linked to fishing behaviour, such as trip length and mobility (whether fishers visit multiple ports). These findings are contributing to a fuller picture of fisher decision making and the trade-offs they face therein and can, for instance, be further used in ecological-economic modeling to project effects of management interventions.

Keywords: Multispecies fisheries, Ecosystem based fisheries management, fisher behaviour

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CM 369: Using Bayesian Belief Networks to assess the provision of services by Portuguese seaforests

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Marine and coastal ecosystems provide essential services for human well-being. Kelp forests and seagrass meadows, key elements of these ecosystems, are responsible for the provision of ecosystem services such as, and not limited to, food provisioning, water purification, and climate regulation. Due to their public goods features these ecosystems are often not considered in public policy decisions, contributing to their degradation, severely impacting the health of these environments, and compromising the provision of their services. Thus, knowledge-driven conservation and restoration efforts are key to inform the design of sustainable public policy to avoid substantial loss of ecosystems. This work uses Bayesian Belief Networks (BBN) to model the abiotic-biotic relationships between the drivers of kelp and seagrass growth, and the provision of key ecosystem services for potential reforestation sites on the Portuguese coast. By employing BBN, we tackle the underlying uncertainty between the drivers of kelp and seagrass growth and the provision of ecosystem services. We take this analysis a step further by exploiting the potential for intertemporal dependencies in the BBN framework. This work serves as a steppingstone to mapping the provision of ecosystem services by kelp and seagrass forests to then assess the net benefits associated to restoration programs.

Keywords: ecosystem services, seaforests, Bayesian Belief Networks, Bayesian inference, ecological modeling, reforestation

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CM 400: Disentangling the landscape of offshore wind energy arrays of the first Spanish Maritime Spatial Plan

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The development of offshore wind energy (OWE) arrays represents a new stage of industrialization of European seas. This research is an ocean planning based trade-off analysis of the 19 high potential offshore wind energy (OWE) arrays approved in March 2023 within the first Spanish Maritime Spatial Plan (POEM - *Plan de Ordenación del Espacio Marítimo*). The trade-off analysis is geospatially explicit and includes an indicator pool of 15 socio-ecological-economic-technological criteria of the Spanish OWE landscape using an ensemble of multi-criteria (MC) algorithms, namely i) TOPSIS (*Technique for Order of Preference by Similarity to Ideal Solution*); ii) WASPAS (*Weighted Aggregated Sum Product Assessment*); iii) Multi-MOORA (*Multi-Objective Optimization by Ration Analysis)*; and iv) VIKOR (*Multi-criteria Optimization and Compromise Solution*). The ensemble enables to prioritize which national OWE arrays should be developed by balancing socio-ecological costs (e.g., proximity to nature protection, cumulative effects, tourism) with socio-economic benefits (technical capacity, jobs, ocean multi-use potential). We complement the MC-ensemble by-passing archetypical expert-based importance weights with a Monte Carlo analysis of 5,000 runs to address the sensitivity of the criteria to multiple variations of importance weights. To further validate the MC-ensemble we compare the resulting prioritization ranking with earlier versions (e.g., 2021) of the Spanish MSP zoning of OWE. Results identify which OWE arrays should be prioritized in multi-sectorial co-existence scenarios, conservation, and by maximizing socio-ecological vs spatial-economic benefits. Among the OWE array landscape we identify optimal sites for each of the Planning Demarcations (Levantine-Balearic, North-Atlantic, Estrecho-Alboran and Canary Islands) and discuss how the study can contribute to transition-based Strategic Environmental Assessment (SEA) and to second generation of national maritime spatial plans in Spain.

Keywords: Maritime Spatial Planning, multi-criteria ensemble, marine renewable energy, socio-ecological system, co-existence scenario

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CM 423: Modelling framework to evaluate societal effects of ecosystem management

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The ecosystem effects of different management options can be predicted through models that simulate the ecosystem functioning under different management scenarios. Optimal management strategies are searched by simulating different management (and other, such as climate) scenarios and finding the management measures that produce desirable results. The desirability of results is often defined through the attainment of policy objectives such as good environmental/ecological status which, however, often do not account for societal consequences of the environmental status even though the consequences can be different for different stakeholder groups. In this work we introduce a method to evaluate management alternatives also in the light of the experiential value of stakeholder groups, using a case study in the Baltic Sea. We use an Ecopath with Ecosim model to simulate the ecosystem responses to management and climate scenarios, and the results of a stakeholder questionnaire on what aspects of the ecosystem they value or detest. The ecosystem responses and the stakeholder values are combined in a Bayesian decision support model to illustrate which management options bring the highest benefits to stakeholders, and whether different stakeholder groups benefit from different management choices. In the case study, the more moderate climate scenario and strict fisheries and nutrient loading management brought the highest benefits to all stakeholders. The method can be used to evaluate and compare the effects of different management alternatives to various stakeholder groups, if their preferences are known.

