

Theme session J

Joining forces for the better
assessment of highly migratory
and other wide-ranging species



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Theme session Report

Theme Session J - Joining forces for the better assessment of highly migratory and other wide-ranging species

Conveners: Estibaliz Díaz (Spain), Patrick Lehodey (France), Patrícia Gonçalves (Portugal)

In addition to the general challenges faced in the assessment of fish stocks, highly migratory and other widely distributed species face common problems. These species pass through different habitats throughout their life cycle; each of which are subject to changing environmental conditions and may face different threats. Thus, classical approach of the current assessment models may need to be adapted for some of these species.

Researchers working on these different groups of species (i.e., tunas, smaller pelagic species and diadromous species) are progressing and developing research strategies to address the challenges they face in assessing these species. However, researchers working on different groups of species have little interaction with each other, so they do not know how each of them solves these problems, nor what solutions they are working on.

During the last few years, different approaches have emerged to improve the assessment of some of these species, e.g., spatialized stock assessment models that consider the spatial heterogeneity in the stock and the fishery fleets and other anthropogenic mortality distribution. This has become even more relevant under the climate change we are facing on, which may affect very differently across the distribution of the species. However, these models require information that is not available for all the species, so alternative approaches are needed in some of those cases.

The main idea behind this session was to bring together researchers who have made progress in solving the specific problems of highly migratory and or widely distributed species. Learning from the experience of each other can provide us with strategies and knowledge we might not otherwise have and will increase our effectiveness by eliminating redundant work.

Content

Four major research topics can be proposed to summarise the presented studies: One devoted to a better understanding of stock structure; a second for the relationships between environmental factors and the life history of fish; a third in the new developments of fish population dynamics models and a last one on the impact of climate change.

Stock structure of widely distributed species

One of the greatest challenges in assessing stocks of widely distributed species is knowing and defining appropriate spatial structure. During Session J, examples of the application of several approaches applied to the study of stock structure have been presented. In the case of Greenland halibut, an approach combining the results from several methods including mark-recapture, genetic markers on adults and juveniles, chemical fingerprint on otoliths and multivariate autoregressive state-space models (MARSS) gave new findings in relation to the currently assumed stock structure for assessment purposes. These findings have potential impacts on stock assessment, exploitation advice and fisheries management, since the biological population and management unit boundaries do not seem to match. This further indicates the need to properly account for the population structure, current management and management procedures would need to be revised. Studies of eel migration patterns and

connectivity between its different rearing areas and spawning areas have progressed. A study tracing the migration of eels from the Azores rivers to the Sargasso Sea provides direct evidence of the arrival of adult European eels at the presumed breeding ground. Another study demonstrated connectivity at three habitat levels for European shad (*Alosa alosa* and *A. fallax*) by tracking natal origin using otolith fingerprints and studying at-sea population mixing using monitoring of natal origin based on otoliths. The interest of using citizen science data has been shown with the case of Atlantic bluefin tuna and the description of a major change in the seasonal range, habitat use and migration of this species, which recovered a former part of its feeding range in the northeast Atlantic after 5-6 decades of rarity.

The use of genetic and isotopes (otolith) studies are increasingly used to characterise population structures. Examples using these techniques have been presented for all the different groups of widely distributed species. Tagging studies continue to be a standard approach. Together with the use of standard plastic tag, electronic tagging is also becoming a shared approach between the different communities of researchers, especially for large pelagic species such as tunas and recently on eels with a successful study revealing their oceanic migrations. Technological progress in the miniaturization of these electronic tags and massive production to reduce their cost are still necessary to hope to see this technology used in routine studies on smaller pelagic species. Overall, the joint use of these new technologies, to which the use of environmental DNA could be added, should be an asset for pooling needs and making it possible to produce them at lower cost. It would therefore be desirable to encourage exchanges and collaborations in this area between the different research communities, both for the collect of data and the sharing of their results (i.e., open databases).

Oceanography and life history of fish

The highly migratory and widely distributed species show interannual variability in abundance due to the impact of oceanographic and environmental patterns, which can affect recruitment and mortality processes and spatial distributions through changes in migratory routes between feeding and spawning areas. Several studies were presented seeking to predict these effects and model them to provide new tools complementary to those currently used in the assessment of species stocks.

Studies using Individual Based Model (IBMs) are useful to investigate the connectivity between spawning and nursery areas, to simulate the drift of eggs and larvae, temperature dependent growth and mortality, and behaviour affecting position in the water column; those phenomena being not included in assessment models. This approach was applied to sea bass and mackerel, revealing the potential for further development on those approaches and their use as to compliment stock assessments. An IBM applied to sea bass simulated the migratory behaviour of adults based on water temperature, swimming speed, food availability and orientation. In this way, the main migration routes for returning adults and spatial distribution, from the time they leave their feeding grounds to their return to coastal areas near their native rivers was defined. Based on statistical relationships, a model of the blue whiting movement during the annual feeding and spawning migrations was presented, that accounts for the influence (strong versus weak) of the subpolar gyre on the migration pattern of the stock and highlights the potential consequences that this have on the species distribution with potential consequences on the fishery and on the stock assessment. Using satellite and electronic tagging data, a three-dimensional habitat model of Atlantic bluefin allowed to characterise the spatial and temporal distribution and the migration phenology of the species across Atlantic ecoregions. An original approach applied to blue whiting implemented fish movement with a particle tracking model using environmental variables (currents, food and temperature) and their gradients. The simulations allowed realistic properties to emerge. The method is suitable for all types of grids and offers flexibility in terms of adjusting the gradient scale.

Stock assessment Models

There are ongoing developments to integrate spatial structure and to account for environmental variability in stock assessment models. A multi-species model approach applied to small pelagics (Atlantic herring, Atlantic mackerel, European sprat and sandeels) is proposed to predict fish migration patterns using a Bayesian spatial modelling. Multiple datasets (e.g., ICES length-at-age and NEODAAS satellite frontal data) are used to investigate the spatial and temporal variability. For the Atlantic Salmon, another model employs a Bayesian hierarchical approach to analyse data from the past five decades, encompassing 25 stock units. It provides a comprehensive representation of spatial and temporal heterogeneity in the mechanisms governing population dynamics. The unified model serves as a benchmark for the ICES, allowing the joint analysis of all stock units and facilitating an understanding of the factors influencing populations in response to changes in marine ecosystems. Furthermore, it offers catch options for marine fisheries operating with a mixture of stocks. GEREM is a model also using a Bayesian approach to estimate eel recruitment over time and at different scales (river, Eel management Unit, and sea regions), accounting for spatial heterogeneity using data from multiple spatially scattered time series. The model EDA estimates the density of eels by extrapolating their abundance along with other biological characteristics (such as size structure, density, and silvering process) from a known river segment to others where data is unavailable. This extrapolation takes into consideration the relevant parameters that influence these characteristics.

Impacts of climate change on migratory fishes

Highly migratory and widely distributed species are and will be impacted by environmental changes in key ocean variables due to climate change. The progress highlighted above in a diversity of modelling approach to integrate spatial processes and environmental drivers of population dynamics should help in the coming years to better understand and also project the impact of climate change on these species. The model HyDiaD is a species distribution model allowing to explore Climate Change Impact on Diadromous Species. It is an hybrid approach between correlative and mechanistic species distribution models in terms of both model complexity (i.e. number of parameters) and data requirements. HyDiaD includes two components: i) the correlation of species observations with abiotic environmental conditions, and ii) biological processes relevant for the distribution of the species, such as population demography, predator-prey interactions, and dispersal dynamic. Once fully validated, the other modelling approaches listed above should also be available to explore future climate change impacts using essential ocean variables simulated by Earth System models.

Conclusions

The studies of stock structure on highly migratory and widely distributed species are complex and highlight the need for adapted assessment methods taking into account the particular dynamics of these species. It seems necessary to rely on the combination of multiple approaches: studies of biological parameters (growth and reproduction), conventional and electronic tagging, genetic analyses, otolith chemistry and modeling. With current and expected future changes linked to climate change, it becomes necessary and urgent to develop new modeling approaches that take these changes into account. The studies presented in Session J represent useful tools to increase the knowledge required to model the dynamics of stock structure and predict abundance variability of highly migratory and widely distributed species. They can be used as a complement in the species stock assessment.

The modeling studies presented during session J illustrate a great diversity of approaches. However, as for the methods of observation and the studies of population structures, many common points exist

whether it concerns the representation of spatial dynamics, key processes of population dynamics or relationships to the main environmental factors (e.g., temperature, productivity and prey distributions) that control these dynamics. Species models based on habitat and environmental variables often lack a quantitative basis while stock estimation models have taken quantitative methods very far but lack explanatory mechanisms combining population dynamics and (changing) environment. We should therefore be able to quickly synthesize and merge these different approaches. To be effective, exchanges and collaborations between the different communities of researchers who participated in this session should be encouraged.

