Addressing human-induced uncertainty in fisheries management

social scientific and interdisciplinary solutions using Bayesian belief networks
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Päivi Haapasaari
Abstract

The complexity, ambiguity and various sources of uncertainty related to fisheries systems are increasingly acknowledged. This has led to questioning the conventional practices of producing the knowledge base for fisheries policy. The prevailing practice relies on biological stock assessments, whereas uncertainties stemming from the behavior of humans are usually ignored. Focusing on biological management advice has further led to defining management objectives and related reference points in biological terms only. Currently, both scientists and managers call for expanding the practical science-policy cycles to incorporate social sciences and economics and to analyze the different types of knowledge in integrated frameworks.

In this thesis, the potential of Bayesian belief networks (BBNs) to broaden the knowledge base of fisheries management is discussed. Applications to social sciences and to interdisciplinary settings are demonstrated in relation to Baltic salmon and Central Baltic herring fisheries. BBNs are based on the idea of structuring problems into acyclic cause-effect relationships and quantifying the relationships with values expressing subjective degree of belief. With their subjective perspective to knowledge, BBNs have features in common with the constructivist and hermeneutic theories of social sciences. This facilitates applications of BBNs to social sciences, and further enables combining social knowledge with biological and economic knowledge. An interdisciplinary model provides a framework to examine interactions between various uncertainties, objectives, and stakeholder interests, and thereby to anticipate consequences of decisions prior to their implementation. Addressing implementation uncertainty by quantifying fishers’ potential reactions to management measures can question decisions calculated optimal by biological or bio-economic models and turn attention to options that fishers support. BBNs provide a decision tool and a device for participatory problem framings, and an illustrative focus of discussion for adaptive co-management processes. The probabilistic basis of the approach implies that it does not involve a claim for truth but provides a framework to address variables and interrelationships that are considered relevant by scientists and other stakeholders, and further to update a model in order to learn about the system that it represents.

The thesis acknowledges the difficulty related to interdisciplinary collaboration caused by the differences in disciplinary practices and paradigms and the scarcity of integrative tools. Through a focus on our research process related to Baltic salmon management, the thesis analyzes what kind of interdisciplinarity between natural scientists, environmental economists and social scientists grew from the need to better understand the complexity and uncertainty inherent to the Baltic salmon fisheries and how divergent knowledge was integrated to support science-based decision making. It is concluded, that interdisciplinarity is an extensive learning process that takes place on three levels: between individuals, between disciplines, and between types of knowledge. Such a learning process is facilitated by formulating a global question and by agreeing a common approach at the outset of a process.
Original articles


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Individual contributions of the authors of articles I – V

I Päivi Haapasaari had the main responsibility in constructing the model, in collecting data, in conducting the analysis and in writing the paper. Catherine Michielsen assisted in model construction and in writing. Timo P. Karjalainen and Kalle Reinikainen assisted in collecting data, and provided comments in writing the paper. Sakari Kuikka presented the original idea, provided a methodological insight into the problem and commented the manuscript. The study was jointly designed.

II Päivi Haapasaari had the main responsibility in constructing the model, in collecting data, in conducting the analysis and in writing the paper. Timo P. Karjalainen assisted in data collecting and analysis, and provided comments in writing the paper. The study was designed jointly by P. Haapasaari and T.P. Karjalainen.

III Päivi Haapasaari initiated the study, based on Sakari Kuikka’s original idea, and it was jointly designed. P. Haapasaari had the responsibility of the sociological part of the modeling, and Soile Kulmala had the responsibility of the bio-economic part. The model structure was built jointly by P. Haapasaari, S. Kulmala and Polina Levontin. P. Levontin and S. Kulmala carried out the technical modeling work and conducted the analysis. P. Haapasaari wrote the sociological part of the paper and S. Kulmala the bio-economic part. P. Levontin put the pieces together, and wrote the introduction, results and conclusions; the others assisted. S. Kuikka provided with methodological insight and commented the manuscript.

IV Päivi Haapasaari had the responsibility of the whole study and the paper: the idea and design of the study, data collecting, analysis, and writing the article. Soile Kulmala and Sakari Kuikka provided their perspective to the problem, and commented the manuscript.

V Päivi Haapasaari had the responsibility of analysing the approach and the models, and in writing the paper. Sakari Kuikka and Samu Mäntyniemi provided comments on the manuscript. The study was designed jointly by Päivi Haapasaari, Samu Mäntyniemi and Sakari Kuikka.
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<tr>
<td>BBN</td>
<td>Bayesian belief network</td>
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<tr>
<td>BIREME</td>
<td>Baltic Sea Research Programme of the Academy of Finland</td>
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<tr>
<td>BIREME-SAP</td>
<td>Baltic Salmon Action Plan in the Bothnian Bay rivers: interdisciplinary modeling of the evolving salmon stocks and socioeconomic aspects (project funded by the BIREME program 2003-2005)</td>
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<tr>
<td>CEC</td>
<td>Commission of the European Communities (EC)</td>
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<td>CFP</td>
<td>Common Fisheries Policy</td>
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<td>EC</td>
<td>European Commission (CEC)</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<tr>
<td>ICES</td>
<td>International Council for the Exploration of the Sea</td>
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<td>ICES ASC</td>
<td>Annual Science Conference of the International Council for the Exploration of the Sea</td>
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<tr>
<td>JAKFISH</td>
<td>Judgement And Knowledge in Fisheries Involving StakeHolders (project funded by EU 7th framework programme)</td>
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<tr>
<td>LTMP</td>
<td>Long Term Management Plan</td>
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<tr>
<td>MSY</td>
<td>Maximum Sustainable Yield</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-Governmental Organization</td>
</tr>
<tr>
<td>SAP</td>
<td>Salmon Action Plan (international salmon stock restoration program 1997-2006)</td>
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<tr>
<td>SAP IA</td>
<td>Salmon Action Plan Impact Assessment (project funded by the European Commission)</td>
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<tr>
<td>SSB</td>
<td>Spawning Stock Biomass</td>
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<td>TAC</td>
<td>Total Allowable Catch</td>
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1. Introduction

“Is it our fault if the networks are simultaneously real, like nature, narrated, like discourse, and collective, like society?” (Bruno Latour 1993: We have never been modern)

1.1. Context of the study

Marine fisheries of the world are in alarming state. The Food and Agriculture Organization of the United Nations reports that in 2008, 32 percent of the stocks were overexploited, depleted, or recovering, 53 percent fully exploited, and only 15 percent moderately fished (FAO 2010). This conveys the message that we, humans, have not been able to use and manage the resources in a sustainable way. Where might be the problem?

Ensuring the sustainable use of fisheries, like other natural resources, has become more and more difficult as human-ecological systems have increased in complexity (Garcia and Charles 2007; 2008). The challenge has been responded to through a wide variety of theories and approaches based on different scientific disciplines. Natural sciences develop stock assessment methodologies, economic sciences examine humans as profit maximizers, and social sciences emphasize the social, cultural, and local nature of resource use and stakeholders’ role in management (McCay and Acheson 1987). In the current world, any of these perspectives as such seems a bit naïve to form the only basis for fisheries management. But still, the prevailing practice in the fisheries management cycle is based on the knowledge produced by the biological sciences, which has further led to defining the management objectives and related reference points in biological terms only. In recent years, the narrow knowledge base for fisheries management has been questioned because it ignores the uncertainties stemming from the behavior of humans, such as fishers, scientists, managers, and decision makers (Symes and Hoefnagel 2010; Fulton et al. 2010). This has been considered a substantive reason for management failures (Symes and Hoefnagel 2010; Fulton et al. 2010).

