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TANK CLEANING AND ITS IMPACT ON THE MARINE ENVIRONMENT

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PREFACE

This report has been produced by researchers at Chalmers University of Technology, active in the Shipping Group at the Institute of Marine Environment. The Shipping Group's goal is to contribute to increased knowledge about the impact of shipping on the marine environment and to provide a basis for possible measures to reduce the load from shipping. Tank cleaning is one of the least explored types of environmental impact from shipping and there are no comprehensive statistics available on which substances are released, in which concentrations and in how large volumes. In addition, there is no comprehensive documentation about where and when tank cleaning is performed.

At the same time, tank cleaning can pose a potentially significant burden on the marine environment. The background to the assignment was therefore the need for collective knowledge regarding tank cleaning from a Swedish marine environment management perspective. The report has been commissioned and financed by the Swedish Agency for Marine and Water Management.

The work of this report can be likened to a jigsaw puzzle; behind the overall picture presented here, there are many people who have contributed with their respective pieces of the puzzle. Your help was essential for us to prepare this report.

To all of you who work in ports and industries and who have provided statistics; you gave the report substance. To the ships and ports that welcomed us, offered coffee and answered our questions. To the Coast Guard, the Swedish Customs, and the Swedish Transport Agency, who shared their experiences and information. To Filip & co at the Swedish Maritime Administration for your persistent work and help in the search for data. To Måns, Jacob, EMSA and HELCOM. To SPBI, KemI and Statistics Sweden. To the ports and authorities outside Sweden's borders, who assisted with information. To Cedre and Race For the Baltic for your commitment. To Kahlid and Anton for your curiosity. To Jan for your knowledge and professional experience. Thanks!

Thanks also to Eva-Lotta Sundblad, the Institute of Marine Environment, Kjell Larsson, Linnaeus University, Fredrik Lindgren, the Swedish Agency for Marine and Water Management and four anonymous reviewers who contributed to improving the report through critical and constructive comments.

The report is written by Anna Lunde Hermansson and Ida-Maja Hassellöv, Chalmers University of Technology. The authors of the report are responsible for the content and conclusions of the report. This is the English version of the Swedish report 2020:6 published in June 2020. Minor factual updates, e.g., regarding regulations that entered into force in 2021 have been made in the English version.

July 8th, 2022
Anna Lunde Hermansson and Ida-Maja Hassellöv

ABBREVATIONS

AIS	Automatic Identification System
BCH code	The Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk
BOD	Biochemical Oxygen Demand
CBD	Convention on Biological Diversity
CDI	Chemical Distribution Institute
Cedre	Centre de Documentation, de Recherche et d'Expérimentations sur les Pollutions Accidentelles des Eaux
CF	Concentration factor
CN-number	Combined Nomenclature
DWT	Deadweigth tonnage
EBSA	Ecologically or Biologically Significant Marine Area
EMODnet	European Marine Observation and Data Network
EMSA	European Maritime Safety Agency
EQS	Environmental Quality Standard
ETBE	Ethyl tert-butyl ether
EU	European Union
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GIS	Geographic Information System
GT	Gross Tonnage, unitless measure of ship size
HaV	Swedish Agency for Marine and Water Management (SwAM)
HELCOM	Helsinki Commission, governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area
HNS	Hazardous and Noxious Substances
IBC code	The International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk
IMDG	International Maritime Dangerous Goods
IMO	The International Maritime Organization, a specialised agency of the United Nations responsible for regulating shipping
KBV	Swedish Coast Guard
LOD	Limit of Detection
MARPOL	The International Convention for the Prevention of Pollution from Ships
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSW	Maritime Single Window
MTBE	Methyl tert-butyl ether
NOAA	National Oceanic and Atmospheric Administration
OCIMF	Oil Companies International Marine Forum
ODME	Oil discharge monitoring equipment
OSPAR	The Convention for the Protection of the Marine Environment of the North- East Atlantic
P&A	Procedures and Arrangement
PAH	Polycyclic aromatic hydrocarbons
PEC	Predicted Environmental Concentration
PM	Particulate mass
PNEC	Predicted No Effect Concentration

