Scenario-based Oil Spill Response Model for Saimaa Inland Waters

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ABSTRACT: As Lake Saimaa in the Eastern Finland is characterized by shallow waters, scattered formations of islands as well as narrow fairways and channels, the maritime safety is of the highest concern. Saimaa deep water route is proven difficult to navigate. Accident statistics indicate that the probability of grounding incident is relatively high in the Saimaa waterways. Several sensitive areas and habitats for endangered species situating in close proximity to the deep water route emphasize the significance of risk prevention. Inland oil spills have high potential to contaminate shorelines and to affect densely populated areas. In parallel with proactive measures, capability to deal with the consequences of an oil spill is needed. In order to improve the oil spill response capability, the regional response authorities initiated a joint project to develop an oil spill response management model for Saimaa inland waters. This paper describes the preliminary results of that development work.

1 INTRODUCTION

1.1 *Aim and scope*

The aim of this paper is to introduce an oil spill response management model for Lake Saimaa inland waters. Inland oil spill response model is based on the results of risk analysis on transportation and storage of oils in Lake Saimaa district, and the oil drift calculation models produced for identified high-risk locations. Modelling enables creation of scenario-based, site-specific contingency plans crucial for inland waters where response strategy is to be selected in a very short space of time. In Saimaa waterways where shores are near, window of opportunity to conduct an effective on-water response is further reduced due to the fast currents. In order to facilitate identification of vulnerable areas and establishing protection priorities and response strategy, management model includes easy-to-use decision support tools for response managers and on-scene response teams. Inland oil spill response management model is developed in close cooperation with the Finnish oil spill response authorities (See Chapter 8).

Responsibility in shipborne pollution response in Finland is divided between environmental and emergency authorities. In case of a major oil spill, the Finnish Environment Institute (SYKE) is the competent government pollution response authority. SYKE, accompanied with the Finnish Border Guard and the Finnish Defence Forces, conducts the oil spill response measures on the open sea. SYKE is also the nationally appointed authority that is empowered to request and give international assistance. The Regional Fire and Rescue Services (RFRS) are in charge of oil response operations in both inland and coastal waters. The Centres for Economic Development, Transport and the Environment (ELY Centres) assist the RFRSs in organising the oil spill response operation as well as approve the regional contingency plans of the RFRSs'. (Hietala & Lampela 2007; SYKE 2017.)

This paper focuses on the field of operation of RFRSs and ELY Centres and, particularly, on their area of responsibility in oil spill response on inland waterways of Lake Saimaa district. Secondly, this paper analyses the oil spill risk resulting from the vessel traffic. The risks originating from the land-based facilities, considered major sources of oil discharges in the region, are beyond the scope of this paper.

1.2 *Structure of the paper*

This paper provides an overview of the development of inland oil spill response model. Firstly, the geographical area, to which the model is targeted, is introduced to describe the unique, and rather challenging environment the response operation is ought to take place. Secondly, the risk assessment directing the contingency planning is presented and the main findings are highlighted, as well as some models to illustrate the impact areas of potential oil spills. Then the sensitiveness of environment and the principles behind the protection prioritisation are discussed in order to reason the map tools developed. In conclusion the outcomes are summarized and some future steps introduced.

2 SAIMAA LAKE AS UNIQUE OPERATING ENVIRONMENT

Lake Saimaa is the largest lake in Finland and the fourth largest lake system in Europe. Surface area of the waterbody is approximately 4400 square kilometers. Lake Saimaa is a labyrinthine lake system where in places there is more shoreline per unit of area than anywhere else in the world; the total length of the shoreline is about 15 000 kilometers. The number of islands within the area is about 14 000. (Finland's Environmental Administration 2015.)

Waterways of Lake Saimaa are considered as part of the main transport corridor in the trans-European transport network (TEN-T). Lake Saimaa is connected to the Gulf of Finland and the Baltic Sea via Saimaa Canal by deep water route for merchant shipping with channel depth of 4,20-4,35 meters. The deep water route starts from the Gulf of Finland, goes through the Saimaa Canal and runs up to Siilinjärvi and Joensuu as illustrated in Figure 3. The total length of the Saimaa deep water route is about 760 kilometers, 255 kilometers of which (33,5 %) is considered difficult to navigate. At Lake Saimaa the navigational challenges are due to the restricted waterways; shallow waters, straits, narrow channels and tight turns combined with the fast currents resulting in limited mistake margins. (Finnish Transport Agency 2015.)