Several scientists focusing on fisheries call for recognizing the holistic empirical realities of fisheries systems by expanding the practical research-policy cycles to incorporate social sciences and economics (Degnbol et al. 2006; Symes and Hoefnagel 2010; Fulton et al. 2010). Very often these calls involve a need to analyze the different types of knowledge in integrated frameworks that accommodate stakeholder viewpoints, address various uncertainties and risks, and deal simultaneously with long- and short term scales (Fletcher 1977; Lane and Stephenson 1995; 1998; 1999; Stephenson and Lane 1995; 2010; Degnbol et al. 2006; Garcia and Charles 2007; 2008; Symes and Hoefnagel 2010). Besides, it is believed that the contribution of individual disciplines as such would be considerably improved if they originated from broader integrated analyses (Degnbol et al. 2006).
The above mentioned proposals among fisheries scientists echo a wider movement in complex environmental problems from the *normal paradigm* (Kuhn 1970) referring to routine disciplinary research practices towards a new problem-oriented paradigm that builds a new bridge between science, policy making and society, between different disciplines, and between academic and practical knowledge (Funtowicz and Ravetz 1993). Such priorities have been manifested in the frameworks of post-normal science (Funtowicz and Ravetz 1993), Mode-2 research (Nowotny et al 2003), sustainability science (Kates et al. 2001; Clark and Dickson 2003), integration and implementation science (Bammer 2005), and transdisciplinarity (Klein et al. 2001).

The new challenges are explicit in the principles and guidelines of the fisheries policy of the European Union. The communication paper of the European Commission (EC) on improving scientific and technical advice for community fisheries management requires an integrated and coherent advice that takes account of ecosystem issues and of environmental, social and economic aspects (CEC 2003). As well, the ecosystem approach to fisheries management adopted by the Common Fisheries Policy (CFP) “...strives to balance diverse societal objectives by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions, and applying an integrated approach to fisheries within ecologically meaningful boundaries” (CEC 2008).

Despite the very obvious need for a paradigm shift in fisheries sector, it has not yet been incorporated in the yearly science-policy cycle of the EC (Symes and Hoefnagel 2010). Management is based on natural scientists’ recommendations on the level of exploitation the fish stocks are assumed to sustain, whereas economic and social scientific knowledge is marginal. It is obvious, that institutional, theoretical and methodological obstacles and challenges have to be overcome and comprehensive intellectual and practical advances reached before truly holistic analyses of fisheries for policy are possible. The goal is to address and assess biological, economic, and social risks and uncertainties in relation to each other and in relation to biological, economic and social objectives, and to embed the results in policy processes.

### 1.2 Aims of the study

The aim of my PhD thesis is to respond to the challenges of incorporating social scientific knowledge in fisheries policy and integrating it with biological and economic knowledge, in theoretical, methodological, and practical terms by using Bayesian belief networks (BBNs). I will address the potential of BBNs to contribute to analyses of human related knowledge (Articles I, II, V) and to interdisciplinary settings (Article III), and discuss how the method lends itself to social sciences. As well, by analyzing our research process involving natural scientists, economists, and social scientists, I reflect on the essence and problems of interdisciplinary collaboration (Article IV). In my thesis I have combined social scientific theories and both qualitative and quantitative social scientific methods.
with the Bayesian approach and decision analysis. The thesis comprises the below listed five articles and themes, and the summarizing part at hand. The main argument of the thesis is that uncertainty in fisheries science and management can be reduced through focusing on the social aspect.

In section 1 of this summary, I present the context, aims and approach of my study and in section 2 the fisheries problems that I have studied. Section 3 is about the Bayesian approach: its theoretical foundation, and its applicability from the social science perspective. In section 4, I introduce the concept of structural uncertainty in relation to fisheries management, and in section 5 I review how it has been addressed from the social science perspective. Section 6 summarizes my contribution to addressing structural uncertainty in fisheries based on the application of BBNs, and presents also the paper focusing on interdisciplinarity. Section 7 offers conclusions. The aim of the summary is to put the thesis in its wider research context. Thus, although the abstracts of the articles are at the end of this summary, the individual articles are referred to from the beginning whenever relevant.


II Haapasaari, P., and Karjalainen, T.P. 2010: Formalizing expert knowledge to compare alternative management plans: sociological perspective to the future management of Baltic salmon stocks. Marine Policy 34: 477-486. The study combines qualitative and quantitative data to compare stakeholders’ preferences on long term management options. (Article II)


V: Haapasaari P., Mäntyniemi S., and Kuikka S. Baltic herring fisheries management: stakeholder views to frame the problem. Submitted. The paper focuses on the different
ways stakeholders frame the problem of the long term management of a fishery, and implications of this. (Article V)

1.3. Approach of the study

I am an anthropologist by education, but have been working with natural scientists for nine years, and almost as long have been a member of a research group focusing on fisheries and environmental issues (Fisheries and Environmental Management Group FEM), in the department of aquatic sciences of the faculty of environmental sciences (University of Helsinki). All my daily fellow workers are natural scientists, specialized in fisheries science, statistics, ecology, hydrobiology, computer science and limnology. Their main focus is on the environmental problems of the Baltic Sea and on fish stock assessments, and they are very advanced in developing risk assessment methodologies based on the Bayesian approach. The head of the group is one of the first and leading Bayesians in the international community of fisheries scientists. Luckily I have a few close social scientist and economist colleagues working with environmental issues elsewhere, to balance discussions.

In this context I have learned to understand the perspective of the stock assessment scientists on the fisheries problems and to take this into account in my studies, although respecting my own background as a social scientist. I have learned to consider humans as part of nature, as factors that cause uncertainty in fisheries management like other drivers in nature and that can be included in models (Dickens 1992). As well, I have, at least to some extent, learned to look at reality in quantitative as well as qualitative terms, i.e. to translate qualities into quantities. The rich qualitative characteristics of human society with all its nuances cannot be captured into numbers, but it is possible to translate relevant qualities into quantities in a way that is reliable (Ratnesar 2005). Numbers enable combining knowledge related to humans with knowledge related to nature, and they provide easily comparable “encapsulated” knowledge to decision makers. For instance, the European Commission (CEC 2003) states the need for quantitative social and economic advice, and refers to the importance of incorporating this into other advice that the Community receives on fisheries.

There are, however, strong arguments against social scientific models that aim at explaining and predicting human behavior in relation to policy decisions. Some authors (Flyvbjerg 2003; MacIntyre 1984; Jentoft 2006) find such models impossible, stressing that human behavior does not follow law-like rules in the same sense as natural processes do, and that it cannot be examined outside of its social context. Thus e.g. Jentoft (2006) wants to see the contribution of social sciences in relation to fisheries management as reflective, deliberative and value-rational (Weber 1978), in contrast to the instrumental and means-end-oriented concept of natural sciences that relies on universal models (phronetic vs. scientific/episteme), and he does not support the idea of integrated analyses involving knowledge from different disciplines. I very much appreciate this viewpoint and
agree that the deliberation about values and power of policy processes is an essential task for fisheries social scientists, as “fisheries management requires more than technical fixes” (Jentoft 2006). However, I do not want to see this issue black-and-white.

