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The ecological effects of oil spills in the Baltic Sea – the national action plan of Finland

Heta Rousi and Harri Kankaanpää (Eds.)

Finnish Environment Institute

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TO THE READER

The intended readership of this action plan comprises researchers and authorities participating in the oil spill impact assessments in Finland, in general, and those responsible for initiating this action, in particular. This action plan may also find use as a source of information on the known impacts of mineral oils as well as guidelines on how to organise ecological impact studies. In this action plan, the term "oil spill" is used to refer to intentional and unintentional mineral oil spills into the sea.

This action plan shall be applied in situations where the risks presented by an oil spill to the marine environment are determined to be significant by the Finnish environmental authority (the Finnish Environment Institute SYKE). Such incidents typically involve the release of several tens, hundreds if not thousands of cubic metres of oil into the sea, or situations where the environment at risk is particularly vulnerable to the impacts of oil spills. The decision to implement this action plan is based on a case-by-case assessment by the unit responsible for environmental damage prevention in collaboration with the person in charge of the ecological action plan presented here. The parties mentioned in this action plan have made a verbal commitment to follow these guidelines.

Section B describes the practical procedures in case of a major oil spill.

In Helsinki on March 15th, 2012

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SECTION A

1 Introduction

Heta Rousi, Heli Haapasaari, Harri Kankaanpää

In spring 2011, the Finnish Environment Institute SYKE and Finland's environmental administration YM initiated a project to prepare a national research and action plan on the ecological impacts of oil in Finland's sea areas. The primary focus of the action plan is preparedness for possible oil spills. The incentive to prepare the plan came from the Helsinki Commission (HELCOM) Recommendation 12/9 (visit: http://www.helcom.fi/Recommendations/en_GB/rec12_9/). In accordance with the HELCOM Recommendation, the plan comprises a survey plan and follow-up survey and includes the following five sections: (1) organization of research work, (2) physical and chemical studies, (3) ecological studies, (4) fishery studies, and (5) documentation (this last section, documentation, will not be discussed in detail within the scope of this publication as each ÖVA organisation is responsible for separately reporting their respective study results, and all reported results will then be included in the final report).

The action plan for major accidents and disasters published by the Ministry of the Interior (2008) states that the level of preparedness in case of offshore oil spills caused by vessels must be improved. Finland's preparedness for oil response actions is good, but not sufficient. In addition to developing adequate response methods, preparedness includes planning research on the impacts of oil on the ecosystem on a national level. A large proportion of the annual 2,000 oil spills in Finland are small spills occurring on land.

Approximately 150 million tonnes of oil is transported annually over the Gulf of Finland. In the near future, this amount is expected to increase to over 260 million tonnes when the Russian oil terminal and pipe projects are completed. Typically, oil spills caused by vessels involve the vessel's own fuel entering the sea as a result of an accident. Following such an accident, oil response equipment is employed to prevent any additional incidents and to recover oil floating on the surface before it pollutes the shoreline.

Based on the effects of the tanker Antonio Gramsci's accident in the early spring of 1979 in Ventspils, Latvia, an ecological oil research and recovery plan was prepared in Finland for oil spill investigations. While the plan contains valuable information, some parts, such as the sections regarding organisation structures and research methods, in particular, are outdated. With the development of research methods, our understanding of oil and its behaviour in the environment and the sensitivity and responses of the ecosystem has improved.

Oil slick on rocks (Photo: Jouko Pirttijärvi/SYKE).

2 Authors of the plan and members of the standing group

Heta Rousi, Harri Kankaanpää, Heli Haapasaari

A group comprising Finnish experts was established to prepare the action plan on the ecological impacts of oil spills in the Baltic Sea. The core group comprised researchers and authorities from various organisations including: the Finnish Environment Institute SYKE (in charge), Finland's environmental administration YM (monitoring the preparation), the Finnish Game and Fisheries Research Institute (RKTL), the Finnish Food Safety Authority Evira, the University of Helsinki (HY), Åbo Akademi University (ÅA), and the National Bureau of Investigation (NBI).

The Research Group Focusing on the Ecological Impacts of Oil (the **ÖVA Group**) comprises the parties involved in the actual assessment of the ecological impacts of oil: SYKE, RKTL, Evira, HY and ÅA. The ÖVA Group is in charge of all activities related to investigating the ecological impacts of oil (the **ÖVA operations**).

In case of an oil spill, the ÖVA Group co-operates with several stakeholders including parties responsible for the upkeep of vessels and analysis, sampling and field experts. Collaborative parties regarding vessels include the Finnish Border Guard, the Finnish Navy, the Rescue Departments, the Finnish Lifeboat Institution (SAR), the University of Helsinki (Tvärminne Zoological Station), and the Finnish Environment Institute SYKE (research vessels Muikku and Aranda). For sampling and field expertise, the core group contacts the WWF representative and the field experts of SYKE and the state forest administration Metsähallitus. Partners in the analysis procedures include the SYKE Laboratory, MetropoliLab (and other possible suppliers) and the Forensics Laboratory of the NBI which provides the ÖVA Group with information on the chemical composition of the oil.

The below chart describes the overall collaboration principles between various authorities in case of an oil spill (Figure 1). The chart also refers to response actions, although these are outside the scope of this plan. **An exact model of ecological impact research is described in Sections 4. and 4.1. (Figures 3, 4 and 5).** Step-by-step instructions are shown in Figure 3, and Figures 4 and 5 give an overview of the ÖVA operations in case of an oil spill.

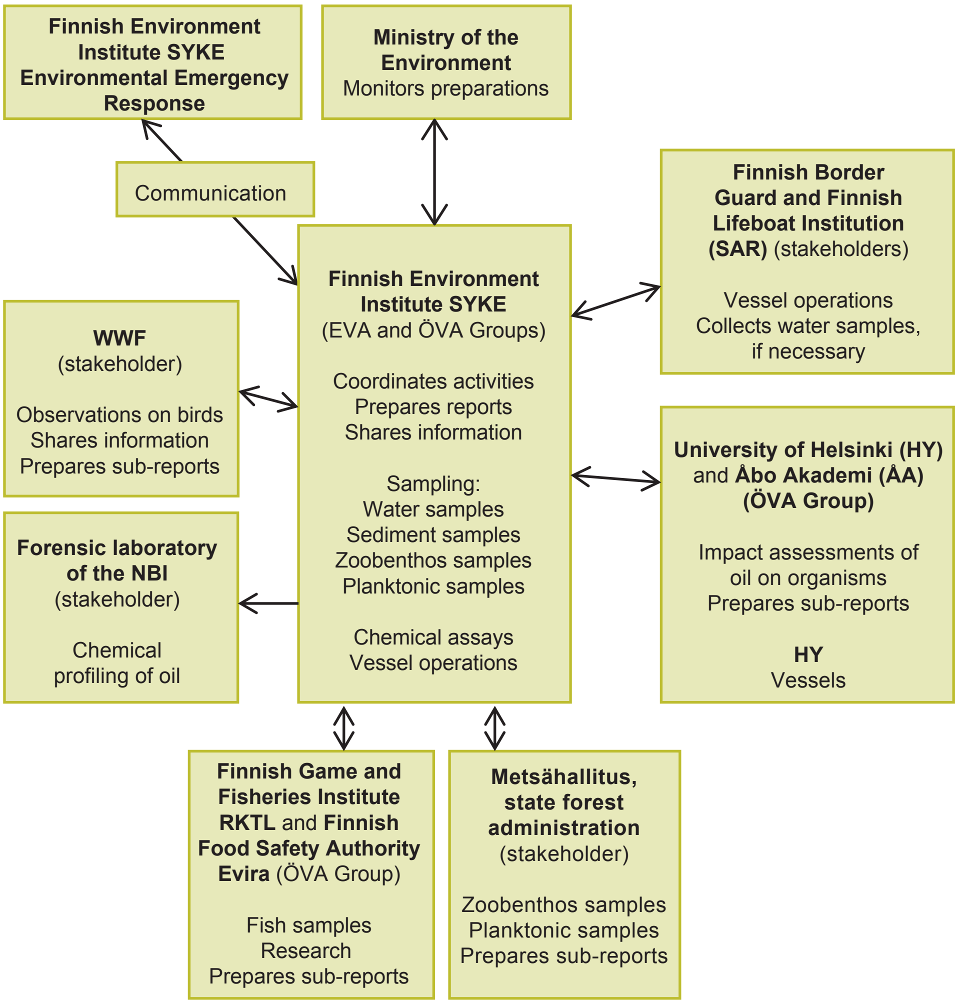


Figure 1. Members of the ÖVA Group, stakeholders and responsibilities (ÖVA Group = the entire oil impact research group; EVA = SYKE's internal standing group responsible for ÖVA operations).

3 Background information

3.1

Vulnerability of the Baltic Sea to oil spills

Heta Rousi, Heli Haapasaari

Due to its characteristics (brackish waters, climate conditions, closed inland sea / slow water exchange, fractal coastline, unique populations) the Baltic Sea has been classified as a particularly sensitive sea area, and oil pollution is likely to have a negative impact on the sensitive ecosystem of the Baltic Sea. The Finnish environmental protection act on shipping (Finnish Act 1672/2009) prohibits the release of oil and oil-containing substances to the sea. The Baltic Sea's brackish conditions present a challenging environment for many species, and seafloor ecosystems in the open sea, in particular, are populated by few species. The existing organisms provide the ecosystem with its buffering ability, and in communities where the number of species is low, the loss of just one vitally important species may in effect cause the whole ecosystem to change.

Furthermore, as the coastline of the Baltic Sea is fragmented, several hundreds of kilometres of coastline may be polluted as a result of a large-scale oil spill unless the spilled oil is recovered in the open sea before it reaches the shoreline.

3.2

Consequences of oil spills

Heta Rousi, Erkki Leppäkoski, Riikka Venesjärvi

This section provides descriptions of previous oil spills and their effects in the Baltic Sea.

In May 1969, the tanker Palva ran aground in the Kökär Archipelago in southwest Finland. In the accident, 120 to 150 tonnes of Russian crude oil was released into the sea, eventually spreading to cover an area of 200 square kilometres (Leppäkoski 1973). Rocky shores, susceptibility to heavy seas, and strong currents facilitated the spread of the oil (Mustonen and Tulkki 1972). Oil traces were also detected in sediments. Due to the oil spill and the chemical recovery operations, some crustacean species temporarily disappeared from the area. Immediately following the oil spill, fish and littoral species were found dead (Pelkonen and Tulkki 1972). Approximately 25% to 33% of the breeding common eider population (*Somateria mollisima*) were killed in the polluted area in 1969 (Soikkeli & Virtanen 1972). The ecosystem of the Kökär archipelago recovered from the Palva accident relatively rapidly (Pelkonen & Tulkki 1972). Although the spill area remained unchanged one year after the accident, the amount of oil was found to have diminished. However, due to the limited scope of the investigations it is likely that not all long-term effects and effects on living organisms were detected (Mustonen & Tulkki 1972).

In October 1977, the tanker Tsesis grounded in the archipelago off Södertälje, Sweden. Over the next few days, approximately 1,100 tonnes of fuel oil was released into the sea, and approximately 400 tonnes remained in the archipelago after the recovery operations (Lindén 1979). The impacts of the oil spill on the ecosystem were severe. Sedimentation of the oil (deposition on the seafloor) occurred rapidly, and the benthos, in particular, was heavily affected. The clam *Macoma balthica* demonstrated highly elevated petroleum hydrocarbon levels (Elmgren et al. 1979). In the mussel *Mytilus trossulus*, formation of byssus (threads used by the mussel for surface attachment) was reduced (Lindén and Foberg 1979). Additionally, the oil severely affected the benthos of the bladderwrack (*Fucus* spp.) zone (Notini 1979). The recovery period for the total area was estimated at two to three years (Lindén et al. 1979), although petroleum hydrocarbons originating from the accident and deposited on the seafloor may have continued to have sublethal long-term effects on the organisms in the area.

In February 1979, the tanker Antonio Gramsci grounded off the Latvian coast releasing 5,000 to 6,000 tonnes of crude oil into the sea. The oil drifted in the Baltic Sea for two to three months before reaching the Stockholm and Åland archipelagos. Due to the season, the weather conditions and favourable winds, a major oil disaster was avoided (Pfister 1980). Additionally, prolonged weathering of the oil reduced its harmful effects. The drifting oil slick clearly affected the littoral benthos (Bonsdorff 1980) and aquatic plants (Suomalainen 1980). Deformations detected among fry were most likely caused by petroleum hydrocarbons (Parmanne and Axell 1980). In Lågskär, the oil caused considerable damage to the common eiders (*Somateria mollisima*) which had begun breeding in early April. The grey seal population (*Halichoerus grypus*) avoided the effects of the oil as in the spring of 1979 pupping occurred east of the spill area, near the entrance to the Gulf of Finland (Stenman 1980). Petroleum hydrocarbons remained in the sea and the sediment layers, and petroleum constituents accumulated in the ecosystem, possibly causing sublethal long-term impacts.

In August 1984, the tanker Eira grounded in the Quark in the Gulf of Bothnia. Approximately 200 tonnes of heavy fuel oil was released into the sea, spreading to cover 1,500 square kilometres of sea and coast, mainly on the Finnish side of the Quark (Nyman et al. 1987). The impacts of the oil on the ecosystem were detected over a considerably larger area than the visible spill area. Oil response operations failed due to storm conditions and an insufficient number of booms. Following the oil spill, small amounts of petroleum hydrocarbons originating from Eira were found in sediment samples and, in the autumn, the *Macoma balthica* clam population accumulated high levels of hydrocarbon compounds (Nyman et al. 1987). Whitefish (*Coregonus lavaretus*) and Baltic herring (*Clupea harengus membras*) temporarily left the area, and deformations were detected in the planktonic fry of herring and *Gobiidae*, which were also exceptionally small in size (Hudd et al. 1987). Furthermore, the oil also directly affected the sea birds in the area (Pahtamaa et al. 1987). Birds in weak condition attracted white-tailed eagles (*Haliaeetus albicilla*) which suffered from the impacts of swallowing oil. Studies show that the environmental impacts of the oil spill were smaller than anticipated, although the long-term impacts could not be determined during the three-year research period (Koivusaari 1987).

The tanker Antonio Gramsci grounded a second time in February 1987, this time near the Porvoo lighthouse in the Gulf of Finland. Around 570 tonnes of crude oil was released into the sea, affecting, for example, local fish catches by polluting salmon hoop nets. Bird communities in the area suffered only minor damage, as the oil drifted towards the opposite shore.

The grounding of the oil tanker Exxon Valdez in arctic waters in March 1989 was one of the biggest ocean oil spills in history and one of the world's most devastating oil spills. The Exxon Valdez struck Prince William Sound's Bligh Reef in Alaska, an area with a similar climate to that of the Baltic Sea, although the biotic and abiotic environments differ due to salinity and tides.

In the Exxon Valdez oil spill, approximately 42,000 cubic metres of crude oil was released into the ocean, polluting at least 1,990 kilometres of natural littoral ecosystem (Peterson et al. 2003). The oil spill caused massive mortality among the ocean animals of the region. An estimated 250,000 seabirds, 1,800 sea otters (*Enhydra lutris*) and 300 common seals (*Phoca vitulina*) died immediately after the accident. In addition to the immediate deaths, the accident caused sublethal long-term changes in the ecosystem, developing over decades and manifesting in various species including fish, sea otters and birds as deformations, disrupted reproduction and increased likelihood of becoming prey (Peterson et al. 2003). The collapse of pink salmon (*Oncorhynchus gorbuscha*) and Pacific herring (*Clupea pallasii*) populations caused economical damage to the local professional fishers.

3.3

Detection and preliminary investigation of oil spills

Niina Viitala, Heli Haapasaari

When oil enters the sea it begins to spread, forming a thin layer on the water surface which drifts with the currents and wind. When an oil spill occurs, the vital information needed to initiate an effective response action includes, firstly, accurate and up-to-date details on the extent of the oil slick and, secondly, the location of its thickest layers. The spill status is determined by gathering information from a number of different sources. The key role, however, is played by the Finnish Border Guard's Dornier surveillance aircraft fitted with specialised environmental monitoring equipment capable of detecting oil slicks as far as 20 nautical miles from the aircraft's flight path. Importantly, the spill monitoring equipment also enables oil slick detection in bad weather conditions and at night. The Finnish Border Guard's helicopter fleet and satellite images can be used as additional sources of information when determining the extent and location of oil slicks. Oil spill response vessels typically carry equipment that can be used to determine the extent of the oil slick. However, the operating radius of such equipment is limited and thus, they cannot be successfully used to determine the total polluted area in the event of large-scale spills.

The Finnish Border Guard aircraft also play a central role in detecting, sampling and investigating smaller marine oil spills. Furthermore, the Finnish Border Guard is entitled to impose an administrative oil pollution fee on vessels discharging mineral oil inside the perimeter of the Finnish exclusive economic zone. The fee is calculated based on the vessel's gross tonnage and spill volume according to the table attached to Finland's Marine Environmental Protection Act. Preliminary investigations of oil spills caused by vessels are conducted centrally by the West Finland Coast Guard, based in Turku.

Before an administrative oil pollution fee can be imposed, it must be confirmed that the oil discharged into the sea is mineral oil. Oil samples are analysed in the Forensics Laboratory of the NBI to determine the type of oil discharged – light or heavy fuel oil, lubricating oil derived from crude oil, synthetic lubricating oil, vegetable oil, etc.

A preliminary investigation is conducted to identify the suspected source of an oil spill. The intent of the offence (i.e. whether the oil spill was intentional or accidental) is an important aspect of the preliminary investigation. Forensic techniques are employed to identify the source of the spill. The Finnish Border Guard or the police collects oil samples from the sea and from the possible sources and delivers the samples to the Forensics Laboratory of the NBI. The laboratory runs analyses to determine the oil type and whether the samples collected from the environment match the samples collected from the suspected source of the oil spill.

Sampling must not be delayed, as the oil composition changes continuously due to multiple environmental factors.

In the case of an oil spill caused by a vessel, the essential information required to initiate a rapid response action includes, firstly, the physical properties and type of oil (density, viscosity, congealing point, water content, paraffin content) and, secondly, how it will behave in water (weathering, emulsification, evaporation, changes in viscosity).

Samples collected from the tanks of the vessel responsible for the discharge are stored in controlled conditions.

If spilled oil reaches the shoreline polluting beaches, property and facilities, it may be necessary to analyse samples collected from the vessel and compare them with samples collected from the polluted areas. These results may be useful if claims for damages are filed.

In large-scale oil spills caused by a vessel, the quality of the oil spill (its chemical composition) will be made available to the ÖVA Group after the preliminary investigation.

Oil leaking from a tanker (Photo: Jouko Pirttijärvi/SYKE).

3.4

Oil surveillance and PAH accumulation in the Baltic Sea

Harri Kankaanpää, Kaarina Lukkari

In Finland, the SYKE Marine Research Centre is responsible for monitoring oil concentrations in the open waters of the Baltic Sea. The target matrix is the sea surface. The total oil concentration and concentrations of separate substances of petroleum origin are not monitored in other layers. The earliest observations of petroleum hydrocarbons in the surface seawater date back to 1977. Observations in the 1970s and 80s were made primarily in spring or summer, but since the 1990s, surface seawater oil levels have been monitored also in winter. The measurements are carried out using an accredited method based on an Intergovernmental Oceanographic Commission (IOC) protocol whereby hydrocarbons are extracted from the seawater into hexane and the fluorescence in the hexane extracts is measured at wavelengths typical for crude oil. This simple, sensitive and cost-effective method renders the dissolved and degraded total oil concentration in the seawater. The method does not reveal which polycyclic aromatic hydrocarbons are emitting the measured fluorescence. In optimal situations, the results gained with this method are reviewed in parallel with the measurement results from aromatic hydrocarbons in seawater analysed separately.

Studies show that the concentration of hydrocarbons in Baltic Sea surface water is higher in winter than in summer. This can be attributed to the fact that warmer temperatures with more sunlight contribute to the degradation, evaporation and microbiological decomposition of petroleum hydrocarbons (Pikkarainen and Lemponen 2005). Over the last few years, the total oil concentration in Baltic subsurface water has been very low (0.1-0.3 $\mu g\ l^{-1}$) during the summer season. During winters, the corresponding concentrations have been higher (0.4-0.8 $\mu g\ l^{-1}$). However, the margin of error in winter-time observations is smaller, rendering them more reliable than observations made in the summer season. Oil concentrations vary over time in analogy with nutrient concentrations – concentrations observed in the winter season best describe the development of oil concentrations. Consequently, the relative proportion of oil concentration observations made in winter is likely to increase in the future.

No HELCOM surveillance data is available on the Finnish coastline, although the network of open sea data collection stations used covers an extensive area of the Baltic Sea, excluding the sea area south of Gotland. In general, total oil concentrations in subsurface water are currently (in 2012) low. According to the International Oil Commission (IOC), the contamination limit is 1.0 $\mu g\ l^{-1}$, while the concentrations in the Baltic Sea have decreased notably since the peak results measured in the 1970s and 1980s (Kankaanpää 2008). The decreasing trend is also visible in the oil concentrations measured between the 1990s and 2010s. Visible regional differences have also been detected in the oil concentrations of seawater – in the Bay of Bothnia and the Bothnian Sea, for example, the observed concentrations are clearly lower compared with concentrations measured in the Gulf of Finland and the Baltic Sea Proper (Pikkarainen & Lemponen 2005). The differences in initial baseline concentrations should be considered when drawing conclusions on the elevated concentrations in the seawater as a result of an oil spill.

