

**Multidisciplinary evaluation and management of an environmentally driven health risk: the case study of herring and dioxin**

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**1) Background, significance and innovation**

Herring is the most important species of the commercial fishery of Finland and the key species in the marine ecosystem of the northern Baltic Sea. Human consumption of herring is 16 000 tonnes in Finland (Anon. 2004c.) and the total Finnish herring catch is around 70 – 90 000 tonnes (Anon. 2004c) which yearly removes approximately 20–25% of the herring biomass of Finnish sea areas (e.g. Stephenson et al, 2001). Dioxin (i.e., polychlorinated dibenzo-*p*-dioxins and dibenzofurans, all these are called dioxin later on) content of the herring is currently so high that EU is considering the closure of the commercial herring fishery (Anon 2004a,b). Dioxin may cause developmental, reproduction and immunological disturbances in humans (Anon. 2004a, FAO/WHO 2002, SCF 2001, USEPA 2000). On the other hand, a too low consumption of fish may also have negative impacts on health (see Wiseman & Gobas, 2002, and Tuomisto et al, 2004, for the analysis of this trade off).

The problem with many existing toxic chemicals in the environment is that they cannot be banned in the same way as chemicals applying for a marketing licence (see Tuomisto, 2004). Therefore only the product, in this case herring, can be banned. Large herring contain more dioxin than the EU limit value 4 pg TEQ<sub>WHO-PCDD/F</sub>/g. A derogation was granted for Finland and Sweden to use those fish until the end of the year 2006, but they cannot be sold to other EU countries (EC 2001). There is also an obligation to inform the public on the safe use of fish in the involved countries. Kiviranta et al (2003) give current PCB and PCDD/F contents.

There seem to be several uncertainties in that logical chain which is used to make inference about the possible health risks of chemicals, and this may especially be the case with dioxin. Experiments on human are not possible, and uncertainties in the inference chain needed are high. The fact that risk information must be expanded from in vitro experiments and observations to humans may lead to high structural uncertainties (Tuomisto, 2004).

Here, risk includes three independent components; 1) amount of toxicants in herring in nature 2) exposure through herring consumption and other sources 3) toxic effect/dose-response). All of them have probabilistic, uncertain elements. In principle, if one component is zero, risk is zero. However, only two first elements can be manipulated, either by manipulation of nature or by manipulation of human behavior (there is no medical treatment against impacts which would be a manipulation of last risk component). Both have

implementation errors (the outcome is not exact given a certain decision) which may have an impact on how they must be used (e.g. in combination to cut the tails of probability distributions, see Fig.2). However, the uncertainties of the last one are also important when evaluating risk and ranking of management actions are likely dependent on this formulation.

There is an urgent need to develop alternative ways to decrease the health risks caused by dioxin. A total closure of the fishery would be a catastrophe for the fishermen, and it might have strong impacts on the ecosystem, as it would lead to a remarkable increase in the biomass of herring. Even currently, there are signs that the growth rate of herring may be deteriorating due to the high number of individuals in the populations, i.e. there are signs of food competition in the population (ICES 2003). Moreover, the decreased consumption of fish may also have negative impacts on the overall human population (see e.g. Wiseman & Gobas, 2002). Therefore, it is of vital importance to study the risk created by dioxin in more details and scientifically evaluate the alternative ways to manage the risks (see also Salaün-Bidart and Salaün, 2002 for a discussion about the role of individuals in risk management).

As the management task is clearly of risk averse type (the tails of the probability distribution matter more than the expected values, Fig.2), it is essential to get realistic uncertainty estimates for the intake of dioxin and for the critical values of consequent health risks. Decision theory (see e.g. Clemen, 1996) and Bayesian nets offer an effective scientific way to evaluate the alternative ways to decrease the risk caused by dioxins. Bayesian nets are effective in integrating evidence from experiments, observational data sets and other models.