Requests to focus on the uncertainty caused by humans to fisheries management are frequent, and the importance of integrating knowledge is increasingly highlighted (Symes and Hoefnagel 2010; ICES ASC 2005; 2009; 2011). It is only us social scientists who can make systematic empirical analyses on the stakeholders’ perspective. In this light I think we should take up the challenge and try to tackle the problems that the natural scientists find important in their work but cannot solve with their scientific tools. We cannot explain or predict human behavior in the strict sense, but based on empirical research we can anticipate what humans will likely do under certain circumstances (e.g. management options). My PhD thesis shows that knowledge related to humans can be modeled, and examined in integrated frameworks with biological knowledge if 1) the model is built based on careful empirical research and transparently analyzed, 2) the model is treated case-specific and bound to the context in which it was built, and considered valid only under those circumstances, 3) the uncertainty included in the model is explicitly acknowledged. Thus, a model including knowledge related to humans must neither be universal nor abstract, but case-specific (see Flyvbjerg 2003; Jentoft 2006).

In the broader community of social scientists, for instance Dickens (1992), and Latour (1993) find the dualism between natural science and social science an obstacle for social science to contribute to the contemporary environmental problems. Dickens (1992) stresses that social scientists and natural scientists should share common working methods and perceptions to be able to understand environmental problems.

“The prospect remains of many ‘experts’ continuing to talk past each other, generating much heat but little light” (Peter Dickens 1992 in Society and Nature: Towards a Green Social Theory)

From the 1970s the social scientists have established their role as contributors to science for fisheries policy, but the knowledge produced by them is not fed into the yearly management cycle (Symes and Hoefnagel 2010). I believe that reconciling the approaches of the social sciences, natural sciences and economics might be a way to succeed in broadening the knowledge base for fisheries management. This is not, though, an easy task. Collaboration between people representing conceptually different disciplines is difficult because of the differences in disciplinary traditions, and because practical frameworks to link different kinds of knowledge are still rare (Hukkinen 2008). In my learning process, BBNs have played a significant role. Through this approach I understood what kind of questions the biologists and economists deal with, how they try to answer them, what kind of nodes can link social sciences with these disciplines, and further, what kind of questions such nodes can include. BBNs finally connected people, disciplines and knowledge. Step by step did I enter the world of the Bayesian thinking, to realize that, being an anthropologist, I actually had been there all the time (see section 3.3.).
2. Addressing complex fisheries problems

2.1. Growing into interdisciplinarity with Baltic salmon

The Baltic salmon fishery (Figure 1) is a schoolbook example of a complex management problem with high uncertainties and high stakes, and salmon is one of the most charismatic species in the Baltic Sea with a long tradition of exploitation. Most of the wild salmon stocks were destroyed or depleted during the 20th century, and the remaining stocks are of varying status (ICES 2011a). As the salmon migrate between their natal rivers and the feeding area situated in the Baltic Main Basin, they are targeted by several fisher groups in different Baltic Sea countries. Thus, the management of the stocks is balancing between uncertainties related to the state of the stocks and the interests of the different stakeholder groups (Anon. 2009, Salmi and Salmi 2010). Large scaled releases of reared salmon to compensate the loss in catches caused by the construction of hydroelectric power plants in salmon rivers do not make the dilemma any easier.
Our multidisciplinary research group involving fisheries biologists, environmental economists, and social scientists, has studied Baltic salmon management from 2003, in three different projects (Article IV). Article I is a product of the first project, which was called the "Baltic Salmon Action Plan in the Bothnian Bay rivers: interdisciplinary modeling of the evolving salmon stocks and socioeconomic aspects" (also called BIREME–SAP). The project, funded by the Baltic Sea Research Programme (BIREME) (2007) of the Academy of Finland, examined not only the salmon stocks, but also the relationship between SAP and the local communities. The aim was to find ways to justify the socio-economic feasibility of the SAP to the local people, and to help them cooperate in achieving the common goals under the high uncertainty about the state of the salmon stocks. As a sociological sub-project, we used BBNs to examine fishers’ commitment to the restoration process of the salmon stocks and resulting behavior in terms of change in catches, and possibilities to improve the commitment by using alternative actions (Table 1). Article II is related to the second project, “Data analysis to support the development of a Baltic Sea salmon management plan” (Salmon Action Plan impact assessment). The project was related to an assignment by the European Commission (EC), considering the assessment of impacts of the SAP and new management options and objectives for the future, and was supposed to form a basis to the EC for designing a new long term management plan (LTMP) for the salmon stocks, as a continuation of the SAP. The sociological sub-project (Article II) compared the utility of four alternative LTMPs in terms of stakeholders’ commitment to them, using BBNs (Table 1). The third project that we have called “integrated model” (Article III), aimed at tying together the results of the different disciplinary studies carried out in the SAP impact assessment project in a holistic decision support model. The aim was to evaluate the robustness of different management decisions to different priorities and various sources of uncertainty. The study focused on the link between commitment of fishers to different management objectives, and the impact of this on the implementation success of individual management measures (Table 1). The project emerged from our own willingness to see whether an interdisciplinary model could be built for the long-term management of the Baltic salmon stocks by using BBNs, and it was realized without special funding applied, like in the other cases. The aim of addressing multiple objectives and uncertainties in one model had been set eight years earlier in BIREME-SAP, but it did not realize then because of difficulties in interdisciplinary collaboration. Thus the integrated model meant not only achieving an objective related to modeling, but also understanding what interdisciplinarity is (Article IV). The three projects (Articles I, II, III) required multi- and interdisciplinary skills and interaction that we did not have at the beginning of our collaboration. Difficulties of and learning interdisciplinarity during our eight years’ research process are reflected in Article IV (Table 1).
2.2. Mapping uncertain causalities of Central Baltic herring fishery

Historically the Central Baltic herring stock has been the largest of five herring stocks in the Baltic Sea (Figure 1). Its spawning stock biomass (SSB) was estimated high in the 1970s but is assumed to have declined until 2001, and current estimates suggest that since the beginning of the 1990s it has been below the long-term average. As well, the mean weight-at-age of individual herring has decreased considerably (by 15-45%) since the 1990s and in recent years it has stabilized at a low level (CEC 2010; ICES 2009; 2011b). The reasons for the poor state of the herring stock are largely unknown and there is no agreed causal structure for the description of its biological productivity. The decline of the SSB is partly caused by the reduction in the growth rate of individual herring, which is supposed to depend on changes in salinity, changes in the composition of zooplankton (prey) community, and competition with sprat (ICES 2011b). The herring stock is also affected by cod predation (ICES 2011b).