PSSA	Particularly Sensitive Sea Area
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RoRo	Roll on-Roll off vessels
SAC	Special Area of Conservation
SCB	Statistics Sweden
SCI	Sites of Community Importance
SF	Safety factor
SGU	Geological Survey of Sweden
SHEBA	Sustainable Shipping and Environment of the Baltic Sea region. A research project funded by the EU BONUS-Programme
SIRE	Ship Inspection Report Programme
SLU	Swedish University of Agricultural Sciences
SM	Suspended material
SMHI	Swedish Meteorological and Hydrological Institute
SOLAS	International Convention for the Safety of Life at Sea
SPA	Special Protection Area
SPBI	Swedish Petroleum & Biofuel Institute
SSN	Safe Sea Net
TRAFA	Transport Analysis
UF	Dilution factor
UN	United Nations
US-EPA	United States Environmental Protection Agency
WISS	Water Information System Sweden
WFD	Water Framework Directive

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SUMMARY

Every year, the seas around Sweden are trafficked by chem- and product tankers that collectively transport hundreds of millions of tons of liquid chemical substances and products in bulk. When ships carry different types of chemicals, the tanks must be cleaned after unloading, before the new product is loaded. The aim of this pre-study was to assess tank cleaning from a marine environment perspective and to review current applicable regulations.

Legal discharges of wash water and chemicals from operational tank cleaning of vessels cause an increased pressure on the marine environment. There are currently no statistics on where and when tank cleaning is performed in Swedish sea areas, but based on observations from aerial and satellite surveillance, and traffic intensity of tankers from AIS data, some areas can be identified as probable areas for discharges. Several of these areas border or overlap with designated protected areas, for example according to Natura 2000.

Current regulations, mainly within the IMO MARPOL Annex II, related to discharge of tank cleaning residues are intricate and leave room for different interpretations. In addition, there is no comprehensive statistics available on the substances that are loaded and unloaded in Sweden. Further, the statistics that are available often contain errors which contribute to major uncertainties in the possible assessment of effects in the marine environment as a result of tank cleaning.

Today, very few of the substances transported in liquid bulk, can with certainty be classified as totally harmless. The regulations should therefore be reviewed and in the absence of reliable statistics and scientific evaluations, all substances discharged in connection with tank cleaning should be classified as hazardous substances. There is consensus within HELCOM that the pressure on the marine environment from hazardous substances in the Baltic Sea must be reduced, which strengthens arguments for applying the precautionary principle and consider a ban of discharges from tank cleaning at sea.

There are various advanced tank cleaning procedures to reduce the residual volume in the tanks. In accordance with previously published results, there is considerable potential for improvement in reducing the concentration of hazardous substances in the environment, by reviewing requirements for extended application of state-of-the-art cleaning procedures.

In order to reduce the impact on the marine environment from tank cleaning, as well as the environmental impact of shipping in general, increased collaboration between the relevant transport and environmental management authorities and other actors such as ports, ship operators and industries is required. Although there is already an ongoing cooperation within marine environment management, there is a lack of harmonization between the regulations for pollution prevention from ships versus the environmental objectives formulated by the management side.

1 INTRODUCTION

Every year, Swedish waters are trafficked by thousands of vessels that transport passengers and different types of goods. In the Baltic Sea, 25% of these vessels are liquid bulk carriers, transporting hundreds of millions of tonnes of liquid bulk each year. Liquid bulk can be defined as products that are pumped into and out of fixed holding tanks on board ships. Today, cargo holds are mainly filled with mineral oil and petroleum products but can also consist of other chemical products as well as vegetable oils and animal fats (Honkanen et al., 2012).

Tank cleaning is carried out when the ships shift between cargo types. Product tankers, or chemical tankers, are designed to be able to carry a variety of liquid products at the same time and need to be flexible in terms of product handling. To avoid contamination, their holding tanks must therefore be cleaned after unloading before a new product can be loaded. Operational tank cleaning generates large volumes of wash water, which is either collected in port or discharged at sea. Tank cleaning is regulated to a certain extent by Annexes I and II of the International Maritime Organization's (IMO) International Convention for the Prevention of Pollution from Ships MARPOL 73/78 (hereinafter referred to as MARPOL), which have been incorporated into Swedish law by the Act (1980:424) on Prevention of Pollution from Ships. However, the existing rules are ambiguous, and there are no readily available statistics on the extent of wash water discharges from tank cleaning in the marine environment.

