Ecological Basis of Risk Analysis for Marine Ecosystems Symposium

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PORVOO
Welcome to Ecological Basis of Risk Analysis for Marine Ecosystems symposium

Uncertainty is an unavoidable part of everyday life. The bus can be late but there may be a wide range of outcomes: you may miss an important meeting or you may just arrive a bit later to work. Getting to work a bit later may not have as severe consequences as missing the meeting. While you might think that the probability of the bus being late is the same in both cases, the fear of missing the meeting may lead you to choose an earlier bus. Therefore, the probability of the bus being late is not, as such, enough to make decisions. You also need to take into account the consequences.

These are examples that illustrate how risk analysis always needs the subjective evaluation of good and bad outcomes. Probability alone is not enough. The measure for good and bad are dependent on what you or your customers value as good or bad.

The same holds for fisheries: the probability for the lowest catch per unit effort ever observed may mean something for fishermen because they realize from their own experience what it means. However, a 10% probability to be below $B_{\text{lim}}$ may not create any impact in the minds of fishermen, as $B_{\text{lim}}$ is very technical and difficult to understand. Discussions with various stakeholders are needed to form a utility function which is based on these views. In the event they are very different, the only reasonable act is to report key parameters for stakeholders and let them come to an agreement on fisheries actions.

There are different levels of uncertainties. Spiegelhalter and Riesch (2011) divide these as:

1) Future events – the unavoidable unpredictability
2) Model parameters – limited information
3) Model structure – limited knowledge
4) Acknowledged inadequacies
5) Unknown inadequacies - ignorance

Of these, the first three can be modelled. The fourth could be an extra border given for uncertainties. The fifth is something we cannot imagine, but some amount of extra uncertainty (unit of CV) could be reserved for that.

The famous philosopher, Donald Rumsfeld, said this in the following words: There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know we don’t know. But there are also unknown unknowns. These are things we do not know we don’t know. Is it time for fisheries to follow his wisdom and reserve some safety margin for total surprises?

In Helsinki, May 2014

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ECOKNOWS IN CONTEXT

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The ECOKNOWS project represents a major initiative in the challenge of improving fisheries assessment methods by integrating new sources of biological knowledge and the study of the ecological basis for risk analysis for marine ecosystems. This perspective attempts to put the ECOKNOWS experience in context by looking at the developments and progress related to this theme over the past 30 years, and by looking forward at outstanding questions and issues.

Looking back, it is instructive to compare the themes and methods of this meeting with those, for example, of the 1998 Symposium ‘Confronting uncertainty in the evaluation and Implementation of fisheries-management systems’ (ICES JMS 56:6 1999). Looking forward, it is important to consider how to address the challenges of evolving domestic and international policies, the move to ‘ecosystem’ and ‘integrated’ management, increasing market (and general public) pressure for certification of sustainability, and the need to obtain and maintain ‘social license’.

The evolving landscape of fishery evaluation and management demands increased participation in management processes and shared stewardship responsibility, and must adapt to changes in both the ecosystem and in public perception. Additionally, it is important to consider fisheries with other activities in more comprehensive evaluations that can support management decisions in an integrated context. Outstanding research priorities include 1) more holistic evaluations that take into account the full suite of ecological, social, economic and institutional objectives related to management, 2) methods to support management trade-offs among diverse objectives and activities, and 3) methods that will allow consideration of the cumulative impacts of multiple activities.
THE ECONOMIC VALUE OF ENVIRONMENTAL DATA: A NOTIONAL INSURANCE SCHEME FOR THE EUROPEAN ANCHOVY

To explain atypical events in anchovy population dynamics in the Gulf of Cadiz, it is crucial to consider environmental processes in a different way from how these are traditionally included in stock-recruitment relationships. In the Gulf of Cádiz, sea surface temperature, intense easterlies and discharges from the Guadalquivir river have been identified as key factors determining anchovy's early life stage mortality. We have constructed an environment-based recruitment model that estimates abundance of juveniles, as well as crucial parameters for the fishery such as natural and fishing mortality. There are few estimates for these parameters in the Gulf of Cádiz because of the lack of reliable information in contrast to other anchovy fisheries. Bayesian state-space models enable estimation of parameters with fewer data than non-Bayesian approaches because they allow the incorporation of prior knowledge. We are able to evaluate how modelling environment-based recruitment affects stock assessment and how responding to environmental information can benefit fisheries management. Further, by simulating a notional insurance scheme we are able to measure the value of using environmental information within a specific management regime defined by a harvest control rule. The main questions are whether incorporating the knowledge of environment in the management of anchovies in the Gulf of Cádiz is likely to reduce the volatility of the population dynamics of Anchovy and how this could benefit the commercial fishery and ecosystem management.

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RISK ASSESSMENT FOR THE EFFECTS OF FISHING: THE NEW ZEALAND APPROACH

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To underpin the assessment and management of the effects of fishing on non-target species, New Zealand has developed a quantitative, spatially-explicit, seasonally-disaggregated version of productivity-susceptibility analysis. The method uses: the intersection of the
distribution and intensity of relevant fishing effort and the distribution of each affected species; captures observed by government observers; and readily-available proxy information for species productivity. It generates estimates of potential annual fatalities in each affected population, even if only sparse or non-representative observer data are available. These estimates can be compared with explicit or implied management targets or limits (e.g., Potential Biological Removals, PBR) to estimate the risk of not achieving those objectives. The method generates absolute rather than relative estimates of impact and risk, propagates uncertainty in all inputs using Bayesian techniques, and provides for disaggregation of risk by season, location, or fishing fleet. Such risk assessments therefore provide a powerful tool for fisheries and research managers to target and prioritise information collection, mitigation, or management action. The analyses are readily and transparently updated to include new information and can be used for performance and risk monitoring. The method has been applied with considerable success to 70 species of New Zealand breeding seabirds and is the basis for management targets defined in New Zealand’s 2013 NPOA-seabirds. It is currently being applied to all marine mammals resident in New Zealand and similar approaches are under development for elasmobranchs and non-target fish species.

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PRIORITISING ECOLOGICAL EFFECTS OF FISHING OFF SW ENGLAND (ICES DIVISIONS VII E,F,G,H) USING SCALE, INTENSITY AND CONSEQUENCE ANALYSIS (SICA)

Scale, intensity and consequence analysis (SICA), a technique of ecological risk assessment for the effects of fishing (ERAEF), was applied to the diverse and economically important marine fisheries based in the southwest peninsula of England in response to concerns about sustainability of fishing. Policy goals for the marine ecosystem supporting fishing grounds were prepared by representatives of fishing and processing industries to guide the SICA. Scientists divided the ecosystem into components (crustaceans, molluscs, elasmobranchs, teleosts, marine mammals, seabirds, turtles, habitats and various communities), listed units of analysis for each, and provided background research. Agents of change, e.g. fisheries, and their activities, e.g. fishing, were also listed. A SICA working group (w.g.) systematically scored the risk of non-achievement of policy goals as a result of effects on each unit of analysis of the agents, taking into account the spatial and temporal scales of the most impacting activity, its intensity and duration of effect. A small proportion of the species and communities gave high risk scores, allowing management to focus on priority issues. SICA is recommended as a preliminary stage for an ecosystem approach to fisheries (EAF) and for best utilising the knowledge of fishers and local specialists.
PREDICTING REFERENCE POINTS FROM LIFE HISTORIES FOR RISK AND STATUS ASSESSMENT

To assess status and risks, management and conservation bodies need reference points for a growing number of fish species. In most regions, however, there is no available information on the population dynamics of a proportion of species affected by fishing. This proportion tends to be higher in poorer countries with high fish diversity and few resources for management. Generic approaches for setting fisheries and conservation reference points based on a few life history parameters are far cheaper than those based on full population assessment, but they are subject to many uncertainties, few of which have been quantified. We develop a tiered approach for estimating reference points for marine fishes from alternate life history parameters. These range from maximum body size to information on maturity, growth and reproduction. Predicted reference points are compared at different levels in the hierarchy and with those reference points obtained from more sophisticated population-based methods. Results quantify some of the uncertainty associated with different sources of input data and assumptions about the relationships among life history parameters. The methods allow us to predict reference points for entire fish assemblages to support risk assessment and provide insight into the uncertainty associated with those predictions.

A METHODOLOGY FOR ASSESSING THE VULNERABILITY OF MARINE FISH STOCKS TO A CHANGING CLIMATE

Climate change is already impacting fishery resources and the communities that depend on them. Environmental changes have been implicated in the shifting distributions, abundances and phenology of fish stocks in many marine ecosystems. These impacts are expected to intensify in the future, increasing the need to understand which fishery resources are the most vulnerable to environmental change. We have developed a tool for conducting a rapid vulnerability assessment for a large number of stocks to create an index of relative vulnerability. The index can help fishery managers identify high vulnerability stocks and
more effectively target limited research and assessment resources on stocks of highest concern. The vulnerability assessment uses existing information and expert elicitation methods to quantify a stocks exposure and sensitivity to expected climate change. Pilot tests have found the methodology to be robust across temperate and tropical marine ecosystems. The methodology has been employed for most commercially important stocks in the north-eastern United States.

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ASSESSING THE QUALITY OF LIFE HISTORY INFORMATION IN PUBLICLY AVAILABLE DATABASES

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Single-species life history parameters are central to ecological risk assessments. However, there has been little independent evaluation of the precision and accuracy of the life history values in global and publicly available databases. We therefore develop a novel method based on a Bayesian errors-in-variables model that compares database entries with estimates from local experts, and we illustrate this process by assessing the accuracy and precision of entries in FishBase, one of the largest and oldest life history databases. This model distinguishes biases among seven life history parameters, two types of information available in FishBase (i.e., published values and those estimated from other parameters), and two taxa (i.e., bony and cartilaginous fishes) relative to values from regional experts in the United States, while accounting for additional variance caused by sex- and region-specific life history traits. For published values in FishBase, the model identifies a small positive bias in natural mortality and negative bias in maximum age, perhaps caused by unacknowledged mortality caused by fishing. For life history values calculated by FishBase, the model identified large and inconsistent biases. The model also demonstrates greatest precision for body size parameters, decreased precision for values derived from geographically distant populations, and greatest between-sex differences in age at maturity. We recommend that our bias and precision estimates be used in future errors-in-variables models as a prior on measurement errors. This approach is broadly applicable to global databases of life history traits and, if used, will encourage further development and improvements in these databases.
THE IMPORTANCE OF UNCERTAINTY: CASE-STUDIES ON ALLEE EFFECTS AND ENVIRONMENTAL RECRUITMENT VARIABILITY

Numerous fish stocks worldwide have rapidly declined due to overfishing and many declined stocks have shown little signs of recovery. These observations have drawn attention to the potential lacks in the knowledge of the drivers of fish population dynamics, particularly at low abundances. Here I will focus on two fundamental biological processes that have not been traditionally considered in fisheries stock assessments and fisheries projections: the demographic Allee effect and environmental variability in recruitment.

