Theme Session Q
Advantages of Bayesian analysis for fisheries and ecological research

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Bayesian analyses are providing innovative new solutions to research and policy problems commonly faced by environmental scientists and decision-makers. Two distinct advantages of Bayesian analyses are that they allow the incorporation of expert knowledge and knowledge from other similar situations in the form of the prior, and they characterize total uncertainty in a compact and useful way via the posterior distribution. This allows the parameterization of processes that may be difficult to analyse by other means and permits sophisticated risk analyses that are requested by managers and policy-makers. Bayesian network analysis has become more common in community studies as a means of propagating information through a network of functional nodes (e.g. species, trophic groups) to reveal dependencies that may otherwise be ignored. Currently, the ecosystem approach to fisheries management needs to take into account these dependencies. There is increasing need to learn about these dependencies from all available information sources and Bayesian networks offer many advantages for this type of analysis.

Papers were sought which explore the use of Bayesian analyses in stock assessment, community ecology, and environmental science with a focus on:

- uses of Bayesian hierarchical modelling to learn about fish population dynamics, fisheries ecology, fisheries dynamics, and environmental processes;
- uses of Bayesian approaches to account for conflicting stakeholder preferences, inform model choice, and account for model choice uncertainty in risk and policy evaluation;
- Bayesian analyses that have elicited expert knowledge and synthesized information contained in large data sets;
- Bayesian network analyses that integrate different types of knowledge (e.g., biological, sociological, and economic).

The 23 abstracts were diverse in their approaches to Bayesian analysis and covered all of the chosen topics of focus. The session took place in two parts, Wednesday 25th at 10:00–13:00 and Thursday 26th at 8:30–12:00. There were no no-shows, and the audience participation varied between approximately 35–70 persons throughout the session, with >50 people present at most times.

A speaker in Session Q, Dr. Arni Magnusson from the MRI, Iceland, received the best presentation award for his talk titled "Uncertainty in age-structured stock assessment of Icelandic saithe: Effect of different assumptions, methods, and excluding data components". As the award committee noted: The presenter gave a comprehensive, well-structured clear presentation. It invoked a good discussion and the presenter answered all question revealing his wealth of knowledge about this topic.

There were a number of clear themes emerging from the session and a general consensus that Bayesian approaches to analysis appear to offer much potential for fisheries and ecological research:

1) The incorporation of prior knowledge in the form of priors is a key topic for ICES due to the need to constrain parameters when data are limited. It is also necessary to ensure that data are consistent with knowledge in the literature. However, care is needed to ensure that models based strongly on priors (where the knowledge is, in turn, based on historical data) is not assessed on the same data – to avoid circularity in analysis.

2) Hierarchical models that can combine data at different levels of granularity and aggregation offer much promise. The sort of data typically available to ICES is heterogeneous and often collected at different spatial and temporal scales.

3) Data integration was common to many talks and the ability of Bayesian models to integrate different types of data, as well as pre-defined models and knowledge into unifying probabilistic models appear to be successfully undertaken by the community.

4) The use of latent variable analysis with a Bayesian framework appears to offer the promise of dealing with missing data and unmeasured factors, though this is appears a relatively unexplored area with only one paper exploring this with respect to identifying regime shifts.

5) Data quality and sound assessment was a common theme amongst papers and in the discussion. Data quality of the different studies varied greatly but it seems clear generally that many commonly available data are noisy and often biased with regards to common assumptions of analysis, and therefore great care must be taken in modelling the uncertainty in the measurement process as well as in the underlying processes.

6) Visualisation techniques may prove useful in the analysis of data and the elicitation of priors. It also seems to offer the ability to highlight inconsistencies between experts.

There now follows a documentation of the key research contributions within these six areas.

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1) Incorporation of Prior Knowledge

Most presentations explored the incorporation of a prior probability distribution for parameters of interest that have been derived from expert knowledge and how this has improved model performance: Robert Thorpe (Q:12) from CEFAS, UK explored a sized-based model with 7 key parameters. The model prior was built from the literature and data were used to both constrain the model and test it. Policy makers are mandated to consider whole-ecosystem approaches to decision-making in fisheries management, but community models are rarely used operationally. One barrier to their uptake is the perception that the uncertainties associated with these models are too great for them to be credible in this context. In R. Thorpe's presentation demonstrated how an important component of this uncertainty is addressed using a sizespectrum model of the North Sea fish community. A high degree of uncertainty was found in projections of community metrics in response to fishing the community at "maximum sustainable yield" (MSY), and wide variations in stock biomasses of individual fish species. However, if the analysis was restricted to combinations of parameters that are both plausible and consistent with ICES stock data, these uncertainties are greatly narrowed. It was also shown how this approach might help with risk-based decision-making. Questions were raised in the session on the ability to deal with tight coupling in the parameter space between species which was a focus of future work.