The dioxin content in fish is age specific: a five year old herring has 3 – 5 times higher dioxin content than a two year old herring (Anon. 2002, Kiviranta et al., 2003). Because the age distribution of the stock is dependent on the fishing pressure, the dioxin level in herring can be controlled to some extent by fisheries management tools. There seems to be some geographical variability as well, but it is unclear whether these are due to sampling uncertainty or whether they are real differences. Dioxin measurements are expensive, and therefore it is important to try to utilize all such existing information, which may explain part of the variance.

The other ways to manage the risk are to inform the consumers on those geographical areas and in those groups of consumers where the risk is highest. The age and sex specific risk can be decreased e.g. by consumer information focused mainly on the most risky age, sex and geographical groups, without having a negative impact on the health of those groups which mainly benefit from the consumption of herring. The alternative hypothesis about all possible health impacts may also change our views about needed management actions.

The project has several innovative aspects. It will apply Bayesian nets (e.g. Jensen, 2001, Varis & Kuikka 1999, Kuikka et al. 1999) to a problem with human (fishing activities, market dynamics, and consumer behavior) and ecosystem components (size and age structure of herring populations, sources of dioxin, ecosystem variability over time and space). In many multidisciplinary projects, the combination of information is the most critical point. First version of this management/decision model is given in Fig. 1. The parameter estimation algorithm of Hugin software (Jensen, 2001 and [www.hugin.com](http://www.hugin.com)) will be applied to most dependencies, but in data poor cases also combinations of expert knowledge and MCMC algorithms may be applied (Gelman et al, 1995). It will apply decision theory to the management of this complex system. The project outcomes will be both of scientific (new methodology) and practical interest (the dioxin policy in Finland and in EU). The project will offer methodological solutions to the other fields of environmental management. The cost – benefit analysis framework provided in Tuomisto et al (2004) will be improved and applied to a more complicated case of herring problem with several decision variables. It is important to note, that the Bayesian approach can be described to be a scientific description of learning process. Models should utilize all relevant information when the human health is dealt with.