Keywords: stakeholder, Bayesian, Baltic Sea, Archipelago Sea, preferences, ECOPATH, ECOSIM

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CM 432: No one cares about tradeoffs until you show how risky they are and how much money is being left in the water; or why marine ecologists like resource economists

Jason S. Link

Ecosystem-based management is primarily about addressing tradeoffs. There are many extant tools, methods, and indicators to do so. But most of these address tradeoffs in terms of biomass, ecological, or even some social or basic economic facets of marine ecosystems. And although those are nice, even regulatory mandated, they often do not elicit a response resulting in action from stakeholders and decision makers. What we are beginning to find is that when one presents these tradeoffs in stark economic terms, the action-oriented responses are much more frequent. In particular, quantifying the amount of unnecessary risk and amount of "money left in the water" are useful measures of exploring tradeoffs. Using examples from the fisheries sector demonstrates that the costs of stock and ecosystem overfishing are not trivial, with foregone yield in the hundreds of millions of US dollars, even when using conservative estimates thereof. Additionally, compared to economic portfolio frontiers, the composite, realized results of fishery landings are riskier and less valuable than they could be. Exploring how these approaches can better elucidate, and elicit responses to, tradeoffs will better catalyze further ecosystem-based management and the benefits derived therefrom.

Keywords: tradeoffs, economic valuation, portfolio analysis, foregone yield, ecosystem overfishing, revenue loss, excessive risk

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CM 487: One too many buyback? The likely consequences of the decommissioning scheme on the Dutch fishery and fishing communities

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Since 2017, the Dutch fishery has faced a perfect storm of cumulation of many challenges. The main challenges are the ban on pulse fishing technique, the implementation of the landing obligation, BREXIT, the plan of substantial area closures for offshore windmill farms and nature conservation areas, COVID-19, the fuel price crisis due to the Russian invasion of Ukraine and lack of qualified crew members. In this context, when the Dutch government opened a decommissioning scheme at the end of 2022, there was such an overwhelming interest to apply to this scheme that a substantial part of the Dutch demersal fleet is expected to cash out and put an end to many family-owned businesses that were often active for generations. In this impact assessment study we look at the expected socio-economic effects of this decommissioning scheme on the functioning of the Dutch fishing sector at sea and on land. How will the fishers remaining active adapt and change their behaviour? What will it mean for the landing volumes of fish and the profitability and employment for the supply chain and technical services such as auctions, processing industry and markets? How will it impact fishing communities?

Using the preliminary list of vessels actually registered to take part in the scheme and historical logbook information, we first identified which fisheries those vessels were active in, which species they targeted, how much they previously fished and in which region and fishing community they were active. Then we assessed the theoretical effect of the scheme on the fishery looking at change in catch and economic performances of the fleet using a set of scenarios on the reaction of the remaining fleet (will the remaining vessels maintain their previous level of effort or increase it to take advantage of the available quota?). Finally, using a baseline measurement the socio-economic importance of fisheries in the communities and value chain of six defined fisheries regions in the Netherlands, we qualitatively assessed the consequences for the scheme for the fishing communities and the value chain. For this we use data collected by quantitative and qualitative methods like digital survey among enterprises, stakeholder consultation via group sessions and individual interviews and by using open data sources (e.g., national statistics).

Keywords: North Sea Dutch fishery, decommissioning scheme, socio-economic impact assessment

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CM 499: Ecotest: a proof of concept for evaluating tradeoffs in multispecies fisheries

Quang C. Huynh[1], Tom Carruthers, Nathan G. Taylor

There is a need for rigorous science to inform decision makers for Ecosystem Based Fisheries Management (EBFM). It is important to establish challenging and plausible scenarios for ecosystem dynamics and then test whether current and potential indicators can reflect stock status. Without the validation of indicators and the testing of relevant policy guidance to mitigate ecosystem impacts, there is a credibility gap between scientific practitioners of ecosystem science and decision makers that need to defend their actions in large multi-party negotiations. A multi-species framework that supports tactical decision making can make significant progress towards the essential goals of EBFM. We present a management strategy evaluation framework called “EcoTest”. This is an extension to openMSE software, used for single-species modeling, that simulates multi-species fisheries dynamics. A range of features are possible in EcoTest, such as the ability to evaluate current indicators as well as design new indicators and identify the conditions under which indicators operate reliably. Here we demonstrate the use of EcoTest using the Atlantic longline fishery as a case study.

