



Environmental risk assessment of the most commonly transported chemicals: case study of Finnish coastal areas

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Abstract The environmental hazard potential of a total of 15 chemicals that are transported through the Finnish coastal areas was assessed in this paper using a scoring method developed for accidents. The study indicates that the chemicals most commonly transported/handled in Finnish ports are methanol, sodium hydroxide solution, acids, pentanes, phenol, xylenes, methyl tert-butyl ether, ethanol and ethanol solutions. For the evaluation of the environmental hazardousness of various chemicals, a priority list of chemicals that are the most commonly transported regionally in marine environments was compiled for this study. The method used has many similarities to other commonly used scoring systems, but this study gave more weight to specific characteristics of an accidental release, water biota and impact on the environment. Nonylphenol, ammonia and sulphuric acid ranked as the most hazardous substances on the list. The results of the study can be used by rescue and environmental authorities and enterprises to improve preparedness for accidents and to mitigate the effects of accidental spills.

Keywords Transportation of chemicals · Environmental risk management · Scoring method · Transport-related accidents · Logistics

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1 Introduction

The Baltic Sea is one of the busiest sea routes in the world, and it is highly sensitive to the environmental impacts of a possible chemical accident. At present, a quarter of the vessels sailing in the Baltic Sea are oil tankers or tankers carrying chemicals (HELCOM 2009). Navigation in the Baltic Sea is challenging due to the sea area's relative shallowness, narrow navigation routes and ice cover in the winter. This is especially true for Finland. Recently, both the number and the volume of chemicals transported in the Baltic Sea have increased significantly (HELCOM 2009), concomitantly raising the spill/ship-collision risk (Kujala et al. 2009). The results of previous studies (e.g. EMSA 2010; Hänninen and Rytönen 2006; Mullai 2007; Suominen and Suhonen 2007) indicate that both the risks and incidents of spills are less well defined for chemical transportation than for oil transportation. According to HELCOM (2012), there have been 1,400 accidents, and 1,520 vessels in total have been involved in the accidents that occurred in the Baltic Sea during the years 1989–2010. One in seven of the accidents involved a tanker. Based on the HELCOM's accident statistics, 210 tankers including crude oil tankers, chemical tankers, oil/chemical product tankers, gas carriers and other types of vessels carrying liquid bulk cargoes were involved in the accidents that occurred in the Baltic Sea during the years 1989–2010. During this period, 28 of all tanker accidents in the Baltic Sea led to some sort of pollution, and in one pollution case only, the spilled substance was a chemical. Generally speaking, the chemical tanker accidents are rare, even though there is always the possibility that such incident may happen. Further, due to the wide range of chemicals transported, it is necessary to identify the potency of different chemicals to cause environmental damage.

International liquid bulk cargoes handled in Baltic Sea ports in 2010 consisted of approximately 290 million tonnes of oil and oil products, 11 million tonnes of liquid chemicals, and 4 million tonnes of other liquid bulk (Holma et al. 2011; Posti and Häkkinen 2012). The share of Finnish ports in all liquid bulk chemicals transported is approximately 3.5 million tonnes annually (Holma et al. 2011; Häkkinen 2009; Posti and Häkkinen 2012). The chemicals most commonly transported in the entire Baltic Sea area are methanol, sodium hydroxide solution, ammonia, sulphuric and phosphoric acid, pentanes, xylenes, methyl tert-butyl ether (MTBE), ethanol and ethanol solutions. At least one hundred to several hundred thousand tonnes, or even a million tonnes, of all these chemicals are transported annually, but since chemical-specific data from all Baltic Sea countries are not available, the exact volumes could not be calculated. Besides these chemicals, high volumes of other chemicals are also transported (e.g. ethylene, propane and butane), and large amounts of fertilisers and vegetable oils are handled in the Baltic Sea ports (Hänninen and Rytönen 2006; Posti and Häkkinen 2012).