Our main conclusions are:

Challenges and Common Themes:

The introductory presentations highlighted the need for assessment methods tailored to migratory species, given their dynamic and widespread nature. The challenges inherent in assessing these species include their transitions through different habitats, their exposure to diverse environmental conditions, and the impact of various threats.

Emerging Approaches:

Highlighting recent advances, the session showcased spatialized stock assessment models designed to account for spatial heterogeneity of the stock and fisheries. These models, particularly relevant in the face of climate change, offer an opportunity to enhance assessment accuracy. However, it was acknowledged that such models often rely on information not universally available for all species, necessitating the exploration of additional approaches.

Collaborative Learning and Knowledge Exchange:

The core objective of the session was to facilitate dialogue among researchers who have made strides in addressing the specific challenges of migratory species. By sharing experiences and strategies, the collective knowledge base could be enriched, eliminating redundancy and enhancing overall effectiveness.

Future Directions and Collaboration:

As the session concluded, a call to action resonated — the need for continued collaboration and information exchange among researchers focusing on migratory fish assessment. The challenges faced by these species necessitate ongoing innovation, and the collective expertise within the scientific community can drive progress. The session laid the foundation for future collaborations and highlighted the importance of a joint effort to advance our understanding and assessment of highly migratory and widely distributed species.

In summary, the session served as a forum for researchers to collectively confront the challenges specific to migratory fish assessment. The exchange of ideas and experiences showcased the potential for collaboration in developing tailored approaches. Moving forward, the scientific community is poised to build on these discussions, fostering a collaborative spirit that will contribute to more effective and informed management of these vital species.

CM 42: HyDiaD model: a tool to explore the effect of climate change on diadromous species assemblage in Western Europe

Patrick Lambert¹, Géraldine Lassalle, Anaïs Janc, Eric Quinton

Diadromous fishes and lampreys are migratory species that share their life cycle between marine and freshwater environments. For some species, climate change is a new threat that may weaken populations already in an alarming situation. For some other species, climate change may provide an opportunity to settle in new catchments.

During the European-funded DiadES project (Interreg Atlantic Area), we developed a hybrid species distribution model named HyDiaD 1.2 for Hybrid model for Diadromous species Distribution. This approach, halfway between correlative and mechanistic modelling, integrates two components: i) the correlation of species observations with physical and climatic predictors at the catchment scale, ii) the simulation of biotic processes relevant to the distribution of the species, such as population demography and dispersal dynamics. This single modelling framework was applied to eleven diadromous species on the European Atlantic coast.

The correlative component provides information on shifts in habitat suitability related to climate scenarios. It was calibrated with boosted regression trees applied to the presence/absence data from 290 European catchments for the 1850-1950 period (EuroDiad 4.0 database). The model was used to simulate population trends in a subset of catchment representative of the Atlantic Area for two time horizons (2050 and 2100) according to two climatic scenarios (RCP4.5 and RCP8.5).

Population dynamics are based on a hockey-stick stock-recruitment relationship with a depensatory effect and the maximum production of recruitment limited by catchment suitability. No direct anthropogenic impacts (habitat degradation, mortality) were included. The dispersal dynamics integrated only accessibility between catchments (kernel function of inter-catchment distance). The calibration of such biotic processes is still challenging, especially for data-poor species. To overcome this difficulty, the parameters set were calibrated based on the elicitation of expert knowledge.

The current outputs of the single-species models were summarised into: (i) maps of species turnover in the catchments and (ii) ranking of species sensitivity (cumulated changes of abundance in catchments). This result interpretation at the species assemblage level (all species pooled/considered together) allowed the definition of species or catchments to prioritize. The relative reliability of the HyDiaD applications between species was discussed, according to modellers' confidence in the abiotic and biotic components and other modelling choices. New developments for HyDiaD were proposed in response.

Keywords: habitat suitability, biological processes, species distribution model, climate-induced shift, multi-species analysis, diadromous species

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CM 81: Using multivariate autoregressive state-space models to examine the stock structure of Greenland halibut in the North Atlantic

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Exploited marine resources can be managed more effectively when accurate information on population structure is available. Greenland halibut in the North Atlantic is managed as four separate offshore stocks. We use Multivariate Autoregressive State-Space (MARSS) models to assess population structure by means of abundance and biomass trends for three of these stocks: (1) Baffin Bay - Davis Strait (Northwest Atlantic Stock), (2) East Greenland, Iceland and Faroes waters (West Nordic Stock) and (3) the Barents and Norwegian Seas (Northeast Arctic Stock). Bottom trawl survey data from each region for 1996-2019 were used to evaluate data support for different population structures. Model alternatives included different levels of parameter complexity and covariates to investigate the impact of climate and fishing on the stocks. All models identified the Northwest Atlantic as an independent population. However, questions were raised about the current management structure in the Northeast Atlantic. The best-fit models treated Greenland halibut in the West Nordic Stock as two independent populations (east and west), with potential connections between eastern Iceland and the Northeast Arctic Stock. These results suggest a mismatch between current stock perception and management boundaries, suggesting that further work is required to delineate stocks and understand potential impacts of management decisions.

Keywords: Population structure, *Reinhardtius hippoglossoides*, multivariate autoregressive state space models, north atlantic ocean, sustainable fisheries management, NAO index

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CM 90: Northeast Atlantic Mackerel; an Individual Based Model to aid spatial management

Joseph W. Watson¹, Nicola D. Walker¹, Rebecca E. Holt², Jennifer A. Graham^{1,3}, Lianne Harrison¹, Kieran Hyder^{1,3}, Richard D. M. Nash¹

Mackerel (*Scomber scombrus*) are highly migratory and those that make up the Northeast Atlantic Mackerel stock (NEAM) are widely distributed from the Iberian Peninsula to the northern Norwegian Sea, and from Greenland to the western Baltic Sea. The variability in inter-annual distribution of the stock has been documented but the drivers of the variability are still uncertain. The variability is of significance to the ecology and productivity of the stock and thus the assessment. Recent shifts in distribution have been linked with climate change but it is still uncertain as to what further changes in distribution may occur in the short and medium time frame. Understanding changes in distribution and productivity are of value in moving toward spatially explicit stock assessment and management of this stock. NEAM are exploited throughout the year over this extensive range and remain one of the most valuable fin fisheries in the Northeast Atlantic. Testament to its economic importance the NEAM stock is covered by surveys throughout many parts of the year, however the full spatial dynamics of NEAM outside these periods is still uncertain. Here we present the current and ongoing plans for a spatially explicit Individual Based Model (IBM) that incorporates information from the mackerel literature, relevant survey and biological/physical datasets to fill in some of the spatial distribution gaps for this stock. The current model covers the Northeast Atlantic and Nordic Seas and contains a full linked life cycle from eggs through to mature spawning mackerel. The model uses an energy budget model driven by sea surface temperature and chlorophyll-a concentration remote sensing data to produce emergent stock dynamic outputs, including spawning stock biomass and weight at age. Crucially the IBM has a fully emergent feeding, and partially constrained emergent spawning sub model that can be used to explore distribution dynamics. Ongoing work will relax the remaining spatial constraints and add connectivity matrices from a particle tracking model to model pelagic drift from spawning grounds to mackerel nursery areas. Further development includes using tagging data to inform the timing and speed of movement between spawning and feeding areas. The intention is to use this model to inform and advise management on Northeast Atlantic mackerel distribution beyond current spatial and temporal survey boundaries.

Keywords: Northeast Atlantic Mackerel, Individual Based Models, spatial-distribution, fisheries advice

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CM 96: Using spatially explicit individual-based models to support management of the European sea bass

Kieran Hyder^{1,2}, Joseph W Watson¹, Nicola D Walker¹, Jennifer A Graham^{1,2}

The European sea bass (*Dicentrarchus labrax*) is a high value fish that is exploited by both commercial and recreational fisheries. Scientific assessments of the northern stock have shown a rapid decline in the spawning stock biomass attributed to poor recruitment and high fishing mortality, and significant reductions in the harvest of sea bass have been implemented to conserve stocks. Individual-based models (IBMs) are simulations of individual 'agents' of organisms that interact with each other and their environment locally and have been shown to be effective management tools in many systems. Here, we present two examples of the application of IBMs to sea bass: a pelagic phase model to assess interannual variation in settlement; and spatiotemporally explicit model to evaluate management strategies. The pelagic phase IBM is used to assess connectivity between spawning and nursery areas. It includes hydrodynamics to simulate the drift of eggs and larvae, temperature dependent growth and mortality, and behaviour affecting position in the water column. The second IBM includes all life stages and individual fish have their own realistic energy budgets driven by observed dynamic maps of phytoplankton density and sea surface temperature. The outputs from these models are discussed in the context of seabass conservation and sustainable management of sea bass fisheries.