It is recommended to apply the above-mentioned fluorescence-based method when monitoring oil concentrations following an oil spill. The method provides valuable data on the oil spread (situation status). This data may also be useful when attempting to define the focus of impact studies. However, use of this method for determining the oil slick area is not recommended. Due to the difficult conditions and elevated risk of contamination, the rendered results would mainly reveal the fluorescence of the surface oil and nothing about the oil concentration in the seawater.

In the HELCOM COMBINE programme, the protocol is only applied when studying surface seawater samples. However, the method can also offer valuable additional information on how deep into the water column the petroleum hydrocarbons have penetrated. Because the method is sensitive, obtaining an overall picture of the distribution of oil in seawater is easier than with chromatographic methods. For example, gas chromatography/mass spectrometry based analyses may render selective compound details, but the sensitivity of the method is not sufficient for analysing petroleum hydrocarbons in seawater. In earlier studies, the quantification of PAHs in seawater samples was difficult using the above mentioned GC/MS method, although the oil surveillance method gave explicit results. Hence, it is recommended that objects and matrices are always studied using the most suitable methods.

In the event of an oil spill, determining the distribution of the oil comes under the ÖVA operations. Due to the characteristics of this procedure, the focus of the investigation is on areas where an oil slick or visible oil film on the water surface is no longer present. The objective is to document the dissolution and spread of oil a) at and beyond the perimeter of the main affected area and b) inside the main affected area once the oil slick or significant amounts of oil are no longer present. Sampling should be extended from surface seawater to subsurface layers. These actions help to obtain data on long-term ecological impacts.

3.5

The composition, properties and weathering of oil

Kaarina Lukkari, Niina Viitala, Kirsten Jørgensen

The chemical composition of crude oil is complex and varied, consisting of thousands of chemical compounds. The crude oil composition depends on the quality of its source material and the conditions, such as temperature and pressure, prevailing when the oil was formed. The key compounds of crude oil include n-alkanes, isoalkanes and cycloalkanes, aromatic hydrocarbons, resins and asphaltenes. Those with the lowest molecular weight are the fastest to vaporise, dissolve and degrade. For example, according to one estimate regarding the Exxon Valdez oil spill, 35% of the 42,000 cubic metres of crude oil spilled into the ocean vaporised. When crude oil is refined its chemical composition is altered, which in turn affects its properties. For example, the lighter fractions separated from crude oil are more readily dissolved, vaporised and degraded.

The various compounds in oil and the chemical properties of their functional groups affect the reactivity, behaviour, bonding, accumulation and migration of oil, and therefore also the toxicity of petroleum compounds in the marine environment. Based on functional groups, various compounds can be isolated from crude oil including phenolic, quinoline, indole, thiophenic, carbazole, carboxylic acid, porphyrin, ketone, furan and acetate compounds. Crude oil containing large, heavy hydrocarbon molecules does not dissolve readily in water. However, crude oil also contains polar compounds containing nitrogen (N), sulphur (S) or oxygen (O) in various functional groups. Increased polarity in connection with oxidisation, for example, improves the water-solubility of some hydrocarbons.

When oil enters the sea, its chemical and physical properties begin to change. The oil initially spreads on the water surface forming a thin film. Some of the oil compounds evaporate, some dissolve in the water and some form emulsions or congeal into tar balls. Large waves may contribute to oil becoming mixed into the water column. Oil may also form micelles, i.e. small droplets containing oil. Micelles were detected after the Deepwater Horizon oil spill at Macondo in the Gulf of Mexico in 2010. Oil can also form dense slicks, either on the water surface or suspended in the water column. Some petroleum hydrocarbons disintegrate by means of photolysis or become absorbed into particulate matter. Aggregates and oil slicks may also sink and be deposited on the seafloor (sedimentation). The viscosity and behaviour of the oil is greatly affected by temperature. High temperatures accelerate the vaporisation, dissolution and biodegradation of the oil compounds. Petroleum hydrocarbons suspended in the water column are exposed to biodegradation (decomposition by micro-organism) and weathering. Compounds which have sunk to the bottom and into the sedimentation layers also undergo weathering.

Aerial view of lifting of JANRA frighter in the Åland waters in 2001 (Photo: Finnish Border Guard)

3.6

Sedimentation of petroleum hydrocarbons

Kaarina Lukkari, Harri Kankaanpää

A proportion of the petroleum hydrocarbon concentrations detected in the marine environment originate from airborne pollution and land-based sources. The hydrocarbon concentrations of seafloor sediments, for example, depend largely on the proximity to urban and industrialized centres, with concentrations tending to decrease with increased distance from urban areas.

When oil enters water, it typically floats on the surface, spreading to form a film. However, the viscosity and density of different oil types vary. Heavier fractions sink in the water column, eventually depositing on the seafloor variably over time. In addition to the properties of the oil type, the time it takes for oil to sink also depends on environmental factors such as the water density (salinity) and particulate matter and the wind speed, waves and currents, which may promote the mixing and breaking up of the oil in the water, or contribute to the surface migration of floating oil.

The distribution of petroleum compounds between particulate matter and seawater depends on the particular compound. If the oil spill occurs before the peak bloom of phytoplankton (and the sedimentation periods that follow shortly after), petroleum compounds sink to the seafloor relatively rapidly. In the Baltic Sea, the sedimentation of organic matter peaks after the diatom spring bloom, at which time the amount of oil sinking to the seafloor will be greater compared to an oil spill occurring after this sedimentation peak. The concentration of organic matter in the water body increases with blooming algae. After the blooming subsides, organic matter sinks to the bottom taking with it any absorbed petroleum hydrocarbons (Kowalewska and Konat 1997). Sedimentation of petroleum hydrocarbons via dead organisms is also possible by means of organisms consuming compounds from the water along with nutrients. Following blooming, the majority of sedimented matter reaches the seafloor in 1 to 3 weeks.

It has been estimated that the deposition rate of organic matter has increased due to eutrophication (Jonsson and Carman 1994, Emeis et el. 2000). Analogously, the deposition rate of oil on the seafloor is likely to increase. The accumulation of petroleum hydrocarbons in organic matter affects their migration with the currents from one area to the next. Organic matter is lighter than coarse mineral substances and sinks slowly in the water column. Hence, organic matter migrates further from its origin before being deposited on the seafloor. The area covered by hydrocarbon-contaminated particulate deposition is thus likely to be significantly larger than the oil slick or the area of the oil spill. Over the years, currents can cause contaminated material to migrate even further from the original spill location. Additionally, the fine organic material topping the sediment is easily mixed back into the water column when, for example, the benthos or fish in search of food disturb the sediment surface. The organic matter and any contaminants it carries accumulate in sedimentation areas where the currents are mild enough to allow the fine material to sink to the bottom (e.g. Schulz and Emeis 2000, Witt and Siegel 2000, Witt and Matthäus 2001).

If oil is dispersed into the water as small droplets, its descent is decelerated. However, its migration, vaporisation, biodegradation and chemical degradation are facilitated as the area reacting with the surrounding solution is increased (see, for example, Page et al. 2000). Oil may be dispersed by waves if they are sufficiently large and break sufficiently sharply. Synthetic surfactants added into water or natural surfactants excreted by specific algae may affect the properties of the waves in such a way that their ability to disperse oil is compromised. Heavy seas have an effect on the sedimentation of oil by contributing to the poorly vaporising and dissolving fractions of oil forming an emulsion-like mass with water (see, for example, Li and Garret 1998, Li at al. 2007). Forming dense slicks on the water may facilitate the sinking of the oil in the water column and its sedimentation on the seafloor. Particles suspended in water, including solids (clay particles) introduced into the sea with rivers or originating from the sediment layer, facilitate the accumulation of oil and its sinking in the water column (Sterling et al. 2004).

3.6.1

The effects of oil properties on sedimentation

Kaarina Lukkari, Harri Kankaanpää

In the 1970s, the amount of petroleum hydrocarbons in the sediment surface layer (0 to 5 cm) was estimated at 10 mg/kg dry matter, on average (Dybern and Fonselius 1981). Polycyclic aromatic hydrocarbons (PAHs) composed of four to six rings are stable and persist in the bottom sediments in abundance (Witt and Trost 1999).

In the Baltic Sea, beyond the littoral zone, the concentrations of PAHs in the sludge sediment range between less than 10 to 5,160 µg/kg dry matter (Witt 1995, Witt & Trost 1999, Ricking & Schulz 2002, Pikkarainen 2004). Measured against total organic concentration (TOC), the highest results have ranged between 3,000 and 6,000 µg/kg TOC.

When oil is released into the sea, some of the compounds vaporise and become dispersed before they sink to the bottom. The petroleum hydrocarbons that sediment typically include heavy, slowly decomposing compounds (e.g. Neff 1979). A significant amount of hydrophilic short-chain hydrocarbons vaporise before reaching any ecological niche. In seawater, the hydrophilic groups of hydrocarbons are attracted by the water column while hydrophobic and lipophilic groups tend to accumulate in organic matter (see Neff 1979).

In seawater, the less soluble compounds adhere to solid particles, particularly organic solids, suspended in the water column, which accelerates their sedimentation. The adhesion of aromatic and polyaromatic compounds to solid particles is particularly strong. Long-chain aliphatic hydrocarbons (the most hydrophobic) sediment most effectively and are predominant in oil products. With increased solubility, hydrocarbons attached to solids are more likely to become detached, which not only affects their dispersion but also sedimentation. For example, the polar groups in resins contribute to their adhesion to solid minerals (e.g. Neff 1979).

In general, all harmful compounds contained in oil and oil products adhere effectively to solids and sink to the seafloor. Compared to younger biosynthetic compounds, hydrocarbons derived from fossil fuels typically have a larger proportion of aromatic structures, thus affecting their degradation rate (Ehrhardt and Burns 1999). Compounds slow to degrade and sediment include some PAHs, resins, asphaltenes and alkylated naphthalenes. Adhesion to solids is strongest in poorly soluble petroleum compounds with large-molecule structures which remain attached to bottom sediment. Degradation in the prevailing conditions is slow and they are eventually buried under new sediment layers. Some petroleum hydrocarbons may persist in the sediment for several years (Boehm et al. 1987). The degradation process of oil-derived hydrocarbons is particularly slow in bottom areas where there is little light (as in all areas of the Baltic Sea) and low oxygen concentrations (variable in the Baltic Sea). Some crude oil may reach the seafloor with minimal weathering. In such cases, the sediment oxygen concentration radically changes and the degradation process is slowed further.

3.6.2

The effect of bottom quality on oil accumulation and oxygen consumption by oil

Kaarina Lukkari

In the Baltic Sea, the seafloor topography and the quality of the seafloor solids vary regionally from rock and moraine to sediment with very high levels of organic content. The higher tendency of petroleum hydrocarbons to adhere to organic matter is also reflected in regional variations in sedimentation concentration. For example, PAH concentrations are more pronounced in marine areas where the upper sediment layers comprise high levels of organic material (Pikkarainen 2005). The decomposing process of organic compounds may be faster if the seafloor consists of coarse sand, where the texture and conditions contribute to sediment oxidation and smaller amounts of organic matter further decrease oxygen consumption. On the other hand, sand and clay are typically migrating sediments, from which petroleum hydrocarbons are likely to gradually migrate, either freely or adhered to solids, to depositional basins.

The microbiological degradation of organic compounds demands oxygen. As was revealed in the major Gulf of Mexico 2012 disaster, for example, the microbiological degradation of petroleum hydrocarbons results in decreased oxygen levels (Rabalais 2011). If high levels of degradable oil-derived compounds were to reach the sediment, this might cause a decrease in oxygen levels resulting in hypoxic conditions. A dense oil layer covering the top sediment could further contribute to lowered sediment oxygen levels by preventing the oxygen consumed in the degradation processes from being replaced with oxygen from the water column. Sediment hypoxia affects benthos prevalence and sediment-water nutrient and element exchange fluxes (Mortimer 1941, Rabalais and Turner 2001). For example, hypoxia may promote the release of iron-bound phosphates in the sediment first to interstitial water and eventually to the water column as a result of iron reduction. The released phosphate adds to the excess nutrient load, thus accelerating biodegradation. Reaching the productive water column depths, the additional phosphate would contribute to algae blooms. Conditions promoting reduction may further contribute to harmful metals, for example, being dissolved into the water.

3.7

The chemical and microbiological weathering of oil

Kirsten Jørgensen, Kaarina Lukkari

The ability to degrade petroleum hydrocarbons is common in marine microbes. Bacteria are highly efficient degraders of hydrocarbons, but archaea, fungi, moulds and yeasts also participate in hydrocarbon degradation. Several different bacterial species have the capacity to degrade hydrocarbons with catalytic enzymes, contributing to the gradual biodegradation of oil-derived compounds (Fritsche and Hoffrichter 2005). Bacteria use hydrocarbons as a source of carbon in their own metabolism.

In aerobic conditions, such as seawater and surface sediment, the first step in degrading aliphatic hydrocarbons is mono-terminal oxidation resulting in a primary alcohol, which is rapidly oxidised first to an aldehyde and then to carboxylic acid by another enzyme. Next, the terminal fraction containing two carbon atoms is broken down and metabolised in the bacterial fatty acid metabolism. As a result of this oxidation process, the hydrocarbon molecule is rendered more polar and becomes more water-soluble. When the chain has been fully broken down, the end-products are carbon dioxide and energy.

Mono-oxygenase enzymes oxidise monoaromatic hydrocarbons, such as benzene, xylene and toluene, to catechol, which is a more polar diol with enhanced water solubility. The ring is then cleaved with dioxygenase. PAHs with more than one benzene ring are first oxidised by dioxygenase.

The best known bacterial species with hydrocarbon degradation capacities include the gram negative *Pseudomonas, Burkholderia, Acinetobacter* and *Xanthomonas* and the gram positive *Mycobacterium, Arthrobacter* and *Bacillus*. However, new DNA research methods have revealed several other species that also share this capacity. In seawater, oil has been found to enrich in *Oceanospirillum* (Hazen et al. 2010) and *Thalassolituus* (Yakimov et al. 2004), in particular, which belong to the gamma proteobacteria.

Petroleum hydrocarbons are also degraded in anoxic conditions, although the degradation rate might be down by half compared to aerobic conditions (see Salminen et al. 2004, Björklöf et al. 2008). Degradation pathways in anoxic conditions are more complex, because anaerobic bacteria have other electron acceptors instead of oxygen. In order of energy-efficiency, the electron acceptors include nitrate, iron (III), manganese (VI) and sulphate. Following this, oil-derived hydrocarbons are broken down through fermentation and methanogenesis (Zengler et el. 1999). In anaerobic processes, hydrocarbons are electron donors. Different bacterial groups degrade hydrocarbons using different methods. Some bacterial species are capable of both anaerobic and aerobic degradation. In the sediment, these degradation processes occur in zones – aerobic degradation in the surface sediment, and as the amount of available oxygen gradually decreases in the subsurface sediment nitrate, manganese (VI), iron (III) and sulphate are used (Froelich et al. 1979). Once the electron acceptors are depleted, degradation continues through fermentation and methanogenesis deeper in the sediment.

Petroleum carbohydrates also become more water soluble through anaerobic degradation. A fumarate addition to the petroleum hydrocarbon chain or ring is used as the initial step in several anaerobic catabolic processes of hydrocarbons (Widdel and Rabus 2002). Fumarate is an organic dicarboxylic acid which occurs as an intermediate in normal bacterial metabolism. The enzyme benzylsuccinate synthase is responsible for the addition. Next, the molecule is activated with coenzyme A (CoA) and degraded gradually by several hydrases, dehydrogenases and hydrolases.

Bacteria which have come into contact with oil may start producing and secreting surfactants (surface active agents) to facilitate uptake of hydrocarbons into the bacterial cell. Rhamnolipids are the most common bacterial biosurfactants (Bordoloi and Konwar 2009). Thus, petroleum hydrocarbons are biologically transformed and become accessible to microbes and other organisms.

Lack of nutrients, low water temperatures and a lack of organisms adapted to the degradation of the compounds constituting the oil spilled are factors which may hinder the effective microbiological degradation of petroleum hydrocarbons (Lindstrom et al. 1991, Del'Arco and de França 1999, Kostka et al. 2011). Higher nutrient availability may thus enhance the degradation of petroleum hydrocarbons by microbial organisms. Furthermore, UV light penetrating the water surface promotes the abiotic degradation of some organic compounds. For example, the alkyl substituents in fossil aromatic hydrocarbons are gradually degraded by light which changes the compound structure, solubility and other properties (Ehrhardt & Burns 1999).

Hydrocarbon biodegradation is slowed by a lack of oxygen. Degradation does occur under anoxic conditions, but the rate is much slower compared to oxic conditions. Degradation of petroleum hydrocarbons which are sedimented into the eutrophic anoxic regions may occur at a slower rate compared to degradation in oxic regions (e.g. Pikkarainen 2008). During production highs the water temperature is typically higher, but microbes with the capacity to degrade hydrocarbons must then also compete for nutrients with algae.

Natural hydrocarbons are also produced as a result of biological activity in seawater. However, the structure of biogenic hydrocarbons is typically simpler (e.g. aliphatic compounds with 6 to 40 carbons, saturated, straight chains) (Clark and Blumer 1967, Youngblood and Blumer 1973). The most important task of sediment micro-organisms is to recycle organic matter and nutrients in biochemical processes. This results in carbon dioxide (CO_2) which dissolves to form bicarbonate (HCO_3^-) while releasing soluble nutrients including ammonia (NH_4^+), nitrate (NO_3^-) and phosphate (PO_4^{3-}). In the sediment layer, these inorganic ions may congeal, bind to sediment particles or spread to the aqueous phase. If, after an accident, oil sinks to the sediment, changes in the sediment micro-organisms begin immediately (Kostka et al. 2011). Populations of oil-degrading organisms increase and microbial diversity tends to decrease. Some short-chain aliphatic hydrocarbons and aromatic compounds are toxic to microbes and impair their membranes (Sikkema et al. 1995). However, as these compounds are the first to evaporate from the water surface, it is therefore unlikely that large amounts ever reach the sediment layer. Should sediment bacteria become exposed to toxic petroleum hydrocarbons, the degradation rate of organic matter might be temporarily decreased. However, as oil itself is a carbon source, its degradation contributes to microbial activity and results in an increase in oil-degrading populations.

A high proportion of hydrophobic compounds may slow the degradation rate of sedimented oil, as compounds that adhere to particle surfaces are not as readily accessible for microbiological degradation. On the other hand, studies have shown that fine-grained mineral sediment stimulates bacterial growth and crude oil degradation (Weise et al. 1999). In addition to mineralisation, some microbes have the capacity to transform the poorly soluble petroleum hydrocarbons to more polar and more soluble degradation products, affecting their binding and migration characteristics in the marine environment (e.g. Bock et al. 1994, Brodkorb and Legge 1992).

Cleaning of oil with a bob cat (Photo: Jouko Pirttijärvi/SYKE).

The microbial communities in the Baltic Seawater column have been recently studied using DNA sequencing methods (Herlemann et al. 2011, Koskinen et al. 2011). Studies show that the composition of microbial communities alters with salinity. However, due to the complexity of the microbial communities it is difficult to determine whether these changes are harmful or beneficial considering the microbial main function. Similar background data is currently not available for sediment micro-organisms. Swift changes in microbial communities may occur as a result of changes in the environment. Because taxonomic variation is not directly comparable with functional variety, it is sometimes more useful to focus on changes in specific functional properties, including changes in the genes of oil-degrading enzymes (e.g. genes *alkB*, *xylE* and PAH-RDHα, Salminen et al.2008) and genes coding the primary metabolic route enzymes involved in organic matter degradation. The natural biodegradation of petroleum hydrocarbons is a beneficial phenomenon, and assessing the degradation process and rate of sedimented oil is essential.

3.8

The physiological effects of oil and its active components

Pekka J.Vuorinen, Kari Lehtonen, Heta Rousi, Pirjo Sainio

Petroleum compounds are accumulated by organisms from the sediment, water, vegetation and nutrients. Birds and marine mammals ingest petroleum hydrocarbons when preening or grooming to remove oil from feathers or fur. Due to its northern location, the water in the Baltic Sea is cold during most of the year, and in low temperatures the hydrocarbon secretion capacity is decreased in many organisms as their metabolisms are also slowed. Thus, hydrocarbons persist longer. However, the temperature effect on organism processes is species-dependent (Fossato 1975). In cold waters, recovery from the harmful effects of oil is slower compared to warmer waters (Fossato 1975). Furthermore, oil dissolves more readily in waters with low salinity and in this respect also the Baltic Sea ecosystem is rendered more vulnerable to the harmful effects of oil (Shaw 1977).

Oil released into the sea has both short-term acute and long-term chronic effects on the exposed organisms. Acute effects may be lethal or include behavioural changes immediately following the oil spill when most toxic compounds have not yet vaporised. Chronic effects manifest as changes in vital functions, including disturbances in reproduction and the immune system. Oil spills are thought to have significant impacts on fish and fish populations, although such effects have not been directly proven in field studies. This may be due to a number of reasons (Lindgren and Lindblom 2004). For example, as fish have a high reproductive potential, even small fish populations can be rapidly replenished. It has also been suggested that fish use their sense of smell to avoid oil slicks. Nevertheless, over the nearly two decades of monitoring after the Exxon Valdez spill, the herring population in the region has not yet recovered and salmon populations have recovered only partially.

In the Baltic Sea, marine and freshwater species live at the limit of their adaptation capacity, rendering them highly vulnerable to environmental change. Ideal indicator species for determining the impacts of oil on populations include species for which data from long-term community or population monitoring is available. Other suitable candidates for indicator species include those, such as the invertebrate *Macoma balthica*, which have a long life span and tolerate harmful environmental stress relatively well and, hence, serve as clear indicators of stress factors.

