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Use of biological life history, genetic, and vulnerability information to optimize the repertoire of oil combating technologies

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There are two decision orientated issues related to the risk of a large oil spill in the Baltic Sea requiring scientific analysis. First of all, how do we justify the requirements for substantial investments to prevent ecosystem impacts prior to accidents? Secondly, when an accident has happened, how do we allocate the available oil combating resources to minimize the harm to ecosystem? We demonstrate that there is a need to deal with these two decisions separately in a multidisciplinary context. This need is based on the combined effects of biological characteristics of the populations at risk and on the technical possibilities to restrict impacts of an oil accident.

There are 3 factors which influence both decisions: 1) vulnerability of populations to oil compounds, 2) uniqueness of populations (genetic specification of the population to the given environment), and 3) recovery potential of populations. In addition, 4) probability of an accident is fundamental for the decisions regarding investments aimed to decrease potential ecosystem tribulations. In the decision making after the accident, 5) ability to protect populations by the available combating technology is a key element.

The aim of this paper is to create a conceptual model for linking the ecosystem values to the oil combating decisions. We develop a first probabilistic model structure, but the exact ways to estimate the required probabilities remains a task to be solved during the OILECO project.

Keywords: oil spill combating, decision analysis, genetic differences, ecosystem impacts

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Introduction

Oil transportation activities have been quickly increasing in the Gulf of Finland (Fig.1). The growth rate has been faster than historically predicted, and we may still underestimate the future oil transportations. The main concern has been the ecosystem impacts of the oil spills, and e.g. in Finland there seems to be a high political support to invest on oil combating technology and on the preventive measures.

However, it is difficult to allocate the investments in a justified way. How much we should invest on oil booms, how much on oil skimming capacity, how much, if any, on oil dispersants, and how much on technical solutions to stop oil leakage?

In the scientific and political discussions, the ecosystem impact seems to be the most essential concern, even though the impact of oil spills on the recreational values has also been expressed. Due to the dominating role of the ecosystem knowledge, we argue that the ecosystem impact should be used as the criteria when evaluating the usefulness of various combating alternatives.

How do we then valuate, or rank the species in an oil spill context? Is a Caspian tern population more valuable than a grey seal population, or is the unique vendace population, in the eastern part of Gulf of Finland, actually one of the best justifications to invest on preventive measures?

Different types of criteria could be applied to this ranking (like the commercial value of the species, or the public interest on the species, or the rarity of the species in Finland). However, we argue that the uniqueness of the geneme of a population, and it's vulnerability to oil spills (how much of genetic variance can be destroyed by one oil spill) should be used as an element in the criteria. The management question is clearly a multicriteria decision task.

This paper is the first scientific paper of a three years OILECO project, which has the following aims:

1. To compile information on the ecosystem values of the Gulf of Finland.
2. To evaluate the sensitivity of the ecosystem components on oil spills.
3. To produce supportive information for the decisions to safeguard the most valuable populations in the Gulf of Finland in the case of oil spill.
4. To evaluate the justifications for the investments on preventive measures.

This paper aims to a first compilation of the argumentation (conceptual model) needed in related decision making, and suggests a probabilistic model structure to be used in these assessments. We do not show any results yet, even though the suggested model structure has been tested with some species.

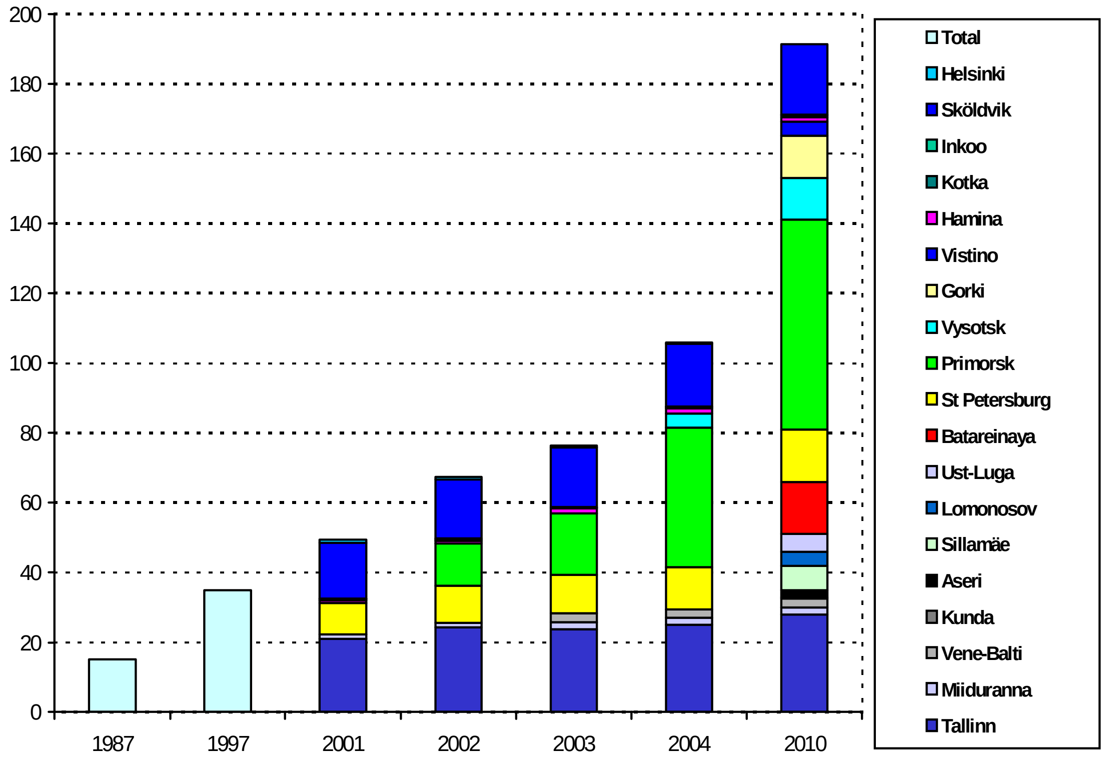

Fig. 1. Oil transportation in the Gulf of Finland in years 1987-2003 and estimated development for 2004 and 2010 (http://www.vtt.fi/uutta/2004/itameri/kaaviot.ppt)