Keywords: Ecosystem based fisheries management, management strategy evaluation, harvest strategy

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CM 544: Fuel use intensity doubled in Norwegian mackerel fisheries after Brexit management breakdown

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To achieve agreed climate targets, management decisions need to promote low-emission fishing practices. While fuel efficiency often goes hand in hand with other fisheries objectives, it is often not considered a management objective in itself. Consequently, management decisions can have large inadvertent impacts on emissions. In the Northeast Atlantic, the withdrawal of the United Kingdom from the EU (Brexit) has altered the management regime for mackerel, providing a natural experiment to assess the importance of management for emissions. Here, we use Vessel Monitoring Systems, logbook and sales slip data to investigate how Brexit has affected the fuel efficiency of the Norwegian mackerel fishery. We find that fuel use intensity (litres fuel per kg fish) and the number of trips per vessel doubled, while the catch per trip almost halved compared to the pre-Brexit period. We estimate that this has required an additional 21 million litres of fuel per year, to an additional fuel cost of ~15 million € yr^{-1}. This in turn causes additional annual emissions of 60 000 ton CO_2 yr^{-1}, corresponding to one million passenger trips by flight between Norway's two largest cities Oslo and Bergen. Since Norwegian mackerel catches increased after Brexit, the total emissions from the Norwegian mackerel fishery almost tripled. Our findings demonstrate that the management regime for transboundary stocks can have enormous impacts on national fisheries' efficiency and CO_2 emissions, underlining the importance of including low fuel use intensity as an explicit fisheries management objective.

Keywords: fisheries emissions, SDG 13, fuel use intensity, management objectives, CO2 emissions

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CM 586: Integrated assessment of the small-scale fisheries in the Azores Archipelago

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Small-scale fisheries play a vital role worldwide, contributing to income generation, food security, and poverty alleviation. However, in recent decades, world fish production has been stagnant; about 35% of world fish stocks are overexploited, and many are data-deficient, with poor knowledge of status. The majority of initiatives aimed at ensuring the sustainability of fisheries concentrate on assessing ecological indicators and finishing traditional single-species assessments, which are not suited for multispecies and multigear Small-scale fisheries. While the Ecosystem Approach to Fisheries has consolidated as the best practice target in fisheries assessment and management – with different approaches developed over the past couple of decades – its implementation has been challenging globally. A comprehensive assessment is essential for a thorough evaluation of the sustainability of the fishing systems because fisheries are complex systems. This study employs a multidisciplinary approach to the sustainability status of the Small-scale fisheries in the Azores Archipelago, Portugal, and was performed using a modified Rapfish method to assess ecological, economic, and social indicators of the fishery. A constrained multidimensional scaling ordination methodology is used in the procedure, and Monte Carlo simulation is used to express uncertainty. data gathering on the ecological, economic, and social aspects of artisanal fishing in the Azores through questionnaires, emails, and phone calls with various specialists and stakeholders in the fishing sector. The preliminary findings indicate that while there is room for development, the ecological, social, and economic indices are satisfactory. Despite the fact that target species have long life cycles and moderate to high vulnerability, the majority of exploited stocks are stable or recovering and are exploited at levels below the msy. Even if the fishery is small-scale, the availability of several government rewards to the fishers may indicate the socioeconomic and cultural significance of the fishery. The majority of exploited populations are stable or recovering and are exploited at levels below the msy, despite the fact that target species have long life cycles and moderate to high degrees of vulnerability. Even if the fishery is small-scale, the fact that the fishers can get a variety of government prizes may be a sign of the financial and cultural importance of the fishery. Fishermen can take advantage of a lot of government benefits. The fishery's good condition of this component may symbolise its economic and cultural worth even when it operates on a small scale.

Keywords: Azores, small-scale fisheries, multidisciplinary approach, rapfish

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CM 600: Including the human dimension can improve scientific advice from stock assessments

