Diagnosis of environmental problems in aquatic ecosystems 11th Sep 2017:

INTERDISCIPLINARY ASSESSMENT OF DIOXIN RISKS IN THE BALTIC SEA

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DREAMS COME TRUE?
1. Compiling knowledge available on the problem in question, gathering new evidence and developing new knowledge

2. Determining what the goals of the society are

3. Exploring alternative ways of achieving the goals

4. Estimating the impacts of the various possible courses of action, taking into account *the uncertain future* and *the organizational structures*

5. Comparing the alternatives by making an assessment of possible impacts and consequences

NB: Computer modelling is not the same as systems analysis, but rather a tool to support different phases of the process!

(Adapted from *Leen Hordijk, IIASA*)
PROJECT GOHERR: Integrated governance of Baltic herring and salmon stocks involving stakeholders (2015-2018)

- Integrated, ecosystem based management of Baltic salmon and herring stocks in focus
- Through more comprehensive understanding of the social-ecological system around salmon and herring, the project aims to suggest sustainable dioxin risk governance.
- GOHERR receives funding from the joint Baltic Sea research and development programme BONUS (2010-2017).
- Consortium: University of Helsinki, University of Aalborg, Swedish University of Agricultural Sciences, Finnish National Institute for Health and Welfare, University of Oulu
CONTENTS OF THE LECTURE

1. Dioxins and dioxin-like compounds in the Baltic Sea ecosystem
2. Risk management today
3. Problem structuring in the DPSIR framework
4. Ecosystem-based risk assessment and management
5. Environmental systems analysis to add understanding about the dioxin risk and evaluate the management options
   • Soft systems analysis: visualizing the areal differences
   • Hard systems analysis: a Bayesian influence diagram model for decision analysis under uncertainty
6. Conclusions
MAIN OBJECTIVE

• Presenting holistic risk diagnosis for the Baltic Sea dioxin problem
• Linking the risk assessment to management
• Presenting two ongoing systems analytical studies to analyse the question in practice
PART 1: DIOXINS AND DIOXIN-LIKE COMPOUNDS IN THE BALTIC SEA ECOSYSTEM
DIOXINS AND DIOXIN-LIKE COMPOUNDS

- A group of highly toxic environmental persistent organic pollutants, including:
  - Polychlorinated dibenzo-\(p\)-dioxins (PCDDs / “dioxins”)
    - 75 congeners
    - 2,3,7,8-Tetrachlorodibenzo-\(p\)-dioxin (TCDD) the most dangerous (TEF = 1)
  - Polychlorinated dibenzofurans (PCDFs / “furans”)
    - 10 isomers having dioxin-like properties
  - Polychlorinated / polybrominated biphenyls (PCBs / PBBs)
    - 12 dioxin-like
- Toxic equivalency factor TEF describes the toxicity
- TEQ: Toxic equivalency sum of the compounds
SOURCES OF DIOXINS IN THE ENVIRONMENT

- By-products of industrial and incomplete burning processes
  - Bleaching paper pulp, pesticide manufacture, waste-burning
  - Wood-burning (heating), traffic
- Also from natural processes, e.g. volcanic eruptions and forest fires
TOTAL PCDD/F CONCENTRATIONS IN THE BALTIC SEA SEDIMENTS

Verta et al. (2007); Assmuth & Jalonen (2005)
EFFECTS ON HUMAN

- Short-term exposure:
  - Skin lesions
  - Altered liver function
- Long-term exposure:
  - Reproductive and developmental problems
  - Impairment of the immune system
  - Impairment of the developing nervous system
  - Interference with hormones
  - Cancer
ENVIRONMENTAL PERSISTENCE AND BIOACCUMULATION

- All groups of dioxin-like compounds are persistent in the environment
- Lipophilicity: tendency to seek for fat-like environments
- Poor water solubility
- Bioaccumulation: the compounds move from water environment to living organisms having lipid cell structures
- Half-life in the body is estimated to be 7 to 11 years
BIOMAGNIFICATION

- The higher an animal is in the food chain, the higher the concentration of dioxins.
HUMAN EXPOSURE

- More than 90% of human exposure is through food: mainly meat and dairy products, fish and shellfish.

- Sensitive groups:
  - Developing fetus is most sensitive to dioxin exposure
  - Newborn, with rapidly developing organ systems

- The main exposure of Finnish people comes from fish, such as herring and salmon
CONCENTRATIONS IN BALTIC SEA HERRING

http://fi.opasnet.org/fi-opwiki/images/a/aa/Aineiden_pitoisuksia_silakassa.png
SHOULD I EAT HERRING OR NOT (THL)?