The marine pollution hazards of thousands of chemicals have been evaluated by such bodies as the Evaluation of Hazardous Substances Working Group, producing a GESAMP Hazard Profile which indexes each substance according to its bio-accumulation, bio-degradation, acute toxicity, chronic toxicity, long-term health effects, and effects on marine wildlife and on benthic habitats. Based on the

GESAMP evaluation, the IMO has set up four different hazard categories: X (major hazard), Y (hazard), Z (minor hazard) and OS, i.e. other substances (no hazard) (IMO 2007). More than 80 % of all the chemicals transported in the Baltic Sea are classified as belonging to the Y category (Häkkinen 2009). This GESAMP categorization is very comprehensive, but chemicals with very different toxicity mechanisms, environmental fate and other physico-chemical properties may end up in the same MARPOL category. The GESAMP categorization is neither a prioritisation method nor can be used to evaluate and rank the hazard potentials of chemicals.

A substance with a relatively low toxicity that is used or transported frequently can pose a risk to human health and the environment. On the other hand, the environmental impact of a more hazardous chemical may be more severe, even if the probability of an accident occurring is very low. Different risk-based scoring methods can be used to compare and categorise chemicals to support, e.g. legislation when prioritising hazardous chemicals. In many scoring systems, chemical exposure is, for example, assessed based on the total consumption, the amount required in a specific industrial process or the history of accidents involving the substance (Adu et al. 2008; Singh et al. 2011). Several indices that combine the chemical hazard and the extent of exposure into a single numerical indicator to rank the risk posed by a chemical have been developed. Davis et al. (1994) introduced 51 chemical ranking systems, and recently, many excellent reviews have been published (e.g. Adu et al. 2008; Singh et al. 2011). Different scoring systems have different weightings and can be grouped into categories based on at least three aspects related to the environment, health and safety. In this study, environmental impacts were emphasised, especially impacts on the biota of the water column. In case of a shipping accident, three major physico-chemical characteristics, including density, water solubility and vapour pressure, determine the fate of the chemical (French McKay et al. 2006). Further, the hazard-ousness of chemicals for the water biota could be determined by their ecotoxicity, persistency and bioavailability.

The objective of this study was to evaluate the environmental risk of the most commonly transported chemicals in case of a shipping accident in the Finnish coastal areas. As a result of the risk assessment, a chemical priority list was compiled using a scoring method. The aim of the priority list is to help the authorities and other stakeholders to pay attention to the most hazardous chemicals and, further, use this information to minimise the risk of chemical accidents. Another aim was to introduce a scoring method in which the number of parameters is optimised to assess the environmental hazard potential of chemicals in other sea areas.

2 Methodology

The study was conducted in two stages. *In the first stage of the study*, the volumes of each chemical handled in Finnish ports were examined to establish which chemicals are handled the most commonly in Finland. Based on this transport data, chemicals included in the environmental risk assessment were chosen. The information on chemicals handled in Finnish ports was obtained directly from a nationwide vessel

traffic system called ‘PortNet’, in which each and every ship calling at a Finnish port is obliged to provide information regarding its schedule, route, cargo, hazardous cargo and maritime fees. The volumes of chemicals (total of exports and imports) handled in Finnish ports in 2 years (2008 and 2010) were collected on the basis of dangerous goods declarations obtained from the PortNet information system. Year 2009 was excluded from the review since the cargo volumes in Finnish ports in that year were significantly lower than in 2008 and 2010, mainly due to the global economic depression at that time (Holma et al. 2011; Särkijärvi et al. 2009; Särkijärvi et al. 2010). The PortNet system showed that the volumes and number of chemicals in selected years were also much higher than those in 2009. Therefore, year 2009 was considered to be too incomparable with the years 2008 and 2010, and including the year 2009 would not give any additional value to our risk assessment study. While the study focused on liquid bulk chemicals, gases transported as liquefied bulk were also taken into account. Chemicals in a packaged form were excluded from the study, as their transportation volumes are much lower than those of bulk chemicals, and the volumes per voyage are also considerably low. For example, 97 % of hazardous cargoes handled in Finnish ports are transported as bulk, and only 3 % as packaged cargo (Häkkinen 2009).