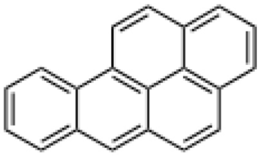
To measure the impact of oil on organisms, it is necessary to first define a reference area outside the oil spill's affected area as well as the impact assessment area itself. Another approach is to compare ecosystem oil concentrations and health before and after the oil spill. Isolating the impact of each factor on an organism is difficult. Therefore, it is recommended that several stress responses are included and that, in addition to monitoring the effects in the environment, oil exposure examinations are performed on organisms under laboratory conditions. Studies should focus on assessing sublethal impacts, because oil occurs in the environment in small concentrations. Measuring PAH concentrations in organisms facilitates the assessment and monitoring of their impact on reproduction and other functions as well as population changes. The acute toxic effects of PAHs in aquatic organisms are detected at concentrations of 0.2 to 10 mg/L, while harmful long-term effects only require 5 to 100 µg/L concentrations (Tuvikene 1995).

3.9

PAHs in oil and their impacts on human health

Ulla Luhtasela, Pekka J.Vuorinen

Crude oil and oil products contain polyaromatic hydrocarbons (PAHs) which are harmful to human health. PAHs are organic compounds containing carbon and hydrogen with two or more fused benzene rings. There are hundreds of known PAH compounds, but the best known and most harmful is benzo(a)pyrene.



The structure of Benzo(a)pyrene

Some PAHs are carcinogenic and genotoxic even in small doses. JECFA (the Joint FAO/WHO Expert Committee on Food Additives) has recommended that the concentrations of 16 PAHs be monitored in foods due to their carcinogenic effect (see Table 1). Carcinogenic potential increases in direct relation to the number of aromatic carbon rings (four or more). Other possible effects of PAH exposure include reproduction disorders, deformations and suppressed immune function (Scientific Committee on Food 2002).

Many oil-derived substances are harmful to humans upon direct contact, and most pose a real threat when found in foods (e.g. fish and clams) and ingested. Oils contain several harmful compounds, but PAHs are the most dangerous to human health when found in foods (Binderup et al. 2004). Following an oil spill, the Finnish Food Safety Authority Evira assesses the safety of food fish and publishes recommendations on fish consumption.

Table 1. Carcinogenic PAHs

benz(a) anthracene	benzo(g,h,i) perylene	dibenzo(a,e) pyrene	indeno(1,2,3-c,d) pyrene
benzo(b) fluoranthene	chrysene	dibenzo(a,h) pyrene	5-methyl- chrysene
benzo(j) fluoranthene	cyclopenta(c,d) pyrene	dibenzo(a,i) pyrene	benzo(c) fluorene
benzo(k) fluoranthene	dibenz(a,h) anthracene	dibenzo(a,l) pyrene	benzo(a) pyrene

3.10

Organisms suitable for impact assessment and their distribution

3.10.1

The effects of oil spills on the marine environment

Riikka Venesjärvi

The effects of an oil spill on the marine environment depend on various factors such as the type of oil spilled, the scale and geographical location of the spill, weather conditions during the accident, and the season. The effects also vary according to the coastal type – the shores of the outer islands are more likely to be exposed than sheltered estuaries. On the other hand, natural disposal of oil is more efficient in the open sea surrounding the islands. There are also seasonal variations in population structures. If an accident occurs during the breeding season, for example, the offspring are also at risk.

Oil can damage living organisms in several ways. Wildlife is exposed to toxic petroleum hydrocarbons through inhalation, consumption and preening or grooming, and through contact and contamination with oil on the water surface or in their breeding grounds. In addition to different types of exposure, other factors also cause variation in the harmful effects of oil. For example, organisms in their early developmental stages are more sensitive to the impacts of oil than adult individuals (Lecklin et al. 2011).

The effects of oil on littoral plants vary from temporary disturbance of photosynthesis to the death of individual plants. Thick oil clogs the plant stomata and interferes with water uptake via the roots (Pezeshki et al. 2000). Oil reaching the shoreline can adhere to the stems and leaves of aquatic plants, causing them to be uprooted by waves. Some benthic organisms such as mussels are able to avoid contamination by closing up and isolating themselves from the environment (Moles 1998, Robertson 1998). In moderately polluted and rapidly cleaned areas, mussel populations are likely to recover as they are flushed by fresh water. Acute mortality has not been detected in fish as often as in other organisms following oil spills, although fish do suffer from the impacts of oil. Exposure to even small oil concentrations results in metabolic changes, for example (Incardona et al. 2009). In the open sea, fish are better able to evade oil pollution than those in littoral waters where the oil spreads towards the shore. Furthermore, littoral zones are shallow and the oil concentrations therefore greater (Fingas 2001). Spawning grounds are often located in littoral waters, where eggs are readily exposed.

Bird species that are active on the water surface and in the littoral zone are highly vulnerable to oil contamination through direct contact and ingestion. Oil on feathers impairs waterproofing and buoyancy, predisposing the bird to drowning and hypothermia (Kennish 1997). For bird populations, the timing of exposure is the more critical factor for assessing the harmful impacts of a spill than the extent of exposure. Another key factor is location – the Baltic Sea region has a limited number of suitable wintering sites and oil spills in such areas are likely to cause significant population damage. Eggs and chicks polluted during breeding may destroy an entire seasonal output. Migrating birds resting on the surface are also particularly vulnerable to oil (Schoz et al. 1992). According to expert assessments, an oil slick may appear to a bird in flight as an attractive landing area compared to the rippling water surface. In general, bird behaviour affects their likelyhood of becoming exposed to oil, resulting in sensitivity differences between species. Birds spending most of their time in the water, including razorbills (Alca torda) and ducks are readily exposed to oil spreading on the water surface (Esler et el. 2002). Of all populations in the Gulf of Finland, these species are the most vulnerable to the harmful impacts of oil (Lecklin et al. 2011). Oil on water prevents seagulls from catching fish, while birds of prey are exposed to oil when ingesting oiled prey (Wiese & Ryan 2003). Contaminated skerries affect birds nesting in the Baltic Sea by forcing them to search for new breeding grounds and thereby leaving successful breeding at risk. Marine mammals such as seals are able to avoid exposure by evading the spreading oil, although, despite a lack of observations to support the assumption, oil exposure in the open sea is thought to pose a risk.

A population's recovery from an oil spill depends greatly on the species' reproductive rate and migration from outside the contaminated area. Oil induced acute mortality or loss of one year's offspring output does not necessarily result in the disappearance of a species as long as its capacity to recover remains sufficient (Albers 2003). Therefore, it is crucially important to identify the species most sensitive to oil in advance, and to take these species into consideration in response operations and monitor any changes.

Unsuccessful breeding affects short-lived species the hardest. Without seed banks in the soil, the destruction of an annual plant generation may wipe out the entire population. In such cases, recovery is dependent on seeds spreading in from other areas. Perennial plants may recover through new growth from underground roots, provided that they have not been impaired by contaminated soil. Invertebrates and fish produce large numbers of offspring at a time, and it would require the contamination of an entire breeding area for the population to suffer the loss of an entire year's output. However, adults will suffer from the long-term effects of oil through feeding, and this is likely to have a harmful impact on fish reproduction (Lecklin et al. 2011). In seabird populations, adult mortality may be detrimental. The populations of species with long life spans, several pre-reproductive years and low annual reproductive output, such as the common guillemot (*Uria aalge*), are likely to suffer more from the deaths of experienced breeders than the loss of one year's output (Österblom et al. 2004). Following an oil spill, species with advanced propagation capacities move or spread to uncontaminated areas. Seal populations with low reproductive capacity are more dependent on successful migration than the survival of pups (Sjöberg and Ball 2000).

Recovering from an oil spill is almost certain for common species. Endangered species, on the other hand, should be observed separately, as many of Finland's rare and endangered species are dependent on ecologically sensitive littoral habitats. Although a large majority of the endangered species are insects and plants unknown to the wider population, their recovery is highly uncertain and they should therefore receive extra attention in oil response operations.

The different habitats along the shores of the Baltic Sea may also be exposed to oil, and their sensitivity is measured in relation to their capacity to recover. Endangered habitats are slow to recover and, hence, highly sensitive to the harmful effects of oil. Sensitivity is further affected by the effectiveness of clean-up operations – slow and difficult removal of oil pollution from littoral meadows, for example, renders the habitat vulnerable. The outer skerries of the archipelago provide an opposite example, as they tend to be cleaned by rough seas without requiring any human assistance and their recovery can therefore be classified as good.

3.10.2

Indicator species selection

Heta Rousi, Riikka Venesjärvi

The behaviour of different animals affects their vulnerability to oil and suitability for use in impact assessment research. Indicator species for oil should be common and sufficiently abundant in the Finnish marine region. On the other hand the use of endangered species as indicators is important if their known habitat is contaminated by oil. Surveillance data is also useful as reference.

The exposure of organisms also depends on the oil type. The acute toxicity of hydrocarbons to organisms is typically greater for light oils than heavy oil types, and they are also more soluble (Hayes et al. 1992, Albers 2003). On the other hand, they evaporate quickly and organism exposure to light oil-derived compounds is much less likely (Mackay 1985). Hydrocarbons in heavy oil types suffocate and clog organisms and persist in the ecosystem much longer than the lighter oil fractions (Albers 2003). Table 2 describes the effects of different oil types on the marine environment.

There is also a seasonal dependency in exposure to oil. In the Northern latitudes, spring is the breeding time for several species and is the worst possible season for oil spills (Rydén et al. 2003). The location of the spill also has an effect on which organisms are exposed to the oil and how severe the impacts are. Most diversity is found in littoral ecosystems, while the open sea bottom ecosystems present only few species, particularly in the northern regions of the Baltic Sea.

Table 2. Effects of different oil types on the marine environment (Helle 2009, modified)

Very light oils (kerosene, gasoline) High concentration of toxic compounds Severe local effects on the water column and littoral species	**Medium oils (crude oils)** Extensive shore pollution, long duration Endangers birds and mammals
Light oils (diesel fuel oils, light crude oils) Moderate concentration of toxic compounds May pollute the littoral zone	**Heavy fuel oils (heavy crude oils, bunker oil)** Severe contamination of littoral zone Major damage to birds and mammals May contaminate sediment layers

The population groups in the Baltic Sea can be classified according to Lecklin et al. (2011) based on the harmful long-term impacts of oil as follows: birds of prey < mussels < perennials, scallop, pelagic fish, wading birds < underwater vegetation, isopoda < green algae, brown algae, helophytes, annuals without seed banks, amphipoda, gulls < ducks < razorbills. However, this classification according to oil exposure cannot be directly applied in determining the most suitable organisms for use as oil pollution indicator species, because even species that are not sensitive to oil can accumulate significant amounts of hydrocarbons in their tissues and thus provide ideal indicators of the ecosystem's exposure to oil pollution.

An oil stained swan is going to be cleansed (Photo: Jouko Pirttijärvi/SYKE).

3.10.3

Aquatic plants and algae

Heta Rousi

Intensive oil exposure results in reduced diversity of plant species. If the oil exposure is minor, the impacts on littoral and aquatic plants remain minimal. When the tanker Palva grounded in the Kökar archipelago in 1969, it was discovered that plants were typically absent from the oil slicks, but did grow adjacent to them. The severe effects of oil on some aquatic and/or littoral plants may be delayed and can be observed only a year or two after the exposure. Hence, assessing the impacts of oil requires long-term monitoring (Committee on Oil in the Sea 1985). Perennial plants generally recover more rapidly than annuals due, for example, to seed banks in the sediment (Burk 1977, Pezeshki et al. 2000).

Eelgrass (*Zostera marina*) is an ideal bioindicator of oil exposure. The impacts of oil on eelgrass vary from minor effects to very severe depending on the depth, oil type and local conditions, for example (Committee on Oil in the Sea 1985).

Laboratory tests and field observations seem to indicate that bladderwrack (*Fucus vesiculosus*) can sustain moderate, short-term exposure to oil fairly well. This could be explained by the fact that oil does not stick to the cell wall of bladderwrack. Another explanation could be that bladderwrack does not extend roots into the sediment (where most oil is deposited) but instead anchors onto rocks above the sediment layers (Ganning and Billing 1974, Percy 1982). Hence, bladderwrack is not recommended for use as a bioindicator. Observations support the notion that many algae withstand oil rather well for the same reasons as bladderwrack.

Some algal genera, such as *Enteromorpha*, *Ulva* and *Porphyra*, become dominant following oil exposure, but this is most likely caused by decreased numbers of grazing invertebrates. However, the phenomenon might be a good indicator of the impacts of oil in areas affected by an oil spill.

It has been observed that the lichen *Verrucaria maura* growing at the water edge has been eliminated in places where it has been exposed to oil, and therefore its presence or absence could be used as a bioindicator in littoral rocky-bottomed ecosystems (Ravanko 1971).

3.10.4

Phytoplankton

Heta Rousi

Observations indicate that when oil is released into the water column, phytoplankton levels increase. This may be caused by a decrease in the amount of grazing zooplankton (Johansson et al. 1980). Small concentrations of oil have been shown to enhance primary production, whereas large oil concentrations and oil abundant in light fractions cause microalgal primary production to decline and mortality to increase (Lappalainen and Kangas 1980, Saha and Konar 1985). Oil in the water column may prevent photosynthesis, and changes in the composition of species occur as a result of the effects of petroleum hydrocarbons (Miller et al. 1978). The harmful effects of petroleum hydrocarbons on phytoplankton may be caused through the following mechanisms, for example: a) acute toxicity of the soluble aromatic fraction, b) chronic toxicity caused by persistent compounds, and c) altered physiochemical conditions beneath an oil slick (e.g. temperature changes) (Miller et al. 1978). Phytoplankton forms the foundation of the biological marine community, and any changes in the amount and distribution of species are reflected in the nutrient network.

3.10.5

Zooplankton

Heta Rousi

Zooplankton is highly sensitive to the impacts of oil in the water column, and observations made in connection with an oil spill in the Baltic Sea indicate that zooplankton declines significantly as a result of oil exposure. However, the effects on zooplankton seem to be transient, lasting only a few days (Johansson et al. 1980). The copepods *Acartia* and *Oithona*, for example, are suitable for use as bioindicators in oil impact research (Lindén et al. 1979, Bellas and Thor 2007). Studies show that the copepod *Eurytemora affinis* is sensitive to naphthalene, in particular (Ott et al. 1978).

The copepod genera *Acartia* and *Oithona* are both widely distributed throughout the Baltic Sea, and *Acartia bifilosa* and *Eurytemora affinis* are among the most prominent copepods in the Gulf of Finland (Viitasalo 1992, Gallienne and Robins 2001, Bellas and Thor 2007). In small concentrations, toxins such as petroleum hydrocarbons and sedimented PAHs have been shown to have sublethal, productivity reducing impacts on copepods (Berdugo et al. 1977, Lotufo 1997). Hence, the reproduction of copepods can be used as an indicator of the impact of petroleum hydrocarbons (Poulet et al. 1995, Bellas and Thor 2007).

3.10.6

Fish

Pekka J. Vuorinen

Common, readily available and commercially important fish species are suitable for use in oil impact research. Additionally, previous research data should be available on the abundance and structure of the selected fish populations.

Suitable species include the Baltic herring (*Clupea harengus membras*) and perch (*Perca fluviatilis*) which have been used in the Baltic Sea biomarker studies, and both of which fulfil the above-mentioned criteria. The European flounder (*Platichthys flesus*) is another suitable indicator species as it has also been used in the Baltic Sea biomarker studies and been the target of various impact studies. However, flounder populations in the Baltic Sea have declined significantly, and finding samples is nowadays problematic. Other possible indicator fish include zander (*Sander lucioperca*), whitefish (*Coregonus lavaretus*), freshwater bream (*Abramis brama*), European sprat (*Sprattus sprattus*) and eelpout (*Zoarces viviparus*). Excluding eelpout, all of the above species are commercially fished, although freshwater bream to a lesser extent. Population monitoring data is available on all other species, except eelpout.

Collecting adequate fish samples could be a challenging undertaking and may necessitate separate fishing operations, as commercial fishing is likely to cease or be banned in areas polluted by oil.

3.10.7

Benthos

Heta Rousi, Kari Lehtonen

Exposure of benthic organisms to the impacts of an oil spill at sea varies greatly depending on their behaviour and metabolism. The best indicator species would most likely include species which have long life spans and are not acutely sensitive to environmental change and, hence, demonstrate unmistakable stress signals, such as the mussels *Macoma balthica* and *Mytilus trossulus* and the isopod *Saduria entomon* (e.g. Rumohr et al. 1996).

Most crustacean species, such as the amphipod *Monoporeia affinis*, are extremely sensitive to the impacts of oil because they readily accumulate hydrocarbons (Sanders et al. 1972, Jacobs 1980, Wake 2005, Lecklin et al. 2011). The impact of fresh oil on *Monoporeia affinis* is immediate and lethal (Björkas 1980). However, crustaceans are motile and the amphipod *Monoporeia affinis* has been known to avoid sediments contaminated with oil. On the other hand, *Monoporeia affinis* may, due to its motility, become stuck in the oil (Percy 1977, Wells and Percy 1985). The isopod *Saduria entomon*, like isopoda in general, tolerates oil pollution well and is therefore an ideal indicator species for oil (Percy 1977, Lindén et al. 1979). However, the isopod can travel relatively long distances and accumulate considerable amounts of oil and yet not express the oil pollution in the research area (Lindén 1979).

The capacity of the mussels *Macoma balthica* and *Mytilus trossulus* to metabolise PAHs is poor. However, these mussels can store the original PAHs in their tissues, and the amount of metabolites (including reactive oxygen species) remains lower. Therefore, the mussels are optimal bioindicators for oil (Lee et al. 1972). Mussels are typically most severely affected by the chronic impacts of oil, because they escape short-term stress, such as an immediate oil spill, by burying into the sediment and closing up (Moles 1998).

Petroleum hydrocarbons are degraded by polychaetes (Van Bernem 1982). Chronic impacts of oil on invertebrate species are rare and only occur in association with large-scale oil spills, because many invertebrate species have planktonic larvae which recolonize the area as soon as the area is clean again (Jacobs 1980, Hawkins et al. 2002). However, some invertebrate species such as many crustaceans (e.g. *Monoporeia affinis*) and scallops lack the planktonic stage (Gomez Gesteira and Dauvin 2000, Valanko 2012).

3.10.8

Seals

Heta Rousi

According to some studies, ringed seals tolerate oil contamination well, because they are protected by a thick blubber layer under the skin (Geraci and Smith 1976, Engelhardt et al. 1977). If the breeding grounds of the ringed seal are contaminated by oil, the newborn pups are the most at risk (Stenman 1980). However, there is little data on the exposure of ringed seals to oil. As a direct result of the Exxon Valdez oil spill in the Prince William Sound, the Pacific Ocean harbour seal population declined in the oiled areas by 43% compared to the 11% mortality rate in unoiled areas (Frost et al. 1994). Analogously, a large-scale oil spill in the Baltic Sea could result in declined seal populations if seal habitats are contaminated.

3.10.9

Birds

Martti Hario, Heta Rousi

In Finland, chronic oiling of birds has not been as closely monitored as on the flat, sandy shores of the southern and southwest Baltic, where beached birds are recorded in regular surveys. These surveys have been conducted for decades and clearly demonstrate the continuous oiling of birds, with cases numbering in the tens of thousands, especially along the busiest shipping routes in the Baltic Sea. One of the busiest and most important routes runs in the middle of the Baltic Sea from the eastern end of the Gulf of Finland. Each year, dozens of illegal spills are registered in Finnish waters, and it is likely that a large number of birds are oiled near Finnish territorial waters. However, as the Finnish coastline is predominantly steep and rocky, oiled birds do not beach onto Finnish shores as readily as on the sandy shores of the Baltic. Thus, the vast majority of oiled birds in Finnish waters die at sea and sink to the bottom.

In the event of a large-scale oil spill, this difficulty in adequately monitoring bird mortality will be pronounced. The number of victims will be difficult to determine without major aerial and marine monitoring efforts. The Finnish Game and Fisheries Institute (RKTL) has extensive surveillance data on the birds of the Finnish archipelago dating back several years, which would be helpful in determining the effect on bird populations. Surveillance organised by the RKTL is carried out by volunteers in 45 areas of the archipelago, from the Bay of Bothnia to its eastern perimeter. The objective is to determine the populations and developmental trends of the 32 species living in the Finnish archipelagic areas based on nest and adult counts. For several locations, a comprehensive time series dates back to 1986. The background data from RKTL has been an important tool in recording previous bird deaths in the Gulf of Finland (1992, 2000, 2006 and 2010) and in both Antonio Gramsci oil spills (in 1979 and 1987).

In terms of impacts on seabirds, the location and timing of the oil spill outweigh the amount of oil spilled in importance. If oil is discharged into the northern Baltic

Sea ecosystem during seabird breeding and nesting, the effects on seabirds can be devastating. Extensive damage to seabird populations can also be expected if oil is discharged into the marine ecosystem in their wintering areas, as survival rates in cold waters are minimal even after cleaning. Bird species that are most active on the water, and thus most vulnerable to surface oil, are the best indicators of oil impacts. Such birds include razorbills, black guillemots, common eiders, long-tailed ducks, great black cormorants and mallards (Häkkinen 1980, Esler et al. 2002, Lecklin et al. 2011).

3.10.10

Species distribution models

FINMARINET - Inventory and planning for the Finnish marine NATURA 2000 network

Heta Rousi, Minna Ronkainen

FINMARINET is a Finnish programme implemented to map the incidence and distribution of key species and important habitats. The first maps are to be published in 2013 and will be available at the Finnish Inventory Program for the Underwater Marine Environment VELMU site at: http://www.ymparisto.fi/default.asp?contentid=401354&lan=FI. This data may later be incorporated into the Situation Awareness System for Environmental Emergency Response (BORIS2) of Finland's environmental administration (see Section 4.2).