( The older you are, the more useful it is to eat herring (decreases the probability of e.g. strokes and heart attacks). BUT if you get Omega-3s and vitamin D from other sources, the utilities are much smaller (the lower panels).)

Herring as the only Omega-3- & vitamin D source

Lost life years (DALY / y)

Female

Male

DALY: disability-adjusted life year

http://fi.opsasnet.org/fi_wiki/images/6/63/Silakansy%C3%B6nnin_DALYt_ik%C3%A4ryhmitt%C3%A4in_ja_sukupuolittain.png
SHOULD I EAT HERRING OR NOT (THL)?
(0 – 50 year olds only)

(Minor risk of cancer due to the dioxin exposure exists at all ages. When it comes to women of fertile age, the main positive and negative effects are those for a fetus (positive effect of the O3s for the brain development -> IQ, "lapsen ÅO", and the negative effects of the dioxins to the teeth of the developing baby, "Hammasvaario")
Bioaccumulation depends on growth and food

- Bioaccumulation is dependent on the quality and quantity of food
- The less an individual needs to eat toxic objects to reach certain weight, the lower the concentration
  - The more energy one food object contains, the better
  - The more energy is allocated to growth (vs. maintenance), the better
- Varies spatially and along the growth
- Concentrations grow from South to North
CONCENTRATION IN FISH IS DEPENDENT ON ITS LENGTH AND GROWTH

Herring:

Baltic proper

Gulf of Bothnia
HERRING GROWTH IN DIFFERENT PARTS OF THE BALTIC SEA

Vainikka et al. (2009). Estimated marginal mean length-at-age in different ICES subdivision.
Kiljunen et al. (2007). Finnish human dietary intake of organochlorines (OCs) in Bothnian Sea herring under different fisheries management scenarios.
USE AND VALUE OF THE BALTIC HERRING CATCH (2014)

142 Milj. kg

- Fur farms export 16%
- Domestic fur farms 31%
- Fishmeal 30%
- Export food 20%
- Domestic food 3%

Prices
- Fur industry 0.17 – 0.20 € / kg
- Fishmeal 0.18 € / kg
- Export 0.30 € / kg (Russia)
- Domestic 0.60 € / kg

PART 2: RISK MANAGEMENT TODAY
BALTIC SALMON:

- Southern areas (ICES-areas 24-26):
  - < 5,5 kg can be sold (Denmark and Poland)
  - 5,5 - 7,9 kg can be sold after removing the fatty ventral part (Poland)
  - In other case, the concentration needs to be analysed
- Northern areas (ICES-areas 27-32):
  - the concentration needs to be analysed before selling for human consumption
CURRENT RISK MANAGEMENT
(EU 2016/688)

BALTIC HERRING:

- Southern areas (ICES-areas 22-27):
  - herring of all sizes can be sold for food
- Norther areas (ICES-areas 28.1, 29-32):
  - >17 cm: the concentration needs to be analysed before selling for human consumption
- Central area (ICES 28.2):
  - > 21 cm: the concentration needs to be analysed before selling for human consumption
Derogations are provided to Finland, Sweden and Latvia for placing on their domestic market and intended for consumption in their territory of wild caught salmon, wild caught Baltic herring larger than 17 cm, originating in the Baltic region exceeding the maximum level.
WHY THE DEROGATIONS?

• The official explanation (EY N:o 1881/2006):
  • Utilities > risks: Removing the fish from human diet may have negative health effects in the Baltic Sea region.
  • National dietary advice provided

• Other explanations (Assmuth & Jalonen 2005; Assmuth 2010):
  • The socio-economic and cultural value of the fisheries
  • Tradition-bound value of the sea fish in the national diets
  • The supply from food in general is on a lower level than e.g. in Central-Europe
DIETARY ADVICE IN FINLAND AND SWEDEN

- Evira (Finland): *Children, young people and persons of fertile age* may not eat large herring, which uncleaned are longer than 17 cm, or alternatively salmon or trout caught in the Baltic Sea more often than *once or twice a month*.

