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Converging biology, economics and social science in fisheries research –lessons learned

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It has been acknowledged that natural sciences cannot provide an adequate basis for the management of complex environmental problems. The scientific knowledge base has to be expanded towards a more holistic direction by incorporating social and economic issues. Besides this, the multifaceted knowledge has to be summarized in a form that can support science-based decision making. Interdisciplinary skills and methodologies are required that enable the integration of knowledge from conceptually different disciplines. We built an integrated decision support tool for the long term management of the Baltic salmon stocks, using the Bayesian networks. It enabled the analysis of the outcomes of different management measures from biological, social and economic perspectives. The synthesis was the final output of a learning process of eight years. We reflect how and what kind of interdisciplinarity between natural scientists, economists and social scientists grew from the need to better understand complexity related to the salmon fisheries in the Baltic Sea, what we learned about the fishery, and what we learned about interdisciplinary collaboration.

Keywords: Bayesian networks, interdisciplinarity, learning, multidisciplinarity

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1. Introduction

It has been acknowledged that natural sciences cannot provide an adequate basis for the management of complex environmental problems, such as fisheries management, and that the scientific knowledge base has to be expanded towards a more holistic direction by incorporating social and economic issues (ICES ASC 2009; Symes and Hoefnagel 2010; Hilborn 2007; CEC 2003). Besides this, the multifaceted knowledge has to be summarized in a form that can support science-based decision making. Interdisciplinary skills and methodologies are required that enable the integration of knowledge from conceptually different disciplines.

We built a holistic decision support model for the long term management of the Baltic salmon stocks. The integrated model was the final output of three different projects and eight years of collaboration, during which the researchers representing different disciplines learned their roles at the common playground.

We reflect how interdisciplinarity between natural scientists, economists and social scientists grew from the need to better understand complexity related to the salmon fisheries in the Baltic Sea, what we learned about the fishery, and what we learned about interdisciplinary collaboration.

2. What interdisciplinarity is?

The concept *interdisciplinarity* is often used interchangeably with the concept *multidisciplinarity*. This kind of use gives the impression that there is only one way of collaborating between disciplines. It is, however, more beneficial to use the concepts to indicate dissimilar forms and intensities of collaboration. Multidisciplinarity means a juxtaposition of monodisciplinary approaches with insignificant interaction between disciplines: sub-projects loosely linked by a topic or a common problem setting, or a combination of expertise to produce new knowledge. Interdisciplinarity, by contrast, builds on interaction. It integrates 1) data to examine relationships between phenomena, 2) methods to be applied in the interdisciplinary problem, or 3) theories, concepts or models to devise a new theoretical approach for interdisciplinary analyses (Huutoniemi et al. 2010).

Klein (1990) emphasizes the character of interdisciplinarity as a process. An ideal interdisciplinary process begins by agreeing a methodological epoch by all disciplines involved and by abstaining from their mono-disciplinary approaches, and by formulating a global question in an interdisciplinary way by acknowledging all the aspects. After that the global question is translated to the specific language of each participating discipline, and checked for its relevance. Finally, a global answer is agreed upon by integrating all particular answers.

Differences in disciplinary practices, paradigms, languages and world views make an interdisciplinary process difficult. The researchers have to overcome the obstacles and to develop a common field where all individual are able to play the common game with common rules and a common language (Galmiche-Tejeda 2004; Lau and Pasquini 2004; Sillitoe 2004).

3. Baltic salmon case study: a process of integration

3.1. Baltic salmon management- an interdisciplinary challenge

Most of the wild salmon stocks of the Baltic Sea have been destroyed or depleted, and the remaining ones are of different status (Karlsson and Karlström 1994; Romakkaniemi 2003; ICES 2010). Thus, the management of Baltic salmon is balancing between restoration of the stocks, and the conflicting interests of different stakeholder groups in different Baltic Sea countries (Anon 2009; Salmi and Salmi 2010). In 1997, an international treaty, Salmon Action Plan (SAP), was established to support the recovery and advisory work related to the salmon stocks until 2010.The objective of the plan was to reach 50% of the potential smolt production capacity in each SAP river (IBSFC and HELCOM 1999; Erkinaro et al. 2003; ICES 2008). After 2010 a long term management plan with new objectives and management measures will be introduced to continue the restoration process (Anon. 2009; ICES 2008).