1.1 AIM AND STRUCTURE OF THE REPORT

The aim of this study is to improve the knowledge regarding tank cleaning operations and to make an initial assessment of whether wash water discharges from tank cleaning operations may cause adverse effects in the marine environment, in both the short and long terms. There are currently no comprehensive statistics on how, where and when tank cleaning discharges occur, and there is thus no knowledge of the types and volumes of discharged substances. In addition, the aim was to identify knowledge gaps and suggest possible needs for further investigation of tank cleaning operations.

Studying the impact of shipping on the marine environment requires good knowledge of the marine environment itself, as well as an understanding of shipping operations and the economic drivers within shipping. Hence, this report begins with a brief description of the marine environment around Sweden, where especially the Baltic Sea is a particularly sensitive marine area. The applicable framework for marine environmental management is also discussed in brief, as are the effects of chemicals in the marine environment. This is followed by a description of how operational tank cleaning processes are carried out, including an overview of existing regulations on how and where wash water may be discharged.

Due to the lack of officially compiled statistics, a preliminary mapping of how and where tank cleaning is carried out, as well as where wash water is discharged, and the possible effects on the marine environment is provided.

1.2 LIMITATIONS

This study aims to investigate the marine environmental effects around Sweden following tank cleaning operations of tanks containing products transported in liquid bulk form, which are regulated in accordance with MARPOL Annex II. Early on, it was concluded that any measures related to tank cleaning will likely involve a greater responsibility for relevant operations on land, such as ports, with additional workload on port reception facilities and greater requirements in terms of waste handling and treatment. However, further investigation of this issue is beyond the scope of this report.

1.3 THE MARINE ENVIRONMENT AROUND SWEDEN

Sweden has a long coastline which borders the Baltic Sea, the Kattegat, and the Skagerrak. These marine areas are surrounded by ten countries (Finland, Russia, Estonia, Latvia, Lithuania, Poland, Germany, Denmark, Norway and Sweden), which means that large catchment areas flow into the relatively shallow sea basins around Sweden. The runoff also results in a salinity gradient from the Kattegat, with higher salinity (S=25‰), to the Bothnian Bay, with very low salinity (S=3‰) (Rodhe and Winsor, 2003). This contributes to a unique and fragile ecosystem that is not found anywhere else on earth.

The runoff also brings eutrophying compounds and various types of contaminants, which is particularly problematic since the Baltic Sea is an inland sea with limited water exchange (Stigebrandt, 2003; Rodhe and Winsor, 2003). This means that the accumulation potential for heavy metals and other environmental toxins is greater than in marine areas with more extensive circulation (Josefsson and Apler, 2019; HELCOM, 2017; Häkkinen and Posti, 2012). The problem of eutrophication, combined with the limited water exchange, also means that large parts of the Baltic Sea seabeds are deoxygenated, and this has a major impact on local biogeochemical processes (Stigebrandt, 2003). Elevated levels of environmental pollutants and toxic substances have been observed in sediments, particularly in the Baltic Sea Area (Josefsson and Apler, 2019).

Previous assessments of conditions in the Baltic Sea (HELCOM HOLAS I and II) and in Swedish waters in accordance with the Marine Strategy Framework Directive (Swedish Agency for Marine and Water Management report 2018:27, 2018) show that Good Environmental Status is not achieved with respect to eutrophication and hazardous substances. Therefore, the Swedish Government commissioned the Swedish Cross-Party Committee on Environmental Objectives (2018–2020) to develop a strategy aiming at reversing the negative trend and improve the conditions for meeting the objectives of the marine-related national environmental quality objectives, such as ‘Sea in balance’, ‘A living coast and archipelago’ and ‘No eutrophication’, as well as Goal 14 of Agenda 2030: Life Below Water.