Using an individual-based simulation model, I explore how an Allee effect and environmental recruitment variability empirically estimated for Atlantic cod will translate into population resilience to fishing and its ability to recover from a low abundance. Both these case-studies stress the fundamental importance of estimating and accounting for uncertainty, in addition to the projections on average effects. Both the Allee effect and the environmental recruitment variability substantially increase uncertainty about the time period required for biomass recovery from overfishing. In contrast, population resilience to fishing is decreased by increasing recruitment variability. In both the cases, the impacts on uncertainty are much larger than those on averages.

IMPROVING SAMPLING EFFICIENCY OF BAYESIAN ACOUSTIC SURVEY MODEL USING STAN SOFTWARE

Computationally complex Bayesian models that have thousands of data points and estimated quantities easily encounter problems with convergence and mixing. Common Markov chain Monte Carlo tools (such as BUGS and JAGS) that rely on Gibbs sampling are known to be poor in sampling efficiently from heavily correlated parameter spaces. This results in unbearably long run times. Relatively new open source sampling software Stan offers an alternative: Instead of Gibbs, Stan utilizes Hamiltonian Monte Carlo sampling and C++ to deal more efficiently with correlated posteriors. We used Stan in our work to estimate the abundance of Bothnian Sea herring using a Bayesian hierarchical model and data from Baltic International Acoustic Survey. Because of the vast amount of spatially complex echosound data, the BIAS model has turned out to be very difficult to sample with JAGS.
We analyse the BIAS model with JAGS and Stan and present the estimated abundances and length compositions. We discuss the pros and cons of the choice of software and highlight the future aims of this work.

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**FISHBASE AS A BAYESIAN LEARNING TOOL**

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Hierarchical Bayesian analysis is the scientific method of choice for summarizing and updating available knowledge by combining new and prior information as well as correlated information. A proof-of-concept of such learning system was established in the online database FishBase (www.fishbase.org), for the simple case of length-weight relationships (LWR) of fishes. A Bayesian tool to estimate LWR parameters a and b for virtually all of the 32,000 known species of fishes was developed as a self-learning tool. The tool uses body shapes of fishes to derive priors for these parameters for each species. It then uses the over 5,600 LWR records for 2,300 species in a hierarchical approach, including LWRs of congeners and family members to provide the best estimates of the parameters a and b with posterior density distributions. These estimates are updated whenever new data on LWR, body shape, or Family assignments are added in FishBase. A new LWR record does not only improve the Bayesian LWR parameters for the respective species but also for all other species within the same genus-body shape and family-body shape groups. For example, the addition of one new LWR record for the Bigtooth pomfret *Brama orcini* resulted in narrower LWR standard deviations for that species and for nine other species in the family Bramidae.

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**THE CONSERVATION PRIORITIZATION SCHEME FOR THREATENED SPECIES AND HABITATS IN THE OIL COMBATING: A CASE STUDY FOR THE NORTHERN BALTIC SEA**

When maritime traffic occurs and vessels transport oil as cargo or fuel, the risk of oil spill exists. Any spill has a potential to harm marine ecosystems. In favourable weather conditions the sites can be protected with booms or protection sheets. However, decision making on the spatial allocation of those is difficult due to limited resources. In this study literature and expert knowledge regarding the species and habitats in the Northern Baltic Sea were used to build an index to evaluate their potential to be safeguarded. Data was selected using quantitative criteria and expert evaluation. Threatened species were included, and this
list was further narrowed down by choosing only species that face a risk of being exposed to oil. Marine and coastal habitat types categorized as threatened were also included. Next, we developed an index-based method in order to prioritize the nature values. We acknowledged the conservation value, legislative status and the oil-induced loss of populations and habitats, their recovery potential, and the effectiveness of booms and sheets. Finally, the difference between the populations and habitats five years after an accident with and without protection actions was compared. The large the difference, the more cost-effective the actions are. Indices do not give absolute estimates on the variables, but rather the relative weights. We assumed that species recovery is dependent on the acute loss, recolonization efficiency and reproductivity. We noticed that the importance of recolonization and reproduction on recovery is varying with the features of species. The assessment of habitat recovery was noticed to be more difficult since more considerations exist. The index was applied to a map application created for the spatial prioritization of oil combating. Different GIS-based applications work as tools of policy instruments, and with these the information on nature values and risks threatening them are given to the managers.

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ECOSYSTEM PERSPECTIVE TO FISH STOCK PRODUCTIVITY AND RECOVERY IN THE PRESENCE OF LIFE-HISTORY CHANGES

Traditional fisheries stock assessment modelling often makes simplifying assumptions about processes underlying fish stock productivity and population dynamics. Yet, both life-history level processes and multi-species interactions can have large effects on the productivity and recovery ability of exploited stocks. An increasing amount of evidence shows that fishing and climate change are changing fish life-histories. Empirically determined rates of change are within the range of 0.5-3% per year and they are positively correlated with fishing intensity. Here we used ecosystem modelling tools to explore ecological and fisheries consequences of decreasing size-at-age of harvested species. We show that even small decreases in fish body size can be amplified by positive feedback loops in the ecosystem and lead to major changes in natural mortality and recovery potential. The impact that the reduced growth rates had on many functional groups in the ecosystem was comparable to the impact caused by the introduction of moderate fishing into an unfished system. Our analyses show that human induced reduction in fish size will alter predation regimes, changing species interactions and strength of natural selection. The outcomes of this interplay between natural and fisheries induced selection on harvested stocks will determine the final rate of growth and maturation changes in harvested stocks and their implications for fisheries management.
STATE-SPACE PRODUCTION MODELS AND GRAPHICAL METHODS FOR ASSESSING AND COMMUNICATING THE STATUS OF THE LAKE NIPIGON WHITEFISH (*COREGONUS CLUPEAFORMIS*) FISHERY

Stock assessment for Lake Nipigon Lake Whitefish (*Coregonus clupeaformis*) is challenging due to logistical difficulties associated with the large size of Lake Nipigon (4848km$^2$), remote sample locations that are great distances from fishing ports and lack of access to assessment infrastructure such as ice and laboratory facilities. The more remote areas of the lake are sporadically sampled via fishery-independent methods. Consequently, time series of CUE, commercial catch at age and growth-related information for Lake Nipigon lake whitefish stocks are absent for some areas and incomplete in others. A series of alternative state-space surplus production models were used to estimate biological reference points, i.e., FMSY and BMSY, and their uncertainty for this fishery. We estimated the historic and current status of the Lake Nipigon lake whitefish fishery and found that both the reference point estimates and stock status were highly uncertain. We also developed a graphical Bayesian inference approach to improve communication about the status of the fishery among stakeholders and managers. Parameter estimates and stock status were highly sensitive to the priors, and the catch and CUE time series used in the analysis. Using data from 1999-2010 resulted in much higher estimates for $r$ and smaller estimates for $K$ than when data from 1917-2010 was used, but the use of the 1999-2010 catch series generated bimodal posterior estimates of $r$ and $K$, and depletion. DIC was used to rank the models and model predictive ability was assessed using Bayesian p-values. All four models were found to be plausible; therefore, a Bayesian decision network model of the fishery was used to estimate and rank the value of information associated with these alternative hypotheses about the population dynamics. The results indicated that the VoI about the population dynamics was high at 18% of the maximum expect value of the annual profit. Options to reduce stock status uncertainty are discussed.

RISK ASSESSMENT OF ALTERNATIVE SEASONAL HARVEST STRATEGIES FOR THE LAKE ERIE WALLEYE (*SANDER VITREUS*) FISHERY: DOES IT MATTER WHEN FISH ARE HARVESTED?

Quotas for the Lake Erie commercial Walleye fishery are set annually on May 1st and end on December 31st but the fishery continues to harvest fish after that date necessitating the setting of interim allocations to cover the period from January 1st and May 1st. The interim
allocations have substantial implications for the social-ecological sustainability of the fishery. Fishery managers face significant uncertainties when developing management strategies for controlling seasonal harvest and, because the Walleye spawning period coincides with this interim allocation period, they have adopted a precautionary approach to setting the interim allocation. We used a risk-based approach to evaluate how the fishery might respond to alternative seasonal harvest strategies. Uncertainty in the stock-recruit relationship was incorporated into the analysis using a Bayesian approach. An extended Ricker function that included log-normally distributed error term described population’s recruitment dynamics. An age-structured model with discrete time was used to simulate the population dynamics and catches and to evaluate risk associated with various management decisions about interim allocations. The results indicated that when the annual fishing mortality rate is low (i.e., < 0.2), removing up to 70% of total annual catch before spawning did not impose significantly higher risk of the population dropping below a threshold of 15 million fishable Walleye than did lower percentages. When the annual fishing mortality rate was higher (i.e., > 0.2), removing up to 70% of total annual catch before spawning did impose significantly higher risk of the population dropping below a threshold of 15 million fish. These results indicate that the ecological risk of higher interim allocations may be lower than was previously thought and that there is a great need to reduce uncertainty about S-R dynamics in this fishery.

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THE IMPACT OF CHANGES IN NATURAL MORTALITY ON THE PERFORMANCE OF MANAGEMENT STRATEGIES FOR THE GULF OF ALASKA WALLEYE POLLOCK (GADUS CHALCOGRAMMUS) FISHERY

A'mar Teresa & Martin Dorn

Management strategy evaluation is used to examine the impact of changes over time in natural mortality on the performance of the current management strategy for the fishery for walleye pollock in the Gulf of Alaska. Changes and trends in natural mortality-at-age are a proxy for changes in predation impacts. Predators of walleye pollock (Gadus chalcogrammus) in the Gulf of Alaska include Pacific cod (Gadus macrocephalus), Pacific halibut (Hippoglossus stenolepis), arrowtooth flounder (Atheresthes stomias), and Steller sea lions (Eumetopias jubatus). While the biomass of several walleye pollock predators has been stable or decreasing since the 1970s, arrowtooth flounder biomass has increased significantly. Arrowtooth flounder predation on walleye pollock is predominantly on smaller fish, thus impacting recruitment. The current management strategy is evaluated under
several scenarios which account for uncertainty regarding changes over time in natural mortality-at-age for young fish.