Our multidisciplinary research group consisting of natural scientists, economists and social scientists investigated the problematic of the long term management of the Baltic salmon stocks from 2003 to 2010. The cooperation began from the notion of the natural scientists of the need to include research related to the human aspect in the management of the salmon stocks.

3.2. The interdisciplinary process

Step 1: Bireme-SAP

The BIREME-SAP project, funded by the BIREME research program of the Academy of Finland (BIREME 2007) aimed at building a holistic decision support tool that would have accounted for not only biological knowledge on salmon, but also economic and social perspectives (BIREME 2007). The problematic revolved around the following questions:

1) How to deal with the high uncertainty in assessing the status of the individual salmon stocks and in setting the management objectives?
2) How to justify the socio-economic feasibility of such a restoration program to the local communities?
3) How to help the local communities to co-operate for achieving the common goals?

The natural scientists developed probabilistic river specific models to assess factors limiting the successful recovery of the salmon stocks (Michielsens 2008, Michielsens 2006a, 2006b). They used the *Bayesian belief networks* in their analyses. The BBNs are graphical models based on causal relationships and underlying probabilistic information regarding the strength of the causalities. The Bayes' rule is used to calculate how change in one variable will result in a chain reaction of impacts in the other connected variables (Jensen 2001; Uusitalo 2007). They had developed an application on the method in the EU-funded PROMOS project (Probabilistic modeling of Baltic salmon stocks, 2000-2002), and had introduced the method to the advisory work of the Baltic salmon working group of the ICES (Mäntyniemi and Romakkaniemi 2002, Michielsens and McAllister 2004, Mäntyniemi et al. 2005, Michielsens et al. 2006a, Michielsens et al. 2006b, Michielsens et al. 2008; ICES 2002). Now they proposed this approach to be applied to integrate economic and sociological information with biological knowledge.

The social scientists adopted the Bayesian nets although reducing human behavior into a model of causalities was at first felt inconvenient; the subjectivist Bayesian approach suited to the hermeneutic thinking of social sciences (Upshur 1999). The data collected by sociological methods was, with the help of a natural scientist, structured into a Bayesian model focusing on fishers' commitment to the salmon stock restoration, possibilities to improve commitment, and impact of commitment on catches (Haapasaari et al. 2007). The project plan did not, however, bind the economists to apply the Bayesian method. They did not believe in the possibilities of the Bayesian method in dynamic optimization and thought that the threshold of publishing papers in their journals of interest was too high for such a method. Instead, they followed the paradigm of natural resource economics and in teamwork with a natural scientist constructed a bio-economic optimization model that addressed the costs and benefits of SAP to different fisher groups (Kulmala et al. 2008). The social scientists and economists did not interact in the scientific sense: they approached the salmon problem from different perspectives using different methods, and hardly any links were seen between them. Learning collaboration with the biologists took their attention and they did not have time to familiarize themselves with each others' studies. Yet, they built good personal relationships with each other.

As the framework synthesizing three disciplines could not be agreed, and the project as a whole remained at the level of multidisciplinarity. The report of the project comprised of three separate studies, and conclusions. It was stated in the report:*"A major step towards true interdisciplinary research has, however been taken within the project to achieve synthesis across different research fields, but still, further integration is needed in the future and even better cooperation is possible"*.

Step 2: SAP IA

The task of the second project was to produce an impact assessment for the EC of the SAP and new management options for the future by combining an ICES report dealing with the impacts of SAP on the salmon populations, with a socio-economic impact assessment. (https://webgate.ec.europa.eu/maritimeforum/node/1088; Anon. 2009: CEC 2009b).