Gulf of Finland as an ecosystem

The properties of the Baltic Sea and the Gulf of Finland as an ecosystem have been reviewed extensively in Furman *et al.* (1998, 2004) and Pajanen *et al.* (2005). Briefly, Baltic Sea is a small sea on a global scale, but it is one of the world's largest brackish water basins, thus ecologically unique and highly sensitive to the environmental impacts. Narrow and shallow straits connect the Baltic to the North Sea. Hence, the exchange of water is limited. It takes up to 30 years for water to be replaced and any contaminants will persist in the Baltic for a long time (HELCOM, 2005). Baltic Sea is geologically young sea; present conditions have existed for only 8 000-10 000 years. Therefore ecosystems have had a little time to adapt and develop after the last ice age.

The Baltic Sea is characterized by strong vertical and horizontal gradients that affect biota. It can be construed as a large estuary with strong salinity gradients (Pajanen *et al.*, 2005). Salinity of the surface waters varies from 20 ppt in the Kattegat to 1-2 ppt in the easternmost Gulf of Finland (HELCOM, 2005). Over 200 rivers drain into the Baltic providing a continual freshwater input. In the river estuaries water is nearly fresh. Permanent stratification limits the vertical mixing of water. Water becomes denser and thus heavier with increasing salinity and decreasing temperature. A stable halocline, a layer of water where salinity levels change rapidly, lies at a depth of around 60-80 m in the Baltic Proper, and at depth exceeding 60 meters in the Gulf of Finland (Furman *et al.*, 1998). Sea surface temperature is fluctuating with seasons varying usually between 0 and 20ºC during the year, the average temperature being 10ºC in the Gulf of Finland. Thermocline prevents the exchange of water during the summer. In the autumn thermocline disappears and the whole water column is mixed, unless there is a halocline to prevent the mixing. During normal winter the ice cover lasts 2 to

4 months in the Gulf of Finland. Low water temperature and ice cover slow down the degradation processes and hence, enhance the effects of contaminants in the Baltic Sea (Furman *et al.*, 1998).

The biodiversity of ecosystems is largely shaped by the environmental variables. Due to variable conditions specific biotopes and a flora and fauna consisting few but specially adapted species have developed. Unique mixture of both marine and freshwater species adapted to the brackish conditions can be found in the Baltic Sea. The number of species declines to the north and east. In the Gulf of Finland species are living close to their physiological tolerance limits and habitats are dominated by freshwater species. Although the number of species is low, the abundance of a single species can be high. Due to the low biodiversity there are only few key species with an important ecological role in the ecosystem. For instance, the bladderwrack zone plays an important role in the coastal ecosystems, providing shelter and a source of food to many invertebrates and fish. The ice age has left behind relict species like crustacean *Mysis relicta*, amphipod *Pontoporeia affinis* and isopod *Mesidotea entomon* (Furman *et al.*,1998).

The ecosystems in the southern and northern coast of the Gulf of Finland are hydrogeographically different. In the north, the coast of Finland has rich archipelago areas with varying habitat types. In the south, the Estonian coastline is rather uniform and exposed without major gulfs or archipelagos and has a comparatively steep coastal slope. Also in Estonia large variety of different biotopes occurs. The biotopes in the Gulf of Finland are determined mainly by substrata, depth and salinity (von Nordheim *et al.*, 1998).

The coastal ecosystem is an area of high primary production and the most diverse communities are found along the coast. The coastal species composition is dependent on the bottom surface (rocky or soft substrates). More than 40% of the Finnish coastline is bedrock (von Nordheim *et al.*, 1998). Coastal areas also provide essential breeding and nursery grounds for many pelagic fish and several invertebrates. However, the coastal marcrofauna communities inhabiting the Baltic Sea are less diverse than those found on the intertidal shores of the other seas (Furman *et al.*, 2004). The lack of intertidal shores and the limited depth reduce the availability of possible habitats and hence limit the number of species. Some water bodies slowly become separated from the sea due to land uplift forming lagoons called flads with high primary production. The flad environments are valuable areas allowing diverse plant and animal life (Appelgren & Mattila, 2005). Also the pelagic open-sea ecosystem plays an important role in primary production. Many of the fishes living in the Baltic Sea are dependent of the pelagic ecosystems (Furman *et al.*,2004).

We conclude that the Gulf of Finland ecosystem is so different compared to any other ecosystem that it is highly likely that many species have genetically adapted to the Gulf of Finland environment. If these populations are lost, we lose the work carried out by evolution after the last ice age. Similar losses are not equally likely in larger sea areas, where environmental gradients are not so strong on so short distances.

This uniqueness has been approved also by management bodies. In the year of 2004 International Maritime Organisation (IMO) designated the Baltic Sea as a Particular Sensitive Sea Area (PSSA). PSSAs are areas of the seas that need special protection through action by the IMO because of their vulnerability to harmful impacts from shipping activities (IMO, 2005). In the Gulf of Finland there are several protected areas that are designated as Natura2000 areas and/or Important Bird Areas (IBA) (Leivo *et al.*, 2002).

Methodology: Bayesian networks

We have decided to apply Bayesian nets to the modeling task. The main reason is that the related uncertainty is very high. The modeling tool must enable the modeling of high uncertainties, and on the other hand, to easily include and describe the impacts of improved knowledge (more narrow probability distributions). The fact that Bayesian nets can also be used as decision models (having utility function to maximize two or more decision options to compare) makes them even more useful in this type of applied scientific questions.