Distribution models are prepared for six research areas including seven natural reserves (see Figure 2). The research areas are located in the Bay of Bothnia (23,026 ha), the Quark archipelago (128,162 ha), the Rauma archipelago (5,350 ha), the Tammisaari area (5,2630 ha), the Archipelago Sea (49,735 ha) and the eastern Gulf of Finland (95,628 ha). Models are based on environmental variables which best characterise the optimal habitat of a species (depth, open waters, salinity, temperature, pH, total nitrogen, total phosphorus, visibility and dissolved oxygen).

Taxons mapped so far include *Chara* sp, *Chara aspera*, *Myriophyllum* sp, *Potamogeton filiformis*, *Potamogeton pectinatus*, *Potamogeton perfoliatus*, *Najas marina*, *Ruppia* sp, *Ranunculus baudotii*, *Tolypella nidifica*, *Zostera marina*, *Fontinalis* sp, *Ephydatia fluviatilis*, *Cordylophora caspia*, *Fucus* sp, *Furcellaria lumbricalis*, *Cladophora aegagrophila*, *Cladophora rupestris*, *Mytilus trossulus*, *Sphacelaria arctica* and *Hildenbrandia rubra*.

Other species will be mapped in the future when sample coverage is sufficient. Communities will also be mapped, provided reliable distribution models can be produced. Distribution models are expected to be useful during oil impact assessment. When an oil spill has occurred, the maps will give immediate data on the habitats at risk.

OILRISK – Application of ecological knowledge in managing oil spill risk

Riikka Venesjärvi

The aim of the OILRISK project is to assess the risk to ecological values and, especially, endangered species and habitats of a possible oil spill. Research data will include information on the animal and plant species of the Gulf of Finland and the Archipelago Sea most vulnerable to the acute and chronic effects of an oil spill, and where the species are situated. An up-to-date species database contributes to enhanced oil contingency planning.

The database will include the locations, conservation value, resilience, probability of exposure and cleanability of endangered littoral species and habitats on land and under water. This information will be applied to assess the value of different habitats, enabling optimal allocation of limited resources in the event of an oil spill.

A map application will be created based on the collected data to combine information on drifting oil slicks and sensitive ecological values. The map application will be ready in 2012 and it will be incorporated into BORIS2, the situation awareness system for environmental emergency response of Finland's environmental administration. In addition to the above-mentioned sea regions, the database can also accommodate information concerning other Finnish sea areas and lakes.

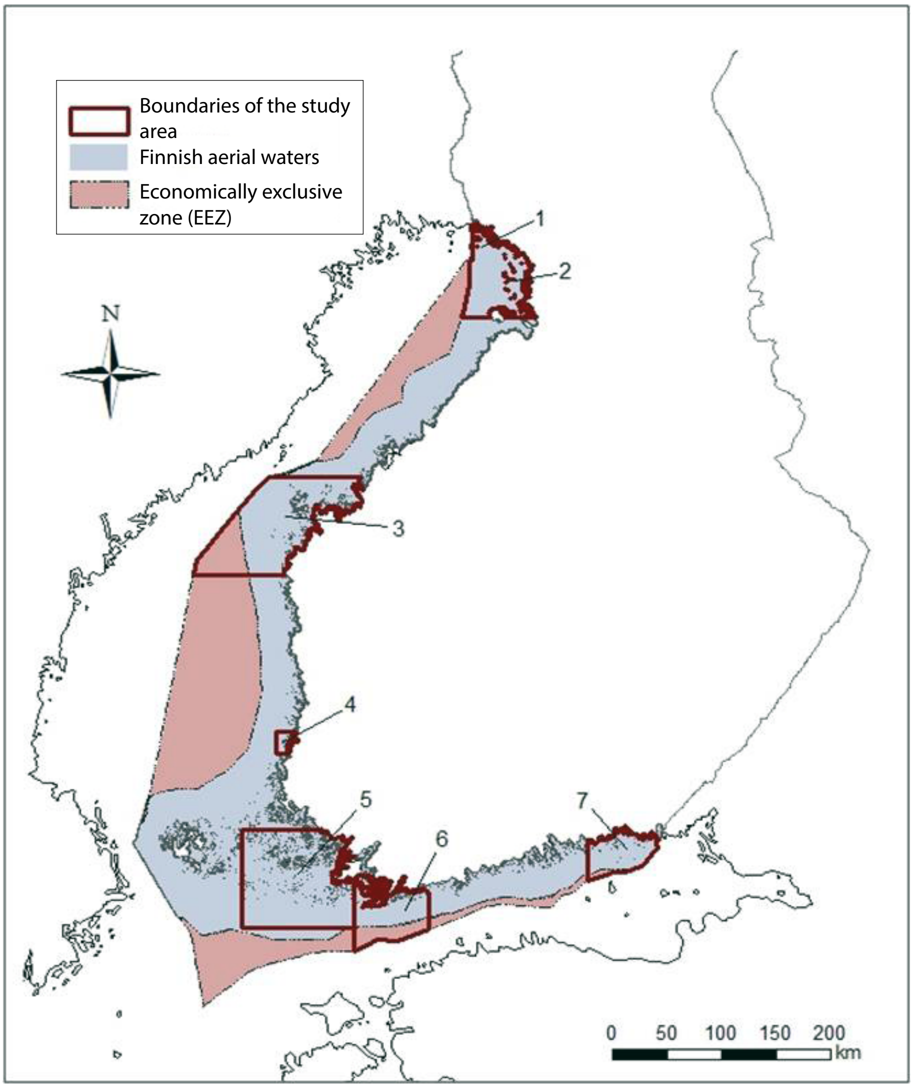


Figure 2. The six research areas of the FINMARINET Programme where the distribution of the above-mentioned species have been mapped and modelled (image by Minna Ronkainen/SYKE)

3.11

Information from chemical analyses

Kari Lehtonen, Harri Kankaanpää, Pekka J.Vuorinen, Pirjo Sainio, Kaarina Lukkari

In case of an oil spill, rough estimates on acute exposure concentrations in the target locations and dominant oil fractions can be based on the oil concentration in the water column. This data can be later applied in post-accident risk assessment and impact forecasting. Sediment concentration measurements can be used to predict the extent of long-term effects, while concentrations measured in living organisms optimally express the total exposure in organisms slow to degrade hydrocarbons. Tissue concentrations detected in indicator organisms combined with data on molecular and physiological impacts measured over the same time period optimally reflect the combined exposure of the habitat and its biological impact. Measuring total oil concentrations is useful for water samples only.

Determining PAH and aliphatic hydrocarbon concentrations (aliphatic hydrocarbons are non-aromatic hydrocarbon compounds, i.e. do not contain a benzene ring or similar structures) is essential to analyse petroleum hydrocarbon accumulation in target organisms. By monitoring these concentrations, it can be discovered how the chemical load in an organism changes over time. Toxicological impacts are estimated over time by monitoring the concentration distribution of compounds affecting the organisms internally. Detecting aliphatic hydrocarbons implies exposure to oil in general, while molecular and physiological impacts are explained by PAH profiling.

SECTION B

4 Operational guidelines in case of an oil spill

Harri Kankaanpää, Heta Rousi, Heli Haapasaari

The duty officer for environmental incidents of the Finnish Environment Institute SYKE or a SYKE environmental response group expert nominated by SYKE's duty officer informs the person in charge of the ÖVA Group and ÖVA operations about an oil spill at sea possibly warranting ÖVA operations. The ecological impacts standing group (EVA), is a group within SYKE. Members of the EVA Group must be familiar with the action plan in advance, and prepared for action in case of a severe oil spill. In addition to SYKE, other organisations belonging to the ÖVA Group should also be prepared for taking part in ÖVA operations.

Note that SYKE has a separate contingency plan and standing group for emergency situations. ÖVA operations have been linked to the operations of this group. The person in charge of the ÖVA Group contacts the leader of SYKE's standing group (see contact details in Appendix 1). Members of the EVA Group are also required to be familiar with this response plan (the document is on SYKE's intranet at: communications → emergency situations → response plan). Communication instructions and contact details in the event of an exceptional situation are also provided on the SYKE intranet, under Communications and Emergency Situations.

The SYKE Marine Research Centre is responsible for implementing the plan and for ensuring that the required EVA Group staff are available under all circumstances. The procedures in the event of an oil spill are given in the chart below (see Figure 3). The chart details the evaluation process and is intended for use as a guideline for the ecological impacts research group (EVA) (see Figure 4).

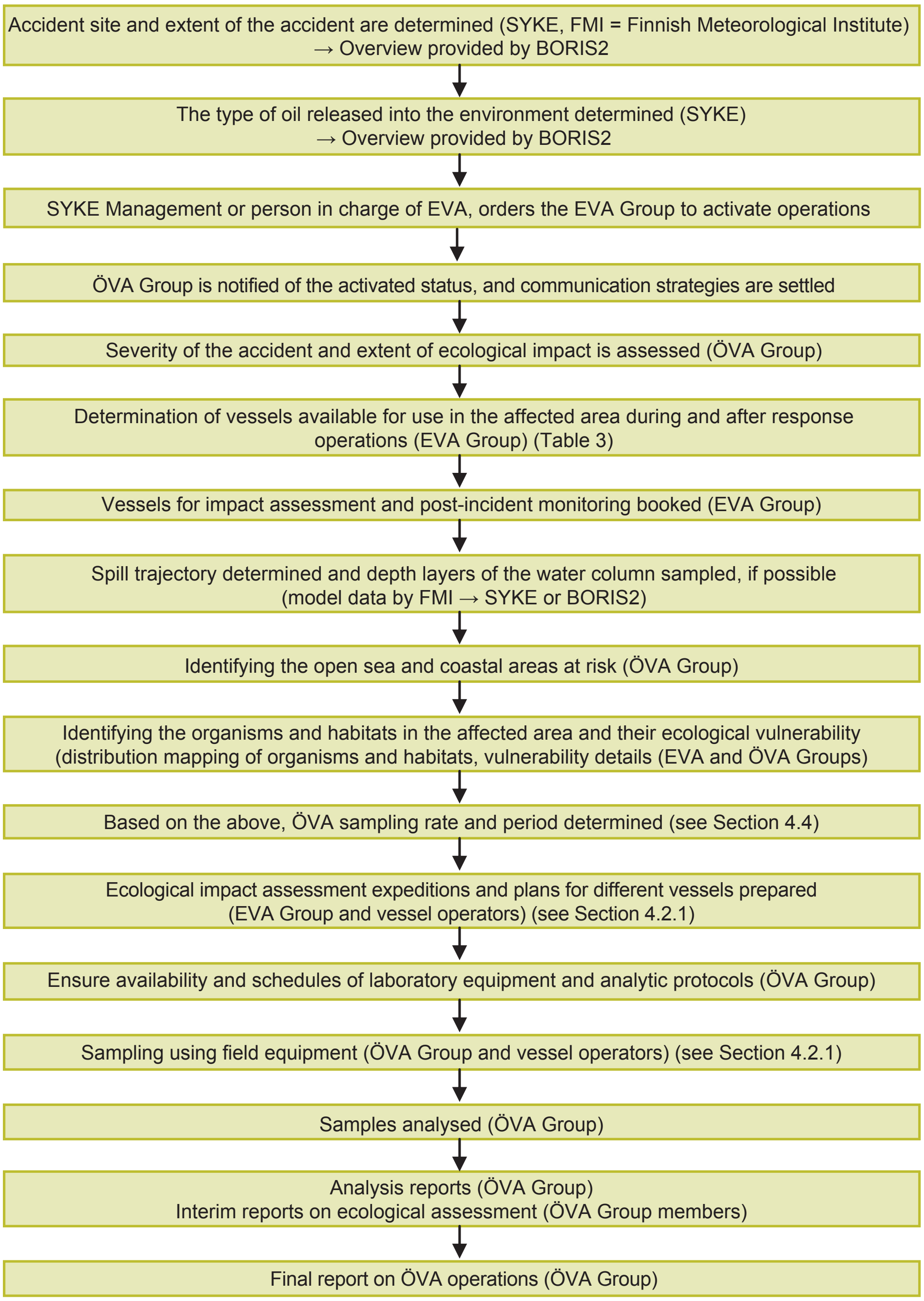


Figure 3. ÖVA operations. EVA = SYKE's internal ecological impacts standing group, ÖVA = Research Group Focusing on the Ecological Impacts of Oil

4.1

Assessment of ecological impacts in case of an oil spill – Division of responsibilities

Harri Kankaanpää, Heta Rousi

Overview

SYKE is responsible for maintaining its internal organisation to ensure ÖVA operations can be initiated without delay in the event of an oil spill (see Figure 5). The person in charge of the ÖVA Group notifies the other members of the ÖVA Group including sample collectors in the field, researchers and laboratory personnel. If analysis services are outsourced, the supplier laboratory should be immediately contacted to schedule time for the analyses and agree on priority.

RKTL takes fish samples, conducts exposure testing on the fish and delivers fish samples to the Finnish Food Safety Authority Evira. Trained SYKE professionals collect surface oil samples to monitor oil concentrations. SYKE also provides the staff to collect samples of zooplankton, benthic organisms and sediment. The state forest administration Metsähallitus also collects samples of organisms. Figure 5 describes the SYKE centres and units participating in post-incident ecological impact monitoring.

Post-incident monitoring of ecological impacts is typically not conducted during acute oil response operations. However, oil response vessels may participate in sample collection towards the end of the response operations.

The person in charge of the EVA Group receives information on a (severe) oil spill threatening the Finnish waters from **SYKE's duty officer for environmental incidents**. This means that an oil spill has taken place at sea either within the Finnish borders or close enough for a significant amount of oil to drift into the Finnish exclusive economic zone or territorial waters. In open waters oil initially drifts on the water surface. The task of the EVA Group is to forecast the ecological niches (layers of water, plankton, sedimented material, sediments, organisms) that the oil will inhabit under the prevailing conditions based on the conditions, quality and scope of the oil spill. The above mentioned baseline data should be reviewed in connection with data provided by BORIS2.

Detailed description of the organisation

In case of an oil spill, SYKE's **ecological effects standing group EVA** is responsible for initiating ÖVA operations (see Figure 4). The group comprises: A) the person in charge of the EVA Group (in charge of operations and communicating with all stakeholders), B) the person responsible for biological impacts (in charge of response tests performed by SYKE), C) research vessel developmental manager (responsible for research vessels Aranda and Muikku), D) the person in charge of oil sampling (responsible for ensuring sample collection equipment is functional), E) the person responsible for oil analytics (responsible for methods applied in determining total oil concentrations), F) oil sample collectors (three, responsible for sampling from SYKE's or other vessels), G) benthic sample collectors (1 to 3, responsible for sampling from SYKE's or other vessels).

The person in charge of the EVA Group takes responsibility for communicating with SYKE Management and Communications about ecological impact assessment. He or she remains in close contact with the environmental damage response group, the BORIS2 information system, the provider of spreading calculations (Finnish Meteorological Institute = FMI), and other third parties involved in ÖVA operations (see Figure 5). All ÖVA-related communication goes through SYKE.

The EVA Group collaborates with the Finnish Border Guard, the Finnish Lifeboat Institution and local groups such as the Tvärminne Zoological Station who are better equipped for coastal operations. If available, the research vessel Muikku can be deployed on coastal research operations. Vessel requirements must be communicated to stakeholders as soon as possible, because the Saduria and SYKE's vessels, for example, must be booked in advance.

4.1.1

Maintaining a sufficient level of ÖVA preparedness

Harri Kankaanpää, Heta Rousi

The SYKE Freshwater center arranges ÖVA emergency rehersals for imaginary oil spills exceeding the threshold for ÖVA operations.

Starting in 2013, SYKE and the Finnish Lifeboat Institution will organise annual exercises involving the collection of surface water samples and their subsequent oil content analysis in an oil impact monitoring laboratory which implements the HELCOM oil surveillance protocol (2013 - 2014 by SYKE).

SYKE is responsible for ensuring that sufficient resources (persons in charge, funding) are made available to the EVA Group and that the equipment required in the operations are up to date (protective equipment, samplers, analysis devices and methods).

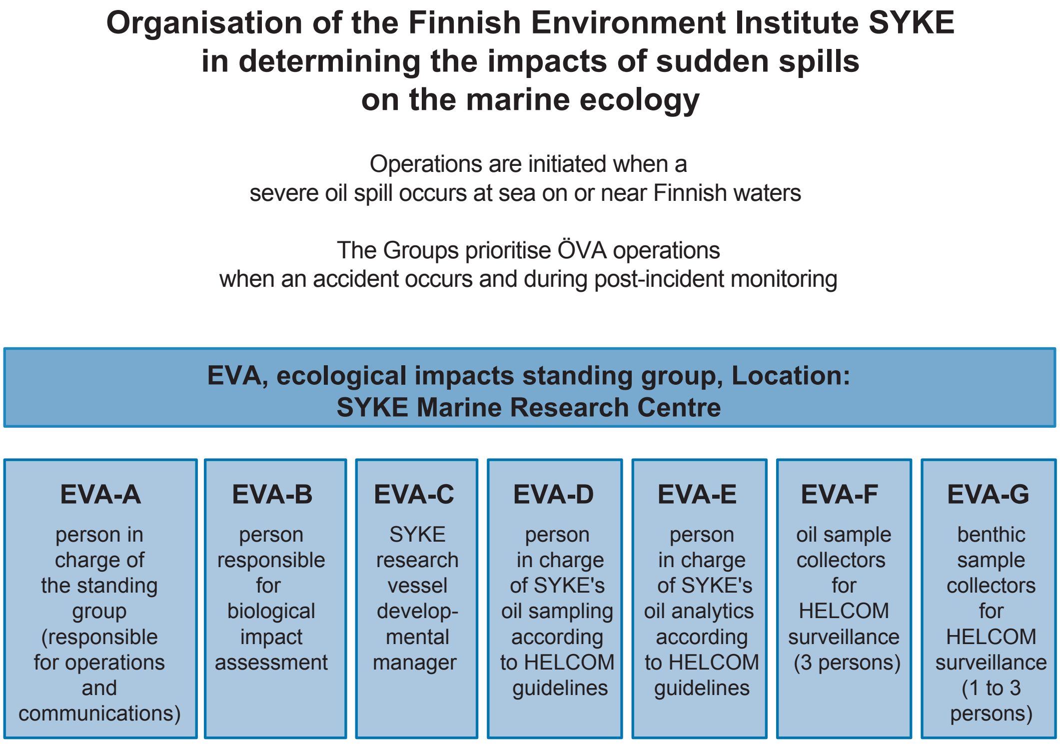
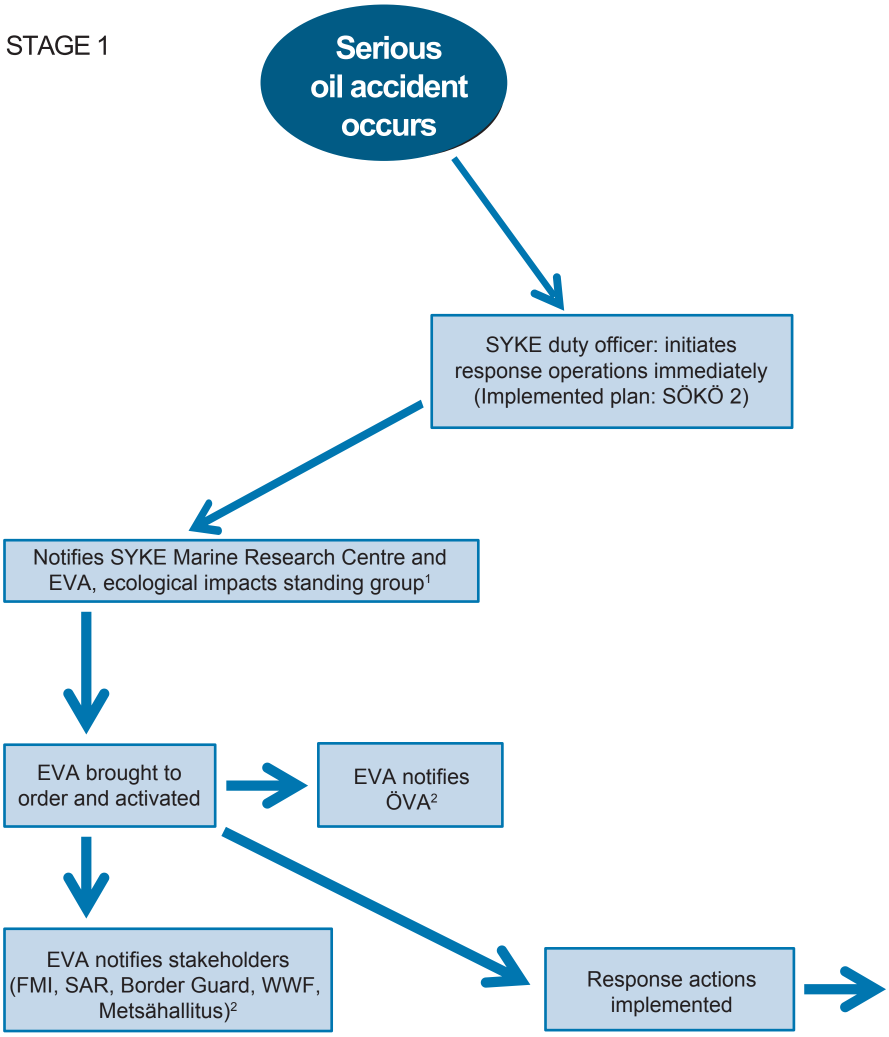
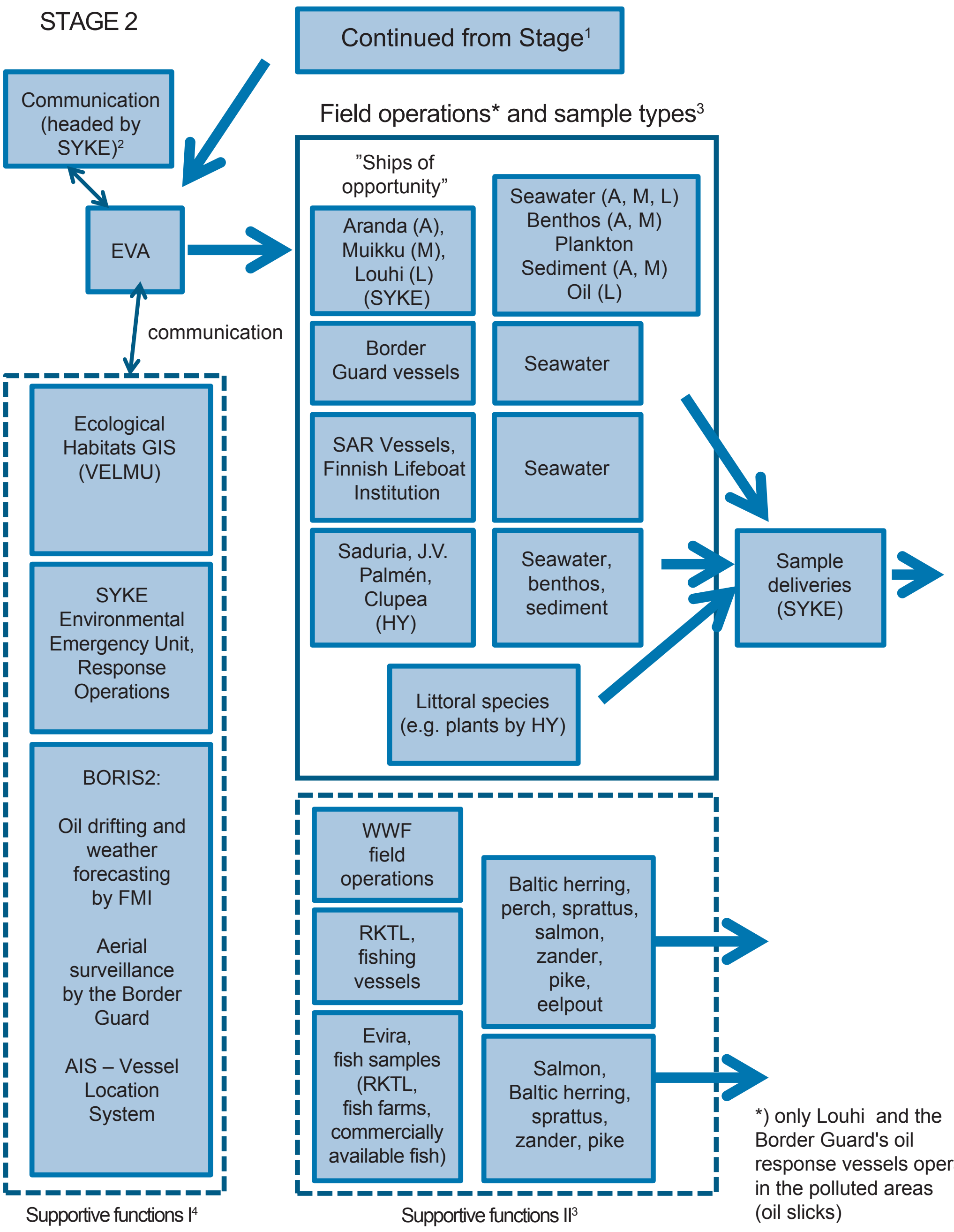