These characteristics complicate also the spill response operations. In places, shallow waters do not allow recovery vessels to operate off the fairway zone. With narrow channels and canals as well as numerous islands and islets, the shoreline is in close proximity to the deep water route - often less than 100 meters away, in some places not more than 50 meters. In case of an oil spill, time for boom deployment to prevent oil washing ashore may be extremely short. Therefore it is noted, that in most areas near to Saimaa deep water route the risk for shoreline contamination is very high. As typical to inland water oil spills (Owens et al. 1993), spill is likely to affect populated areas and contaminate surface and groundwater water supplies.

In Saimaa region accessibility of threatened or contaminated shores may be limited, except for mainland where shoreline can be reached via small cottage roads. Most islands instead are difficult to reach as there are no roads, bridge connections, harbours or other kind of infrastructure and, in most cases, no space for helicopter landing due to dense forests.

The shallow waters and small water volume make the Lake Saimaa highly sensitive to oil pollution. Also cold winters and long periods of ice coverage slow the physical, chemical and biological decomposition of harmful substances (HELCOM 2010). In addition, several environmentally sensitive areas as well as habitats for endangered species are situated close the Saimaa deep-water route. For example, Saimaa is a sole habitat for critically endangered Saimaa ringed seal *(Pusa hispida saimensis)*. (Toivola 2015.) These characteristics necessitates a high-level preparedness with feasible action plans both for incident prevention, response and recovery.

3 RISK FOR SHIPBORNE OIL SPILL AT LAKE SAIMAA

3.1 *Estimated spill volume*

Due to the environmental sensitivity of the Lake Saimaa the transportation of hazardous liquid substances, including oil and oil products, is prohibited. However, as there sails over 1500 vessels a year each of which carrying approximately 50 tonnes of bunker fuel oil, the total volume of oil transported annually exceeds 75 000 cubic meters. Most common bunker oils used are light fuel oils (MGO, MDO) with densities varying from 838,8 to 840,5 kg/m^3 (Heino et al. 2017). Results of the risk analysis indicated that volume of oil likely to spill, resulting from the damages typical to the incident scenarios of the area, is from 20 to 30 cubic meters, vessels in general carrying up to 100 cubic meters fuel oil each (Halonen et al. 2016).

3.2 *Probability of vessel accidents*

Risk assessment, accident probability and spatial distribution were based on the statistical data on incidents occurred between 1978 and 2014 on the Saimaa inland waterways. The nature of accident, position, vessel type, flag state, damages and environmental impacts, if any, were analysed from accident reports.

The results of the risk assessment is based on 116 cases considered relevant, excluding the occupational accidents and accidents of small crafts such as pleasure boats. Figure 1 shows the annual number of ship collisions and groundings within the period of study. As can be seen, accidents occur every year, the average accident frequency being five (5) incidents per year. (Halonen et al. 2016.)

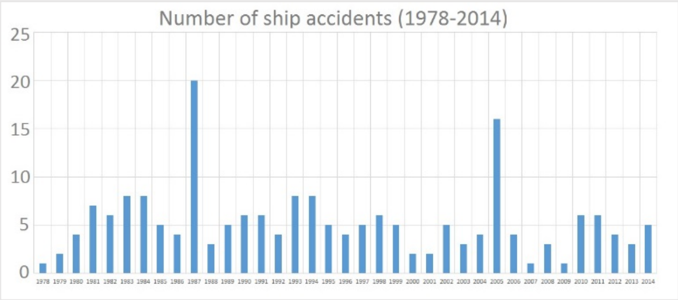

Figure 1. Number of ship accidents in Lake Saimaa between years 1978-2014 (Häkkinen 2016).

When the annual accident frequency was compared to the traffic density of the period, no clear correlation could be found. The causality might rather be derived from circumstantial factors, such as variations in water levels. According to the Finnish Maritime Administration (2007) two peaks in number of accidents seen in Figure 1, are explained by the altered procedures in accident reporting system, the increase of incidents being proportional to the improvement in reporting.

On Saimaa inland waterways, probability of a ship accident varies monthly (See Figure 2). Comparison of the number of incidents and the traffic volumes of each month indicates that the accidental risk is highest during autumn months, in November especially. At that specific time, primary causes reported were related to the prevailing conditions such as restricted visibility due to darkness or snowfall, or manoeuvring failures due to heavy ice conditions or drifted ice channels. (Halonen et al. 2016.)