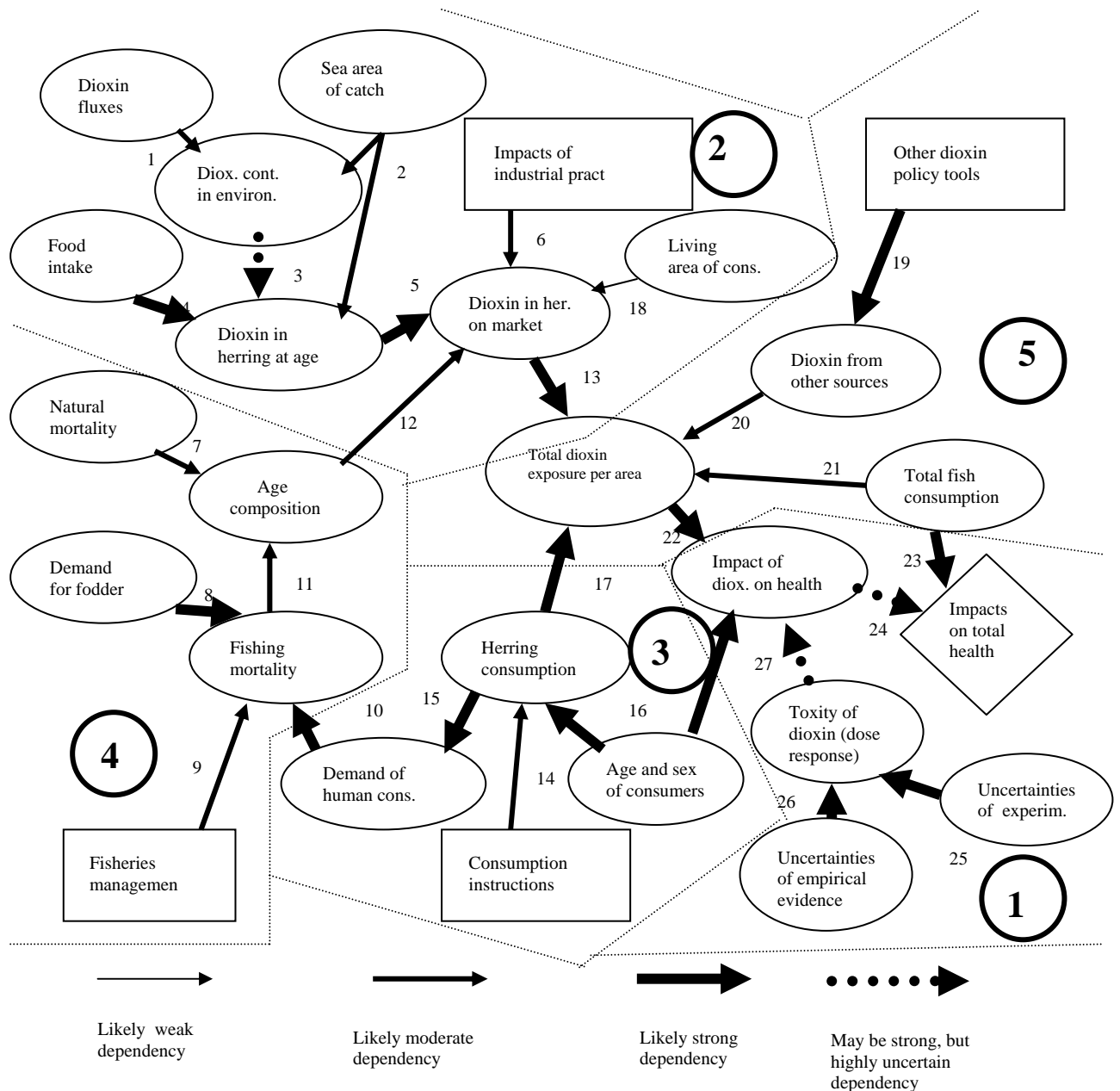


Fig. 1. The preliminary structure of the final probabilistic management model (using Bayesian net notation, see e.g. Jensen, 2001), which consists of the probabilistic information obtained in separate (numbered) analysis.. The ellipses describe probabilistic variables, the arrows conditional (likelihood) dependencies, squares describe control variables (decision variables) and diamond shape describes objective function to be minimized/maximised. The cover of analysis of each paper is given by lines. The first version of the model will be created as the first step in the project. It will be based on existing knowledge (combination of published studies and expert knowledge) and the first analysis results will be used to especially focus the study effort on those parts of the problem which seem to dominate from the point of view of decision making. Most of the variables are age- and sex specific, but this classification is not described here. The strength of the arrows describes first view about the strength of dependencies.

## (2) Objectives and methods

The project has four objectives:

- 1) to evaluate the uncertainty related to threshold values of dioxin
- 2) to develop risk analysis models to estimate current human risks caused by herring consumption
- 3) to evaluate the relative impacts of alternative ways to manage the health risk caused by herring consumption by applying risk management decision models
- 4) to educate one scientist to Bayesian analysis and to the modeling of links between ecosystem health and human health.

The high uncertainties involved in the problems will be modeled by Bayesian techniques, and the decision theory will be applied to the final part of the analysis. In the decision model (first version given in Fig. 1), some of the probabilistic variables will be treated as partly controllable variables, i.e. decision variables, and by this control the risk for human population can be decreased.

The uncertainty and the high variability in general play a key roles in the whole analysis, because extreme intake of dioxin should be avoided. These have a low probability, but as the risk is the probability times the impact, the upper tails of the probability distributions of dioxin intake have a crucial role in conclusions. This is described in Fig. 2, which shows that the variance estimate of the prediction may actually be more important criteria than the expected value. As the critical value may be in the tails of the distribution, the use of point estimate models may be totally misleading (policy A has lower expected value but a higher probability to be above critical limit). This is likely to be a fundamental issue in the whole analysis.