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ADAPTIVE MANAGEMENT OF LIVING MARINE RESOURCES BY INTEGRATING DIFFERENT DATA SOURCES AND KEY ECOLOGICAL PROCESSES

Institute of Marine Research and the Centre for Ecological and Evolutionary Synthesis (University of Oslo) collaborate on large nationally funded research project ADMAR, which aims at developing a framework for adaptive management utilizing information from a wide range of sources using various modeling approaches. Particularly we focus on evaluating the feasibility and consequences of incorporating indicators generated by assessment and ecosystem models into the harvest and to test the performance of these HCRs. An eco-HCR framework translates legislatively stated management objectives into numerical, testable algorithms. According to these objectives, we have designed eco-HCR algorithms that use objectives and data as inputs and TACs for the commercially-important resources as outputs.

The main question addressed is to what extent quotas based on harvest rules remain acceptable as prudent management decisions when the data basis is poor, and when uncertainties in modeling and data are taken into account. We test the performance of eco-HCRs for data poor stocks, where information on stock sizes is limited but where stock development to varying degrees is associated with other trends in the system, such as e.g. ocean temperatures or abundances of prey or predators. Long term stock development and fisheries under the different HCRs is simulated, allowing to assess the performance in terms of long term stability and size of both fish stocks and yields. More specific questions to answer in this respect are: what is the level of source information and understanding of ecological processes required to develop well performing eco-HCRs? What is the cost, in terms of stock development and yield, in using eco-HCRs for data-poor stocks relative to traditional HCRs for data rich stocks? Results from various parts of the ADMAR-project will be discussed.
RISK ASSESSMENT FOR SOURCING SEAFOOD

Advice on “which fish to eat or avoid” is currently available from many sources (notably from the NGO sector) allied with scoring systems. This advice can vary and be at differing levels of detail. Varying or conflicting advice has created confusion for both the supply chain and consumers. Seafood buyers need robust, up-to-date and structured information on environmental risks when sourcing seafood. Depending on a buyer's needs, this may encompass the risks to the health of a particular stock, or the risks associated with the wider environmental impacts of different fisheries.

The UK Seafish Industry Authority scheme for Risk Assessment for Sourcing Seafood (RASS) will provide UK seafood buyers and processors with information on the biological status of fish stocks from which fish are either landed or imported into the UK, and the environmental impacts of fisheries catching these stocks. A key feature of RASS is that it will present risk scores for four themes: 1) stock status, 2) stock management, 3) habitat impact, and 4) bycatch impact.

Seafish have developed the RASS scoring mechanisms and an online tool for disseminating this information to our key stakeholders. It is envisaged that RASS will facilitate a two-way dialogue between the producers of science and the users of science. In this case informing the UK seafood industry sourcing policies, and allowing industry and the science community to prioritise areas for future research to reduce high-risk uncertainties.

USING LINEAR PROGRAMING FOR BOUNDED OPTIMIZATION: MAXIMIZING HARVEST WHILE MINIMIZING IMPACT ON WEAK STOCKS AND BY-CATCH SPECIES

Pacific salmon management is time-sensitive and complex; fishing seasons are short and many salmon fisheries operate on a mixture of stocks. There has been a policy shift away from managing stock complexes as a whole, towards management of the individual stocks that make up the mixed stock fisheries. This presents a challenge to managers, as decisions about openings of fishing areas need to be made with limited in-season data. In order to address this management challenge I present a flexible model for in-season management of complex fisheries and demonstrate its application using the Skeena River salmon fisheries. The model maximizes the benefits of fisheries using a linear programing algorithm to
optimize fishery openings. This linear programing model maximizes the value of the fish caught by fishing fleets operating on a mixture of stocks of fish while preventing extinction of non-target weak stocks. The decision of how many days to open the fishery is driven by the value of the different components of the stock to different fleets, but is maximized only within a domain defined by conservation limits. In addition to being able to maximizing the harvest available within the Skeena River system, the in-season model can be used in other ways; management performance is evaluated through retrospective analysis, the value of information from different types of fishery monitoring is calculated, and conservation constraints that limit fishery operations are identified. This analysis yields management tactics that if adopted can increase catches on the Skeena while preventing extinction of non-target weak stocks, and calculation of the costs to the fishery of incremental reductions in the risk of extirpation of weak co-migrating stocks.

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DECISION SUPPORT FOR RISK MANAGEMENT IN MIXED FISHERIES

Polina Levontin, Adrian Leach, Rebecca Whitlock, Xaris Apostolidis, Axel Rossberg, Rudi Voss, John Mumford, John Holt

Successful implementation of risk based management depends on effective communication of risks. Mixed fisheries pose particular problems in expressing uncertainty in management. We give examples of current decision inputs derived from single species reference points and suggest how improved stock-recruitment estimates have an impact on management in mixed fisheries. We use icon array visualisation to portray the impact of the new tools for assimilating information about stock-recruitment and other priors on the model output. In order to facilitate decision making, an intuitive representation of the modelling uncertainties is more desirable in a mixed case than it is in a single stock case. The Baltic fishery is a mixed fishery, in the sense that there are strong ecological interactions between stocks, for which simulation modelling has been completed. We present a visual decision support tool to make the value of information and risk trade-offs more immediately apparent and comprehensible to different stakeholders.
A MULTI-STOCK APPROACH TO ASSESSING THE IMPACTS OF HARBOUR SEAL PREDATION ON PACIFIC SALMON IN THE SALISH SEA

Benjamin Nelson, Murdoch McAllister, Andrew Trites

Since the 1970s, marine survival rates of two of the historically most valuable commercial and recreational salmon species in western North America, Chinook and coho, have declined dramatically, particularly in the Salish Sea, British Columbia, Canada. This is a large body of water adjacent to the most densely populated coastal region in western Canada. In contrast, harbour seals, which are known predators of these species have been steadily increasing in the Salish Sea and appear to be at, or close to, carrying capacity. This has led some scientists to hypothesize that seal predation is impeding the recovery of numerous salmon stocks, which, despite being harvested at relatively low rates for a few decades, have not returned to their historic abundances. While this is likely due to multiple factors like ocean productivity, habitat loss and interspecific competition, previous studies in Canada and United States have shown that even small numbers of pinnipeds are capable of high predation rates on returning adult salmon (>40-50%) in some years. We examine the relationship between harbour seal abundance and salmon productivity for over 20 populations of Chinook and coho salmon throughout the Salish Sea by employing stock-recruitment modelling. Our analysis shows that seal abundance is positively correlated with declines in salmon productivity for some stocks. We are currently developing more detailed modelling approaches to quantify the overall impact of changes in seal predation rates on salmon abundance and potential fisheries yields. Finally, we plan to use this approach to evaluate relationships between other environmental covariates (e.g., zooplankton abundance, pink salmon abundance, ocean conditions, etc.) and salmon productivity.
Theme 2. Decision modelling in fisheries management

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ADD A LITTLE SPICE TO YOUR LIFE

Much like cooking the art of modelling is knowing when to add that little bit of extra spice. The number of foodweb and end-to-end models are growing in number and coverage of the global oceans. While they are an informative means of exploring system dynamics they are not an appropriate risk assessment tool for many applications (such as tactical stock assessments). Nevertheless experience with such models and other multi-species methods is providing insights into what kinds of ecological idiosyncrasies can undermine the performance of population dynamics with static parameters. Environmental drivers, habitat dependencies, critical predator or prey linkages can shape population trajectories by creating bottlenecks at key points in a stock’s life history. In addition, shifting environmental regimes and ecosystem status are highlighting the importance of considering non-stationary parameters - not just for recruitment, but also size and natural mortality rates. Not all of these additional concerns will always be relevant, this is not a call for more complexity "just in case". Instead it is a simple reminder that good model practice is to periodically revise what are key processes, links and feedbacks that need to be considered for the case in point, to check the assumptions. This is something that is being more widely recognised as new hybrid and intermediate model types proliferate and ocean ecosystems change around us. As with any discipline in its early steps, however, a lot can be learnt from sharing lessons to date.

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TWO SIDES OF THE SAME COIN: STAKEHOLDERS AND INDICATORS INFORM DECISION-MAKING

Deirdre Duggan, Keith Farnsworth, Sarah Kraak, David Reid, Dorothy Dankel

Incorporating economic, social and ecological indicators into ecosystem management decisions, whilst simultaneously evaluating options according to different interests of stakeholders is a challenge in fisheries management. We introduce a framework that uses Signal Detection Theory which categorises a management response as one of four
possibilities depending on the presence or absence of a warning signal from a chosen indicator (Miss, False Alarm and two types of Hit). We apply Signal Detection Theory to a Celtic Sea case study and propose a decision support tool capable of integrating multiple indicators and incorporating stakeholder interests. The interest strengths of six stakeholder groups in four management objectives, obtained from an evidence-based categorisation of current stakeholders of the Celtic Sea, are incorporated into the decision support tool. We used 21 indicators, qualified either as "warning signal on" (indicator outside reference value) or "warning signal off" (indicator within reference value). As each indicator can take one of two forms there are over 2 million possible combinations of warning signals on and off, covering all indicator eventualities a management system may have to respond to. We compare and evaluate preferred stakeholder management responses to each combination. Conflict occurs among 5-10% of all indicator combinations depending on the level of risk applied. Results suggest seven indicators encapsulate the conflict amongst stakeholders. Resources needed to support the data collection for these seven indicators could be prioritized by managers. We explain our framework as a tool for ecosystem and stakeholder conflict management.

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DEALING WITH UNCERTAINTY IN RECENT CANADIAN PACIFIC GROUNDFISH STOCK ASSESSMENTS

We discuss the methods used in several recent age-structured stock assessments of Canadian Pacific groundfish species, such as Pacific Ocean Perch and Yellowmouth Rockfish. Uncertainty is formally captured using a Bayesian approach, specifically adopting the Awatea/Coleraine code developed by Ray Hilborn and colleagues. We demonstrate a set of outputs that communicate model results to fisheries managers and stakeholders in usable and understandable formats. Figures include historical reconstructions of biomass, current status of stocks relative to reference points, and projections of future biomass under different levels of constant catch. Decision tables present the probabilities of exceeding reference points in future years under the various catch levels. All these figures and tables retain the Bayesian uncertainty from the model output. Further figures, such as temporal phase plots of biomass and exploitation rate relative to reference points, do not include the full uncertainty, since doing so creates a cluttered figure that provides little extra usable information to fisheries managers. Although the models are technically complex, the consistent approach applied during recent assessments to summarise the results has been appreciated by managers and stakeholders. The visual outputs provide them with effective and comprehensive advice. We
end by discussing how, in practice, the managers use the probabilistic decision tables to help set total allowable catches.