In the second stage of the study, the environmental hazardousness of a total of 15 chemicals chosen on the basis of the PortNet analysis was evaluated. Of these, ten chemicals are transported in very high volumes through the Finnish ports (Table 2), and the remainder have a significant environmental hazard potential. The risk assessment was carried out using a scoring method originally developed to estimate the environmental risk in chemical accidents on land (Häkkinen et al. 2010). For this reason, some parameters used in this study naturally are different. In soil studies, the density-to-viscosity ratio has an influence on the chemical mobility in soil, but this value has no role in an aquatic environment. The above-mentioned parameter was replaced by density in this study. In addition, volatility threshold values for a marine environment were determined according to French McKay et al. (2006), while threshold values for land accident scenarios are based on Nikunen and Leinonen (2002).

The method used has many similarities to other commonly used scoring systems, but this study gave more weight to specific characteristics of an accidental release, water biota and impact on the environment. The chemicals were assessed based on nine parameters which were considered the main factors affecting their environmental fate or mobility, ecotoxicology and probability of being involved in an accident (Table 1). For each parameter, the chemicals were assessed on a scale of 1 to 3, the most hazardous chemicals receiving 3 points. The total number of points was added up, and a priority list for hazardous chemicals was formed. The parameter values for chemicals were obtained from tens of scientific articles, from EU documents, Canada and United States Environmental Agency risk assessment reports, field literature and databases (the original values are presented in more detailed in Häkkinen et al. 2010). Data gaps were filled in by means of a modelling exercise using the US EPA’s EPISuite program. EPISuite has been used worldwide in several scoring methods to fill in data gaps (e.g. Juraske et al. 2007). The environmental fate and ecotoxicology values used in the scoring and their references have been compiled in Häkkinen et al. (2010) for most chemicals and are not presented in this paper. For NExBTL (renewable biodiesel, a product name), the

Table 1 Parameters and threshold levels of the scoring method used for risk assessment

Parameter	1 Point	2 Points	3 Points
Volatility (vapour pressure) ^a	>0.1 kPa, Highly volatile	10 ⁻⁵ to 0.1 kPa, Semi-volatile	<10 ⁻⁵ kPa, Non-volatile
Density ^a	<1.025 g/cm ³ , Floater	>1.025 g/cm ³ , Sinker	
Water solubility ^{b,c}	0.1–10 mg/l, Poorly soluble	10–1,000 mg/l, Soluble	>1,000 mg/l, Highly soluble
Persistence ^d (BIOWIN3 half life)	Days to weeks	Weeks	Weeks to months
Bioaccumulation (logK _{ow}) ^b	<3, Not bioaccumulative	3–5, Slightly/moderately bioaccumulative	>5, Very bioaccumulative
Acute toxicity (LC/EC50) ^b	>100 mg/l, Slightly toxic	1–100 mg/l, Toxic/hazardous	<1 mg/l, Very toxic
Chronic toxicity (NOEC) ^b	>1 mg/l, Slightly toxic	0.1–1.0 mg/l, Toxic/hazardous	<0.1 mg/l, Very toxic
Transportation volume	<10,000 tonnes	10,000–100,000 tonnes	>100,000 tonnes

Additional points (0.5–1) were scored by chemicals having other significant hazardous environmental impacts (see text)

^a Volatility threshold values and density were determined according to French McKay et al. (2006)

^b Threshold values from Nikunen and Leinonen (2002) were used for guidance in the classification of most parameters

^c Toluene diisocyanate (TDI) only scored 1 point for solubility due to degradation by hydrolysis

^d NExBTL does not have a BIOWIN value, but 1 point was given to it based on experimental half-lives from literature

parameter values were obtained from the ECHA (2012) database and California Environmental Protection Agency (2010). For a more detailed description of the parameters used, please refer to the following section.

2.1 Parameters assessed

Three major physico-chemical characteristics, i.e. density, water solubility and vapour pressure, determine the fate of a chemical in case of a shipping accident (French McKay et al. 2006). *Water solubility* is the most important parameter when assessing the chemical's hazard potential for water environment and biota. In the scoring method, the most water soluble chemicals were considered most likely to enter the water column and to spread over wider areas, and therefore to be the most hazardous. *Density* determines a chemical's buoyancy relative to water. The chemical quickly disperses if its water solubility is high, but floats or sinks depending on its density if its solubility is low. Since ecotoxicological effect on water column biota was weighted in this study, chemicals that sink (density > 1.025 g/cm³) scored 2 points, while floaters scored 1 point (density < 1.025 g/cm³) (GESAMP 2002; French McKay et al. 2006). Many risk scenarios take the opposite view, especially when public health is a priority. *The volatility* of the chemicals was assessed based on vapour pressure. The highest points were scored by compounds with poor volatility (low vapour pressure), since a larger portion of these chemicals stay in the water column (Table 1) and, therefore, the environmental impact of non-volatile chemicals is higher.