The final inference will be done mathematically, but the Fig. 1 can be used to explain the logic in the Bayesian net models. In the case of fisheries management option, the assumption about decrease in herring dioxin content is based on several uncertain and likely somewhat weak causal relationships, whereas in the case of focusing instructions for consumers, the shorter and stronger chain may give a stronger chance to control dioxin risk. Therefore, this may lead to more certain management impacts (decrease of variance in Fig. 2). These two elements can be described as implementation uncertainty (probability of desired outcome given the decision) and assessment uncertainty (probability of a certain state of nature given measurement/assessment result).

Bayes rule can calculate information from impacts to cause, and it can integrate the uncertain evidence from several sources (Jensen, 2001). Therefore, in a complicated inference, it can offer remarkable ways to save money in sampling and monitoring programs. The Bayesian nets offer a methodologically solid way to model processes, where some of the links of the model (arrows in Fig. 1) are related to the information (like likelihood between hypothesis and observations) and some are related to real causal relationships through which the system can be manipulated. Fig. 3 gives a graphical description of a Bayesian net. In that link, the likelihood probabilities describe the relationship of true state of nature and the measurement, but similar dependency can be used to describe probabilistic dependency of two variables.

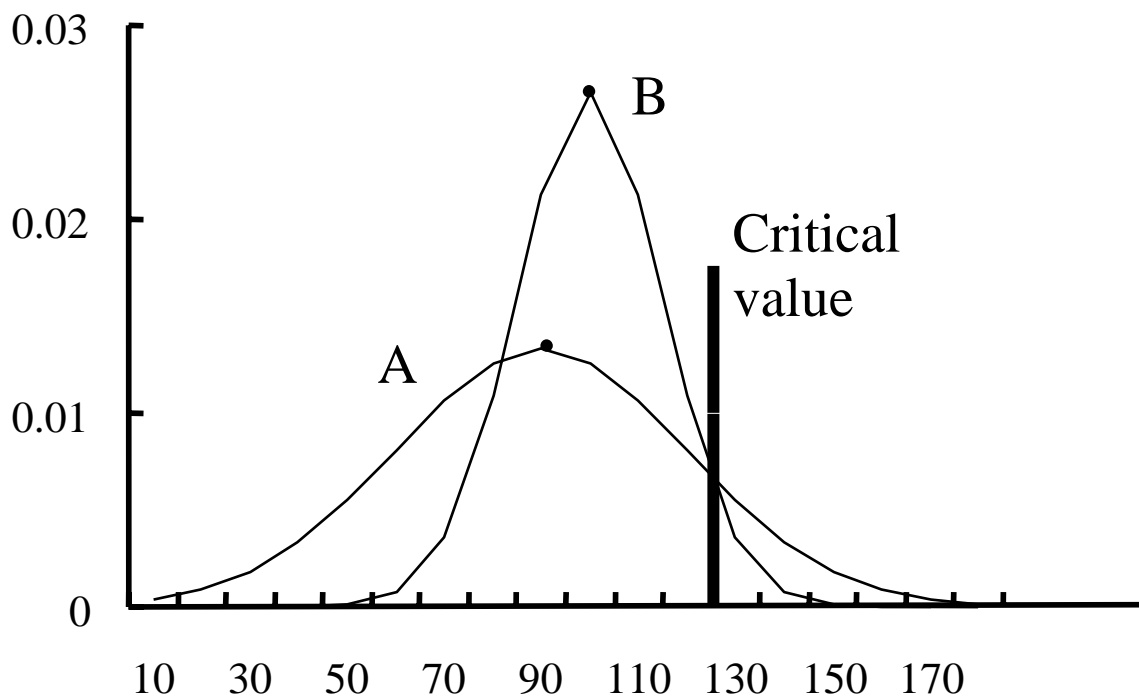
However, all these considerations must be explicitly analyzed before giving any advice for the management, as all management options are costly and they have some long-term impacts. This is the core of the application.