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THE VALUE OF INFORMATION FROM MODELLING COMPENSATORY RELEASES OF REARED BALTIC SALMON IN FINLAND  

Polina Levontin, Atso Romakkaniemi, Henni Pulkkinen, John Mumford, Adrian Leach  

Salmon depend on access to spawning areas in the rivers to reproduce. Generating electricity from rivers requires building dams which often limits the ability for salmon to reach suitable spawning grounds. This conflict, in Finland, was addressed by an agreement by electricity companies to build hatcheries to supplement a population of salmon available to fishers. Original agreements were made based on models and biological knowledge that have since become outdated. In the near future, spurred by issues which have become evident since the introduction of reared salmon in the Baltic, these agreements will probably be re-opened and renegotiated. The model that is used to assess Baltic salmon stocks has undergone rapid development in the last couple of years. In this paper we consider the implications for one river of including new data and improving the model during the ECOKNOWS project. We calculate how the estimated number of reared fish required for compensation for population losses due the operation of dams has changed because of recent model development.

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A COMPARISON OF SCIENTIFIC APPROACHES FOR COMPREHENSIVE FISHERY EVALUATION  

The expanding scope of fisheries management is evident in broad-scale efforts to adopt an “ecosystem approach”, to consider the cumulative impacts of all activities on the ecosystem, and to incorporate harvesters and other stakeholders in management decisions. Collectively, these requirements highlight a need for decision support tools that can account for a growing set of ecological, economic, and social considerations and move fisheries management toward a more holistic and participatory process. In this talk we evaluate a range of analytical methods (e.g. ecological risk assessment, management strategy evaluation, adaptive management) in terms of their ability to integrate ecological, social and economic objectives in the provision of management advice. Our evaluation is based on criteria related to both the methodology and stakeholder participation. These include the ability to represent
trade-offs among objectives, cost, data requirement, ease of communication, and ease of inclusion in current fisheries management processes. The goals of this synthesis are twofold: (1) to inform a shared understanding of the advantages and disadvantages of each method with our collaborators in the Canadian Fisheries Research Network, which include government scientists and managers, academics, and members of the fishing industry, and (2) to identify best practices and guidelines for application of comprehensive methods in fisheries management.

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JOINING CONSERVATION BIOLOGY AND FISHERIES MANAGEMENT
CLASSICAL MODELING APPROACHES FOR SPINY LOBSTER SMALL SCALE
FISHERIES MANAGEMENT IN ECUADOR

Soledad Luna, Marc Tylor & Uta Berger

The small scale fisheries of green spiny lobster (*Panulirus gracilis*) represent an important resource for the artisanal fisheries in the Galapagos Marine Reserve and the Galera-San Francisco Marine Reserve in mainland Ecuador. Catch and effort data show a high variability among sites and years due to fishing pressure, environmental variations such as El Niño Southern Oscillation (ENSO) and recruitment dynamics. Such variations constitute a real challenge to decision making and management planning. An individual based population viability analysis (PVA) was used to simulate and analyze the trajectory of the spiny lobster population dynamics under different management and environmental scenarios. As well a Virtual Population Analysis (VPA), a catch forecast model and a surplus production model were applied to analyze the fisheries dynamics. PVAs demand a high amount of information, whereas VPAs and surplus production models are more accessible for data poor small scale fisheries. Using published information, catch and effort data and the knowledge from the Ecuadorian fishermen, managers and scientists, the classical conservation biology and fisheries analyses are compared. Furthermore, it is showed that the linkage of both approaches contribute to risk assessment and management by mutually enriching the knowledge and by explicitly acknowledging the feedback among the exploited population and the fisheries socio-economic dynamics.
Theme 3. Probabilistic fish stock assessment

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A NOVEL METHOD FOR STOCK ASSESSMENT UNDER BIOLOGICAL DATA LIMITATION

Shin-Ichiro Nakayama, Seiji Akimoto, Momoko Ichinokawa, Hiroshi Okamura

Fishery scientists who conduct stock assessments sometimes encounter problems with lack of biological information. We propose a novel method of stock assessment that can work even under serious biological data limitation. The method can estimate population parameters (intrinsic growth rate, carrying capacity etc.) from several years of daily CPUE data by combining traditional DeLury’s depletion model and a production model.

As an example of application, we introduce a stock assessment of Japanese Spiky Sea Cucumber (Apostichopus japonicus) in a small fishing ground located in Tokyo Bay. Stock assessment of A. japonicus is difficult due to the lack of biological information and the existence of “hidden resource”: fishers can catch only individuals in the fishing sand area, and therefore there remains a resource that they cannot access. We first estimated annual abundances of A. japonicus in the fishing area by DeLury’s model. Then, using a Bayesian approach, population parameters were estimated by fitting a modified production model that takes into account the hidden resource. Although we needed to use an informative prior distribution on an intrinsic growth rate to have a stable solution, the simulation analysis showed that our method potentially works well even under no biological information if the time series is sufficiently long. Our method can be widely applied to other data poor species.

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ALTERNATIVE APPROACHES TO ESTIMATION OF GENERIC REFERENCE POINTS

Polina Levontin, Rainer Froese, John Mumford, Adrian Leach, Henni Pulkkinen, Samu Mantyniemi

This paper considers several approaches toward estimating reference points in a generic way. Generic reference points are those reference points that can be applied towards a range of fisheries, or that are constructed from a range of data using statistical methods that
synthesize information, or even pre-agreed values that depend on some characteristic of the species such as availability of knowledge about it. In this paper we propose several computational methods. The first one links to analysis which estimates parameters of the stock-recruitment relationship based on ICES and FishBase data using a hierarchical Bayesian model. This method is first applied to several herring stocks, but the code is generic and applicable to other case studies where stock-recruitment parameters are available. We compare it with a novel Bayesian approach which uses simpler structural assumptions about stock-recruitment relationships; the latter method was tested as an alternative way to calculate robust and generic reference points. Both methods are consistent with previously published meta-analysis of reference points for herring stocks.

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ELICITATION OF STAKEHOLDER INPUTS IN FISHERIES MODELLING AND STRATEGIC PLANNING

Adrian Leach, Polina Levontin, Rebecca Whitlock, Xaris Apostolidis, John Holt, John Mumford

Stakeholder opinions can inform and support both fisheries modelling and policy making. Policy makers are increasingly influenced by stakeholders, including industry, scientists and other interest groups. To enable stakeholders to participate in the various stages, from modelling to the implementation and evaluation of a new management strategy, new tools are required. We developed, tested and implemented a variety of interactive graphical tools whose primary purpose was to facilitate systematic knowledge elicitation and data integration. The ECOKNOWS Stock-Recruitment Elicitation tool is an Excel based method for guiding experts through the process of expressing their beliefs about the variables of interest. Its main advantage is providing an immediate visual feedback of the distributions enabling stakeholders to arrive at a specification that most closely reflects their subjective opinions. Uncertainty in stakeholder judgement presents a challenge for elicitation so we have enabled uncertainty to be captured and represented explicitly.
MOVING BEYOND THE ‘BEST ASSESSMENT’ PARADIGM – THE INTERNATIONAL PACIFIC HALIBUT COMMISSION EXPERIENCE

It is standard practice to conduct fisheries stock assessments generating a point estimate of stock size, which is then translated into one or more future fishery catch targets and limits. Fisheries managers increasingly require estimates of uncertainty, which are generated through a variety of statistical methods, for explicit or implicit use in decision-making. The general approach often relies on the output of a single stock assessment model, and therefore does not thoroughly account for alternative hypotheses or major sources of uncertainty such as fixed parameter values, model approach (e.g., age-structured, surplus-production), model structure (e.g., treatment of spatial dynamics, delineation of fishing fleets) and data weighting. Assessment scientists following this paradigm can easily fall into the trap of endlessly searching for the ‘perfect’ model, when the real goal is to describe the dynamics of the stock and pass this information effectively to managers. In 2012, the International Pacific Halibut Commission made the transition from point estimates to risk-assessment, based on a decision table produced for the annual management process. The decision table represents a composite of probability-weighted results from alternative models, allowing a comparison of potential benefits (fishery yields) with the probabilities of various risk metrics, including stock and fishery trends and status. In 2013, the approach was extended to include the use of an ‘ensemble’ of models, following methods used in climate and hurricane forecasting. These changes have led to increased transparency about perceived risk, the availability of more information for the decision makers, and a clear delineation between scientific and policy considerations. Potential future extensions and improvements to the approach, as well as a brief summary of decisions based on this information will also be discussed.

EMBEDDING ATLANTIC SALMON POPULATION DYNAMICS AND STOCK ASSESSMENT WITHIN A HIERARCHICAL BAYESIAN INTEGRATED LIFE CYCLE MODELLING FRAMEWORK

Atlantic salmon are assessed and managed at several spatial scales, from river specific stock units (e.g., national assessment, assessment in the Baltic (ICES WGBAST)) to national or broader regional complexes (e.g., management of mixed stock fisheries in the Eastern North Atlantic Ocean (ENAO), ICES WGNAS). Hierarchical Bayesien (HB) integrated life cycle
models are proposed as a template for harmonizing different modelling approaches. Models are written in a state-space form to separate stochastic processes of the population dynamics (age and stage-structured) and of the observations. Ecological processes and various sources of data can be modelled in a probabilistic rationale, with their associated sources of variability in a hierarchy of spatial scales. This provides a framework for harmonizing the models structure and parameterization between different stock units while maintaining the specificities and associated levels of detail in data assimilation. To demonstrate the approach we developed a HB model that improves on the understanding of key drivers for the population dynamics of Atlantic salmon and the stock assessment approach used by ICES WGNAS in the ENAO. The model captures the dynamics of 5 population complexes considered by ICES for stock assessment in the ENAO. It assimilates a 42-year time series of data (1970-2012) compiled by ICES WGNAS. The hierarchical structure provides a tool for (i) assimilating various sources of data at multiple scales; (ii) separating out signals in demographic traits at different temporal (e.g., year, decades) and spatial scales (e.g., specific or common to the 5 complexes). Results show that both survival during the first months at sea and the proportion of salmon returning to freshwater after two years at sea exhibit common decreasing trends in the 5 complexes. Results support the hypothesis of a response of salmon populations to broad scale ecosystem changes.