To date, the impact of shipping on the marine environment has received limited attention, but an initial comprehensive assessment of the environmental impact of shipping's operational discharges and its contribution to underwater noise in the Baltic Sea was carried out in 2018 as part of the EU BONUS project SHEBA (Sustainable Shipping and the Environment of the Baltic Sea Region). However, the project did not include wash water discharges from vessels' tank cleaning (Moldanová et al., 2018).

1.4 CHEMICALS IN THE MARINE ENVIRONMENT

Chemicals and anthropogenically derived products that are discharged into the marine environment can affect molecular, individual, and societal levels, and can result in cascade effects that have a major impact on entire ecosystems (Figure 1). Several reports (Cunha et al., 2016; Tornero and Hanke, 2016) describe the difficulty of obtaining an overview of potential discharges of tankers – both those resulting from accidents and those resulting from operational activities – and their impact on the marine environment. This is partly due to a lack of available information but is also due to the complexity and diversity of the different substances.

The consequences of the discharges also depend on factors such as the substance's properties. Important properties that are often mentioned when evaluating the effects on the marine environment include volatility, density and solubility in seawater (Cunha et al., 2016; Honkanen et al., 2012). How a substance is being discharged, the properties of the surrounding environment, the time of year and the weather conditions are also key factors.

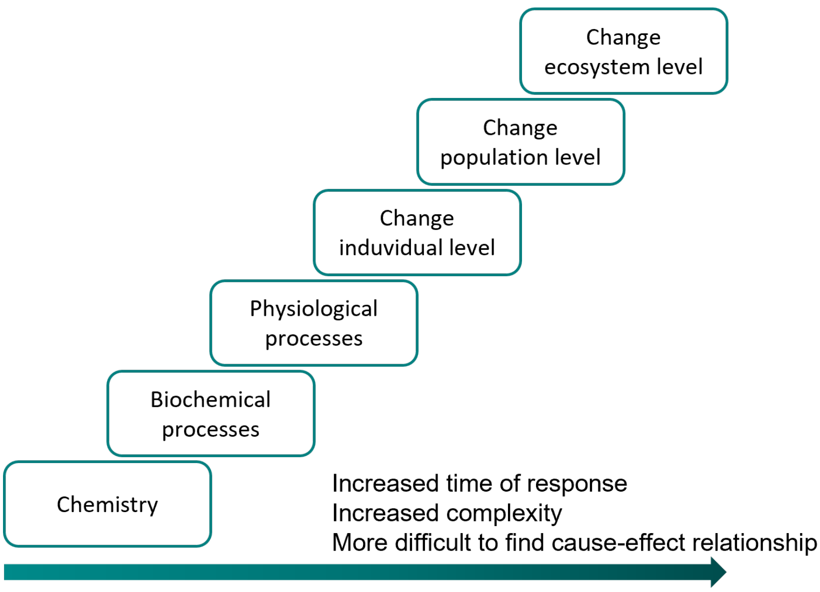

Figure 1. Illustration of how small-scale change at molecular level can affect both small- and large-scale processes.

1.4.1 Assessing the risks of chemical discharges in the marine environment

The term risk can be defined in several different ways, depending on what is being investigated, but can be explained as the combination of the likelihood of an event to occur and the consequences of such an event. If the consequences are severe and the likelihood is high, the risk becomes very high. The likelihood of a discharge occurring at a given position depends on the frequency of tank cleaning operations in an area, which in turn is related to the traffic intensity of liquid bulk carriers in the area.

When assessing the consequences of discharges of various substances in the marine environment, many different factors need to be considered. Bioavailability and toxicity can describe a substance's impact on biota. The substance's behaviour in water, air and sediment can provide information on how the substance will be spread (Cunha et al., 2016). Degradation rate and reactivity are other factors that determine where and how a substance may impact the environment (Cunha et al., 2016). In general, a substance that is discharged will be diluted and degraded (Honkanen et al., 2012). However, the rate of degradation, and the eventual consequences of the degradation products, are more difficult to determine. For example, some degradation products may become increasingly bioavailable and toxic than the originally discharged substance, while other may become rather harmless during biochemical degradation processes (Ying et al., 2002; NRC US, 2009).