The biodegradability of chemicals was defined using BIOWIN3 values modelled using the US EPA's EPISuite program. The modelled values were used to harmonise half-life values. *The bioaccumulation* of chemicals was estimated using the octanol–water partition coefficient (K_{OW}). The greater the K_{OW} , the more hydrophobic and bioaccumulative the chemical is. The majority of the chemicals studied are not bioaccumulative ($\log K_{OW} < 3$) and can be considered relatively non-hazardous to the environment. *The acute and chronic toxicity* of chemicals were examined for three trophic levels (algae, *Daphnia magna*—water flea and fish) based on the lowest acute LC/EC50 (lethal/effective concentration, where 50 % of organisms are affected) and chronic NOEC (no observed effect concentration) values defined. Acute and chronic toxicity were examined individually by calculating the averages of points scored for toxicity for the three trophic levels.

Based on studies that include all transport modes, the greatest accident probability is posed by the most commonly transported chemicals, i.e. liquid fuels (Mullai and Larsson 2008, Häkkinen et al. 2010). *The volumes transported by sea* obtained from the PortNet system were thus used to indicate the probability of chemical exposure. In addition, some chemicals scored 0.5–1 additional points if they had significant *hazardous environmental impacts*, for instance based on their carcinogenic potential or endocrine effects. Simple weight-of-evidence approach was applied by focusing on the chemicals' mechanisms of toxicity (e.g. carcinogenicity, endocrine disruption or other additional hazardous property as criteria). Therefore three scored chemicals received 0.5 carcinogenicity point, some others 0.5 HP points, but ammonia and nonylphenol got 1 additional point each by having several hazardous properties in terms of transport accidents and especially impact to the environment.

Table 2 Volumes of chemicals handled in Finnish ports (exports + imports) in 2008 and 2010

2008		2010	
Chemical	Volume (tonnes)	Chemical	Volume (tonnes)
Methanol	866,323	Methanol	746,141
Sodium hydroxide solution	359,424	Sodium hydroxide solution	380,331
Xylenes	206,558	Pentanes	315,978
Ethanol and ethanol solutions	149,535	Xylenes	161,894
Phosphoric acid	133,147	Methyl tert-butyl ether (MTBE)	159,660
Pentanes	124,548	Aromatic free solvents (e.g. white spirit and NESSOL)	155,363
Methyl tert-butyl ether (MTBE)	119,539	Ethanol and ethanol solutions	122,018
Phenol + acetone	119,065	Parafines	111,079
Aromatic free solvents (e.g. white spirit and NESSOL)	111,479	Phosphoric acid	91,797
Propane	107,260	Phenol	87,359
Ethyl tert-butyl ether (ETBE)	73,646	Propane	84,027
Phenol	73,040	Acetone	73,815
Ammonia	72,088	NExBTL	73,298
Propylene	66,818	Phenol + acetone	72,427
Sulphuric acid	62,822	Styrene	71,934
Butadiene	60,340	Benzene	69,240
Styrene	59,423	Formic acid	68,427
Hexafluorosilicic acid	57,896	Butanoles	67,890
Benzene	56,841	Hexafluorosilicic acid	56,006
Tert-amyl ethyl ether (TAEE)	54,239	Ammonia	51,632
Total of other chemicals	625,837	Total of other chemicals	435,876
Total	3,559,868	Total	3,456,192