Keywords: European sea bass, Individual Based Models, fisheries advice

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CM 103: The importance of assessing the alternate life strategies of the European eel

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Catadromous fishes are migratory species that complete most of their feeding and growth in freshwater ecosystems but spawn in marine waters. In catadromous species, large within-species variation can be found in migration timing, life-history strategies, and the prevalence of habitat switching. Anguillid eels spend most of their life cycle growing in brackish-water or freshwater habitats before returning to the open ocean for spawning. However, some individuals skip the freshwater phase and remain in the sea, growing in marine coastal habitats. Other individuals shift between habitats. The contribution of these marine-resident eels to the spawning stock is unknown, both in terms of quantity (i.e., proportion out of the total stock) and quality (e.g., lipid stores, parasite prevalence), nor is it assessed: The current management framework is mainly based on the freshwater part of the population, and some of the alternative behaviors, such as eels residing in marine water, are not currently accounted for in population assessments. Measuring recruitment and/or spawner escapement in coastal habitats is more challenging than in physically constrained freshwater systems.

We present a suite of methods that are available to study facultative catadromy in eels (or other species), and how these were used in a large-scale study on *Anguilla anguilla* in Norway, where marine residency of eels is more prevalent than in the southern part of the species distribution. The migratory history of 470 individuals sampled in fresh-, brackish and salt- water locations were elucidated using otolith microchemistry. On average, 20% of the sampled eel were 'habitat shifters'. Eels residing in saltwater habitats grew twice as fast. Fatty acid and stable isotope analyses indicated that eels caught in marine and fresh- water had higher lipid contents compared to those captured in brackish water, and that marine eels fed at a higher trophic level compared to freshwater eels. Analyses of the parasite fauna indicated that marine resident eels had entered freshwater (or had eaten freshwater prey) during their lifetime. Blood markers obtained by non-lethal sampling were successful in their ability to predict migratory strategy. Collecting blood and determining salinity-habitat history during coastal monitoring surveys would provide the necessary information to quantify the proportion of marine resident eels versus transient eels coming from freshwater. It is currently unknown whether trends in the abundance of eels living in marine waters mirror the declines observed in freshwater. Resolving this issue will be important for future monitoring and management of this species.

Keywords: Anguillid, facultative catadromy, liquid biopsy, *anguilla anguilla*, marine eels

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CM 114: How we finally tracked European eels all the way to the Sargasso Sea

Rosalind M. Wright, Adam T. Piper, Kim Aarestrup, Jose M. N. Azevedo, George Cowan, Andy Don, Matthew Gollock, Sara Rodriguez Ramallo, Randolph Velterop¹, Alan Walker, Håkan Westerberg, David Righton

Where do European eels (*Anguilla anguilla*) come from? A simple question, yet one that has led the European eel to have one of the richest scientific histories of any species. Where European eels start and end their lives is a mystery that has perplexed generations from Aristotle to Freud. The journey to their breeding place in the Sargasso Sea near Bermuda, has long been considered one of the most impressive feats of animal migration observed in nature.

The European eel is critically endangered (according to the most recent IUCN assessment) and has suffered a 95% decline in recruitment since the 1980s, attributed in part to factors occurring during the marine phases of its life-cycle. As an adult, the European eel undertakes the longest spawning migration of all anguillid eels, a distance of 5000 to 10,000 km across the Atlantic Ocean to the Sargasso Sea. However, despite the passage of almost 100 years since Johannes Schmidt proposed the Sargasso Sea as the breeding place of European eels on the basis of larval surveys, no eggs or spawning adults have ever been sampled there to confirm this. Fundamental questions therefore remain about the oceanic migration of adult eels, including navigation mechanisms, the routes taken, timings of arrival, swimming speed and spawning locations. We attached satellite tags to 26 eels from rivers in the Azores archipelago and tracked them for periods between 40 and 366 days and provide the first direct evidence of adult European eels reaching their presumed breeding place in the Sargasso Sea.

Keywords: European eel, migration, Sargasso Sea, pop-up satellite tags

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CM 118: Unveiling spatial structures in *Maurolicus muelleri* distribution in the Northeast Atlantic

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Recent years have highlighted the need to improve our knowledge on the mesopelagic environment. The potential of the mesopelagic resource has attracted a lot of attention and research was directed towards creating a sustainable management. Among the steps required to achieve such a goal is the study of the fish biomass and understanding the drivers of its distribution. The work presented here uses geostatistical analyses to improve our knowledge on the wide-ranging species *Maurolicus muelleri* in western Ireland. This species is quite common in the upper mesopelagic and its relatively important biomass has led to a growing interest in its potential harvest. While the presence of the species has been documented in the study area, very little is known about its spatio-temporal dynamic and its environmental drivers. Therefore, this work aims to characterize, if they exist, the main structures in *M. muelleri* distribution and their potential drivers. The first part of the work has been to create a time series of yearly distributions. We used multi-frequency acoustics discrimination algorithms to reprocess data from a pre-existing annual survey (the International Blue Whiting Spawning Stock survey) which led to a dataset describing the distribution of *M. muelleri* over 16 years in the North East Atlantic. The choice was made to only keep data collected during daytime, excluding the periods where diel migrations to the surface happened. Then, we used geostatistics and more specifically Minimum-Maximum Autocorrelation Factors (MAFs), to unveil recurring spatial patterns. Preliminary results indicate that main patterns highlight the importance of shallower areas in the distribution of *M. muelleri*, leaving regions with deeper waters without particular structure in the time series. The presence of eddies in the latter regions might be a factor explaining the lack of pattern, as sea surface height (a proxy to measure the presence of eddies) was found to be structured at the same spatial scale as the mesopelagic fish biomass. This work will shed more light on the different processes that can shape the distribution of the biomass, potentially highlighting local or regional effects that we should consider if we want to integrate spatial heterogeneity in the biomass estimation of wide-ranging species.

Keywords: mesopelagic fish, acoustic surveys, geostatistical analysis, timeseries

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CM 135: Evaluating stress and mortality during trap and transport in the European eel

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The construction of dams and hydropower plants in rivers has blocked migratory routes for numerous species of fish. Artificial transport around migration barriers, so called trap-and-transport, is used as a management tool to mitigate fish population declines. There is however a lack of studies evaluating the efficiency of trap-and-transport, in particular for downstream transport of catadromous species such as the European eel, *Anguilla anguilla*. The transported animals may experience stress from handling and transport, and if mortality occurs, this has obvious direct negative effects that need to be considered for this management measure. For critically endangered species, such as the European eel, it is essential to ensure that conservation efforts work as intended. In this study we used data from trap-and-transport protocols from several years to evaluate mortality rates of the European eel in the trap-and-transport process. We found that the average mortality rate was generally low but could be as high as 10% in fish corves prior to transportation. To achieve more detailed data, heart rate was measured using biologgers throughout the different steps of trap and transport, investigating the effects of water temperature/season and fish corf density. The European eel is generally regarded as a tolerant species, and as such mortality during trap-and-transport should be very low or absent, which was not always the case. Reducing the time that eels are kept in fish corves prior to transportation and recuing the transportation time could decrease mortality, especially at high water temperatures. We conclude that although trap-and-transport, fishways, and other alternatives aiming at reducing negative impacts of dams on diadromous fish can reduce mortality, all those measures require maintenance and human interference, wherefore removal of migration barriers should be the long-term management goal.

Keywords: management, conservation, trap-and-haul, migration barrier, assisted migration, diadromous

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CM 157: Identification of the migratory tactics of stocked European sturgeon (*Acipenser sturio*) using chemistry of hard structures and organs

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The European sturgeon (*Acipenser sturio*) is a critically endangered species and conservation programs are ongoing in Western Europe. The Gironde-Garonne-Dordogne watershed is the cradle of the last natural reproduction of the species in 1994. A reintroduction program has been implemented to restore this population with more than 1.7 million captive-bred juveniles released into the Garonne and Dordogne rivers between 2007 and 2015. Knowledge on the movement and habitat use patterns across all life phases is critical to ensure protection of the reintroduced individuals. However, data on the exchanges of juveniles between the estuarine and marine areas and the subsequent marine life phase are scarce. An indirect approach using chemical tracers in hard body structures was selected to reconstruct the migratory trajectories of the European sturgeon between the Gironde estuary and the sea. The incidental capture of 7 immature individuals by fishermen at various locations along the French coast provided specimens from which different structures and organs could be extracted. Changes in ambient salinity across environments encountered by sturgeons throughout their lifetime were investigated through the analysis of chronological patterns in Sr:Ca and Ba:Ca ratios of pectoral fin rays and dorsal scutes. In addition, patterns of stable isotopes recorded in metabolically stable eye lenses were analysed to identify a potential shift in resources used coinciding with a shift from estuarine to coastal environments. The analysis of the stable isotope ratios in muscle, liver and fins as well as stomach contents provide some additional information about habitat use and diet at sea. This study allows testing the relevance of multiple environmental tracers collected from diverse tissues for assessing migratory patterns, with the objectives of applying them on non-lethal sampling in the future. It provides insights into the life at sea and the importance of the connectivity between the estuary and the sea for the species, as well as the existence of one or several migratory tactics within the stocked population.