The idea behind Bayesian belief networks is fairly simple. They mimic the human inference: the human mind connects variables by means of logic and in the inference more weight is given to better knowledge. If something is unknown (= no information), it should not be reflected in other parts of the model.

This mimicry is easy to explain; belief networks have been developed on the field of artificial intelligence (AI) research where one of the aims is to describe human logic (see Pearl, 1988 for a detailed text on belief networks). According to the experiences obtained (see Varis and Kuikka, 1999, for an overview), this close relationship between human thinking and belief networks can also be seen in the elicitation process of expert knowledge.

The relationship between the variables is presented by conditional probabilities. The knowledge is ‘collected’ from the different parts of the model. Observations can be included and they update the knowledge of the network accordingly. In Bayesian decision analysis and in belief network modeling the structure of the entire model is uncertain, not only the parameters. The amount (quality) of knowledge is described by the shape of a probability distribution and the model is used for uncertain reasoning. The books of Almond (1995), Shafer (1996) and Jensen (2001) are detailed presentations on the use of belief networks.

The present application area of Bayesian belief networks is wide (see e.g. Jensen, 1996). They are mostly applied to assess the state of a system by using direct observations, prior knowledge and causal dependencies. They are very effective compared with rule-based systems (if x then y), especially if there are significant uncertainties in the causal relationships between the variables.

Another important use of belief networks is in the field of decision analysis, where modifications of belief networks, i.e. influence diagrams, are used to analyze decision problems. The use of influence diagrams is close to the use of decision trees, but in complicated problems the corresponding graphical representation is more easily understood. Therefore, it is easier for an expert, or for other stakeholders, to assess the suggested model structure.

Bayesian belief networks can include the following types of variables:

a) Probabilistic nodes: probabilistic variables, including conditional probabilities or prior probabilities

b) Deterministic nodes: including arithmetic functions and IF-THEN-ELSE rules

c) Decision nodes: control variables, values selected by decision makers

d) Expected value/utility nodes: objective variables, nodes to be maximized or minimized

If the model is used only to assess the state of the system, it can include probabilistic nodes only. Moreover, the types of variables can also be algorithm and software specific. For example Hugin software (http://www.hugin.dk/) is based on the algorithm presented in Lauritzen and Spiegelhalter (1988). This software allows the modeling of observing new information to any of the probabilistic variables. After observing one value, the beliefs on the state of the other variables are updated on the basis of the new information. In this algorithm, the information obtained can also go ‘against’ the direction of conditional probabilities shown by arrows. Computation is based on so called *junction trees* (e.g. Jensen, 2001).

Components of the model

Fig.2 shows the elements graphically, when thinking e.g. the justifications to prevent oil spill (upper part of the figure) and the priorisation of the species when an oil spill has happened (lower part). The probability of an spill, sensitivity of the species, and their conservation value and recovery potential are obviously relevant in the considerations before an accident,. After an oil spill, when deciding how to prioritize the species in combating activities, the probability does not matter anymore. There are three similar elements as above, but an additional element is the mitigation potential, i.e. whether existing oil combating tools can be used to safeguard the species.

In order to demonstrate what type of elements must be included to the probability evaluations, we discuss the model components in this section.

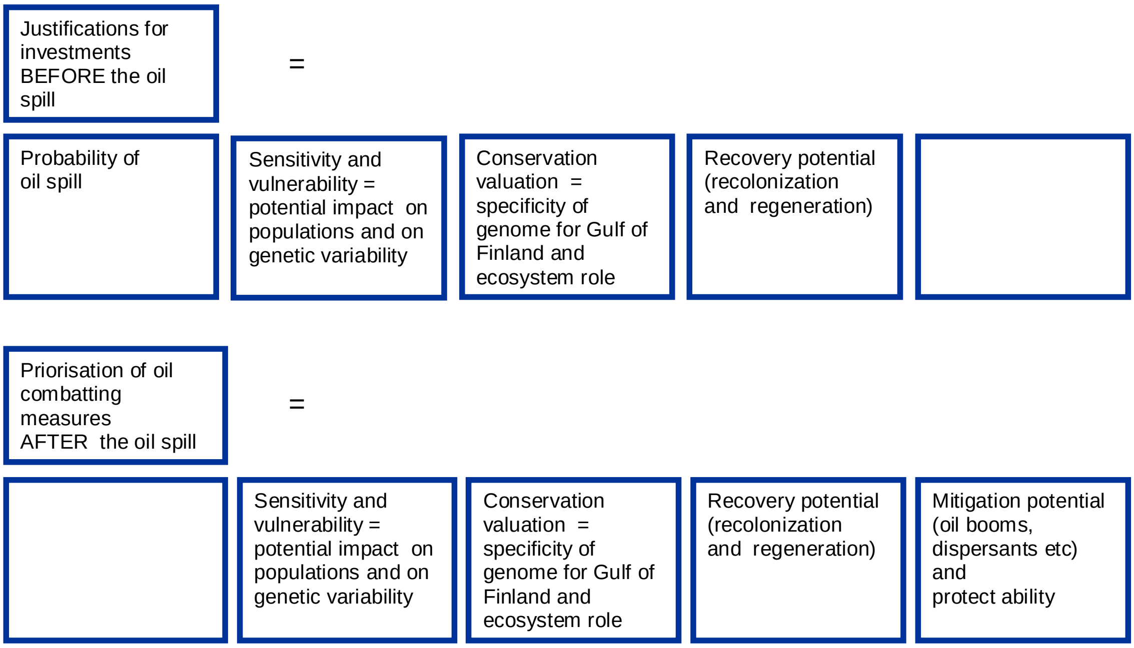

Fig. 2. The model components for preventive considerations (upper part) and for the priorisation of combating measures after the oil spill (lower part).