Figure 4. SYKE organisation – EVA, ecological impacts standing group



[1] For the organisation of EVA, see Figure 4

[2] For contact information of the ÖVA group and supportive functions, see Appendix 1



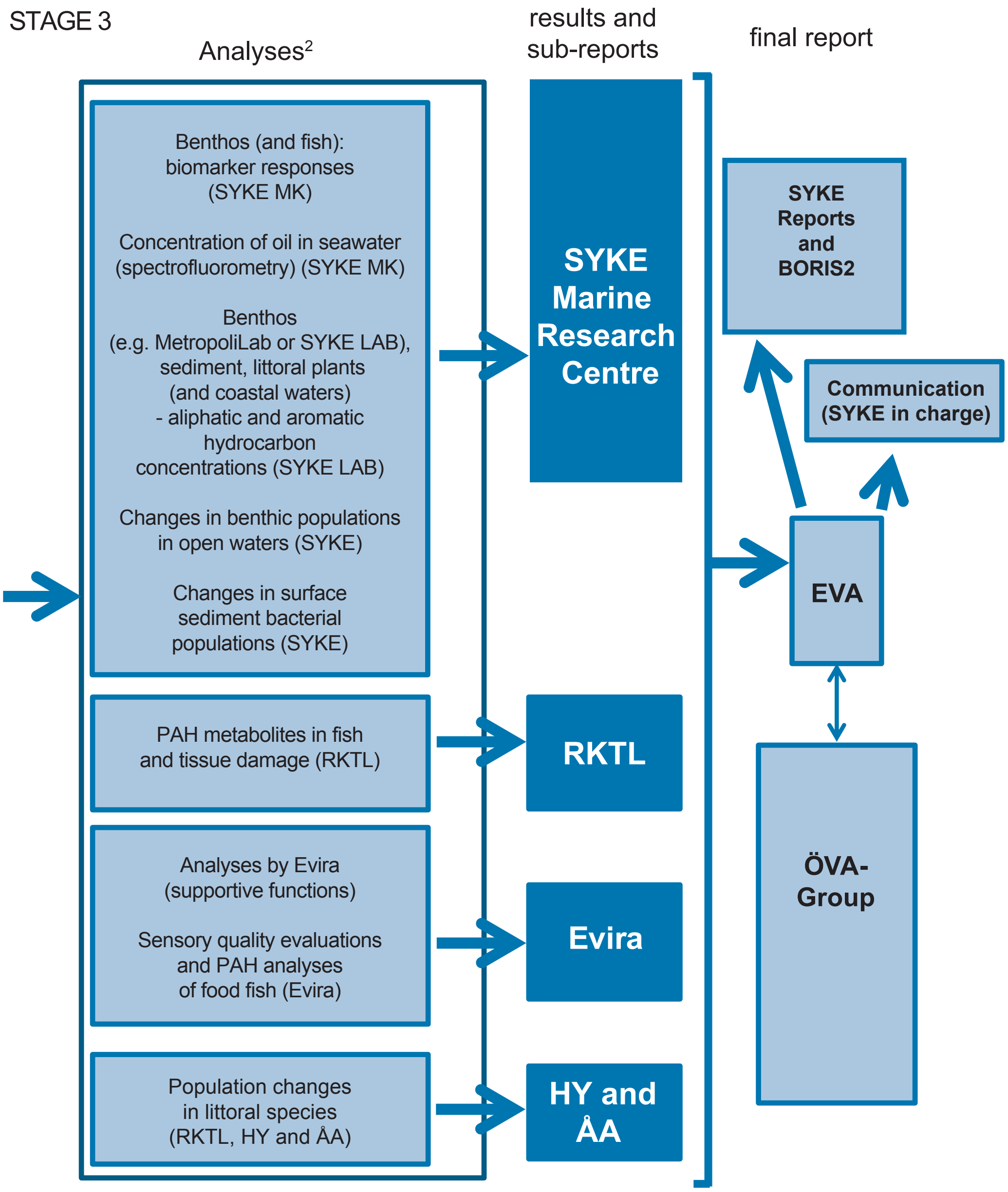
*) only Louhi and the Border Guard's oil response vessels operate in the polluted areas (oil slicks)

[1] For the organisation of EVA, see Figure 4

[2] For contact information of the ÖVA group and supportive functions, see Appendix 1

[3] Vessel and field operations (see contact information in Appendix 1)

[4] Background data by SYKE and other stakeholders



[2] For contact information of the ÖVA group and supportive functions, see Appendix 1

Figure 5. Flow chart of the ecological impact assessment of sudden oil spills

4.2

Supportive functions

Meri Hietala, Heta Rousi

Since 2006, all Finnish oil spill response authorities have had access to the Baltic Oil Response Information System (BORIS), a GIS for oil spill response hosted by SYKE (see http://hertta.vyh.fi/boris). The system incorporates geographical information data maintained by the Finnish environmental administration as well as separate material and operations supporting oil response activities. BORIS was replaced by an updated version, BORIS2, in summer 2012.

The updated version BORIS2 is an Internet-based system offering review data in real time and accessible by all national oil spill response authorities. For more information on the system and its development, visit: www.ymparisto.fi/syke/boris2. The BORIS2 system provides oil spill response authorities with information on high priority protected targets, resources available for response work, and the situation at sea and weather conditions.

When you log in to BORIS2, a window opens with tabs to review and upload information regarding an oil spill. These will include details of the oil spill, aerial and satellite surveillance images, observation reports by coastal reconnaissance units, data on polluted areas, and action plans regarding the response activities. Reports can be printed from the BORIS2 system for participants unable to access the BORIS2 system.

VELMU is the Finnish Inventory Programme for the Underwater Marine Environment. Background data on benthic habitats is available from the VELMU personnel and archiving institutions. Data gathered in the VELMU programme will be available in electronic format at: http://www.ymparisto.fi/default.asp?contentid=401354&lan=FI. In the future, data on species and habitats collected within the VELMU project will be available for uploading to the BORIS system.

Aerial surveillance provides essential information on optimal sample targeting, and is incorporated into the BORIS system. This information is also made available by the Finnish Border Guard.

Oil spill trajectory forecasts (in 2012) only depict the oil spread on the water surface, not in the subsurface layers. If primary or background information on trajectory models is required for the purpose of target sampling activities, please contact the Finnish Meteorological Institute.

For contact details of the supportive functions, see Appendix 1 (last updated on 31 March 2012).

4.2.1

Sampling equipment available in different regions of the Baltic Sea

Heta Rousi, Harri Kankaanpää, Heli Haapasaari

Vessels available for use in OVÄ operations are provided by (situation on 31 March 2012) the Finnish Environment Institute, the Finnish Navy, the Finnish Border Guard, the Finnish Lifeboat Institution, and the University of Helsinki (Tvärminne Zoological Station). In case of large-scale oil spills, the Finnish Environment Institute will prioritise the use of its research vessels to ensure that ecological impact assessments can be conducted according to this plan of action. In practice, this will mean employing any research vessels docked at harbour and rerouting vessels at sea towards the polluted area as required at the appropriate time.

The Finnish territorial waters are depicted in Figure 6. Below is a listing of vessels available for ecological impact assessment.

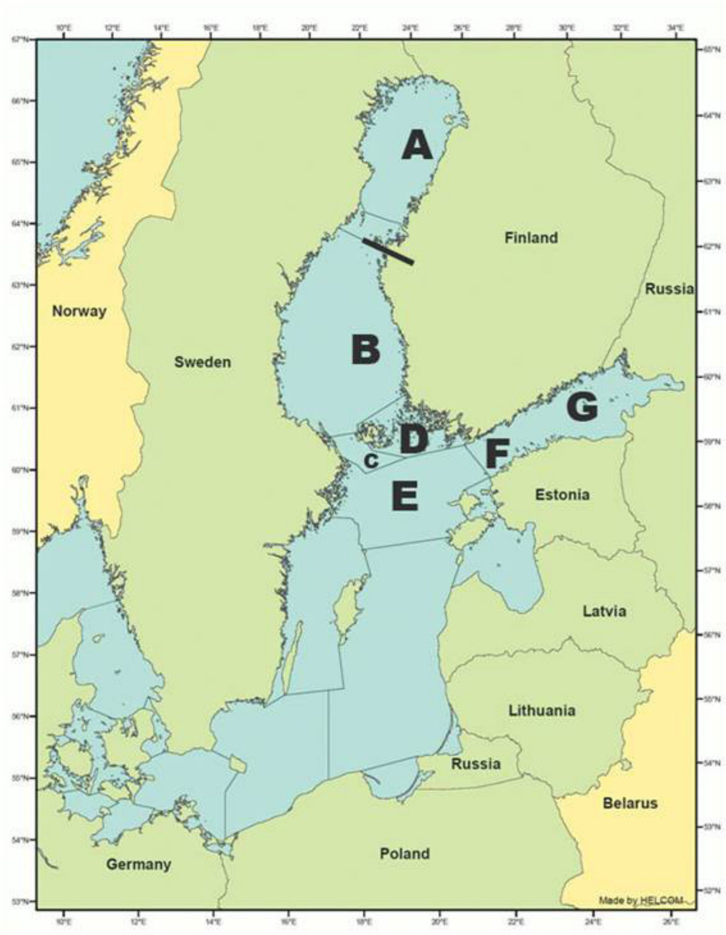


Figure 6. Regions of the Baltic Sea. ÖVA operations are conducted in Finnish waters. Region A: Bay of Bothnia and the Quark. Region B: Bothnian Sea. Region C: Sea of Åland. Region D: Archipelago Sea. Region E: Northern Baltic Proper. Region F: Western Gulf of Finland. Region G: Eastern Gulf of Finland.

SYKE

Aranda
Homeport: Helsinki, Speed: 10 kn, marine research vessel, excellent deployability for all ÖVA operations.

Muikku
Homeport: Savonlinna, Speed: 10 kn, marine research vessel, deployable for coastal ÖVA operations under all conditions, and for ÖVA operations on the high seas under good conditions.

THE FINNISH NAVY

Louhi
Homeport: Upinniemi, Kirkkonummi, Speed: 15 kn in open water, multipurpose vessel, primary task under SYKE operations is oil spill response. Seawater, benthic organism and sediment samples can be collected from the ship, if necessary. The ship has a small onboard laboratory for preliminary sample processing.

THE FINNISH BORDER GUARD

The Finnish Border Guard operates six offshore patrol vessels, three of which are equipped for oil spill response. Additionally, the Border Guard operates several dozens of coastal patrol craft. In addition to watercraft, the Border Guard operates aircraft, including helicopters. Some of these are listed below. For more information, visit the Border Guard website at: http://www.raja.fi/rvl/home.nsf/pages/indexfin. In case of a maritime accident, information on the availability of Border Guard vessels can be enquired from the person in charge of the environmental incident response group and the Boarder Guard contact person (see Appendix 1).

Gulf of Finland Coast Guard

The Gulf of Finland Coast Guard operates two patrol vessels: Tavi and Merikarhu. Both are registered in Helsinki. A third vessel is to be commissioned in the near future.

Merikarhu – Speed: 12–15 kn, patrol and oil spill response duties, seawater sampling, CTD probe, flow samples, no laboratories.

Tavi – Speed: 14–20 kn, patrol duties, seawater sampling, CTD probe, flow samples, no laboratory.

Border Guard vessel to be commissioned: equipped with onboard laboratory facilities and cabin space for 40 passengers. Plans include research containers.

West Finland Coast Guard

The West Finland Coast Guard operates four patrol vessels which are registered in Turku.

Tursas – Speed: 11 kn, patrol and oil spill response duties, seawater sampling, CTD probe, flow samples, no laboratory.

Uisko – Speed: 12 kn, patrol and oil spill response duties (Uisko is capable of travelling in 50 cm fast ice), seawater sampling, CTD probe, flow samples, no laboratory.

Telkkä – Speed: 12 kn, patrol duties, seawater sampling, CTD probe, flow samples, no laboratory.

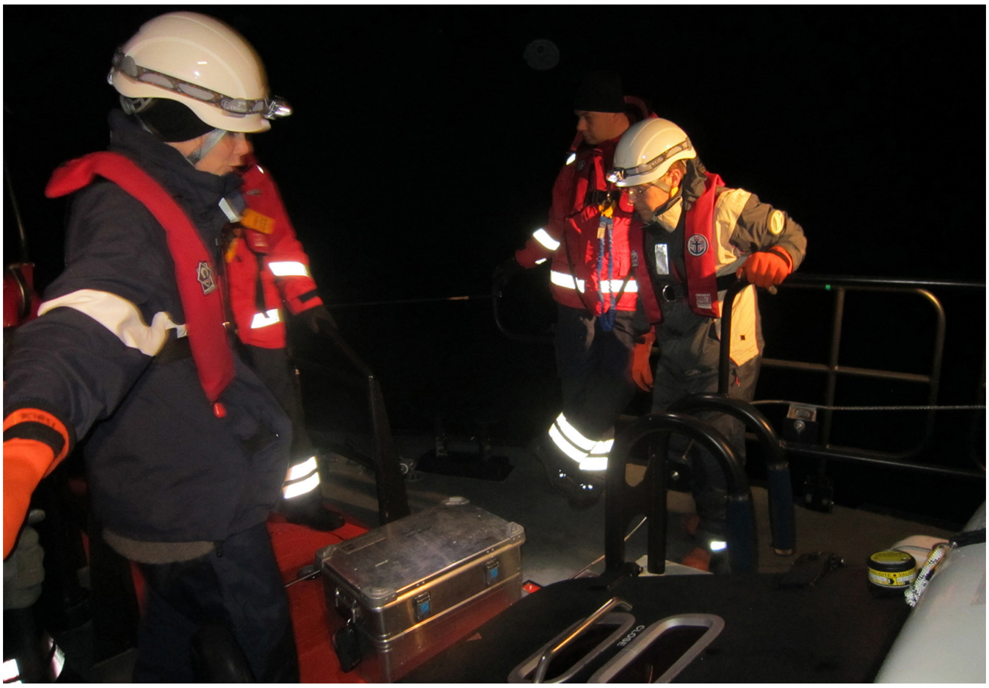
Tiira – Speed: 11 kn, patrol duties, seawater sampling, CTD probe, flow samples, no laboratory.

Finnish Lifeboat Institution's boat (Photo: Jouko Pirttijärvi/SYKE).

THE FINNISH LIFEBOAT INSTITUTION

Vessels are deployable for water sampling only, excluding vessel type PV5 which, subject to testing, may be deployable for benthic sampling.

Hamina: PV Hallikari, Speed: 32 kn, Range: 130 nm; and PV Pikkumusta, Speed: 34 kn.
Kotka: PV Kotka, Speed: > 32 kn, Range: 150 nm; and PV 2, Speed: 35 kn, Range: 120 nm.
Loviisa: PV Degerby, Speed: 28 kn, Range: 110 nm.
Porvoo: PR Mac Elliot, Speed: 18 kn, Range: 200 nm.
Helsinki: PV5 Rautauoma, Speed: 30 kn, Range: 150 nm; and PR Jenny Wihuri, Speed: 18 kn, Range: 400 nm.
Porkkala: PV Aktia, Speed: 30 kn, Range: 170 nm; and PV2, Speed: 35 kn, Range: 120 nm.
Inkoo: PV Fagerö, Speed: 30 kn.
Hanko: PR Russarö, Speed: 16 kn, Range: 200 nm; and PV Betty, Speed: 30 kn, Range: 50 nm.
Archipelago Sea and Länsi-Turunmaa: PV Paroc, Speed: 19 kn, Range: 140 nm; and PV Galilei, Speed: 32 kn, Range: 52 kn.
Turku: PV Otkantti, Speed: 10 kn; PV Rajakari, Speed: 20 kn; PV Arvinsilmä, Speed: 17 kn; and PV Viittakari, Speed: 17 kn.
Salo: PV Draken, Speed: 28/34 kn; AV Tossu, Speed: 30 kn; and AV Boistö 3, Speed: 28/34 kn.
Naantali: PV Nunnalahti, Speed: 10 kn, Range: 100 nm; and PV Teuvo, Speed: 30 kn, Range: 50 nm.
Uusikaupunki: PR Janne Malèn, Speed: 18 kn, Range: 200 nm; and PV Vekara, Speed: 28 kn, Range 70 nm.
Sydväst: PV Paroc, Speed: 19 kn.
Rauma: PV Hoppe, Speed: 10 kn; and PV2, Speed: 33kn.
Pori: PR Reposaari I, Speed: 9 kn; and PV Repo, Speed: 30 kn.
Kaskinen: PR Torbay, Speed: 15 kn, Range: 130 nm; and PV Orion, Speed: 30 kn, Range: 60 nm.
Vaasa: PV Wärtsilä Rescue, Speed: 35/46 kn, Range: 100 nm.
Korsnäs: Targa rescue, Speed: 32 kn; and AV 16, Speed: 32 kn.
Pietarsaari: PV Otto Malm, Speed: 30 kn, Range: 50 to 60 nm; and AV Mini Otto, Speed: 35 kn, Range: 30 nm.
Kokkola: PR Sälgrund, Speed: 9 kn, Range: 250 nm; and PV Matts, Speed: 32 kn, Range: approx. 80 nm.
Raahe: PR Niilo Saarinen, Speed: 9 kn; PV Pikku Niilo, Speed: 28 kn; AV Aave, Speed: 32 kn.
Oulu: PV Toppila, Speed: 16 kn, Range: 200 nm; PV Hailuoto, Speed: 30 kn, Range: 50 nm.
Kemi: PR Hebe, Speed: 18 kn, Range: 100 nm; and PV Laitakari, Speed: 32 kn, Range: 20 nm.
Tornio: PV Karppe, Speed: 32 kn.



Preparations for sample collection aboard Rautauoma, a type PV5 vessel of the Finnish Lifeboat Institution (photograph by Heta Rousi/SYKE)

UNIVERSITY OF HELSINKI / TVÄRMINNE ZOOLOGICAL STATION

Access to the local laboratory infrastructure for sample preparation and analysis is a key benefit of the zoological station vessels.