Due to the risk averse management, there are two important steps in the overall estimation of uncertainties: 1) the correct estimation of variance (=uncertainty) of a given model and 2) the probability that a given model is correct, must also be assessed. As some causal dependencies

behind the dioxin problem are highly uncertain (exact biological impacts and exact food web sources of dioxin), Bayesian nets are superior to model this type of uncertainty. They allow the integration of alternative model outcomes by making it possible to give probabilities for models (see a fisheries application in Kuikka et al, 1999). In other words, they are focused on the model selection (structural) uncertainty, which is considered to be more important than parameter uncertainty, which is usually in focus in Bayesian estimation (e.g. Punt & Hilborn, 1997, Chatfield, 1995, Zellner, 1995). Borsuk et al. (2004) give a recent review in water quality modeling. They stress the need to combine model outcomes with Bayesian nets in complicated problems.

The project is highly multidisciplinary in combining the knowledge from herring fishery and markets to the knowledge about herring production dynamics and ecosystem understanding.

According to a literature review, the current project will be the first to use this methodological approach in analyzing dioxin problem, or similar type of risk analysis (see, however, Tuomisto et al., 2004, for the use of a decision model in the case of salmon consumption). Some of the details of the methods are also described in the section 5 which is focused on individual papers.



*Fig. 2. The impact or risk averse decision rule and uncertainty of model outcomes on desired management actions. In a case the “Critical value” is the critical limit, the management suggesting B probability distribution (with higher expected value) should be preferred as it gives a lower probability that realized values are over the critical value. This may be the case when comparing two management alternatives in herring – dioxin problem. This is the reason why point estimate models should not be used.*

### **(3) Researchers and resources**

The coordinator of the project is professor Sakari Kuikka (professor in Fisheries biology). His special area is risk assessment and uncertainty methodology, especially Bayesian methods. He has been coordinating EU projects utilizing Bayesian methods and is currently working in EU projects utilizing Bayesian methods. The principal investigator will be selected in the beginning of the project. This applicant must have good skills in statistical modeling and in

biology. (S)he will also carry out his/her PhD during the project. There are several strong candidates, but the final selection must be based on a public application process.

The research will be carried out as a joint project between University of Helsinki and several Research Institutes. Mr. Anssi Ahvonen, head of the statistical unit (Finnish Game and Fisheries Research Institute) will take care of the methods and data needs of the total catches and markets of herring. Dr Timo Assmuth (Finnish Environmental Institute) will supervise in the general aspects of dioxin risk, and Dr Heikki Peltonen (Finnish Environmental Institute) and Dr Pekka Vuorinen (Finnish Game and Fisheries Research Institute) will supervise in the ecosystem – dioxin relationships. Docent Jouni Tuomisto (National Public Health Institute, Kuopio,) will be supervising in the dioxin – health relationships. Mr Jukka Pönni (FGFRI) will provide the data for the herring population analysis. The specific skills are needed in carrying out various analyses and the scientists will be co-authors in the papers. In addition, several of the input values for the modeling must be based on the analysis of the original data sets of dioxin content and herring catch statistics, and not only on the published values. All institutes have committed to the project and consider it as an important analysis which is not currently carried out by anyone neither in Finland nor in the EU. The current studies measure the dioxin content, but they do not consider the uncertainty or management of the whole process.

#### 4) Financial plan

The decided finance does not cover the following, but the rest will be asked from alternative sources.

- 1) Salary of the scientist (Phd candidate) 36 months \* 2000 euros \* 1.45 = 104 400 euros (34 800/year).
- 2) Traveling costs: 5 years \* 4 000 = 20 000 euros
- 3) Other costs: 5 years \* 1000 = 5 000 euros

Altogether 39 800 euros per year, 199 000 euros for the whole five years period.

The other institutes involved will pay the salaries of their participants. The project will cover the traveling costs to project meetings. All data sets from institutes will be obtained for free, the inclusion of scientists as authors, and the possibility to adapt new methodological tools, are the interest of the institutes.