According to ICES (2011b) the stock is harvested outside of safe biological limits. The fishery is restricted by defining a yearly total allowable catch (TAC), by quotas and by technical measures (gear specifications, mesh size, fishing area). The catches go to human consumption, fish meal, and mink farms (CEC 2009). Mixed fishing of herring with sprat causes uncertainty to reported catches, and is also assumed to affect indirectly the cod stock, because also sprat is a major prey of cod (ICES 2009; 2011b; CEC 2009). Currently there are no explicit management objectives for the herring stock, but the European Commission (EC) is developing a long-term management plan (LTMP) for the pelagic stocks of the Baltic Sea, including the Central Baltic herring (CEC 2010); the overall aim is the maximum sustainable yield (MSY) like in other EU fisheries. Specific questions that have been raised in relation to the forthcoming LTMP concern e.g. cause-effect relationships in the fishery, management objectives, targets and trigger points, technical measures, adequateness of data, scientific analyses, and objectives for research (CEC 2010). An important question is also the shift from the stock-by-stock based management towards a fisheries-based management approach and further to ecosystem-based management (CEC 2010).

In the study related to Article V we focused on the perspective of different stakeholders on the management problem of the Central Baltic herring fishery. We wanted to see what kind of causal diagrams describing the links between biological elements and elements related to exploitation will be built by individuals representing different actor groups, and what the different views of these stakeholders would mean to management (Table 1). The study was realized in the framework of JAKFISH project (Judgement And Knowledge in Fisheries Involving StakeHolders, EU 7th Framework Programme, grant agreement 212969), that aimed at developing institutions, practices and tools for dealing with scientific support to policy under high uncertainty, and at studying how the current scientific processes take into account the multi-objective nature of fisheries management.
3. Bayesian belief networks – a tool to link different types of knowledge

3.1. Mathematics on top of common sense

Bayesian belief networks (BBNs) based on conditional probabilities, are a flexible tool to drill down to uncertainty and to link different types of knowledge (Shachter 1986; Varis et al. 1990; Spiegelhalter et al. 1993; Varis and Kuikka 1999). The approach is based on the idea of structuring problems into acyclic cause-effect relationships in order to examine how a change in one variable affects another variable. The Bayes theorem is used to update prior probability on the basis of new information, to get a posterior understanding of the problem (Spiegelhalter et al. 1993; Dennis 1996; Pearl 1988; Jensen 2001) (Figure 2). A BBN can consist solely of random variables, but it can be extended to an influence diagram that can assist decision making under uncertainty, by adding variables that can be controlled (managerial decisions) and variables related to utility, loss, or preference of the decisions (Shachter 1986; Pearl 1988; Varis et al. 1990; Oliver and Smith 1990; Varis and Kuikka 1999; Jensen 2001).

Usually a BBN consists of a qualitative part and a related quantitative part. The qualitative part depicts variables (propositions, attributes, issues, events) and their relationships, and the quantitative part indicates the strengths of the relationships by joint probability distributions where probability expresses the degree of belief (Spiegelhalter et al. 1993; Gelman et al. 1995; Jensen, Articles I, II, III). Sometimes it may be useful to build a scenario-type qualitative model where the influence between variables is expressed e.g. by the thickness of the arrows (the stronger the effect the thicker the arrow) (Article V) (Varis and Fraboulet-Jussila 2002; Varis and Lahtela 2002), or by indicators “positive”, “negative”, “zero” or “ambiguous” (Wellman 1990; Druzdzel and Henrion 1993; Renooij and van der Gaag 1998).

The graphical model structures are usually built based on expert understanding of the causalities, and the probabilities indicate the expert’s degree of belief about an event, i.e. a willingness to believe, take action or change mind on the basis of new information (Shachter 1986; Pearl 1988; Spiegelhalter et al. 1993; Malakoff 1999). This is to say, that the Bayesian methodology builds on subjective knowledge. Two people analyzing the same evidence can arrive at significantly different conclusions if they start with different beliefs and experiences (Malakoff 1999; Article V). Especially different views about causalities may lead to different conclusions (Article V; Punt and Hilborn 1997). As a statistical method the Bayesian approach differs fundamentally from the frequentist inference that builds on the ideal of objectivity, unbiased analyses, experimental evidence and infinite sampling (Malakoff 1999); no wonder that it has been called “mathematics on top of common sense” (Malakoff 1999). But as much as mathematics the Bayesian approach is philosophy. For me the philosophical side of the approach and its link to social sciences has been the most relevant and also the most interesting issue.
3.2. Focus is on problem

The probabilistic presentation of the relationships of variables is the salient point in BBNs. It implies an explicit treatment of uncertainties, and allows for the use of different types of knowledge in one model (Article III). Each relationship can be quantified independently by a suitable sub-model, depending on the type of information available (Varis and Kuikka 1997; Borsuk et al. 2004). Previous studies, existing data sets, newly collected data, and expert knowledge are commonly combined (Varis and Kuikka 1997; Varis and Kuikka 1999; Uusitalo et al. 2005; Kuikka et al. 2011a), and it is also possible to integrate knowledge produced by different disciplines (Article III). For post normal problems it is noteworthy, that BBNs enable stakeholder knowledge, opinions, and values to be combined with biological and economic knowledge, in order to analyze uncertainties related to the state of nature in light of uncertainties related to humans. The possibility to use various sources of information makes the approach workable both for cases with rich data sets and complicated models, and with small sample sizes using pure expert knowledge (Jensen 2001; Uusitalo 2007). Thus, for applications incorporating social scientific knowledge it is important to note that the probabilistic approach does not restrict the data collection and analysis methods (Ratnesar 2005).

Typically Bayesian networks are used to represent and systematically structure complicated systems, to update beliefs in light of new information, to predict or anticipate future, to support decision making in light of utility, and to find strategies to solve uncertain problems (Varis and Kuikka 1999; Uusitalo 2007). They have been found useful in addressing structural uncertainty and in model selection (Kuikka et al. 1999; Varis and Kuikka 1999). They enable research to be combined with management (Varis et al. 1990; Jensen 2001), and analyses of decision problems even in cases where legislation does not define the objectives of management (Varis et al. 1990; Kuikka et al. 2011a). The method offers a way to create learning chains in science: the posteriors of one study can be used as priors in subsequent studies (Kuikka et al. 2011a).

BBNs approach a system in an inductive (Ramsey 1926) way, focusing on the problem and its inherent interrelationships. Their aim is not, however, to find the objective truth or mechanistic explanations about a problem but rather to build an instrumental model or a heuristic device that enables one to successfully summarize and systematize data and to predict phenomena (Hájek and Hartmann 2008). Predictions, especially those that a posteriori prove to have been successful enable one to learn about the system (Colombo and Seriès 2011).

3.3. Bayesian epistemology and social sciences

The Bayesian epistemology does not claim or take positions on truth, justification, or factivity of knowledge but builds around subjective belief reduced to a probability function or to a probability space (model). This implies that the conditions for the belief hold only if an actor or a model says they do so (Ramsey 1926; de Finetti 1975; Nau 2001;
Hájek and Hartmann 2008). Shafer (1981) associates the degree of belief to a constructive view; probability judgment is a matter of assessing evidence and constructing reasonable numerical beliefs. For a social scientist the subjectivist Bayesian thinking is easy to approach, because it resembles the constructivist theories of social sciences that often form the theoretical framework for, especially qualitatively oriented, social scientific studies. Constructivism sees knowledge not as a picture of reality but as (social) constructions of human mind that “fit” rather than “match” reality (von Glasersfeld 1984; Bodner 1986; Delanty 2002). Such constructions reflect the ideologies, preferences, group dynamics, values and world views of their creators.

