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THE ENVIRONMENTAL IMPACTS OF OIL SHIPPING AND OFFSHORE WIND POWER AT THE EASTERN GULF OF FINLAND
-
A BAYESIAN APPROACH TO MARINE SPATIAL PLANNING

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Tiivistelmä – Referat – Abstract

The seas and oceans are the scene of multiple human actions, all of which cause pressures on the marine environment. Marine spatial planning (MSP) systematizes the evaluations of the spatial impacts of the human actions and take into consideration the cumulative impacts of the actions. A probabilistic model is constructed to estimate the impacts of oil shipping and offshore wind power on 16 species. The quantitative indicators of impacts are the loss of breeding success of 5 birds, the loss of the early development stages of 3 fish species and the change in the probability of presence/absence of 3 benthic species and 5 algae. The thesis model works as an independent application, but can be merged as such into a MSP tool that works with a geoinformatic system (GIS) interface. The impacts of offshore wind power and oil shipping, and especially the possible oil spill, have been studied at other marine areas, but there are only few studies about their impacts in the brackish water conditions of the Baltic Sea. The study area of this thesis is the eastern Gulf of Finland (EGOF).

The model is constructed using Bayesian networks (BNs) which are graphical probabilistic models. The most important human pressures caused by the actions are identified based on literature and placed in the model accordingly. The pressures caused by operational offshore wind power are the disturbance to birds and underwater noise. The pressures caused by oil shipping are underwater noise and the oil exposure of species after a possible oil spill. The attenuation of the pressures as a function of increasing distance from the source of pressure is calculated mathematically, where possible. Expert elicitation is conducted to fill in the gaps in existing data over the subject. Altogether 6 experts were interviewed and another two were consulted informally. The different types of data are integrated in the BN, which allows quantified comparisons between different management options and alternative scenarios.

The model predicts that both human actions have negative impacts on the marine environment of the EGOF. The impacts of an offshore wind mill will realize without uncertainty but they will be negligible. An oil spill, on the other hand, is unlikely to happen, but if it does, the losses will be extensive. The disturbance of the wind mill on birds extends to some hundreds of metres from the mill, depending on the bird species. The losses of the early development stages of fish caused by the underwater noise of a wind mill are nearly certainly below 20% at all distances from the mill for all studied species. With the most likely sound pressure levels of tankers, the losses to the early development stages of the fish also remain below 20% with a high level of certainty at all distances. At these tanker noise levels, the harmless noise class of <90 dB re 1µPa will be reached at some kilometres of the fairway, depending on the original noise level from a tanker. Three alternative oil shipping scenarios for 2020 were compared. The differences among the scenarios are negligible both when it comes to the impacts of underwater noise on fish and to the probability of a species to get exposed to oil.

The model successfully describes the impacts of the human pressures that are known to take place, such as the impacts of offshore wind power, but requires a GIS environment and drift models to be able to predict the probabilities of an oil exposure. The applicability of the model can be increased by taking into consideration additional human actions and a wider selection of human pressures. The thesis model is a part of a MSP tool produced in TOPCONS (Transboundary tools for the spatial planning and conservation of the Gulf of Finland) project, which is a prototype of a tool that can be later applied at marine areas worldwide.

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Tiivistelmä – Referat – Abstract

Useat merille ja valtamerille sijoittuvat toiminnot, kuten laivaliikenne ja energiantuotanto, aiheuttavat paineita meriympäristölle. Merialuesuunnittelulla pyritään systematisoimaan ympäristövaikutusten spatiaalisuuden arviointia ja ottamaan huomioon myös toiminnoista aiheutuvat kumulatiiviset vaikutukset. Tässä työssä rakennetaan todennäköisyyspohjainen malli, jolla arvioidaan öljykuljetusten ja merituulivoiman vaikutuksia 16 lajiin. Indikaattorit, joilla vaikutuksia kuvataan, ovat tappio viiden linnun pesimiseen, tappio kolmen kalalajin varhaiskehitysvaiheisiin ja viiden levän ja kolmen pohjaeläimen kuolleisuus. Pro gradu –työn malli toimii itsenäisenä sovelluksena, mutta se voidaan sisällyttää sellaisenaan myös paikkatietoympäristössä toimivaan merialuesuunnittelutyökaluun. Merituulivoimaa ja öljykuljetuksia ja etenkin niihin liittyvää mahdollista öljyvuotoa on tutkittu muilla merialueilla, mutta Itämeren murtovesiolosuhteissa niitä on tutkittu vain vähän. Pro gradu -työn tutkimusalue on itäinen Suomenlahti.

Työn malli on rakennettu bayes-verkoilla, jotka ovat graafisia todennäköisyysmalleja. Merkittävimmät toimintojen aiheuttamat paineet identifioidaan kirjallisuuden perusteella ja sijoitetaan verkkomalliin syy-seuraussuhteiden mukaisesti. Käytön aikaisen merituulivoiman aiheuttamat paineet ovat lintuihin kohdistuva häiriö ja vedenalainen melu. Öljykuljetusten aiheuttamat paineet ovat vedenalainen melu ja lajien altistuminen öljylle mahdollisen öljyonnettomuuden seurauksena. Paineiden vaimenemista kuvataan etäisyyden funktiona niiltä osin kuin mahdollista. Puuttuvaa dataa paikataan tekemällä asiantuntijahaastatteluja. Työssä haastateltiin yhteensä kuutta asiantuntijaa, joiden lisäksi kahta asiantuntijaa konsultoitiin epämuodollisesti. Erityyppiset tiedot yhdistetään bayes-verkossa, mikä mahdollistaa eri skenaarioiden ja vaihtoehtojen kvantifioidun vertailun.

Malli ennustaa molemmilla toiminnoilla olevan negatiivisia vaikutuksia itäisen Suomenlahden meriympäristöön. Merituulivoiman vaikutukset toteutuvat varmasti mutta ne ovat vähäpätöisiä. Öljyonnettomuuden todennäköisyys taas on hyvin pieni, mutta mikäli se tapahtuu, tappiot eri lajeille ovat mittavat. Tuulivoiman lintuihin kohdistuva häiriö ulottuu lajista riippuen joidenkin satojen metrien päähän tuulivoimalasta. Tuulivoimalan vedenalaisen melun aiheuttama tappio kalojen varhaiskehitysvaiheille jää hyvin todennäköisesti alle 20%:iin kaikilla etäisyyksillä tuulivoimalasta. Myös öljytankkereiden yleisimmillä äänenpainetasoilla kalojen varhaiskehitysvaiheiden tappio jäävä alle 20%:n luokkaan hyvin suurella todennäköisyydellä. Samoilla lähtöäänenpainetasoilla harmiton, alle 90 dB re 1µPa:n äänenpaineluokka saavutetaan joidenkin kilometrien etäisyydellä väylästä äänenpaineen tarkasta lähtötasosta riippuen. Mallissa verrattiin kolmea vaihtoehtoista öljyliikenneskenaariota vuodelle 2020. Skenaarioiden erot ovat mitättömät tarkasteltaessa niin vedenalaisen melun vaikutuksia kaloihin kuin lajien öljyaltistumisriskiä.

Malli kuvaa menestyksekkäästi niiden paineiden vaikutusta, joiden tiedetään realisoituvan, kuten molemmat merituulivoiman aiheuttamat paineet. Toisaalta, malli vaatii paikkatietoympäristön ja virtausmallin, jotta öljyyntymistodennäköisyyksiä voidaan ennustaa. Mallin soveltuvuutta ja toimivuutta voidaan parantaa lisäämällä tutkittavien toimintojen ja paineiden määrää. Pro gradu –työssä kehitetty malli on osa TOPCONS-projektissa (Transboundary tools for the spatial planning and conservation of the Gulf of Finland) tuotettua merialuesuunnittelutyökalun prototyyppiä, jonka tulevat versiot ovat sovellettavissa muille merialueille maailmanlaajuisesti.

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ABBREVIATIONS:

AIS	Automatic Identification System
BIAS	Baltic Sea Information on the Acoustic Soundscape
BN	Bayesian network
CPT	Conditional probability table
BSAP	Baltic Sea Action Plan
EU	European Union
EGOF	Eastern Gulf of Finland
ENPI CBC	European Neighbourhood and Partnership Instrument – Cross Border Cooperation
GIS	Geoinformatic systems
GOF	Gulf of Finalnd
HELCOM	Baltic Marine Environment Protection Commission - Helsinki Comission
HENVI	Helsinki University Centre for Environment
IMO	International Maritime Organisation
MIMIC	Minimizing risks of maritime oil transport by holistic safety strategies
MSP	Marine Spatial Planning
SL	Source level
SPL	Sound pressure level
SYKE	Finnish Environment Institute
TOPCONS	Transboundary tools for the spatial planning and conservation of the Gulf of Finland
PL	Propagation loss
PSSA	Particularly sensitive area

1. Introduction

The global consumption of energy is constantly growing (EIA 2014), and its methods of production change as the burning of carbon is strived to be decreased (*e.g.* Akella et al. 2009; Wilhelmsson et al. 2010: 1). The oceans and seas have always been a passageway for products and passengers, and their use has been expanded to other fields, such as offshore energy production. The European Marine Strategy Framework Directive (European parliament and European council 2008) states that the human pressures on natural marine resources are often too high, as is the demand for marine ecological services.

Marine spatial planning (MSP) is needed to ensure that the cumulative effects of human actions at sea can be observed and dealt with. MSP is *"a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process"* (Ehler & Douvere 2009). It is a tool to support the implementation of an ecosystem based approach in marine management (Stelzenmüller et al. 2010), and a way to facilitate the implementation of several EU initiatives, such as the Marine Strategy Framework Directive, the Renewable Energy Directive and the Habitats Directive (COM 2013) as well as the Baltic Sea Action Plan (BSAP) (Backer et al. 2010).

In this thesis, a probabilistic spatial model is constructed to analyse the impacts of two human actions, oil shipping and offshore wind power, on 16 different species at the eastern Gulf of Finland (EGOF). The thesis model is built using Bayesian networks, and it is a part of a prototype MSP tool which answers to the needs addressed in the above mentioned documents. Given the vulnerability and the transboundary status of the EGOF, there is a real demand for MSP and decision analysis tools.

The marine environment is a challenging area of and management, since actions performed in one country may cause direct or indirect impacts on the regional waters of another. The challenges for the management of the marine environment are often multidisciplinary, as are the solutions to them. In this thesis the phenomena are viewed from a spatial viewpoint, making the approach geographical, even though the management of the problem is analysed in an ecological framework. The need for the thesis model rises from three elements:

1) the current and future energy needs that are driving the studied human actions;
2) marine spatial planning, and
3) the ecological point of view (figure 1).

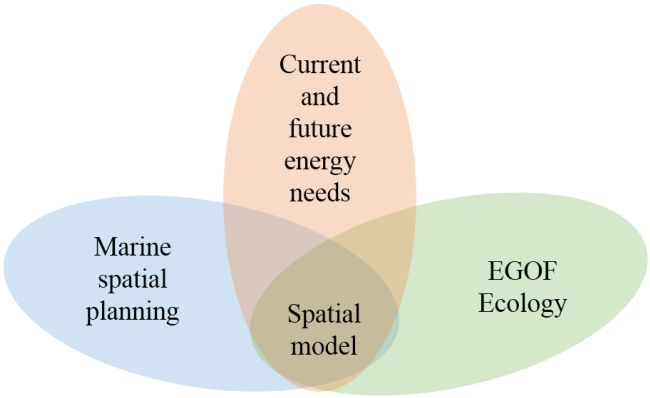


Figure 1. The framework of the spatial model developed in this thesis. The need for the model rises from the current and future needs of energy and from the increasing use of the seas. The ecology of the seas has to be taken into account in order to plan sustainable solutions to answer to the future needs of energy consumption and marine spatial planning.

The key objectives of this master's thesis are to develop a spatial model to assess the impacts of two human actions on the marine ecosystem and to produce results using the model, as well as to analyse and discuss the usefulness and overall success of the model and the method. The objectives can be summarized into three research questions, which are

1) What are the environmental impacts of offshore wind power and the increase of oil shipping at the eastern Gulf of Finland?
2) What are the cumulative effects of the actions?
3) How reliable are the results produced by the selected method?

The first two questions are answered on the basis of the model in the results' chapter of this thesis. The third one is answered in the discussion part, where the overall success of the model is assessed. The most important environmental impacts of the human actions are identified and presented in chapter 2. The used methods are described in chapter 3, and chapter 4 presents the model itself. Chapter 5 presents and discusses the results produced with the model, and the overall success of the model and the process are discussed in chapter 6 (figure 2). The thesis works with three types of data: project data, publications and expert judgements.

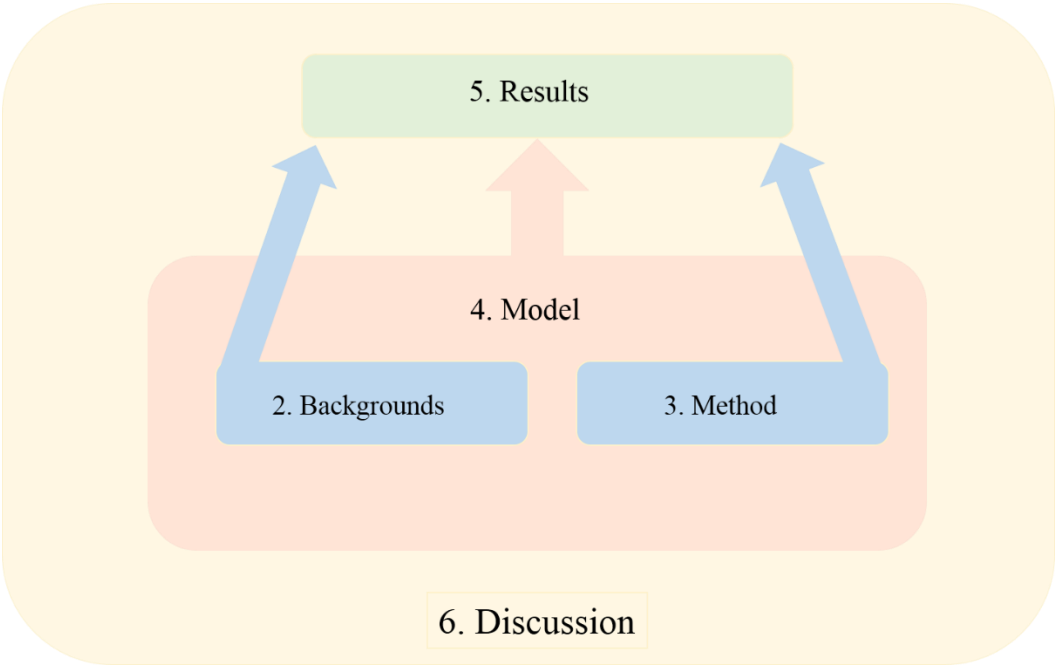


Figure 2.The structure of this master's thesis. The outcomes of chapters 2 and 3 are joined together in chapter 4, and the three chapters together form the basis for chapter 5, which presents and discusses the results of the model. Chapter 6 discusses the suitability of the method and the overall success of the model.

The thesis is a part of TOPCONS project (Transboundary tools for the spatial planning and conservation of the Gulf of Finland, funded by ENPI CBC), and the model constructed in this thesis is designed so that it works independently but can be directly applied into the TOPCONS MSP-tool and work in the background of a geoinformatic system (GIS) interface. The tool works at the EGOF with a 100 x 100 metre grid size. In the future, the MSP tool can be applied to other marine areas worldwide. The thesis is a part of Helsinki University Centre for Environment (HENVI) multidisciplinary Baltic Sea master's thesis programme.

2. Backgrounds

Human actions put pressures on the ecosystem. This thesis uses the definition by Korpinen et al. (2012), according to which an anthropogenic pressure (from now on human pressure) is a "*human-derived stress factor causing either temporary or permanent disturbance or damage to or loss of one or several components of an ecosystem*." The pressure may cause direct damage to the ecosystem, or it may change for example the physical or chemical circumstances of the area and thus cause indirect damage. The term *environmental impact* is

used for the impacts that human pressures cause in the ecosystem. Table 1 shows an example of how human actions, human pressures and environmental impacts are related.

Table 1. Human actions, human pressures and environmental impacts.

Human action ►	Human pressure ►	Environmental impact
Oil shipping	Oil exposure	Oil-induced loss
	Underwater noise	Loss due to decreased ability to sense predation

Bayesian networks (BNs) are used to complete a risk analysis of the human actions in the EGOF. A BN (also called Bayes network, belief network, Bayes belief net) is a probabilistic graphical model that describes the conditional dependencies between factors as well as their degree of uncertainty.

2.1 The eastern Gulf of Finland

The Baltic Sea is one of the largest brackish water bodies in the world, and its biological, chemical and physiological characteristics are unique. Also the flora and fauna of brackish waters are unique (Lecklin et al. 2011) and the brackish water ecosystems are very vulnerable. The Gulf of Finland (GOF) is one the main basins of the Baltic Sea.

The GOF is the easternmost part of the Baltic Sea and it is about 400 kilometres long and 58–135 kilometres wide. It is a shallow narrow bay, with an average depth of 37 metres. River Neva, which is the biggest river in the Baltic runoff area, lets out to sea at the tip of the GOF (Kotilainen et al. 2012). In a study on the human pressures and their potential impact on the Baltic Sea ecosystem by Korpinen et al. (2012), the Gulf of Finland was ranked among the places with the highest cumulative impacts of human actions on the marine ecosystem, and the nutrient load of the GOF is two- or threefold compared to the rest of the Baltic Sea. About 20 million people live in the drainage basin of the GOF (Hänninen et al. 2004: 18).

The study area of this thesis is the eastern Gulf of Finland. It covers Finnish and Russian waters eastwards from in Pyhtää on the Finnish coast, stretching to the end of the gulf up to St. Petersburg, and ending at the Russian-Estonian border (Figure 3).

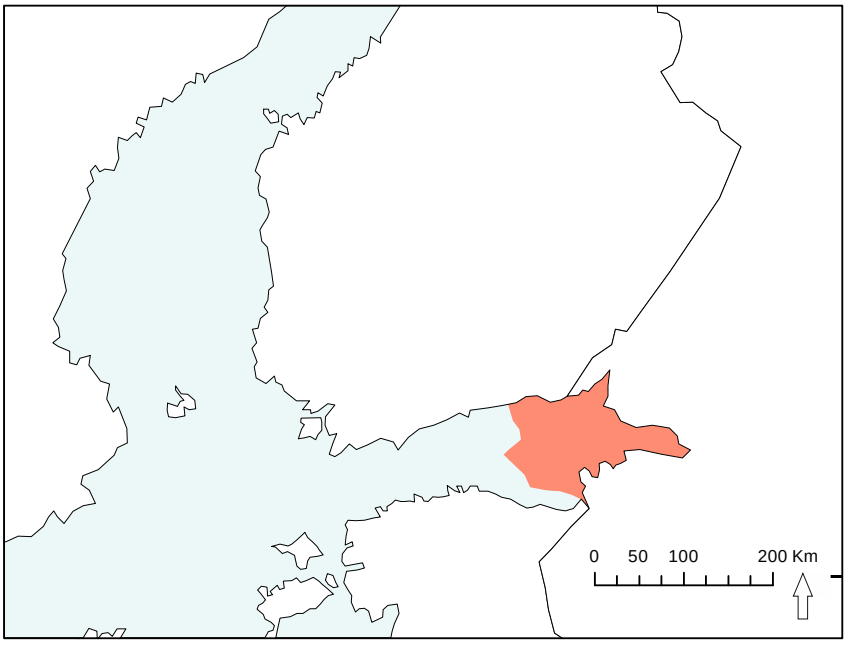


Figure 3. The study area. The area covers the end of the Gulf of Finland east of Pyhtää on the Finnish coast and the Russian-Estonian border on the south coast.