The natural scientists collated relevant information from ICES reports and Baltic Sea countries, negotiated with the European Commission, and put together the report. The social scientists explored social impacts of SAP and commitment of different fisher groups to alternative long term management plans for the future, using the BBNs (Haapasaari and Karjalainen 2010; Anon. 2009). They saw the method useful for the task, because it enabled condensing verbal information into easily comparable quantitative values and potentially combining the information with knowledge from other fields, and because it allowed the use of a small data set (Haapasaari and Karjalainen 2010; Anon. 2009). They were now able to carry out the modeling without help of natural scientists, but needed them in defining details for a survey. The economists constructed a bio-economic simulation model of the salmon fishery, to evaluate the performance of management during the SAP, to assess consequences of future management options, and to quantify trade-offs under each proposed policy. They analyzed economic impacts of different management options on commercial fisheries for every country and gear, under each management option and each environmental scenario (Anon. 2009). The biological part of the model was identical to the population model used by the ICES (ICES 2008).

The project did not aim at a methodological or theoretical synthesis, and its output was a multidisciplinary report. It described the sub-studies separately and in the summary combined them to make conclusions and recommendations.

Step 3: The Integrated model

In an unofficial continuation of the SAP IA project, a methodological epoch was finally reached and the results of the SAP IA project synthesized in a BBN model that can be regarded a new theoretical approach to fisheries management. The aim was to evaluate the robustness of different management decisions to different priorities and various sources of uncertainty, by combining biological, economic, and social knowledge. The initiative came from a social scientist that had both personal and scientific ambition to demonstrate that the integration was both possible and useful. The economist that in the course of years and continuous discussions with the natural scientists and the social scientists had became acquainted with the Bayesian method, was now ready to try it. A natural scientist was asked to take responsibility of technical details and a professor to supervise. The model structure was built jointly based on subjective understanding of the researchers on causalities needed to examine the biological, economic and social tradeoffs related to the alternative management measures and objectives. The economic and biological values were derived from the stochastic simulations carried out in the SAP IA. The sociological data was based on the study of commitment to different management objectives, and on the social scientists' understanding on the relationship between commitment and implementation uncertainty. Conference papers and a refereed paper were jointly written (Levontin et al., 2009; Levontin et al. 2011). Each researcher had specialized on a certain part of the integrated model, but also had an idea on the other parts and their linkages to the overall model.

Refreshing perspectives to the fishery

The interdisciplinary process increased our understanding on interdependencies underlying the salmon fishery. We identified links between factors, different kinds of knowledge and different fields of research.

The natural scientists examined causalities and related uncertainties regarding the potential of different salmon stocks to recover. Their models included mainly biological variables, and the influence of human behavior on fish stocks was restricted to reported catches (Michielsens et al. 2008). The bio-economic models showed how to arrange the salmon fishery in an economically optimal and biologically sustainable way simultaneously (Kulmala et al. 2008). These analyses were based on assumption of perfect implementation and rational behavior of fishermen. The social analysis addressed the uncertainty related to the human behavior through examining how fishers' commitment to management objectives influences the end result of management. The concept emphasized the fact that management success not only depended on compliance, i.e. technical following of established rules, but on the support of fishers to the management objectives and all related management and assessment activities, which could be assessed a priori (Haapasaari et al. 2007, Haapasaari and Karjalainen 2010). We hypothesized that if fishers are committed, their fishing behavior and further the outcomes of management will become more predictable, and vice versa.

In the integrated model, we translated the concept commitment to implementation uncertainty, by reasoning the implementation success of different management measures in relation to fishers' commitment to different management objectives. We studied how the results of the bio-economic model regarding optimal management would change if the effect of the implementation uncertainty would be taken into account in a quantitative manner. Moreover, as the salmon problematic included many conflicting management objectives and uncertainties, the model made it possible to examine different management objectives and options in terms of biological, commercial, recreational and social utility (Levontin et al. 2011). The integrated model showed that the preferred management plan cannot be deduced directly from different sub-studies but that a tool that allows us to study the complex problem from different angles is needed.