#### (5) Scientific approach, expected results and dissemination

The outcomes of the project are the following articles which are used as elements of the Phd candidate, who is responsible for most of the practical analysis. The same numbers are used in Fig. 1 which also includes the causal relationships dealt in the text and separate papers. The first, but unpublished step will to refine the model structure of Fig. 1 and to obtain current estimates of probabilities from literature and/or expert knowledge. When comparing the final estimates in the end to this prior model, the achievements of the project are easy to demonstrate (prior – posterior of the project). In a case there are probabilistic connections in the final model for which there is no data, the probabilities will be based on expert views (see the approach in Varis and Kuikka, 1997, Tuomisto et al, 2004 and Uusitalo et al, 2004).

**Paper 1) Evaluation of the uncertainties of the critical residue levels in herring.** This Bayesian meta-analysis is based on the published, currently available estimates of residue levels and on their uncertainties (=probability distributions). In a case they are conditional on alternative hypothesis, these hypothesis will be used in the models of this sub problem to describe the structure of conditional dependencies. The whole logic of inference in estimating critical residual and its uncertainties will be modeled. Both the evidence obtained from experiments and empiristic studies will be included (links 25, 26, 27). A Bayesian net model is

created which enables the combination of estimates from individual studies (meta-analysis, see Jensen 2001, Kennedy & O’Hagan 2001, Kuikka et al, 1999).

The currently used limiting values seem to be selected by using the most risk averse results (minimin approach) from single studies. This neglects the fact that the highest uncertainty is caused by the partly conflicting results of various studies. Therefore, this minimin approach leads likely to a “too risk averse limit”, especially when we consider the healthy impacts of fish consumption. The paper will provide probabilistic limits for residue levels instead of fixed single values which is more realistic description of quality of knowledge. The use of hypothesis in this model enables also a value-of-information analysis (Clemen, 1996) in the final decision model, i.e. showing which hypothesis should be studied in more details to improve the management of the problem (see Kuikka et al 1999 and Tuomisto et al, 2004 for applications). It is likely that the important part of the final model, i.e. utility function, must have several alternative formats, as the positive impacts of fish consumption, negative impacts of dioxin and collapse risk of herring stocks (in a case hard fishing pressure is used as management tool) must be compared here. It is a difficult trade off.

		State of nature		
		1000	1500	2000
Measure- ment/study	500	0.2		
	1000	0.6	0.2	
	1500	0.2	0.6	0.2
	2000		0.2	0.6
	2500			0.2