Keywords: sturgeon, habitat use, fin ray, eye lens, trace elements, stable isotopes

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CM 186: Adding fleet structure to assessments of highly migratory species can improve selectivity estimates: an example for eastern Atlantic Bluefin Tuna

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Highly migratory species present challenges for conventional stock assessment modeling because they are targeted by a diversity of fishing fleets. For example, Eastern Atlantic and Mediterranean Bluefin Tuna (*Thunnus thynnus*) is a complex stock fished by many countries utilizing different gear types. Further, regulatory changes over time have affected fishers' behavior and age composition of their catch. The multi-fleet, mixed-area nature of the fishery combined with rebuilding age structure of the population make selectivity estimation difficult. Previous stock assessments modeled aggregate catch-at-age, with catch from all countries and gears combined, and derived selectivity of fishery-dependent stock indices from partial catch-at-age. However, the traditional virtual population analysis could not reliably estimate selectivity of the oldest age as the stock recovered, and a single-fleet statistical catch at age model had poorly estimated selectivity parameters and age composition residual patterns. We expanded the single-fleet statistical catch at age model to include fleet structure, estimate fleet-specific selectivity, and improve the age specification of fishery-dependent stock indices. Results from multi-fleet models show a relatively good fit to data, with some remaining patterns in age composition residuals due to the still mixed gear/area nature of some fleets. Selectivity was well estimated for most fleets, either as functional forms or age-specific parameters, which were consistent with the general retention patterns of trap, bait boat and longline fleets. Historical estimates of biomass and fishing mortality differed from the single fleet statistical catch at age and the virtual population analysis model, suggesting model sensitivity to fleet structure. This case study demonstrates the advantages of fleet structure for stock assessment of highly migratory and other wide-ranging species with heterogeneous fisheries.

Keywords: highly migratory species, Atlantic bluefin tuna, selectivity, fleets

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CM 193: Improving the Assessment of the European Eel (*Anguilla anguilla*) in Sweden

Rob van Gemert

The European eel (*Anguilla anguilla*) is a catadromous fish species that is found in marine, brackish, and fresh waters of almost all European and North African countries. Its wide distribution and unique life history makes assessment difficult. Despite the fact that all European eels form a single panmictic population, stock status is mostly assessed on the country-level. In Sweden, different assessment methods are used for different geographical areas, depending on data availability. For the inland waters, the assessment is based on abundance estimates of young eel, which are extrapolated to abundance estimates of adult eel. For the Baltic coast waters, the assessment is based on a mark-recapture study, analysed with survival analysis. For the West coast waters, the assessment is based on catch-per-unit-effort trends from fyke net surveys. Each of these three methods comes with its own advantages and disadvantages, and not all methods are able to estimate all relevant indicators of stock status. Here, the strengths and drawbacks of each assessment method used in Sweden will be presented. Furthermore, ideas are presented for how the future assessment of European eel in Sweden could be improved, with particular focus on fisheries-independent methods for monitoring and assessment.

Keywords: European eel, stock assessment, monitoring, diadromy

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CM 213: Pink salmon connect oceans and experts amidst rapid change

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The need to assess shifts in the distributions of species, and the resulting potential impacts and opportunities, is an acute and increasing international challenge across a rapidly changing planet. Highly migratory fish are on the move and may no longer be constrained to a single ocean. Species that are iconic in one ocean, however, may be unwanted in another. Pink salmon, a quintessential Pacific species, are accessing the Arctic Ocean and are rapidly expanding across the eastern Atlantic Ocean in recent years. These fish, which can be quite abundant, are interacting with native species and ecosystems that have never experienced pink salmon before, with undetermined risks and benefits. Although there is an immediate need for management and conservation action in the Atlantic basin, there is untapped knowledge about pink salmon from the Pacific, where the species is well-studied. This knowledge gradient presents an opportunity for information exchange to discuss common challenges and guide future approaches. As part of the International Year of the Salmon initiative, the North Pacific Anadromous Fish Commission (NPAFC) and the International Council for the Exploration of the Sea (ICES) Working Group on Science to Support Conservation, Restoration, and Management of Diadromous Species (WGDIAD) recognized there was potential for improved inter-ocean-basin collaboration on salmon, and pink salmon in particular given shared scientific and management challenges. Experts attended the first meeting of the Northern Hemisphere Pink Salmon Expert Group, held on October 2-3, 2022, in Vancouver, Canada. They discussed the current state of knowledge for pink salmon, focusing on range expansion into the Atlantic and Arctic oceans, including trends in distribution and abundance, research and monitoring approaches, potential inter-specific interactions, mitigation efforts, and plans for future collaborations. Here, we present the highlights of that initial meeting, discuss the progress made since, and outline next steps to continue collaborations that guide future strategies. To monitor and assess the impacts and opportunities of broad-scale distributional shifts, the connectivity of our oceans needs to be matched by connections among researchers and institutions.

Keywords: distributional shifts, climate change, Atlantic Ocean, Pacific Ocean, Arctic Ocean, connectivity, pink salmon, collaboration

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CM 217: The (in)complete diet of Northeast Atlantic mackerel (*Scomber scombrus*) during its summer migration into Icelandic waters, using DNA barcoding and visual analysis

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Marine ecosystems are under an increasing threat from climate change on top of environmental variability. Highly migratory pelagic fish species occupying large and different marine ecosystems might respond to such changes by altering migration patterns, distribution and feeding habits. The Northeast Atlantic mackerel (*Scomber scombrus*) is a highly migratory pelagic species which has proven to be a very ferocious predator, exhibiting both particle and filter feeding, being able to gain about 43% in body weight on average while feeding in Icelandic waters during the summer. Previously published studies on diet preferences for mackerel, have shown that during the summer migration into Icelandic waters, their diet was dominated by calanoid copepod species (>60% of stomach weight) but that euphausiids, amphipods and large crustaceans also play an essential role.

In this presentation, we will present an analysis of the summer diet of mackerel in Icelandic waters using DNA metabarcoding together with visual stomach analysis from 116 mackerel caught around Iceland in the summer of 2012. DNA-based molecular methods were used as a trial to understand the full diet of mackerel in this study, since they are a useful tool for analysing the diets of fish with greater accuracy and resolution than traditional morphology-based methods, especially for easily digested prey. Although we did hypothesise that morphological and molecular diet analyses would reveal similar prey taxa in terms of richness and diversity, granting for a higher taxonomic resolution (i.e. more species-level prey identifications) when using metabarcoding, we were somewhat surprised by the results. From the DNA analysis, we found as we expected, that Crustaceans (i.e. copepods, amphipods, krill) were the most dominant prey items (relative read abundance, RRA, of about 65%), but surprisingly, Ctenophores, Tunicates and Fish contributed much more than anticipated. Also, a lot more species were revealed through genetic analysis that was not seen by the visual analysis at all, the same was true for a few species the other way around.

This presentation will provide information on a highly migratory fish's feeding ecology and diet, which can provide much-needed information on growth conditions, feeding competition and distributional shifts, as well as supporting fish stock assessment and EBFM models. We will also, inform the audience of the session about our experiences, what was good and not so good about using molecular methods for diet analysis, where to go from here and what uses it may have for the community at large.

Keywords: mackerel, pelagic, migratory, diet, DNA

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CM 220: Towards a range-wide assessment of European eel: recent steps undertaken at the regional scale in the Mediterranean within the GFCM European eel Research Programme, in view of a multiannual Regional management plan

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Aim of this contribution is to present results of recent initiatives undertaken in the Mediterranean Region to contribute to assessment and management of the European eel (*Anguilla anguilla*, L. 1758), consistent with the overall strategy carried out for stock recovery and conservation of this species across its entire distribution range.

Based on the unique life cycle, which takes place between the continental waters of Europe and the Mediterranean, where the species grows and sexually matures, and the Atlantic Ocean, to which eel is linked for reproduction, the species can be considered highly migratory, and a shared resource for what concerns management and exploitation. The population is fragmented in a myriad of sub-populations distributed at very different latitudes, in habitats highly variable for ecological characteristics and anthropogenic pressures, and heterogeneously exploited. As a result of the numerous natural or human induced impacts occurring in the many habitats through which eel life cycle takes place, including fishing pressure, a consisted decline of the stock ensued. A long debate has been taking place over the last 20 years, on the measures to protect the global eel stock and to guarantee its recovery, while maintaining its sustainable exploitation. This also addressed the need to consider the role of the Mediterranean Region, to ensure that efforts towards a common objective are put forward by all riparian Countries. Since 2014 the General Fisheries Commission for the Mediterranean (GFCM, Food and Agriculture Organization of the United Nations) has acted as key player, towards establishing a Mediterranean framework to take part in the overall process, taking into account regional geographic, climatic, and socio-economic peculiarities.