Although the tank cleaning discharges from individual vessels are relatively small and quickly diluted, there may still be a risk to the marine environment, especially if multiple ships discharge wash water in the same geographical area. Paradoxically, the instructions for daily tank cleaning routines state that cooling water inlet should not be operated at the same time as operational wash water discharges (extract from Procedure & Arrangement protocol, P&A manual, and MARPOL Annex II). If wash water were to have no effect on the environment, there would reasonably be no risk involved in cooling water inlets being operated simultaneously. MARPOL Annex II (Reg. 12.8) states that the vessel's discharge pipe(s) should be arranged as to avoid taking in residues and water that have already been discharged once. Yet the water is considered clean enough to be released into the environment. Chronic exposure often leads to responses that do not necessarily result in increased mortality but can still have a major effect on the ecosystem structure of the marine environment (Honkanen et al., 2012).

1.4.2 Threshold values and environmental quality standards

The impact of a discharge into the marine environment depends on the concentration of the substance(s), as well as its toxicity. The impact may also depend on the time of year and which organisms that are being exposed to the substance(s). A commonly used method that indicates whether a discharge is likely to have a negative impact on the marine environment, involves first estimating the resulting predicted environmental concentration (PEC) and then comparing it to predicted no-effect concentration (PNEC) (REACH, 2008).

Equation 1: $$R = \frac{\text{PEC}}{\text{PNEC}}$$

where R is the ratio between PEC and PNEC. If R > 1, this means that the discharge is likely to have a negative effect on the marine environment. PNEC values are based on toxicity studies, usually carried out in a laboratory, with one substance at a time (EC, 2003). It is therefore important to review the PNEC values used and, if necessary, use a safety factor (SF), also called assessment factor, where the value of SF is determined based on the number of available studies on different types of organisms (EC, 2003). If there are only acute toxicity tests available, REACH (2008) suggests dividing the PNEC by at least SF = 1000. The greater the number of studies conducted, the lower the SF value required.

A similar limit value is the Environmental Quality Standard (EQS), which is defined as the concentration of a specific pollutant or mixture of pollutants in water, sediment or biota that must not be exceeded if human health and the environment are to be protected (EC (2000) Article 2 (35)). The EQS values are currently used to investigate whether marine areas meet good chemical status and good environmental status and also for planning purposes to ensure that excessive discharges to the environment do not occur. The same data used to calculate PNEC values is also used to determine the EQS, and these parameters are often used in parallel.

According to EC (2003), the following equation is recommended for calculating the local concentration (c) in nearby surface waters after a discharge with concentration (C_{out}):

Equation 2: $$c = \frac{C_{out}}{1+(K_{oc} \text{ x SM x DF})}$$

where K_{OC} is a partition coefficient describing the substance's affinity for water versus organic matter, SM is the concentration of suspended matter in the water (in this report, organic matter), and DF is a dilution factor that changes depending on where the discharge takes place.

1.5 TANKERS CARRYING PRODUCTS AS LIQUID BULK

Every year, hundreds of millions of tonnes of around 2000 different chemicals (not including oil) are transported at sea (Tornero and Hanke, 2016), and this figure is expected to increase (Cunha et al., 2015). Chemicals and chemical-like products can be transported in a variety of ways, in both packaged and bulk forms, and the applicable regulations are partly based on the mode of transport. Products shipped in bulk may be in solid, liquid or gas form. This study aims to investigate the effects of tank cleaning for tanks containing products transported as liquid bulk that are regulated in accordance with MARPOL Annex II (see section 1.6 Applicable regulations and tank cleaning). Examples of products transported as liquid bulk include alcohols, vegetable oils, acids and bases, as well as other raw materials for the chemical industry (Tornero and Hanke, 2016). In addition to oil and petroleum products, about 15 million tonnes of products were transported as liquid bulk in the Baltic Sea Area in 2010 (Häkkinen and Posti, 2012; Honkanen et al., 2012).