Andrea N. Chan[1], Katell Hamon, Patrick Lynch, Jonathan White

Managing fish stocks to meet conservation and (ecological, economic, and social) sustainability goals requires managers to balance often competing social, environmental, and economic objectives. Fisheries operate in social-ecological systems, and as such, fish population interactions with social systems must be characterized if the system is to be successfully managed. There is a need for better integration between social science and population dynamics research programs in support of fisheries stock assessments – which will require more interdisciplinary collaboration and stakeholder engagement. While management decisions on total allowable catch, fishing areas, and seasons are often noted as needing to evaluate trade-offs, the individual decisions made by survey scientists, data processors, and stock assessment model developers during the advice process can also include trade-offs. For example, what data streams should be included in the stock assessment? How should fishery-dependent data be standardized? NOAA Fisheries published a report with recommendations for including more socioeconomic information in the fishery stock assessment process, which includes data collection, data processing, stock assessment models (e.g., specifying catchability and selectivity), projections of abundance and catch, application of harvest control rules, and the delivery of scientific advice. In this presentation, we use the U.S. case study as a starting point for identifying ways that ICES can build capacity over the long-term for better informing these trade-offs by further integrating data and expertise from the human dimension. Notably, there are existing scientific and collaboration tools that could be applied across diverse fisheries and management scenarios. Local and traditional ecological knowledge can provide information on fishing practices and mortality. Working groups of biologists, economists, social scientists, fishers, and other stakeholders can build conceptual models of multispecies-multifisheries-ecosystem interactions and inform the choice of harvest control rules. By prioritizing interdisciplinary collaboration and integrated analyses in support of assessments, the ICES community can provide more holistic evidence to advise on trade-offs among competing uses of marine resources.

Keywords: fish, fisheries, stock assessment, social science, economics, human dimensions, ecosystem based fisheries management, scientific advice

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CM 602: Managing trade-offs between yields, quota consumption and resilience in the Bay of Biscay

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The adoption of ecosystem-based management as a goal in world fisheries went through the recognition of the complexity of the exploited systems —both with regard to exploited species and to the exploitation component— and by the recognition that management goals to be reached are diverse and sometimes contradictory. Fisheries in which several fleets harvest several species are called 'mixed fisheries'. In such fisheries, technical interactions due to the use of unselective gears imply that achieving a management goal for a species—*e.g.* reaching this species' Maximum Sustainable Yield— affects the other ones. If a landing obligation is implemented, this situation can lead to economically missing the mark if fishing must stop when the quota of a 'choke species' is exhausted. In other cases, it could lead to overharvest less productive or resilient species. The Bay of Biscay demersal fishery is a motivating case study to explore these trade-offs as several high-valued species including sole (*Solea solea*), hake (*Merluccius merluccius*) and Norway lobster (*Nephrops norvegicus*) share the same habitat and are exploited in diverse proportion by fleets practicing different *metiers.*

Here, we develop a time and space explicit ISIS-Fish model of the Bay of Biscay in which these three species are harvested by nearly 40 different fleets. With this tool, we project this fishery with and without landing obligation and compute the associated long-term equilibria. We then bring to light for each species a number of trade-offs between objectives of different nature. Such trade-offs are e.g., between high yields from a single species vs. overall quota consumption for the community (either in deficit or in excess), short term vs. equilibrium yields and survival, or yields vs. resilience of the populations. The latter, of critical importance for EBM although rarely assessed in the fishery management literature, is measured as a return time to equilibrium and obtained by numerically estimating the eigenvalues of the modelled system. We finally we see how spatial, seasonal and *metier* regulations can alter these trade-offs and lead to win-win situations, allowing a better achievement of the socio-economic and ecological objectives of the fishery.

Keywords: mixed fisheries, trade-offs, technical interactions, fleet dynamics, resilience, Bay of Biscay

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CM 631: Ecological, economic, and policy drivers of the benefits, costs, and trade-offs of spatial management

Daniel A. Ovando

There is a growing movement to expand the use of spatial management measures such as Marine Protected Areas (MPAs) in both coastal and pelagic ecosystems, notably of late in the form of the recently signed United Nations High Seas Treaty which lays the groundwork for the creation of networks of MPAs in international waters. Properly designed MPAs can be effective tools for conservation and fisheries management. However, designing effective spatial management strategies can be challenging because marine ecosystems are highly dynamic and opaque, and extractive entities such as fishing fleets can respond in complex ways to changes in the state of ecosystems, economic incentives, and policies. This complexity can lead to tools such as MPAs producing challenging trade-offs among multiple objectives; while MPAs can produce win-wins by helping rebuild overfished populations, an MPA network can also produce conservation gains at the expense of economic benefits, or even induce trade-offs in the conservation status of different fished species if closures displace rather than remove fishing effort. We use a spatially-explicit multi-species and multi-fleet operating model, marlin, to explore the key drivers of ecological and socio-economic benefits, costs, and trade-offs of MPAs. We first present a case study of a pelagic tuna fishery in which we show how alternative MPA design strategies affect the biomass of pelagic species and the economics of fishing fleets under climate-driven range shifts. We then present a more general simulation analysis demonstrating how different ecological, economic, and policy variables interact to affect the outcomes of MPAs. Our work demonstrates how intermediate complexity simulation of coupled bio-economic dynamics can help communities predict and potentially manage trade-offs between conservation, fisheries yields, and distributional outcomes of spatial management policies in marine ecosystems.

Keywords: marine protected areas, trade-offs, bio-economic modeling, high seas, spatial-temporal modeling

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