Another paper that focused on building priors from literature was the work by Chiara Franco at Essex, UK (Q:06). This focused on building Bayesian networks models of coral carbonate budgets combining priors from literature based on expertise in Jamaican reefs and updating with data from Grenada and Indonesia. Cross-validation was used to test the model within the same region and sensitivity analysis was used to see how the model predicted in other regions. Coral reefs experienced a general decline and loss of ecological functions, due to anthropogenic and climatic stresses. A Bayesian Belief Network (BN) was proposed in order to understand the influences of past, present and future disturbances on the growth (accretion) and destruction (erosion) of this ecosystem. The BN was parameterised on empirical data from Indonesia (WP) and the Caribbean (GR) carbonate budgets, and data obtained from the literature (LT). Validation of the model was conducted by assessing the predictive accuracy of the model for the output node. Predicted and actual values, derived from bootstrapping the WP-GR dataset, were analysed using chi-square. Furthermore, cross-validation was conducted on combinations of training and testing sets generated from the LT, WP and GR data. Questions in the session highlighted the time-consuming but valuable nature of network building based on expertise. Santiago Cervino (Q11) from IEO, Spain built a General Population Dynamic Model (GPDM) of European hake. The current GPDM model, developed in the ECOKNOWS project, was adapted with informative priors to explore improvement. European hake is a main target fish for the fleet operating in Atlantic waters, although there are many biological unknowns that compromise the quality of the current assessment and scientific advice. Growth, natural mortality and reproduction are the main biological processes required to develop population dynamic models for assessment purposes. Informative priors for biological key parameters have been developed based on available data for Northern hake combined with information from other hake species all over the world. This information is analyzed on the light of ecological theory for life history invariants (LHI) to produce the required priors. LHI figures are relatively constant among similar species. Information from other hakes may help to fill the gap in assessment and management of European hake. Questions raised in the session on the pros and cons of using these informative priors to improve hake assessment were discussed.

A slightly different approach to exploring priors was explored by Mike Hawkshaw from UBC, Canada (Q:19). Sockeye Salmon was modelled incorporating a recruitment model and the effect on the posterior was explored as data were collected. Salmon stock management is extremely time-sensitive; fishing seasons are short, and decisions have to be made about harvest levels usually while information about the run-size and timing is still being collected. This presents a challenge to managers, as the application of any harvest control rule that depends on stock sizes to determine allowable harvest rates or allowable catches requires accurate in-season estimates of abundance. Current methods of in-season run-size estimation could be improved by quantitatively incorporating prior knowledge about the run timing and stock size from several sources (including historical run timing, stock-recruitment data, and previous year classes), and by explicitly presenting probabilities associated with the estimates of run timing and abundance. A general Bayesian method for estimating salmon run timing and run size based upon prior information and data collected in-season has been developed. This method was applied to historical data from the Skeena River salmon runs, and the accuracy of prediction from the new method was compared with the existing methods in use on the Skeena River. The figure below shows the estimates of run size for a single fishing season. Questions raised in the session concerned expanding this work to incorporate economic impact.