1.5.1 Size and design of liquid bulk carriers

Vessels designed for transporting liquid bulk products, but primarily used for transporting other products than mineral oil, are often within a size range of 3000 to 30 000 deadweight tonnage (DWT) (Eyres and Bruce, 2012). In principle, every vessel is unique and both smaller (1000 DWT) and larger (up to 60 000 DWT) liquid bulk carriers carrying chemicals and chemical-like products exist. These vessels are often equipped with 10–60 separate holding tanks (Figure 2) of varying capacities (Häkkinen and Posti, 2012; Höfer et al., 2013; Honkanen et al., 2012). On a vessel certified to carry chemicals, each holding tank must be capable of being decoupled from the rest of the holding tanks. In other words, all pipes, pumps, valves and manifolds must be separate and tank-specific.

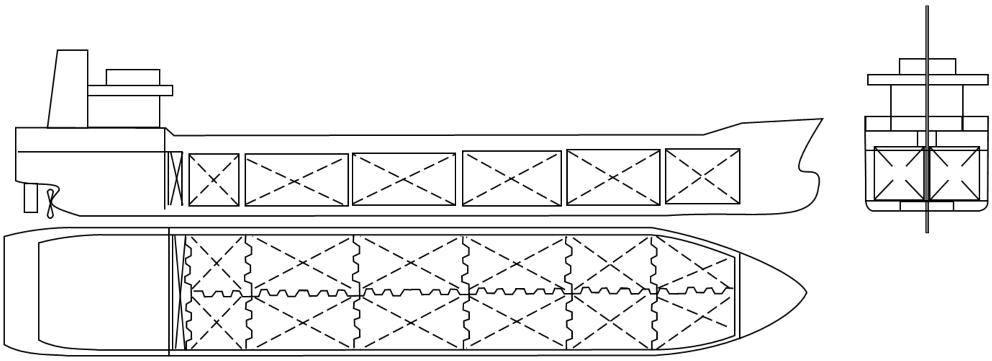

Figure 2. Schematic cross-section of a typical 12,700 DWT chemical tanker with separate tanks capable of transporting various chemicals as liquid bulk. Modified sketch based on Eyres and Bruce (2012).

The logistic constraints are indeed demanding on board a chemical tanker that handles multiple different chemicals. The products are not always compatible with each other, and accidental mixing can have major health-related and environmental consequences. In addition to compatibility issues between substances, some chemicals must be transported hot while other products require refrigeration. More than ten different types of products are rarely carried on the same liquid bulk carrier (Honkanen et al., 2012).

1.5.2 Increasing tank shipping globally and in the Baltic Sea

In 2013, some 315 million tonnes of liquid bulk were transported in the Baltic Sea (HELCOM, 2018b), which can be compared to 290 million tonnes in 2010 (Honkanen et al., 2012; Häkkinen and Posti, 2012). Globally, liquid bulk carrier trade (both petroleum products and chemicals) has more than doubled during the last 50 years, increasing from 1440 million tonnes in 1970 to 3194 million tonnes in 2018 (UNCTAD, 2019). The volume of chemicals transported by ships globally has increased at a similar rate, from 132 million tonnes in 1996 to 287 million tonnes in 2016 (Şanlıer, 2018). As a result of the recent Covid-19 pandemic, most forecasts for industrial and economic growth are highly uncertain. Prior to the outbreak of the pandemic, chemical production was expected to continue to increase, which will probably result in a continued increase in the transportation of chemicals via shipping (Roose et al., 2011). All liquid bulk carrier trade is estimated to grow at an annual rate of 2.2% during the period 2019–2024 (UNCTAD, 2019). An increased traffic intensity would mean a greater risk of incidents and accidents, as well as a generally higher frequency of discharges, which is particularly important to try to prevent in a confined area like the Baltic Sea (HELCOM, 2013; Cunha et al., 2015; Häkkinen and Posti, 2014; Şanlıer, 2018).