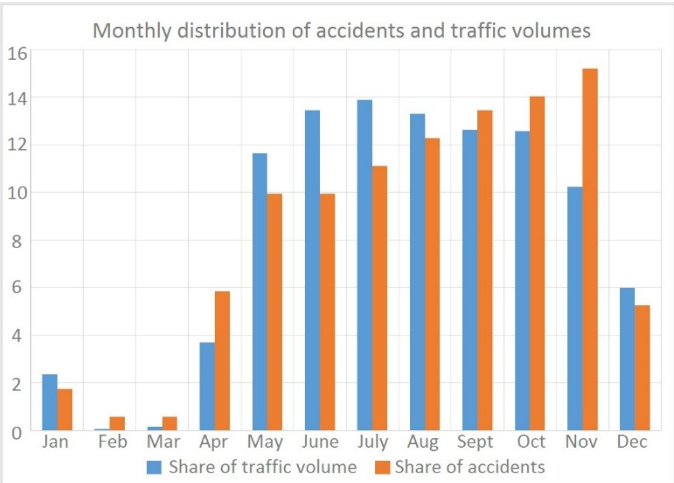

Figure 2. Monthly distribution of accidents in relation to the traffic volume (Häkkinen 2016).

The second highest accidental risk is apparent in April when the annual navigation season in Lake Saimaa and in the Saimaa Canal usually begins (Finnish Transport Agency 2015). At the time, the traffic is hampered by partial ice coverage and the maritime navigational aids displaced or damaged by drifting ice might cause uncertainty to the positioning of the vessel (Halonen et al. 2016). Figure 2 presents the monthly share of traffic volumes (with blue columns) and the monthly share of incidents (with orange columns). As can be seen, the traffic ceases for the most part during the winter months as the Saimaa Canal is closed.

In the accidents of Saimaa deep water route, dry cargo vessels represented 54,1 % of the ship types involved. Majority (69,3 %) of the accidents were groundings, the rest (30,7 %) comprising of collisions. The main collisions types were identified as collisions with bridges (11,5 %), collision with fixed fairway structures and canal locks (7,7 %) and collisions with another ship (3,8 %). The distribution of the accident types have remained same over 40 years period of study, only the collisions with bridges indicating a subtle decreasing trend. (Halonen et al. 2016.)

Based on the severity of the damages and consequences reported, 11,1 % of the accidents resulted in structural damages potential to cause spillage of fuel oil or lubricant oils. Thus, with the prevailing accident frequency, an accident resulting in an oil spill is likely to happen every 1,5 year. It is however worth of noting that no major oil spills have occurred in Saimaa inland waters during the period of the study. (Halonen et al. 2016.)

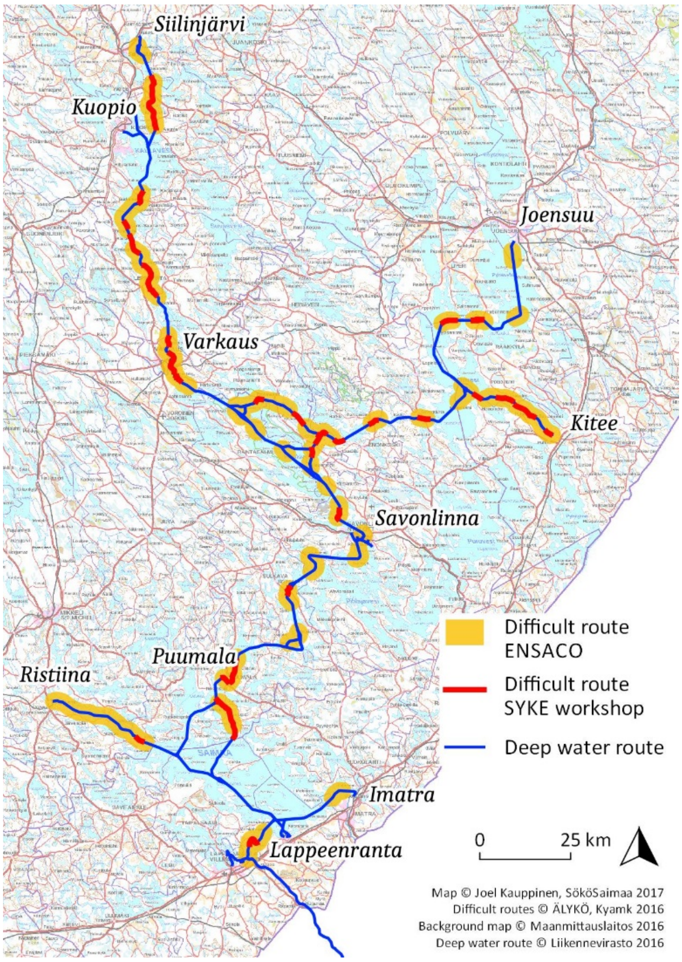

Figure 3. High risk areas of Saimaa inland waterways (Kauppinen 2017).