Constructivism takes a variety of more or less radical forms and is related to a range of approaches (relativism, phenomenology, social constructionism, hermeneutics) all of which emphasize the subject, the subject’s interaction and social processes in knowledge production, and the role of understanding and interpretation in the analysis. The most radical forms of constructivism claim that the scientific theories cannot achieve truth in terms of a match to reality, but viability, i.e. that they prove adequate in the contexts in which they were created (von Glasersfeld 1984). Thus they do not see it possible to assess the objective validity of the scientific knowledge. The less radical forms balance between the social understanding and the information given by the reality: finding the truth is the aim of research, but it is acknowledged that several social factors like ideologies and interests skew the viewpoint and thus the results of the study (Delanty 2002). In contrast, realism and related theories (positivism, rationalism, empirism, naturalism, critical realism) put emphasis on the externality of reality from human knowledge, and stress the objectivity of science or knowledge based on empiria and experience that is value-free, and pursues the truth (Delanty 2002).

The Bayesian thinking shares its basic “common sense” idea of updating knowledge with hermeneutic theory (Gadamer 2004; Upshur 1999; Delanty 2002) (Figure 2). The theory is based on the hermeneutic circle that views knowledge as a process where humans constantly update their understanding of the world. As people interpret the world from particular limited horizons, they are prejudiced, i.e. they have a pre-understanding (Bayesian “prior”, Pearl 1988) embedded in particular historical and socio-cultural contexts (“historically effected consciousness”). A fusion of several horizons leads to a novel understanding (Bayesian “posterior”, Pearl 1988), which is something new, but includes the past. Hermeneutic research emphasizes interpreting and reinterpreting events or texts in their context, by analyzing their meanings to humans and culture (Bernard 2006). As well, in the Bayesian approach the interpretative dimension gives weight to contextual and experimental factors (Malakoff 1999).

Like hermeneutic research, building a Bayesian model requires data interpretation in order to decide the model structure and to assign values for the links between variables (Ratnesar 2005). Further, understanding the results of the model implies interpretation. Thus, a model includes not only pieces of information concerning its variables, links, and probabilities or other indicators of the strength of the links, but also their interpretation, i.e. the subjective element. The interpretation means analyzing the parts of the model
against the whole, the whole against the parts, and further, the model against the social context (Ratnesar 2005). The interpretative nature of BBNs based on the subjective degree of belief recognizes that data is constructed, imperfect and incomplete, and that "true probabilities" do not exist (Ratnesar 2005; de Finetti 1975; Ramsey 1926; Nau 2001). But at the same time, it implies the meaningfulness of talking about probability and its origins (Ratnesar 2005).

Figure 2. Updating prior knowledge with new evidence to achieve a posterior understanding on a problem, as seen by the Bayesian theory and by the hermeneutic theory. As knowledge accumulates, the probability distribution narrows (Kuikka et al. 2011b).
3.4. Applications of Bayesian belief networks

Applications of BBNs can be found in a wide variety of scientific fields: e.g. in medical sciences (Uebersax 2004), neurosciences (Colombo and Seriès 2011), and law (Davis 2003). In social sciences, BBNs have been used e.g. to examine social capital in virtual communities (Daniel et al. 2003; Daniel 2007; 2009), and students’ learning styles in web-based education systems (García et al. 2007). There are a couple of introductive, methodologically and statistically oriented books to Bayesian inference with an emphasis on social science applications (Jackman 2009; Gill 2002).

Aguleira et al. (2011) make a review on applications of BBNs in environmental modeling, and conclude that the potential of the approach in this field is largely unexploited. The approach has been mostly used to model the influence of biological factors on each other (Varis and Kuikka 1997; Marcot et al. 2001), whereas social scientific applications and interdisciplinary models are rarer. Hukkinen (1993) applied BBNs to redefine a drainage problem by aggregating inconsistent causal deduction rules of individual experts. The potential of the approach in integrating biological, social, and economic system components has been utilized especially in the field of water resource management (Varis et al. 1990; Kragt et al. 2009a; Kragt et al. 2009b; Sadoddin et al. 2005; Ticehurst et al. 2007; Farmani and Henriksen, 2009; Borsuk et al. 2001; Borsuk et al. 2004). Newton et al. (2006) used BBNs to predict the impacts of commercializing non-timber forest products on livelihoods, and Ge et al. (2011) to examine factors that determine the use of antibiotics by farmers in livestock production. Haines-Young (2011) drew on several case studies to examine the use of BBNs to map ecosystem services and to model scenario outcomes, and to represent stakeholder values.

In fisheries science BBNs (Kuikka et al. 1999; Kuikka and Varis 1997; Varis and Kuikka 1999; Hammond and Ellis 2001) and other Bayesian methodologies (Punt and Hilborn 1997; Mäntyniemi and Romakkanemi 2002; Michielsens and McAllister 2004) have achieved an established status. But still, BBN applications that address uncertainty related to humans in fisheries management seem to be nearly non-existent; this is where my niche is located. Little et al (2004) examined information flows among fishing vessel captains using BBNs, and its effect on the dynamics and resource exploitation of a fishery. Peterson and Evans (2003) used BBNs in a decision analysis for sport fisheries management, incorporating ‘angler satisfaction’ as the utility of the decision.
4. Structural uncertainty

In biological fisheries science, the concept of structural uncertainty is generally used to denote the basic ignorance about the components, dynamics and inherent internal interactions of a fishery system (Charles 1998; 2001; De Young et al. 1999; Hammond and O’Brien 2001; McAllister and Kirchner 2002). In sociology, ignorance (sometimes referred to as “unknown unknowns”) has been analyzed e.g. by Wynne (1992; 2002; 2005), by Funtowicz and Ravetz (1990), and by Gross (2007). The concept points to the borders and limits of knowing, and includes the awareness of new knowledge potentially leading to new ignorance by uncovering limits of the newly gained knowledge (Wynne 1992; Gross 2007). Structural uncertainty is used to refer both to inherently biological phenomena (e.g. species structure, spatial heterogeneity, stock concentrations, migration patterns, fish-fish and fish-environment interactions) and to social factors affecting the fishery (fleet structure, technological change, management objectives and how they are pursued, objectives of stakeholders and how they are pursued, fishers’ response to regulations, decision making, and adaptation of actors to new management institutions) (Charles 1998; 2001; De Young et al. 1999). Its presence has been recognized (Charles 1998; 2001; Francis and Shotton 1997; Hammond and O’Brien 2001; Punt and Hilborn 1997): 1) in models, referring to the ignored or misunderstood functional relationships inherent to the system represented by the model, 2) in the implementation of management actions, referring to the unknown extent to which they can be implemented successfully, and 3) in the institutional management framework, referring to diffuse interactions of organizations and people involved.