This led, *inter alia*, to the establishment of an *ad-hoc* research programme in 2020 which concluded in February 2022. Results allowed to achieve a considerable in-depth data collection and analysis regarding eel Mediterranean local stocks, their habitats, exploitation methods, management frameworks, and recruitment in the Region. Information was analysed at different levels (site, management unit, country, habitat typology, Regional), and provided the basis for a model-based evaluation of alternative management strategies, to evaluate their possible effectiveness on the escapement of spawners, as well as on landings.

Results, besides constituting a contribution to the knowledge-base and data availability at the Regional level, and a basis for providing advice for eel management in the Mediterranean, represent an important step to contribute towards assessment at the global stock scale.

Keywords: European eel, *Anguilla anguilla*, Mediterranean, management, assessment

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CM 222: Two endangered ray species endemic to Europe, *Leucoraja fullonica* and *L. circularis*, biogeography, stock status, and prospects for management and conservation

Ailbhe S. Kavanagh¹, Maurice W. Clarke, Paul Coleman, Declan Quigley

The *Leucoraja* genus of rays contains several species that are endemic to Europe. This study focusses on 2 species, *Leucoraja fullonica* the shagreen ray and *Leucoraja circularis* the sandy ray, which are unique among European marine fishes in that they are listed on the European Red list of species at risk of extinction yet are also subject to a total allowable catch under the EU's Common Fisheries Policy. Neither of these species is well documented in the scientific literature, with few studies of life history. Available data dating back to 1835 and as recently as 2022 have been compiled from multiple sources across Europe, including the ICES DATRAS database. These data confirm a patchy biogeography with several widely separated populations, displaying differing abundance trends. The distribution of these species ranged from waters off the Shetland Islands to as far south as the Gulf of Cadiz. Statistical modelling demonstrated the influence of multiple environmental factors on the distributions of both species. In addition, general increases in frequency of occurrence, mean annual biomass landed, and mean CPUE for both species were recorded with significant variability over the time period examined. This study builds on the available life history information to infer sustainable fishing mortality levels which are low. The inherent biological vulnerability and fragmented biogeography confirms that further loss of biological diversity due to commercial catch or bycatch, including of individual populations, in European waters would have negative consequences for the species. The solutions will not be straightforward given the degree of fishing effort taking place in these waters.

Keywords: *Leucoraja*, distribution, conservation, bycatch

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CM 251: Getting a grip on eels: Towards a better assessment of a critically endangered species

Jan-Dag Pohlmann¹, Caroline Durif

The critically endangered European eel (*Anguilla anguilla*) is a widely distributed diadromous species occurring in marine and fresh waters from Iceland in the Northwest, to North Africa in the south and the eastern Baltic and Mediterranean in the East. As such, the European eel is subject to a wide variety of environmental conditions, different jurisdictions, fisheries and other anthropogenic impacts, posing challenges to managers and scientists alike.

As a panmictic species, the assessment of the European eel naturally focuses on the whole stock level, clearly showing a severe decline of recruitment which started in the 1980s. In 2007 EU member states were obliged to develop national eel management plans to facilitate the recovery of the stock, but given the stocks wide distribution, management has to be applied on much smaller spatial scales typically defined by national territories or river basin districts. To better address management needs, provide an improved understanding of stock dynamics on different spatial scales and ultimately facilitate a more operational advice, ICES initiated the workshop on the future of eel advice in 2021. After careful review of the current assessment methods, ICES standards and available data, a roadmap towards a novel assessment approach, combining information from small scale spatial models in a superordinate model for the whole stock, was developed. This approach aims to utilize all available information on environmental conditions, habitats and habitat fragmentation, fisheries and other anthropogenic impacts as well as the distribution of eel in order to account for the numerous spatial differences affecting the stock while maintaining an assessment of the stock as a whole.

First steps have been made towards the implementation of the roadmap. Potential synergies with other migratory species have been identified but many challenges must still be overcome. This talk aims to provide an overview of the recent developments and future plans in eel stock assessment, highlighting the potential of this approach for both scientists and manager and potentially also other migratory species in order to join forces for a better assessment of these species.

Keywords: European eel, management, assessment, model, diadromous, WGEEL, migratory species

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CM 265: Spatial heterogeneity in recruitment trends of the European eel across Europe and influence of environmental factors

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The European eel (*Anguilla anguilla*) is a catadromous migratory species, breeding in the Sargasso Sea and growing over a wide continental range. When juveniles reach the continental shelves of Europe and Africa, a process known as recruitment, the spatial distribution of the European eel ranges from the Barents Sea (72°N) to the southern limit of Morocco (30°N). Despite its large distribution area, the European eel is thought to be panmictic and, as such, is assessed at its distribution scale. However, while recruitment trends used to be rather similar among regions, new modelling exercises have highlighted regional differences in trends, including in recent years. During this talk, we will show how the relative contribution of different regions to total recruitment has varied over the years. Because of the long larval drift of the European eel across the Atlantic, we suspect that those differences might be related to changes in oceanic conditions. In this context, we assess the relation between regional trends in recruitment and environmental indices, such as SST and NAO, through cross-correlation analysis. We expect nearby areas to display similar temporal trends in recruitment and similar correlation values between recruitment and environmental variables. This work is part of a bigger project that provides indicators at the European scale, while taking into account spatial synchrony in the population dynamics among different regions. This approach, which acknowledges spatial heterogeneity, will help management decisions at both the species' range and local levels.

Keywords: European eel, recruitment, environment, regime shift, spatial heterogeneity, HGAM, cross-correlation

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CM 297: Estimating eel density in Swedish inland waters using electrofishing data

Torbjörn Säterberg¹, Rob van Gemert, Cédric Briand

The European eel (*Anguilla anguilla*) is an example of a highly migratory and wide-ranging species. It spawns in the Sargasso Sea and recruits as young eel to brackish, marine and fresh water systems across Europe and Northern Africa. European eel is typically assessed at the national level or within other geographically defined areas.

The assessment of the eel stock in Swedish inland waters is currently based on a reconstruction of the stock from young eels that are either naturally recruiting or being restocked to inland waters. One of the most important data sources used in this assessment are recruitment time series that are assembled from elver traps in a number of rivers. However, as the number of operating traps are gradually decreasing, a novel method for assessing eel abundance in Swedish inland waters is needed.

In this talk, a first attempt of assessing eel density in Sweden using electrofishing-monitoring data is presented and discussed. Eel Density Analysis (EDA) - a statistical model, which has been used to link eel density estimates to river network characteristics in a number of European countries - is applied to data from the Swedish national database for electrofishing data. The first step in building the EDA model is to adapt an existing and highly resolved GIS river network describing the Swedish river system to the oriented river network database developed in the SUDOANG project. Then, the second step is to calibrate the EDA model to existing electrofishing data. Predictions from EDA are then compared to the recruitment time series currently used in the Swedish inland assessment, and the implications of using EDA as a future assessment tool in Swedish inland waters are discussed.

Keywords: European eel, stock assessment, Eel Density Analysis

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CM 300: Food for models: knowledge on metapopulations functioning and marine habitat use of European shads (*A. alosa* and *A. fallax*) brought by a qualitative retrospective approach

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Like other anadromous species, European shads (*Alosa alosa* and *A. fallax*) reproduce in rivers, migrate to marine habitats to grow and sexually mature before returning to their spawning grounds. Shads express alternative reproductive strategies, spawning either in their natal or origin river (homing) or in a different river (straying). Straying induces exchanges of spawners between shad populations, implying connectivity across marine habitats. Overall, we have identified three levels of habitat connectivity that are key issues for shads: the river to sea continuum, the connectivity within the marine habitats, and the connectivity between populations. Within the DiadES INTERREG Atlantic Area project, we have collectively addressed three levels of connectivity in shads using case studies distributed along the Atlantic Arc for populations facing various degrees of human-induced pressures. An approach based on otolith natal fingerprints was used in different European contexts to track shad natal origin, to infer individuals' movements between natal and sampling sites. Land to sea connectivity was studied in the context of restoration projects (Mondego River, Garonne River). The populations mixing at sea, connectivity and marine habitat use was investigated using the otolith-based natal origin tracking of shads sampled as bycatch in marine habitats of the North Western Iberian Peninsula. Lastly, the study of the level of exchange of shad spawners between different populations in rivers of southern Ireland, southern and eastern UK and northern France was undertaken by sampling spawners on rivers and adults at sea. Results confirmed the essential role of habitat connectivity throughout all stages of their life cycle. The three case studies provided food for new generation of models to address the fluxes of exchanges within and between *A. alosa* and *A. fallax* populations.