1.5.3 Liquid bulk transported via shipping and handled in Sweden

According to statistics from Eurostat, the total handling (both imports and exports) of liquid bulk, transported via shipping and handled in Sweden, reached approximately 63 million tonnes in 2018. The governmental agency Transport Analysis' statistical report for the same year (TRAFA, 2018) stated that 65 074 000 tonnes were transported as liquid bulk to/from Sweden in 2018. The majority (>90%, according to Transport Analysis' latest figures) consisted of mineral oils and petroleum products, which are regulated under MARPOL Annex I (see section 1.6 Applicable regulations and tank cleaning) and will therefore not be addressed in detail in this report. Out of the liquid bulk handled in Sweden, about 50% originates from the local region, i.e. from Sweden, Norway or one of the other HELCOM nations.

1.6 APPLICABLE REGULATIONS AND TANK CLEANING

The handling of hazardous substances at sea is primarily regulated by two different sets of IMO regulations. One is the International Convention for the Safety of Life at Sea (SOLAS Convention), which has the main aim of ensuring the safety of vessels and personnel. The other convention, MARPOL, focuses on preventing and controlling pollution from shipping. MARPOL includes six different annexes, with Annex I covering mineral oil, while Annex II addresses other hazardous and toxic substances carried as liquid bulk.

1.6.1 IMO PSSAs and Special Areas

The Baltic Sea is a designated Particularly Sensitive Sea Area (PSSA), which means that it meets the criteria described in the Revised Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas (PSSAs) (IMO, 2005). PSSAs are areas of significant ecological and/or socioeconomic value and are also sensitive to anthropogenic activities.

The Baltic Sea Area is also a designated Special Area with respect to MARPOL Annexes I, IV, V and VI, which means that there are stricter rules for handling oil, waste and emissions to air. Discharges of solutions containing mineral oils and petroleum products are not permitted in the Baltic Sea Area nor in the waters of northwest Europe (Figure 3)

(MARPOL Annex I Reg. 34.B). For all vessels with a gross tonnage above 150 GT, oil detection monitoring equipment (ODME) is also required. An ODME continuously monitors discharges of water containing oil and stops the outflow if the discharge of oil exceeds 30 litres per nautical mile (MARPOL Annex I, Reg. 31 and Reg. 34). However, discharges of oil are always prohibited within 50 nautical miles of the nearest land or in designated Special Areas under MARPOL Annex I, including the Baltic Sea Area. MARPOL Annex II was revised in 2004, with the aim of helping to protect the marine environment from the effects of operational discharges and accidental spills from ships (Höfer et al., 2013). The revised version introduced a new classification system and stricter rules for all marine areas. Currently, only Antarctica is a designated Special Area under MARPOL Annex II, implying that there is a total ban on discharges south of S60° (MARPOL Annex II, Reg. 13.8).

1.6.2 IMO MARPOL Annex II

The substances covered by MARPOL Annex II (Reg. 6.1) are classified as X, Y, Z or O.S. (‘other substances’) (Table 1). Liquids that are not classified accordingly, are not allowed to be transported via shipping, and discharges are totally prohibited (MARPOL Annex II, Reg. 6.3). This also applies to tank cleaning residues and ballast water (MARPOL Annex II, Reg. 13.1.3). Under MARPOL, all liquid substances transported by ships must be classified in accordance with the International Maritime Dangerous Goods Code (the IMDG Code), in the case of packaged goods (MARPOL Annex III), or the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (the IBC Code), in the case of goods carried as liquid bulk (MARPOL Annex II).

Table 1. Definitions of the categories of products transported as liquid bulk. The definitions are based on MARPOL Annex II regulation 6.