Bridging the gaps between disciplines

The methodological epoch

Accepting the application of the Bayesian approach by all participants meant a methodological epoch in our process. The method provided a tool 1) to integrate the biological, economic and social knowledge and uncertainties related to the long term management of the Baltic salmon stocks, using probabilities as the common language, and 2) to build a decision support tool through adding variables including managerial decisions and variables related to utilities of these decisions.

The integrated model was built based on separate answers to the global question, translated into the language of the different disciplines, and after that retranslated to the common probabilistic language, in order to produce the global answer. The Bayesian modeling built interdependence between the disciplines, and bridged the gap between them.

Developing interdisciplinary skills

Twelve to fifteen people participated in Bireme SAP and SAP IA projects, but only four persons went through a real process of interdisicplinarity. The process included different multi- and interdisciplinary sub-studies and phases that benefited achieving the objective of the process, i.e. building the integrated decision support model.

The process did not follow Klein’s (1990) ideal model of interdisicplinarity. A synthesizing framework was defined in the Bireme-SAP project plan, but a consensus on it was not reached during the project. Thus, dealing commonly with a global question and corresponding role negotiation failed. Different perceptions on what good science is among project participants was an obstacle for the methodological epoch. A common language was, however, developing between economists and natural scientists, and between natural scientists and social scientists, who worked in small teams.

The SAP IA –project did not aim at interdisciplinarity, but it was an important continuation of regular meetings, reporting, and presentations. The start of this project was easier than the previous, as the researchers already had gone through their initiation to collaboration between disciplines. They were also more familiar with the overall topic, Baltic salmon management. The researchers now worked at the same campus, which enabled frequent informal discussions and the essential stupid questions. They learned to know each other, and a common interdisciplinary field started to develop where all were able to play the common game with the common rules. This led to the clarification of roles and approaches in the interdisciplinary wholeness. This all was crucial for overall ideating, and for the decision to finally try the interdisciplinary model.

Building the integrated model required the researchers to be able to think holistically, to understand not only their own but also the other approaches, and to develop and use a common language understandable for all. All the disciplinary teams equally had to understand the task. The natural scientists dominated the collaboration at the beginning, but as the social scientists and economists gradually took their role as fisheries experts, they also could take more responsibility in the wholeness.

Lessons learnt: how to integrate?

Interdisciplinarity is difficult because the researchers involved have a foot on two or several fields: they have to master the paradigm of their own discipline but also understand elements from the other fields. In addition to this they have to be able to outline the holistic picture.

We see interdisciplinarity as a process of learning that requires time and cumulating experience; probably interdisicplinarity cannot be learned from books. It is a process between people working together. In our process small collaborative teams turned out most productive. It was important for the participants to get to know each other and their way of thinking. In this, good personal chemistry was essential. Interdisciplinarity seems to be the more difficult the more disciplines there are involved. Thus, learning interdisciplinarity between two disciplines before adding more disciplines may facilitate our process.

As in any research project, project plan has its important role in interdisicplinarity. It is essential to involve all participants in project planning. If all of them can accept the methodological epoch in the project planning phase, the first step in role negotiation has already been taken.

Continuous dialogue between researchers, disciplines and knowledge is the key to interdisciplinarity.