Keywords: anadromous species, connectivity, natal origin, otolith microchemistry, metapopulation functioning, assessment

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CM 307: Atlantic bluefin tuna (*Thunnus thynnus*) three-dimensional distribution and its phenology across Atlantic ecoregions

Martín Cabello de los Cobos¹, Haritz Arrizabalaga¹, Igor Arregui¹, Guillem Chust¹, María José Juan-Jordá², Iñigo Onandia¹

The Atlantic bluefin tuna (ABFT) is an emblematic species widely distributed and targeted since ancient times. Known for its capability to perform transoceanic migrations, that vary seasonally and annually, and its endothermic adaptations, ABFT can use a variety of habitats with a wide range of environmental conditions. Consequently, this voracious species can exert top-down pressure on a variety of ecosystems encountered along its lifecycle. Historically, the lack of data and knowledge on spatial distribution of the species has limited the management of ABFT and it has also impeded to model its top-down effects on local marine ecosystems.

With the electronic tagging of juvenile individuals for more than 15 years, we have gathered key information concerning the horizontal and vertical behaviour of ABFT in the Atlantic Ocean. Combining this tagging data with satellite telemetry, we built a three-dimensional habitat model and characterized the spatial and temporal distribution of ABFT in the Atlantic Ocean. This allowed to characterize the migration phenology of ABFT across Atlantic ecoregions.

We expect that the integration of the habitat preferences and three-dimensional distribution of ABFT into spatially structured population dynamic models will improve the management of this species as well as modelling its top-down effects spatially across different ecoregions of the Atlantic Ocean.

Keywords: Atlantic bluefin tuna, electronic tagging, migration, 3D habitat, ecoregions, phenology

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CM 324: Strength in unity: three countries working together to assess the status of the European eel on a large scale

Maria Mateo¹, Estibaliz Díaz, Laurent Beaulaton, Hilaire Drouineau, Maria Korta, Elsa Amilhat, Carlos Antunes, Agnès Bardonnnet, Carlos Fernandez-Delgado, Isabel Domingos, Lluís Zamora, Cédric Briand

The European eel (*Anguilla anguilla*) is a catadromous species that grows in fresh or brackish/coastal habitats until its oceanic spawning migration. The eel is outside biological limits and considered as critically endangered. The European Commission required member states to submit a management plan establishing measures for the eel recovery in 2007 (Regulation C1100/2007). However, the population has not recovered. The European eel constitutes a single fish stock, but its distribution range includes a wide variety of latitudes and habitats, environmental conditions, and jurisdictions and therefore used to be managed and assessed as separate almost independent units. The variability of implemented assessment methods has limited the scope and effectiveness of management measures, hampering eel recovery. In the SUDOANG project, we aimed to provide a common assessment of the European eel in Southwestern Europe (France, Portugal and Spain). To do so, first, we built a standardized spatial database on eels and their habitat. By building a common river network from different databases available in the three countries, the SUDOANG 1.0.4 database provides tools to quickly accumulate information, i.e., distance to the sea, cumulated number of obstacles and height, among others, along the river or along the natural path of migration from/to the sea. It also compiles information about some human pressures (106360 obstacles). The river network and attribute tables support ecological assessment of the rivers and should be potentially useful for any studies on other diadromous or freshwater fishes. Second, we assessed the European eel stock using two indicators: recruitment using the Glass Eel Recruitment Estimation Bayesian Model (GEREM) and escapement using the Eel Density Analysis (EDA) model. GEREM estimates annual recruitment at different spatial scales and was fitted on different types of time-series recruitment since 1960's. EDA estimates the biomass of silver eels using data of routine electrofishing surveys. These two models are important since (1) their comparison provides information on the evolution of the stock and anthropogenic pressures at different spatial scales, (2) they can be used to derive indicators requested by the European Commission in the context of the regulation. During the talk, we'll briefly present the models and tools produced in SUDOANG. We have provided for the first time an eel and river common database and escapement estimate with a common methodology in the three mentioned countries. We believe that such frameworks are essential for the recovery of the species and should be extended to its entire range.

Keywords: European eel, standardized database, wide distributed species model, SUDOANG

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CM 345: Trends in Atlantic bluefin tuna (*Thunnus thynnus*) mixing proportions inferred from combined otolith chemistry and genetic data

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The Atlantic bluefin tuna (ABT, *Thunnus thynnus*) is a large pelagic migratory species that lives mainly in the temperate ecosystem of the North Atlantic Ocean and adjacent seas. The management plan for ABT considers two management units (stocks) separated by the 45°W meridian, assuming that the western stock spawns in or near the Gulf of Mexico and the eastern stock in or near the Mediterranean Sea. Challenging this assumption, several studies have shown that mixing occurs between the two management areas, which results in uncertainties about the degree of connectivity between the two stocks with implications for stock assessment and management advice. Here, we have revised otolith stable isotope ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) and a subset of Single Nucleotide Polymorphism (SNP) genotype data selected to trace genetic origin from the same >1000 ABT individuals captured throughout the Atlantic Ocean over the past 10 years. When used independently, both data sources result in different levels of stock identification resolution, including unresolved or contradictory assignments. When used complementarily, presumed incongruences are solved and provide additional insights into ABFT population structure. The contributions of the eastern and western populations to four different mixing areas in the Atlantic Ocean were estimated, and trends in connectivity patterns were assessed. Preliminary results indicate year to year variation in the movement and exchange of ABT in mixing zones. The improved knowledge of the spatial dynamics of the species will provide insights into the complexity and drivers of ABT stock mixing during the last decade, paving the way for informed management that ensures a sustainable exploitation of the species.

Keywords: bluefin tuna, otolith microchemistry, genomics, population connectivity

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CM 365: Seasonality or migration pattern behind "false" growth bands formed the fin spine of the Atlantic bluefin?

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Fisheries assessment depends on accurate age assignments, particularly those for long-lived fish species such as Atlantic bluefin tuna (*Thunnus thynnus*). Fin spines have proven useful for direct ageing of the eastern Atlantic and Mediterranean bluefin tuna stock at least for small and medium sized specimens, by counting the pair of opaque and translucent bands (bipartite structure) presumably yearly formed. However, the appearance of sub-annual or "false" (hereafter) annuli as an important issue in ageing remains unexplored in terms of their seasonal periodicity. We aimed to analyse the oxygen isotope composition ($\delta^{18}\text{O}$) and manganese (Mn^{55}) ratios assayed across fin spine growth increments to assess any periodicity or seasonal pattern that can help to discern between "true" and "false" annulus providing a good proxy of age and consequently enhancing our age interpretation. Time series analysis was subsequently employed to compare periodicity of fin spine annulus formation to oscillations in the $\delta^{18}\text{O}$ and Mn spine profile measured. The Mn profile showed a seasonal pattern that was significantly correlated with true annuli indicating that can be a good chemical clock' proxy. Minor but significant sub-annular cycles (2 cycles per annulus also called double band) were also detected with a significant higher appearance from sixth annulus and beyond whereas the absence or low frequency of "false" at younger growth increments (i.e., before the fifth) might indicate that the appearance of false annuli might not be a fortuitous event. The fluctuating pattern of $\delta^{18}\text{O}$ along fin spine growth trajectory was not significantly correlated with "true" annuli but indicate intra- and interannual isotopic composition variation over the lifetime of the animal that might be useful for detecting movements among water bodies with strong $\delta^{18}\text{O}$ gradients such as Atlantic-Mediterranean migration of the juvenile ABFT. Considering this, further research combining chemical markers along with tagging and genetic data would be needed to elucidate whether the presence of these "false" bands at older ages could complement our understanding of foraging-spawning migration patterns in juveniles bluefin tuna.

Keywords: Atlantic bluefin tuna, dorsal fin spines, $\delta^{18}\text{O}$, Mn^{55} , false annuli

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CM 376: Multinational project to study population structure of Greenland halibut, a highly migratory deep-sea flatfish, in the North Atlantic

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Migratory marine fishes are often allocated to stocks that reflect pragmatic considerations and may not represent the species' actual spatial population structure, increasing the risk of mismanagement and unsustainable harvesting. The NORSUSTAIN project brings together institutes from six different countries to study the spatial population structure of Greenland halibut (*Reinhardtius hippoglossoides*), a highly migratory benthopelagic deep-water marine flatfish which supports important fisheries in the North Atlantic. We present preliminary findings of this project including an already published mark-recapture review as well as genetic and modeling studies. We find evidence for migrations across management units in the North Atlantic indicating two regional offshore populations: one in the Northeast Atlantic, where the previously defined West Nordic and Northeast Arctic stocks, currently managed separately, likely belong to a single population that spans from the Kara Sea to Southeast Greenland; and one in the Northwest Atlantic where migration was observed between the Newfoundland and Labrador stock and the Northwest Arctic stock in Davis Strait and Baffin Bay. The area around and west of Iceland is likely a transition zone between the Northwest and Northeast Atlantic populations, and we cannot exclude the possibility of other smaller local spawning areas across the North Atlantic. Our results indicate a complex spatial and temporal population structure for this long lived highly dispersive species and stock borders that are arbitrary. We comment on the effects of revising the stock borders to more closely resemble biological populations.