Probability of an oil spill

Fortunately, so far no large-scale oil spill has occurred in the Gulf of Finland. In the whole Baltic Sea 55-60 maritime accidents occur per year, not all leading to (significant) oil spills. Large oil spills with the magnitude of thousands of tons have been very rare. One of the largest accidents in recent years in the Baltic Sea occurred in 2001, when oil tanker *Baltic Carrier* collided with the bulk carrier *Tern* releasing 2700 tons of heavy fuel oil on to the coast of Denmark (Hänninen and Rytkönen, 2004). Baltic Sea has some of the densest maritime traffic in the world. Maritime oil transport has increased during the last years and is estimated to grow even more strongly in the future. In the year of 2000 the total amount of oil transported on the Gulf of Finland was 40 million tons and it may reach 190 million tons by the year of 2010 (Rytkönen & Vasilyev, 2005).

As the volume of traffic grows, so does the risk of accidents. In the Gulf of Finland new oil transport capacity has been rapidly built up in Russia, where totally new oil terminals have been built. Also the old existing harbours like Muuga oil terminal in Estonia has been under reconstruction. This year Primorsk oil terminal will ship up to 50 million tons of oil products with tankers that can carry 100 000 to 150 000 tons of oil. (Hänninen and Rytkönen, 2004). The growth of the maritime traffic is expected to continue. Not only the volume but also the characteristics of the oil tanker fleet have changed. Economic factors favour the use of maximum size tankers and tanker size has increased in oil transportation. For example, the average tanker size visiting the Port of Muuga has doubled over the period of 1998-2001, from 19000 tons to 41900 tons (Hänninen and Rytkönen, 2004).

The primary parameters defining the areas as high-risk are dense traffic including large oil tankers and the existence of severe ice conditions during winter. The most riskful area is predicted to be the area between Helsinki and Tallinn, because of the dense passenger traffic between these cities. In 2000 there were more than 30 calls of passenger vessels each day from Helsinki to Tallinn.

Together with an increase in oil transport over the last decades there have been improvements in maritime safety. Several means to improve safety in the Baltic Sea and the Gulf of Finland area have been developed to decrease the risk of collision and oil spill (for review see Hänninen and Rytkönen, 2005). In 2004 GOFREP (**G**ulf **o**f **F**inland ship **rep**orting-system) for the international waters of the Gulf of Finland was adopted by International Maritime Organization (IMO). The system will reduce the risk of two vessels colliding by 80 % (Rytkönen & Vasilyev, 2005). In 2005 HELCOM launched an Automatic Identification System (AIS) for monitoring maritime traffic in the Baltic Sea. The system provides automatically the information about the ship to other ships and to the coastal authorities. Still, in spite of the improved maritime safety systems, human related accidents represent around 80% of the total amount of accidents (Rytkönen & Vasilyev, 2005).

The occurrence of oil spills in the Baltic has been estimated to be 0,35 spills per 1000 journeys. It would mean 14 accidents per year causing oil spills in the Gulf of Finland including spills of bunker oil from any type of vessels. Probability of cargo oil spill would be 1-2 per year varying from some hundreds of tons to thousand of tons of oil. However, in true world oil spills of magnitude over 30-40 tons have occurred in Finland once every 39 months i.e. four oil spills in Finland during last 13 years (Jolma, 2005).

Sensitivity of the species and populations to oil spills

Oil spill can cause serious impacts on organisms and habitats. Organisms may be affected by oil in several ways - as a result of physical contamination (smothering) and by toxic effects of chemical. An effect can be direct damage to an organism or damage to the ability of an environment to support an organism. Unfortunately, very often it is easier to detect an effect than determine its significance.

The environment of the species, together with its sensitivity to oil, will determine the effects an oil spill is likely to have. In open water, organisms have often ability to escape from the oil spill area. Animals that live closer to shore are generally in higher risk of oil contamination. In shallow waters oil may harm nesting sites of many species. Main factors which determine seriousness of impact are type of oil, weather conditions, physical and biological characteristic of the area, and time of the year (NOAA, 2004).

White and Baker (1999) have reviewed the possible effects of oil on different organisms. In brief, oil does not readily penetrate most seaweed, which will survive oil pollution. In perennial plants recovery can take place through new growth from underground roots. Annual plants are more sensitive. Among invertebrates amphipods seem to be particularly sensitive. For molluscs and crustaceans observations after oil spills have been controversial. Fish eggs, larvae and young fish are vulnerable, possibly because higher sensitivity to oil toxicity and higher probability of exposure, whereas adult fishes seem to be more resistant to oil partly because they can have avoidance reactions. Birds living in the shore are less likely to become lethally oiled than seabirds. Fouling of eggs may cause embryonic mortality of birds. Finally, those marine mammals relying on fur for insulation are suffering hypothermia like the birds. Baltic ringed seal and Grey seal (excluding pups), are at less risk because they have a layer of insulating blubber under the skin.

Chronic toxicity is related to changes in metabolism, growth, reproduction and ability to survive. The survivors may have a competitive advantage. All these responses to oil contamination will eventually more or less reflect to the population and community level, including alterations in population and community structure and/or dynamics. Indirect effects can be as important as direct effects in structuring communities. These indirect effects are for example the changes in trophic cascades and biogenic habitat loss after the oil spill (NAS, 2003; Peterson *et al.*, 2003). Furthermore, possible reason for the observed reduction in reproductive success at e.g. oiled shag (*Phalacrocorax aristotelis*) colonies after *Prestige* oil spill was suggested to be due to low food availability after the oil spill (Velando *et al*., 2005).

Conservation values of populations

Among the model components, it is likely that the conservation values have a dominating role. This is the same as in any decision analysis, where the definition of utility function is usually an important part of the analysis. This is natural in the sense, that utility functions create the logic by which decision alternatives are ranked.