- Livsmedelsverket (Sweden): *Recommended maximum consumption of Baltic Sea herring and salmon for children up to 18 years and women in childbearing age is 2-3 times per year*. For other groups the recommended maximum consumption is once a week.
PROS AND CONS OF THE CURRENT STRATEGIES
(Assmuth 2010)

- Concentration limits (EU, excluding Finland, Sweden and Latvia)
  + No implementation uncertainty
  - Problems to fisheries, loss of the health benefits from fish eating, inflexible management, the basis for the limit values is not clear

- Dietary recommendations (FIN, SWE and LTV)
  + Balancing the risks and utilities, enables flexible management, acknowledging national special needs
  - Higher implementation uncertainty: effectivity of the advisory system?, need for active publicity campaigns and follow-up system.
HOW TO IMPROVE THE GOVERNANCE?
(Assmuth 2010)

- More holistic approach needed, to balance utilities and risks
- Open and active risk communication needed
- Integrated governance with other sectors of the Baltic region
  - Especially strengthening the links between fisheries, health and environmental sectors
  - Paying attention also to the origin of the problem: controlling the dioxin formation, emissions and spreading
PART 3:
PROBLEM STRUCTURING IN THE DPSIR -FRAMEWORK
DPSIR-FRAMEWORK FOR STRUCTURING A HUMAN-ENVIRONMENT SYSTEM

Drivers
Needs behind the pressures

Pressures
causes harm in the system

Impacts
Instruments to assess the harm

States
Harm caused by the pressure

Responses
According to the instruments, should we react?

What part of the system should be managed?

How / to what degree the system is affected by the pressures?

How harmful the effects are seen?
(How the society valuates them?)

How much certain level of need creates pressure?
DPSIR FOR THE DIOXIN PROBLEM

**D: Human need to produce materials, to move etc.**

**P: Burning processes**  
(industry, traffic)

**S: Increased dioxin conc. in the environment**  
-> dioxins accumulating along the food webs  
-> increased dioxin levels in the human diet  
(also other top predators)

**I: Increasing Burden of Disease**  
(if eating fish) / Negative effect to fisheries sector (if not eating fish)

What part of the system should be managed?

According to the instruments, should we react?

How harmful the effects are seen?  
(How the society valuates them?)

How / to what degree the system is affected by the pressures?
POTENTIAL RESPONSES

-> D: Produce less, travel less, consume less, develop novel innovations that decreases the needs

-> P: Develop more effective and ecological technologies to production and transport

-> S: Manipulate the food web?
   - Fish growth
     Manipulate / controll the human diet?
     - Fishing / trade regulations / dietary advise

-> I: Try to affect peoples’ ”feeling of loss”
COMPENSATING THE LOSSES

- Compensatory protein sources
- Compensatory payments to fishermen
- Developing new traditions
- Manipulating peoples’ risk attitudes
  - Public risk communication ("What is the risk?")
    - What do we know?
    - How much uncertainty is related to the current knowledge?
    - How are the current limit concentrations decided?
- Research -> getting more information
THE BEST DECISION?

- What should be done depends on our
  - OBJECTIVES
    - Short-term or long-term?
  - RISK ATTITUDE
    - Risk tolerance / risk aversiveness
- The both depends on our VALUES
  - Personal gains
  - Sense of fairness, ethics
THE "SENSE OF RISK"

- Always individual
- Value of eating fish:
  - "I like the taste"
  - "It's healthy"
  - "It's a traditional food"
  - "I fished it myself"
- Value of having lively fisheries
  - Saving the old culture
  - Economics
RISK TOLERANCE

- Personal (intuitive) risk assessment
- "How likely it is to me to get some of those diseases if I eat fish vs. if not?"
- How do I value my health?
- How much do I value the benefits against the risks?
UNCERTAINTIES IN THE SYSTEM

- Uncertainties related to D, P & S and their dependencies
- Uncertainty related to the effectivity of management
  - Implementation uncertainty
    - Human-driven
    - Nature-driven
- Variability among individuals related to "Impacts"
  - Values -> objectives and risk attitudes
  - What is the collectively best decision?
PART 4: 
ECOSYSTEM-BASED RISK ASSESSMENT AND MANAGEMENT
ECOSYSTEM-BASED MANAGEMENT CONCEPT

- Functioning of the ecosystem
  - Interactions within the ecosystem
  - Interactions between the ecosystem and human society
- Human as an active player: part of the ecosystem
  - Causing pressure
  - Being part of the food web
  - Using other ecosystem services
ECOSYSTEM-BASED FISHERIES MANAGEMENT

- Interdisciplinary approach to achieve **sustainable use of the resources**.
- Should aim for balancing diverse societal objectives by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions (FAO, 2003).

Sustainability is an integrative concept that considers environmental, social, and economic aspects as its three fundamental dimensions, so called **three pillars of sustainability** (e.g. Hansmann et al. 2012)
"ECOSYSTEM-BASED RISK ASSESSMENT" APPROACH

DPSIR for structuring the problem: what parts of it we could control?

...reaching / maintaining the sustainability?

Fisheries (econ.)
Human well-being
Culture (social)
Fish stocks (ecol.)