Keywords: biogeography, distribution, fisheries, population structure, *Reinhardtius hippoglossoides*, tagging, genetics, modelling

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CM 409: Assessing and forecasting recruitment of wide-ranging migratory fishes: the case of the European eel

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The European eel (*Anguilla anguilla*) is a catadromous migratory species whose reproduction occurs in the Sargasso Sea and whose growth takes place in continental waterbodies. The European eel is distributed over a 90,000 km² area, in continental waters from the Barents Sea to the southern limit of Morocco including the Mediterranean and Baltic basins. Due to panmixia of the species, the stock analysis should be conducted at the scale of the species' entire range. In this context, recruitment is thought to be one of the most reliable indicators, less impacted by local continental conditions than other existing indicators. However, achieving a single indicator of recruitment at the population scale using data coming from multiple spatially scattered time series is not straightforward. In this talk, we detail and compare different methods used to assess recruitment at the population scale, using the scattered time series and accounting for the widespread distribution. More specifically, we present the GLM approach used by the ICES Working Group on Eels, and the hierarchical model GEREM, which was used in the SUDOANG project (Interreg Sudoe) and that allows the estimation of regional sub-indicators. Then, we analyze methods that can predict recruitment while accounting for modifications in recruitment trends in specific zones. To do so, we develop and compare (i) new recruitment forecasting models and (ii) indicators quantifying models' fitting and forecasting abilities regarding management, fishery and conservation. Due to its flexibility and since it did not favor one criterion over the others, the so-called random slope model turned out to be a suitable candidate among models presented here when it comes to assessing and forecasting glass eel recruitment. Since the French glass eel fishery is a TAC-regulated recruitment fishery, recruitment forecasting is even more important, as for any recruitment fishery. More generally, recruitment forecasting is crucial to fisheries science and management, and aims at informing stakeholder's decisions.

Keywords: European eel, recruitment, regime shift, Bayesian assessment model, stock management

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CM 484: Fish movement driven by environmental gradients: a solution to modelling feeding and spawning migrations of blue whiting

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Large fluctuations of the blue whiting stock in the North-East Atlantic have raised concerns on the sustainability of the fishery in a context of climate change and have led to the need for new population models capable of capturing the complex spatial dynamics of this highly migratory fish. Some studies have exposed a possible link between climate variations and the population spatial dynamics, which could explain the observed variation in stock recruitment. Both their location on their main spawning grounds and their subsequent feeding migration pathways seem to be affected by the subpolar gyre strength. Therefore, to allow us to study the effect of climate on the stock and make predictions on its future spatial distribution, it is necessary to develop a model describing long-distance fish migrations driven by bio-geophysical factors.

In this study, movement of adult fish was implemented by adding the swimming velocity components directly to the flow fields used in a particle tracking model. Swimming direction was determined by environmental gradients, which were calculated using a modified version of Ritter's algorithm. The method is suitable for all types of grid in any spatial reference system, and it offers flexibility in terms of adjusting the gradient scale. In the model, successful feeding migrations were driven by currents, food and temperature, while successful spawning migrations were mainly affected by local values and gradients of temperature and salinity. Repeated runs of the fish migration model revealed emergent properties which agree with the empirical story: (1) feeding migration pathways varied with both climate and the initial position of individuals on spawning grounds, (2) spawning location of an individual was influenced by both climate and the location of its feeding area, and (3) migration timing was important for both spawning and feeding success. Once combined with a population growth model, this allows us to make predictions of the population spatial distribution. Thus, we recommend this mechanistic approach of modelling fish migrations driven by environmental gradients as a tool to study the indirect effect of climate on recruitment.

Keywords: blue whiting, population dynamics, spatial dynamics, mechanistic model, feeding migration, spawning migration, environmental drivers, gradient calculation algorithm

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CM 527: Collecting data to support sustainable Pollack (*Pollachius pollachius*) fisheries in the English Channel

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Pollack (*Pollachius pollachius*) is an important species for both commercial and recreational fishers across the North Atlantic, representing a landed value of £4-5million per year and 6% of recreational catches (UK). Despite the social and economic significance, this species is defined as “data limited” with many large evidence gaps on population trends and their spatial ecology. Over the past 20 years ICES has reported a 72% decline in commercial landings within the Celtic seas and English Channel (ICES sub areas 6 & 7), suggesting substantial population declines. Research is therefore required to support management efforts.

Pollack are however highly susceptible to effects of barotrauma when captured at depths below 10-15m, which typically results in high mortality when conducting sampling. Working with 15 charter vessels at several ports across the Southwest UK, Plymouth university has developed a tagging protocol which uses “descending devices” to re-pressurize fish at depths of 30-40m. Subsequent telemetry via the implantation of acoustic transmitters has then been used to assess: spatial movements, habitat use and post-release mortality.

To date, 50 fish have been tagged and tracked using descending devices across the southwest UK. Preliminary results have suggested high survival rates following capture when descending devices are used. Telemetry data highlighted that while fish display high residency to within 5-10km, individuals move over large distances (50-100km). By working collaboratively with the charter boat sector across the region the project has established trust and buy-in from industry representatives. The project is also liaising with regulatory bodies at both regional and national levels to collect data to support stock assessments and help improve sustainability within a critical fishery.

Keywords: acoustic telemetry, fish, pollack

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CM 530: PREDICT: Investigating fine-scale oceanographic drivers of variation on pelagic fish migration routes in the North Sea

Georgina L. Hunt¹, Beth E. Scott, Benjamin J. Williamson, Natalie Isaksson, David Bould, Emma Ahart

Spatial and temporal variations in fish and migration routes, especially important pelagic, zooplankton-eating species (e.g., Atlantic herring *Clupea harengus*), may be driven by biweekly, seasonal and annual changes in the timing and locations of where new primary production is created in shelf seas. There are a number of fine-scale oceanographic features that have been identified as important locations with very high and predictable primary production (i.e., foraging opportunities), including fronts with high gradients of density change (tidal and shelf edge fronts) and bank/trough areas where internal waves are created. In collaboration with the University of Aberdeen, Ørsted, and the Environmental Research Institute at the University of the Highlands and Islands, the PREDICT project aims to investigate these temporally ephemeral, but recurring fine-scale features to predict mechanisms of variability in pelagic fish migration patterns in the North Sea. Using a Bayesian spatial modelling approach involving Integrated Nested Laplace Approximation (INLA), we bring together multiple datasets (e.g., ICES length-at-age and NEODAAS satellite frontal data) to investigate the years, regions and finer-scale features to recreate fish migration patterns of four pelagic species: Atlantic herring, Atlantic mackerel *Scomber scombrus*, European sprat *Sprattus sprattus* and sandeels *Ammodytes* spp.

This approach will enable us to generate dynamic seasonal maps of overlap for the four species to elucidate spatio-temporal trends in growth rates to enable a tracking of annual cohorts with a greater degree of precision, thereby allowing a greater understanding of possible spatial effects driven by climate change. By focusing on these pelagic fish species, which are focal prey for many seabirds and marine mammals, the creation of individual and combined migration maps will help us to identify where locations of future offshore windfarms may overlap with fish high use areas; thus, allowing for locations of high risk during the annual cycle of fish movements to be identified.

Keywords: herring, mackerel, sprat, sandeels, growth rates, inla, spatial and temporal distributions, environmental impact, offshore wind farm effects

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CM 576: Time-space documentation of the recovery / expansion of summer feeding habitat in the northeast Atlantic by bluefin tuna based on observations from multiple sources

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Highly migratory species present many challenges to fisheries management and sustainable exploitation, including their movements within and across jurisdictions, and those in the high seas. These challenges are amplified by data limitations including a lack of fishery-independent information and time series such as research surveys for estimating stock abundance and distribution at various life stages. As a result, distributions and abundances often rely on commercial fisheries data which are usually limited in time-space coverage to areas where catches and selectivity are highest. Consequently, knowledge of species biology outside these periods of the year and areas is limited. Here, we use data from multiple sources, including a large amount of citizen science data, to describe a major change in the seasonal range, habitat use and migration of a large, highly migratory species, the Atlantic bluefin tuna (*Thunnus thynnus*). This change occurred in the early 2010s when the species recovered a former part of its feeding range in the northeast Atlantic after 5-6 decades of rarity, and when it expanded its range to areas not previously known to science. This stock recovery and spatial expansion occurred when the population biomass was increasing as part of a recovery plan implemented 5-10 years earlier during the late 2000s. However, during the 2000s-2010s, this species was only lightly exploited in the northern part of the Northeast Atlantic so information about the timing and spatial extent of this event based on targeted fishing data is negligible. We have partly filled this gap by compiling observations from other data sources in the region. The observations were made in a large area from the Øresund-Kattegat-Skagerrak in the east to the Denmark Strait in the west, and far north into Norwegian waters. The observations include direct sightings of bluefin tunas swimming and jumping at the surface by diverse observers (e. g., members of the public, employees on sea-going vessels, commercial fishermen targeting other species, scientists), stranding of tunas on beaches, and some limited bycatch data. These observations provide new time-space insights to the recovery and expansion of the former habitat of bluefin tunas, and how this event might be related to fishery management decisions and large-scale climate-ocean variability. Furthermore, the wide spatial-time coverage identifies new hypotheses about the connectivity among feeding areas. The findings demonstrate the potential and value of multiple data sources for understanding species ecology and its dynamics.