Usually the number of killed animals is the public concern. However, the expert knowledge analysis in Juntunen *et al.* (2005) suggests, that in the long term the oil spills have likely a relatively small impact on the populations. Most of the assessed populations would be recovered in ten years. However, the case is different if there is a risk to loose such populations permanently, which has been adapted genetically to the environmental settings in the Gulf of Finland. In such case, the migrations from other population would not necessarily lead to a recovery of the population in the same way as would happen, if the recovering population originates from the original population adapted to the area.

Therefore, we suggest to use the risk of losing such genetic material, which is especially and exclusively adapted to Gulf of Finland environment. Moreover, we will also include the role of the species in the ecosystem as an additional element, because large changes in the biomass of ecosystem key species may have long term impacts in the ecosystem.

However, it is not trivial to judge whether a population is genetically adapted to the Gulf of Finland, and how large an oil spill must be to destroy such part of genetic variance, which would reflect permanently to the recovery possibilities of a population. The problem with the genetic analysis (like microsatellites) is, that they are focused on the non-functional part of the genome, i.e. they describe only, whether the two compared populations have been isolated in the sense of reproduction. Therefore, the application of modern genetic methods to the given task is not straightforward.

The methodology to find such genetically adaptive mechanisms, which matter in the recovery potential after an oil spill, must be based on the functional features of the individuals and populations. For example in the case of Baltic cod, the egg experiments have been able to show, that the eggs of Baltic cod have better buoyancy in the Baltic brackish water than the cod of North Sea (Nissling and Westin, 1997), which is a clear demonstration that the Baltic population has genetically adapted to the Baltic environment. Similar evidence would be needed for other populations in order to show the importance and uniqueness of their genetic adaptations. This is a major task for experimental ecology. The OILECO project can only use the existing publications, expert knowledge or indirect inference based on e.g. the physiological features of the individuals. Especially regarding birds this is difficult, because many observed differences in the behavior of the individuals may be due to the learning, not on genetic differences. The methodology and logic of this part of reasoning are yet to be developed.

We may consider one example, demonstrating how different conclusions may be done when applying a “traditional”, fisheries orientated total valuation, or alternatively the genetically orientated approach described above. From the resource exploitation point of view, it is clear that herring, sprat and salmon would be the most important species (Finnish commercial total catch of herring and sprat is 2.7 million kg in the Gulf of Finland in 2005, www.rktl.fi). However, it is clear that these species would get migrating individuals from other areas in the case of an oil spill. The total catch of vendace (*Coregonus albula*) is, on the other hand, very low, but a total collapse of this population would lead to an irrecoverable damage, as similar genetic material would likely not migrate to the area. The closest vendace populations exist in the northernmost part of the Gulf of Bothnia, and they are likely adapted to quite different environmental settings than the Gulf of Finland populations. Thus, also environmental knowledge may have a role when trying to carry out a probabilistic estimate for the recovery potential and the conservation value of a population.

The other criterion in the conservation value of populations is a more classical one, i.e. the ecosystem role of the populations. It is to some extent a very contrary to the genetic valuation above, which favors small and unique populations. So called “key species” have high biomasses like bladderwrack (*Fucus vesiculosus*) and blue mussel (*Mytilus edulis*). Further analysis is needed to judge which other species may belong to this group in the Gulf of Finland.

Recovery potential of populations

This model component is likely to enable the use of more systematic and classical modeling tools, at least for some populations.

Recovery potential of severely impacted populations will be modeled to achieve probability estimates for recovery and time needed for recovery. Two recovery mechanisms will be considered: reproduction and recolonization. Recovery will fail without sufficient reproduction and, therefore, the rate of population increase at low population densities is the driving force of recovery dynamics.

The relationship between spawner abundance and subsequent mean recruitment is commonly described for fishes by the following models:

$R=\alpha S e^{-\beta S}$	Ricker model
$R=\alpha S/(1+(S/K))$	Beverton and Holt model
$R=\alpha S^{\delta}/(1+(S^{\delta}/K))$	Beverton and Holt model for the Allee effect (if $\delta>1$ (Thompson, 1993))

where *R* is recruitment, *S* is spawner abundance, and *K* is carrying capacity. The parameter α in the first two models has dimensions of recruitment per unit spawner abundance and gives the slope of the function at S=0. The slope at the origin of the spawner-recruitment curve can be interpreted as the maximum reproductive rate (Myers, 2001) which is central to estimating population growth rate.

Dynamic biomass models or age-structured models will be used depending on the quantity and quality of the available information of the population life history attributes. Models will be adjusted to account for the possibility of depensation (e.g. Allee effect) at low population densities, if judged to be necessary based on information about the life history or dynamics of the populations. Applicable information about fish populations will be available in a database containing worldwide spawner-recruitment data (Myers *et al.,* 1995).

Recovery may be enhanced by immigration from the adjacent populations in addition to reproduction by the impacted local population. When appropriate, life history models will be incorporated in metapopulation context to account for recolonization effects. To evaluate the time scales involved in recolonization, the simple Levins (1970) equation will be considered:

$$\frac{dP}{dt} = mP(1-P) - eP$$

where P is the fraction of all subpopulation areas occupied at time t, m the colonization parameter, and e the extinction parameter. The rate of colonization of empty areas (extirpated due to an oil spill) is assumed to be proportional to $P(1-P)$, where $P<1$. The equilibrium value of P is $P_E=1-e/m$, and therefore the metapopulation will persist as long as $e/m<1$. For persistence to occur, recolonization must take place at a sufficiently high rate within the metapopulation to offset the rate of extinctions (Hanski, 1997). In our application, P represents the proportion of major reproduction habitats (e.g. spawning grounds) that are occupied. The influence of harvesting on the metapopulation dynamics can be incorporated in the model by adding an extinction component due to harvest (Smedbol and Wroblewski, 2002). This will facilitate conclusions about the need of harvesting restrictions.