3.3 *Accident locations*

Geographical information of the incidents reported enabled identification of the most high-risk locations along the Saimaa deep water route. Distribution of incident positions revealed 104 fairway segments where the probability of incident was considered higher. These fairway segments were typically narrow channels or passages with strong current, canals, bridge openings or ferry crossings. Figure 3 provides an overview of the high risk areas of the Saimaa inland waterways. From a total of 116 incidents analysed, half (52,0 %) occurred on these identified risk locations. Figure 4 provides a close-up of one of the high accidental risk locations.

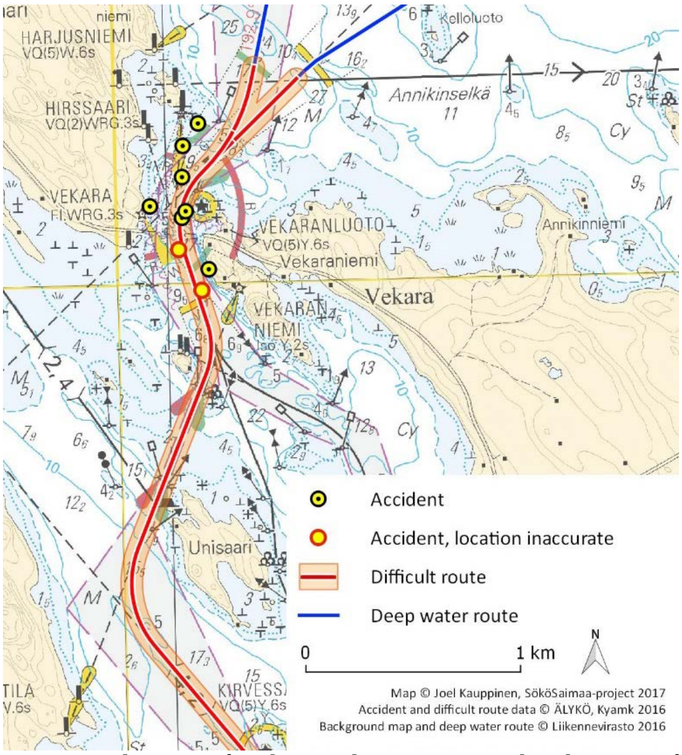

Figure 4. Close-up of Vekaransalmi strait considered as one of the high accidental risk locations in South-Savo region (Kauppinen 2017).

When examining the number of incidents, most (35) occurred in Saimaa Canal in South Carelia, following the Kyrönsalmi strait (18) and Vekaransalmi strait (10) in South Savo. Regarding to the incident frequency in relation to the traffic volumes, the most significant risk locations were i) Ristiina fairway, ii) Konnus Canal, iii) Vihtakanta Canal and iv) Kyrönsalmi strait. (Halonen et al. 2016.)

Due to the low accident rate, relatively few incidents have occurred within the study period, though the timeframe was prolonged to cover the entire duration the statistics in question have been recorded. As the statistical data was limited, it was recognized that expert judgements were needed in order to derive valid conclusions. As Pedersen (2010) states, although the historical data would provide realistic figures, they nevertheless are inadequate to use for future predictions since they are relevant to the ship's structures and navigation equipment of the past, differing from those used today. Alongside with the technical development, the improvements in vessel traffic service, watch keeping and safety protocols, manning requirements etc. have altered, and will alter, the operational environment on inland waters. Thus, the expert advice was of great importance. It allowed identification of such risk locations where no incidents have yet occurred, but which are considered to pose a potential risk.

4 OIL DRIFT MODELS FOR HIGH-RISK LOCATIONS

The route specific probabilities directed the studies on the impacts of a potential oil spill. These studies involve the modelling of the spreading of the oil with estimated spill volumes, and identification of the resources at risk within area likely to be impacted. The impact area was derived from the modelling outcome. Oil drift calculation models were produced for six most significant high-risk locations.