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INFORMATION USE IN STOCK ASSESSMENTS – A BAYESIAN STATE-SPACE ASSESSMENT MODEL FOR HERRING (CLUPEA HARENGUS) IN NORTHERN BALTIC SEA

Anna Gårdmark, Andreas C Bryhn, Henni Pulkkinen, Rebecca Whitlock, Mikaela Bergenius, Sakari Kuikka and Samu Mäntyniemi

Precautionary and efficient fisheries management requires knowledge of fish stock status and fishing impacts, as well as of how likely it is that this status is true. Fish stock assessment models are therefore increasingly accounting for how e.g. observation uncertainties propagate to population estimates. However, traditional stock assessment models commonly rely mainly on fisheries and survey catch time series data. Here we develop a Bayesian state-space assessment model to analyze the effect of accounting for additional information on environmental pressures, here on recruitment, for estimates of a herring stock in the Bothnian Sea (northern Baltic Sea) for over 30 years. The model additionally accounts for prior biological knowledge on important population processes elicited from scientific literature and alternative data sources, and integrates the population dynamic model with different sets of observations data. Results show that including an observation model of population abundance indices from acoustic survey narrows the
posterior probability interval for spawning stock biomass, despite of only four years of data. In contrast, accounting for the temperature- and food-dependent survival of young-of-the-year herring had no effect on estimated SSB for the last ten years, and only minor effect on estimates for the 1980- and 1990-ies. Both model set-ups yield historical population trends that are strikingly different from those of a state-space model, used for annual advice, and which does not include prior information on biological processes. However, achieving acceptable model results in our novel model required substantial computer power and computational time, which may constrain the practical use of the model in stock assessments. Findings in the paper suggest that it may be worthwhile to test a wider variety of model assumptions and to increase the number of observation methods in order to obtain reliable herring stock estimates in the Bothnian Sea.

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A BAYESIAN APPROACH TO IMPLEMENT NEW BIOLOGICAL KNOWLEDGE IN THE EUROPEAN HAKE ASSESSMENT MODEL

European hake is an important fishing resource in the North Atlantic area. The current biological knowledge has gaps that might affect the quality of the hake assessment. Growth, natural mortality and reproduction are the main biological processes required to develop population dynamic models for assessment purposes. The parameters defining these processes such as Von Bertalanffy asymptotic length and growth rate, natural mortality, length at 50% of maturity and Beverton-Holt steepness are currently estimated outside the model and are set as constants. This approach does not take into account the uncertainty associated with these variables. Bayesian models provide a suitable platform to implement solutions to this kind of problems by considering uncertainty and allowing the use of additional biological knowledge in the form of informative priors. In this work we are presenting the progress on the development of a hake population model with informative priors based on life history invariants. First, a Bayesian model was developed to represent the dynamics of the hake population. Afterwards, available biological data for Northern hake was combined with life history invariants estimated from other hake species using a hierarchical analysis. Informative priors were developed for the key biological parameters. Finally these informative priors were implemented in the dynamic model. Our results suggest that information from other hake species may help to fill the biological gaps in the assessment and management of European hake.
Catches of sea trout (*Salmo trutta*) in the Baltic Sea have undergone steep declines in recent decades and the majority of stocks, while lacking formal assessments, are thought to be overexploited. We assess the potential viability of naturally-reproducing sea trout stocks in Rivers Isojoki and Lestijoki (Finland) under a range of exploitation scenarios. Our analysis synthesizes prior information from a variety of sources, notably Bayesian mark-recapture analyses of Carlin tag returns, hierarchical meta-analysis of biological parameters and expert opinion. First results from Bayesian mark-recapture models indicated relatively high annual harvest rates and low survivorship to spawning age. Using an age and stage-structured population dynamics model, we evaluate the effect of increasing the current minimum landing size for sea trout in the recreational fishery. Sea trout are caught as bycatch in the gill- and fyke-net fisheries for whitefish (*Coregonus maraena*); a further aim of this work is to investigate the effect of fishing gear regulations aimed at conserving sea trout stocks on whitefish yields.

The ability to rapidly include uncertainty in the parameters and model structure of fisheries stock assessment models offers significant benefits to the provision of advice. The a4a initiative (https://fishreg.jrc.ec.europa.eu/web/a4a) is developing an approach to stock assessment that takes into account uncertainty about the stock dynamics (growth, recruitment, and maturity), exploitation by commercial fleets (selection pattern) and model structure. The initiative considers parameter uncertainty in the stock life history parameters, including the growth and natural mortality parameters. For example, distributions of the parameters can be set with copulas (Sklar, A., 1959) using prior information from expert opinion or online sources, like Fishbase. Uncertainty in model selection is also a key feature of the a4a approach. It is important that alternative plausible hypothesis about the state of the
fishery (perhaps coming from a range of experts) can be efficiently turned into models. To this end, different models for life history processes, such as growth and natural mortality, and also fishing activity, such as fleet selectivity and fishing mortality, can be easily employed in the a4a approach. Model averaging methods can then be used to integrate uncertainty across the different sources. We present an example of how parameter and model uncertainty can be easily incorporated into the stock assessment process, starting only from length-based observations of catch and indices of abundance. Distributions of life history parameters are estimated and a range of models structures based on plausible hypothesis are used. Finally, we use model averaging to integrate uncertainty across the distinct components of the models.

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PRIOR INFORMATION – WHAT IS IT, WHAT DOES IT TELL US, AND HOW TO MAKE IT USEFUL?

Atso Romakkaniemi, Samu Mäntyniemi, Rainer Froese, Rebecca Whitlock, Adrian Leach, Henni Pulkkinen, Sakari Kuikka, Xaris Apostolidis, Polina Levontin, John Mumford, Etienne Rivot, Vaishav Soni, Konstantinos Stergiou

This talk discusses the concept of prior information. It addresses the questions of how informative priors can be specified, and how they can be utilised in Bayesian inference in the context of fish stock assessment. The nature of different information sources is described and various methods of analysis to process information into formal informative priors are demonstrated. Advice is offered for the incorporation of priors in models, as well as for the interpretation of priors vs. posteriors. The talk is built around the contents of an ICES Cooperative Research Reports manuscript, which is intended to guide best practice for the provision of prior information for Bayesian stock assessment. The audience of the symposium is encouraged to give feedback on the manuscript, with the aim of improving it before the publication.

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IMPROVING COMPUTATIONAL SPEED IN BAYESIAN FISHERIES STOCK ASSESSMENT

Models that are realistic in terms of their biological assumptions tend to be more complex than most of the traditional fisheries stock assessment models. This complexity leads to
practical problems with the stock status estimates: the estimation time may take several hours or days to complete even on a high-end computer. The estimation is usually done using Monte Carlo sampling methods. These methods implement different ways of producing samples from the probability distribution of the model parameters. Monte Carlo sampling is a tempting method for solving posterior parameter estimation problems because of its ease of use and several freely available software implementations. However, it usually requires tremendous amounts of computation because of its probabilistic nature; the more accurate estimates we want the larger number of independent posterior samples we need, and the more correlated the parameters are the more time it takes for the algorithms to produce independent samples that represent the true posterior distribution. We present methods that we have used to improve the computation. The improvements are made at three levels, each improving the analyses speed in different ways. The first level is the model and its intrinsic complexity, the second level consists of the algorithms used for the estimation, and the third level is the actual hardware used to carry out the computations. For the model level we propose methods to decrease the computational complexity by finding suitable re-parameterizations, simplifications and approximations for various parts of the model to allow faster sampling and better convergence of the algorithms. For the algorithm level we have explored the Hamiltonian Monte Carlo sampling methods instead of the traditional Gibbs sampling. The hardware level consists of using super computers and parallel computation.

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NEW CHALLENGES IN DEVELOPMENT OF PROBABILISTIC MODELLING IN FISHERIES

Sakari Kuikka & Samu Mäntyniemi

The GPDM model (General Population Dynamic Model) of ECOKNOWS includes several novelty approaches for biological modelling. It allows better description of biological processes both on individual level of the fish (e.g. mean fecundity of fish) and major population dynamic levels, like the relationship of produced eggs and the provided recruitment to the stock. The model has opened new views to the dynamics of e.g. Baltic herring stocks. There is still a need for additional elements. For example, the allee effect is missing and therefore the stock dynamics on very low level may give too optimistic view of the future stock development. The potential for multispecies interactions has not been utilised at the moment, and only first steps have been taken to fully account for genetic impacts of fishing. Also the density dependent catchability would be important to be taken into account in many applications. While these kinds of important features can be easily accommodated in the GPDM framework, they add to the already high computational load.
This emphasizes the need to direct efforts to development of more efficient computational methods. Developed modelling does not include economic nor sociological processes. Fisheries management is about managing humans, not fish, so the social and economic processes should be included to the modelling framework. There is an obvious lack of probabilistic economic and social models to be used as starting points. There is obvious need to study how the risk communication of the results should be arranged. When biological uncertainties are modelled in a realistic way, the overall uncertainties about the future are easily huge. End users that are used to see forecasts made by point estimate models have difficulties to realize how difficult the prediction of future stock dynamics really is. Also the use and role of prior probabilities included is a challenge for risk communication.

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COMPUTING BAYES FACTORS TO EVALUATE THE CREDIBILITY OF DIFFERENT MODEL RUNS IN FISHERIES STOCK ASSESSMENT

It is common in fish stock assessments for analysts to account for uncertainty by presenting results from different model runs. The different runs could include different settings for priors, historic catches, the stock-recruit function, vulnerability by age, stock-mixing, catchability and predator-prey interactions. Key results can be highly sensitive to these different settings. In both scientific and policy contexts, it may thus be of interest to evaluate the credibility of different model runs. I review the concept of Bayes factor (BF) and how it’s been computed and applied to evaluate the credibility of different assessment model runs. These include, e.g., stock assessments that have modeled interannual variation in predation on rockfish by seals, and others that have considered different hypotheses about the shape of the surplus production function. BFs provide an objective and rational basis with which to rank the credibility of different model runs and, where very small, eliminate particular scenarios from consideration. BFs have often shown that different runs are similarly credible but, in some instances, shown that some model runs are considerably less credible than others and provided a useful framework with which to address a broad range of uncertainties in fish stock assessments. BFs require numerical approximation and results from numerous stock assessments indicate that importance sampling offers a numerically stable and reliable technique for their computation. Available MCMC methods to compute BFs are either difficult to implement correctly for stock assessment type models or yield highly unstable approximations. Furthermore, care needs to be taken in formulating priors for parameters within each model so as to avoid inadvertent prior ranking of models. Model credibility rankings obtained by BFs can also deviate considerably from rankings determined by other approaches such as AIC, suggesting that AIC approximations of model weights.
ENVIRONMENT AND ANCHOVY LANDINGS: A BAYESIAN MODEL WITH DUAL-TIME RESOLUTION

Recent studies illustrate the importance of coupling the life-cycle with environmental conditions for the modelling of the anchovy population dynamics in the Gulf of Cádiz (NE Atlantic). Intense easterlies, stratification of the water column and discharges from the Guadalquivir River have been identified as main factors driving the dynamics of anchovy (*Engraulis encrasicus*) during the early life stages. The natural scale of the process and the availability of weekly data make it logical to model these early stages under this time resolution. After recruitment, anchovies are less susceptible to adverse environment and their mortality is mainly caused by fishing which is aggregated into monthly statistics. We have developed a new Bayesian model with a dual resolution including the change of time-scale inherent in the ontogenic development. Our model provides consistent estimates of stock-dynamics while representing the uncertainty that characterizes the ecosystem influence on recruitment.