Analyses will be carried out to 5-15 species or populations including possibly birds, seals, fishes, and bottom fauna and flora. The simulations will be Monte Carlo type, to provide probabilistic estimates to be further used in the Bayesian network model.

Mitigation potential

The objective of this model component is to support decision making and allocation of oil combating resources after the oil spill has happened. Major categories of appropriate technologies have developed: mechanical recovery (booms and skimmers), chemical treatment, bioremediation and *in-situ* burning (EPA, 1999). In a major spill, it may be possible for all response techniques to be used simultaneously. The goal is to find the right mix of equipment, personnel, and techniques that will minimize the impacts of the spill.

When an oil spill occur it is critical to contain the spill as quickly as possible in order to minimize danger and potential damage to natural resources. Booms and skimmers are used to restrict the spread of oil (EPA, 1999). Booms are floating barriers to oil that are placed around a sensitive site, such as beaches used as nesting habitat, to prevent oil from reaching it. The oil collected with booms are removed from the sea surface with skimmers. The principal strategy is to skim the oil from the water surface as quickly and completely as possible.

Chemical and biological treatments of oil can be used to minimize impacts to biologically sensitive shoreline environments as well as economically-important areas. Dispersants are used in order to break up surface oil slicks and facilitate the movement of oil particles into the water column where they are subjected to natural prosesses. Dispersants are most effective when applied immediately following a spill. Heavy crude oils do not disperse as well as light and medium weight oils. There is evidence that dispersed oil degrades more quickly than undispersed oil, perhaps because the total surface area of an oil slick increases as dispersants break up the slick into small droplets.

Use of the dispersants might be less useful in the Gulf of Finland than in salt-water because dispersants work best in warm water and at salinity close to that of full seawater (NOAA, 2004). Both dispersants and dispersed oil particles are known to be toxic to some marine organisms. In the past dispersants used were far more toxic to aquatic biota than today but still long-term effects are not known. Dispersant can be used to save valuable bird colonies but at the same time pelagic and benthic animals suffer more from toxic effects of oil as it becomes more dissoluble (Singer *et al.*, 1998). In any particular situation, the decision to use dispersants involves balancing the potential advantages of dispersant use - removing oil from the water surface and avoiding some shoreline impacts - with the potential disadvantages, such as impacts to plankton and benthic fauna. Part of the work of planning the response to potential oil spills is the difficult task of evaluating these tradeoffs, which requires careful consideration of the resources and issues involved.

Due to the sensitive ecology of the Baltic Sea, it has been agreed in the Helsinki Convention that the oil combating policy of Baltic Sea countries is based on mechanical combating and minimizing the use of dispersants is recommended. In Finland, the Finnish Environment Centre (SYKE) is the only authority to allow the use of dispersants.

Other biological agents such as nutrients, enzymes and micro-organisms that increases the rate at which natural biodegradation occurs can be used to help natural bioremediation (EPA, 1999).

The clean-up of shores manually or mechanically is a time and money consuming effort. Methods used include wiping with absorbent materials, pressure washing, raking and bulldozing. Pressure washing usually does more harm by driving oil deeper into the beach and by dislodging or killing many organisms (EPA, 1999). Lighter oils evaporate quickly and do not contaminate shorelines. Heavier oils form thick water-oil emulsions which cling to rocks and sand. Different shores react differently to oil pollution.

In-situ burning of an oil slick before it reaches the coast is another alternative. However, there are health (toxic fumes) and safety aspects to be considered (Roos, 2001). Burn residues may sink, with potential long-term effects on sea bed ecology and fisheries (White and Baker, 1999). Plant and animal deaths and other adverse biological impacts may result from the localized temperature elevations at the sea surface. The long-term effects of burn residues on exposed populations of marine organisms have not been investigated. On the other hand, *in-situ* burning may provide less damaging alternative than traditional mechanical recovery in wetlands where harsh mechanic cleaning can cause more damage than the oil itself (Mullin and Champ, 2003). Furthermore when oil is spilled into water containing ice, burning can remove much more oil than conventional means (EPA, 1999).

Our methodological conclusion is that most of the above discussed model components include so complicated elements when applied to ecosystem level, that a use of deterministic, or even a rule based model is not justified. We believe that the use of educated experts and application of Bayesian nets is the preferred first step.. Some of the dependencies can likely be updated with different type of modeling tools later on.

Probabilistic model structure

Our work is a continuation to the work done by Juntunen *et al.* (2005), but focusing on the biological side of the model only. This biological side seems to be the dominating one in the justification of oil combating investments. We will go into biological details because the analysis by Juntunen *et al.*

(2005) demonstrates that more detailed knowledge is required. This means also that more variables are needed, and species specific probabilities are required for an adequate analysis.

The very extensive work carried out on fish populations (see e.g. Myers, 1995) demonstrates that the reproduction potential of a population is a highly uncertain even concerning very long and extensive data series from undisturbed ecosystems. As we have (luckily) very limited amount of knowledge about large scale oil spills, it is obvious that uncertainty is a dominating feature of the modeling, which recalls for probabilistic methods. Bayesian networks offer a flexible way to combine the knowledge into a probabilistic model.

Fig 3 shows the preliminary probabilistic model version including the components described earlier. The node (variable) "Species" includes all species considered. When using the model, this variable must be fixed to represent the species considered. The node "Oil spill" has currently only two outcomes: Yes and No. The probabilities given for these outcomes are the current probabilistic estimates for oil spills. When the outcome "Yes" is chosen, the calculated probabilities describe the knowledge related to interest variables after an accident has taken place.