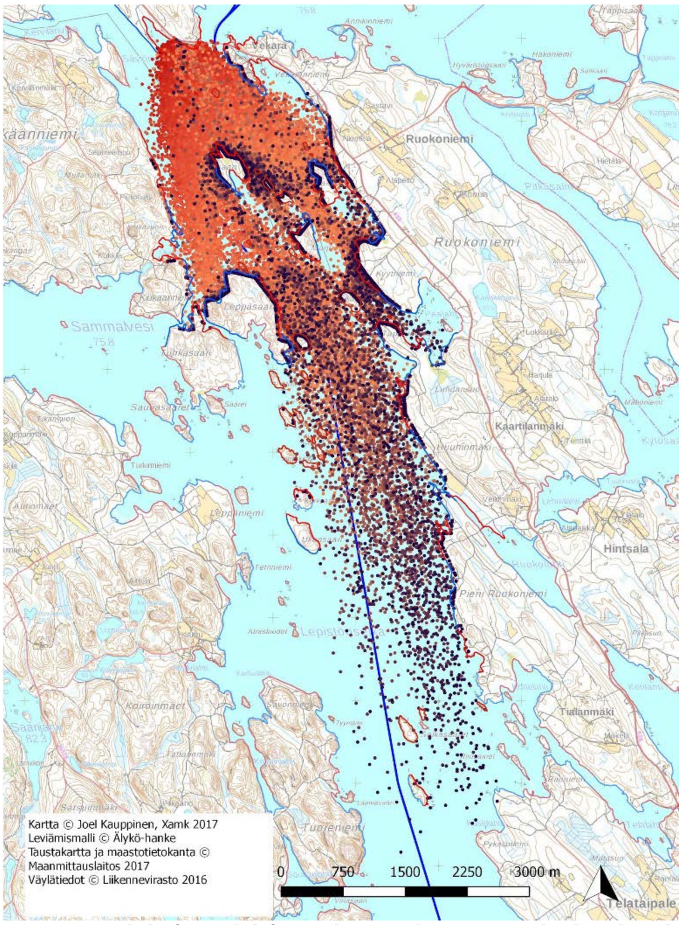

Figure 5. Oil drift model for Vekaransalmi strait calculated with 25 tonnes of light fuel oil (Kauppinen 2017).

An example of the drift calculation model for shipborne spillage of light fuel oil in Vekaransalmi strait is presented in Figure 5, the colors representing the extent of the spreading in given time intervals up to 48 hours. This drift model demonstrated that an oil spill of 25 tonnes by volume is likely to affect eventually over 90 kilometers of shoreline including 100 small islands or islets. Within 48 hours with no intervening actions, oil contaminates 50 kilometers of shoreline (Halonen et al. 2017.)

Drift models were of particular interest as prevailing fast currents are considered dominant factors in determining a response strategy. Together with demonstrating the effects of currents and winds on the oil trajectories (Häkkinen 2016), the drift modelling was used to display the effectiveness of specific, variously timed interventions. As result, the modelling calculations indicated, that the actions of the crew of the vessel involved are considered most effective, and in many cases, a single chance to restrict the oil from spreading. Especially in Lake Saimaa region where, due to long distances, it takes hours the RFRS reaches the incident scene, the response measures of the crew members are of highest importance (Heino et al. 2017). It is therefore recommended that in these particularly sensitive areas, the response capabilities of merchant vessels are improved to higher level than generally required by the SOPEP regulations (Shipboard Oil Pollution Emergency Plan, regulated by IMO).

Based on the drift modelling, amount of spilled oil has a minor effect to the extent of the impacted area. The spreading is more subject to the wind and currents as well as the duration of the leakage, than to the volume spilt. This finding was also supported by the results of modelling marine oil spills (Jolma 2009). Instead, the volume of spilled oil has an influence on the level of shoreline contamination (Jolma 2009; Kauppinen 2014). Figure 6 demonstrates the minor differences in the extent of impact areas resulting from oil spills of two different volume.

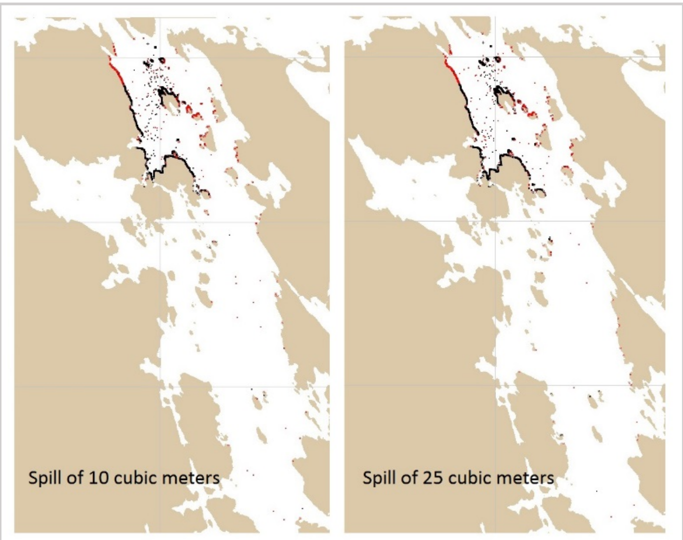

Figure 6. Comparative drift models for 10 to 25 cubic meters oil spills with impact areas of similar extent (Kauppinen 2017).