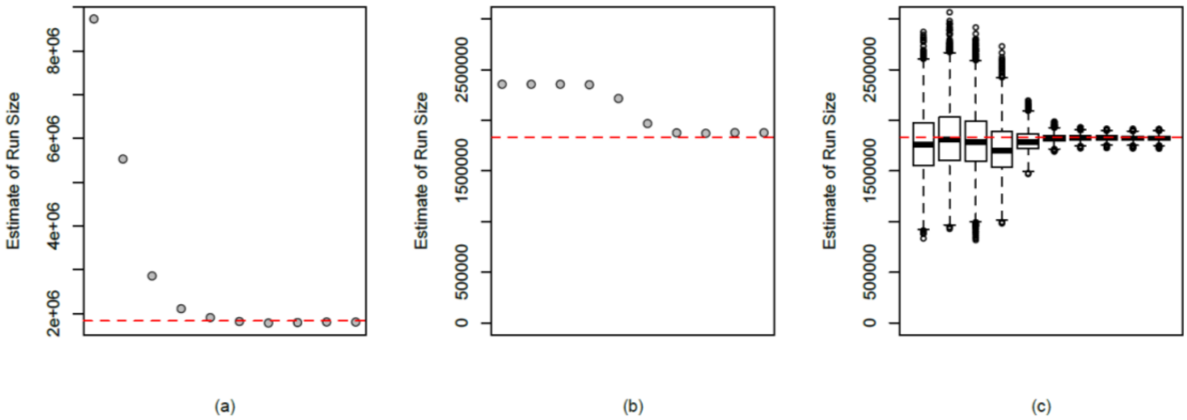

Figure 1: A sample simulation result showing estimates of run size for a single fishing season. In each fishing season the run size was estimated 10 times as the run passed though a gauntlet and an index fishery. The red line shows the simulated run size, while each plots show how the estimate of run size changes as the fishery progresses. Plot (a) shows an area-under-the-curve estimate, plot (b) shows a weighted combination of pre-season and area-under-the-curve estimation, and plot (c) shows bar plots of the posterior distribution of the run size estimate using the Bayesian model.

Anna Kuparinen (Q:02) from University of Helsinki, Finland asked a number of important key questions for Bayesian modelling, such as how to build informative priors and how to balance data and knowledge. A review of the literature was outlined on the processes and factors that affect the viability and growth of natural fish populations. Particular emphasis was on declined populations and processes prominent at a low abundance, such as the Allee effect. These findings were then contrasted to the biological assumptions made in mainstream stock assessment models, and it was demonstrated how biological realism could be increased within the hierarchical Bayesian model context. The need was emphasised for an efficient use of general biological knowledge and theories of life-histories, population dynamics and evolution, as well as knowledge from other populations of the same or related species. These sources of information go beyond traditional stock assessment data but can be important for capturing and correctly describing relevant biological processes underlying population productivity, particularly in data poor situations.

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2) Hierarchical Models

Hierarchical models have been used widely within the community with considerable success. There was quite a degree of interest from the audience on the use of HBMs though there were some questions on the difficulty in matching aggregated data to localised fine-grain data. Etienne Rivot from Agrocampus Ouest, France (Q:03) looked at HBMs for life-cycle models with a spatial perspective. Model Integration was explored and some key issues highlighted including missing data, the heterogeneity of surveys, and some transitions not being observed. HBMs were developed on common sole with spatial effects (the drift of larvae). In particular, HBMs were shown to address issues of nested scales in the process or observation components of integrated models. They are a red thread for linking together disparate observations (e.g., surveys, catches, realized at various life stages and different scales) in a coherent whole. They also provide tools for separating out signals at different temporal (e.g., year, decades) and spatial (e.g., local, global) scales in demographic traits (i.e., abundance and vital rates at different life stages, vital rates). Hence, they improve the capacity to identify responses to key influential stressors associated with different scales. Questions were asked on the difference between hierarchical based models and normal BN models and there was clearly an interest in the audience for exploring these further. There was concern as to how to link aggregated data (such as catch data here) to detailed local data (such as the spatial details of the nurseries here). Henni Pulkinen from FGFRI, Finland (Q:09) exploited the acoustic survey from the Baltic Sea along with catch data. A Bayesian approach was adopted to modelling uncertainties in the data using priors (e.g. target species size). A hierarchical structure was used and a comparison made of Bayesian estimates to data of age composition and abundance. The Baltic International Acoustic Survey (BIAS) is carried out annually as a part of the European Union Data Collection Framework to estimate the herring and sprat resources in the Baltic Sea. Survey data from 2010-2012 were analysed with a Bayesian model and estimates presented for the age and length distributions of the Bothnian Sea herring stock. These estimates were compared with the standard BIAS estimates and the input data. Questions raised in the session concerned the modelling of depth explicitly were raised (which was highlighted as a time-consuming exercise) and suggestions from the audience included incorporating more age groups within the model. Felix Massiot-Granier from Agrocampus Ouest, France (Q04) also used a hierarchical approach. A life cycle model of Atlantic salmon migration was used in conjunction with catch data to build a multi-scale hierarchical model with local and global variables. Expertise and data were integrated and used to identify a regime shift. Questions were asked during the session on the technical and practical issues in building these sort of models – and the need for a framework to assist in this. There was also a question on the need to incorporate compensation (recovery) so that the model was rich enough to capture the dynamics of the population. Jonas Jonasson of MRI, Iceland (Q:18) used a Bayesian hierarchical surplus model of whelk distribution. This was a state space model with priors on the growth model. A convincing comparison was made between models with informative and uninformative priors. Hierarchical Bayesian methods are suitable for estimating reference points for data-poor stocks, as they can borrow strength from fisheries with more information. That is the case in the restricted whelk (*Buccinum undatum*) fishery in Iceland, which initiated in late 1990 with annual catches from almost zero to 1300 t. Recent recommendations have been based on average historical catch and logbook statistics. Monthly-scaled CPUE data were used to get a better estimate of whelk population dynamics as an index of biomass in a Bayesian Schaefer surplus production model. Two models were compared: the first treated the fishery as one unit ("Simple" model), whereas the second analysed the fishery as being composed of 6 spatial sub-units (Hierarchical model). Three different levels of fishing mortality were imposed to analyse the risk of high population depletion and also compared results when catches were evenly distributed over sub-units compared to status quo catch distributions. The hierarchical model seems better because it yields more flexibility to include trends among subareas that are not similar and it was not biased like the simple model. The results yield population parameter distributions that can be used as prior information for assessments of whelk elsewhere. In the session questions were asked about the richness of the data (which generally displayed a downward trajectory) and this theme of data quality recurred throughout the session (see Data Quality later).