One of the advantages of the Bayesian network models is that they can be linked together through the conditional probabilities. In this case we aim to develop the biological part of the overall model of Juntunen *et al.* (2005) to be more detailed, and then link this model component later on to the overall model.

It should be noticed, that the justified model structure may include more variables than suggested in Fig. 3 (like the conservation value is described to be dependent on "Ecosystem role" and on "Genetic uniqueness", which were also discussed separately above). This type of more detailed structure in the model is justified if it helps to evaluate the probabilistic dependencies. However, the inclusion of several variables and several arrows also complicates the evaluations, which may in some cases lead to worse estimates (due to complicatedness) than a more simple structure.

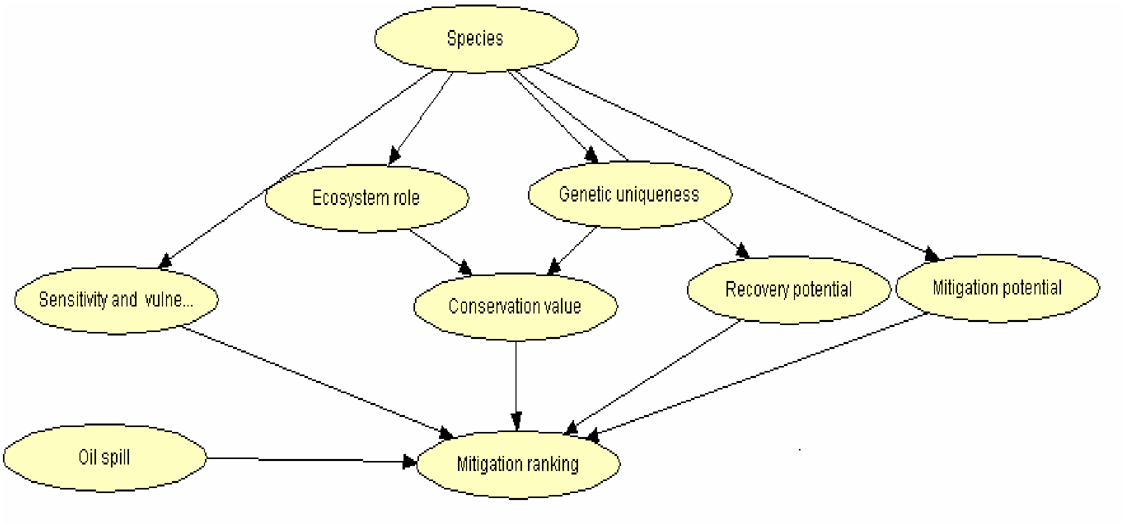

Fig.3. The model component of the probabilistic model. Each link (arrow) describes a probabilistic dependency described by conditional probability table. This model will be combined later on to the full model described in Juntunen et al. (2005).

Future challenges

The most critical part of the modeling is the biological impact of the oil spill. In the recovery analysis, changes in the ecosystem and food web - induced by direct exposure to oil or by indirect effects via species interactions - may significantly influence the probability of recovery. These changes have not received much emphasis so far and the analysis should be elaborated to account for processes affecting carrying capacity and stability of the ecosystem.

All populations, and the populations being at the highest risk in particular, are found only in limited geographical areas and habitats. Therefore, spatial considerations are necessary for the Gulf of Finland applications. The analysis, conclusions, and recommendations must be transferred to geographical information system (GIS) to be effective and influential.

Differences among the experts dominate in the uncertainty analysis of expert knowledge (Uusitalo *et al.* 2005). Therefore, we should interact with several experts in the evaluations and use Bayesian nets to combine their knowlege and associated uncertainties. However, these evaluations require profound knowledge and the absolute number of experts is likely not high.

References

Almond, R.G. 1995. Graphical Belief Modeling. Chapman & Hall. London. 427 pp.

Appelgren, K. and Mattila, J. 2005. Variation in vegetation communities in shallow bays of the Northern Balti Sea. *Aquat. Bot.* **83**: 1-13.

U.S. Environmental Protection Agency (EPA). 1999. Understanding oil spills and oil spill response. EPA 540-K-99-007. U.S Environmental Agency. Cincinnati, Ohio. Available online at http://www.epa.gov/oilspill/pdfbook.htm

Furman, E., Dahlström, H. and Hamari, R. 1998. The Baltic – Man and Nature. Otava Publishing Company Ltd., Helsinki. 160 pp.

Furman, E., Välipakka, P., Munsterhjelm, R. and Nöjd, A. 2004. Baltic Sea –Environment and Ecology. Slide series and booklet. Available online at http://www.helcom.fi/press_office/news_baltic/en_GB/balticnews11062004/

Hanski, I. 1997. Metapopulation dynamics: from concepts and observations to predictive models. In: *Metapopulation biology: ecoogy, genetics, and evolution*. pp. 69-91. Hanski, I. and Gilpin, M.E.(Eds.), Academic Press, Edinburgh.

HELCOM. 2005. The nature of the Baltic Sea. Available online at http://www.helcom.fi/environment2/nature/en_GB/nature/

Hänninen, S. and Rytkönen, J. 2004. Oil transportation and terminal development in the Gulf of Finland. VTT Publications 547. Available online at http://www.vtt.fi/int/pdf/publications/2004/P547.pdf

International Maritime Organization (IMO) 2005. Special Areas and Particularly Sensitive Sea Areas. Available online at http://www.imo.org/

Jensen, F.V. 2001. Bayesian Networks and Decision Graphs. Statistics for Engineering and Information Science. New York: Springer Verlag, 268 pp.

Jolma, K. 2005. Threat of oil spill in Gulf of Finland and SYKE new technology to deal with. Petroleum association of Japan - Oil Spill Symposium. Tokyo, Japan. Available online at http://www.pcs.gr.jp/doc/esymposium/2005/2005_Jolma_E.pdf

Juntunen, T., Rosqvist, T., Kuikka, S. & Rytkönen, J. 2005. Assessment of oil combatting technologies using Bayesian networks – an application in the Baltic Sea. Submitted manuscript.