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BAYESIAN APPROACH TO FISHERIES STOCK ASSESSMENT

Despite their growing popularity, many of the Bayesian stock assessments have only partially followed the logic of Bayesian reasoning. The most notable deviation has been the idea borrowed from statistical data analysis, according to which all the model parameters should be statistically identifiable based on the observed data at hand. This has led to the practice of using different model structures depending on the amount of data available. The aim of the ECOKNOWS project was to develop a Bayesian stock assessment modeling framework which allows for biologically credible population dynamics and is able to quantify the uncertainty arising from the usual confounding of the model parameters. The General Population Dynamics Model (GPDM) was designed to have a modular structure which describes the essential features of the population dynamics. The population can be structured by one or more attributes. For example, age-growth and length-species structures can be specified. The transition of the population from one time step to the next is defined as a probability distribution. This distribution is derived from the assumption that individual fish are correlated due to schooling behavior or patchy environment. Tailoring the GPDM
model to an assessment problem requires thorough search for existing information. An important part of the project was to develop ways to formulate the information found from literature, databases and experts into prior probability distributions that describe how well the biology of the population is known. Once the alternative model structures and prior distributions for parameters have been specified, the Bayesian approach is to update these beliefs in the light of observed assessment data. Usually the data is not very informative about most of the parameters, but can provide new insights about parameter combinations. This poses a difficult computational challenge.

Theme 4. Oil spill and eutrophication risk analysis

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A BAYESIAN PREDICTIVE APPROACH FOR OIL SPILL IDENTIFICATION

Statistical comparison of oil samples is an integral part of oil spill identification, which deals with the process of linking an oil spill with its source of origin. In current practice, a frequentist hypothesis test is often used to evaluate evidence in support of a match between a spill and a source sample. As frequentist tests are only able to evaluate evidence against a hypothesis but not in support of it, we argue that this leads to unsound statistical reasoning. Moreover, currently only verbal conclusions on a very coarse scale can be made about the match between two samples, whereas a finer quantitative assessment would often be preferred. To address these issues, we propose a Bayesian predictive approach for evaluating the similarity between the chemical compositions of two oil samples.

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A BAYESIAN NETWORK APPLICATION FOR ASSESSING THE COLLISION INDUCED RISK OF AN OIL ACCIDENT IN THE GULF OF FINLAND

The continuing growth of the maritime oil transportation at the Gulf of Finland (GoF), North-Eastern Baltic Sea increases environmental risks by raising the probability of oil accidents. A probabilistic risk assessment application is presented, that integrates the work of a multi-disciplinary research team and information from several sources. Bayesian Networks as a method enable large amount of information about causalities to be integrated
and utilized in probabilistic inference. Key results concerning the likely future development of maritime traffic and oil transportations in the area and the following risk of environmental pollution are provided. Two alternative risk management options, decreasing the probability of tanker collisions, are compared.

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RISK ANALYSIS OF ASSUMED NEARSHORE OIL SPILLS: DRIFT SIMULATIONS USING MODEL BASED LONG-TERM RECONSTRUCTIONS OF METEO-MARINE CONDITIONS

In October 1998 the cargo vessel Pallas ran aground close to the island of Amrum and leaked 244 tons of oil. The subsequent oil spill affected about 12,000 sea birds located in the North Frisian Wadden Sea. We take this real accident as an example scenario for an oil spill endangering the Wadden Sea. Specific consequences of an accident, however, depend on local meteorological and hydrodynamic conditions. We study how the Pallas accident scenario might have developed had it happened at any other time. For this purpose we use model based reconstructions of meteo-marine conditions in the years 1993-2003 as a quite reliable surrogate for reality. In particular we also investigate whether and how often the application of chemical oil dispersants could have helped to prevent pollution of intertidal areas. We calculate the variability of simulated oil spills and their consequences by applying the particle drift model PELETS. An oil weathering module includes the processes of spreading, evaporation, and dispersion. Hypothetical oil spill events at the same location where the cargo vessel Pallas ran aground were initialized every 24 hours within the 11 year simulation period. As maximum integration time for each event was set to 14 days. For each event we compared two scenarios, with and without the application of chemical dispersants respectively. As oil dispersed in the water column is less affected by wind forcing than oil slicks on the surface, the application of chemical dispersants may affect the drift path of an oil spill and thereby potentially prevent the Wadden Sea from being polluted. The ensemble simulations we performed (about 4000 under various realistic weather conditions) allow for assessing benefits from the application of dispersants within the framework of a risk analysis.
EVALUATING THE COST-EFFECTIVENESS OF OPTIONAL MEASURES TO CONTROL OIL ACCIDENT RISKS

Bayesian networks enable the integration of different types of information and submodels into large metamodels. This feature can be utilized in the analyses of extremely complex entities and in the evaluations of alternative actions in managing the related risks. We built a decision support model to analyse the cost-effectiveness of optional measures in reducing the risks of oil accidents in the Gulf of Finland. The model integrates results of models that estimate the likely annual number of collision and grounding accidents in relation to scenarios for oil transportation volumes for the future, and a submodel that estimates the oil leakage and the amount of oil in the sea, resulting from the different accident scenarios. Based on this information, we evaluated the cost-effectiveness of the following options: 1) a new navigation support system for the communication between ships and shore (Enhanced Navigation Support System ENSI), 2) extending the obligation of tankers and passenger ships to use external pilot, and 3) improving the crashworthiness of tankers. The implementation and maintenance costs of the risk control options were analysed in relation to the theoretical annual oil recovery costs. The results indicate that ENSI would be the most cost-effective measure to control the oil accident risks, and that pilotage and improvements in crashworthiness are effective but costly.

A WEB AND MOBILE MAP APPLICATION FOR SUPPORTING COMBATING OPERATIONS IN MINIMIZING ECOLOGICAL IMPACTS FROM OIL SPILLS

Maritime oil transportation continues to grow as the demand on energy increases around the world. The Gulf of Finland, the innermost part of the Baltic Sea, is an area that witnessed significant increase in oil transportation in the last two decades. The amount of transported oil is expected to be 200 Mt in 2015, a tenfold increase since 1995. Such figures in an area with intensive maritime traffic call for a full preparedness for potential oil spills. Nature values on the coastal areas are a potential recipient of the ecological risk posed by an oil spill. The availability and accuracy of information on nature values is crucial for enhancing the efficiency of oil spill combating operations and thus minimizing the harm on the coastal ecosystems. We present here geospatial web services and a map application, the OILRISK Map, which we developed for decision support of the oil combating teams. During the oil
spill combating operations spatial decisions must be made, in order to prioritize nature values to be protected based on their sensitivity to oiling and response to safeguarding. We exploit advances in geospatial technology to develop a web map application that can be used from mobile devices in the field for real time decision support. This is a part of work done in the OILRISK project, Applications of Ecological Knowledge in Managing Oil Spill Risk (2009-2013). The development of decision support systems like the one presented here involves people from different backgrounds and with different interests. It also requires clear definition of the hazard, the risk recipients, the response needed, and the environment of the end user. We discuss issues related to and lessons learned from the development of the OILRISK Map.

**Theme 5. Environmental risk assessment for marine areas**

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**TRAWLING: FINDING COMMON GROUND ON THE SCIENTIFIC KNOWLEDGE REGARDING BEST PRACTICES**

An international collaboration is attempting to summarize what is known about the impacts of mobile bottom contact gear on biota and seafood production. While the project is roughly half done, this talk summarizes the approach and gives highlights of progress to date. A central feature of the project is a risk analysis that calculates the impact of bottom contact gear on different taxa in a range of marine ecosystems. Major data assembly is being done on scientific studies of the impact of bottom trawls on benthic biota, and on the extent of trawl effort in different ecosystems. In addition, we are also reviewing what is known about the indirect impact of bottom contact gear on target species and will evaluate the consequences of a range of proposed best practices for bottom trawling. Additional details about the project and the study committee are available at [http://trawlingpractices.wordpress.com/](http://trawlingpractices.wordpress.com/)
A PRELIMINARY MICE APPROACH FOR EUROPEAN HAKE (MERLUCCUS MERLUCCIUS) AND NORWAY LOBSTER (NEPHROPS NORVEGICUS) INHABITING THE CENTRAL ADRIATIC SEA

Angelini S., Hillary R., Morello E. B., Plaganyi É. E., Martinelli M., Manfredi C., Isajlović I., Santojanni A.