Compiled from the PortNet system in 2012

3 Results

3.1 Liquid bulk chemicals handled in Finnish ports

According to the PortNet system, Finnish ports handled approximately 3.5 million tonnes of liquid bulk chemicals consisting of some 60 different chemicals in 2010. Eight of these chemicals were handled in volumes exceeding 100,000 tonnes, and 37 chemicals in volumes exceeding 10,000 tonnes. The chemicals handled in the greatest volumes were methanol, sodium hydroxide solution and pentanes (Table 2). Of all liquid bulk chemicals handled in Finnish ports in 2010, the exports of liquid bulk chemicals accounted for about 73 %, and the imports of liquid bulk chemicals for about 27 %. The liquid bulk chemicals exported in the greatest quantities were methanol, pentanes and xylenes, while the most commonly transported liquid bulk chemicals were sodium hydroxide solution, ethanol, ethanol solutions and propane. Compared to 2008, the total volume of liquid bulk chemicals handled in Finnish ports

in 2010 decreased by approximately 3 %. The number of different liquid bulk chemicals also decreased from 80 to 57. However, the most commonly handled liquid bulk chemicals remained more or less the same as in 2008 in 2010, nine out of ten of the most commonly handled chemicals being the same in these years. Only the amounts of these nine chemicals varied in the years under scrutiny.

3.2 Environmental risk assessment of chemicals using the scoring method

In the second stage of the study, the environmental hazardousness of a total of 15 chemicals that are transported through the Finnish ports was assessed using a scoring method originally developed by Häkkinen et al. (2010), even though the method was slightly modified for the purposes of this study (for details, see the ‘Methodology’ section). Of these 15 chemicals chosen for assessment, 10 or 11 can be classified as chemicals with very high volume depending on the year (Table 3), and 6 of them belong to the top 10 chemicals handled in the Finnish ports. The remainder of the chemicals, namely toluene diisocyanate (TDI), 1-decene, epichlorohydrin and nonylphenol, are transported in lower volumes, and they were included in the assessment on the grounds of pre-evaluations of their environmental properties and due to the fact that they represent very different types of chemicals. In addition, a decision was made to include NExBTL in the evaluation because it represents a new renewable diesel with potentially very high transport volumes in the future.

Table 3 Chemicals and their volumes (in tonnes) chosen for the environmental risk assessment on the basis of the PortNet analysis

2008		2010	
Chemical	Volume (tonnes)	Chemical	Volume (tonnes)
Methanol	866,323	Methanol	746,141
Xylenes	206,558	Pentanes	315,978
Ethanol and ethanol solutions	149,535	Xylenes	161,894
Pentanes	124,548	Methyl tert-butyl ether (MTBE)	159,660
Methyl tert-butyl ether (MTBE)	119,539	Ethanol and ethanol solutions	122,018
Phenol + acetone	119,065	Phenol	87,359
Phenol	73,040	NExBTL	73,298
Ammonia	72,088	Phenol + acetone	72,427
Sulphuric acid	62,822	Styrene	71,934
Styrene	59,423	Benzene	69,240
Benzene	56,841	Ammonia	51,632
Nonylphenol ethoxylates	29,160	Sulphuric acid	25,172
NExBTL	12,806	Nonylphenol ethoxylates	11,082
Epichlorohydrin	9,328	Alpha olefines (e.g. 1-decene)	3,737
Alpha olefines (e.g. 1-decene)	7,058	Epichlorohydrin	480
Toluene diisocyanate	23	Toluene diisocyanate	23

Compiled from the Finnish Transport Agency figures in 2012

The chemicals were ranked by summing up the scores for all the parameters (Table 4). The chemicals with the highest total score can be considered the ones with the greatest environmental risk. In case of a shipping accident, the greatest risk to the environment is posed by chemicals with a high solubility, which stay in the water column and are bioavailable, persistent and toxic to organisms. Most of the chemicals studied are highly water soluble, while nonylphenol, TDI, 1-decene and NExBTL are only moderately soluble in water. Based on BIOWIN3 values, benzene is the most persistent of the chemicals observed and thus presents the highest long-term risk to the environment. For the most part, the modelled values correlate well with experimental values found in the scientific literature (the original values presented in more detailed in Häkkinen et al. 2010), however excluding inorganic compounds. Of the chemicals studied, only 1-decene and nonylphenol are highly bioaccumulative. Based on their density, nonylphenol, sulphuric acid, phenol, epichlorohydrin and TDI are so-called sinkers and will enter the water column, although sulphuric acid also has a high volatility, which will affect its migration in the opposite way. The most toxic chemicals in this study were nonylphenol and ammonia, while ethanol, MTBE and NExBTL were the least toxic.