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3) The Use of Latent Variables

Latent variables within the Bayesian network framework were explored though only explicitly discussed in one talk. Neda Trifonova from Brunel, UK (Q:07) used dynamic Bayesian networks with latent variables to model biomass and structural change (using a combination of fish and environmental data). The models were inferred using a combination of diet matrices and biomass data (using EM approaches). Bootstrapped networks were explored to identify links with confidence for follow up. In this study, dynamic Bayesian networks with latent variables have been applied in order to predict future biomass of different key species such as cod and haddock as well as functional collapse, where the underlying food web structure dramatically changes irrevocably (regime shift). Comparison is made between fitted latent variables to a number of metrics, previously published as predictors of regime shifts. The hidden variable appears to reflect the variance of different species biomass, whilst in others it seems that it is modelling some other effect. In addition, a non-parametric bootstrap was applied to estimate the confidence of features of networks learned from the data which allows us to identify pairwise relations of high confidence between species. Questions displayed an interest in latent variable analysis and the testing regime. Some issues were raised on how to interpret the latent variable but it was generally agreed that this is an area that can offer potential in modelling species interaction.

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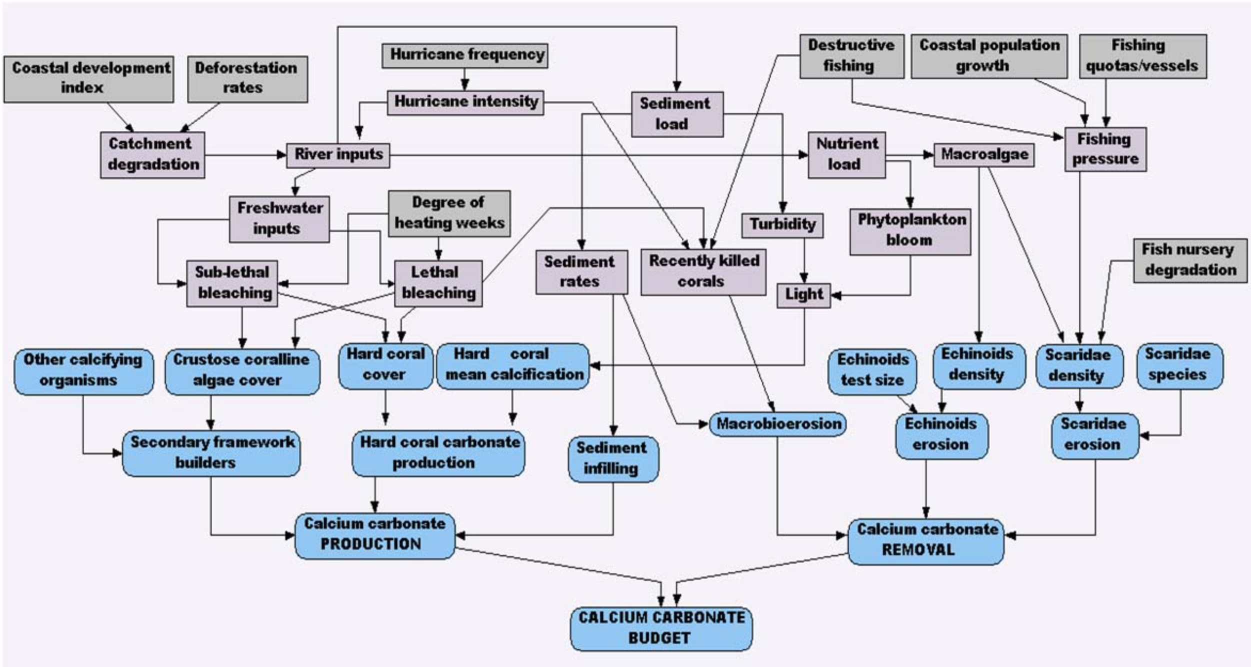
4) Data Integration