LITERATURE CITED

Anon., 2009. Data Analysis to Support the Development of a Baltic Sea Salmon Action Plan SI2.491891, FISH/2007/03 - Lot 6. Finnish Game and Fisheries Research Institute. Helsinki. http://ec.europa.eu/fisheries/documentation/studies/study_baltic_sea_salmon_action_plan/index_en.htm

BIREME, 2007. Baltic Sea Research Programme BIREME 2003–2006. Evaluation report. Publications of the Academy of Finland 5/07. Helsinki, Academy of Finland. [online] URL: http://www.aka.fi/Tiedostot/Tiedostot/Julkaisut/5_07_Bireme.pdf

CEC, 2003. Communication from the Commission. Improving scientific and technical advice for Community fisheries management 2003/C 47/06). Official Journal of the European Union C 47 / 5-16. [online] URL: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2003:047:0005:0016:EN:PDF

CEC, 2009a. Green Paper. Reform of the Common Fisheries Policy.Commission of the European Communities. COM (2009) 163 final. Brussels, 22.4.2009. [online] URL: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0163:FIN:EN:PDF

CEC, 2009b. Consultation paper to support development of a Baltic salmon management plan. European Commission. Directorate general for maritime affairs and fisheries. MARE D(2009) 1460 (Annex), Brussels 13.2.2009. [online] URL: http://ec.europa.eu/fisheries/partners/consultations/baltic_salmon/consultation_document_en.pdf

Erkinaro J., A. Mäkipetäys, K. Juntunen, A. Romakkaniemi, E. Jokikokko, E. Ikonen, and A. Huhmarniemi. 2003: Itämeren lohikantojen elvytysohjelma SAP vuosina 1997-2002. Kalatutkimuksia 186, Riista- ja kalatalouden tutkimuslaitos, Helsinki. Only in Finnish.

Galmiche-Tejeda, A. 2004. Who is interdisciplinary? Two views, two goals, professionals and farmers. Interdisciplinary Science Reviews 29(1): 77-95.

Haapasaari, P., C. G. J. Michielsens, T. P. Karjalainen, K. Reinikainen, and S. Kuikka. 2007. Management measures and fishers' commitment to sustainable exploitation: a case study of Atlantic salmon fisheries in the Baltic Sea. ICES Journal of Marine Science 64: 825–833.

Haapasaari, P., and T. P. Karjalainen 2010. Formalizing expert knowledge to compare alternative management plans: sociological perspective to the future management of BAltic salmon stocks. Marine Policy 34: 477-486.

Huutoniemi, K., J. T. Klein, H. Bruun, and J. Hukkinen. 2010. Analyzing interdisciplinarity: typology and indicators. Research Policy 39: 79-88.

IBSFC and HELCOM, 1999. Baltic salmon rivers—status in the late 1990s as reported by the countries in the Baltic region. The Swedish Environmental Protection Agency, the Swedish National Board of Fisheries.

ICES, 2002. Report of the Baltic Salmon and Trout Assessment Working Group. Advisory Committee on Fishery Management. ICES CM 2002/ACFM:13. Riga, Latvia 3-12 April 2002.

ICES. 2008. ICES Advice, 2008. Book 8, Baltic Sea. Report of the ICES Advisory Committee, 2008. [online] URL: http://www.ices.dk/products/icesadvice/2008/ICES%20ADVICE%202008%20Book%208.pdf

ICES, 2010. Report of the Working Group on Baltic Salmon and Trout (WGBAST), 24-31March 2010, St Petersburg, Russia. ICES Advisory Committee. ICES CM 2010/ACOM:08. [online] URL: http://www.ices.dk/committe/acom/comwork/report/2010/2010/sal-2231.pdf

ICES ASC, 2009. ICES Annual Science Confrence 2009. 21-25 September 2009, Berlin. Germany. Theme session O. [online] URL: http://www.ices.dk/iceswork/asc/2009/themesessions.asp.

Hilborn, R. 2007. Managing fisheries is managing people: what has been learned? Fish and Fisheries 8:285-296.

Karlsson L. and O. Karlström. 1994. The Baltic salmon (Salmo Salar L): its history, present situation and future. Dana 10:61–85.

Jensen F. V. 2001. Bayesian Networks and Decision Graphs. New York, Springer.

Klein, J. T. 1990. Interdisciplinarity. History, Theory, and Practice. Detroit, Michigan.