The salinity at the EGOF is lower than in the GOF in general (Alenius et al. 1998) and the biota changes along with the salinity. Freshwater species too can be found at the study area (Leppäkoski & Olenin 2000). Nearly all of the bottom types that can be found in Finnish waters can be found at the EGOF. The EGOF is shallower than the GOF in general its average depth being only 25 metres.

Especially the shallow coasts have faced enormous changes caused for instance by polluted sediments and harmful substances (Korpinen et al. 2012). Also excessive nutrient input, fisheries and increased shipping have an impact on the sensitive ecosystems of GOF (Hänninen et al. 2004: 16). In 2004, The Marine Environment Protection Committee of the International Maritime Organization (IMO) designated the Baltic Sea a particularly sensitive area (PSSA). Due to this status, the bordering countries can set exceptionally high standards for oil transportation in their territorial waters. However, Russia has not signed the agreement, and Russian-registered ships and Russian waters are an exception to the special standards (Hänninen et al. 2004: 23).

2.2 Studied species

The environmental impacts are studied on 16 species of organisms (table 2), which were determined by TOPCONS project. The species include two littoral fish (perch and pikeperch) and one pelagic fish (Baltic herring), two waders (ruddy turnstone and ringed plover), two ducks (tufted duck and velvet scoter) and a gull (lesser black-backed gull). The key species consist of both benthos and algae, including two mussels (blue mussel and Baltic macoma) and a worm (*Marenzelleria*), three separate algae (*Cladophora rupestris*, bladder wrack and clasping leaf pondweed) and two groups of algae (muskgrasses and watermilfoils). The existence of the species is determined by habitat type and quality.

Table 2.The studied species.

		Key species	
Fish	Birds	Benthos	Algae
Perch *Perca fluviatilis*	Ruddy turnstone *Arenaria intepres*	Blue mussel *Mytilus edulis*	Cladophora rupestris *Cladophora rupestris*
Baltic herring *Clupea harengus membras*	Tufted duck *Aythya fuligula*	Marenzelleria *Marenzelleria*	Bladder wrack *Fucus vesiculosus*
Pikeperch *Sander lucioperca*	Ringed plover *Charadrius hiaticula*	Baltic macoma *Macoma baltica*	Muskgrass *Chara sp*
	Velvet scoter *Melanitta fusca*		Watermilfoil *Myriophyllum sp*
	Lesser black-backed gull *Larus fuscus*		Clasping leaf pondweed *Potamogeton perfoliatus*

For each group of organisms, the impacts of the human pressures are viewed on the most sensitive stage of the life cycle: the breeding season of birds, the early development stages of fish and the presence / absence for the key species.

2.3 Studied human actions

2.3.1 Oil shipping

The Baltic Sea is very densely shipped: According to the Automatic Identification System (AIS) there are constantly around 2000 ships in the sea, around 25% of which are tankers (HELCOM 2014). Out of the tankers navigating in the GOF in 2010, 61% carried chemicals, including both oil products and chemicals, and 36% carried oil (Haapasaari et al. 2014). Measured in the number of vessels, nearly 15% of all maritime transportation worldwide takes place in the Baltic Sea (Brunila & Storgård 2012). Oil shipping, which stands for the transportation of oil and its products by tankers, is the only form of shipping that is taken into account in this study. Tankers are included in this study due to the risk of oil spills related to oil shipping.

The direct impacts of shipping are the waves and tides caused by the movement of the ship in the water as well as the emissions into the air and water. The indirect impacts are for example the changes in morphology that are caused by increased siltation. The turbulence caused by shipping mobilizes sediment and may smother nearby communities (Davenport & Switalaki 2006: 335). The transported sediments turn originally hard substrates into mixed substrates, and thus change the habitat type near the fairway (Madekivi 1993).

Underwater noise is one of the mechanisms through which shipping affects the ecosystem. The largest single noise source in shipping is the cavitation at the propellers (Hildebrand 2009), and other sources are the vibrations of the hull, mechanical motor noise and the sounds of the hull hitting the water (Madekivi 1993). In the winter also ice causes noise. The noise caused by shipping is low frequency (mainly 10–1000Hz) and travels a long distance underwater (OSPAR 2009). According to Madekivi (1993) the normal impacts of shipping on the environment are small taking into account the overall state of the Baltic Sea.

According to Hänninen & Rytkönen (2004: 16) oil is the single largest cause of environmental damage caused by shipping in the Baltic Sea. Accidental oil spills compose only a small part of the total amount of oil that ends up in the ecosystem (Kotta et al. 2006; Hänninen & Rytkönen 2004). However, the impacts of an accidental oil spill, especially a large one, can be very severe and dramatic, and therefore they need to be studied. What makes studying an oil spill challenging is that there is very little local before-after –data. For

the same reason the preparation for a possible spill cannot be done based on first hand data only, but instead the possible consequences of the spill have to be modelled. It has to be taken into account too, that the results of research done on oil spills in the oceans, where salinity levels are much higher than in the Baltic Sea, are only partially compatible with the Baltic Sea (Lecklin et al. 2011).

St. Petersburg, Helsinki and Tallinn are the main ports in the GOF, and the largest oil harbours are Primorsk in Russia, Sköldvik in Finland and Muuga in Estonia (Hänninen 2004: 17). In addition to these, the Russian port of Ust-Luga, which started its operation in December of 2011, is one of the largest oil harbours in the GOF. In 2009 approximately 290 million tonnes of oil and oil products were transported in the Baltic Sea. Over half of this amount was shipped via the GOF, where the oil transportation volume nearly quadrupled between 2002 and 2012 (Brunila & Storgård 2012). In 2012 there were 124 ship accidents in the Baltic Sea. Globally the trend is declining (Burgherr 2007), but according to Aps et al. (2009) the risk for incidental oil spills is growing as traffic increases. In 2001–2010 an average of 7% of all ship accidents in the Baltic Sea led into some sort of contamination, and a third of the vessels included in the accidents were tankers (HELCOM 2012). Once an oil spill has happened, it is almost impossible to prevent the oil from reaching the shore (Aps et al. 2009).

It is uncertain how the volumes of oil transported in the GOF will change in the future. Brunila & Storgård (2012) presented three scenarios for the development of oil transportation in the GOF until years 2020 and 2030. In their study, nine experts gave their opinion on the most likely as well as the minimum and maximum amounts for oil being transported in both years and each scenario. According to them, the amount of oil shipped through the GOF will continue to grow until 2020, but due to a shift towards greener energy in the European Union, the amounts in the scenarios decrease by 2030. This thesis uses the scenarios of 2020 (chapter 4.1). Given the current political situation, it is very hard to assess whether these scenarios are realistic, or how their likelihoods may have changed since the expert analysis.

2.3.2 Offshore wind power

The increasing global energy needs together with the need to decrease carbon use require steps towards renewable energy. According to Wilhelmsson et al. (2010: 1) the potential of

offshore wind power is only now being recognised, and the capacity to produce offshore wind power is likely to grow significantly in the near future.

Finland has agreed to increase the production of renewable energy so that by 2020 38% of energy used in Finland will be produced by renewable sources (Ministry of Employment and the Economy 2013). At the end of 2013, the wind power capacity in Finland was 447 MW from 209 wind turbines, and the wind power consumption in Finland was 0,9% of all energy consumption (Turkia et al. 2014). The amount of wind power produced offshore in Finland is marginal but growing: wind power projects of the amount of 11 013 MW have been published, and of these projects worth of 2974 MW are planned offshore (Turkia 2014). In general, expectations on offshore wind power are high, as winds are often stronger and wind conditions more stable offshore than on land (Bergström et al. 2014).

In Europe 53 offshore wind farms had been built by 2013 and ten more were under construction (Nicolle 2013). Wind farms consist of tens or hundreds of mills. In the study area, there are currently no plans for offshore wind farms (VTT statistics 2014), although in Kotka there is an approved plan for three wind mills, two of which are built on land and one offshore (Harjula et al. 2012). In this the environmental impacts of single wind mills are evaluated, although a lot of the international studies on offshore wind power are on wind farms (*e.g.* Exo et al. 2006; Fox et al. 2006; Bergström et al. 2012).

The life cycle of a wind mill can be divided into three phases: construction, operation and decommissioning (Gill 2005). Some add a fourth phase, which is the pre-construction phase during which boat traffic in the area increases and possible geological surveys are carried out (see *e.g.* Nedwell & Howell 2004; Kikuchin 2010). The construction and decommissioning stages are short in duration, and also their impacts on the environment are mainly temporary (Petersen & Malm 2006). This thesis focuses on the long-term impacts of the operational stage.

Wilhelmsson et al. (2010: 13) made a classification of the spatiality of the impacts of offshore wind power. In their overview they looked into the impacts of wind power on, among others, fish, birds and benthos. Their spatial classification consisted of four classes, the smallest of which, labelled *very local,* ranged from 0–10 metres from the turbine, the following classes being *local, broad* and *very broad* and ranging from 10–100 metres, 100–

1000 metres and over 1000 metres from the turbine, respectively. This classification was altered to better suit the needs of this thesis. Additional classes were added to different studied groups (birds, fish) depending on their sensitivity to the human actions.

2.4 Impacts of the human actions

There are various studies on the effects of oil shipping and offshore wind power worldwide, but because the Baltic Sea is brackish water body with unique habitats, results from other seas and oceans are not entirely compatible. There are some studies made on these human pressures in the GOF and other parts of the Baltic Sea. Bergström et al. (2014) conducted a generalized impact assessment on the effects of offshore wind farms on marine wildlife in Sweden. They selected their study points ranging from marine conditions (30 permille salinity) to nearly fresh water conditions (2 permille salinity). Aps et al. (2009) used Bayesian inference to analyse the potential oil spill related risks at the southern GOF. Their study included variables for the season of the spill, the water body and the ecological sensitivity as well as the risk distribution. A thorough overview of the impacts of offshore wind power was conducted by the International Union for Conservation of Nature (IUCN) in cooperation with E.ON Climate and Renewables and Swedish International Development Cooperation Agency (SIDA) (Wilhelmsson et al. 2010).

Lecklin et al. (2011) analysed the biological acute and long term impacts of an oil spill in the GOF using a BN. They took into account more oil-related factors than is possible in this thesis, such as the type and amount of the oil, as well as the acute and long term impacts in the populations. Also factors like oil recovery and the recolonization of the exposed area were looked into, and a *most probable spill* scenario and a *worst case scenario* spill were defined. In their study, most of the studied species were likely to be fully recovered within 10 years of the spill, when the spill was a *most probable spill*. Also Dicks (1999) stated that according to several post-spill studies, the marine environment is resilient to short-term changes in the environment, and thus an oil spill will rarely cause permanent effects.

2.4.1 Pressures caused by oil shipping

Oil shipping influences the environment through the underwater noise caused by tankers and the possible oil spill and the oil exposure of species that follows. Once in water, oil has direct and indirect environmental impacts. The mortality of plants and animals due to oil exposure

are the most obvious direct impacts. The toxic effects of oil cause mortality both in flora and in fauna, and it can also physically smother both (Dicks 1999). The indirect impacts are longer in duration, and they influence the species via, for example, deteriorated habitats (Aps et al. 2009) or through a decreased ability to reproduce. Oil can also change the key species thus altering the biological communities (Dicks 1999). The greatest impacts are likely to be found near the shores (ITOPF 2002) making shallow water species and near shore nursery areas vulnerable. According to Kingston (2002) in most cases the recovery of the environment will be complete in 2-10 years after the oil exposure.

The type and the amount of oil, among others, should be taken into account when trying to understand the possible outcomes of an oil spill (ITOPF 2002). Also the season and the weather conditions make a difference in the environmental impacts of the spill (Kingston 2002). Many physical and chemical changes occur to oil in water: it starts to spread, evaporate, disperse and emulsify (ITOPF 2011). The ratio of these depends on the type of the oil: the lighter it is, the more evaporates. The dispersion rate too depends on the type of the oil as well as the weather conditions: waves cause mixing of oil into the upper part of the water column. Many oil types take up water and form thick emulsions. In later phases the oil that remains in the water can go through photo-oxidation, sedimentation and biodegradation, which are all long term processes. Most oil types are lighter than water and thus only sink when attached to particles in the water (ITOPF 2011). In the Baltic Sea, the low mean temperature is one factor, which slows down the decomposition of oil (Keinänen et al. 2012).

2.4.2 Pressures caused by offshore wind power

Wind power is a clean form of energy production – it requires no fuel and has no emissions. Still, as all forms of energy production, wind power too has an impact on the environment (Wilhelmsson et al. 2010). The environmental impacts of offshore wind power can be divided into direct and indirect impacts. Direct impacts are for instance the changes in seabed, new underwater constructions, noise and electromagnetic fields. Indirect impacts are for instance the changes in the availability of food, competition, predation and replacement of species with others (Gill 2005). Wind mills are built in shallow waters, at the depth of less than 20 meters, which are also important resting, breeding and feeding sites to several

species. Due to lower construction costs, turbines are often planned in waters less than 10 metres deep where possible (Vehanen et al. 2010).

There are three different types of offshore turbine foundations. The majority of the offshore wind mills have monopile foundations meaning that they stand on one construction with the diameter of approximately 6 metres. Another common structure type is the tripod, that has three feet, 1,5–2 metres in diameter each. Both foundation types are set by pile driving (Betke et al. 2004). Noise is one of the pressures caused by offshore wind power, and the greatest underwater noise disturbance is caused by the construction phase in the life cycle of the mind mill. During pile driving work, the sound pressure level can be up to 260 dB re 1 µPa (Nedwell et al. 2003). Sound moves faster in water than it does in air, and it also attenuates significantly slower, so the noise of the construction phase can be very loud at the radius of tens of kilometres (Di Napoli 2007).

With wind power only the constant impacts of the human actions are studied. This means that the impacts of the construction or decommissioning stage are not included, even though some of the most radical environmental impacts follow these stages. Especially the pile driving work during the construction phase is a heavy pressure, and the shockwaves caused by piling can be lethal to fish. The turbidity increases during the construction decreasing the visibility in the proximity of the wind mill (Vehanen et al. 2010) and the increase in vessel traffic before and during the construction phase cause underwater noise (Nedwell & Howell 2004). These effects may have a significant impact on species, but they are mainly temporary of nature (Petersen & Malm 2006) and including them would have posed the question of species recovery, meaning how quickly the dead or expulsed individuals will be replaced by others. This is unique to every species and every location. For offshore wind power the studied human pressures are the operational underwater noise and the disturbance above surface to birds during the active phase of the wind mill.

2.4.3 Impacts of oil shipping and wind energy production on the different groups of organisms

Impacts on fish

Oil exposure has serious impacts on individual fish, but according to Keinänen et al. (2012) its impacts on fish stock remain small or unclear, since fish can easily avoid oil exposure by moving away from it, and the reproduction rates of fish are high and thus the recovery of the

fish stock is fast and efficient. There are, however, differences between fish species, and the sub-lethal effects on oil can have a long term influence on the populations. Shallow water fish get different kind of exposures to oil than deep water fish, and also the reactions to oil differ between different species. All fish are more vulnerable to oil in their juvenile stages (Keinänen et al. 2012). A study of the sensitivity of the early development stages of the Baltic herring to oil (Venesjärvi & Karjalainen) showed, that oil exposure increased the mortality most to hatched larvae. Also the larvae that hatched during the exposure was more sensitive to the impacts of oil than larvae that had not been exposed to oil while hatching.

According to Wilhelmsson et al. (2010: 14) the long term impacts of operational wind power constructions on fish are the disturbance caused by the operational noise, the exclusion of trawling, electromagnetic fields, noise masking bioacoustics and artificial reef effects. Trawling exclusion and electromagnetic fields are connected mainly with large offshore wind parks, and they are not discussed in more detail here.

Fish have two sensory systems for hearing: the inner ear and the lateral line (Kikuchin 2010). Very high sound pressure levels cause mortality in fish, and significantly lower pressures can cause physical injuries, stress and changes in behaviour. The operational noise of the wind mills is significantly lower than that of the construction phase, but it is still higher than the ambient noise of the seas and can cause changes in the behaviour of fish (Vehanen et al. 2010). Fish are more vulnerable to predation in noisy conditions because the anthropogenic noise masks the voices which usually enable fish to survive. According to a study made by Kikuchi (2010), fish that are above average in their hearing abilities (hearing specialists) can sense the wind mill at the distance of four kilometres, and fish with average hearing abilities can sense it from about one kilometre away.

In this thesis, the disturbance by operational noise and the masking noise are joined as one variable, *Noise wind*. According to Wilhelmsson et al. (2010: 14) the impacts of operational noise on fish are local or very local, meaning that they range from less than 10 to 100 meters**.**

Impacts on birds

Organisms get exposed to oil not only from water, but also from vegetation, food and sediments. Birds that are exposed to oil lose their buoyancy and waterproof capabilities as well as the ability to regulate their body temperature, which causes increased mortality

especially in lower temperatures. Birds also ingest oil while preening their feathers or by eating contaminated food, which causes increased mortality due to the toxicity and carcinogens of oil (Peterson et al. 2003b).

Birds are often the first group that is considered when the environmental impacts of wind power are discussed. Bird collisions to wind turbines are perhaps the most visible impact of wind power, but it is only one of the mechanisms through which wind mills have an impact on birds. Fox et al. (2006) name three pressures, which they call *hazard factors*, on how wind mills affect bird populations. These hazard factors are

1) Visual stimulus-avoidance response
2) Physical habitat loss / modification / gain, and
3) Collision mortality

All of these cause physical effects to the environment, such as barriers to movement, or collision with rotors or other structures. These effects can cause direct mortality or they can have an impact on the energy economy of the bird thus reducing their survival rates (Fox et al. 2006). According to Finnish estimations, the mortality caused by wind mills in Finland is one bird / mill / year (Birdlife Finland 2014). In Nysted wind farm in Denmark the collision mortality of several bird species was studied and no bird species came near the increase in mortality of 1% due to turbine collisions (Petersen et al. 2006). The loss to populations, in the case of most bird species, is small, and collision risk in general is more connected with bird migrations than with breeding.

The disturbance caused by operating wind turbines can exclude birds from their most suitable breeding, roosting and feeding sites. According to Exo et al. (2003) divers, scoters, geese and waders are especially sensitive to suffer habitat loss due to wind power. The degree of disturbance is a sum of many factors, and the species specific sensitiveness is only one of them. Others are for instance the availability of suitable habitats in the same area (Exo et al. 2003).