Nonylphenol scored one additional point based on its other hazardous impacts, as it is known to be an endocrine disrupter and very persistent in the environment. Benzene and epichlorohydrin are carcinogenic chemicals, and for this reason, both scored 0.5 additional points. TDI is known to be a genotoxic and possibly carcinogenic chemical that is very toxic to mammals and degrades into more persistent and toxic toluene diamine. Ammonia is a very complex chemical that can affect water pH and may cause eutrophication of water if spilled in large volumes. If spilled in water, it has very low toxicity values (= high toxicity) (e.g. lowest acute toxicity value for fish is 0.083 mg/l and lowest chronic value 0.07 mg/l). Additionally, it also forms highly toxic gas clouds (Häkkinen et al. 2010).

Nonylphenol was determined as the most hazardous of the chemicals studied in case of a marine spill. Besides its toxicity, it is very persistent, bioaccumulative and has a moderate solubility in water. Nonylphenol is not one of the most commonly transported chemicals in the Baltic Sea, but approximately 10–30 thousand tonnes of nonylphenol ethoxylates are transported annually through Finnish coastal areas. When spilled in the environment, nonylphenol ethoxylates are transformed into more harmful nonylphenol, and this worst-case scenario was evaluated in this study. Other very hazardous substances on the priority list were sulphuric acid and phenol. The least hazardous chemicals were renewable biodiesel NExBTL and alpha olefin 1-decene, both of which bioaccumulate easily but are readily biodegradable and relatively non-toxic.

4 Comparison with other risk assessment methods

In a potential shipping accident, the greatest risk to the environment is posed by chemicals with high solubility, which stay in the water column, are bioavailable, persistent and toxic to organisms. Our study indicates that nonylphenol is the most toxic of the chemicals studied and the most hazardous if spilled in the sea. It is persistent, bioaccumulative and has a moderate solubility in water. Nonylphenol is actually transported in the form of nonylphenol ethoxylates, but if spilled in the

Table 4 Scores for different parameters, total score and placement on the priority list

Chemical	Water solubility	Density	Volatility	Biodegradability	Bioaccumulation	Acute toxicity	Chronic toxicity	Transport volume	Hazardous impacts	Total	Placement
Nonylphenol	1	2	2	3	3	3	3	2	1	20	1
Sulphuric acid	3	2	3	2	1	2	2.5	2	0	17.5	2
Phenol	3	2	2	2	1	2	2	3	0	17	3
Ammonia	3	1	1	2	1	3	2.5	2	1	16.5	4
Benzene	3	1	1	3	1	2	1.5	2	0.5	15	5
Styrene	2	1	1	2	2	2.3	2.5	2	0	14.8	6
Xylenes	2	1	1	2	2	2	1.3	3	0	14.3	7
Epichlorohydrin	3	2	1	2	1	2	1.5	1	0.5	14	8
MTBE	3	1	1	2	1	1	1	3	0	13	9
<i>n</i> -Pentane	2	1	1	1	2	2	1	3	0	13	9
Methanol	3	1	1	1	1	1.3	1	3	0	12.3	11
TDI	1	2	2	1	2	1.7	1	1	0.5	12.2	12
Ethanol	3	1	1	1	1	1	1	3	0	12	13
1-Decene	1	1	1	2	3	1.3	1	1	0	11.3	14
NExBTL	1	1	1	1	3	1	1	2	0	11	15