Owing to interacting oceanographic and biological characteristics, the central Adriatic Sea is a very species-rich area, making it an important fishing ground both for Italian and Croatian vessels. Fishing activity is mainly focused on demersal resources, the most important commercial species being European hake (Merluccius merluccius) and Norway lobster (Nephrops norvegicus). These two species are exploited by the same fishing gear and share most of their prey. In the last two decades their catches have rapidly declined, despite a reduction in fishing effort. These features make the Central Adriatic Sea an appropriate area to apply a Model of Intermediate Complexity for Ecosystem assessments (MICE) approach with the aim of 1) evaluating the state of these resources, and 2) evaluating different management strategies. MICE joins the best features of single species models with an ecosystem view, being both question and data-driven with system uncertainty accounted for directly. The model uses single species stock assessment outputs as the starting point and proceeds in describing the plausible trophodynamic and technical interactions within this defined system. Following the MICE philosophy (i.e. reduction of complexity), prey items were grouped into few meaningful groups based on their life-history characteristics. Biomass dynamics of these groups were described using a simple equation covering the reproductive, density-dependent, predator consumption and harvesting dynamics. Biomass dynamics were projected for ten years, allowing preliminary evaluation of management strategies. The study shows a high fishing pressure on the juvenile individuals of the predator species that lead to a quick decline of these stocks. The slight increasing trends of prey groups do not compensate for the loss of the predator species, underlining the primary need to protect the recruits of hake and Norway lobster in an area which is known for its nursery properties with regards to hake.
A RISK-BASED APPROACH TO EVALUATING NORTHEAST U.S. FISH COMMUNITY VULNERABILITY TO CLIMATE CHANGE

Wesley Patrick, Sarah Gaichas, Jason Link, Jon Hare

Risk assessment methods are used worldwide to evaluate threats posed by fisheries and other impacts on living marine resources, and to prioritize management of these threats. We derive a simplified risk analysis for aggregate fish communities as a preliminary tool to identify priorities for further detailed assessment. Because some of the largest observed rates of sea surface temperature increase are on the northeast U.S. continental shelf, we focused on climate change-driven risks to marine communities in this region. We evaluated climate vulnerability for six communities across two ecosystems: both commercial and non-commercial demersal fish, pelagic fish, and benthic invertebrates in the Gulf of Maine (GOM) and Mid-Atlantic bight (MAB). We first evaluated the probability that anticipated climate changes (e.g. warming water, decreased salinity, increased acidity, altered boundary currents) would occur in these regions, and rated the potential severity of change over the next 10 years. Then, we evaluated the sensitivity of each biological community in each region using 12 attributes (e.g. habitat and prey specificity, temperature and acidity sensitivity, larval dispersal, adult mobility, population productivity, etc.). Exposure to the key climate risks was related to community sensitivity in each region for an overall assessment of climate vulnerability. Climate risks from increased surface water temperature, sea level rise, and earlier spring were rated moderate to high in both regions, with additional risks in the GOM from increased bottom water temperature, stratification and river inputs. Benthic invertebrates were rated most sensitive, with demersals intermediate and pelagics lowest. Two MAB communities were rated more sensitive than corresponding GOM communities, but greater short term climate risks in the GOM indicated increased exposure for GOM communities. Overall, this simple analysis may help prioritize short-term regional climate risk management actions.
The New England Aquarium (NEAq) uses risk assessments to advise seafood companies on how to implement visionary and realistic sourcing policies to ensure greater environmental accountability throughout their supply chains. Much of this advice for wild seafood is generated by NEAq’s Wild Fisheries Decision Ranking Tool (WFDRT), a unique methodology of assessing environmental risk that provides comparable and actionable results. Using the WFDRT, NEAq compares environmental impacts of discrete fishery sectors of the same or similar species. The WFDRT utilizes data on five factors (called decision points, or DPs) that are critical to defining the long-term viability of a fishery and its ecosystem: stock health, fishery management, takes of endangered, threatened, and protected species, habitat impacts, and target/non-target species bycatch. The data for each DP are weighted and mapped on decision matrices. After all fishery sectors for a given species have been assessed, the resulting locations on the main decision matrix directly reflect their relative impact. NEAq formulates recommendations based on the spread of these rankings. Where there is a clear distinction among sectors, sourcing recommendations usually take on one or more of the following forms: engage with stakeholders to address areas of concern; increase promotions of or switch to more sustainable options; or reduce the percentage of, or halt sales of a particular species or source. By using the WFDRT, fishery sectors that receive lower rankings are encouraged to address outstanding issues; only by shifting to better practices will their relative rankings improve. Similarly, a high-ranked sector will have to show continual improvement to maintain its position as the preferable source. By engaging in this assessment process with NEAq, businesses are able to implement sustainable sourcing policies and work with their suppliers to improve the environmental performance of the fisheries they source from.
concepts of risk, vulnerability and impact were often synonymously used. While all studies expressed risk as a combination of the exposure to a pressure with a measure of sensitivity, the quantification of the latter remained still a difficult task often involving expert knowledge. Also an explicit assessment of uncertainty was often lacking. To address some of the identified gaps we used a GIS-Bayesian Belief Network framework to showcase the steps of risk characterisation, risk analysis and risk evaluation in relation to benthic disturbance by bottom trawling in the German EEZ and coastal waters of the North Sea. The risk analysis produced spatial explicit measures of disturbance of benthic communities where values >1 reflected higher level of bottom trawling frequencies in relation to local frequencies of potential recovery. We found great differences in spatial patterns of disturbance when assigning different impact weights to the six fishing fleets distinguished. For the risk evaluation we simulated a spatial shift of the international fishing effort of two beam trawl fleets, which are affected the most by future offshore wind development. Assumed findings for the prior distribution of the trawling frequencies resulted in an increase of local disturbance ratios in 9 % of the study area. Results highlighted the need for spatial explicit measures and underlined that fact that local disturbance ratios averaged over the study area are meaningless and not useful to support decision making processes. In conclusion, MSP processes should embed ERA frameworks which allow for the integration of multiple risk assessments and the quantification of related uncertainties at a common spatial scale.

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ON THE USE OF GRAPHICAL MODELS FOR MERGING STATISTICAL ANALYSES AND CAUSAL CONCEPTS FOR MANAGEMENT PURPOSES

Identification of interaction structures is probably the most crucial point in multivariate regression. A Bayesian Network (BN) may comprise a whole hierarchy of such statistical models. To properly represent effects of interventions (management actions), links in a BN (predictors in multiple regression) should represent causal relationships. Unfortunately it is impossible to derive cause-effect relationships from observed data. At the utmost, monitoring data will reveal patterns of conditional independences (represented in undirected graphical models) as shadows of the underlying causal processes. We illustrate the approach for the example of inter-annual variations of spring conditions at monitoring station Helgoland Roads (German Bight). In a second step we introduce a directed graph consistent with the analyzed set of conditional independences. This directed graph interpreted in terms of linear multiple regression models provides a basis for extensive Monte-Carlo simulations. In numerical experiments we study the reliability of models calibrated based on different sample sizes. We show that imposing the constraints of a conditional independence graph
may improve robustness by a reduction of over-fitting. Problems that arise from small sample sizes may partly be compensated by the use of information about interactions in a larger context. We conclude that graphical models are useful in two respects, both related to the merging of statistical analysis and causal concepts for management purposes. Firstly, conditional independence graphs may serve as characteristic fingerprints of multivariate observations to be compared, for instance, with graphs analyzed from corresponding causal model simulations. Secondly, we propose using conditional independence graphs for better calibration of statistical models based on small samples. The latter aspect is relevant for scenario simulations that form the basis for subsequent risk analyses.

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ASSESSING THE CURRENT STATUS OF BALTIC GREY SEAL POPULATION AND PREDICTING ITS FUTURE

The population size of Baltic grey seals (*Halichoerus grypus*) has substantially increased in recent years leading to a conflict between seals and coastal fisheries in the Baltic Sea. Grey seals damage fishing gear and catches and an unknown number of seals drown in fishing gear. This has led to the need for new management measures and, thus, a better understanding of the current status and future trend of the grey seal population under alternative management scenarios. We build a biologically consistent state space model to estimate the temporal changes in the seal population and predict the development of the population under alternative management options. As the uncertainty related to the subject is high, several complementary data sets are used and specific attention is paid to model construction and prior elicitation. These include, for example, survey counts, by-catch estimates from earlier studies, fishing and hunting statistics, statistics from sampled grey seals, expert interviews and literature. The model is age-sex structured and provides estimates, among others, for the population size and total by-catch in age-sex classes. We forecast the population development under a few alternative management decisions related to hunting and by-catch, and different ice extent scenarios in the breeding areas of Baltic grey seals that are based on climate warming scenarios. The results indicate a clear difference in the natural, hunting and by-catch mortalities between males and females. These differences have also direct effect on the expected long-term outcomes of alternative management decisions. Moreover, the sea ice extent in the Baltic has clear effect on pup survival and the worst climate warming scenarios will likely affect the Baltic grey seal population negatively.
UNDERSTANDING ENVIRONMENTAL EXTERNALITIES IN TERMS OF ECOLOGICAL RISK

Externalities or external costs, i.e. non-market effects in the utilization of ecosystem services (ES), are trailed for plaice as a target species for fisheries in the southern North Sea, for benthic habitats affected by the fisheries and for a non-target by-catch species, thornback ray, in relation to catches obtained from the plaice fisheries as ES. Alternatively to monetary valuation of ES and their corresponding environmental impacts, relative ecological risk assessment (RERA) is applied to quantify externalities in a historical period 1924 to 1938 and for 1985-2010 with the German EEZ as reference area. Two reference levels are adopted for each ecosystem component, i.e. the target reference level representing conditions equivalent to maximum sustainable yield (MSY), and the limit reference level indicating a high risk of extinction. During the entire period, ecosystem state was below the target reference level for all ecosystem components representing a state of chronic negative change except for plaice in the years 2008-2010, when fisheries was approaching MSY levels. Due to high fishing effort in the 1930s, 10 percent of the selected benthic communities and thornback ray were confronted a high risk of extinction. For benthic communities, exchange with less impacted sites is assumed to have replenished the more impacted sites, whereas thornback ray became locally extinct. The relationship between utilization of ES and externalities is not invariant, caused by changes in the ecosystems carrying capacity and technological progress. Spatial management is proposed as one means to alleviate externalities while still exploiting ES. It is suggested that the target reference level is sufficient to meet requirements for Critical Natural Capital, thus linking the RERA concept and the economic concept of strong sustainability.
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COMPARISON OF ASSESSMENT METHODS FOR DATA-POOR STOCKS: CASE STUDY OF GREENLAND HALIBUT OFFSHORE WEST GREENLAND

A case study of stock assessment for the Greenland halibut fishery in west Greenland is presented. The traditional stock assessment methods used so far for the stock fail to provide any reference points and the results obtained are considered highly biased due to the limitations of the available data. Therefore, in this work, alternative assessment methods developed for data poor cases are applied to Greenland halibut, to efficiently utilize all the available information on the species and to produce reference points for the stock. The data limited methods used are: 1) the catch-MSY tool utilizing available catch data, 2) the yield-per-recruit analysis utilizing life history invariants, and 3) the DCAC method utilizing total catch data. The models yielded similar results: a precautionary proxy of $F_{MSY}=0.8-0.15$ year$^{-1}$, $B_{MSY}= 160000$ t, and $MSY= 19000$ t. The performance and limitations of the models were evaluated, concluding that there is a need to improve the methods used in the assessment of data-poor stocks. To this end, future research directions involve the development of a stock assessment model that balances reasonable realism and complexity required for assessing data-poor stocks. Hierarchical Bayesian methods will be used for the development of the model, as they allow for the formal incorporation of a wide range of information provided by various fields of biological research and utilize available data from other similar stocks.