Most presentations involved the integration of different types of data into a single model. This has sometimes been achieved through the use of informative priors (integrating literature data with survey / catch data), though many papers also explored the ability of "bolting on" new variables / models into a network (the "Lego effect"). Often the data were heterogeneous involving socio-economic, survey data, and mathematical models (e.g. growth). Chiara Franco's paper (Q:07) discussed earlier was a strong example of this, combining all of these types of model within one unifying network (See figure below where colours indicate different types of data).



Annukka Lehikonen from Helsinki, Finland (Q:13) explicitly highlighted the "Lego brick nature" of Bayesian models with an example for managing the oil leakage risk in increased traffic in the Baltic Sea. Bayesian networks (BNs) are often praised on their ease to update-characteristic. This is commonly understood as either updating the conditional probability tables when new data or knowledge appears or updating our prior knowledge by setting some of the variables to a "known" state. In addition to that, BNs are relatively easy to update in a sense that the structures can be modified to answer different research questions. In many cases, selected nodes and their defined mutual dependencies can be detached from the original model and linked to another BN as such. It is also possible to integrate whole BNs as submodels to larger entities – metamodels, which are useful e.g. for policy analysis where alternative management actions affecting different parts of the system should be evaluated and compared. A process of building a cross-disciplinary BN is proposed for minimizing the ecosystem risks caused by the increasing oil transport in the Gulf of Finland (GoF), North-Eastern Baltic Sea. This integrative metamodel enables searching for the best management actions in the light of current knowledge and uncertainties. The use of an “expert uncertainty node” to capture variability in expertise was introduced and the model explored predicting amongst other things, boat collisions, and oil spill impact. There were questions on the need to model different belief scenarios explicitly (using the expert uncertainty node and this was to be explored further). Margarita Rincon of the National Spanish Research Council also explored how to combine different models (Q:05): Anchovy dynamics in Cadiz were the focus with the use of a GPDM to model anchovy populations from eggs. 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 the main factors driving the dynamics of anchovy (*Engraulis encrasicolus*) during early life stages. This study involved developing a new Bayesian model with weekly resolution for early life stages and monthly for juveniles and adults. This dual time step resolution is appropriate to resolve environmental effects on recruits and anthropogenic effects, i.e. fishing, on adult fish. The model of growth provides coherent length frequency predictors and the Bayesian approach supplies the uncertainty measure, providing a plausible environmentally driven stock-recruitment relationship. Questions were asked on issues concerning the risk of propagation of errors from combining different models.

Polina Levontin from Imperial College, London (Q:10) - presented by Margarita Rincon - carried out an investigation to calculate the value of using environmental information on anchovy recruitment. Fisheries were compared under Harvest Control Rules to those that are not. To explain atypical events in catch evolution in anchovy population dynamics in the Gulf of Cadiz, it is crucial to consider environmental processes that are not included in traditional stock-recruitment relationships. Using the posterior distributions from a previous Bayesian model, anchovy population dynamics were simulated with a fishing mortality that changes according to an environmentally driven harvest control rule (HCR). A notional insurance scheme illustrates how this new HCR encourages sustainability while reducing risk compared with a HCR which does not respond to environmental factors that force stock dynamics. Calculating the difference in required premiums of the hypothetical insurance scheme allows the calculation of the value of using environmental information. Questions were raised on how well the resultant models reflect all scenarios, how the approach will be used in practice and the need to incorporate uncertainty more fully (currently some if it is deterministic)