Whereas the other main sources of uncertainty (random fluctuations, uncertainty related to parameters and states of nature) are relatively well understood and can be treated with analytical risk assessment and management procedures (Francis and Shotton 1997), structural uncertainty is generally considered intractable to conceptualize and to deal with, especially in quantitative terms (Charles 1998; 2001; Wynne 1992). Structural uncertainties are thus excluded from fisheries analyses (Hammond and O’Brien 2001), which diminishes their adequacy and may imply unanticipated surprises in fishery management, or lead to incorrect choices by decision makers (Charles 1998; 2001, Cunningham and Maguire 2002; De Young et al. 1999; Schnute and Richards 2001, Degnbol and McCay 2007). A robust and adaptive management system and the implementation of a precautionary approach are recommended as ways to address the extensive risk created by the structural uncertainty in fisheries analyses (Charles 1998; 2001; Wynne 1992). Outside fisheries, the post-normal science scholars propose qualitative uncertainty tools such as uncertainty matrices (Walker et al. 2003), and pedigree matrices (Numerical Unit Spread Assessment Pedigree, NUSAP, Funtowicz and Ravetz 1990) to systematically characterize and typify uncertainties in complex environmental problems (Dankel et al. 2012; Röckmann et al. 2012). JAKFISH project (EU 7th framework programme) elaborated the use of these tools in fisheries problems (Röckmann et al. 2012; Dankel et al. 2012).
It has to be remembered, however, that uncertainties do not exist objectively in nature but subjectively within the minds of individuals (Ramsey 1926; deFinetti 1975; Nau 2001). Uncertainty is a dimension of human knowledge, and points at lack of knowledge. According to the theory of Berger and Luckmann (1967) knowledge is subjective in essence but constructed in the dialectic process between the individual and society, i.e. in the interaction between people. Thus knowledge can be seen to be embedded in the social reality of particular groups, and conditioned by perspective (Berger and Luckmann 1967; Hacking 2001). This implies the idea that uncertainty is a matter of perspective; and further, that actually there are nothing but “human-induced” uncertainties.

Therefore it is useful to consider a fishery not just as a complex of socio-ecological relationships in the nature, but as a cognitive system rooted in different cultural contexts (Antal and Hukkinen 2010). For instance, in cognitive anthropology (Kronenfeld et al. 2011), the concept of cultural models is used to refer to the “presupposed, taken-for-granted models of the world that are widely shared (although not necessarily to the exclusion of other, alternative models) by the members of a society and that play an enormous role in their understanding of the world and behavior in it” (Holland and Quinn 1987). There are several understandings of how a fishery functions and how it should be managed. The way scientists and fishers piece together a fishery problem may considerably differ from each other and in circumstances of high uncertainty and high stakes, the different understandings can manifest as ambiguity, confusion and controversy (Pahl-Wostl 2007; Jones 2011). Thus, to increase the overall understanding of a fishery system including the different perspectives to it, a fusion of horizons (Gadamer 2004) is needed. In addition to this, learning over time, and constant updating and adjusting knowledge is required (Carpenter and Gunderson 2001).

Techniques such as Conceptual Content Cognitive Maps (3CM) (Austin 1994; Kearney and Kaplan 1997), Actors, Resources, Dynamics, and Interactions (ARDI) (Etienne et al. 2011), fuzzy cognitive mapping (Ozesmi and Ozesmi 2004) and various others have been used to elicit stakeholders’ mental models related to environmental problems (Jones et al. 2011; Fortuin et al. 2011). All of them provide a tool to structure and communicate complex issues, to recognize various perspectives and to help build shared understanding. They have also potential to guide environmental research processes and problem solving, and to integrate different types of knowledge (Hukkinen 1993; 1999; Pavao-Zuckerman 2000; Heemskerk et al. 2003; Fortuin et al. 2011; Jones et al. 2011). Armitage et al. (2007), and Olsson and Folke (2004) suggest adaptive co-management and governance approaches to respond and cope with the diversity of perspectives, complexity and uncertainty.

BBNs have been found useful in addressing structural uncertainties related to biological factors (Varis and Kuikka 1999). In the next sections and in Articles I-V I demonstrate how the method lends itself to analyses of structural uncertainty related to humans in the fisheries field. In section 5 I reflect my study in relation to other studies that have approached human-induced structural uncertainties through different kinds of (modeling) approaches.
5. Responding to structural uncertainty

5.1. What will fishers do?

Although the motivation and dynamics of fisher behavior and its impact on fisheries management has received increasing attention in recent years, empirical studies are still few (Fulton et al. 2011). Van Putten et al. (2011) made a comprehensive review on literature focusing on empirical applications of behavioral models to explain and predict fleet dynamics, and concluded that in most studies economic factors are included as dominant drivers of fishing behavior, but the inclusion of social factors is very limited.

The most fertile field of study investigating fishers’ reactions to regulations focuses on compliance. The concept refers to behavior that conforms to the requirements of the expected behavior in relation to imposed management measures (Hönneland 1999). Hönneland (1999) developed a theoretical model to explain compliance of individual actors. Gezelius (2002) explored the dynamics of compliance and non-compliance among a group of fishermen, based on an ethnographic fieldwork. Nielsen (2003) and Nielsen and Mathiesen (2003) developed and applied an analytical framework to examine factors that impact rule compliance. The concept has also been incorporated in economic models (Furlong 1991; Sutinen and Gauvin 1989; Hatcher and Pascoe 2006).

We used BBNs to examine fishers’ commitment to the restoration process of the salmon stocks, possibilities to improve commitment, and the impact of commitment on catches (Article I) (Table 1). The study also included an evaluation of various management, commitment and knowledge actions to improve commitment. Commitment refers to a general attitude or a voluntary support to a management framework, and can be seen as an aid to increase compliance and to decrease enforcement costs. We found it a fruitful concept to be applied in ex-ante considerations of implementation uncertainty of management procedures. Studying commitment meant getting to know fishers’ perspective, and enabled modifying the management framework in a direction that the different fisher groups could commit to. Through the variable “catch”, this model could be linked with biological and/or economic variables, in order to examine the impact of change in catches on the fish stock (Michielsens et al. 2005a; Michielsens et al. 2005b).

Case specific empirical studies aiming at anticipating fisher behavior prior to implementation of management measures are rarely carried out. Metcalf et al. (2010) used qualitative modeling to predict the effects of a fishing closure on the behavior of recreational fishers. Pedroza and Salas (2011) applied the theory of change and coping strategies to analyze stakeholders’ responds to changes in the fishing sector (resource, market, policy). Valcic (2009) compared simulated behavioral response with actual response of fishers to a spatial policy using a discrete choice model.
The categorization of structural uncertainty suggested that also the behavior of other actors in the science-policy cycles related to fisheries cause uncertainty and can lead to management failures. In this respect, the work of scientists has been focused on by Finlayson (1994) and by Wilson (2009), activities of managers by Wilen and Homans (1998) and by Stouten et al. (2011), and that of decision makers by Leal et al. (2010).

5.2. Multiple objectives

A variety of methods have been applied to evaluate alternative management strategies and/or objectives from different perspectives. For instance, Smith et al. (1999) and Mapstone et al. (2008) found the MSE (management strategy evaluation) approach useful for quantitative tradeoffs across a range of management objectives, for identifying and incorporating key uncertainties, and for communicating results to relevant actors. Wattage et al. (2005) used choice experiments to evaluate management objectives, and Dorow et al. (2009) a multivariate stated preference method to elicit preferences of stakeholders for a portfolio of measures to conserve a fish stock.

We used BBNs to evaluate alternative long term management plans for the Baltic salmon stocks (Article II) (Table 1). We examined different stakeholder groups’ viewpoints, and coupled these in order to lay foundation for a compromise. The results of the study were used by the European Commission in designing the long term management plan for the Baltic salmon stocks. We combined the results of this study with biological and economic knowledge when building the integrated model described in Article III.