In Denmark, thorough studies on the environmental impacts of offshore wind farms have been conducted in the wind farms in Horns Rev and Nysted (see *e.g.* Kahlert et al. 2004; Petersen et al. 2006; Maar et al. 2009). Horns Rev is situated in the North Sea, so it carries less relevance with this thesis than the results from Nysted, which is located in the Baltic

Sea about 11,5 kilometres south of Lolland. Petersen et al. (2006) studied the effects on the distribution of bird species both at Horns Rev and Nysted offshore wind farms by using aerial surveys and radar studies. At both sites there were avoidance reactions by birds, but responses were species specific: some avoided the whole wind farm area as well as the surrounding zones, while others were attracted to the structures. Like Petersen et al. (2006) state, their conclusions are still preliminary after 2 years of research, and as in the case of all before-after-control-impact work, conclusions can only be drawn site-specifically. Their study did not include the impacts of offshore wind power on the breeding of birds.

Exo et al. (2003) estimated that impacts of offshore wind power on birds are greater than the impacts of onshore wind power. This is explained by the size of the turbines, which in general are higher on sea than on land, and by the increase of boat traffic which arises from the maintenance of the turbines.

In this thesis, the focus is on the breeding birds. Impacts of wind turbines on feeding, resting and migration of birds have been studied (see *e.g* Desholm et al. 2006; Huepopp et al. 2006; Petersen et al. 2006) but the impacts on breeding are less known. A follow-up study on birds was conducted at Ajos wind farm in Kemi, where altogether 10 wind mills are located on either the shore or on artificial islands. There no impacts were witnessed in the amount of nesting birds in the before-after comparisons (Parviainen & Sauvola 2011 cit. Pöyry Management Consulting Oy). Due to lacking knowledge in this field, expert elicitation is used to fill the gaps in literature.

Impacts on key species

The reef effect is one of the most important environmental impacts of offshore wind power. It means the replacement of soft bottom species with hard bottom species, when new hard constructions are being introduced underwater (Gill 2005). The foot of the wind mill functions as an artificial reef that attracts mussels and other hard bottom species. They then form the base for a hard bottom habitat. The reef effect increases the heterogeneity of species as well as the number of individuals (Wilhelmsson et al. 2010: 34) and thus can be seen to have a positive impact on the biodiversity. According to Wilhelmsson et al. (2010: 13) the changes caused by the reef effect are long term but very local, ranging to only some meters around the turbine.

The key species are all vulnerable to oil, although some of their habitats are in depths that are unlikely to be reached by oil. The toxic compounds of oil and its products are, however, a threat to both the algae and the benthos. Offshore wind mills can cause local losses of habitats to the key species (Wilhelmsson et al. 2010: 14), but these are minor in scale.

The impacts discussed so far are direct impacts that influence the species through the exposure to sound, visual disturbance or oil. The human actions also cause indirect impacts, which instead of influencing the species directly alter the circumstances by changing the environmental variables, such as the salinity or the temperature. In this thesis the indirect impacts of the human actions come from the changes that oil shipping causes in siltation. The additional movement and resuspension of sediments, which is caused by shipping, increases turbidity and changes the surface substrate type. These changes have an impact on the key species, and in some situations, on fish. The indirect impacts are included in the final TOPCONS tool, which takes into account the prevailing states of the environmental variables in the study area. The thesis model does not include the indirect impacts, but they are taken into account in the additional part to the thesis model (see 4.6).

2.5 Underwater noise

Underwater noise is a pressure shared by both human actions, and it turned out to be a more complex issue than expected. Some of its general principles are presented here. Noise generally refers to an unpleasant or a loud sound, or a sound that is somehow inappropriate or out of place. In this thesis sounds, and more precisely sound pressure levels, describe any sounds, natural or anthropogenic, whereas noise refers to loud or disturbing anthropogenic sounds.

The decibel scale (dB) is a logarithmic scale that compares the quantities of intensity with each other. In air, the decibel scale is set so that the hearing threshold of a person with normal hearing is at 0 dB at a frequency of 1000 Hz (Chapman et al. 1998). Underwater this stands for 26 dB. The basic principles of sound propagation are the same in water as they are in the air (Slakkeboorn et al. 2010) with some differences. Most importantly, under water the standard reference sound pressure is 1 micropascal (µPa), whereas in the air the corresponding standard pressure is 20µPa.

The most common measure to describe underwater sounds is the Sound Pressure Level (SPL), which is measured in decibels referenced to 1µPa. SPL values are written as dB re 1µPa (Nedwell & Howell 2004). Other important measures of underwater noise are the Source Level (SL), which is measured at a 1 metre distance from the noise source or corrected to match the level (written dB re 1µPa @ 1m) and the Received Level (RL), which is the SPL at the location of the observer (Chapman et al. 1998). There are several more measures to describe underwater sounds and their impacts, such as the species specific hearing thresholds, that describe the audibility of sounds to different species of animals, the SEL (Sound Exposure Level), which describes the level from the point of view of the animal, and the Peak Sound Pressure Level (SPL_{peak}), which is used to describe sound pulses that may be loud but short in duration (Nedwell & Howell 2004). The Sound Pressure Level (SPL) is the most suitable metric to describe continuous sound, like that of shipping or an operational wind mill (Robinson et al. 2014).

Sound is a wave movement, which needs a medium to propagate. Sounds propagate differently in the water as they do in the air, because the molecular density of the water is notably bigger than that of air. Sound travels about five times faster in water than in air, which also means that the wavelengths are five times longer in water (Slakkeboorn et al. 2010). Because of this, sound loses its energy slower and attenuates less in water than with the same distance in the air. The speed of attenuation depends on many features, such as the bottom type, geomorphology and the salinity and the temperature of the water (Madsen 2006).

The underwater environment is never quiet irrespectively of state of the sea. Underwater sounds can be distributed into natural sound and anthropogenic sounds (Verfuß et al. 2014). Waves, wind, ice and rain cause sounds, which travel great distances in water and create the base for a constant ambient noise, as do the biological sounds. Whales, for instance communicate by sound, and in open oceans the communication distances reach hundreds of kilometres. Porpoises, doplhins and seals too vocalize underwater, and also fish use sounds to communicate (Verfuß et al. 2014).

Ambient noise levels result from both anthropogenic and natural sounds (Hildebrand 2009). The increase of vessel traffic has added up to the ambient noise levels, and it is already impossible to distinguish which fractions of ambient sounds are anthropogenic and which

are natural. Over 80% of global freight is transported by motored ships, which are the main cause of anthropogenic noise in the oceans and the seas (Slakkeboorn et al 2010).

The underwater soundscape is now studied thoroughly for the first time in the Baltic Sea in BIAS (Baltic Sea Information on the Acoustic Soundscape) project. The Institute for Environmental Research SYKE is the Finnish partner in BIAS, which began in 2012 and aims to map and model the soundscape of the Baltic Sea. Senior Adviser and BIAS project responsible Jukka Pajala from SYKE was met with to discuss the underwater sounds of the Baltic Sea, to get approval for the methods selected in this thesis and to get insights especially on how to deal with the underwater noise caused by shipping.

3. Methods

The work on this thesis contained four main components:

a) Identification of the most important human pressures caused by oil shipping and offshore wind power;
b) Construction of the Bayesian network;
c) Expert elicitation;
d) Analysis of the results and the assessment of the model.

The most important human pressures caused by oil shipping and offshore wind power were identified by a literature review. A probabilistic model was built using Bayesian networks in Hugin Professional 7.6 software. The probability distributions of the human pressures were, where possible, calculated mathematically and some of the distributions for pressures as well as the probability distributions for the losses of species were elicited from experts. The four phases overlapped, and especially the construction and modification of the BN was an ongoing task throughout the whole process.

3.1 Bayesian inference

Bayesian inference is named after referent and amateur mathematician Thomas Bayes (1701–1761). The inference has its roots in the Bayes theorem, with which we can study how new observations influence the accuracy of the hypothesis (Myllymäki & Tirri 1998).

As Jensen (1996) wrote, in Bayesian inference we focus on the question *how can observations change our belief of non-observed events?* The key in Bayesian inference is the use of probability as a measure of uncertainty (Uusitalo et al. 2005). The probability for any event is the measure of how likely it is to occur, where the probability of 0 means that the event certainly will not occur and the probability of 1 means that the event certainly will occur (O'Hagan et al. 2006). Any value between 0 and 1 indicates uncertainty. In Bayes theorem, there are three kinds of probabilities:

Prior probability, is the probability (P) which is valid before any observations have been made. P(A) is the prior probability for A. A stands for hypothesis.

Conditional probability is the probability for the observation B being true if the hypothesis A is true, *i.e.* P(B|A), or "the probability of B given A".

Posterior probability is the probability for the hypothesis A being true when the observations have been taken into account, *i.e.* P(A|B), or "the probability of A given B (Nokelainen 2003). Posterior probability quantifies the best available knowledge after the new evidence has been observed, given the model structure and prior information.

The theorem can be written

$$P(A \mid B) = \frac{P(B|A)P(A)}{P(B)}$$

Bayesian inference is a form of inductive reasoning (Tenenbaum 2006), meaning that a conclusion or a theory is being formed on the basis of evidence. Bayesian inference provides an explicit expression of the amount of uncertainty within the variables (Ellison 1996).

3.2 Bayesian networks

Bayesian networks (BNs) are graphical probabilistic models that consist of a set of variables, which are shown as nodes, and a set of directed links between the nodes. These links are shown as arcs with an arrow, and they represent the causal connection between the nodes. In mathematical terms, the network is called a directed acyclic graph (Jensen 1996). It is directed, because the links that connect the nodes have a direction, meaning one causes

another. Acyclic means that the network cannot deal with loops, for instance *poor marketing -> poor sales -> limited funds for marketing -> poor marketing.*

The terms *child* and *parent* are used to describe the relations between the nodes in a BN. *Child* refers to a node that has incoming arcs and thus has a conditional dependency on another node, and the nodes that influence other nodes and have outgoing arcs are called *parents* (Jensen 1996). A node can be both a child and a parent at the same time, since in many phenomena an effect of one variable is the cause of another.

The belief of the value of each variable is presented as a probability distribution. The wider the probability distribution is, the more there is uncertainty over the variable (Uusitalo et al. 2005). If all possible outcomes are equally likely, the result is a uniform distribution. Usually as information accumulates, the certainty increases and the distributions grow narrower. Each variable has one or more probability distributions related to it. Parent nodes (variables) have one probability distribution called an unconditional distribution (Bromely et al. 2005). If the node has parents, it has one probability distribution for each possible combination of the values of its parents (Jensen 1996).

In environmental research data often have continuous values, which have to be discretized to a set of values (Uusitalo 2007). The discretized values represent the probability of each state. The states are mutually exclusive (Jensen 1996), meaning that the variable can finally get one and only one of the states, and the discretized values have to add up to 1. The probability distributions are presented in each nodes' conditional probability table (CPT). The CPT quantifies the probability that the variable will get a particular state. It takes into account every possible state of its parents, since it is conditioned to them (Uusitalo 2007). When new evidence appears in the parent nodes, also the CPT of the child node will change accordingly (Bromley et al. 2005). In many cases, there is limited or non-existent data for one or several nodes of the BN, and in this case expert elicitation is used. Expert opinion represents the best estimate available in cases that have not been studied before, or that are impossible to predict precisely (Bromley et al. 2005).

3.3 Bayesian networks in environmental sciences

BNs have their origins in artificial intelligence research, but their use has spread into many disciplines, such as medical research (*e.g.* Gu, Yin et al. 2013) and all the more to environmental research (*e.g.* Peterson et al. 2003a, Uusitalo et al. 2005, Wellen et al. 2014). BNs have recently gained more users because the development of software has allowed a wider crowd to use them on desktop computers. BNs deal with large amounts of interlinked data and thus require computers with high speed and large memory (Bromley et al. 2005). This development has taken place mainly in the 2000's, and the BN software are constantly developing, but the theoretical development of the BNs took place mostly in the 1980's and 1990's (Uusitalo 2007).

In BNs, uncertainty is explicitly represented, which makes them an important tool especially in fields where data are often uncertain or scarce (Bromley et al. 2005). This makes them very suitable in modelling ecosystems and environmental management, which are complex domains (Uusitalo 2007). BNs are at their best when comparing different options of action. They are useful in the environmental field also because by using Bayes' theorem it is possible to calculate both the probability distributions of the children given the values of the parents and the distributions of the parents given the value of their children. Uusitalo (2007) studied the advantages and challenges of BNs in environmental modelling. According to her, one of the most useful features of BNs is that there is no such thing as "too little data." Another highly useful aspect is that BNs allow combining different types of data, like statistical data and expert knowledge.

BNs have potential in many fields of geographical research. They have been used, for instance, in integrated water resource planning in urban areas by Bromley et al. (2005), whose research suggests that stakeholders' views can be easily included in the model making BNs a useful tool in any kind of planning. BNs allow an integrated analysis, since they accept many types of data ranging from physical to social and economic, and they can deal with both objective and subjective information. BNs are a useful tool to assist decision making and make it more transparent by showing the possible impacts of actions on the linked variables. The final decision as well as the responsibility is on the planner (Bromley et al. 2005).

3.4 Expert elicitation

The data for BNs can originate from several different sources: publications, statistics, actual data, model outputs, and expert judgment. In this study, using expert knowledge was necessary, because quantitative information needed for the model has not been published, leaving expert knowledge the only source of information available. Altogether 6 experts were interviewed for the thesis: two bird experts, two fish experts and one expert of the key species (benthos and algae). Also an expert of maritime traffic was interviewed, and in addition to these, underwater noise and modelling it was informally discussed with a seventh domain expert.

Interviews are a very common and a useful way to gather information. An interview can be in many ways like a spontaneous conversation with the difference that it is institutional: the interviewer has a goal, which is to get the information she needs, and therefore the interviewer asks questions and guides the direction of the conversation (Ruusuvuori & Tiittula 2005). In Bayesian context, interviews of experts are generally called expert elicitation.

According to Kuhnert et al. (2010), there has been a recent increase in the use of expert elicitation in ecological models, including BNs, for two reasons. The first reason is that in ecology the required data often doesn't exist or it is lacking. The second reason rises from the use of ecological models in management: situations change quickly, and management decisions will have to be made before there is a possibility to produce hard data. This is true for instance in the case of an oil spill, where decisions will have to be made immediately to minimize the damage, and experts of the field can, with a decent accuracy, answer to questions about management decisions and their consequences.

An expert is a person who has a great knowledge of the subject. According to O'Hagan et al. (2006) selecting the experts is one of the most important stages in the whole elicitation process, and therefore a good knowledge of the studied field and its experts is required. In this thesis, the experts were chosen according to the recommendations of the thesis supervisors and based on recent publications and projects in the field of study. There are several methods of expert elicitation for a BN, and Kuhnert et al. (2010) give an overview of the different techniques and their pitfalls. They present eight different means of expert

elicitation. The one chosen in this thesis is performing direct interviews that aim to result in a probability distribution. This method requires a high level of expertise and some knowledge of probability theory from the experts.

O'Hagan et al. (2006) introduce structures of an elicitation process, and Mäntyniemi (2008) has made a five-step revision of them. The first step is the background and preparation work. In this phase the model is designed and the variables that will be elicited are identified. In the second phase the experts are identified and recruited. Suitable experts are willing to be interviewed and lack stake in the findings of the research. The third step is to motivate and train the experts. They are informed of the reasons of the research and of what will be done with the results. This was done in the interview with a presentation of the topic and the method, and by describing the use of the results. The fourth step is the structuring and decomposition, where the final structure of the model is designed and the evidence that the experts will use are reviewed. In this thesis, the experts were only met once, and the fourth step was integrated into step 1, since the model was designed mainly without the help of experts. The final phase in Mäntyniemi's (2008) revision is the elicitation itself. This consists of making the questions, fitting the distribution and checking the results with the expert. In this thesis a feedback mechanism was designed for the experts to be able to check the consistency of their results.

Semi-structured expert interviews were conducted for this thesis. In a semi-structured interview it is typical that some but not all of the questions and themes are set beforehand (Ruusuvuori & Tiittula 2005). Although the interviewer has a list of questions, the interviewee is offered the chance to bring out issues they feel are important (Longhurst 2010). In this case, the experts were asked to complete a table of probabilities and answer a few questions that were defined beforehand. In addition, the experts were encouraged to think out loud while completing the probability tables, and the experts brought up their thoughts about the issue and also about the method. The interview forms (appendices I-IV) were printed out and handed to the expert in the interview. Sending the questions to the experts beforehand was not an option in this case, since the method was new to many of them, and it was explained to them with a Power Point-presentation in the beginning of the interview.

According to O'Hagan et al. (2006) for a single expert, a face-to-face interview is without a doubt the best option. The interviewer can make sure that the expert has understood the question correctly and there is room for discussion over the topic. In this thesis 4 single expert interviews and one interview with more than one expert were conducted. The interviews with more than one expert are called group elicitation. All interviews were recorded.

Group elicitations generally require a long time, because the discussions between the experts can be lengthy and agreeing on responses takes time. They allow for the experts to share their knowledge and views and work on the distributions together (O'Hagan et al. 2006) so even though a group interview may be challenging to arrange and require a long time, the results are generally good and no special functions are needed to join the results of separate expert elicitations. If two experts are interviewed about the same topic separately, the researcher has to find an appropriate way to join the uncertainties of their responses (Kuhnert et al. 2010). This can be avoided by interviewing the experts in a group elicitation, or by using a single expert, who directly answers to the question of uncertainty with a set of probabilities.

According to Kuhnert el al. (2010), getting the question right is often the most difficult part in the elicitation process. Shaping the question poorly can lead into an unwanted bias. To avoid ambiguity or biases, a practice interview was conducted and it was found very useful. The expertise of the interviewee is certainly the single most important single thing in the elicitation process. However, the success of the process depends also on the personality and the experience of the expert (O'Hagan et al. 2006) and on the overall success in the communication between the interviewer and the expert.

As recommended by Kuhnert et al. (2010) in the case of a single expert, a face-to-face style elicitation with visual feedback was conducted. A feedback cycle is important in any expert elicitation, so that the expert can check the consistency of their responses, but it is particularly important when only one expert answers for the whole group of organisms. An MS Excel graph was designed to visualize the shape of the given distribution. This helped the experts to check the consistency of their responses and made it possible to compare the uncertainty between different species.

Two types of experts were interviewed for this thesis: five species experts and one expert of the human pressures. The experts were interviewed in July–September 2014 and the interviews took place in Helsinki, Espoo, Porvoo and Kotka.

4. The model

"*Building models forces us to think clearly about the subject, and articulate that thinking into the form of the model."* (Uusitalo 2007)

A BN was built to conduct a probabilistic risk analysis on the impacts of oil shipping and offshore wind power on fish, birds, and key species (table 2) in the EGOF. The model consists of a main model (figure 4) and three sub models, one for fish (figure 5), for birds (figure 6) and for key species (figure 7). In figure 4 the sub models are encapsulated in the nodes that have an impact on them, which are marked with a grey outline. The rectangle (*Wind mill*) denotes a decision variable, where a concrete decision will be made whether a mill is being constructed or not. The other human action, *Oil shipping*, is not a decision variable *per se*, since the states of the variable are three alternative scenarios having probabilities elicited form a maritime transportation experts.