Jose Fernandes of Plymouth Marine Lab, UK (Q:01) adopted a different approach to combining models by using multi-class models in forecasting anchovy recruitment. Simple Bayesian models based on a single species were combined into multi-class models for predicting a number of species simultaneously. A multi-species approach to fisheries management requires taking into account the interactions between species in order to improve recruitment forecasting. Recent advances in Bayesian networks direct the learning of models with several interrelated variables to be forecasted simultaneously. These are known as multi-dimensional Bayesian network classifiers (MDBNs). Pre-processing steps are critical for the posterior learning of the model in these kinds of domains. Therefore, in this study, a set of 'state-of-the-art' uni-dimensional pre-processing methods, within the categories of missing data imputation, feature discretisation and subset selection, are adapted to be used with MDBNs. A framework that includes the proposed multi-dimensional supervised pre-processing methods, coupled with a MDBN classifier, is tested for fish recruitment forecasting. The correctly forecasting of three fish species (anchovy, sardine and hake) simultaneously is doubled (from 17.3% to 29.5%) using the multi-dimensional approach in comparison to mono-species models. The probability assessments also show high improvement reducing the average error (Brier score) from 0.35 to 0.27. These differences are superior to the forecasting of species by pairs. Questions were raised in the session on the interpretation of links in terms of causality versus correlation (another common theme throughout the session).

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5) Data Quality and Assessment of Models

Data Quality and how to assess models (the trade-off between training the model and testing it) were raised as issues in the discussions and highlighted in a number of papers. For example, Anna Gårdmark et al. from SUAS, Sweden (Q:15) – presented by Andreas Bryhn - compared a Bayesian GPDM to the current ICES SAM model for herring dynamics looking at zooplankton dependent recruitment on herring stock estimates. Data were used on numbers, weight and an acoustic survey and different observation models were explored. Fish stock assessment is associated with substantial uncertainties stemming from measurement uncertainty, natural variability and knowledge gaps regarding the structure and function of each stock. However, large parts of the current stock assessment in Europe fail to convey the extent of such uncertainty to managers. A Bayesian state-space assessment model was developed for a herring stock in the Bothnian Sea (northern Baltic Sea). Results suggest that a basic model setup with minimal assumptions and minimal observation data may underestimate the spawning stock biomass and, correspondingly, overestimate fishing mortality. A model setup including environmentally-dependent recruitment and adding observation data from acoustic surveys yielded herring biomass and mortality estimates which largely corroborated estimates from currently used assessment models during years for which input data availability was high. However, achieving acceptable model results 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. Questions highlighted that determining which predictions are "best" is difficult without a "gold-standard".

There were also issues highlighted with assessing different analysis methods: Arni Magnusson of MRI, Iceland (Q:20) compared different approaches including MCMC, bootstrap, and the Delta approach on saithe stock assessment data – but general conclusions over the most suitable approach were not easy to determine as they vary over datasets and predictors. Stock assessment of Icelandic saithe is based on similar data as the cod and haddock, but is subject to greater uncertainty. This is apparent from large residuals between the data and model fit, as well as retrospective estimation errors. To provide the best management advice, the modeller should explore both model uncertainty (assumptions about the true dynamics) and estimation uncertainty (probability statements about stock status). The objective is to understand and utilize the information contained in the data, and to avoid making the advice overly sensitive to violated assumptions. In this study, the saithe data are analyzed using a suite of related statistical catch-at-age models, applying different uncertainty methods to quantify the uncertainty. The results are interpreted in light of previous studies based on simulations, focusing on what makes fisheries data informative and the use of different uncertainty methods.

Ulrika Sahlin from Lund, Sweden (Q:17) explicitly discussed the issues of quality– a meta analysis is combined with quantitative modelling using Bayesian principles: planktivore management linking food web dynamics to fisheries in Baltic Sea. Methods to assess quality were explored including issues with exchangeability over timeseries, predicting the future based on past observations, and making extrapolations on out of range of data. In order to assure quality in scientific advice to policy there is a need to look at the process behind the production of knowledge to support decisions. Bayesian evidence synthesis is a framework to integrate empirical data, external model predictions and expert judgements using one or several probabilistic models of the system to be managed and of the link between observations and relevant parameters. Environmental systems are under influence by several changes, e.g., in climate, land-use or harvest pressure. There are changes that drive systems into alternative states, which make them different from what we have experienced before. Changes could also drive parameters governing systems out of the range of historical observations, such that predictions of future system states are extrapolations with low reliability. One approach of quality assurance is to acknowledge low reliability in models and their impact on resulting advice. There was a discussion on what way a questionable assumption of exchangeability challenges confidence in Bayesian analysis. As a case-study, evidence synthesis is used for scientific advice on clupeid reduction as a management strategy to restore high biomasses of cod in Baltic Sea. A key issue highlighted was that predicting totally novel events with no available historical data and is something that was highlighted in the discussion. Alternatives to supervised methods could offer a solution here such as state-estimation approaches from engineering (e.g. predicting non-normal events).