Lauritzen, S.L. and Spiegelhalter, D.J. 1988. Local computations with probabilities on graphical structures and their application to expert systems. *J. Roy. Stat. Soc. B. Met.* **50**, 157-224.

Leivo, M., Asanti,T., Koskimies, P. Lammi, E., Lampolahti, J., Mikkola-Roos, M. and Virolainen, E. 2002. Suomen tärkeät lintualueet FINIBA. BirdLife Suomen julkaisuja nro 4. Suomen graafiset palvelut, Kuopio. 142 pp. (in Finnish)

Levins, R. 1970. Extinction. In: *Some mathematical problems in biology*. pp. 77-107. Desternhaber, M. (Ed), American Mathematical Society, Providence.

Lindgren, C. and Lindblom E. 2004. Short-term effects of accidental oil pollution in waters of the Nordic Countries. IVL Swedish Environmental Research Institute Ltd, Arkivnr U964. Available online at http://www.norden.org/miljoe/hlg/sk/shortterm_oil_%20pollution.pdf

Mullin, J.V. and Champ, M.A. 2003. Introduction/Overview to *in situ* burning of oil spill. *Spill Sci. Tech. Bull.* **8**: 323-330.

Myers, R.A. 2001. Stock and recruitment: generalizations about maximum reproductive rate, density dependence, and variability using meta-analytic approaches. *ICES J. Mar. Sci* **58**: 937-951.

Myers, R.A., Bridson, J., and Barrowman, N.J. 1995. Summary of Worldwide Spawner and Recruitment data. *Can. Tech. Rep. Fish. Aquat. Sci.* 2024. 327pp.

National Academy of Sciences (NAS). 2003. Oil in the sea III: Inputs, fates, and effects. National Academy Press. Washington, D.C. Available online at http://www.nap.edu/openbook/0309084385

National Oceanic and Atmospheric Administration (NOAA). 2004. An Introduction to Coastal Habitats and Biological Resources for Oil Spill Response. Report No.HMRAD 92-4. Hazardous Materials Response and Assessment Division, National Oceanic and Atmospheric Administration. Seattle,Washington.
Available online at http://response.resoration.noaa.gov/oilaids/monterey

Nissling, A. and Westin, L. 1997. Salinity requirements for successful spawning of Baltic and Belt Sea cod and the potential for cod stock interactions in the Baltic Sea. *Mar. Ecol. Prog. Ser.* **152**: 261-271.

von Nordheim, Henning and Boedeker, Dieter (eds.). 1998. Red list of marine and coastal biotopes and biotope complexes of the Baltic Sea, Belt Sea and Kattegat : including a comprehensive description and classification system for all Baltic marine and coastal biotopes. Helsinki, Baltic Marine Environment Protection Commission - Helsinki Commission. P. 71-94. Baltic Sea Environment Proceedings ; 75.
Available online at http://www.helcom.fi/publications/bsep/en_GB/bseplist/

Pajanen, K., Soulanto, M. and Sikk. E. (eds.) 2005. Suomenlahti – alkumerestä nykymereksi. Helsingin kaupungin ympäristökeskus ja Kustantajat Sarmala Oy. (in Finnish)

Pearl, J. 1988. Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference. Morgan-Kaufman, San Mateo, CA. 552 pp.

Peterson, C.H., Rice, S.D., Short, J.W., Esler, D., Bodkin, J.L., Ballachey, B.E. and Irons, D.B. 2003. Long-term ecosystem response to the *Exxon Valdez* oil spill. *Science* **302**: 2082-2086.

Roos, C. 2001. Conservation values of the Gulf of Finland – threats of vessel traffic and prevention measures. WWF Finland.

Rytkönen, J. and Vasilyev, V. 2005. Baltic oil spill safety – Recent trends of marine oil transportation in the Baltic Sea. 28th Arctic and Marine Oilspill (AMOP) Technical Seminar, Calgary, Canada.

Smedbol, R. K. and Wroblewski, J. S. 2002. Metapopulation theory and northern cod population structure: interdependency of subpopulations in recovery of a groundfish population. *Fis. Res.* **55**: 161-174.

Singer, M.M., George, S., Lee, I., Jacobson, S., Weetman, L.L., Blondina, G., Tjeerdema, R.S., Aurand, D. and Sowby, M.L. 1998. Effects of dispersant treatment on the acute aquatic toxicity of petroleum hydrocarbons. *Arch. Environ. Contam. Toxicol.* **34**: 177-187.

Thompson, G.G. 1993. A proposal for a threshold stock size and maximum fishing mortality rate. In: *Risk evaluation and biological reference points for fisheries management*, pp 67-81. Smith. S. J., Hunt, J. J., and Rivard, D. (Eds.) Canadian Special Publication of Fisheries and Aquatic Sciences, 120.

Uusitalo, L., Kuikka, S., and Romakkaniemi A. 2005. Estimation of Atlantic salmon smolt carrying capacity of rivers using expert knowledge. *ICES J. Mar. Sci.* **62**: 708-722.

Varis, O. and Kuikka, S. 1999. Learning Bayesian Decision Analysis by Doing: Lessons from Environmental and Natural Resources Management. *Ecol. Model.* **119**: 177-195.

Velando, A. Álvarez, D., Mouriño, J., Arcos, F. and Barros, Á. 2005. Population trends and reproductive success of the European shag *Phalacrocorax aristotelis* on the Iberian Penisula following the Prestige oil spill. *J. Ornithol.* **146**: 116-120.

White, I.C. and Baker, J.M. 1999. The *Sea Empress* oil spill in context. International Conference on the Sea Empress Oil Spill 1998. Cardiff, Wales.