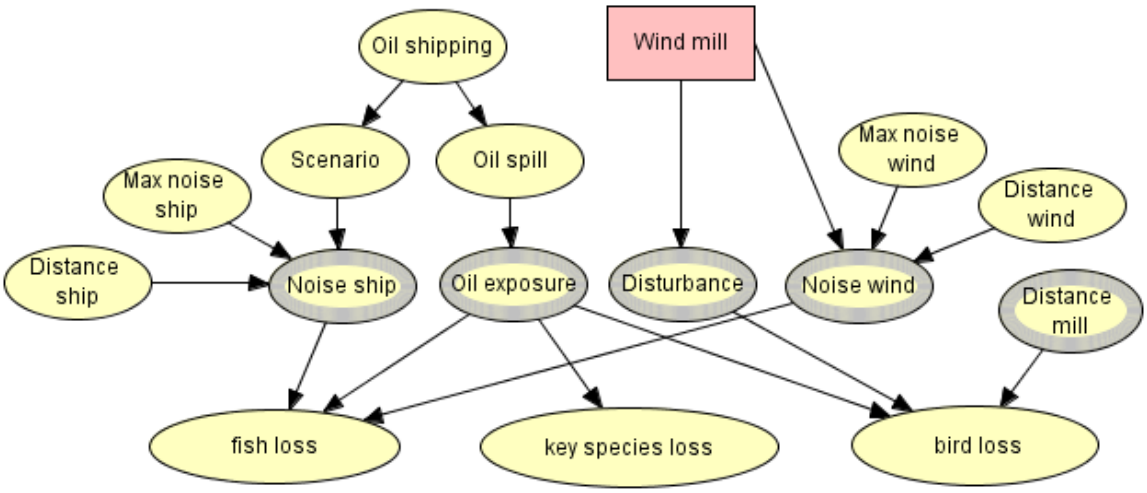


Figure 4. The thesis model where a rectangle denotes the decision variable and ellipses denote random variables. The nodes with a grey edge are parents in the submodels (figures 5-7).

The human actions are at the top of the model hierarchy being the parents of the human pressures or related variables. The pressures and impacts were placed in the model according

to the causal relations between them. Additional variables were added to measure the propagation of underwater noise. Both oil shipping and will mill have a node and probability distribution for underwater noise. Their cumulative impact is estimated on fish. The possible states of the variables as well as their relations are expressed in table 3.

Table 3. Structure of the model. The [brackets] indicate that the states are the same for all species that are included in the corresponding submodels, see figures 5-7.

Variable	Discretized states	Conditional on
Wind mill	Mill, No mill	None, decision variable
Oil shipping	Slow development 2020, Average development 2020, Strong development 2020	None
Oil Spill	Spill, No spill	Oil shipping
Oil exposure	Exposure, No exposure	Oil spill
Max noise ship	130–140, 140–150, 156–160, 160–170, 170–180, 180–190, 190–200 dB re 1 µPa	None
Distance ship	0–100 m, 100–500 m, 500–1000 m , 1000–2000 m, 2000–4000 m, 4000–6000 m, 6000–10 000 m, 10 000–12 000 m	None
Scenario	0 1 2	Oil shipping
Noise ship	<90 dB re 1 µPa 90–190 dB re µPa >190 dB re 1µPa	Max noise ship, Distance ship, Scenario
Max noise wind	80–90, 90–100, 100–110, 110–120, 120–130, 130–140, 140–150 dB re 1 µPa	None
Distance wind	0–100 m, 100–500 m, 500–1000 m , 1000–2000 m, 2000–4000 m, 4000–6000 m, 6000–10 000 m, 10 000–12 000 m	None

Distance mill	<100 m, 100–500 m, 500–1000 m, >1000m	None
Noise wind	<90 dB re 1 µPa 90–190 dB re µPa >190 dB re 1µPa	Wind mill, Max noise wind, Distance wind
Disturbance	0–100m, 100–500m, 500–1000m, <1000m	Wind mill
[Fish] loss	0–20%, 20–50%, 50–80%, 80–100%	Oil exposure, Noise ship, Noise wind
[Key species] loss	0–20%, 20–50%, 50–80%, 80–100%	Oil exposure
[Bird] loss	0–20%, 20–50%, 50–80%, 80–100%	Disturbance, Oil exposure

In the model, the probability of a state is expressed with a number between 0 and 1. The states of the pressures were set so that when each of the pressures is in its lowest state or negative, the loss to each species will certainly be of the lowest class. The impact of the human actions was analysed through the loss caused by the human pressure. The losses are expressed in terms of reduction in population abundance (table 4).

Table 4. The classes of the loss variables.

Reduction in population size	Verbal definition
80–100%	Nearly all (individuals leave the area or die)
50–80%	Over half
20–50%	Less than half
0–20%	Small part

The lowest class covers a wide range of scenarios, and for many species there is a great difference whether the loss is 0 or 20%. To avoid a situation, where the loss of up to 20% is given to each grid square on the entire study area, a safety limit, beyond which the loss will certainly be 0%, was asked from the experts and added to the final TOPCONS tool. By

making this adjustment the expert could also make distinctions between locations, that otherwise would be in the same class.

4.1 Oil shipping

Brunila and Storgård (2012) made a state analysis of oil transportation volumes in the GOF and created scenarios for the volumes in 2020 and 2030. Their scenarios for 2020 are used as alternative states of oil shipping (*Oil shipping*) in this thesis.

In the Slow Development scenario, the economic growth in the European Union will be stagnant and heavy industries will have moved to other continents. The global demand for oil decreases, and no new investments are made in Russia to increase the oil transportation volumes. The traffic in Ust–Luga will have started as planned. The expected total volume of oil transported via the GOF is 170,6 million tonnes.

The Average Development scenario represents a "business as usual" situation: The economy, the population, the technology as well as the societies in Europe will develop as they have in the past decades. Heavy industries continue to exist in Europe, and the demand for oil is growing. Some green innovations will have been made. A Baltic pipeline system will have been finished and connected to Ust-Luga, and both Ust-Luga and Primorsk ports operate at full capacity. The volume of oil shipped through the GOF is 187,1 million tonnes.

In the Strong Development scenario, there is fast economic development in both Europe and Russia. Oil prices will be high, and large investments will have been made in tankers and ports. The EU invests in green technology and renewable energy, but oil remains the main energy source. The expected volume of transported oil in the GOF is 201 million tonnes (table 5).

Table 5. MIMIC scenarios for 2020.

	Million tonnes	Change from Slow dev. scenario
Slow Development 2020	170.6	–
Average Development 2020	187.1	+10%
Strong Development 2020	201.5	+18%

The work of Brunila & Storgård (2012) is part of MIMIC (Minimizing risks of maritime oil transport by holistic safety strategies) project. In MIMIC project experts were asked to bet on the scenario they thought would be the most likely, and in this thesis these expert probabilities are used as a probability distribution for the alternative scenarios. The most likely scenario was, according to the experts, the Average Development scenario, which got the probability of 0.43. The Slow Development and the Strong Development scenarios got probabilities of 0.36 and 0.21 respectively (Lehikoinen, pers. comm.).

4.1.1 Oil spill

In the model, the potential oil spills and their consequences are described by two nodes. The node *Oil spill* defines the probability of an oil spill in each development scenario for 2020. The second node, *Oil exposure*, describes the probability of the oil slick to reach a grid square at the study area. It is assumed that each tanker accident leads into a spill, and that the season makes no difference in the spill probability. There are several ways to model oil spills (Li et al. 2012). There is, however, recent discussion over reliability of oil spill models (see *e.g.* Goerlandt & Kujala 2014) and about their inherent uncertainty (Sormunen et al. 2014). Considering both this critique and the simplifications made in the thesis model, the best option was to use expert judgment. The probabilities for an oil spill are defined at the spatial scope of the entire GOF.

The final TOPCONS tool will get the probability of oil exposure from SpillMod oil drift models, which are operated by SYKE and Helsinki City Rescue Department. Two out of the five SpillMod accident hotspots are at the EGOF, and the final TOPCONS tool which is used in a GIS environment calculates an oil exposure probability for each square at the study region taking into account the proximity of each accident hot spot. The thesis model is not spatially referenced at this point and therefore the squares each get a uniform distribution for the probability of oil exposure. When the consequences of oil exposure are predicted, the alternative states (exposure/no exposure) can be instantiated in the model. The uniform distribution enables the relative comparison of the impacts between the scenarios.

4.1.2 Underwater noise

Vessels cause low frequency noise, which overlaps with the hearing frequencies of fish and other marine species. All fish, as far as is known, sense sounds (Slabbekoorn et al. 2010). Cavitation, meaning the situation where local pressure drops at the propeller tips causing the

water to vaporize and form steam bubbles, is a significant mechanism of shipping noise across all frequencies (Hildebrand 2009). Other sources of noise come from the vibrations of the vessel's hull, mechanical motor noise and the sounds of the hull hitting the water (Madekivi 1993). Each vessel produces a unique acoustic signature. According to Jukka Palaja (pers. comm.) an individual ship cannot be identified at distances greater than 10 km, and for some frequencies, 5 km. Each individual vessel contributes to the ambient noise levels beyond these distances, but the amplitude of the contribution is hard if not impossible to define.

The tankers form only a part of the vessel noise in the study area, and since sound propagates well in water, predicting the exact sound conditions of the study area based on tanker numbers is not possible. In this thesis it was chosen to study the average maximum noise level at any point of the fairway in the different scenarios for 2020. This means that in the model, the Slow Development scenario stands for one vessel at the hearing distance, and the Average and Strong Development scenarios stand for 1,1 and 1,2 vessels, meaning 10% and 20% increase in noise levels, respectively. Since the decibel scale is logarithmic, a 10% increase of sound pressure underwater corresponds to an increase of about 1dB (Wille 2005: 444).

The propagation loss model is used in this thesis to describe the attenuation of sound with distance. Long range propagation loss in shallow depths can be described with equation 1. (Dekeling et al. 2013).

Equation 1. The propagation loss equation.

$$PL(R) = 15log10\left(\frac{R}{Rref}\right) + 5log10(\frac{\eta H}{\pi Rref})$$

where

PL(R) = propagation loss at the distance of R
R = the distance between the sound source and the observation point
Rref = reference radius, at which the reference sound is measured, 1 metre in this case
η = reflection loss gradient for bottom type, in this case sand (=0,25)
H = water depth. The average water depth of the study area is 25 metres

This is the basic equation to calculate the propagation loss in the average conditions of the EGOF. It describes attenuation of sound pressure to the distance of R. To estimate the SPL at the distance R, the PL is subtracted from the original SL (equation 2). The maximum SLs in the model are in the node *Max noise ship*. To describe the increase of noise in the alternative scenarios, an additional *Scenario* node was added to the model. This node adds decibels to the maximum SL.

Equation 2. The equation for the SPL at the distance of R.

$$SPL(R) = Max\ noise\ ship + Scenario - (15log10\left(\frac{R}{Rref}\right) + 5\log 10\left(\frac{\eta H}{\pi Rref}\right))$$

Very different SLs for tankers have been reported. The super tankers in the oceans can cause SLs of up to 180–198 dB re 1µPa @ 1m (see *e.g.* Hildebrand 2004; Erbe et al 2012). Nedwell & Howell (2004) report measurements ranging between 152–192 dB re 1µPa @ 1m. According to the personal communication with BIAS project responsible Jukka Pajala the source levels of the tankers that operate at the GOF generally vary between 140–160 dB re 1µPa @ 1m. In the model, all measured values, even the highest and lowest ones, are considered possible, and a normally distributed probability distribution is given to the different noise classes in the *Max noise ship* node.

Since low frequency noise travels through massive distances, there are no natural soundscape marine areas left in the world. Sound cannot, however, propagate if the wavelength is more than 4 times the water depth, so for example sounds below 60Hz can't propagate in 6 metre deep water (Madsen 2006). This means that many coastal zones are protected from some frequencies of sound. Fish reproduction takes place mainly in the coastal zone, so larval and juvenile fish may not be exposed to the lowest frequencies. Higher frequencies attenuate relatively fast, and the lower ones cannot reach the shallow waters, so the situation may be better than the model, which does not take a stand on the frequencies, implies.

4.2 Offshore wind power

4.2.1 Disturbance

Wind mills affect birds through disturbance (*Disturbance*), which in this model is defined as noise above surface, the movement and the blinking caused by the rotors of the turbine, and

the visual stimulus and visual disturbance caused by the construction itself. The states in the variable are distances from the wind mill. The experts were first asked to estimate the magnitude of the loss of breeding birds at each distance, and then asked to give an estimate of the magnitude of the loss at the same distance from the wind mill if the square is also exposed to oil.

4.2.2 Underwater noise

The underwater noise of wind mills is generated by the gearbox mesh and the generator and transferred to water through the turbine towers. The wavelengths of the noise are within the hearing range of fish (Bergström 2014). The noise levels can increase with the age of the wind mill, as parts of it start wearing out (Nedwell & Howell 2004).

The attenuation of underwater noise has been described with the equation of the volume of a cylinder by for instance Betke et al. (2004) in the North Sea and Lindell (2003) in the Baltic Sea. The equation describes how the sound pressure spreads evenly to all directions between the bottom and the surface. However, it does not take into account the natural conditions, where the sound pressure propagation is hindered by qualities of the environment. The bottom type, the salinity and the temperature of the water all have an impact on the sound propagation (Madsen 2006). Betke et al. (2006) and Lindell (2003) among others have made measure-based corrections to the equation but still, according to Dekeling et al. (2013) the cylindrical propagation equation only describes the reality within the radius of the length of a few depths from the noise source. In the circumstances of the EGOF this would only be around 100 metres. Therefore it was decided to use the propagation loss model, which better describes the propagation at longer distances and works in shallow conditions (Verfuß et al. 2014).

The equation is the same as for the shipping noise, with an additional coefficient to determine whether there is a mill (coefficient 1) or not (coefficient 0) (equation 3).

Equation 3. The SPL at the distance of R of the offshore wind mill.

$$SPL(R) = (Max\ noise\ wind - \left(15log10\left(\frac{R}{Rref}\right) + 5\log 10\left(\frac{\eta H}{\pi Rref}\right)\right) * (coefficient)$$

The size, type and age of the turbine as well as the weather conditions all have an impact on the amount of noise emitted by the turbine. The measurements range from around 80 dB re 1µPa @1m (Wilhelmsson et al. 2010) up to 153 dB re 1µPa @1m (Nedwell & Howell 2004). According to Wilhelmsson (2010) the normal operational noise varies between 80–110 dB re 1µPa @1m. In the *Noise wind* node, a normal distribution is given to cover all measured values that were found in literature.

4.3 Birds

The impact of human actions on birds comes through the possible oil exposure and the disturbance of the wind mill (figure 5). The starting point is a situation where there is no operational wind mill and no exposure to oil due to an accidental oil spill. In this situation the loss in breeding birds is 0%. The impacts of both pressures were asked from experts first separately, then as cumulative impacts. The classes and the distances were selected beforehand according to literature. The experts had a chance to correct the distances, if they felt like it would provide a more accurate result. A visual feedback chart was designed. The studied birds are ruddy turnstone (*Arenaria intepres*), tufted duck (*Aythya fuligula*), ringed plover, velvet scoter (*Melanitta fusca*) and lesser black-backed gull (*Larus fuscus*).

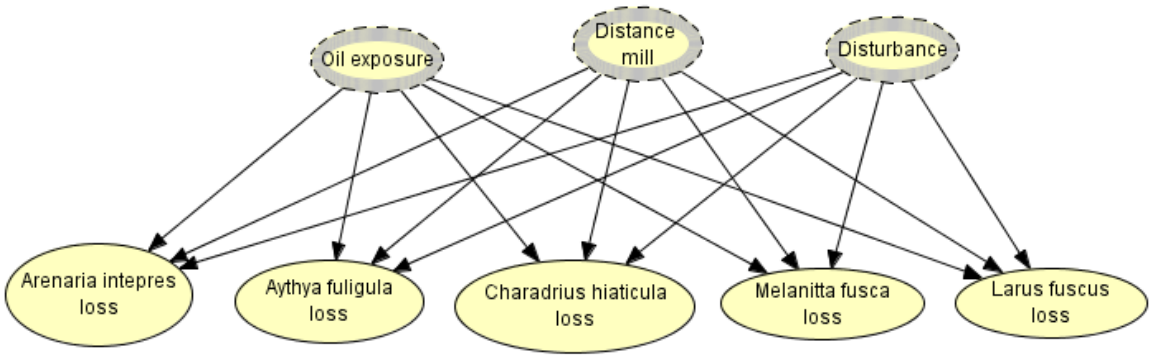


Figure 5. The submodel for birds.

Two bird experts were interviewed to form the probability distributions. Expert 1 did not feel confident to answer the questions considering the oil exposure, since very few details of the spill were available. Instead the relative sensitiveness of different bird species to oil was discussed. The probability distributions considering the disturbance caused by a wind turbine are the mean probabilities of the distributions given by both experts, whereas the distribution for oil exposure is based on the estimations of Expert 2.

4.4 Fish

The analysis applies to the early developmental stages of fish which include both the spawn and the juvenile fish. The impacts of the human pressures are analysed on three fish species: perch *(Perca fluviatilis)*, Baltic herring *(Clupea harengus membras)* and pikeperch *(Sander lucioperca)* (figure 6).

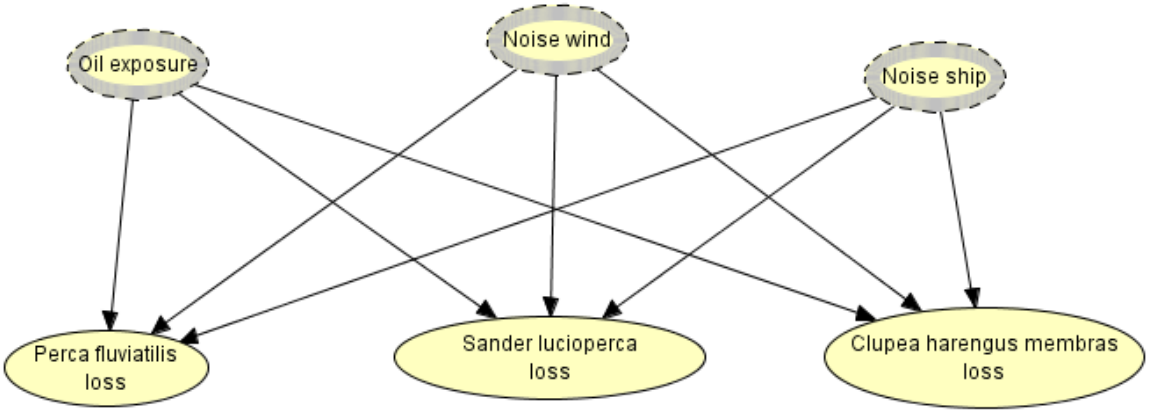


Figure 6. The submodel for fish.