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6) Visualisation

Visualisation of data and expertise was raised as a useful tool for assisting in eliciting reliable expertise. It also highlighted the variation amongst experts not only between different stakeholders. Annukka Lehikonen's presentation (Q:13) already highlighted this with the use of an expert uncertainty node. Adrian Leach of Imperial College, London – presented by John Mumford - (Q:08) explored three applied cases of priors for Bayesian stock assessment. The focus was on the visualisation of knowledge elicitation. The outcome of the expert's estimate was simulated by propagating this through the model to allow them to visualize the effect of their estimates and then to fine-tune. As a result, the study identified degrees of consensus between experts (little consensus on interactions and risk attitudes of managers). Stakeholder opinions should inform and support modelling and policy making. Graphical tools were developed, tested and implemented to facilitate knowledge elicitation, estimation of Bayesian priors and data integration. Visualization of uncertainty was a central feature and gave direct feedback, helping to clarify disagreements between stakeholders and leading to consensus. Tools were tested with diverse groups and, by articulating different voices, aided inclusive governance. Formal elicitation methods (interviews, workshops, repeatable performance feedback, and questionnaires) have been developed and used to represent expert knowledge in fisheries. Here, transparency, consistency and feedback in the elicitation process were facilitated by interactive visualization of uncertainty. Three novel methods are shown, to: 1) scope sources of uncertainty for Eastern Bluefin Tuna (EBFT) as the first step in risk analysis and MSE(ICCAT GBYP); 2) elicit and summarize stakeholder beliefs about indicators (MYFISH); 3) elicit expert parameter estimates for priors in Bayesian stock assessment models (ECOKNOWS). The figure below demonstrates the visualisation of differences in expert opinion: Importance, Uncertainty and Representation (in current assessment) of each variable was shown by the position and size of a hoop. Each hoop represents an individual view so the degree of consensus in different dimensions is depicted. A large hoop (high uncertainty) towards the upper right corner represented high concern and a candidate for inclusion in an MSE approach. Each view is represented by circles (colour denotes stakeholder and size denotes certainty).

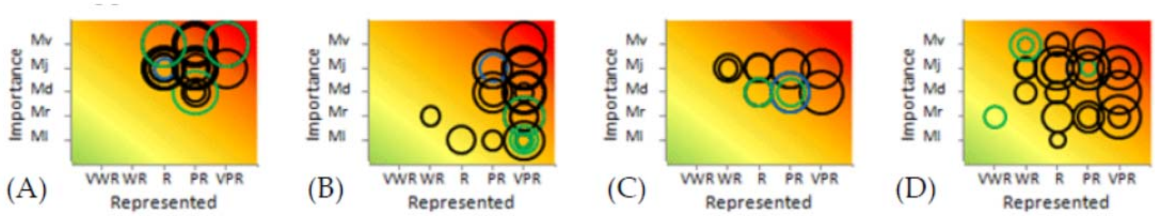

Figure 1. Four examples: A) Environmentally driven recruitment variability and density dependence ; (B) Interactions with other species; (C) Stationarity, cohort year effects, density; (D) Risk attitudes of managers. Clusters of hoops show degree of consensus. Key: Black, Scientists; Green, NGOs; Blue, Managers.

Questions included allowing experts to consult the available data to make their knowledge available. It was also noted that this approach was like "Bayesian updating in person rather than in sililco" and could offer much improvement in estimates. Samu Mäntyniemi from Helsinki, Finland (Q:16) used data compression of music to discuss how to model stock assessment without losing fidelity in the data. The study presents a state-space modelling framework for the purposes of stock assessment. The approach consists of a core population dynamics model and user definable biological functions and observation models. The stochastic population dynamics builds on the notion of correlated survival and capture events among individuals. The correlation is thought to arise as a combination of schooling behaviour, a spatially patchy environment and common but unobserved environmental factors affecting all the individuals. The model can be tailored to each case by choosing appropriate models for the biological processes. Uncertainty about the model parameters and about the appropriate model structures is then described using prior distributions. Different combinations of, for example, age, size, phenotype, life-stage, species and spatial location can be used to structure the population. In order to update the prior knowledge, the model can be fitted to data by defining appropriate observation models. Much like the biological parameters, the observation models must also be tailored to fit each individual case. Currently the modelling framework is implemented using JAGS software, which provides automated MCMC sampling for almost any acyclic Bayesian model.