Kulmala, S., M. Laukkanen, and C. G. J. Michielsens. 2008. Reconciling economic and biological modeling of migratory fish stocks: Optimal management of the Atlantic salmon fishery in the Baltic Sea. Ecological Economics 64: 716-728.

Lau, L., and M. W. Pasquini. 2004. Meeting grounds: perceiving and defining interdisciplinarity across the arts, social sciences and sciences. Interdisciplinary Science Reviews 29: 49-64.

Levontin, P., S. Kulmala, P. Haapasaari, and K. Parkkila.2009. Synthesising biological, economic and sociological knowledge using Bayesian Belief Networks to support broadly based fisheries policy: the case of devising a new Baltic salmon management plan. Proceedings of ICES Annual Science Confrence, 21-25 September 2009, Berlin, Germany. CM 2009/O:14.

Levontin, P., S. Kulmala, P. Haapasaari, and S. Kuikka. 2011. Integration of biological, economic and sociological knowledge by Bayesian belief networks: the interdisciplinary evaluation of potential Baltic salmon management plan. ICES Journal of Marine Science 68: 632-638.

Michielsens, C. G. J., and M. K. McAllister. 2004. A Bayesian hierarchical analysis of stock-recruit data: quantifying structural and parameter uncertainties. Canadian Journal of Fisheries and Aquatic Sciences 61: 1032-1047.

Michielsens C. G. J., M. K. McAllister, S. Kuikka., T. Pakarinen, L. Karlsson, A. Romakkaniemi, I. Perä, and S. Mäntyniemi. 2006a. A Bayesian state-space mark-recapture model to estimate exploitation rates in mixed-stock fisheries. Canadian Journal of Fisheries and Aquatic Sciences 63(2): 321-334.

Michielsens, C. G. J., S. Mäntyniemi, and P. J. Vuorinen. 2006b. Estimation of annual mortality rates caused by Early Mortality Syndromes (EMS) and their impact on salmonid stock-recruit relationships. Canadian Journal of Fisheries and Aquatic Sciences 63: 1968-1981.

Michielsens C. G. J., M. K. McAllister, S. Kuikka, S. Mäntyniemi, A. Romakkaniemi, T. Pakarinen, L. Karlsson, and L. Uusitalo. 2008. Combining multiple Bayesian data analyses in a sequential Bayesian framework for quantitative fisheries stock assessment. Canadian Journal of Fisheries and Aquatic Sciences 65: 962-974.

Mäntyniemi, S., and A. Romakkaniemi. 2002. Bayesian mark-recapture estimation with an application to a salmonid smolt population. Canadian Journal of Fisheries and Aquatic Sciences 59: 1748-1758.

Mäntyniemi, S., A. Romakkaniemi, and E. Arjas. 2005. Bayesian removal estimation of a population size under unequal catchability. Canadian Journal of Fisheries and Aquatic Sciences 62: 291-300.

Romakkaniemi, A., I. Perä, L. Karlsson, E. Jutila, U. Carlsson, and T. Pakarinen. 2003. Development of wild Atlantic salmon stocks in the rivers of the northern Baltic Sea in response to management measures. ICES Journal of Marine Science 60:329–42

Salmi J., and P. Salmi. 2010. Fishing tourism, biodiversity protection and regional politics in the River Tornionjoki, Finland. Fisheries Management and Ecology 17:192-198.

Sillitoe, P. 2004. Interdisciplinary experiences: working with indigenous knowledge in development. Interdisciplinary Science Reviews 29(1): 6-23.

Symes D., and E. Hoefnagel. 2010. Fisheries policy research and the social sciences in Europe. Challenges for the 21st century. Marine Policy 34: 268-275.

Upshur, R.E.G. 1999. Priors and prejudice. Theoretical medicine and bioethics 20: 319-327.

Uusitalo, L. 2007. Advantages and challenges of Bayesian networks in environmental modeling. Ecological Modelling 203 (3-4): 312-318.