Richardson et al. (1995) present a common framework for noise impact assessment on marine life. They introduce four zones of influence on the hearing of marine mammals, which are *the zone of audibility, the zone of responsiveness, the zone of masking* and *the zone of hearing loss, discomfort, or injury* (Richardson et al. 1995: 325). This classification was used as the base for the classification of the noise zones for fish. In this thesis, the two middle zones were aggregated into a "grey area", where the behavioural changes and losses of juvenile fish begin to appear. The limits of the noise classes were set with an expert.

A group interview of two experts was conducted to form the probability distribution for the loss in early development phases of fish. Expert 3 answered especially to the questions concerning the impacts of noise on juvenile fish, and Expert 4 estimated the losses to juvenile fish due to oil exposure. The two experts were both present when forming the distributions and they had the chance to discuss the cumulative impacts of noise and oil exposure together.

4.5 Key species

The key species in this study are three species of benthos and five species of algae. The loss of key species is described as oil-induced mortality. The benthos have some level of an ability to sense pressure, so they are not completely immune to noise, but the impacts are small, so only the impacts of an oil exposure are studied (figure 7).

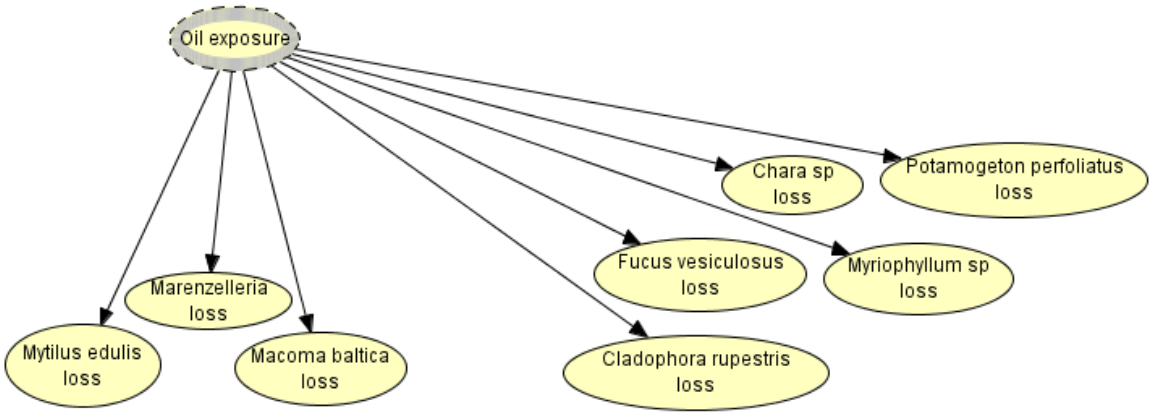


Figure 7. The submodel for key species.

A single expert interview was made for the studied eight key species, three of which are species of benthos and five of which are algae. The benthos are blue mussel (*Mytilus edulis*), Baltic macoma (*Macoma baltica*) and marenzelleria (*Marenzelleria*). The algae are cladophora rupestris (*Cladophora rupestris)*, bladder wrack (*Fucus vesiculosus*), watermilfoil (*Myriophyllum sp),* muskgrass (*Chara sp*) and clasping leaf pondweed (*Potamogeton perfoliatus*).

4.6 Indirect impacts

An additional part of the model (figure 8) describes the indirect impacts of the human pressures. The additional part was designed in this thesis, but it was left out of the final thesis model, because it cannot be used without site specific background information. The final spatially referenced TOPCONS tool will use the additional part too.

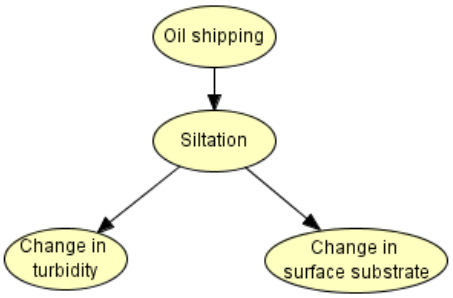


Figure 8. The additional part of the model representing the impacts of oil shipping on two of the environmental variables of the TOPCONS project.

The indirect impacts are the changes that oil shipping causes in two of the measured environmental variables of TOPCONS project, *turbidity* and *surface substrate*. The human pressure that causes the changes in the environmental variables is labelled *Siltation*. It stands for the resuspension of sediments and organic matter, which causes an increase in turbidity, and due to physical abrasion and erosion as well as the movements of sediments, it causes changes in surface substrate both at the fairway and around it.

In the additional part, the change in turbidity is described in percentage in each scenario, and the changes in surface substrate are described with the following logic: due to the upwelling and mobilization of sediments, the surface type will change from harder into softer in the vicinity of the fairway. The TOPCONS tool deals with three bottom types: coarse, sand and mud. The coarse bottom can turn into sand (1 step softer) or into mud (2 steps softer), and a sandy bottom can turn into a muddy bottom (1 step softer).

5. Results

5.1 Loss of juvenile fish

5.1.1 Juvenile fish and underwater noise

The underwater noise variables (*Noise wind* and *Noise ship*) consist of three alternative noise classes that were selected so that the middle class, 90 - 190 dB re 1µPa, represents a “grey area”. At these sound pressure levels behaviour changes start appearing. In the highest class (above 190 dB re 1µPa) physical injuries start taking place. The class below 90 dB re 1µPa is considered harmless and the losses caused to juvenile fish are certainly in the lowest class of under 20%.

The experts were asked to estimate the mortality of the juvenile fish. Very high noise pulses may cause direct mortality to fish (*e.g.* Ruggerone et al. 2008) but as Expert 3 pointed out, only a part of the mortality comes through the physical injuries, and the majority results indirectly from either the masking of other sounds, which prevents the fish from sensing predation, or alternatively through the weakened ability to communicate or sense the environment by using sounds.

The SLs caused by tankers depend on several variables, such as the age and the size of the tanker. The loudest noise class of over 190 dB re 1µPa only occurs in the immediate vicinity of the tankers of the loudest type, which are unlikely at the GOF. Even with this type of a tanker, the zone where the levels reach the limit of 190 dB re 1µPa is within 5 metres from the fairway for the Strong Development scenario and about 4 metres for the Average and Slow Development scenarios. With operational wind mills, the highest noise class cannot be reached. For the most common tanker noise source levels, there is still a lot of variance between the sizes of the grey area. According to Pajala (pers. comm.) the SLs of 140–160 dB re 1 µPa @1m are the most common ones in the conditions of the GOF. With the SL of 140 dB re 1µPa @1m, the harmless 90 dB re 1µPa limit is reached at the distance of 1,7 kilometres from the fairway, whereas with a source level of 160 dB re 1µPa @1m, a 36,5km distance is needed for the sound to attenuate to under 90 dB re 1µPa.

In all other nodes of the model, the states have been selected so that when the node is in its furthest or negative state, there is no impact on the species. With the distances from the fairway this was not possible. With the selected method of calculation, the loudest possible tanker noises of 190–200 dB re 1µPa @ 1m would remain in the grey area of 90–190 dB re 1µPa up to the distance of thousands of kilometres. The EGOF is narrow and the fairway runs horizontally through the area, so the coastal waters are never more than 100km away from the fairway. This means that in the case of shipping, a completely harmless zone does not exist, if any of the tankers' SLs are above 167dB re 1 µPa @1m. With the source level of 167 dB re 1 µPa @1m the SPL will have attenuated to less than 90 dB with 100km, which would, in theory, be a possible distance in the EGOF. Even when observing the wind mill noise only, there is always some shipping noise present, unless the model states are selected in an unrealistic way.

In a hypothetical situation, where the *Max noise ship* is set at its lowest class, 130–140 dB re 1µPa @1m and the *Distance ship* is set at its furthest class of 10 000–12 000 metres, the impacts of wind power remain very small. With the wind mill within a distance of <100 metres, the loss to Baltic herring remains at 0–20% with the probability of 0,90 and for the perch and the pikeperch with the probability of 0,9997. Damage caused to the early development stages of fish due to an operational wind mill alone is almost certainly less than 20% (figure 9).

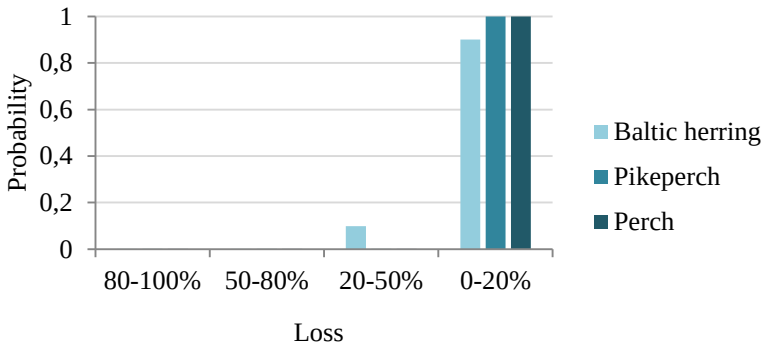


Figure 9. A hypothetical situation, where there is no noise from shipping and a wind mill at the distance of <100 metres. The wind mill SLs are not selected.

When there is an operational wind mill within 100 metres, and the shipping scenario, the distance to the fairway and the source levels for shipping are left undefined, the probabilities of more extensive losses grow. This situation describes the reality better than the one above, since in reality some shipping noise will always be present in the EGOF. For juvenile Baltic herrings in this case, the probability for a 0–20% loss is 0,76 and for a 20–50% loss 0,19. Even a 50–80% loss is possible with the probability of 0,046. For the perch, the 0–20% loss still gets a high probability of 0,95 and for the pikeperch a probability of 0,91 (figure 10). The difference between the species is explained by the hearing mechanisms of the fish: Baltic herring is a hearing specialist and perch and pikeperch have average hearing capabilities.

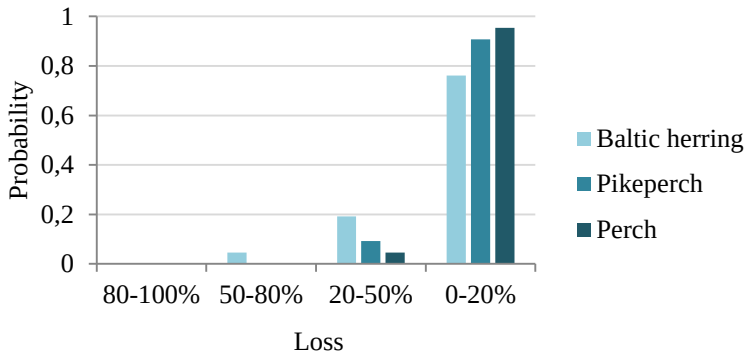


Figure 10. The situation at the distance of <100 metres from a wind mill. No selections are made for the distance from the fairway, the SL of shipping or wind mill SPLs.

A situation, where an offshore wind mill and a fairway are both located within a 100 metres from the observation point, presents a worst case scenario for noise. In this case, without determining the SLs of the ship or the mill, the losses to juvenile Baltic herrings remain below 20% with a 0,75 probability. For the perch and the pikeperch the loss remains within 20% with probabilities as high as 0,95 and 0,90, respectively. These probabilities include the possible oil spill, which explains the small possibilities for losses over 50% and 80% (figure 11).

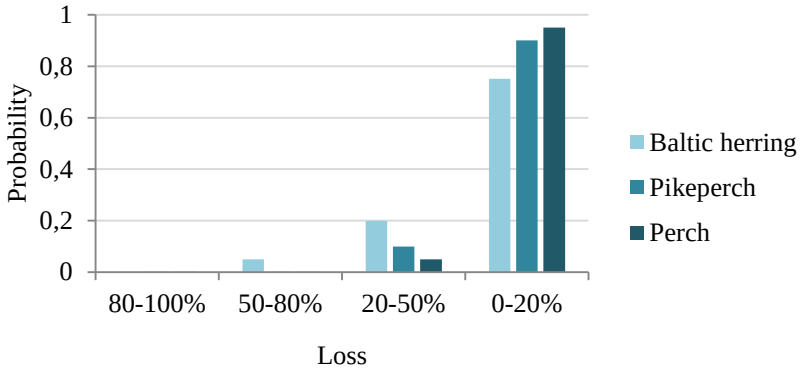


Figure 11. The worst case scenario, where both the fairway and a wind mill are located at the distance of <100 metres from the observation point. No selections are made for the source levels of either.

The losses between the situation, where the distance to the tanker is undefined (figure 10) and the worst case scenario (figure 11) are surprisingly small. This is explained by the classification of the sound pressure levels: The grey zone class is very wide (90–190 dB re 1µPa), and sound levels will most likely be within this class, whether the noise source is very near or relatively far of the observation point.

5.1.2 Juvenile fish and oil

Oil exposure and exposure to underwater noise are two very different kinds of pressures, which was brought up by the experts too. While noise can be disturbing, oil has toxic and even lethal effects on organisms. With underwater noise, the more fish get exposed to it, the more accustomed to it they grow, while with oil, on the contrary, the longer the exposure is, the more severe are the damages.

If an oil slick reaches a 100x100 metres square, it can kill nearly all fish within it. Here, according Expert 4, the oil type plays a very important role. Light oil types that evaporate quickly and float on the surface may not get in physical contact with fish, even if they were in the same location but at different depths. Still, light oil types and their products can be very toxic, and thus cause severe damage if organisms do get exposed to them Expert 4). According to the experts, in the case of a large oil spill, the distance to the wind mill or to the fairway no longer plays a role in the losses of juvenile fish, because the impacts of the oil exposure are notably more dramatic. According to the probability distributions given by the experts, without knowing the type of the oil, the size of the spill or the probability for the oil slick to reach shore, no distinction between the sensitiveness of fish species to oil can be made. For the early development stages of each fish, the most likely loss is between 50–80%, while the losses of over 80% and less than 20% remain unlikely (figure 12).

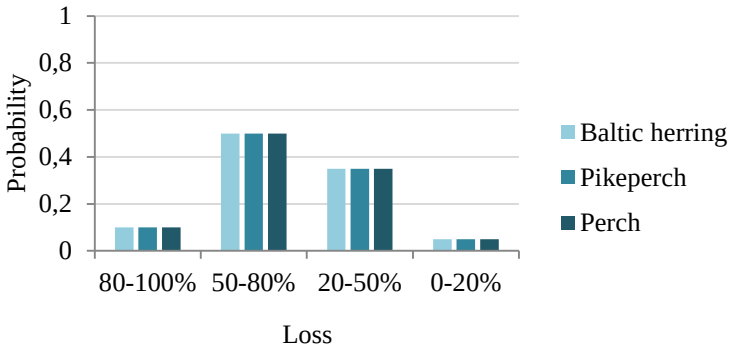


Figure 12. A situation where fish are exposed to oil and no noise sources are present. No distinction can be made between the sensitivenss of the fish unless further information about the spill is available

In some studies (see *e.g.* Lecklin et al. 2011) the length of oiled coastline has been used as one measure of the severity of the spill. The information about the length of oiled coastline comes from drift models in a GIS environment. The nursery areas of fish are in different kinds of locations: for instance the perch lays its eggs closer to the shoreline than the

pikeperch (Expert 4) and therefore, if an oil slick is known to reach the coastline, juvenile perch are in a more fragile position than juvenile pikeperch. According to Expert 4 there is also a difference in the sensitiveness of fish depending on whether they are eggs or juvenile fish.

5.1.3 Cumulative impacts and relative sensitiveness of fish

Fish species differ from one another on the basis of their hearing abilities. Out of the studied fish the Baltic herring is a hearing specialist. Its sensitiveness to sounds stands out from the probability distributions given by the expert: with an increase in sensitiveness to noise, also the possible reactions to noise become more varied.

According to Expert 4 so far only two researches on juvenile fishes reactions to noise have been published worldwide, and they too give contradictory results, one stating, that there is a greater mortality and the growth speed is smaller under noisy conditions than in a control group (Banner & Hyat 1973), and the other one suggesting that there is no difference in the growth of juvenile fish between a noisy tank and a more quiet tank (Wysocki et al. 2007). The expert himself believes that noise has some physical impact on juvenile fish, but the effects mainly come indirectly through increased predation and changed alimentation. The experts also pointed out that it is impossible to determine which SPL:s are harmless and which are harmful, and the limits used in this thesis are estimations and cannot be taken as absolute limits.

5.2 Loss of breeding birds

5.2.1 Breeding birds and disturbance

Little research on the impacts of wind power on the breeding of birds has been done while studies on wintering and migrations are plentiful. The probabilities for birds and the disturbance of wind power are the averages of probability distributions given by Experts 1 and 2, and the probability distributions for oil exposure are given by Expert 2. The estimations of the relative sensitiveness of the bird species of Expert 1 are also considered here even though they are not included in the final model.

The zones for the disturbance were measured in distances from the wind mill. According to Expert 1 no studies measuring the radius of the disturbance from the mill have been done.

The losses to the breeding of birds do not usually originate directly from the disturbance itself, but rather from the loss of feeding sites, for example (Expert 1). The direct disturbance caused by the wind mills is considered very small by both experts. Only in one case one of the experts estimated that there will certainly be an over 20% loss in breeding due to the disturbance. This is the case of the nesting of the velvet scoter at <100 metres from the turbine estimated by Expert 2. Also Expert 1 considers the velvet scoter the most sensitive to the disturbance caused by wind mills. Expert 2 however sees that there is a 0,5 probability that the velvet scoter will experience a loss of less than 20% at the distance of 100 metres from the mill.

On the breeding of waders Expert 1 sees very little loss caused by disturbance. Avoidance reactions of waders have been witnessed but mainly onshore. Expert 2 sees a lot of uncertainty in the reactions of waders to disturbance at short distances from the turbine. Both experts agree that with waders, disturbance has very little if any effect at distances greater than 500 metres.

In general the probability distributions for disturbance are wide at the shortest distance (0–100 metres), but they quickly grow more narrow as moving further away from the turbine. This change describes well the reality: it is hard to say with certainty what will happen very close to a new construction, when there are very few studies on the topic. Figures 13 and 14 show an example of this in the case of the tufted duck.

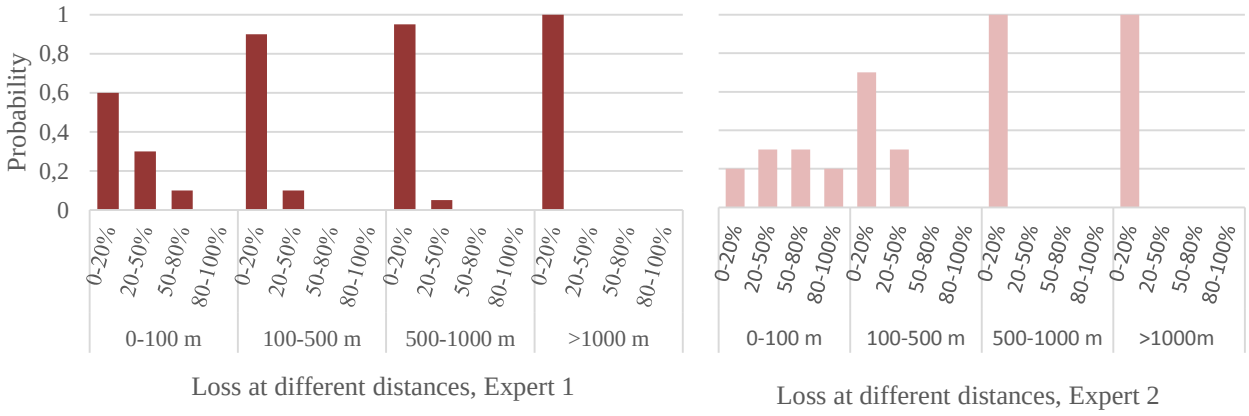


Figure 13. The probability distributions for the loss of the tufted duck at 0-100 metres form the wind mill estimated by Expert 1 on the left and Expert 2 on the right.