Saduria – Speed: 9 kn, benthos collection, sediment and water samples, small range, suitable only for coastal operations, no laboratory.
Clupea – Speed: 10 kn, water sample collection.
J.A. Palmén – Speed: 17 kn, water sample collection.

The availability of vessels for ecological impact assessment should be confirmed as early as possible. The affected area in relation to the vessel location/homeport, onboard equipment, operating range, speed, other duties, etc. are considered when evaluating vessel suitability. Vessels already in the vicinity of the affected area should be primarily used. This is the most cost-effective approach, cost-efficiency being an important consideration in EVA operations. Information from the BORIS system and annual route plans of the research vessels can be used to provide an overall picture of the vessel situation. For contact details on vessel pooling, see Appendix 1 (last updated on 31 March 2012)

If the Finnish research vessels Aranda, Muikku and Saduria are not available, sampling outside the oil slick is conducted from Border Guard or Finnish Lifeboat Institution vessels. However, the Border Guard's oil spill response vessels are primarily involved in oil spill response duties. The other Border Guard vessels are available for research purposes.

4.2.2

General observations on sample collecting and vessels

Heta Rousi, Heli Haapasaari, Harri Kankaanpää

The research vessels are ideal for all sampling operations, as they have the required equipment, functions and level of safety. However, the research vessels must not enter the oil slick to collect samples. In ÖVA operations, sampling is limited to the area outside the visible oil slick and for baseline studies and surveillance measurements.

Vessels on oil spill response duty will sample the oil slick and the containers of the vessel which caused the spill. While performing their duties, the oil spill response vessels will become oiled. Therefore, their use in sample collection outside the main affected area after the oil spill response operations when the vessel is returning to port, should be carefully considered. Oil samples collected by oil spill response vessels are typically not part of the ÖVA assessments. Samples can be collected in connection with oil spill response activities, if necessary, and delivered to the ÖVA Group to be used as references in chemical analyses.

Response vessels – and other vessels – not intended for research purposes can, nevertheless, take oil samples from water. The pending addition to the Borders Guard fleet could be fitted out for deployment for all ÖVA operations.

An expert in border security and sea rescue operations, the Finnish Border Guard, subordinated to the Ministry of the Interior, co-operates with the Finnish Environment Institute SYKE on maritime surveillance and oil spill response duties. In case of an oil spill, the Border Guard collects oil samples from water to identify the oil, and delivers the samples to the Forensics Laboratory of the NBI for analysis. When necessary, the Border Guard personnel will collect samples independently and send them to be analysed.

The Finnish Lifeboat Institution operates under the Ministry of the Interior and the Border Guard as a maritime rescue authority. The association provides search and rescue services to people in distress at sea, but also participates in other alert situations at sea. Members of the Finnish Lifeboat Institution are trained and able to collaborate with SYKE on environmental monitoring duties and tasks related to sample collection. Surface sampling has been tested with the type PV5 vessel Rautauoma off the coast of Helsinki. The vessel proved well-suited to collecting oil samples from water. Equipped with a 180-metre rope winch, the PV5 type vessel can also be used for benthic sampling. However, the necessary equipment for benthic sample collection, including the van Veen sampler, buckets, and a portable freezer, liquid nitrogen or dry ice for ecotoxicological samples, must be loaded aboard the ship. All other Finnish Lifeboat Institution vessels are also likely to be suitable for surface water sample collection. The Lifeboat Institution's vessels are located along the Finnish coasts (except Åland which is covered by the Ålands sjöräddningssälskap) which enables using the vessel(s) closest to the affected area for research purposes.

Access to the Tvärminne laboratory infrastructure for sample preparation and analysis is an asset when using the vessels of the University of Helsinki Tvärminne Zoological Station (Saduria, Clupea, and J. A. Palmén). The vessel Saduria is adapted for benthic and sediment sampling.

4.3

Collecting samples – Timing and targeting

Harri Kankaanpää, Heta Rousi

Basic principles for conducting ecological impact assessments in known affected areas and the surrounding waters:

1) The operations must not disturb oil spill response operations.
2) When collecting samples from research vessels, significant amounts of oil should not be detectable on the surface or in subsurface layers.
3) Field operations in different areas are to be conducted only after the oil slick has been recovered, or it has vaporised, sunk or drifted beyond Finnish territorial waters.
4) Benthic sampling from oil spill response vessels should not result in sample contamination.

For ÖVA purposes, samples are primarily not collected from the oil slick or using vessels which have been in contact with the oil slick. Oil spill response vessels may be used to collect benthic samples (in the main affected area), but sample contamination during sampling must be minimised. If samples can be collected without risk of contamination from oil in surface or subsurface water, the samples are suitable for use in the ecological impact assessment described in this action plan.

Ideally, baseline data will be available from several sea areas prior to a large-scale oil spill. Acute stage studies immediately following an oil spill are likely to require separately organised expeditions, unless Aranda or Muikku happen to be in the vicinity of the oil spill area and the research programme can accommodate changes to include oil sampling. Any changes must be cleared with the research vessel coordination groups and expedition leaders (see Appendix 1).

The annual coastal surveillance expedition in the Gulf of Finland by the vessel Muikku typically takes place during the first two weeks of August. The expedition involves collecting benthic, sediment, water and phytoplankton samples. Other sampling could be included, but this must be cleared with the expedition leader in advance. The vessel Aranda conducts several annual expeditions. The COMBINE 1 expedition is conducted in Finnish open waters in January or February and involves nutrient, hydrographic, oil concentration, zooplankton and invasive species monitoring. COMBINE 2 is conducted in Finnish open waters and the Baltic proper during May and/or June, and the expedition involves zoobenthos, hydrographic and benthic oxygen level monitoring. COMBINE 3 is conducted in Finnish open waters and the Baltic proper during August and involves salinity, oxygen level, nutrient, seawater oil concentration, phytoplankton and zooplankton measurements.

Generally, only vessels adapted for marine research are suitable for sample collection meeting quality criteria (including sediment and plankton samples). Such vessels also typically have facilities for sample post-processing and laboratory testing. However, all vessels can be used for seawater sampling, and other vessels should be employed if research vessels are not available.

4.4

Sampling rate and period

Harri Kankaanpää, Ulla Luhtasela

If an oil spill takes place during the seasonal phytoplankton bloom (March-May or July-August), a proportion of petroleum hydrocarbons will bind to the plankton. Under such conditions, it is necessary to analyse the plankton. When the plankton bloom is over, the remaining material will sink to the bottom, increasing the amount of petroleum hydrocarbons deposited on the seafloor. This should be noted when planning sediment sample collection.

Remote sensing, fluorescence monitoring and plankton species surveillance are used in determining the stage of phytoplankton bloom development.

If an oil spill occurs when the sea is frozen, samples of ice need not be collected, but the movements of the polluted ice should be taken into consideration when planning sample collections. If gaps are present in the polluted ice, sampling the zoobenthos may be possible, although the risk of sample contamination should be carefully considered.

Sampling under appropriate conditions:

When comparing results, it is important to use results from a matching season, i.e. results from samples collected in the winter are never compared with results from summer samples.

A. Seawater samples
    A1. First samples collected as early as possible
    A2. Samples collected every 1 to 2 weeks for the next two months
    A3. Samples collected once a month for the next six months
    A4. Samples collected 2 to 4 times a year for the next 5 to 10 years

B. Zoobenthos samples
    B1. First samples collected as early as possible
    B2. Samples collected one week from the oil spill (unless collected in B1)
    B3. Samples collected approximately every two months for one year
    B4. Samples collected approximately two times a year for the next 5 to 10 years

C. Littoral aquatic plant samples
    C1. First samples collected as early as possible
    C2. Samples collected approximately every two months for one year

  - C3. Samples collected 1 to 2 times a year for the next 5 to 10 years
- D. Sediment samples
  - D1. First samples collected as early as possible
  - D2. Samples collected approximately 2 to 3 weeks after the next algal bloom peak
  - D3. Samples collected approximately every 1 to 3 years for the next 5 to 15 years

- E. Plankton samples (if the oil spill occurs during or close to the phytoplankton bloom)
  - E1. First samples collected as soon as plankton is detected
  - E2. Samples collected approximately every 1 to 2 weeks during spring bloom until the summer bloom ends
  - E3. If the spring bloom is over: samples collected approximately every 1 to 2 weeks until the summer bloom ends
  - E4. One sample collection from next year's spring bloom

- F. Fish samples
  - F1. First samples collected as early as possible
  - F2. Samples collected approximately every 1 to 2 weeks for two months if increased PAH concentrations detected in fish (or heavy metals)
  - F3. Surveillance samples collected once a year from one or more fish species selected case-by-case, if necessary

Interruptions caused by prevailing conditions are allowed.

4.5

Seawater sampling

Harri Kankaanpää

When collecting seawater samples, it should be understood that the distribution of petroleum hydrocarbons in water is not necessarily homogeneous. Oil may be suspended in the water column, but undetectable from the surface.

Typically, ÖVA sampling is not conducted under conditions where the oil concentrations in seawater are significant (an oil slick or visible film). Using the available aerial surveillance and satellite data together with oil dispersion forecasts, seawater sampling is targeted at areas outside the oil slick or to areas where the surface oil has either vaporised or sunk deeper into the water column. Depending on the situation, seawater samples are collected in coastal waters and the open sea within the borders of the Finnish exclusive economic zone. If necessary, permission is obtained to continue operations extending to the exclusive economic zones of other countries.

Oil samples are collected in accordance with HELCOM COMBINE (SYKE guidelines). Seawater samples are collected from subsurface water and from a 1-metre depth. Provided the sampling site is deep enough, samples are collected from 10 metres, bottom depth /2 and bottom +1 metre. Sampling is preferably started from the deepest layers where possible. A Hydro-Bios sampling device or similar apparatus is employed to collect samples from over 10 metres.

In addition to the two parallel samples normally collected, a duplicate set of parallel seawater samples is collected from each sampling depth to accommodate more detailed hydrocarbon analyses, if possible. Prior to the analysis, the sample (1 litre) is stored at +4°C. Samples not used in HELCOM surveillance analyses can be acidified with mineral acid to pH 2.

If there is an apparent risk of sampling device contamination, special attention must be paid to clean-up of the samplers between each collected sample. Sampling must always be performed by trained professionals only.

According to the HELCOM COMBINE protocol (SYKE), samples must be analysed at the SYKE Marine Research Centre as soon as possible. The calibration area applied in the oil monitoring protocol is extended to a minimum of 5.0 µg/L.

When operating on ships other than Aranda which do not have onboard analysis equipment, sample extraction is initiated on site by adding the necessary amount of hexane.

Under the EVA's coordination, the Finnish environment authorities may decide on additional procedures for seawater sample collection.

4.5.1

Assessing the obtained results

Harri Kankaanpää

Results obtained from surface water samples should be compared with results from samples collected shortly before the oil spill, during the same season. Never compare results between winter and summer samples. No accurate reference data for samples from deeper layers are available, but surface water oil concentrations can be used as approximate reference points (see Table 3).

Table 3. Typical concentrations detected in various areas of the Baltic Sea in the 2000s and 2010s, applicable as reference points.

Region	Typical oil concentration between 2000 and 2012 (µg/L)
Bothnian Bay	0.4-0.7 (winter) 0.1-0.3 (summer)
Gulf of Bothnia (other areas)	0.3-0.8 (winter) 0.1-0.3 (summer)
Åland Sea	0.4-0.7 (winter) 0.2-0.3 (summer)
Northern Baltic proper (to the border of Finland's EEZ)	0.6-1.0 (winter) 0.2-0.5 (summer)
Gulf of Finland, West	0.5-0.7 (for a short period 1.4; winter) 0.2-0.5 (summer)
Gulf of Finland, Central	0.4-0.9 (winter); notable variations in concentration 0.2-0.5 (summer); notable variations in concentration
Gulf of Finland, East	0.3-1.0 (winter) 0.2-0.5 (summer)

Lower concentrations are detected towards the end of the period. In comparisons, surveillance data from the year 2012 should be included.

The most important threshold values for seawater contamination are 0.2, 1.0, 1.5 and 2.5 µg/L. See below for guidelines on how to interpret seawater concentrations obtained using the HELCOM COMBINE protocol.

If the oil concentration is 0.2 or 0.3 µg/L or less, it is considered low and no other conclusions should be drawn.

If none of the below criteria are met, the seawater is not perceptibly contaminated by oil.

If the concentration falls into the below range, but the stated percentages are not reached, the seawater contamination level can nevertheless be declared with an additional note stating that the oil spill has not induced a change in baseline oil concentrations.

- If the oil concentration in seawater is between 0.50 and 0.99 µg/L in winter and at the same time at least 50% greater than the average winter oil concentrations in the target area over the past five years, the analysed seawater is most likely **mildly contaminated by oil from the oil spill.**
- If the oil concentration in seawater is between 0.40 and 0.99 µg/L in summer and at the same time at least 100% greater than the average summer oil concentrations in the target area over the past five years, the analysed seawater is most likely **mildly contaminated by oil from the oil spill.**
- If the oil concentration in seawater is between 1.00 and 1.50 µg/L in winter, the analysed seawater layer is most likely **contaminated by oil in general**. If, additionally, the detected concentration in the target area is at least 50% greater than the average winter oil concentrations over the past five years, the seawater is most likely **contaminated by oil from the oil spill**.
- If the oil concentration in seawater is between 1.00 and 1.50 µg/L in summer, the analysed seawater layer is most likely **contaminated by oil in general**. If, additionally, the detected concentration in the target area is least 100% greater than the average summer oil concentrations over the past five years, the seawater is most likely **contaminated by oil from the oil spill**.
- If the oil concentration in a seawater sample is between 1.51 and 2.50 µg/L in summer, the analysed seawater layer is most likely **severely contaminated by oil in general**. If the detected concentration in the target area is least 100% greater than the average summer concentrations over the past five years, the seawater is most likely **severely contaminated by oil from the oil spill**.
- If the detected oil concentration in a seawater sample is between 1.51 and 2.50 µg/L in winter, the analysed seawater layer is most likely **severely contaminated by oil in general**. If, additionally, the detected concentration in the target area is least 50% greater than the average winter oil concentrations over the past five years, the seawater is most likely **severely contaminated by oil from the oil spill**.
- If the detected oil concentration exceeds 2.5 µg/L at any time while remaining less than 100% greater than the average oil concentrations in the same season over the past five years, the seawater is **very severely contaminated by oil and the oil from the oil spill has contributed to an increase in the baseline concentration.**
- If the detected oil concentration exceeds 2.5 µg/L at any time and is at the same time at least 100% greater than the average oil concentrations in the same season over the past five years, the seawater is **very severely contaminated by oil and the oil from the oil spill has contributed to a significant increase in the baseline concentration.**

Criteria specifications and other additional information:

- Results obtained from the sampling area are compared to earlier concentration results obtained from samples collected near the research site (preferably within a 5 nm radius).
- If this is not possible, use the general marine concentration ranges as reference (see Table 3).
- “Summer” refers to the period between April and September.
- “Winter” refers to the period between October and March.
- Useful additional information can be obtained from the aliphatic/aromatic hydrocarbon ratio of the mineral oil. This will contribute to a more accurate picture regarding the impacts of marine oil pollution on organisms for the overall assessment. **In the overall assessment, data obtained is combined with observations from impact and population assessments.**

- Hexane extracts from samples which have been discovered to be contaminated in accordance with the HELCOM COMBINE protocol are shipped to be analysed in more detail (hydrocarbon content analysis).

Example:
In June, two trained professionals collect seawater samples aboard a vessel operated by the Finnish Lifeboat Institution in the coastal waters of Porvoo, near Sondbytrasket. No oil film has been detected in the area. The oil concentration of the surface water is 0.8 µg/L. Over the past five years, the average concentration within a 2 nm radius has been 0.4 µg/L.

Conclusions:
Detected concentration in summer: 0.8 µg/L. Seawater not definitely contaminated by oil. The detected concentration is 100% greater than the reference value: (0.8-0.4) / 0.4 x 100% = 100%. The seawater is most likely mildly contaminated by oil from an oil spill.

4.6

Oil sampling and analysis in criminal investigations

Niina Viitala

This section only applies in situations where an ecological impact assessment is used to assist in a criminal investigation or to gain information on the oil type.

Oil samples sent to the forensics laboratory are typically samples of oil spilled into the sea and collected from the environment, and reference samples from the suspected source – a water sample and a bilge sample, for example. Oil samples are analysed to determine their content (light fuel oil, heavy fuel oil, lubricating oil, etc.). Identifying a single commercial product from an oil sample is difficult without a reference sample, because manufacturers change their oil compositions on a monthly basis.

The prevailing conditions may hinder the sampling process. Obtaining a representative sample from an oil spill site usually requires special equipment. Accessing the site may in itself be difficult, and collecting a reference sample from nearly empty tanks or very narrow pipelines, for example, presents challenges with respect to both the collector's professional skills and the sampling equipment.

Sampling equipment must always be thoroughly cleaned, unless disposable equipment is used. The oil composition may be different in the middle and at the edges of the accident area. Therefore, samples should be collected from different areas of the accident site. Preventing water and solids from entering the sample may be difficult. The optimal sample size for oil identification is 10 to 100 mL. Store oil samples in a sealed container, protected from light, at +4°C. Do not freeze oil samples. Glass jars are recommended, although they are easily breakable, which may in certain circumstances prevent their use as sample containers. If using plastic containers, use only HDPE containers internationally tested and approved for oil sampling.

An optimal sample comprises 100% oil. However, in practice, this is virtually impossible to accomplish in the field. Collecting oil into a container directly from a thin film on the water surface is a challenging task, as the oil tends to retreat from the container and the most common result is a container filled with water. Collecting the reference sample from a tank is often much easier. Effective use of the sampling container will also be affected by the physical distance to the sampling point, e.g., the distance from the ship to the sea.

The best method for sampling a thin film of oil is to use absorbing ETFE mesh. The material is lowered onto the water surface by means of a line or wire. The mesh only absorbs oil, not water. The ethylene tetrafluoroethylene (ETFE) mesh is then folded into a fireproof bag, a glass jar, or an HDPE container. Oil can be collected from a wide area using an ETFE mesh. It is recommended that the oil sample jars/containers are packed into fireproof bags in case of leaks.

Oils are likely to stain the sampling equipment and protective gear worn by the sampler. Make sure samples are not contaminated by oil from stained equipment.

Collected oil samples should be sent to the forensics laboratory without delay. Ensure the shipping temperature is correct. The oil samples in fireproof bags are packed into an ice chest containing ice packs. Use of soft ice chests which can be reshaped to take up less space in a shipping carton is recommended. If samples are delivered by mail, the shipping instructions of the Finnish postal service must be followed. One parcel can contain a maximum of 1 litre of oil, and the maximum container size is 0.5 litres. Fill the container to a maximum of ¾ to allow for thermal expansion. A further consideration when mailing samples is to ensure they will not be left standing at the post office. It is recommended that samples are delivered to the forensics laboratory directly.

Substances released into the environment can be dangerous to human health. Use protective gear, disposable gloves and a safety mask when collecting samples.

The forensics laboratory analyses oil samples according to the international standard CEN/TR 15522-2:2006 Oil spill identification. Waterborne petroleum and petroleum products. The method is applied in the comparison of samples collected from the environment (hydrocarbons C9 to C40) and the reference samples, and to identify the origin of the oil. Oil is identified as light or heavy fuel oil or lubricant oil. Concentrations, however, cannot be determined, as the method is qualitative. The threshold values for observed oil concentrations are estimated based on the detection limits. Detection limits have been determined for gas oil and heavy fuel oil, which are the most common oil sample findings. The detection limit for gas oil is 5 mL/L and for heavy fuel oil 5 g/L.

Dichloromethane is used to extract oil from soil, water, mesh and plant samples collected from the environment. The acquired extract or dilution is analysed using a flame ionization detector for gas chromatography. Chromatograms of the oil sample and the reference sample are compared, and if the visual outputs are similar, testing is continued with GC-MS. Weathering of the spilled oil – as described above – complicates the comparison process.

The below table can be applied as a tool to conclude whether the two samples analysed have the same origin. The classification comprises five result groups (see Table 4).

Table 4. Determining the probability of samples originating from the same source

Result Group	Probability	Definition
1.	Shared origin highly likely	In terms of identification, significant similarities and no notable differences were detected between the two samples. Weathering accounts for the detected differences. According to the analysis, the two samples are highly likely to originate from the same source.
2.	Shared origin likely	In terms of identification, similarities were detected between the two samples. Weathering could not account for all detected differences. Detected differences may be explained by uneven sample quality. Samples are unlikely to not share the same origin.
3.	Inconclusive	Based on the results, no conclusive results on the similarity and origin of the samples can be drawn.
4.	Shared origin unlikely	In terms of identification, significant differences and few similarities were detected between the two samples. Samples are very unlikely to be of shared origin.
5.	Samples are of different origin	Significant differences were detected between the two samples. Based on the results of the analysis, the two samples are from different sources.

The Forensics Laboratory of the NBI is an accredited laboratory using accredited methods for oil sample analysis. Analyses by the forensics laboratory always aim at identifying the oil sample and its source. The forensics laboratory determines the type of oil contained in the sample (e.g. gas oil, heavy fuel oil, crude oil, lubrication oil, vegetable oil, etc.). Before the Border Guard can impose an administrative oil pollution fee, it is necessary to confirm that the oil discharged is mineral oil. The analysis method is applied to compare two samples and determine whether they share the same origin.

The forensics laboratory runs laboratory tests in crime and accident investigations to determine the course of actions and to provide data supporting guilt or innocence. The vast majority of its clients are preliminary investigation officials, although other authorities also use the laboratory's services. The services of the forensics laboratory are free of charge.