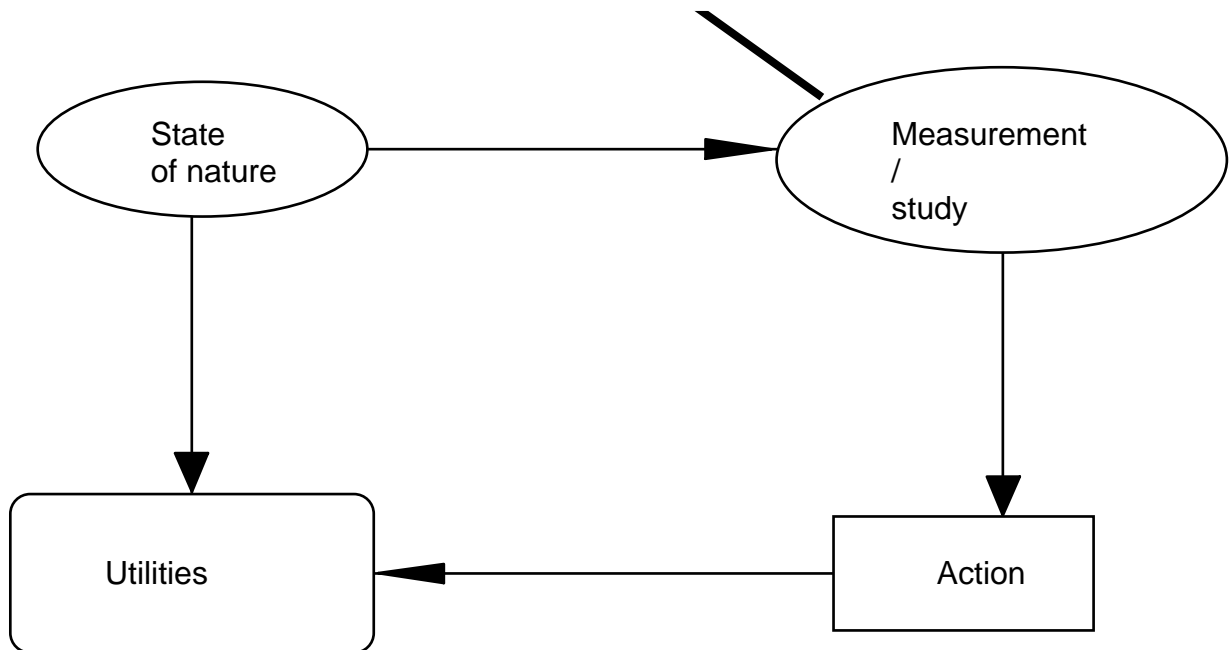


Fig 3. A general structure of a Bayesian net model. Here the dependency of measurement/study on the true state of nature is given by likelihood function (uncertainty in measurement, correct by probability 0.6). Similarly, the dependencies of variables (like in Fig. 2) can be described by conditional probabilistic dependencies which describe how the

*dependencies are known. Utilities depend on action and real (unknown) state of nature.*

**Paper 2) The variance of the dioxin content in the catch and on the markets.** This is a probabilistic simulation model to simulate the mean and variance of the dioxin content of the fish, and how this content is accumulated over geographical units. It takes into account the fact that consumed herring have variable dioxin levels, depending on the fishing area and size distribution of the herring. The dioxin content in the sea (links 1, 2 and 3) may not come into the final model, as these are likely very poorly understood mechanisms. The model will also take into account the proportional source of herring in different geographical units (link 13 to be area specific, describing the source of herring). These are some of the key elements in the estimation of overall risk, and they are also important elements for the management of the risk. The industrial practices may also have an impact on dioxin content, which provides a potential way to control the risk, but this is likely not included to the final model due to the lack of detailed information. In that case, the variability must be included to the prior distribution of dioxin in herring at age. The input data (catches and their distribution in Finland) will be obtained from fisheries statistics of Finnish Game and Fisheries Research Institute and from fishing companies through interviews. The outcome is a set of probability distributions for area specific dioxin contents in herring on the market to be used in the final model.

**Paper 3) The management of risks.** This paper will combine the results of the other four papers, i.e. it is a metamodel of all project results. The first version of the model structure is given in Fig. 1. It is a Bayesian influence diagram model (Jensen 2001, Varis & Kuikka 1999), having at least three alternative management decisions (ways to impact the risk): fisheries management, management of the human consumer behavior (either by giving strict limits or by informing the most sensitive age and sex groups of consumers, i.e. mainly young females) and the management of other dioxin sources (this is needed to show the connections between management tools). The model is based on the overall uncertainty estimates of all components of the process from the sea to consumers. The aim of the management will be to decrease the dioxin intake of the risky groups, but to preserve consumption of herring in those groups, where the consumption has likely positive impacts. In a case there are clear geographical differences in dioxin exposure, the required instructions could also be area specific.

The first version of this model (the prior model for the whole problem) will be created in the very beginning of the project in order to help focusing the analysis during the project to those connections, which are likely the most important ones. The outcome of this paper in the end of the project is the final major outcome: the ranking and interdependencies of the possible management tools to decrease the overall risk caused by dioxin and balance that with the other impacts of fish consumption and fish stock collapse risk. The value of information analysis (VOI) of that model may be used as justification of the next proposal after this project.