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In addition to the presentations, two posters were presented: Aaron Greenberg from UBC, Canada presented a poster titled "Catch and Effort analysis of Dungeness Crab in B.C." (Q:25)**:** A time series of landings and days fished going from the year 1951 through 2012 were explored. These data enable the examination of how catch per day fished has evolved over time and while identifying possible spatial correlations in catch per day fished. Four analysis were undertaken: a pairs plot of catch per day fished, a linear regression model of catch per day fished against numbers of days fished, a quadratic model of catch against number of days fished and a Bayesian State Space Schafer production model. Jose Fernandes from PML, UK presented a poster titled "A Bayesian network for evaluation of setting and reaching the targets of the Water Framework Directive." (Q:23)**:** This work describes the development of the EU Water Framework Directive central water quality elements from 1970 to 2010 in the Gulf of Finland, a eutrophied sub-basin of the Baltic Sea. The likelihood of accomplishing the management objectives simultaneously is assessed using Bayesian networks. The objectives of good ecological status in summer-time nutrient concentration, chlorophyll a concentration and Secchi depth are not met at present and it is unlikely for them to be achieved in the near future, despite the decreasing trend in nutrient concentrations last years. It was demonstrated that neither phosphorus nor nitrogen alone controls summer-time plankton growth. Reaching good ecological status in nutrients does not necessarily lead to good ecological status of chlorophyll-a, even though a dependency between the parameters does exist. In addition, Secchi depth status is strongly related to chlorophyll-a status in three of the four study-areas.

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In conclusion: the session has documented considerable advances in the use of Bayesian modelling approaches within the ICES community. Whilst it has highlighted certain issues with the practicalities of implementing such models (such as care with priors and model assessment, convergence problems of HBMs), it has demonstrated that Bayesian approaches to analysis can offer genuine advantages over other commonly applied, non-Bayesian approaches. In particular the papers presented in this session have demonstrated the ability of Bayesian approaches to integrate heterogeneous data, including data of different types (discrete, continuous etc.) and data from many different types of study including socio-economic, catch and survey data. They can also accommodate data measured at different granularities (through hierarchical models); as well as pre-defined models through the ability to bolt on new nodes within Bayesian networks and explore the effect of inference through the use of Bayesian posterior distributions with summarize all available knowledge about the quantities of interest. Human expertise can be incorporated in the forms of priors though care must be taken to deal with inconsistencies between experts and the balance between prior knowledge and data must be carefully made (whilst avoiding circularity in assessing models on data that has influenced prior knowledge). The flexibility of Bayesian network analysis is shown through the use of dynamic Bayesian networks (and other related state-space models), which enable the extension of Bayesian networks into the temporal domain to model time-series and forecast future states, and latent variables which can also be incorporated to model unmeasured effects (a common issue with datasets used in the ICES community). Finally, the transparency offered by the Bayesian approach to analysis is a major advantage whereby all variables included require explicit definition, conditional probabilities for outcomes of interest can be readily interpreted by experts and stakeholders, and the ability to graphically and probabilistically query the outcomes of resulting models, makes the understanding of results obtained from Bayesian analysis highly intuitive and relatively trivial for non-analysts and analysts alike.

Some other key points that were raised at the session and in the ICES ASC meeting general include the need for closer collaboration between data analysts, modellers, ecologists, and environmental scientists. Bioinformatics has made strides in knowledge of complex underlying mechanisms thanks to a close collaborations between biologists and modellers. Students are trained up as bioinformaticians (not computer scientists who solve biological problems). In the same way, a generation of scientists is needed who are comfortable with using Bayesian approaches to analysis. Rather than just pressing a button in a statistical package and documenting the results, full interaction with the models is necessary and the Bayesian framework naturally facilitates this. The session has shown that this is starting to happen but more schemes such as training of young scientists in this area (undergraduate and post graduate courses) and targeted funding will clearly help. Another issue is data sharing, which is clearly beginning to take place and there were talks and questions that demonstrated knowledge on and comparisons to the same datasets, but this needs to be taken forward so that people can develop state-of-the-art algorithms and techniques that are better designed for the available data, rather than trying to make do using off-the-shelf packages that have been designed for situations that have substantially better sampling properties than are common in fisheries and aquatic ecology.

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