Oil being cleaned from ice (Photo: Jouko Pirttijärvi/SYKE).

4.7

Sediment sampling

Harri Kankaanpää

The preferred sample collection method involves the use of automated sediment traps (with programmable sampling intervals and periods) deployed from a research vessel and with a relatively large catch area (preferably approximately 1 m^2). The traps can be deployed if the water surface has no significant oil film or layer. The optimal installation period in the Baltic Sea is just prior to the next spring or summer bloom. To avoid collection of suspended solids, the trap should be deployed at a depth of least 10 metres from the bottom and at least 10 metres from the surface. An optimal installation site is above an active depositional basin in an area where water currents and maritime traffic is reduced. Time is not an essential parameter, hence, the sampling time per sediment trap bottle can be 2 to 4 weeks. This period is usually sufficient to collect enough sample material for chemical analysis. During equipment installation, the sample bottles are filled with seawater. If the samples contain preserved biological specimens, these can be analysed for different planktonic species (never add formalin to the samples). The sample containers must be stored in a cool place or frozen after sample collection (sediment traps retrieved from the sea).

4.7.1

Collecting sediment samples

Harri Kankaanpää

Sediment samples are collected from the seafloor within the affected area at a site suitable for sediment sampling (mud or sludge). Figure 7 shows a typical sounding example of structural variations in the Baltic Sea (Gulf of Finland) floor. If the quality of the seafloor is not known, it must be determined using hydroacoustic devices. Sediment samples are collected at sea from a research vessel equipped with dynamic or similar steering. The sampling site should be selected based on known sedimentation – areas subject to erosion or migration are not acceptable. Information on seafloor quality is available from Finnish sediment studies and from parties responsible for maintaining relevant databases. Selecting target areas within the affected region where the sedimentation rate is high is recommended. When collecting samples, use several active sedimentation points to obtain a comprehensive overview of the distribution of harmful substances in the soft sediment layers.

Sediment concentrations of harmful, oil-derived substances should be determined over a period of several years. Collecting samples immediately after an oil spill is essential, but afterwards samples need not be collected very often – in areas with rapid sedimentation, sampling intervals of 1, 3, 6 and 10 years after the oil spill should suffice. Decisions on follow-up sampling are made based on previous observations. When the sedimentation rate is slow, the respective sampling intervals (following the immediate sample collection after the sedimentation peak) can be 2, 5 and 12 years.

Samples are collected using gravity corers with a core tube minimum inner diameter of 7 to 8 cm. Sampling is performed in accordance with the valid instructions. The sediment layer is divided into subsamples 0.2 to 1 cm thick. Harmful substances originating from the spill and deposited on the seafloor are best detected from the top sediment layer which should, therefore, be sampled with extreme caution. Usually, the applied interval is 1 cm. However, provided it is possible with the dividing equipment and known sensitivity of the chemical analysis, a top sediment sample of 0.2 to 0.5 cm thickness can be collected to ensure that the most recent sediment material can be examined separately and that recent changes can be differentiated from the earlier chemical status. A sufficient number of sediment samples are collected for each analysis (hydrocarbon quantification). The appearance of the sediment samples

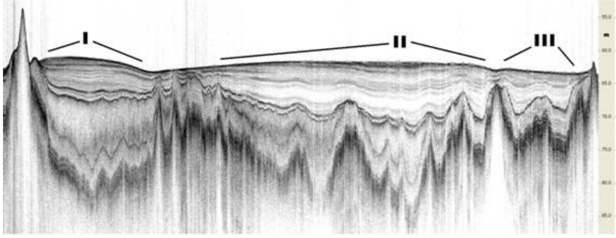


Figure 7. Structural variation in the seafloor of the Gulf of Finland. The horizontal range in the image (x axis) is approximately 2 nautical miles, and the depth is 85 meters. Soft sediment optimal for sampling is found at locations I, II and III. In the other areas of the image, currents/erosion carry the majority of sinking particles elsewhere.

(lack of oxygen) is assessed. Biological and biochemical responses are not determined from the sediment samples. As the total organic carbon concentration (TOC) greatly affects the intensity of hydrocarbon accumulation, this should be determined from the sediment samples. Analysis results are compared with baseline data from corresponding areas. Oil-derived compounds will most likely also be detected in the deeper sediment layers before the baseline level is reached.

More comprehensive sediment sampling can be performed at mud and sludge sites in the affected region by sampling deeper than the original 0.5 cm depth, to around 5–40 cm. An optimal sampling site for a more extensive sample series is one that has been in the affected area for a prolonged time, and where sedimentation has been continuous as demonstrated by echo soundings (as thick as possible pack of recent sediment layers). These extensive sample series are useful for determining background hydrocarbon levels to be applied as a reference against those obtained from the surface sediment samples. Ideally, the ages of the sediment layers are determined using radio isotope dating. Samples should be stored without delay at -78°C and analysed as soon as possible after collection. Sample collection should be carried out by trained professionals.

4.8

Sampling the benthos

Heta Rousi

Sampling stations should be sufficiently densely located to ensure adequate coverage of the habitats in the target area. The minimum requirement is to cover the different depth zones. If habitat mapping data is available for the area (see Section 3.9), sampling should be targeted at known habitats. See Section 4.4 “Sampling rate and period” for information on how often samples should be collected after an oil spill. To determine the effects of oil on the distribution and abundance of benthic fauna, it is essential to compare the benthic situation and oil concentration in the benthos after an oil spill to the situation preceding the accident. If no baseline data is available for the affected area, comparisons can be made against a reference area with a similar ecosystem. However, because oil sedimentation is slow and takes days if not weeks, baseline levels can be determined immediately after an oil spill.

Samples of the benthic organisms are collected after an oil spill preferably from research vessels specifically adapted for sampling purposes – Aranda and Louhi for sampling in open waters, and Muikku for sampling in coastal regions. Alternatively, the research vessel Saduria operated by the University of Helsinki Tvärminne Zoological Station or the PV5-grade watercraft of the Finnish Lifeboat Institution can be used for benthic sampling (see Sections 4.2.1 and 4.2.2).

The applied sampling method must be comparable with previous samples. Hence, the HELCOM COMBINE instructions on collecting benthic samples (HELCOM, Annex C-8) must be followed. The instructions can be downloaded at: http://www.helcom.fi/groups/monas/CombineManual/AnnexesC/en_GB/annex8.

To ensure comparability with other benthic population studies, use 0.5 mm and 1 mm sieves.

In the collection, storage and analysis of benthic samples, the HELCOM guidelines on studying and monitoring the effects of harmful substances (downloadable at: http://www.helcom.fi/groups/monas/CombineManual/PartD/en_GB/main/) must be taken into consideration. For examples of suitable indicator species, see Section 3.10: “Organisms suitable for impact assessment and their distribution”.

Aerial image of an oil spill and response operations (Photo: Finnish Border Guard)

4.9

Planktonic samples

Heta Rousi

The species composition and size of zooplankton and phytoplankton communities exposed to an oil spill are compared to populations outside the affected area and to the situation in the affected area prior to the oil spill. For instructions on sampling rate, see Section 4.4 "Sampling rate and period".

Zooplankton should be sampled by means of vertical hauls (approximate speed 0.5 m/s) using a WP-2 net of 100 µm mesh size. Sampling is conducted according to the HELCOM instructions on zooplankton sampling (HELCOM Annex C-7), which can be downloaded at: http://www.helcom.fi/groups/monas/CombineManual/AnnexesC/en_GB/annex7/.

It is recommended to take phytoplankton samples from the 0–20 m water column using a plankton net with a 10 µm or 25 µm mesh size (larger in the case of higher phytoplankton concentrations). Sampling is conducted according to the HELCOM instructions on phytoplankton sampling (HELCOM Annex C-6), which can be downloaded at: http://www.helcom.fi/groups/monas/CombineManual/AnnexesC/en_GB/annex6

In case aliphatic hydrocarbons are measured from planktonic samples, the HELCOM guidelines on studying and monitoring the effects of harmful substances (downloadable at: http://www.helcom.fi/groups/monas/CombineManual/PartD/en_GB/main/) can be followed. However, plankton is not generally included as target organisms for measurement of harmful substances.

4.10

Other sampling to study the impacts on organisms

Heta Rousi

Plant and macro algae samples can be collected from oiled areas for hydrocarbon analysis. In the collection, storage and analysis of biological samples, the HELCOM guidelines on studying and monitoring the effects of harmful substances (downloadable at: http://www.helcom.fi/groups/monas/CombineManual/PartD/en_GB/main/) are followed.

For example, WWF and SYKE specialists may collect samples of oiled birds to determine how much oil the birds have accumulated during the accident. The overall condition of the birds is noted in the patient records. The WWF also shares information from its own observations and measurements on the impacts of oil on the ecosystem (especially regarding birds and seals). To obtain this information, the person in charge of the ÖVA Group should contact the WWF contact person (for contact details, see Appendix 1). The WWF files a report on its observations concerning the impacts of the oil spill on the ecosystem with special reference to birds. SYKE is in charge of all other communication.

4.11

Collecting fish samples

Ulla Luhtasela, Pekka J. Vuorinen

The Finnish Food Safety Authority Evira is responsible for conducting research on Finnish food-fish species to determine their safety for human consumption. The Finnish Game and Fisheries Research Institute RKTL collects and sends samples to Evira according to Evira's instructions. RKTL also collects samples for its own use. Evira also obtains additional samples from local fish farms, if necessary. Samples from fish farms are collected in collaboration with the municipal food control authority.

Fish samples must be collected according to Commission Regulation 333/2007 (and its amendment 836/2011) for legal comparisons of PAH and heavy metal concentrations detected in fish after an oil spill, and for local mapping of the situation.

Pooling, where several base unit samples form a representative combination sample, is the basic principle applied in fish sampling. A base unit sample comprises individual specimens. At least three base unit samples are combined to form a combination sample weighing at least 1 kg. In the case of large fish, base unit samples weighing a minimum of 100 grams are removed from the middle sections of the fish and compiled to form a combination sample weighing a minimum of 1 kg. Sampling instructions include guidelines on how to handle the samples during collection and analysis.

Samples collected for PAH determination must be protected from light and the use of plastic containers (black plastic bags, in particular) should be avoided, as these may affect the PAH concentrations.

Samples are also collected for sensory evaluations to determine the commercial quality of a fish by its appearance, texture, smell and taste. Sensory evaluations complement the data obtained by chemical analyses to determine whether the fish can be recommended for human consumption. Sensory evaluations reduce the need for chemical analyses. Proper storage of the samples is especially important to avoid fish quality deterioration prior to the sensory evaluation. Furthermore, the sample size must be sufficiently large (at least 2 kg comprising a minimum of three whole specimens), as the samples will be evaluated both raw and cooked.

4.11.1

Practical instructions for the sampling of fish for chemical analyses

Ulla Luhtasela, Pekka J.Vuorinen

Fish are caught from the area suspected of pollution and grouped into samples according to the instructions below:

1. One combination sample comprises approximately 1 kg of specimens from the same species and of about the same size (base unit samples); a minimum of three fish per sample.
2. The sample fish are measured and weighed, their gender detemined and an appropriate ossification (e.g. scale) extracted for age determination and placed in a small paper bag which is labelled.
3. If the fish are large, remove the middle sections to assemble a combination sample weighing one kilogram.
4. All base unit samples belonging to a combination sample are packed in aluminium foil or a paper bag. The foil wrap or paper bag is then inserted into a plastic bag with a sampling certificate. Use food-grade plastic bags.
5. Carefully add the following information on the sampling certificate:
   a. sampling date and time
   b. sampling site
   c. species (in both Finnish and Latin, if possible)
   d. number of specimens contained in the sample
   e. weight and length of each specimen
   f. details of the person who collected the sample
   g. age and gender of the specimens determined
6. Store the samples in a refrigerator (at 0°C to 3°C) until they are shipped to the laboratory. If shipping to the laboratory takes over 48 hours, freeze the samples and store at -20°C. Make sure the samples remain frozen during shipping.
7. Sending the samples to a laboratory (Evira, Customs Laboratory or MTT Agrifood Research Finland) must be arranged in advance.

4.11.2

Practical instructions for the sampling of fish for sensory evaluations

Ulla Luhtasela, Pekka J.Vuorinen

Fish are caught from the area suspected of pollution and grouped into samples according to the instructions below:

1. One combination sample comprises a minimum of three whole fish of the same species and of about the same size.
2. The sample fish are measured and weighed, their gender determined and an appropriate ossification (e.g. scale) extracted for age determination and placed in a small paper bag which is labelled.
3. The minimum sample size is 2 kg. If a sample comprising three whole fish weighs under 2 kg, the number of specimens is increased.
4. All specimens belonging to a combination sample are packed into a Styrofoam chest filled with ice and stored frozen (the sample fish are submerged in ice).
5. If packing and storing frozen samples is not possible, wrap the samples in aluminium foil or insert into a plastic bag. Fish samples wrapped in foil or inserted into a plastic bag are then inserted into a plastic bag with a sampling

certificate. Use food-grade plastic bags and aluminium foil, and ensure the samples are not tainted by external odours or flavours.

6. Carefully add the following information on the sampling certificate:
   a. sampling date and time
   b. sampling site
   c. species (in both Finnish and Latin, if possible)
   d. number of specimens contained in the sample
   e. weight and length of each specimen
   f. details of the person who collected the sample
7. Store the samples in a refrigerator (at 0°C to 3°C) until they are shipped to the laboratory. If shipping to the laboratory takes over 48 hours, freeze the samples and store at -20°C. Make sure the samples remain frozen during shipping. Make sure frozen samples do not thaw during shipping. Monitor the temperature during shipping using a temperature data logger, for example.
8. Samples are sent to Evira's laboratory for analysis.

4.12

Eligibility of fish for human consumption

Ulla Luhtasela

Sensory quality evaluation

The appearance, texture, smell and taste of fish are assessed by sensory evaluation. These characteristics are scored according to their deviation from a perfect sample as follows.

Scoring
5 very good compared to a flawless fish
4 good compared to a flawless fish
3 satisfactory compared to a flawless fish (minor flaws)
2 not good compared to a flawless fish (definite flaws)
1 very poor compared to a flawless fish (major flaws)
(0 not suitable for human consumption)

If, according to the sensory evaluation, the fish quality is significantly deteriorated (e.g. due to an oil spill), the fish is not recommended for human consumption. If the score is 2 to 0 points, this is an indication of significantly deteriorated quality. Using such low quality fish for human consumption can be forbidden in accordance with Article 14 of Regulation 178/2004.

Contaminants

Chemical risks cannot always be determined by sensory evaluations, and hence, chemical analyses are also necessary. PAHs are the most important oil-derived groups of compounds affecting food. The accumulation of certain heavy metals, such as mercury, lead, cadmium and arsenic, in fish may limit their use for human consumption. Maximum contaminant levels in fish have been defined in Commission Regulation No 1881/2006 and its amendments, setting maximum levels for certain contaminants in foodstuffs. The maximum level of mercury (Hg) is 0.5 mg/kg, lead (Pb) 0.3 mg/kg and cadmium (Cd) 0.05 mg/kg. An acceptable maximum level has not been determined for arsenic.

Benzo(a)pyrene (B(a)P) is the only PAH with a maximum level in fresh fish (2 µg/kg) defined in Commission Regulation No 1881/2006. Amendment 835/2011 to Regulation No 1881/2006 states that PAHs are rapidly metabolised and do not accumulate in fish. Hence, the maximum levels for PAHs in fresh fish are no longer validated.

The threshold value for B(a)P (2 µg/kg) can, however, be used as an indicator of oil-derived contamination when evaluating fish for human consumption. In the case of an oil spill, contamination by PAHs other than B(a)P should be examined and their concentrations considered when evaluating the use of fish for human consumption.

Environmental quality norms for organisms are defined in the Priority substances directive (2008/106/EC) of the European Parliament and Council. According to the Directive, the allowed maximum level of benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene and indeno(1,2,3-cd)pyrene in fish is 2 µg/kg.

If such PAH concentrations are detected in fresh fish, oil contamination is highly probable, as under normal conditions PAH concentrations do not reach such high levels in fish. It is impossible to examine fish for all harmful, oil-derived compounds. However, when PAH concentrations in fresh fish rise to the levels detected in smoked fish, oil contamination is highly probable and the fish is not recommended for human consumption.

According to the Finnish Food Act 23/2006, the primary responsibility for food safety is borne by the food business operator. A food business operator must ensure the safety of food to consumers by means of in-house inspections, including chemical analyses. The food business operator is further responsible for ensuring that fish products sold, processed or delivered do not originate from an oil spill area. Random test surveillance by food authorities and restrictions imposed on fishing do not eliminate the operator's responsibility for ensuring the safety of his/her products.

4.13

Responses at the molecular and cellular levels

Kari Lehtonen

Petroleum hydrocarbons are so complex that their effects at the molecular and cellular levels vary a great deal depending on the structure of the compounds. However, it is important to recognise that the total effect is the sum of several, indistinguishable effects by numerous different compounds.

The following responses at the molecular and cellular levels have been applied to monitor the biological impacts of some recent major oil spills (*Exxon Valdez*, *Erika* and *Prestige*) on living organisms. In recent years, they have also been tested in detecting the effects of harmful substances on the Baltic Sea communities, and in determining local reference levels.

Accelerated detoxification

Exposure to several harmful organic compounds, including PAHs, causes an increase in cytochrome P_{450} system activity. The first stage of biotransfer of compounds occurs in this enzyme complex and results in metabolites and reactive oxygen species. In environmental monitoring, this biomarker has been measured since the 1970s using 7-ethoxyresorufin-O-deethylase (EROD). EROD activity in fish is measured from deep-frozen liver samples. EROD activity determinations are performed by RKTL and SYKE.

Genotoxicity

One of the most sensitive biomarkers of exposure is the increased density of cellular micronuclei, indicating genotoxic effects. In marine environments, PAHs have been shown to cause the number of micronuclei to increase. Microscopy is used to determine the density of micronuclei, and several different cells (liver, blood, gill, kidney, etc.) from various organisms (fish and mussels, in this case) can be used for the determination. In Finland, micronuclei density determinations are currently carried out in hospitals only, but the method is easy to adopt. Samples used for micronuclei determination may also be used for determining other indicators of genotoxicity. The method does not require cold storage and is recommended for implementation as a biological impact monitoring parameter in the Baltic Sea by the HELCOM CORESET project.

Oxidative stress

Detoxification always results in increased cellular reactive oxygen levels. To neutralise these reactive oxygen species the cellular antioxidant defence system is induced, which is reflected in the increased activity of the so-called oxidative stress biomarker enzymes. Existing methods include determining catalase, glutathione reductase, superoxide dismutase, glutathione peroxidase and glutathione-S transferase, which is also related to activated detoxification. The amount of lipid peroxidation reflecting the failing of antioxidant defence can be employed as a biomarker. In Finland, these determinations in marine populations are conducted by SYKE, RKTL and the Turku University Department of Animal Physiology.

5 Assessing the chemical and ecological status of marine environments

Ulla Luhtasela

A suggested update to the EC Directive on water policies includes environmental quality norms for specific PAHs.

Mussels are known to effectively accumulate PAHs from water, but do not possess the metabolic capacity to degrade them. Fish, such as the European flounder, and birds, such as common eiders, feeding on benthic organisms become contaminated by PAHs over time. Official examinations are performed to map areas where concentrations in fish and other seafood rise to levels requiring restrictions on fishing (Scientific Committee on Food 2002).

5.1

Chemical assays

5.1.1

Assays on PAHs and aliphatic hydrocarbons

Harri Kankaanpää

Hydrocarbons are analysed from the samples delivered to the laboratory as soon as possible. The laboratories are responsible for adequate sample storage. The sample amount required for laboratory assays (number of specimens, amount of tissue or total weight) must be confirmed in advance from the analysing laboratory. This kind of preliminary information must be confirmed before initiating field studies, and taken into consideration during sample collection.

PAH and aliphatic hydrocarbon concentrations are determined from solid samples, in particular, and selected seawater extracts when possible. The results are applied in estimating the number of PAHs representing different levels of toxicity present in the samples. In the future, the results are proportioned to responses from impact assessments.

Concentrations of aliphatic compounds containing 7 to 40 carbon atoms are determined from all sample types, if possible. The extent to which aliphatic hydrocarbons originating from the oil spill, in particular, are transferred to the analysed sample, is determined based on the results. These results may be further reviewed against the distribution and concentrations of hydrocarbons discovered in forensic investigations.

Performing the above-mentioned chemical assays can be cost-effectively divided between the different stakeholders. An example is given in Table 5 below.

Table 5. A summary of the matrices, parameters and methods employed in impact studies. [1] Evira performs sensory evaluations of the deterioration of fish. For contact details of the different laboratories, see Appendix 1 (last updated on 31 March 2012).

Matrix	**Parameter**	**Method**	**By:**
Seawater	Total oil concentration	Spectrofluorometry	SYKE Marine Research Centre
Seawater	Aliphatic hydrocarbons and PAHs	Gas and/or liquid chromatography	SYKE LAB or outsourced
Zooplankton/ phytoplankton	Aliphatic hydrocarbons and PAHs	Gas and/or liquid chromatography	SYKE LAB or outsourced
Sediment matter (seston)	Aliphatic hydrocarbons and PAHs	Gas and/or liquid chromatography	SYKE LAB or outsourced
Benthos	Aliphatic hydrocarbons and PAHs	Gas and/or liquid chromatography	SYKE LAB or outsourced to e.g. Metropolilab
Sediment layers	Aliphatic hydrocarbons and PAHs	Gas and/or liquid chromatography	SYKE LAB or outsourced
Littoral plants	Aliphatic hydrocarbons and PAHs	Gas and/or liquid chromatography	SYKE LAB or outsourced
Food fish	PAHs and heavy metals[1]	Gas and/or liquid chromatography, ICP/AAS	Evira or outsourced

6 Total impact assessment reports

Harri Kankaanpää, Heta Rousi

To determine the total impact of harmful substances, factors indicative of an oil spill including biomarkers, population changes and concentrations of various compounds are reviewed to obtain an overall understanding of the severity of an oil spill.