The chemicals with the highest points pose the greatest environmental risk

environment, it will be present as nonylphenol; and this study analysed the worst-case scenario. Other very hazardous substances were sulphuric acid and ammonia (Table 4). The Drogou et al. (2005) project identified 100 chemicals that are the most commonly transported between major European ports as part of the trade through the English Channel to the rest of the world. The assessment was based on both transport volumes and the GESAMP hazard profile. The project highlighted such chemicals as benzene, styrene, vegetable oil, xylene, methanol, sulphuric acid, phenol, vinyl acetate and acrylonitrile. It concluded that these chemicals were the ones that have a high spillage probability but that may not result in significant environmental impacts. Similarly, French McKay et al. (2006) applied a predictive modelling approach to a selected range of chemicals transported by sea in bulk and concluded that phenol and formaldehyde present the greatest risk to aquatic biota. Furthermore, Guerbet and Jouany (2002) used the SIRIS method to evaluate 90 chemicals based on the risk they pose to the aquatic environment. Only a handful of chemicals included in our study were included in the study by Guerbet and Jouany (2002). Benzene, for example, ranked 6th (high risk for the environment) and chloroform 14th, while such chemicals as xylenes came in 88th place. Harold et al. (2011) evaluated human health risks of transported chemicals based on the GESAMP ratings for toxicity and irritancy. Their evaluation gives more weight to chemicals that are floaters, form gas clouds, irritate and are toxic, such as chlorine (Harold et al. 2011). It is clear that different weightings have a certain impact on the difference in results produced by these studies. In this paper, the focus was to assess the environmental effects of the selected chemicals, with emphasis on water column biota and accident probability.

The scoring method and parameters used in this study have both similarities and differences when compared to other scoring systems. Chemicals are assessed from the point of view of their environmental hazard in systems such as ERICA (Boriani et al. 2010), CROSS (Jeong and An 2012), PestScreen (Juraska et al. 2007), EURAM (Hansen et al. 1999) and CHEMS-1 (Swanson et al. 1997). Most of these methods rely on calculating the Predicted Environmental Concentration (PEC), creating environmental models on the basis of monitoring data. In this study, however, PEC was not determined for maritime accidents, as this would require complex 3D modelling using such programs as CHEMMAP (French McKay et al. 2006), and this was beyond the scope of the study. CHEMS-1 (Swanson et al. 1997) had very similar parameters to those used in our scoring method, including toxicity values, persistence, bioaccumulation, degradation and amount of release. In their Environmental Consequence Index, Arunraj and Maiti (2009) had a different approach and focused on the environmental fate and distribution of chemicals as did Davis et al. (1994) with a different parameter set. On the other hand, the EURAM method (Hansen et al. 1999), which had separate scores for human health and the environment, had similarities to our scoring method, but risks to human health are weighted more in the EURAM method.

5 Conclusions

This paper discusses the most commonly handled liquid bulk chemicals in the Finnish ports and, especially, the environmental hazard potential of chemicals evaluated using a

novel prioritizing scoring method. A user-friendly method for evaluating chemical hazardousness in the maritime environment was introduced. The method was used to evaluate the environmental hazardousness of chemicals transported through the Finnish coastal areas, but it can also be applied to other sea areas.

The chemicals most commonly transported through the Finnish ports are mainly the same as in other sea areas (AMRIE 2005). This in turn shows that the safety issues related to the maritime transport of chemicals are similar in different sea areas around the world. Naturally, the hazardousness of a chemical spill depends on the vulnerability of the environment. Compared to large oceans, the Finnish coastal areas are shallow with a low water exchange rate, and they are covered by ice for extended periods in winter. Once released in the Baltic Sea, hazardous substances may remain there for decades, accumulating in food webs until they reach toxic levels and cause harmful effects on the sensitive ecosystem. The most commonly handled chemicals in Finnish and other ports are usually basic industrial chemicals (e.g. methanol, sodium hydroxide solution, xylenes, ammonia, phosphoric acid and ethanol) that often have been overlooked in environmental assessments. Many of these chemicals have a surprisingly high environmental hazard potential. To evaluate the environmental hazardousness of different chemicals, a priority list of chemicals that are regionally the most commonly transported by sea was formed in this study. The method used has many similarities with other commonly used scoring systems. However, it gives more weight to the specific characteristics of an accidental release and the impact on the aquatic environment. Nonylphenol, ammonia and sulphuric acid were ranked as the most hazardous substances on the list.

This paper discusses the special case of Finnish coastal areas, focusing on a limited number of chemicals. In the future, all liquid bulk chemicals transported by sea should be evaluated thoroughly, weighting their effects on water biota. A similar evaluation should also be carried out for chemicals transported in packaged form. The information on chemical risks can be used by rescue and environmental authorities and enterprises to improve preparedness for accidents and to mitigate their effect in the case of an accidental spill.

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