At short distances the loss to the breeding of the tufted duck can be anything between 0% and 100%. According to Expert 1, the most likely loss is between 0% and 20% whereas

Expert 2 believes the most likely loss to be something between 20% and 80%. The average of these two distributions (figure 14) is used in the model.

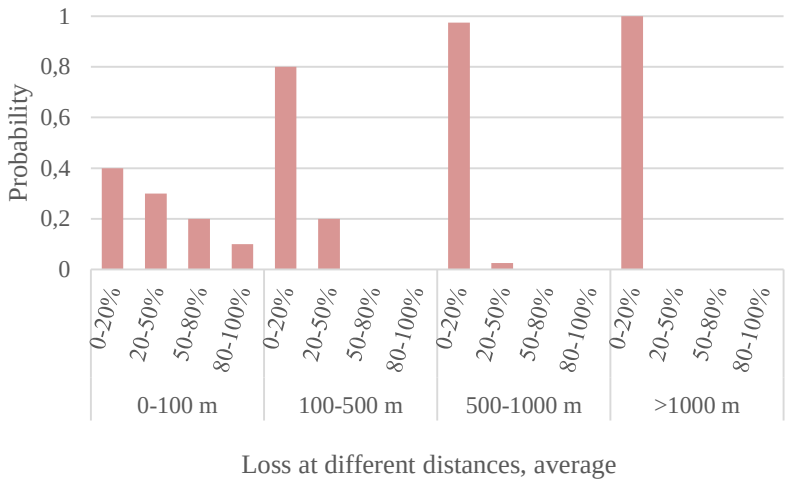


Figure 14. The average of the probability distributions given by the two experts for the losses of the tufted duck at the distance of 0-100 metres from the wind mill.

At distances >1000 metres from a wind mill, the loss to the breeding for all bird species remains nearly certainly at less than 20%. When moving closer to the mill, the differences between bird species start to show. At 500–1000 metres, the loss to the lesser black-backed gull may be 20–50% with a 0,075 certainty, while with other species the likelihood for this class remains in 0,01–0,025 (figure 15). The nearly non–existent chance of the loss being greater than 50% comes from the possibility of an oil spill.

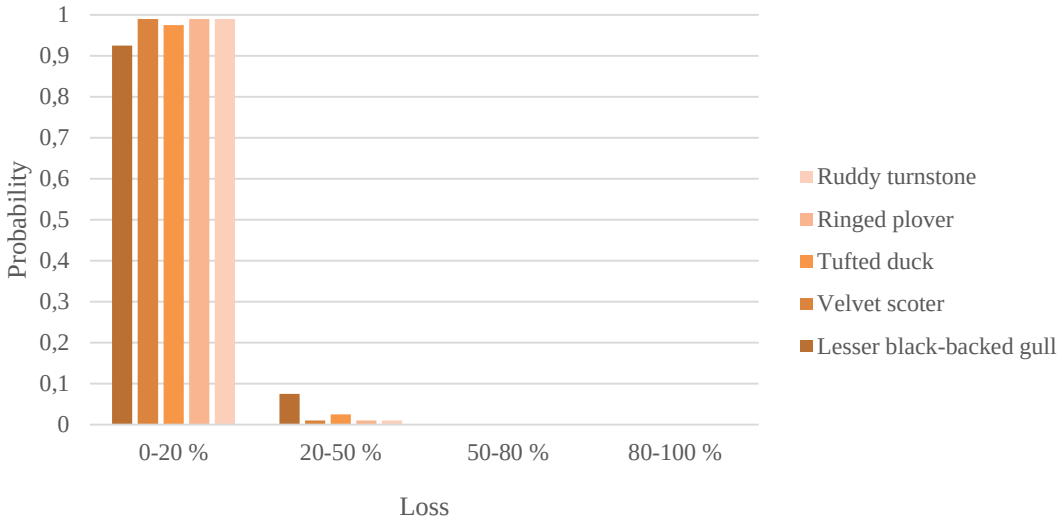


Figure 15. The loss of different bird species at the distance of 500-1000 metres from the wind mill.

Moving to the radius of 100–500 metres the uncertainty grows. As can be seen in figure 16, for all species the loss of 0–20% in breeding remains the most probable class, but for the lesser black-backed gull, the probability of it has dropped to 0,65, while for the ringed plover it has remained in over 0,9. For the lesser black-backed gull any loss is considered possible.

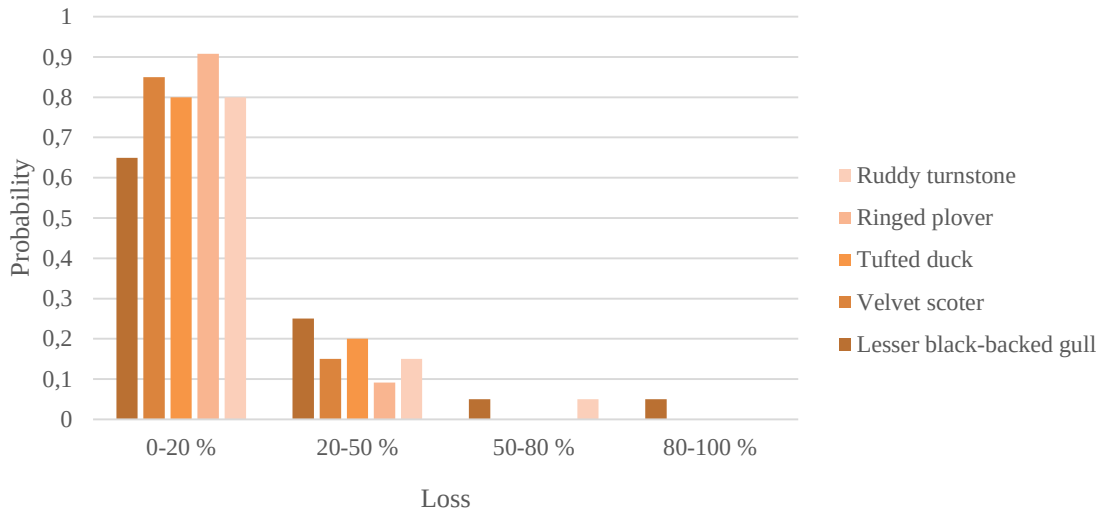


Figure 16. The loss of different bird species at the distance of 100-500 metres from the wind mill.

The uncertainty is greatest within 100 metres from the turbine. For each bird, the class of the smallest loss remains the most likely, but the distributions are notably wider than further away from the mill (figure 17).

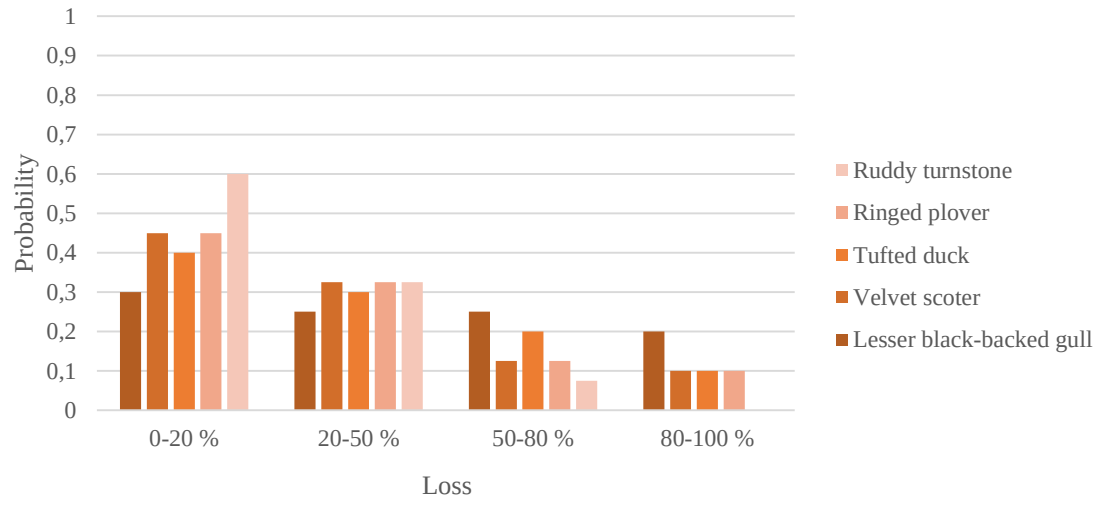


Figure 17. The loss of different bird species at the distance of 0-100 metres from the wind mill.

When there isn't an operational wind mill at the distance of 1000 metres, the losses of all studied bird species remain in the smallest class, 0–20%, with the certainty of 0.9996–0,9998 irrespectively of the oil shipping development scenario. The uncertainty in the losses grow notably as moving closer to the mill.

5.2.2 Breeding birds and oil exposure

With oil exposure, the probability distribution looks different compared to the disturbance distributions mainly in two ways. First of all, according to Expert 2, if the area is exposed to oil, it no longer makes a difference whether there is a wind turbine nearby or not. Also Expert 1 agreed on this. Second of all, the losses are likely to concern the majority of the breeding unlike with disturbance (figure 18). The distributions given by Expert 2 are narrow compared to the distributions of disturbance, which means the level of uncertainty is smaller.

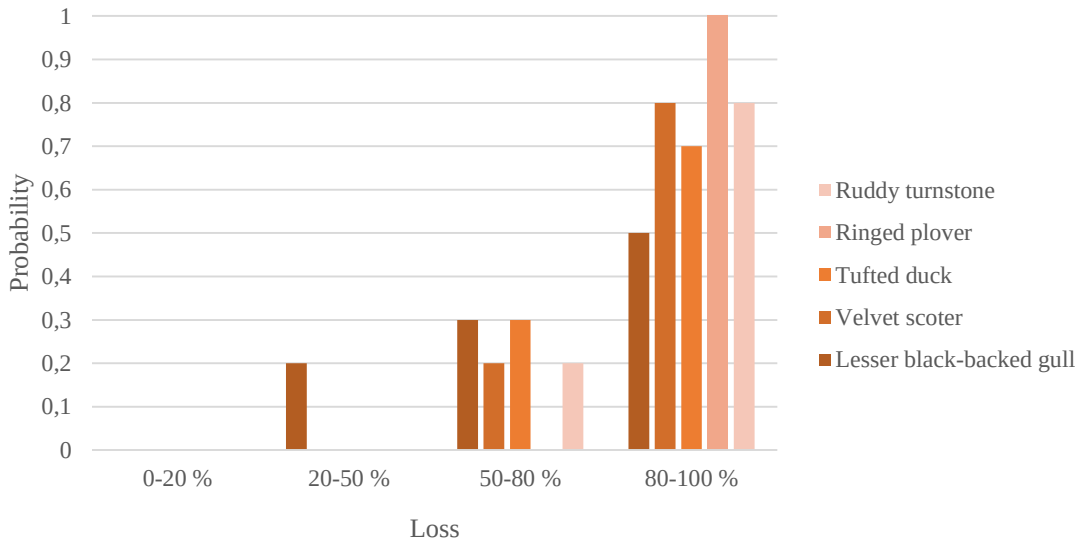


Figure 18. The loss of different species when the location is exposed to oil at all distances from the mill. The distance to the wind mill no longer makes a different once the location is exposed to oil.

Even though the consequences of an oil spill have been described as *dramatic* by the experts, Expert 1 points out that the spill would have to be massive to cause such exposure to oil that all breeding would fail. The lesser black-backed gull has slightly better chances of survival than the other four species.

Cumulative impacts and relative sensitiveness of birds

According to the expert elicitation, the influences of oil are so dramatic that if a location gets exposed to oil, it no longer makes a difference whether there is a wind mill nearby or not. None of the studied species are completely loyal to their nesting sites, however the studied waders live for a surprisingly long time and often return to the same breeding sites. Out of the studied birds the ducks are the least loyal to their breeding sites, but on the other hand they are very selective over the quality of the nesting site (Expert 1).

According to Expert 1, out of the five studied species the velvet scoter is the most sensitive to oil, since it is a sea duck that dives. In his opinion the waders are the most capable ones of surviving an oil spill, since they overnight onshore. Expert 2 does not see a clear distinction between the losses in breeding of ducks and waders. According to him, the ringed plover is the most sensitive species to oil, and the other wader, ruddy turnstone, comes in second together with the velvet scoter. This differs from Expert 1:s estimation, based on which the two waders are the least sensitive to oil. This brings out well both the problem and the advantage of using various experts in expert elicitation. Expert 1 pointed out that the relative sensitiveness to oil was the most difficult to define in the cases of the ringed plover and the ruddy turnstone, since there are arguments both for why they would be sensitive and resistant to oil. This supports the distributions given by Expert 2, who ranked these birds as the most sensitive ones, and leaves little if any contradiction between the estimations of the two experts.

The lesser black-backed gull gets exposed to oil catching fish from the waters near the coast. Expert 2 estimates that since the lesser black-backed gull flies higher and nests further from the water than the other species, it is better equipped to survive a spill. In general it is in less contact with water than the other species. The same reasons, on the other hand, make it more vulnerable to wind mills, especially through the collision risk (figure 15-17). According to Expert 2, the losses to the breeding of the lesser black-backed gull are the most uncertain: it may be anything from 20% to 100%, whereas the losses of ducks and waders vary between 50% and 100%.

In the interviews the interdependency of species came up: According to Expert 1 some water birds tend to nest in sea gull colonies. The wind mill in itself may not have an impact on a water bird, but if it disturbs the sea gull colony, it may destroy the habitat of the water bird

as well. The length of oiled coastline would be helpful when estimating the impacts of oil on breeding birds, and also the shoreline type makes a difference: the ringed plover for instance feeds on sandy beaches whereas the ruddy turnstone feeds on rocky shores.

Since studies on the subject are few if any, the best available data is the expert judgement. Also the experts themselves highlighted, that their estimations are namely estimations, and carry more relevance when analysing the relative sensitiveness of different species than when looking at the absolute metric distances from the wind mill.

Impacts during construction phase

The model deals with the impacts of wind power during its active phase, and does not take into consideration the construction phase. Probably the most dramatic impacts of wind power occur in the construction phase, especially through pile driving. Therefore the experts were also asked to give a safety limit, beyond which the construction can be going on without disturbing the breeding of birds. According to Expert 1, in the case of gulls this safety zone would be some hundreds of metres, and for the waders even less. According to Expert 2, a decent safety zone would be ranging from 250 metres (ringed plover) up to 700 metres (lesser black-backed gull), but he would prefer if the pile driving work took place outside the nesting season altogether. The coastal waters of the GOF are frozen approximately 3,5-4,5 months annually, and the open waters are frozen between 1,5 and 3,5 months of the year (Seinä 2012). This leaves approximately two thirds of the year ice free, and according to Expert 2 the pile driving could easily be scheduled for the ice free period without taking place during the breeding of the birds. Also in the case of the construction of a windmill, the greatest influences on breeding birds do not come directly from the pile driving, but the impacts are indirect, such as losing alimentation due to the repulsion of fish.

5.3 Loss of key species

According to the model, the only pressure affecting the key species is oil exposure. Expert 5 points out that we are familiar with how oil acts on the surface of the water, but we do not know very well how much of the oil will sink and under which circumstances. Not knowing the oil type makes the estimation harder, especially with benthos, whose habitats are in the bottom sediments. The species themselves may be very sensitive to oil, but the likelihood of them getting exposed to oil is small. For example according to Expert 5, if the marenzelleria

get exposed to oil, a 80-100% loss is certain, but the probability of the exposure is small, since the marenzelleria live in depths greater than 5 metres, and the vast majority in depths of over 10 or 20 metres.

5.3.1 Algae and oil

According to Expert 5, the most sensitive ones out of the five algae are the clasping leaf pondweed, the muskgrass and the watermilfoil. They all are present in relatively shallow waters, mainly in depths under 2 metres, which explains why they are likely to get exposed to oil. They do, however, have roots, so their recovery is secured. When the location is known to get exposed to oil, the most probable loss for these three species is 80–100%. The probability for this loss is as high as 0,8, whereas the probability for a 50–80% loss is 0,2.

Also for the bladder wrack the most probable loss is 80–100%, but in its case the probability for the loss of over 80% is slightly smaller than with the three earlier mentioned species, and accordingly the probability for the loss of 50–80% is slightly larger. The bladder wrack grows usually on open coasts, and oil reaches locations like these fairly easily, which adds up the vulnerability of the bladder wrack. For all of these four algae the loss is certainly 50% or more according to Expert 5 (figure 19).

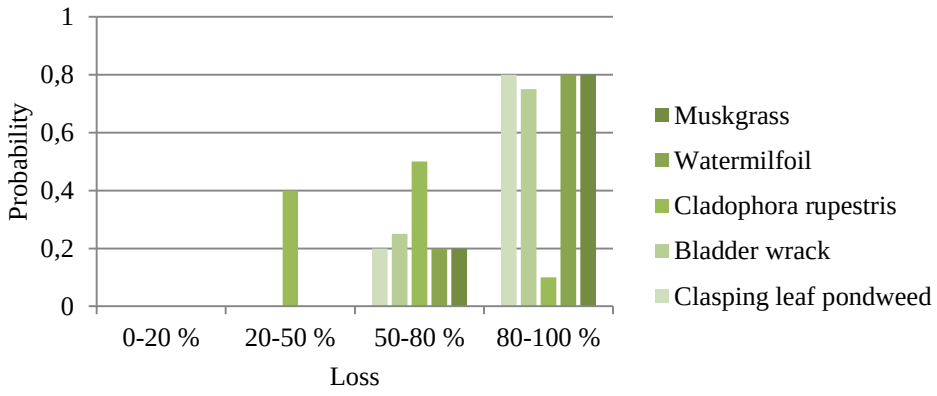


Figure 19. The loss of algae when in the same location with oil.

The habitats of the *Cladophora rupestris* are in slightly deeper waters, and also its probability distribution differs from the distributions of the other algae: the most likely loss is 50–80% with the likelihood of 0,5, but the probability for the loss of 20–50% is nearly as high, 0,4. There is a 0,1 probability for the loss to exceed 80%. The differences are explained mainly by the depth and the habitat type of the alga.