5.3. Fishery as a cognitive system

There seem to be very few studies that focus on the diverging ways of stakeholders to conceive a complex fishery problem. Verweij and van Densen (2010) examined differences between stakeholders in causal reasoning related to impacts of certain management measures on fish stocks, and Leleu et al. (2012) analyzed fishers’ perceptions of the performance of a marine protected area.

In Article V, we approached structural uncertainty by involving stakeholders in framing the problem of Central Baltic herring fishery management, using causal diagrams (Table 1). The approach turned attention to the logic of reasoning of different stakeholders. It showed what parts of a management problem the parties saw similarly and where their views differed, and it brought to light several issues that are missing from the current stock assessment and management procedures. The approach enables further development of the models by augmenting them with probabilistic data.
5.4. How to integrate knowledge?

In 1995, Lane and Stephenson (1995; 1998; 1999) and Stephenson and Lane (1995; 2010) introduced fisheries management science, a rigorous framework to combine fisheries science with fisheries management, and biological objectives and uncertainties with social and economic ones, in order to assess alternative management scenarios and to manage risk. Today, integrated frameworks are still relatively rare, but clearly an interest in the issue has arisen in the fisheries domain. It has been acknowledged that approaches that enable uniting biological and social elements are difficult to achieve (Paterson et al. 2010). Another problem is differences in practices, paradigms, languages and world views between disciplines, which complicate collaboration between natural scientists, social scientists and economists (Hukkinen 2008; Pickett et al. 1999; Strang 2009; Pavao-Zuckerman 2000; Article IV).

Espinosa-Romero et al. (2011) proposed a structured decision making approach to evaluate and choose among social, economic and biological constituents, objectives and performance measures when developing ecosystem based management. Wind and de Kok (2002) developed a decision support system for estuarine and coastal-zone management that integrated available knowledge and data to assess impacts of possible measures, and addressed the temporal and spatial dynamics of the system. Catchpole et al. (2005) integrated biological and social data to determine the main driving forces behind discard patterns. Paterson et al. (2010) developed an electronic decision support tool based on a hierarchical tree approach, to assist managers in evaluating the implementation of an ecosystem approach. Seung and Zhang (2011) presented theoretical foundations for a multi-attribute utility function approach that can assist in choosing between multiple objectives. Tesfamichael and Pitcher (2006) performed a comparative evaluation of the sustainability status of a number of fisheries using 44 scored attributes in ecological, economic, technological and ethical fields, using a multidimensional scaling technique.

We synthesized the sociological, economic, and biological findings of the SAP impact assessment project in one BBN model. The aim was to evaluate the robustness of different management decisions to different management objectives and various sources of uncertainty. The study focused on the link between the commitment of fishers to different management objectives, and the impact of this on the implementation success of individual management measures (Table 1).

Integration of knowledge from conceptually different disciplines requires interdisciplinary skills, practices, and methodologies. Through an ethnographic study focusing on our own research process, we analyzed how and what kind of interdisciplinarity between natural scientists, environmental economists, and social scientists grew from the need to better understand the complexity and uncertainty inherent to the Baltic salmon fisheries, and how divergent knowledge was integrated in a form that can support science-based decision making (Article IV).
In Article I, the aim was to include stakeholders’ viewpoints within an evaluation framework of different management procedures related to Salmon Action Plan (SAP) (Table 1). The BBN methodology, in the form of influence diagrams, was applied to 1) graphically present factors influencing fishers’ commitment to sustainable exploitation, 2) quantitatively express the effect of these factors on commitment, 3) predict changes in commitment given expected changes in the causal factors as a result of changes in management measures, and 4) predict the effect of changes in commitment on the exploitation of the stocks, in terms of change in catches. Focused semi-structured interviews of key informants representing fishers and fisheries administrators were carried out to map out factors that affected fishers’ commitment to the restoration of the salmon stocks. The interpretation of the interviews led to building of the graphical model structure. Quantitative information for the BBN model was acquired through a postal questionnaire distributed to 1000 salmon fishers (respond rate 33%). The potential impact
of the commitment and knowledge actions were deduced from additional interviews of key persons.

In the data analysis we assumed that the conditional probability distributions according to the results of the questionnaire were multinomial and that the prior uncertainty followed a Dirichlet distribution, ensuring that their sum was equal to one. Therefore, the parameters of the posterior probability distributions for the conditional probability tables were calculated as the sum of the parameters of the prior distribution and the observed counts (Gelman et al. 1995). In the case of interviews, the qualitative answers of key informants were summarized in one-sentence statements, and then converted applying Druzdzel’s (1996) translation table between verbal and numerical probabilities. The probabilities resulting from different interviews were averaged. Thus, the final tables were based on data obtained from the questionnaire and on expert views (Burgman 2005). The results showed that fishers’ commitment depended on their belief in recovering possibilities of the stocks, their trust in other actors and in the management framework, their sense of justice in relation to fisheries management, and their economic interest in fishing: the more fishers relied on fishing as their source of income, the less was their commitment and the smaller was the impact of changes in commitment on subsequent catches. The results also suggested that commitment could be improved by selecting management measures favored by fishers and by combining them with ‘knowledge actions’ in order to share the latest scientific information with fishers, and ‘commitment actions’ to increase trust, consensus and cooperation among actors. The results also indicated that providing fishers with the opportunity to participate in management processes would enhance their commitment to sustainable exploitation of the salmon stocks.

In Article II, we compared different fisher groups’ viewpoints on alternative long term management plans for Baltic salmon stocks (Table 1). BBNs (influence diagrams) were used to 1) build a simple graphical model depicting the commitment of different fisher groups from different countries to alternative long term management plans, 2) express the commitment in quantitative terms, 3) examine the commitment utility of the options in relation to different fisher groups, countries, and as an average. A web-questionnaire was targeted to experts that represented different fisher groups in different Baltic Sea countries. They were asked to evaluate alternative future management plans for the Baltic salmon stocks, by interpreting and expressing the views of their reference group. The questionnaire included both structured and open questions. The responses to the structured questions were converted into probabilities by the Dirichlet formula (Gelman et al. 1995) and used to populate the conditional probability tables of the BBN. Answers to the open questions were qualitatively analyzed using the QSR NVivo software (Bazeley 2007), both to check the reliability of the BBN and to interpret its results. The results of Article II showed that the different groups had very different opinions on the alternative management plans, based on their interests and their understanding of the impact of the options on the fish stocks and their fishing activity. The commercial fishers selected options that they considered less critical for them regarding potential fishing restrictions whereas the recreational sector preferred high smolt production targets.
In relation to the intention of the European Commission to develop a long term management plan for the Baltic salmon stocks, Article III evaluated the robustness of alternative management decisions to different priorities and sources of uncertainty in an interdisciplinary setting, and highlighted implementation uncertainty (Table 1). BBNs (influence diagram) were applied to 1) build a graphical model based on uncertain variables (derived from biological, economic and sociological sub-studies), alternative management objectives and measures, and different utilities, 2) express the strength of the links in terms of conditional probabilities, 3) analyze the biological, commercial, recreational and social utility of the alternative management objectives and measures, given the implementation uncertainty of management measures resulting from fishers commitment to the different management objectives. The bio-economic part of the model concerned the evaluation of four optional management measures (effort reductions) using a stochastic bio-economic model for different scenarios for environmental conditions that can influence recruitment success. The sociological part related to fishers’ commitment to the alternative management objectives as investigated in Article II, and to the relationship between commitment and the implementation success of the management decisions. The link between commitment and implementation was constructed based on expert opinion grounded in the sociological research related both to Articles I and II. The final decision model showed that tradeoffs between commercial and recreational fisheries and the conservation concerns would lead to very different management conclusions. The model provided a tool to search for a compromise in terms of the utility functions, given the implementation success stemming from fishers’ preferences. The model also enabled taking into account environmental uncertainty in ranking the management plans.