Keywords: bluefin tuna, observations, habitat, migration, distribution, feeding, northeast Atlantic

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CM 577: A hierarchical bayesian life cycle model for atlantic salmon stock assessment at the North Atlantic basin scale

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Assessing fish stock is particularly challenging in the case of highly migratory species which interact with a multitude of single and/or synergistic factors at different points in time and space during their life cycle. For instance, the life cycle of anadromous fish, such as salmonids, relies on population-specific freshwater habitats for reproduction and juvenile growth, and marine habitats shared by multiple populations for feeding and maturation. This makes these species sensitive to multiple environmental and anthropic stressors acting at different spatial scales, with factors operating at sea potentially having synchronizing effects on the dynamics of large groups of populations.

We developed a new stock assessment model for Atlantic salmon (*salmo salar*) in the North Atlantic basin that allows (i) to incorporate a comprehensive representation of the spatial and temporal heterogeneity of the mechanisms controlling the population dynamics and (ii) to collectively analyze the dynamics of multiple populations within a same species that in certain periods share common environments.

The model tracks the abundance of fish through time and life stages from eggs to adults that return to spawn in their homewater after one or two winters spent at sea, and for all stock units (SU) in Northern Europe, Southern Europe and North America (total 25 SU). It is fitted to time series of data within a Bayesian hierarchical framework, to analyze the dynamics of the past 5 decades (hindcasting) and forecast the populations dynamics under different fisheries management scenarios.

The new framework constitutes a benchmark for the assessment and forecast models used by ICES for Atlantic salmon stock assessment in the North Atlantic. The dynamic of all SU are jointly analyzed within a single unified hierarchical Bayesian life cycle approach. It provides a framework for analyzing the mechanisms that shape population responses to variations in marine ecosystems. In particular, it allows for modelling covariations among all SU and for partitioning the effects of fisheries from the effects of environmental factors at a hierarchy of spatial scales. Last, this model is a new tool to provide catch options for any marine fisheries that operate on a mixture of stocks.

Keywords: hierarchical Bayesian model, *salmo salar*, multi-populations, spatial covariation, stage-based life cycle model, state space model

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CM 591: Genetic based methodologies to improve tuna fish stock assessment

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Understanding fish stock distribution and dynamics is fundamental for accurate fisheries assessment; however, this can be particularly challenging for highly migratory transboundary species such as tunas. During the last decades, genetic-based methodologies have been proved efficient to trace the origin and reveal connectivity patterns of marine fish species. Here, we studied the population structure and connectivity in three tuna species of high commercial importance, Atlantic bluefin (*Thunnus thynnus*), bigeye (*Thunnus obesus*) and skipjack (*Katsuwonus pelamis*) tunas in the Atlantic, Indian, and both oceans, respectively. Using thousands of Restriction-site Associated DNA sequencing (RAD-seq) derived genomic variants from ~500 samples per species, we found genetic differentiation between spawning components (Gulf of Mexico and Mediterranean) in Atlantic bluefin tuna, genetic connectivity with presence of adaptive genomic variants at different proportions along the Indian Ocean in bigeye tuna, and insights of the genetic connectivity between the Indian and Atlantic oceans in skipjack tuna. Additionally, for Atlantic bluefin tuna, the analysis of 3,700 feeding aggregation mixed-stock samples were assigned to their natal origin using a 96-marker genotyping assay, revealing wide stock mixing and helping to estimate the stock proportions at each sampled location. The discrepancies between the stock definition used in the assessment and the population structure revealed by our results, along with their implications for the management and conservation strategies of these three tuna species, will be discussed. Our results contribute to the knowledge of the population connectivity of three tuna species, challenging the current management paradigm and provide highly valuable insights for an informed revision of management units of these species.

Keywords: tuna, fish stock, genomics, population connectivity

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CM 609: Relationships between fish size and otolith characteristics of four mesopelagic and one benthopelagic fish species in Icelandic waters (family Lotidae, Myctophidae and Paralepididae)

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Though the mesopelagic fish communities surrounding Iceland are diverse and abundant, little is known about the biology and ecology of many species. In this study, we analyzed specimens of one benthopelagic fish and four mesopelagic fishes sampled from the southern coast of Iceland, Iceland Basin and Irminger Sea: *Gaidropsarus argentatus*, *Benthosema glaciale*, *Notoscopelus kroyeri*, *Arctozenus risso* and *Paralepis coregonoides*. The specimens were collected during the Spring (IESNS) and Summer (IESSNS) International Ecosystem Survey of the Nordic Seas during May and July in 2020 and 2021. Multiple size measurements were taken for each species, and the sagittal otoliths were removed. The length, width and area of each otolith were measured. Length-weight relationships (LWR) were determined for each species, along with growth parameters such as the regression coefficient (b) and the coefficient of determination (r^2). Two myctophid species showed positive allometric growth ($b > 3$) and the juvenile *G. argentatus* showed negative allometric growth ($b < 3$). The relationships between otolith size and fish length and weight were examined for each species, and regression models were used to assess their strength. All five species had significant relationships between otolith size and fish length and weight, although the relationship strength varied depending on the otolith measurement examined. For *G. argentatus*, *B. glaciale* and *N. kroyeri*, regional comparisons were conducted comparing LWR models and otolith-fish size regressions. *G. argentatus* otoliths were on average wider and shorter, along with a lower body weight at length for specimens from the Irminger Sea than those from the Iceland Basin. LWR also significantly differed for the two myctophid species between regions sampled in 2020, with offshore specimens having lower weights at a given length in the Iceland Basin compared to the Irminger Sea and southern inshore waters. There were difficulties identifying between the two Paralepididae species and conclusions on their LWR and otoliths must take that into consideration. Further work is necessary to separate these species to analyze these relationships more in-depth. This study shows regional differences within these pelagic fish populations, potentially caused by environmental conditions such as currents, temperature, and bathymetry. Furthermore, we provide morphometric relationships that can be applied to research on the diet of marine predators in this region of the North Atlantic.

Keywords: length–weight relationships, somatic size, North Atlantic, pelagic fishes, otolith size, Irminger Sea, Iceland Basin

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CM 661: How selective tidal transport of European eel larvae into the Mediterranean Sea could be used for future recruitment assessment

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The European eel (*Anguilla anguilla*) has suffered a substantial recruitment decline in recent decades and its panmictic stock is considered critically endangered. The European and North-African Shelves of the Atlantic Ocean, including the Mediterranean Sea together with their tributaries, form the natural distribution range of the European eel. Uncertainty, however, still exists regarding the importance of the Mediterranean Sea as a growth habitat. Additionally, the magnitude of the areas production of silver eels and thus its contribution to the spawning stock of the species is also unknown. Until now, the mechanisms that control the yearly recruitment of young-of-the-year larvae from the Atlantic into the Mediterranean are not well understood, and recruitment data for the area are derived from complex and laborious glass and yellow eel time series in transitional waters. Consequently, knowledge about transport and dispersal mechanisms of late-stage leptocephalus larvae after their journey from the Sargasso Sea are crucial for a better understanding of the yearly recruitment in this region.

The Strait of Gibraltar constitutes a narrow bottleneck and is the only direct connection between the Atlantic Ocean and the Mediterranean Sea. Here, we present data from a scientific research cruise (M185 of the German research Vessel METEOR) conducted in the Strait of Gibraltar. We collected robust data on hydrography and larval abundance during one tidal event cycle (24h) of the changing oceanographic conditions in the Strait, that play a decisive role in timing and magnitude of larval recruitment events into the Mediterranean Sea. Findings from this investigation have potential for the development of a designated larval recruitment survey in the Strait that would lead to substantial improvements in the assessment of the species for the Mediterranean, as well as the overall status and development of the entire stock.

Keywords: management, recruitment, monitoring, conservation, larval migration

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