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EVOLUTIONARY PRESSURES UNDER THE CURRENT FISHING PRACTICES FOR EUROPEAN HAKE (MERLUCCIUS MERLUCCIUS)

The dynamics and viability of the exploited fish populations are increasingly endangered by the impact of modern fisheries. The increasing fishing pressure has been recorded to cause declines in age and size at maturation in a variety of marine fish species. To test that potential impact in relation to European hake (Merluccius merluccius), I have aimed to detect heritable phenotypic changes in the hake population under the current fishing intensity. Using a data-set of 64 individual-based growth parameters of the species and an individual-based simulation, which incorporates quantitative genetics, ecological processes and biological characteristics, I have simulated ecological and evolutionary dynamics of
hake. Species phenotypic traits were observed through three different scenarios which showed significant ecological consequences for hake population under the current fishing strategies. However, no evolutionary changes were detected in life-history traits, e.g. growth and age and size at maturation. Nevertheless, the ecological impact observed under the current fishing practices can pose a severe risk through direct population declines and, therefore, would need further reconsideration in order to preserve future hake fisheries.

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A MARINE SPATIAL PLANNING TOOL FOR THE CONSERVATION OF MARINE ECOSYSTEM IN THE EASTERN BALTIC SEA

Developing efficient measures to protect the marine ecosystems requires interdisciplinary approach. Ecological knowledge based on marine biology and fisheries science must be integrated with information about human pressures. Interactive and self-learning technical solutions aid in interpreting the accumulated knowledge. Finally, this knowledge must be communicated to the stakeholders. In our study we collect knowledge on geology, biology and human pressures from the Gulf of Finland (GOF), which is the easternmost part of the Baltic Sea. The objectives are 1) to determine any correlation between the geological and environmental parameters and species diversity, and also 2) to assess methodologies to predict species occurrences. Next, 3) to determine the impacts of human actions, e.g. marine oil transportations and fish farming, on marine ecosystems. On the basis of the results obtained, we perform a decision analysis between demand for marine resources and conservation of nature values. The analysis is carried out using a Bayesian network (BN) and incorporated into a GIS-based marine spatial planning (MSP) tool which can be used to identify the locations with competing or compatible conservation value and human activities. In our study we have chosen to measure marine nature values as a presence of certain benthic key species or fish larvae. In order to do this, the BN also includes a species occurrence prediction model. The BN can take multiple objectives into account and help planners to achieve sustainable reconciliation of human activities and nature values, such as the cumulative impacts of acute oil spills and the long-term impacts of fish farming on marine ecosystem in order to improve plans for potentially harmful uses, such as safer locations for shipping lanes in the GOF.
PROACTIVE GOVERNANCE TO MINIMIZE OIL ACCIDENT RISKS IN THE GULF OF FINLAND

It has been acknowledged that ensuring maritime safety in the Gulf of Finland requires proactive and predictive safety management approaches in addition to the current reactive approach. While the reactive way means responding to events that have already happened, proactivity is based on analysing risks, and the predictive approach strives to identify potential future problems by interpreting the performance of the system in its actual operations. We reviewed procedures of risk governance both from the theoretical and practical perspective, focusing on examples from the fields of fisheries management and nuclear safety management. Based on that, we propose a proactive governance framework for minimizing the oil accident and other maritime risks in the Gulf of Finland. The regional framework stresses the importance of communication and stakeholder involvement in identifying and managing risks. We believe that a participatory risk governance framework can improve maritime safety both by developing effective management measures and by enhancing safety culture in shipping companies and among seafarers. It can also provide a path towards predictive maritime safety management.

GULF OF FINLAND UNDER PRESSURE - INTEGRATED ANALYSIS AND MANAGEMENT ADVICE FOR THE HERRING FISHERY

Baltic Sea is highly stressed brackish water basin and it is currently in unhealthy ecological status. The major concern is excessive nutrient load causing eutrophication with negative impact on spawning habitat quality and oxygen concentration in the coastal zone. Simultaneously, rapidly increasing oil tanker traffic poses a threat to the ecosystem. Recognition of the key stressors calls for holistic approach, but understanding and managing ecosystems under numerous anthropogenic pressures require methods that enable quantitative analysis about joint effects of different factors in one framework. We constructed a Bayesian influence diagram, which includes three stressors present in the Gulf of Finland. The outcome of the integrative model is a set of probability distributions for future nutrient concentrations, herring stock biomass, and achieving the internationally
adopted water quality targets. The derived probability distributions can be used to forecast the probability of reaching the management targets for each alternative combination of management actions. We quantify the impact of fishery, nutrient load and an oil spill on the Baltic herring population dynamics. The probabilistic population dynamic model also includes sea surface temperature, salinity, and abundance of sprat and cod stocks as explanatory variables.

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LESSONS TO AVOID A FISHERIES SCIENCE SCANDAL

Fisheries science that informs policy-making is plagued by uncertainties; the stakes of the policies are high and value-laden and should be treated as an example of post-normal science (PNS). To achieve robust governance, understanding of the characteristics and implications of the scientific uncertainties for management strategies is central to the overall problem. This can be achieved using tools such as pedigree matrices and uncertainty matrices, as developed by PNS scholars and used in similar science policy arenas on other complex issues.

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APPLYING A RISK-ASSESSMENT FRAMEWORK TO AQUACULTURE-ENVIRONMENT INTERACTIONS IN CANADA

Ingrid Burgetz, Daniel McPhee, G. Jay Parsons

Aquaculture activities in Canada have been increasing, following similar trends worldwide. Consistent with predictions by the UN-FAO, the aquaculture industry in Canada is looking to increase production. Concurrent with this increase in production there is a changing aquaculture regulatory framework in Canada, and social license questions, particularly around the interactions between finfish aquaculture and wild salmon populations. The assessment of environment-aquaculture interactions is a component of Canadian regulatory and policy decisions; however, until now this has primarily been achieved for specific situations and using a more directed approach to the characterization of risks. As a result, there is an increased interest by resource managers and aquaculture regulators in Canada for more standardized, robust, and predictable approaches to the characterization of the environmental risks associated with aquaculture practices in order to inform policy and
management decisions and regulatory development. In response, an aquaculture science environmental risk assessment framework has been developed, and is being finalized for implementation within the Department of Fisheries and Oceans Canada. This risk-assessment framework is modeled principally on the ISO 31000 risk management framework (ISO, 2009), with elaborations specific to the aquaculture context within Canada. Previously, a “Pathways of Effects” of Aquaculture in Canada was developed and scientifically validated (DFO, 2009), which characterized aquaculture activities and the associated stressors and effects. This Pathways of Effects model of interactions will be the basis for the development of aquaculture science risk assessments specific to aquaculture activities in Canada. Initial assessments will focus on determining the risk of pathogen transfer, and by extension disease occurrence, from farmed Atlantic salmon to specific Pacific salmon species or stocks, and assessing risks associated with genetic interactions between escaped farmed Atlantic salmon and native Atlantic salmon populations in Eastern Canada.

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CASH FLOW MODELLING TO ASSESS ENTERPRISE LEVEL FINANCIAL VIABILITY AND THE IMPACTS OF POLICY OPTIONS ON A SMALL BOAT GROUNDFISH FLEET IN BRITISH COLUMBIA, CANADA

British Columbia (BC) groundfish fisheries have undergone major change in recent years. An integrated groundfish management regime was introduced in 2006 which included 100% monitoring and expansion of the individual transferable quota system. Despite the opportunities for the small boat fleet presented by integration, rising costs and limited access to quota have been identified as major challenges for these small, independent enterprises. Concerns have been raised about the long term financial viability of the fleet. To address these concerns, approaches to evaluate the long-term impacts of different policy and management options are being developed within a Management Strategy Evaluation (MSE) framework, which includes population dynamics and fleet dynamics components. A central aspect of the fleet dynamics component is the assessment of enterprise level financial viability. Cash flow analysis is commonly used in finance to value an enterprise and assess financial metrics such as rate of return. Typically, cash flow models are used where there is full access to company financials. Cash flow modelling can also be used to assess a specific project, company or industry sector by a third party. In such cases and where the financial data is not readily available, data must be compiled from a variety of public and/or confidential sources. In the case of the BC fishery analysis, financial data has been compiled over a number of years from both public sources as well as industry sources providing
confidential data, yet significant data gaps remain. Simulation modelling techniques will be employed to address these data gaps. The cash flow model will then be used to inform the fleet dynamics model. Initial results of the cash flow analysis suggest that a critical determinant of enterprise viability is the degree to which fishing quota must be leased, with the costs of quota leasing being the largest single cost category for vessels leasing the majority of the quota that they fish.

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USE OF BAYESIAN DECISION NETWORK MODELLING TO EVALUATE THE IMPACTS OF BOCACCIO MANAGEMENT OPTIONS ON A SMALL BOAT GROUNDFISH FLEET IN BRITISH COLUMBIA, CANADA

D.N. Edwards, M. McAllister, D.G. Edwards

An integrated management regime including extension of the individual transferable quota system and 100% onboard monitoring was introduced in the British Columbia (BC) groundfish fisheries in 2006, largely in response to concerns over the depletion of rockfish populations caught in the fisheries. Continuing concerns over the status of some species have led to a number of management changes since 2006, including the establishment of total allowable catches and the implementation of individual transferable quotas for additional species. Concerns have been raised that these management actions could have wide-reaching negative impacts on the small boat fleet. In particular, Bocaccio rockfish has been noted as both a species that does not appear to be recovering and where management actions to reduce catch could drastically limit fishing opportunities. Bocaccio is primarily caught by the groundfish trawl fleet (>80%), but is also caught in small numbers by other fleets including groundfish hook and line. A Bayesian Decision Network (BDN) model was developed to explore the impacts and trade-offs between different catch limit and fleet allocation options on the stock and on the groundfish fishing fleets. The BDN model clearly demonstrated the importance of allocation. An important feature of the BDN analysis was the ability to evaluate the impact of key assumptions in the model, particularly with respect to interception rates in the different fisheries and the relationship with stock size. This ability, coupled with the fast response time of the Hugin software, points to opportunities to use the BDN approach within the stakeholder processes central to the management of the BC groundfish fishery. Discussions with industry also served to demonstrate the application of BDN modelling beyond the BC groundfish example for the assessment of options and trade-offs in fisheries management elsewhere in Canada.
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