The most important phenomena for assessing the total impacts of oil, include population changes observed after an oil spill and evidently caused by the oil spill. Population changes can be measured by changes in the size of the entire population, changes in age distribution, or changes in the number of young (or eggs, for example). Attention is focused on various target populations, and the severity of changes in the different species is evaluated. After the investigations, an assessment of the total impact on the entire ecosystem is performed. A severity index depicts the total impact of an oil spill on an ecosystem.

Biomarkers, for example, are internationally used when assessing the total impact of harmful substances. Laboratory tests are used to determine the impacts of different concentrations of various compounds, such as hydrocarbons, on different organisms (Peakall 1994, http://www.springerlink.com/content/m0223417n37v2989/fulltext.pdf).

A total impact assessment is annually conducted until the oil spill follow-up studies are completed. A calculation model based on a weighted combination of different parameters is employed in total impact assessments. For example:

$$K = \frac{1}{3}\left(\sum_{i=1}^{n} P_i\, p_i\, n^{-1} + \sum_{j=1}^{m} V_j\, v_j\, m^{-1} + \sum_{k=1}^{o} C_k\, c_k\, o^{-1}\right)$$

where K = impact intensity index (value range from 0 to 1; 0 = no effects, 1 = significant effects)

n = number of incidents in population impact
P_i = change in population i using a scale from 0 to 1 (0 = no change; 1 = severe change)
p_i = weighing factor (0-1) for each population change in the total assessment

m = number of biological response parameters
V_j = change in biological response using a scale from 0 to 1 (0 = no change; 1 = severe change)
v_j = weighing factor (0-1) for each biological response in the total assessment

o = number of relevant chemical compounds (e.g. most toxic PAHs) in the assessment
C_k = concentration of relevant chemical compounds from 0 to 1 (0 = not detected 1 = concentrations greatly exceeding threshold limits)
c_k = weighing factor (0-1) for concentrations of relevant chemical compounds in the total assessment

7 Reporting and communications

Harri Kankaanpää, Ulla Luhtasela

Members of the ÖVA Group hand the obtained results and drawn conclusions to the responsible party (SYKE). Interim reports covering the different sectors are required in addition to the final report. Evira, for example, informs consumers about possible restrictions on fish consumption on its Web pages and publishes announcements in real time.

The responsibilities of SYKE:
- Informing about the oil spill and impact assessment.
- Summary report based on all results, explaining the background to the oil spill and its detected effects over a selected time period.
- Report publicly distributed in electronic format.
- Report published in BORIS.
- Information on the effects of oil spills based on observations delivered to those responsible for communication and information sharing.

7.1

RASFF – The European Rapid Alert System for Food and Feed

Ulla Luhtasela

The Finnish Food safety Authority Evira is the Finnish contact point of the EU Rapid Alert System for Food and Feed (RASFF). Other members include the European Commission (DG SANCO), the European Food Safety Authority (EFSA), and the member states. The member states notify the Commission about food and feed batches harmful to health. The Commission then checks the notification before making it available to the other member states for information and corrective action. The RASFF enables rapid notification of the effects of an oil spill on foodstuffs if deemed necessary by research results.

8 Funding

Harri Kankaanpää, Heta Rousi

As a general rule, direct ÖVA expenses incurred by an oil spill are initially covered by SYKE funds. Additional funding is obtained from international funds, if necessary. Expenses include all costs incurred to the participants as well as outsourcing costs (laboratory services) related to the response operations (see Tables 6 and 7). The Finnish government recovers the expenses in full from the responsible party for the oil spill after possible legal proceedings. Oil spills trigger response operations which, in turn, trigger investigation operations for which the polluter is liable. As such, the polluter is also liable for the costs of impact assessments. The International Tanker Owners Pollution Federation Limited (ITOPF) requires an impact assessment plan in order to decide on funding. Therefore, the research plan must be prepared as soon as possible, during the initial stages of ÖVA operations.

The estimated vessel expenses are based on the organisation of the first two investigative expeditions by Finnish research vessels. The estimated total duration is two weeks of full-time field work. Additional samples are collected on 5 to 10 other occasions during the first year. In the following years, the annual sampling and analysis is reduced to 20% of the initial year.

Two years from the oil spill, at the latest, the impact assessment studies can be included in the agenda of other expeditions (such as HELCOM COMBINE surveillance) which will significantly reduce the sampling costs (to 1 to 2 additional days on a research vessel per expedition).

Besides the vessels, the second largest expenditure is incurred by chemical analyses of the sediment, water and organism samples. The chemical analyses may be performed by the laboratories of the research institutes or outsourced, for example, to Metropolilab. Based on the 2012 price level, PAH analyses performed by MetropoliLab cost EUR 120 per water sample, EUR 90 per sediment sample and EUR 200 per biological sample (excluding VAT). The cost of PAH analysis of food fish performed by Evira’s laboratory is EUR 443.42 per sample (VAT EUR 82.92) when outsourced. However, if the analyses are part of Evira’s mapping process, no additional costs incur from ÖVA operations. Evira only performs analyses on food fish.

The total annual oil spill surveillance costs after the first year are estimated at 20% of the costs incurred during the first 12 months of the oil spill (see Sections 4.3 and 4.4). If environmental monitoring were continued for approximately five years, total costs for the period would not exceed EUR 700.000, as shown in the table below.

Vessel expenses are based on the assumption that one day costs approximately EUR 20.000. The cost of chemical PAH analyses by SYKE during the year of the oil spill are based on an estimated sampling at 10 stations in the affected area over approximately 10 expeditions per year resulting in a total of 100 combination samples of mussels. SYKE’s estimates of the number of biochemical analyses is based on samples collected at 300 stations per year (three duplicates from each station, total number of analyses 900 and price/per sample 100 €). The annual vessel expenses during the follow-up years are based on the inclusion of sampling in the agendas of other expeditions, which results in approximately 4 additional days. Other annual costs incurred in the follow-up years are based on an estimated 80% decrease in the number of studies compared to the first year.

The Finnish Navy's multipurpose vessel Louhi (Photo: Jukka Pajala).

Table 6. Estimated costs of ÖVA operations during the first 12 months of the oil spill. RKTL's exposure tests and biochemical assays are not included here. Cost estimates are based on 2012 price levels.

Type of Cost	**Research costs (€), year of occurrence**
Assembling the response group, operation	no additional costs (except possible overtime)
Sampling, equipment procurement and maintenance	approx. 5.000
Research vessels Aranda and Muikku (total of two weeks +)	approx. 280.000
Louhi multipurpose vessel (2 to 3 days)	max 50.000
Additional costs from other vessels (fuel costs etc.)	max 20.000
SYKE sampling (additional costs incurred from daily allowances) Benthos counts (overtime)	approx. 4.000 approx. 10.000
HELCOM seawater oil analyses	approx. 1.000
Reporting	approx. 5.000
Communications	no additional costs (except possible overtime)
Overtime in YM facilities	approx. 10.000
Operations, excluding Finland's environmental administration	max 10.000
Chemical analyses (PAH) Biochemical analyses by SYKE	max 25.000 approx. 100.000
Other biological response measurements by the ÖVA Group	approx. 50.000
Total	**max 570,000**

Table 7. Estimated annual costs of ÖVA operations over a period of 2 to 6 years following the oil spill (over 12 months from the accident). RKTL's exposure tests and biochemical assays are not included here. Cost estimates are based on 2012 price levels.

Type of Cost	**Research costs (€), year of occurrence**
Assembling the response group, operation	no additional costs (except possible overtime)
Equipment acquisition and maintenance	approx. 1.000
Research vessels Aranda and Muikku 2 x 2 additional vessel days per year)	approx. 80.000
Louhi, multipurpose vessel	approx. 10.000
Additional costs from other vessels	max 4.000
Sampling by SYKE (personnel expenses)	max 8 00
HELCOM seawater oil analyses	max 2 00
Reporting	max 1.000
Communications	no additional costs (except possible overtime)
Overtime in YM facilities	max 2.000
Operations, excluding Finland's environmental administration	max 2.000
Chemical analyses (PAH) Chemical analyses by SYKE	max 5.000 approx. 20.000
Other biological response measurements by the ÖVA Group	approx. 10.000
Total	**max 135 000**

SECTION C

9 Need for further assessments

Harri Kankaanpää, Heta Rousi

Baseline concentrations are useful for determining the situation prior to an oil spill. Baseline data is available for total surface water oil concentrations in open waters (surveillance data from coastal areas is not available). Sufficient information regarding intermediaries and parameters (other than biological responses describing organism health status) related to ÖVA operations is not available for any area.

The annual coastal surveillance by Muikku, and Aranda's HELCOM COMBINE monitoring 2 to 3 times a year are employed for baseline assessment. Both vessels collect samples and gather the total oil concentration data required for baseline analyses. Other analyses are performed on land.

9.1

Baseline analyses of hydrocarbons and biological responses in selected species in 2013 or 2014

Samples of organisms are collected in Finnish territorial waters in connection with annual SYKE surveillance expeditions (Aranda and Muikku) for biomaterials other than fish (collaboration with RKTL and Evira for baseline studies of fish). Chemical analyses of samples are performed either by SYKE or the Metroplilab laboratory. Biological response baseline levels for organisms (*Mytilus trossulus* and *Macoma balthica*) are determined by the SYKE Marine Research Centre.

SYKE's research vessel Aranda (Photo: Jan-Erik Bruun/SYKE).

9.2

Baseline concentrations in coastal waters

Coastal waters are not included in the HELCOM COMBINE programme. Samples for the baseline concentrationn assessment are collected from the Gulf of Finland during Muikku's annual surveillance tours. Samples from other sea areas are collected from Aranda where the depth is sufficient. In shallow waters, the Border Guard and Lifeboat Institution watercraft are employed. Aranda can also be deployed to collect additional water samples from the open sea.

Total oil concentrations can be immediately determined onboard the Aranda. Samples collected from other vessels are analysed either in the Aranda laboratory or at the SYKE Marine Research Centre laboratory.

9.3

Estimated costs

The estimated costs incurred by the baseline assessment data gathering expeditions are shown in Table 8. The costs of analysing PAH in seawater, organism and sediment samples are based on an estimated 20 water samples (20 areas) and 30 organism samples (30 areas) for each group of organisms (zoobenthos, fish, zooplankton, phytoplankton aquatic plants/algae). Costs are based on the prices listed in Section 8. The cost of measuring biological responses is based on the assumption that 30 stations are involved in biomarker studies and 100 analyses worth EUR 100 each are conducted on samples collected at the stations.

Table 8. Estimated costs of the baseline studies. Estimated expenses based on 2012 price levels.

Type of cost	Research costs (€)
Research vessel Aranda (Gulf of Bothnia, Archipelago Sea, Northern Baltic proper, Gulf of Finland - approx. 4 additional days)	approx. 80.000
Research vessel Muikku (Gulf of Finland, approx. 2 additional days)	approx. 20.000
Onboard sampling and analyses (additional daily allowances)	approx. 1.000
HELCOM seawater oil analyses (additional reagent costs)	approx. 5 00
Additional costs from other vessels (fuel)	approx. 5.000
PAH analyses (seawater, organisms, sediment)	approx. 26.400
Measuring biological responses	approx. 20.000
Total	**approx. 152.900**

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Appendix 1.
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Major vessel operators (last updated 31 March 2012)

SYKE - Research Vessels Aranda and Muikku	Finnish Navy - Multipurpose Vessel Louhi	HY - Research Vessels Saduria, J.A. Palmén and Clupea	Finnish Border Guard - Aircraft and Watercraft	Finnish Lifeboat Institution - Vessels
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Supportive functions (last updated 31 March 2012)

Finnish Meteorological Institute - Oil Slick modelling	Border Guard - Aerial surveillance	VELMU - Habitat information	National Bureau of Investigation	WWF - Field operations
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Oil spill response		**BORIS**		
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Laboratories (last updated 31 March 2012)

SYKE Research and Innovation Laboratories	MetropoliLab
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DOCUMENTATION PAGE

Publisher	Finnish Environment Institute (SYKE)			*Date* December 2012
Author(s)	Heta Rousi and Harri Kankaanpää (Eds.)			
Title of publication	**The ecological effects of oil spills in the Baltic Sea – the national action plan of Finland**			
Publication series and number	Environmental Administration Guidelines 6en/2012			
Theme of publication	Nature			
Parts of publication/ other project publications				

Abstract

When oil enters the sea as a result of an oil spill it causes both immediate and long-term changes in the biotic and abiotic environments. This publication is the first uniform Finnish national plan of action in the case of large-scale oil pollution incidents. For this report, a working group comprising researchers, experts and authorities has compiled essential current information on the impact of oil on marine ecology as well as guidelines on how to conduct research and sampling. Furthermore, the areas of research responsibilities have been clearly defined. The focus of this report is on the impact of mineral oils.

It has been found in connection with earlier oil spills that the impacts of petroleum hydrocarbons on living organisms extend beyond the visibly polluted area. This action plan therefore provides instructions on how to survey the ecological impacts of oil irrespective of the extent of the oil spill, and covering areas beyond the main affected area. In addition to acute-stage research, monitoring of long-term effects and oil levels is also necessary.

The Baltic Sea is a particularly vulnerable sea area. The number of oil spills caused by vessels has decreased over the past decades due to tighter requirements regarding vessel condition, strict sanctions on spills and improved overall surveillance and route planning, while the amount of vessel traffic has significantly increased. Over the period from 1995 to 2010, oil transport in the Gulf of Finland increased nearly 10-fold, and this trend is expected to continue as Russia opens new oil terminals and increases the capacity of its existing terminals. Furthermore, it is possible that significant amounts of oil enter the sea from onshore sources, such as industrial plants.

This action plan aims to provide guidelines in case of an oil spill for the Finnish authorities responsible for studying the impacts of oil on the marine ecosystems in Finland. The publication is divided into three sections: Section A contains general background information on the impacts of oil spills on the marine environment and approaches required to carry out the impact studies; Section B describes step-by-step instructions on how to initiate the necessary procedures in case of an oil spill; and in Section C, the need for further study on baseline oil levels in marine ecosystems is discussed. Section B may be used as a standalone guide.

Keywords	oil spill, impact research, Baltic Sea, action plan, mineral oil content, compounds of mineral oil			
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KUVAILULEHTI

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Tekijä(t)	Heta Rousi ja Harri Kankaanpää (toim.)			
Julkaisun nimi	**The ecological effects of oil spills in the Baltic Sea – the national action plan of Finland** (Itämerellä tapahtuvien öljyvahinkojen ekologiset seuraukset; Suomen kansallinen toimintasuunnitelma)			
Julkaisusarjan nimi ja numero	Ympäristöhallinnon ohjeita 6en/2012			
Julkaisun teema	Luonto			
Julkaisun osat/ muut saman projektin tuottamat julkaisut				
Tiivistelmä	Öljyvahinkojen seurauksena mereen päässyt öljy aiheuttaa eliöissä ja elottomassa ympäristössä välittömiä ja pitkäaikaisia muutoksia. Tämä julkaisu on ensimmäinen kansallinen, yhtenäinen toimintasuunnitelma laajamittaisia öljyvahinkotilanteita varten. Raportissa tutkijoista, asiantuntijoista ja viranomaisista koostuva työryhmä on koonnut yhteen olennaisen nykytiedon öljyn meriekologisista vaikutuksista, tutkimuksesta ja näytteenotosta sekä jakaa selkeästi vastuualueet tutkimuksen toimintaketjussa. Tarkastelun kohteena ovat mineraaliöljyjen aiheuttamat vaikutukset. Öljyvahinkojen yhteydessä on havaittu, että öljy-yhdisteiden vaikutukset eliöstöön ulottuvat näkyvästi saastuneen alueen ulkopuolelle ja siksi tämä toimintasuunnitelma antaa ohjeet öljyn ekologisten vaikutusten tutkimukseen käytännössä kaiken suuruisissa öljyvahinkotilanteissa ja öljyvahingon päävaikutusalueen ulkopuolella. Akuuttivaiheen tutkimuksien lisäksi öljyn pitkäaikaisten vaikutusten ja pitoisuuksien seuranta on tarpeellista. Itämeri on erittäin herkkä merialue. Alusöljyvahinkojen määrä on alueella pienentynyt viime vuosikymmenten aikana muun muassa tiukentuneista alusten kuntovaatimuksista, koventuneista päästörangaistuksista, valvonnasta ja alusliikenteen reititysjärjestelmistä johtuen, samalla kun alusliikenteen määrä on kuitenkin lisääntynyt voimakkaasti. Suomenlahden öljykuljetusmäärä kasvoi vuosien 1995 ja 2010 välisenä aikana lähes kymmenkertaiseksi ja kasvun odotetaan jatkuvan yhä, kun Venäjä avaa uusia öljyterminaaleja ja kasvattaa olemassa olevien terminaaliensa kapasiteettia. Mereen saattaa joutua huomattaviakin määriä öljyä myös rannikolla sijaitsevasta kohteesta, kuten teollisuuslaitoksesta. Tämä toimintasuunnitelma on tarkoitettu oppaaksi öljyvahinkotilanteeseen niille viranomaisille, jotka vastaavat öljyn meriekologisten vaikutusten tutkimisesta Suomessa. Julkaisu jakautuu kolmeen osioon: taustatietoja sisältävässä osassa (osa A) tarkastellaan öljyvahingon seurauksia meriluonnossa ja vaikutusselvityksen vaatimia menettelyitä yleisellä tasolla, toimintaosiossa (osa B) kuvataan vaihe vaiheelta ne toimenpiteet, jotka käynnistetään öljyvahinkotilanteessa ja kolmannessa osiossa (osa C) tuodaan esiin tarpeet lisäselvityksistä koskien meriekosysteemissä olevan öljyn taustapitoisuuksia. Teoksen B-osaa voidaan käyttää yksinkertaisesti pelkkänä toimintaohjeena.			
Asiasanat	Öljyvahinko, vaikutustutkimus, Itämeri, toimintasuunnitelma, öljypitoisuus, öljy-yhdisteet			
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Painopaikka ja -aika				

PRESENTATIONSBLAD

Utgivare	Finlands miljöcentral (SYKE)			*Datum* December 2012
Författare	Heta Rousi och Harri Kankaanpää (red.)			
Publikationens titel	**The ecological effects of oil spills in the Baltic Sea – the national action plan of Finland** (Ekologiska konsekvenser av oljeskador på Östersjön; Finlands nationella handlingsplan)			
Publikationsserie och nummer	Miljöförvaltningens anvisningar 6en/2012			
Publikationens tema	Natur			
Publikationens delar/ andra publikationer inom samma projekt				
Sammandrag	Olja som hamnat i havet till följd av oljeskador orsakar direkta och långvariga ändringar hos organismer och i den abiotiska miljön. Denna publikation är den första nationella, gemensamma handlingsplanen för situationer med omfattande oljeföroreningar. I rapporten har en arbetsgrupp bestående av forskare, experter och myndigheter samlat de väsentliga kunskaperna från idag om oljans marinekologiska konsekvenser samt om oljeutredningar och -provtagningar. Arbetsgruppen delar tydligt upp ansvarsområdena inom utredningens verksamhetskedja. Föremålet för undersökningen är mineraloljornas konsekvenser. I samband med oljeskador har man upptäckt att oljeföreningarna påverkar biota utanför det synligt förorenade området. Därför innehåller denna handlingsplan praktiska anvisningar om utredningen av oljans ekologiska konsekvenser i oljeskadesituationer oavsett omfattning och utanför oljeskadans huvudsakliga verkningsområde. Utöver utredningarna i det akuta stadiet är det nödvändigt att följa upp oljans långsiktiga effekter och halter. Östersjön är en mycket känslig marin region. Antalet fartygsoljeskador i området har minskat de senaste årtiondena bland annat tack vare åtstramade krav på fartygens skick, hårdare bestraffningar för utsläpp, övervakning och fartygstrafikens routingsystem. Samtidigt har dock fartygstrafiken ökat kraftigt. Antalet oljetransporter i Finska viken nästan tiodubblades mellan 1995 och 2010, och ökningen förväntas fortgå när Ryssland öppnar nya oljeterminaler och utökar kapaciteten i sina befintliga terminaler. Betydande mängder olja kan också rinna ut i havet från ett objekt vid kusten, till exempel en industrianläggning. Denna handlingsplan är avsedd som en guide i oljeskadesituationer för myndigheter som ansvarar för utredningen av oljans marinekologiska konsekvenser i Finland. Publikationen består av tre delar: i delen med bakgrundsinformation (del A) granskas följderna av oljeolyckor i den marina naturen och de allmänna förfaranden som krävs enligt konsekvensutredningen, i verksamhetsdelen (del B) beskrivs steg för steg de åtgärder som vidtas i en oljeskadesituation och den tredje delen (del C) tar upp behoven av ytterligare utredningar gällande bakgrundshalterna av olja i det marina ekosystemet. Del B är enkel att använda som en ren instruktion.			
Nyckelord	oljeskada, påverkningstudie, Östersjö, handlingsplan, oljehalt, oljeföreningar			
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THE ECOLOGICAL EFFECTS OF OIL SPILLS IN THE BALTIC SEA – THE NATIONAL ACTION PLAN OF FINLAND

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