5.3.2 Benthos and oil

When the location of the habitat is exposed to oil, even a 80–100% loss is possible albeit not likely for the blue mussel. According to Expert 5 the likelihood of a loss of this extent is 0,1, as it also for the loss of 20–50%. The probability for a 50–80% loss is 0,8 (figure 20). The probability distribution of the blue mussel is pointed, meaning that it has a clear peak at one of the classes and the probabilities for other classes are significantly smaller. The blue mussel is capable of closing its shell, which increases its chances of surviving an oil spill. Out of the main habitats of the three species of benthos, the blue mussels' are in the lowest depths. This makes the oil exposure more likely.

With the Baltic tellin the probability distribution has a very different shape: the loss is certainly something between 20 and 80%, and there is no distinction within this range. The Baltic tellins' habitats are on soft surface substrates at varying depths. It is a mussel, so it is capable of closing its shell, and once the shell is closed, the mussel changes its metabolism so that it can survive inside the shell for up to 1–2 weeks, leaving the light fractions of oil enough time to evaporate (Expert 5).

For the marenzelleria the most likely loss is between 20–50%, but there is also a possibility for a smaller or a larger loss. An 80–100% loss is not considered possible for this species. The distribution has a clear but low peak at 20–50% with a probability of 0,5, while the probabilities for the 0–20% and 50–80% class are 0,3 and 0,2 respectively. One of the reasons for the uncertainty is the range of different kinds of habitats where the marenzelleria worm can be met. At open sea the likelihood of getting exposed to oil is a lot smaller than at a shallow bay. The marenzelleria does not have similar means of survival as the mussels, but it lives mainly in greater depths than the Baltic tellin, so its risk of exposure is smaller.

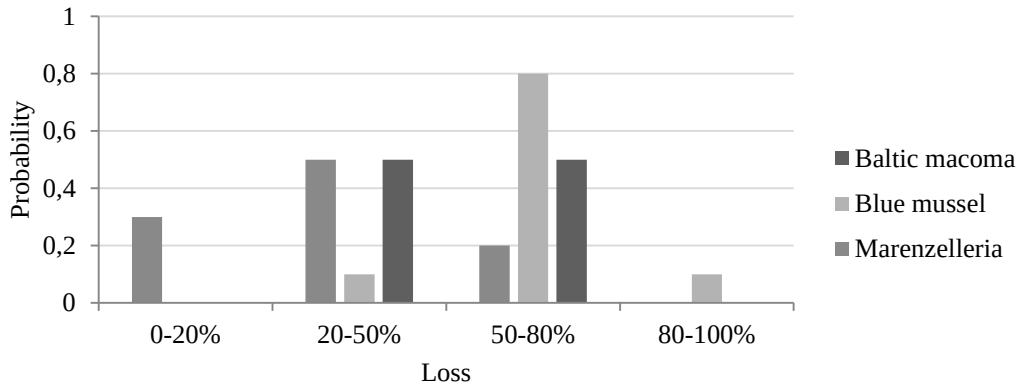


Figure 20. The loss to the bentos when in the same location with oil.

The relative sensitiveness of the key species is hard to estimate, since their probability distributions are so different. However, the blue mussel seems to stand out with the probability for somewhat larger losses than the two other species. The key species in general are safe, and in the basic situation of the model all of their losses remain in less than 20% with a certainty of 0,9999. However, if a spill was to occur and the oil slick reaches the location of the species, the losses are extensive.

5.4 Oil shipping scenarios for 2020

The differences between the three alternative oil shipping scenarios remain fairly small. The likelihood of an oil spill in each scenario is vary from 0,00065 in the Slow Development scenario to 0,00075 in the Strong Development scenario. In the normal situation of the model, where no decisions have been made on the *Oil spill* node, there is no difference between the scenarios from the point of view of the species when it comes to the risk of oil-induced losses.

Expert 6 brought up that an oil spill is a very different kind of a pressure compared to the other pressures of the model, noise and disturbance. If a tanker engine is running, there will be noise, and if there are more ships, there is more noise. The reasons behind oil spills are more complex, and consist of operation, management, human behaviour and actions of authorities, among others. This makes it very difficult to estimate a probability for an oil spill to occur under different traffic scenarios. The risk of an oil spill does not necessarily increase when traffic increases, since mitigation methods will be used (Expert 6).

The possible oil exposure is the only pressure which has an impact on all groups of studied organisms, and even though its probability is small, its consequences may be massive, so it has to be considered in detail. In a hypothetical situation where there is no exposure to underwater noise caused by shipping and no wind mills, the relative sensitiveness of species to oil is as presented in figure 21.

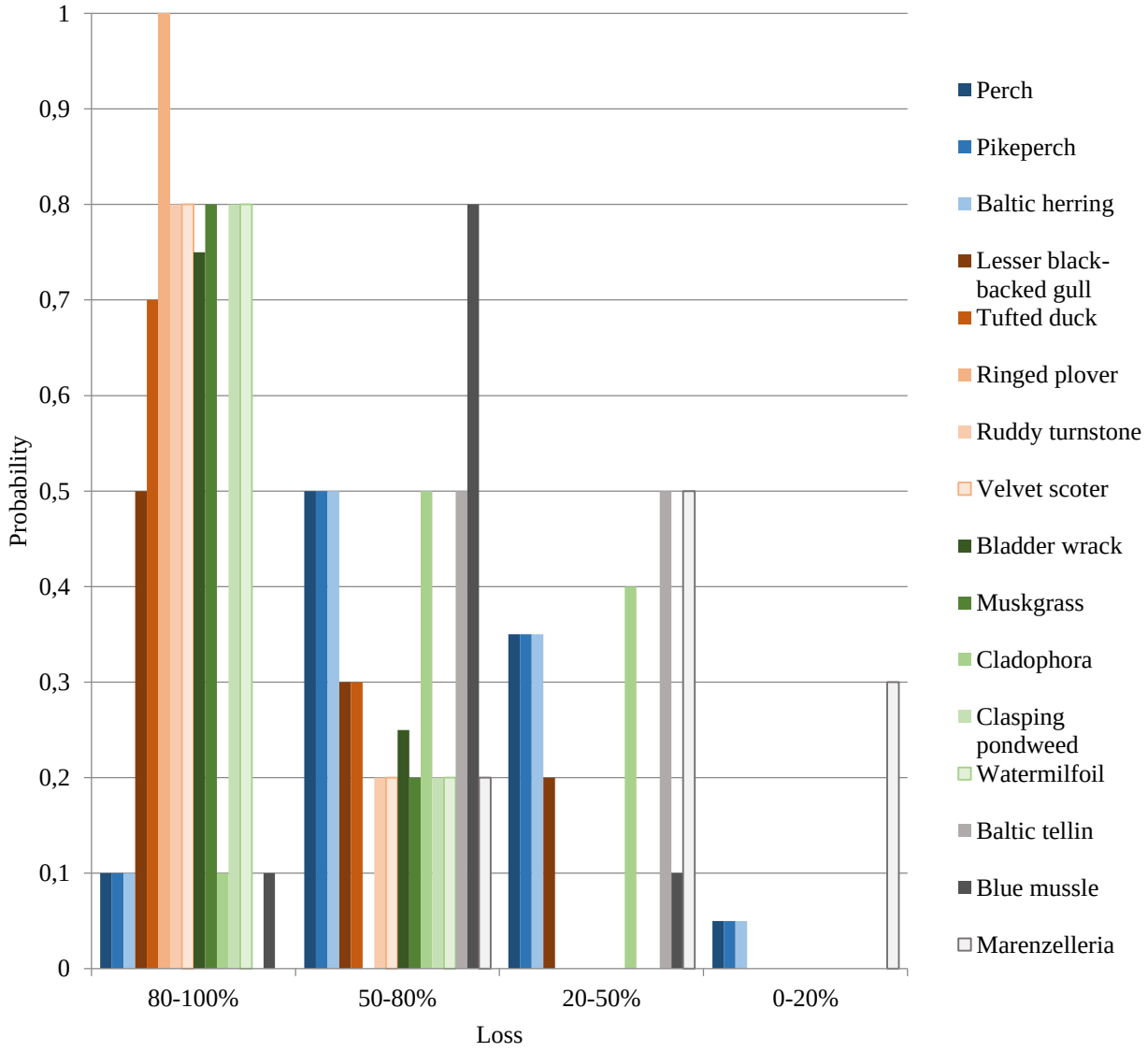


Figure 21. The loss caused to each of the studied species when the square of their habitat gets exposed to oil. Fish species are marked with shades of blue, birds with red, algae with green and benthos with grey.

The comparisons have to be made with caution, since the losses have been estimated by several experts and are somewhat subjective. Also the different nature of the losses in each class of organisms has to be taken into account: with birds the loss is in the breeding of birds, while with the key species it describes mortality and with fish the loss only takes into account

the juvenile stages. Therefore this data should not be used to make generalizations of the overall sensitiveness of the species, or of the severity of the situation from the point of view of the whole populations.

In this thesis, the underwater noise caused by a single tanker experiences a 10% (1dB re 1µPa) increase, when shipping increases with 10%, and a 20% (2dB re 1µPa) increase, when shipping increases with 20%. The difference between the three development scenarios remains small from the point of view of the species, as can be seen in the case of the Baltic herring in figure 22.

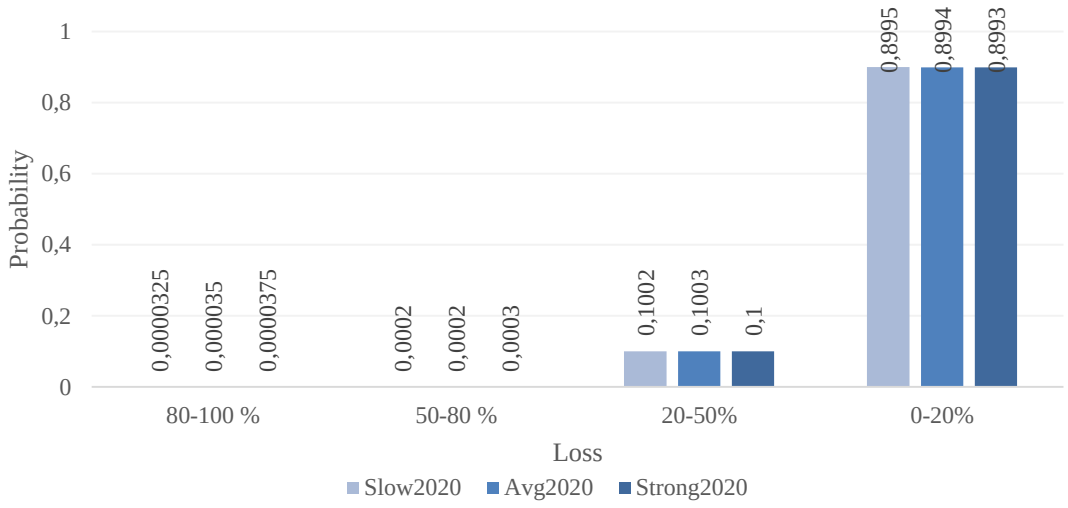


Figure 22. The probability distribution for the loss of juvenile Baltic herring in each oil shipping development scenario for 2020.

5.5 Offshore wind power

Offshore wind power causes two pressures that have impacts on two different groups of organisms. Figure 23 presents the situation at 0–100 metres from an operational wind mill. The losses to early development stages of fish remain in the lowest classes with a high probability whereas for birds losses of any amplitude are considered possible. No judgements about the overall sensitiveness of the groups of species can be made, since the loss of breeding birds means that the breeding is found impossible at the certain location, whereas with the early development stages of fish, the losses come through mortality. For all species, it is more likely for the loss to be under 50% than over.

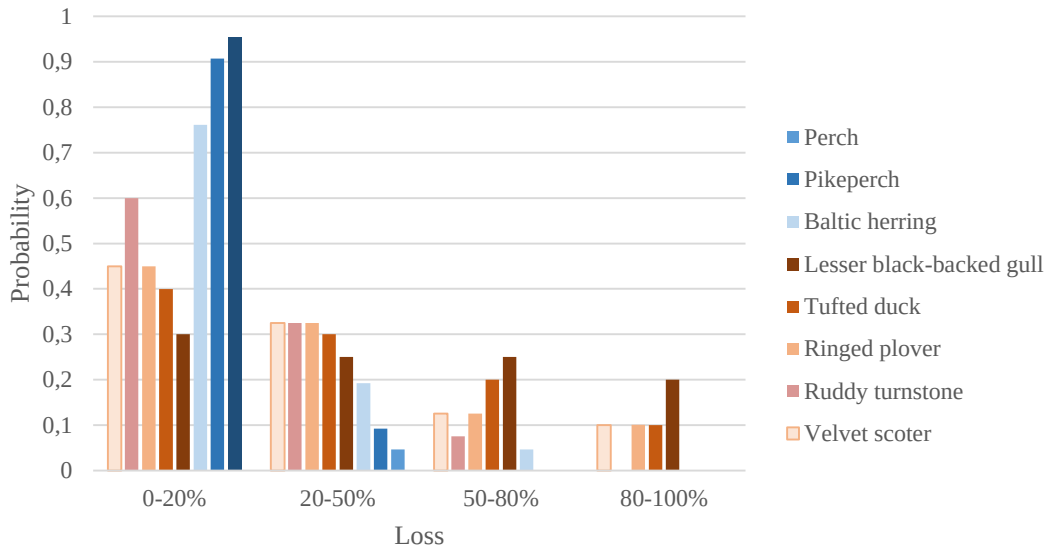


Figure 23. The impacts of an offshore wind mill on the breeding of birds and on juvenile fish a the distance of less than 100 metres from the mill. The losses to juvenile fish come from the mortality caused by underwater noise, directly of indirectly, and the losses in breeding birds are explained by the disturbance caused by the wind mill, which are the blinking of lights, shadows, movement and sounds.

The differences start evening out quickly, as can be seen in figure 24 which represents the situation at the distance of 100–500 metres from the mill. At the distance of 1000 metres from the mill, losses of both groups remain in the smallest class with a very high probability.

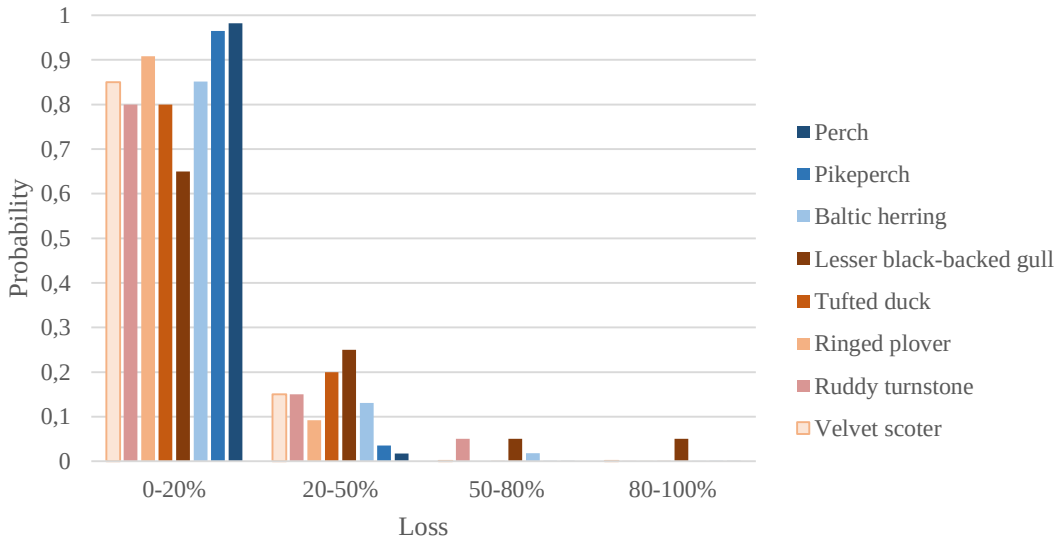


Figure 24. The impacts of an offshore wind mill on the breeding of birds and on juvenile fish at the distance of 100–500 metres from the wind mill. The losses to juvenile fish come from the mortality caused by the disturbance and masking of underwater noise, and the losses in breeding birds are explained by the disturbance caused by the wind mill, meaning the blinking of lights, shadows, movement and sounds.

6. Discussion

6.1 Evaluation of the method

Several experts mentioned, that estimating the probability distributions in the other parts of the thesis model seemed doable, but the part considering their field of expertise was highly challenging. This proves both the strength and the weakness in BNs. The strength is that they present reality well enough to be useful, yet they make enough simplifications to be able to be handled. On the other hand they simplify each issue up to the point, where the experts of specific fields have difficulties in giving probability distributions, since so many simplifications have been made and so much uncertainty is involved.

The expert elicitation process was successful and the results were good. According to Kuhnert et al. (2010), the use of multiple experts would be beneficial for many types of expert data elicitation. This is because obtaining the level of precision that is hoped for can be challenging when only one expert is being used. In this study the use of single experts was found sufficient, since the experts had a robust knowledge in their field and the interview questions were straightforward. A pilot interview was held to make sure, that a person with no previous knowledge of the method would be able to understand the framework and the questions. Despite the pilot interview, one of the questions turned out to be too ambiguous in the first interview. For the following interviews, this part was structured better, and the following experts were able to produce the required probability distributions.

An expert elicitation feedback mechanism was built for the experts to be able to check the consistency of their results. The tool was a MS Excel sheet, that visualized the responses of the expert, and it was used in the interviews considering birds, where the impacts of two pressures (*Disturbance* and *Oil exposure*) were observed on five different species. According to Kuhnert et al. (2010) the feedback is the most important when only one expert answers for the entire group of organisms. The feedback mechanism was found very useful in the interviews with two pressures. Juvenile fish are exposed to three pressures, which made the visualization of feedback more complicated and less useful. Only one pressure has an impact on the key species, so the use of the feedback tool was not found necessary in this interview. There were slight differences in the ways in which feedback was given, which

may mean that the interviewees were put in slightly different positions and their responses are not completely comparable.

In two cases an expert pointed out an inconsistency or a defect in the questions of the interview. These cases were dealt with according to the situation, and suggestions from the experts were taken into account. This brought up one of the flaws of expert elicitation: the interviewer should have a decent knowledge in the subject of the interview to avoid asking wrong questions. This means that expert elicitation can only be used within the fields that are already familiar to the interviewer, which narrows down the possible topics of research, or that the questions should be prepared in cooperation with the experts. In this case the expert should be involved in a longer process, which might decrease the willingness of the experts to participate. In general the questions were made as explicit and straight forward as possible. This is important because there is uncertainty involved in every level of the process, and it cumulates within it, so at least the original questions should be unambiguous as possible.

In general the method served well in studying the human actions and the related human pressures. Joining different types of data worked flawlessly with the BN, and the model enables the quantified comparison between different states of variables.

6.2 Considerations about the developed model

The model includes the most central human pressures caused by the studied actions. It describes the impacts fairly accurately, with certain limitations. The model works with the continuous impacts of the human actions, leaving out, for instance, the pile driving work completed during the construction phase of offshore wind power, which is a heavy pressure. By observing the continuous impacts only, the questions concerning species recovery and replacement could be ignored altogether. Also the season was left undefined in the model, even though there is a difference between for instance an oil spill in the spring or in the autumn, especially when it comes to reproduction of species. Some simplifications considering underwater sounds were made, such as ignoring the frequencies.