The modelling enables creation of site-specific, scenario-based contingency plans as the exposed areas and resources at risk can be analysed to direct the response resources accordingly. In addition to site-specific analysis on environmental impacts, the models were used for assessing the optimal access points and other logistical arrangements. These resulted in creation of separate tools, operational maps and maps introducing the vulnerable objects, to be discussed later in this paper.

The outcomes of the drift calculations are presented as oil drift scenarios and the data is included in the national situational awareness system (see Chapter 6) where it can be analysed connected with other spatial data, and used for site-specific planning.

5 PROTECTION PRIORITIES FOR NATURE AREAS AND SPECIES

The specific characteristics of the Lake Saimaa, the several environmental protection areas and numerous vulnerable species, makes the selection of response strategy difficult. One look at the sensitivity map (Toivola 2015) tells, that the entire area is covered with objects having a protection status of some sort. To facilitate the decision situation the response teams will be confronting, these objects, protected areas, sensitive ecosystems, critical habitats, endangered species and key resources considered sensitive to oil spills, are grouped into response priority ranks in order to facilitate establishing protection priorities and response strategy.

Protection prioritisation for the Saimaa nature areas and species is based on the methodology developed in Bothnian Bay oil spill development project (PÖK 2013). For the purpose of prioritisation, data on species and biotopes were mainly collected from the existing data sources, except the data on birds which was assembled from the information collected by the voluntary bird specialists. Saimaa prioritizing work is a synthesis of the efforts of ten environment specialists representing i.a. the ELY Centres and State Forest Enterprise (See Chapter 8).

Main objective of the prioritizing work was to produce viable, easy-to-use tool for oil spill responders. The protection prioritisation offers the response managers opportunity to take into account the vulnerable nature objects and areas when considering the response options. Prioritisation principles, jointly agreed prior an incident, helps resolving the issue of competing priorities in the event of limited protection and clean-up resources. Overall, the prioritisation improves both preparedness and spill response capability as decision making is based on profound analyses.

Prioritisation method bases on the objects' conservation status enhanced with experts judgements on how harmful the oil spill would be to the object in question. The conservation classification used is the International Union for Conservation of Nature (IUCN) scale (Figure 7). If the species is classified into Vulnerable (VU), Near Threatened (NT) and Least Concern (LC) classes, its regional conservation status or certain Natura-status raises the prioritisation a class higher.

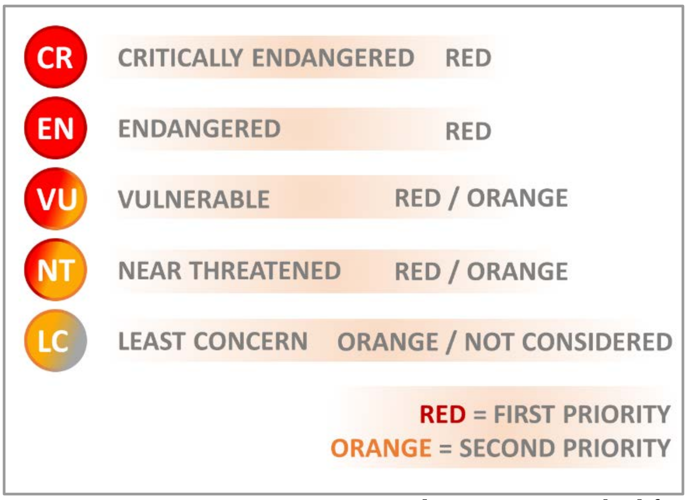

Figure 7. IUCN conservation status and prioritizing method for Saimaa vulnerable nature objects (Kauppinen 2017).