EBM: Human as an active player
- Causing pressure
- Being part of the food web
UNCERTAINTY AND VARIABILITY IN TIME AND SPACE

- Management plans should be directed to future!
- All the elements vary in space and are likely to develop in time
  - Local / regional strategies?
  - Short-term / long-term strategies?

NB! The wider the area, the more variability within it -> the more uncertainty in the assessment

NB! The longer the period of assessment / prediction, the higher the uncertainty about the development of everything
PART 5: ENVIRONMENTAL SYSTEMS ANALYSIS TO ADD UNDERSTANDING ABOUT THE DIOXIN RISK AND EVALUATE THE MANAGEMENT OPTIONS
SOFT SYSTEMS ANALYSIS: VISUALIZING THE AREAL DIFFERENCES

- Visualization of the different basins in the Baltic Sea
- Spatial differences in the system, potentially affecting the optimal regional management strategies, are in focus

Figure. An example
AREAL DIFFERENCES IN KEY BIOTIC, ABIOTIC AND ANTHROPOGENIC INTERACTIONS AFFECTING THE DIOXIN FLUX

- Plankton, benthic, fish, sea bird and mammal communities
- Feeding habits, competition, migration
  - food webs
- Hydrographic conditions
- Eutrophication
- Fisheries
- Sources
- Levels
- Congener profiles

Figure. Edited from http://gis.ices.dk/sf/index.html?widget=StatRec#
THE BASIC MODEL

- D-concentr. (Herring / salmon)
  - Biomagnification
  - Food D-concentr.
  - Growth
  - Fat %
  - Diet composition
  - Food availability

Food availability

- Growth

- Diet composition
Questions to be studied:

• What is the best way to reduce the consumers’ intake of dioxins from Baltic herring and salmon?

• Holistically thinking, how to control the dioxin problem in a sustainable manner?

• What variables in the system have the highest value of information?
  • Where the additional knowledge would be most useful?
INTEGRATED MODELLING

- Systems analytic approach to bring together diverse types of information, theories and data originating from different scientific areas (Laniak et al. 2013).

- Integration can happen in different ways and on different levels (Voinov & Shugart 2013)
  - **Modular model coupling**: connecting output of one model to serve as the input of another.
  - **Integral modelling**: the collaborative and coordinative function of the model template is highlighted.
BAYESIAN NETWORKS AND INFLUENCE DIAGRAMS

- Graphical models for causal reasoning under uncertainty. ID is a specific type of a BN for decision analytic purposes.
- BN and ID provide manageable platforms for compiling and structuring knowledge of different types and forms.
- Useful in tasks needed especially when analyzing complex environmental issues:
  - Problem structuring and visualizing
  - Quantitative systemic learning
**PRINCIPLE OF THE METHOD**

- **Graphical representation** is an acyclic graph, describing relationships (arcs) between variables (nodes).

- **Numerical representation** consists of the node-specific probability tables containing information on the probability of a variable being in a certain state (given the state of its parents).

\[
P(C|A,B) = \frac{P(A,B|C)P(C)}{P(A,B)}
\]

<table>
<thead>
<tr>
<th>Unconditional probability table for B:</th>
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<tbody>
<tr>
<td>State B1</td>
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<td>State B2</td>
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<th>Conditional Probability Table for C:</th>
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<tr>
<td>A</td>
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</tr>
<tr>
<td>B</td>
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<tr>
<td>State C1</td>
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<tr>
<td>State C2</td>
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<tr>
<td>State C3</td>
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</tbody>
</table>
PRINCIPLE OF THE METHOD: INFLUENCE DIAGRAM

- A BN augmented with decision and utility nodes
- Capable of solving decision making problems.
- In a decision variable, the mutually alternative measures are defined.
- Utility node is used for defining the criteria, against which the decisions are evaluated and compared.
GOHERR – INTEGRATED DECISION ANALYSIS TO REDUCE THE DIOXIN RISKS TO HUMAN HEALTH

CONSUMERS
Fish consumption & health effects

ECOSYSTEM
Accumulation of dioxins to herring & salmon

REGULATION

IMPROVED INFO

GUIDANCE

FISHING

NUTRIENT LOADING

DIOXIN LOADING

BURDEN OF DISEASE

VALUE OF CATCH

ECO-SYSTEM’S HEALTH

Presentation Name / Firstname Lastname 13/09/2017 57
PART 6: CONCLUSIONS
DIOXIN AS A BOUNDARY OBJECT BETWEEN SCIENTIFIC AND SOCIETAL FIELDS

Fig. 24. 'Blind men and the seal': Conceptualization of different perceptions of and perspectives on the Baltic fish dioxin problem.

Assmuth & Jalonen 2005, s. 291
LIST OF REFERENCES