In the final thesis model no variable describes the changes that occur in the seabed due to either of the human actions. New wind mill constructions cover parts of the seabed and may

demolish habitats. The Baltic tellin, for instance, lives on soft surface substrates, and when new hard constructions and concrete areas on the seabed are introduced, the Baltic tellin loses its habitats. The blue mussel, on the other hand, would gain of the same change, since it needs hard substrates to attach to. According to Petersen & Malm (2006), the reef effect, meaning the introduction of new hard substrates and the subsequent changes in the biota, is the single most important environmental impact of offshore wind power. This is highlighted in large wind farms. Oil shipping causes increased turbidity and substrate type changes near the fairway affecting especially the habitats of the key species. These changes can be estimated with the additional part of the model (see 4.6), but they are not included in the thesis model or the results.

The depth of the marine area has not been taken into account in the model, which brings some inaccuracy to the estimations of the loss of fish and key species. The habitats that are in great depths are less likely to get exposed to oil, and even if the absolute sensitiveness of the species was greater than of a species that lives near the surface, the overall loss due to an oil spills may be smaller. Here also the location of the studied square makes a difference. If a square is at open sea with an average depth of tens of metres, it is very unlikely for the oil to get in touch with the benthos. According to an expert, there is no physical mechanism how the dissolving fractions of oil would reach depths of 50 to 60 metres. The situation is significantly different at a shallow bay with depths less than 5 metres and no chance for the oil to leave the bay once it has entered. The model does not make a distinction between these two situations, which increases the uncertainty in the model.

The probability distribution for the oil spill variable was based on the assumption that more oil means more tankers, and more tankers lead into a greater accident risk. In 2009 the largest tanker in the GOF was of the size of 117 100 deadweight tonnage (Brunila & Storgård 2012). The deadweight tonnage (dwt) means the total weight the tanker can support including also the fuel, the ballast waters and the crew. The maximum tanker size that can be used at the GOF is 150 000 dwt (ITOPF 2003 cit. Brunila & Storgård 2012) and the Primorsk terminal can support tankers of this size, so it is possible that the tanker size at the GOF will grow. Even if the amount of transported oil would grow, the number of tankers may stay the same or even decrease. If assumed that more tankers lead into a bigger risk of an oil spill, the risk may even decrease as transported volumes grow. However if the tankers are larger, the

consequences of a possible spill are more severe. Also the noise levels are expected to rise as shipping amounts increase, but with fewer tankers of newer technologies, sound pressure levels may even decrease.

If the average tanker size at the GOF seems to grow, new estimations should be made both on the risk of the accident and on the impacts of the spill. The shipping scenarios for 2020 and the associated expert elicitation were made in 2009–2010. The current political situation may affect both the scenarios and their probabilities. In this thesis the original probabilities were used, but for further versions of the model, new expert elicitation and updating of the scenarios should be done.

When looking at the results of the thesis, it can be noted that even at distances, where none of the constant pressures should affect the species, there is a small possibility for a 80–100% loss for all species. This probability comes from the possible oil exposure. Even though the probabilities are small (10^{-5}), they are still an overestimate. The probability of an exposure once a spill has happened is set to 50-50, meaning that in case of an oil spill, 1 out of 2 grid squares at the EGOF would get exposed to oil. An oil slick spreads about 20km2 in 24 hours (SÖKÖ II 2011). To reach 50% of the EGOF, the spill would have to be extremely large and the recovery work inefficient. This is practically impossible, but the 50-50 rate is used for precautionary reasons and since real data on the probabilities of oil exposures are not available. Real probabilities will be used in the spatially referenced TOPCONS tool, which uses SpillMod drift models to describe the spreading of oil.

One of the main goals of the thesis was to observe the cumulative impacts of the human actions. This worked well with the different types of noise, but with the cumulative impacts of noise and oil or disturbance and oil, the impacts of the oil exposure were so dramatic, that the impacts of the other pressures no longer had on effect on the losses. The cumulative impacts on fish and birds are equal to the impacts of oil.

According to Box & Draper (1987: 424) *"all models are wrong, but some are useful."* The model built in this thesis gives a correct although simplistic image of the consequences of the human actions at the EGOF. The main reason for the simplicity is the limited number of studied pressures, which can be increased in later versions of the model. When taking into account the above mentioned limitations, the model is able to give valid predictions of the

consequences of the studied human pressures in the conditions of the study area, making it useful in the sustainable planning and conservation on the EGOF.

6.2.1 Comparison to earlier results

This thesis looks into aspects of the ecology of the EGOF that have not been studied before, so earlier results are few. Lecklin et al. (2011) studied the acute and long term impacts of oil in the GOF using BNs. Their results considering the relative sensitiveness of the species to oil are very similar to those produced in this thesis.

Lecklin et al. (2011) estimated that in the long term the Baltic herring is less sensitive to oil than the perch and the pikeperch. This is probably because the Baltic herring is a pelagic fish while the two other are littoral, which may mean they are more affected by oil. The fish experts in the thesis regarded the sensitivity to be similar among all three species, since so little was known of the qualities of the oil. However it does make sense that the littoral species suffer more of oil than the pelagic ones, since the oil slicks generally will reach the shore (Aps 2009) and influence there for a lot longer time than at open water. At open water fish are also more capable to avoid to exposed areas.

With birds, Lecklin et al. (2011) suggested that the ducks are more sensitive than the gulls, which on their part are more sensitive than the waders. This order matches the one given by Expert 1. Expert 2 struggled to decide whether to place the waders among least or the most sensitive ones to oil, finally ending up with the latter. Since Expert 1 didn't feel confident to estimate the probability distributions for the birds in the case of an oil exposure, the distributions in the model are based on Expert 2:s estimations and thus different slightly from the order of sensitiveness presented by Lecklin et al. (2011).

The results of Lecklin et al. (2011) include most of the key species that are studied in this thesis. With algae, the ones that are mentioned appear in the same order according to their relative sensitiveness as the algae in this thesis. The bivalves are the least sensitive group out of all the species studied by Lecklin et al. (2011), which is slightly contradictory with the results of this thesis. However it has to be stated that with the bivalves, as it is with other key species, the losses are measured directly in mortality rates, whereas with the other groups the losses may include some level of expulsion and the groups do not cover the whole populations, so the results are not fully comparable.

6.2.2 The model in MSP

When planning the location of wind mills, the environmental impacts have to be considered, but it has to be recognized that they are a secondary criteria, whereas the wind circumstances and the possibilities of energy transfer are more important factors. Also shipping develops depending on other features than the environmental impacts.

The thesis model was built to predict, what the consequences of human actions may be. The model quantifies the impacts of human actions and enables the comparisons between alternative management decisions. The model or the MSP tool alone cannot make management decisions, but they can be used to assist decision making and planning on different spatial levels. The thesis model is a strong first step towards a tool that will be able to predict the environmental impacts with an accuracy that is adequate to be used as a guidance tool in decision making and MSP, and which in the future will be adapted to other marine areas too.

6.3 Suggestions for further research and development of the model

The type and the amount of oil as well as the length of oiled coastline in an oil spill are recommended variables for further versions of the model. Knowing these three, the experts would have a significantly better basis on which to build their estimations of the oil-induced losses of different species. Accidental oil spills respond only to a small part of the oil that ends up into the seas: Kotta et al. (2006) estimate that the total annual oil load into the Baltic Sea is up to 40 000 – 50 000 tonnes, and over half of this originates from rivers (Backlund 1993 cit. Kotta et al. 2006) and according to Hänninen & Rytkönen (2004) it has been estimated that 10 000 tons of oil end up in the Baltic Sea annually due to illegal charges. Expert 1 pointed out that the also the small oil emissions cause great damages to birds, and for example the long tailed duck (*Clangula hyemalis*) is endangered everywhere in the world due to small but constant exposures to oil. In further versions of the model, the oil originating from other sources than accidental spills should be taken into account too.

The species that were studied in this thesis were selected in TOPCONS project and represent different types of habitats. An expert expressed his concern about there being no auks in the selection of birds, even though it is known that auks have suffered massive losses due to oil spills. Lecklin et al. (2011) stated that auks are the most vulnerable group of organisms in

the GOF, and according to the expert, auk colonies should definitely be prioritized when making decisions concerning the management of oil spills, and thus be included in the model. Also including the relationships between the organisms would bring added value to the model: if an alga disappears, a fish that was not affected by a pressure may lose its spawning sites, and on the other hand if one fish species suffers great losses, other species may have a better chance of survival due to decreased predation. The relationships between species are complex and require further research and quantification before they can be implemented into the model.

Up to date there is no comprehensive understanding on what the underwater soundscape is like, nor are there universal standards for a good status of the sea when it comes to underwater sounds. Should some areas try to be kept as silent as possible by concentrating the noise sources in other areas, or should the noise sources be spread out as evenly as possible trying to ensure that the cumulative noise levels do not reach critical values at any location? Up to what extent would it even be possible to create silent zones? New guidelines for the noise levels of terrestrial wind power have been introduced recently posing the question, whether there should be similar guidelines concerning underwater noise too. More research on underwater noise and its impacts is needed to answer questions like these. The issues concerning underwater noise gain more importance if the model is expanded to deal with offshore wind farms. In that case also the electromagnetic fields caused by electricity transfer should be taken into reconsideration, since their importance grows as the amount of transported electricity grows. The habitat loss and the physical loss of seabed should also be included in the model, if it were expanded to deal with the pressures of offshore wind farms.

The pressures that follow the human actions are different of nature. Some pressures are certain but small others being unlikely but dramatic. A form of risk calculation should be added to the model to increase its usability in management. The likelihood and severity of the pressure should be combined, and when thinking about management procedures, quantified comparisons between the high probability – low impact pressures and the low probability – high impact pressures could be made.

7. Conclusions

This thesis analysed the environmental impacts of offshore wind mills and oil shipping in a probabilistic framework. The study area was the eastern Gulf of Finland. The objectives were to develop a model that is used as an elemental part of a marine spatial planning tool prototype and runs both with and without a GIS interface. This thesis provides insight to three research questions:

1) What are the most likely environmental impacts caused by additional offshore wind power and the increase of oil shipping at the eastern Gulf of Finland?
2) What are the cumulative effects of the actions?
3) How reliable are the results produced by the selected method?

The two first questions were answered by a literature review and by the model itself. The most important human pressures were identified based on literature and publications (chapter 2), and the pressures were modelled in a Bayesian network (chapter 4). Expert interviews were made to elicit probability distributions for the key life history variables of the studied species. Attenuation of the pressures was described using explicit mathematical descriptions when available. The results were viewed and analysed (chapter 5), and the inconsistencies and flaws of the model were identified (chapter 6). The obtained results were compared with an earlier publication which studied partially the same species at the GOF, but was focused on a different set of human pressures. The method and the usability of the model were discussed, and proposals of improvements and validations to the model were made (chapter 6).

The model predicts that additional offshore wind power and the increase of oil shipping will negatively influence the marine environment. The spatial scope of the impacts depends on the type and magnitude of the pressure. According to the model, the disturbance caused to birds by an operational wind mill extends only some hundreds of metres, whereas the underwater noise of the noisiest possible tankers can carry for hundreds of kilometres before reaching a certainly harmless sound pressure level for fish. The losses caused to the species by offshore wind power and the underwater noise of shipping are minor and there is no major uncertainty in this conclusion. However, the impacts of an oil spill can be extensive.

The model provides reliable predictions about the environmental impacts caused by the studied pressures once known that the pressure will take place. For example, the consequences of a new operational offshore wind mill are described trustworthily by the model. On the other hand, the uncertainty of predictions is large for possible oil spills and the related risk of oil exposure unless a GIS environment is applied. The consequences of the exposure are well described by the probability distribution given by an expert, but the probability of an oil slick to reach a location should be modelled in a spatial framework.

Marine spatial planning is essential, because actors of several sectors operate in the marine environment, and the cumulative impacts of their activities have to be assessed in a joint framework. The developed model considers three human pressures and their cumulative impacts. Even more human actions and pressures could be added to the model to obtain a better understanding of the cumulative stress at the EGOF. Once done, the group of beneficiaries of the transboundary MSP tool will be extensive, including municipal officials, the business sector and scientists.

The current model is a part of the first step towards a marine spatial planning tool, which can be implemented in other marine areas and contribute to the ecosystem based planning and conservation of marine areas worldwide.

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APPENDICES

APPENDIX I

The interview sheet for the interviews considering the breeding of birds. Sheets are identical for each bird species.

Haastattelu, karikukko – *Arenaria intepres* H01

Kuinka suuri tappio pesinnälle aiheutuu, kun lähistöllä on toimiva tuulivoimala?

Sijainti on muuten sopiva pesimiselle. Lähtötilanne = ei voimalaa = tappio 0%.

Kuinka suuri osa pesinnästä epäonnistuu?	0-100 m	100-500 m	500-1000 m	> 1000m
Lähes kaikki (80-100%)				
Yli puolet (50-80%)				
Alle puolet (20-50%)				
Pieni osa (0-20%)				

a) Kullakin etäisyydellä, mikä on mielestäsi todennäköisin tappio?
b) Kuinka varma olet siitä (1=täysin varma, muut vaihtoehdot mahdottomia)
c) Mitkä muut vaihtoehdot ovat mahdollisia? Kuinka suuren todennäköisyyden antaisit niille (1=täysin varma, 0=täysin mahdoton)

Kuinka kaukana tuulivoimalasta sen aiheuttamalla häiriöllä ei ole enää mitään merkitystä linnun pesimiseen?

Miten tilanne muuttuu, jos lähistöllä on tuulivoimala **ja** alue on öljyyntynyt?

Kuinka suuri osa pesinnästä epäonnistuu, jos alue on öljyyntynyt?	0-100 m	100-500 m	500-1000 m	> 1000m
Lähes kaikki (80-100%)				
Yli puolet (50-80%)				
Alle puolet (20-50%)				
Pieni osa (0-20%)				

APPENDIX II

Interview sheet for interviews considering the early development stages of fish. Sheets for each fish species are identical.

Silakka - *Clupea harengus membras* H03 1/2

1) Varhaiskehitysvaiheet ja melu

Kuinka suuri osa kaloista kuolee varhaiskehitysvaiheissa (mäti- ja poikasvaihe), kun merituulivoima ja/tai tankkerit aiheuttavat äänenpainetta eri voimakkuuksilla?

Tuulivoimalan melu / Laivaliikenteen melu	**Osuus varhaiskehitysvaiheissa olevista kaloista**	>190dB re 1µPa			90-190dB re 1µPa			<90 dB re 1µPa		
		>190	90-190	<90	>190	90-190	<90	>190	90-190	<90
	Lähes kaikki (80-100%)									
	Yli puolet (50-80%)									
	Alle puolet (20-50%)									
	Pieni osa (0-20%)									

Kuinka suuri osuus mädistä / kalanpoikasista kuolee kussakin melutilanteessa? Kuinka varma olet siitä?

Mikä on ylin äänenpaine, jolla ei ole mitään vaikutusta kalojen varhaiskehityksen onnistumiseen? _____

2) Aikuiset yksilöt ja melu

Kuinka suuri osa kutemisesta jää tapahtumatta eri meluolosuhteissa?

Tuulivoimalan melu / Laivaliikenteen melu	**Osuus kutemisesta, joka jää tapahtumatta**	>190dB re 1µPa			90-190dB re 1µPa			<90 dB re 1µPa		
		>190	90-190	<90	>190	90-190	<90	>190	90-190	<90
	Lähes kaikki (80-100%)									
	Yli puolet (50-80%)									
	Alle puolet (20-50%)									
	Pieni osa (0-20%)									

3) Öljyyntyminen ja varhaiskehitysvaiheet

Miten tilanne kalojen varhaiskehitysvaiheiden suhteen muuttuu, jos alue on myös öljyyntynyt?

Kuinka suuri osa kaloista kuolee varhaiskehitysvaiheissa eri meluolosuhteissa, kun alue on myös öljyyntynyt?

Tuulivoimalan melu	**Osuus varhaiskehitysvaiheissa olevista kaloista**	>190dB re 1µPa			90-190dB re 1µPa			<90 dB re 1µPa		
Laivaliikenteen melu		>190	90-190	<90	>190	90-190	<90	>190	90-190	<90
	Lähes kaikki (80-100%)									
	Yli puolet (50-80%)									
	Alle puolet (20-50%)									
	Pieni osa (0-20%)									

4) Öljyyntyminen ja aikuiset yksilöt

Kuinka suuri osa kutemisesta jää tapahtumatta eri meluolosuhteissa, kun alue on myös öljyyntynyt?

Tuulivoimalan melu	**Osuus kutemisesta, joka jää tapahtumatta**	>190dB re 1µPa			90-190dB re 1µPa			<90 dB re 1µPa		
Laivaliikenteen melu		>190	90-190	<90	>190	90-190	<90	>190	90-190	<90
	Lähes kaikki (80-100%)									
	Yli puolet (50-80%)									
	Alle puolet (20-50%)									
	Pieni osa (0-20%)									

APPENDIX III

The interview sheet for the interviews considering key species. Sheets are identical for each alga and each benthic species.

Näkinparta (*Chara sp)* H04

Öljyn vaikutukset leviin

Kuinka suuri osa levästä tuhoutuu, kun se joutuu kosketuksiin öljyn kanssa?

Tappio	**Todennäköisyys**
Lähes kaikki (80-100%)	
Yli puolet (50-80%)	
Alle puolet (20-50%)	
Pieni osa 0-20%)	

Mikä on todennäköisin tappio?

Kuinka varma olet siitä?

Mitkä muut vaihtoehdot ovat mahdollisia? Kuinka varma olet niistä?

Eri vaihtoehtojen todennäköisyys yhteensä = 1, eli on varmaa, että jokin vaihtoehdoista toteutuu.

Monisukasmato (*Marenzelleria)* H04

Öljyn vaikutukset pohjaeläimiin

Kuinka suuri osa monisukasmadoista kuolee, kun ne joutuvat kosketuksiin öljyn kanssa?

Tappio	**Todennäköisyys**
Lähes kaikki (80-100%)	
Yli puolet (50-80%)	
Alle puolet (20-50%)	
Pieni osa 0-20%)	

Mikä on todennäköisin tappio?

Kuinka varma olet siitä?

Mitkä muut vaihtoehdot ovat mahdollisia? Kuinka varma olet niistä

Eri vaihtoehtojen todennäköisyys = 1, eli on varmaa, että jokin vaihtoehdoista toteutuu.

APPENDIX IV

Interview sheet for the oil spill interview.

Oil spill H05

What is the probability for a tanker accident to happen in each MIMIC 2020 scenario?

MIMIC 2012	Million tonnes	Change %
Year 2009	150.6	
Slow development 2020	170.6	13.30%
Average development 2020	187.1	24.20%
Strong development 2020	201.5	33.80%

Brunila, O-P & J. Storgård (2012). Oil transportation in the Gulf of Finland in 2020 and 2030

	Slow2020	Avg2020	Strong2020
Spill			

Assumptions:

- Any tanker accident will lead into a spill
- No distinction between oil types
- No distinction between seasons (/average of seasons)