The result of the prioritisation work is a simple two class model. Vulnerable objects are classified after their status into either first or second priority class and visualized accordingly. Figure 8 demonstrates the visualisation of the priority classes. Red objects are considered as first priority and orange objects as second priority. In case of an oil spill, this colour-coded system provides quick and easy visual determination of the protection priority class of the object or the area at risk. The prioritised sensitivity information is integrated into static map series as well as into an interactive web-based situational awareness system (See Chapter 6).

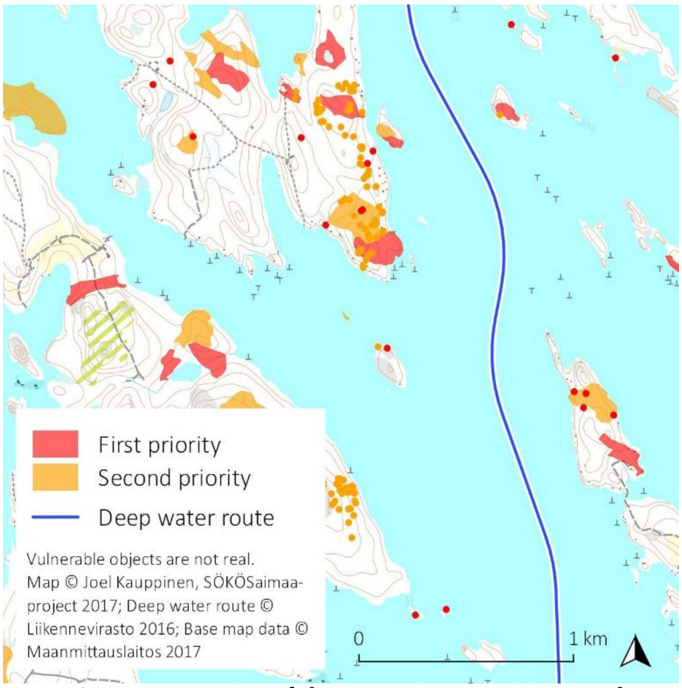

Figure 8. Demonstration of the protection prioritisation classes for sensitive natural resources. Map sample is generated based on fictive data. (Kauppinen 2017)

Protection prioritisation maps were generated as follows. The data was gathered on the area defined with a 1000 meter buffer from the shoreline in order to include vulnerable objects likely to be affected by onshore response operations. The size of the area ended up to be approximately 10 000 square kilometers.

Biotope data included 153 different biotope types in total, 76 types of which were classified as red and 77 types were classified as orange. Biotopes were categorized into groups according to their type and the prioritisation was ranked by groups. The largest groups of biotopes were groves (classified as red) and flood meadows (classified as orange).

Endangered species constituted of 309 prioritized species in total, 144 species of which were ranked into red class and 168 species into orange class. This number of species excludes all birds and Saimaa ringed seal that were analysed separately. In Saimaa area, the Siberian flying squirrel *(Pteromys volans)* is the most common endangered species with over 5700 observations. According to the IUCN-scale Siberian flying squirrel should, as an endangered species, belong to the red class. It was however lowered to the orange class for an oil spill does not affect to the squirrel habitat. A Spring pasqueflower *(Pulsatilla vernalis)* is the second common endangered species in Saimaa region with 225 observations. There are also several other endangered species in the region with a few observations reported.

Saimaa ringed seal *(Pusa hispida saimensis)* was treated separately in the classification process because of its special status as one of the most endangered seal species. Data used for classification included the known nesting and resting spots of the seals. The Saimaa ringed seal is characterized by the breeding site fidelity, and thus the nesting spots are to be protected in order to ensure the nesting success. According to the specialist judgements, i.a. Sipilä (2016), contamination of nesting spots would have serious impacts for the survival of the species. In the classification process the criteria originally developed for analysing the adverse effects of human activity for nesting and resting spots of the seals was applied. In this criterion, most frequently used nesting areas receive the highest scores and rarely used resting areas situated away from nesting areas receive the lowest score. As the result, the scores are given from 1 to 10. All seal nesting or resting places that received four or more scores were classified into red protection prioritisation class, the rest of the places receiving the orange status.

The data on birds was collected from the voluntary bird specialists participating in counting the birds. The data consisted mostly of waterbirds and shorebirds (gulls) and information gaps were filled with data from Finnish important bird areas and Natura-datasets with less precise data quality. Bird datasets when incorporated into map formed large areas in the viewpoint of oil spill response. In protection prioritisation, these areas were left in orange class even though the area would have filled the criterion of the red class in order to maintain equality between objects.