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## **Curriculum Vitae**

**Name:** Kuikka, Olli Sakari

**Date of Birth:** 8.2.1960, Kaarina, Finland

**Citizenship:** Finnish

**Marital Status:** Married, four children

**Education:** 12.11.1987 Msc in Fisheries Management, University Of Helsinki

29.5.1998 PhD in Fisheries Management, University of Helsinki

22.11.1999 Docent in Fisheries Management, University of Helsinki

Studies in management science and in applied mathematics in the Helsinki University of Technology and economic studies in the Helsinki School of Economics, 1987 - 1991

Young scientist Summer Program in International Institute for Applied Systems Analysis , 1989

**Profess. career:** Assistant in Fisheries Science, Department of Limnology, University of Helsinki, 1985 - 1997

Research Officer, Finnish Game and Fisheries Research Institute, 1987 - 1991

Visiting Scientist, University of Tromsø, Norway 1991

Acting Head of Statistical and Economic Studies,

**Finnish Game and Fisheries Research Institute 1991 - 1993**

**Senior Scientist, Finnish Game and Fisheries Research Institute 1993 - 1995**

**Senior Scientist, Finnish Environment Institute, 1995 - 1996 Topic: uncertainty analysis of climatic change**

**Senior Scientist, Finnish Game and Fisheries Research Institute 1996 –**

**Visiting scientist, Commonwealth Science and Industry research Organisation (CSIRO), Hobart, Australia, 2000 – 2001.**

**Current position:  
Professor in Fisheries Science  
University of Helsinki  
Department of Biosciences  
5 years position, starting in 1.1.2004 -**

#### **Other duties**

**Member of Scientific, Technical and Economic Committee for Fisheries (European Commission) 1997 – 2001 and again since February 2003**

**Member of ICES Advisory Committee for Fisheries Management, 1999 -2000**

**Member of ICES Management Committee, since 1997**

**Member of ICES Baltic Salmon and Trout Assessment Working Group**

**Teaching in the University of Helsinki, Fisheries science and in the Helsinki University of Technology**

**Consultant for the Foreign Ministry of Finland, planning of the second phase of Lake Tanganyika Research, 1996**

**Coordinator of EU – funded project PROMOS – Probabilistic Modelling of Baltic Salmon Stocks with three different participating countries, 2000 - 2002**

**Language proficiency**

**Excellent knowledge in English and good in Swedish, satisfactory in German**

**Key qualifications:**

- **Decision analysis (several applications both in fisheries and environmental management problems)**
- **Technical measures in fisheries management**
- **Fisheries management of large international systems**
- **Fisheries management of small scale fisheries systems**
- **Risk and uncertainty analysis (several applications both in fisheries and environmental management problems)**
- **Climatic change studies in the Finnish Environment Institute**
- **Combining multidisciplinary information in management context**

**Other duties/grants/qualifications**

**Scientific grant from Finnish Academy in 2000 for a visit to Australia, CSIRO.**

**Has acted/is acting as a Phd. mentor for: Phd. Outi Heikinheimo, M. Sc. Mika Rahikainen, M. Sc. Jani Pellikka and M. Sc. Laura Uusitalo.**

**Evaluated as qualified to the professorship of Fisheries Management, University of Helsinki, 2001.**

**Evaluator and expert of several international scientific organisations (e.g. International Council for the Exploration of the Sea, National Science Foundation of USA, Commission of European Union)**

**No other academic grants during the last 5 years.**

## **5) Scientific publications 10/04/2006**

**Professor Sakari Kuikka**

**University of Helsinki**

### **A) Articles in peer-reviewed international scientific journals**

A1) Salminen, M., Kuikka, S. & Erkamo, E. 1994. Divergence in the Feeding Migration of Baltic Salmon (*Salmo Salar*); the Significance of Smolt Size. *Nordic J. Freshw. Res.* 69:32-42.

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