By focusing on our own research process related to the three projects described in section 2.1, Article IV analyzes how and what kind of interdisciplinarity between natural scientists, environmental economists and social scientists grew from the need to better understand the complexity related to salmon fisheries in the Baltic Sea, and how data from these conceptually different fields was integrated. The study included observation of meetings and other collaborative occasions, discussions with researchers, interviews of them, and analysis of project documents. The empirical findings suggest that interdisciplinarity is an extensive learning process that takes place on three levels: between individuals, between disciplines, and between types of knowledge. Such a learning process is facilitated by agreeing to a methodological epochè, i.e. by abstaining from approaching the topic by monodisciplinary methods, and by formulating a global question at the outset of a process.

Article V is about involving stakeholders to frame the problem of the long term management of Central Baltic herring fishery. BBNs, again in the form of influence diagrams were used to 1) graphically present how different stakeholders piece together the management problem related to the Central Baltic herring fishery, including random variables, objectives, and management measures, and causalities between them, 2) express the assumed strength of the links between the variables by simple graphical classification of the arrows into three different thicknesses. The knowledge and opinions of five
stakeholders representing fishers, environmental NGOs, managers, decision makers, and scientists from three Baltic Sea countries (Estonia, Finland, and Sweden) was elicited in separate interview workshops. The views of the stakeholders were structured into influence diagrams, and compared. The study demonstrated differences between the stakeholders in the way they framed the fishery problem: the influence diagrams differed from each other by their contents, by their complexity, and by their temporal and spatial scale. Two of the stakeholders framed a biological problem, one a problem of balance between nature and society, one an economic problem and one a management problem. Objectives specified by the interviewees mostly related to the sustainability of the fish stock and to the fishing livelihood, but more specific objectives considered dioxin content in herring, genetic diversity, and the using of herring catch for alternative purposes. Only two of the stakeholders considered the effect of management measures strong in achieving objectives, whereas three of them considered their impact relatively small compared to some other external factors, like demand and price of fish. The analysis did not provide numerical estimates of probabilities, but this will be the next step in the study process.

7. Conclusions

Theme session O of the Annual Science Conference of the International Council for the Exploration of the Sea in 2009 concerned society and culture as part of fisheries. The session emphasized that in order to manage and solve fisheries problems, the interests and behavior of people must be included in systems analyses, and that the social and economic interests must be balanced within the limits of environmental sustainability (ICES ASC 2009). The session called for papers related to experiences in including economic and social information in fisheries analysis and advice, asking why, how, and by whom this challenge can or should be responded.

In my thesis, I have provided answers to these questions. I have demonstrated the applicability of Bayesian belief networks to social scientific thinking, to analyses of social scientific knowledge, and to integration of social knowledge with biological and economic knowledge.

The subjective perspective of BBNs to knowledge, the degree of belief, makes the approach appropriate and flexible for addressing structural uncertainty related to complex problems. This feature makes it possible to combine different types of knowledge, and “facts” with values, and to parallel the “human factor” with natural factors in a model. Thus BBNs can be applied within different disciplines and across disciplines, and it can function as a bridge between disciplines. A BBN structures research and a conditional probability table offers direct questions to be answered. Thus the approach facilitates interdisciplinary learning within a model, but as well between researchers.

My study shows the usefulness of BBNs in handling human-induced structural uncertainty. The subjective perspective with its requirement for interpretation rather than
explaining phenomena brings the Bayesian approach close to the interpretative theories of social sciences. The probabilistic basis of BBNs also implies that the approach does not involve a claim for truth, but that it provides a framework to address those variables and interrelationships that are regarded relevant by different stakeholders and further to update a model in order to learn about the system that it represents. I have shown how probabilities can be used to describe issues related to humans, and how such knowledge thus can be made useful to other scientists and end users in an explicit form.

Although the Bayesian approach is based on mathematics, its subjective orientation to knowledge is approachable for a social scientist inclined to soft research methods. Using the degree of belief as the measure of knowledge makes it possible to combine different types of knowledge, given that it is translated into probabilities. For a social scientist this implies, that both qualitative and quantitative methods for collecting data can be used, depending on the case. The mathematical basis of the approach does not either require everyone applying it to become an expert on the Bayesian calculus. Much more important for a social scientist it is to familiarize her/himself with the Bayesian philosophy and its applicability to social sciences. A social scientist has to understand how the Bayes theorem works but in applying it s/he can rely on softwares designed for the calculus and on colleagues more qualified in mathematics. In this respect the Bayesian approach supports the idea of interdisciplinary collaboration: it is one of the core ideas of interdisciplinarity that experts of different fields complement each other.

Bayesian statistics is becoming a common method in biological advisory science related to fisheries. My study demonstrates that the applications can be extended to incorporate human-induced uncertainties, thereby broadening the knowledge base of the science-policy cycle of fisheries management. An interdisciplinary model provides a framework to examine interactions between various uncertainties, objectives, and stakeholder interests, and thus to predict consequences of decisions prior to their implementation. As well, a BBN allows analyzing the impact of preferred decisions on different aims or assumptions. Addressing implementation uncertainty by quantifying fishers’ potential reactions to management measures can question decisions calculated optimal by using purely biological or bio-economic models, and turn attention to options that fishers support. BBNs can provide a device for participatory problem framing, and an illustrative focus of discussion for adaptive co-management processes. In such contexts they can bring modeling approaches closer to the diverse stakeholder groups, redefine fishery problems, and highlight issues not considered before. The graphical form of a BBN represents a complex problem in a transparent way and enables learning about its generic behavior.

Funtowitz and Ravetz (1993) argue that in the current environmental problems uncertainty related to natural factors is so high, that value related issues may be more decisive for risk assessment and for the setting of policy than the assumed facts. They propose a focus of science from factual knowledge to values and perceptions, as a potential way to more successful management. This would also mean moving from objectivist approaches to approaches that emphasize subjective perceptions. BBNs offer one solution.
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CEC 2010. Commission non-paper on the establishment of a multi-annual plan for pelagic stocks in the Baltic Sea and the fisheries exploiting those stocks. DGMare, Brussels.


Daniel, B. K. M. 2007. A Bayesian belief network computational model of social capital in virtual communities. A thesis submitted to The college of graduate studies and research in partial fulfillment of the requirements for an interdisciplinary degree of doctor of philosophy in computer science and educational and communications technology. University of Saskatchewan, Saskatoon, Saskatchewan, Canada. [online] URL: http://library.usask.ca/theses/available/etd-07132007-141903/


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.