As regards to the fish species, the Grayling *(Thymallus thymallus)* was represented in the data. It is classified as a near threatened species (NT, visualised as orange line) in Lake Saimaa (Rassi et al. 2010). Typical habitats for Graylings are shoals where they are known to live or go for spawn.

Analysis of the sensitive areas indicate that 2432 shore segments, with shoreline length of 1584 kilometers in total, possess nature objects vulnerable to oil spills (not including birds and Grayling). Over 13 % of these shores (327 segments with shoreline length of 206 kilometers) locate within one kilometer radius from the high-risk fairway sections. Regarding to the potential environmental impacts, severe consequences are more likely in Tappuvirta fairway where distinctly more nature objects are situated within one kilometer radius of the route.

Most challenging aspect with this straightforward method of prioritisation was to reach results equal between specific resources such as different species and biotopes. Other remarkable defect found was the data's reliability and lacking coverage in some areas. As directed by Finnish legislation, the data on vulnerable biotopes and species was classified as confidential official documents (Act on the Openness of Government Activities 621/1999).

6 MAP AND GIS TOOLS

The project produced three series of static maps. The first map set illustrates ship accidents on high risk routes (See Figure 4) inserted on nautical chart including fairway zones, aids to navigation and water depths facilitating the analyzation of route-dependent reasons making each route risky. These *Risk Maps* are used for planning and training purposes, as well as for risk prevention.

The second set of maps created are called *Operational Maps* providing shoreline segmentation and logistics data, like locations of temporary storage sites for oily wastes. Map sets for each of four RFRS regions are produced on terrain maps and on nautical charts with similar operational elements. Map set covering the whole area includes 588 map sheets, index pages and legend, accompanied with data sheets for 157 transport and storage points with detailed information, pictures and aerial photographs. These maps are meant for use during an incident response as well as for contingency planning.

The third set of maps identifies sensitive environmental resources, vulnerable species and nature areas. These *Prioritisation Maps* provide all objects within the area with protection priority class together with similar shoreline information than the operational maps. Prioritisation map set includes 178 map sheets, index and legend pages. These maps are used by the response managers to define the priorities for protection and to select response tactics.

Response tools developed are compatible with the existing operational systems of response authorities to ensure the feasibility and durability of the outputs. Produced GIS-data is available through national situation awareness system BORIS 2.0 developed by SYKE. BORIS, acronym from words Baltic Oil Response Information System, is a web based geographic information system for spill response planning and data storage (SYKE 2017). The system allows user to combine several data layers to e.g. study relations between high-risk fairways, spill trajectories and vulnerable resources, and offers an access to additional, more specific information than the static maps can provide.

7 CONCLUSIONS

Lake Saimaa is a unique combination of sensitive freshwater environment, heavy vessel traffic and shallow waters with seasonal variations such as cold climate and ice coverage. Risk for shoreline oil contamination is high and several high-risk fairway sections situate near shores with vulnerable nature objects causing significant risk for the environment. Saimaa deep water route is proven difficult to navigate due to its narrowness and fast currents. It is recognized that the probability of ship accidents is relatively high in the Saimaa watercourse. Ship incidents are reported every year, yet no large scale oil spills have occurred. Since the risk cannot be entirely eliminated it is important to get prepared for response operation to ensure the consequences are minimized. As large parts of the Saimaa waterbody are too shallow for oil spill response vessels to operate and long distances hamper the effectiveness of immediate response measures, abilities of merchant vessel crews to limit the spreading of the oil should be supported. Self-sufficiency of merchant fleet, by providing oil booms and sorbent material onboard, is recommended in order to widen the window of opportunity for effective response.

The project results, described in this paper, serve as practical tools contributing to the scenario-based site-specific contingency planning. Easy-to-use decision support tools, such as response priority ranks represented with colour codes and guidelines introducing preferred response methods for various freshwater habitats and shoreline types, facilitate establishing response strategy. Results are compiled into an inland oil spill response manual, which will be published as a web based application.

As the project is underway, there is still many subjects to develop and further studies are needed. As the risk analysis presented in this paper is based on estimations derived from statistical data and expert knowledge, there is need to elaborate these assessments with mathematical modelling. Also the studies on environmental impacts of an oil spill need to be extended to cover socio-economic impacts.

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The inland oil spill response management model is a joint effort of the project working group comprised of the designated spill response specialists representing the above mentioned rescue services together with the Finnish Transport Agency, the Emergency Service College, the Finnish Environment Institute and the Centres for Economic Development, Transport and the Environment of South Savo, North Savo, North Karelia and Southeast Finland (ELY Centres).

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