CATEGORY	DESCRIPTION ACCORDING TO MARPOL ANNEX 2 REGULATION 6
X	Noxious liquid substances which, if discharged into the sea from tank cleaning or deballasting operations, are deemed to present a major hazard to either marine resources or human health and, therefore, justify the prohibition of the discharge into the marine environment;
Y	Noxious liquid substances which, if discharged into the sea from tank cleaning or deballasting operations, are deemed to present a hazard to either marine resources or human health or cause harm to amenities or other legitimate uses of the sea and therefore justify a limitation on the quality and quantity of the discharge into the marine environment;
Z	Noxious liquid substances which, if discharged into the sea from tank cleaning or deballasting operations, are deemed to present a minor hazard to either marine resources or human health and therefore justify less stringent restrictions on the quality and quantity of the discharge into the marine environment;
O.S.	Substances indicated as OS (Other substances) in the pollution category column of chapter 18 of the International Bulk Chemical Code which have been evaluated and found to fall outside category X, Y or Z as defined in regulation 6.1 of this Annex because they are, at present, considered to present no harm to marine resources, human health, amenities or other legitimate uses of the sea when discharged into the sea from tank cleaning or deballasting operations. The discharge of bilge or ballast water or other residues or mixtures containing only substances referred to as "Other Substances" shall not be subject to any requirements of the Annex

The IBC Code

All vessels built after July 1st 1986 with the intention of carrying liquid bulk must comply with the IBC Code. For older vessels, there are equivalent regulations in the Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (the BCH Code). The IBC Code presents an international standard for transporting liquid bulk safely. With the implementation of the MARPOL Convention, the IBC Code was adopted as a mandatory requirement under MARPOL Annex II. The code lists the substances covered by MARPOL Annex II, specifies the classes to which the products belong, and details the construction and handling requirements that must be followed when transporting chemicals as liquid bulk. Vessels are classified as Type 1, 2 or 3 (IMO (2014) 2.1.2), which determines which classes (X, Y, Z) of products that may be transported. Type 1 vessels are certified to transport products with the highest risk of general damage in the event of an incident. These vessels must be designed to withstand more serious accidents while maintaining intact cargo holds. The IBC Code also defines the types of tanks to be used for specific products in order to minimise the risk of damage, leaks and other unforeseen events (IMO (2014) chapter 4.1).

Based on the classification of all substances listed in chapter 17 of the IBC Code, every year a risk profile is compiled by the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP). Here, each substance is defined in accordance with thirteen different categories, using both numerical ratings and qualitative descriptions, which can then be used to classify the products (MARPOL Annex II, Appendix I). The risk assessment carried out by GESAMP is in line with GHS (the US Globally Harmonized System of Classification and Labelling of Chemicals) and its European counterpart, REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals). More information about the selected categories, including descriptions and grading systems, can be found in the latest GESAMP report (Höfer et al., 2013). In summary, the categories reflect the products' bioaccumulation potential, the toxicity, and the hazard to health and the marine environment.

The P&A manual

MARPOL Annex II also describes how the vessel's mandatory handling manual (the P&A manual) should be designed and followed. This manual must be approved by the vessel's flag state. The P&A manual describes how holding tanks should be cleaned and how operational discharges should be carried out. Tank cleaning procedures are not only dependent on the product that has been stored in the holding tank, but also on the next product to be stored.

1.6.3 Post-unloading regulations for different categories of liquid bulk

Different types of vessels that carry different categories of liquid bulk are subject to different post-unloading regulations (Table 2). Depending on the year in which the vessel was constructed, different quantities of strip, i.e. what remains in the pipe, pump and holding tank after unloading, are permitted. Newer vessels may be fitted with an additional pumping device with smaller pipes that enable the strip to be reduced to volumes corresponding to a coffee cup. This is also known as a super strip system.

Classification in accordance with MARPOL Annex II and prewash requirements

Holding tanks containing class X substances must undergo what is known as a prewash, where the entire holding tank is rinsed after unloading, until the concentration of the original substance is less than 0.1% (by weight). All wash water – or slop – from the prewash must be pumped ashore and disposed of before the vessel is allowed to leave the dock. The responsible authority or operator then has the task of taking care of the wash water from the prewash. Prewash is also compulsory for holding tanks that have contained class Y substances if the substance is defined as solidifying or high viscosity under MARPOL Annex II (Reg. 1.15.1, 1.17.1). There are some differences in the prewash routines, depending on whether the substance is class X or class Y and whether they are solidifying or non-solidifying (MARPOL Annex II, Appendix VI). For instance, the minimum number of wash cycles for class X products is twice as many as for class Y products, and it is only for non-solidifying substances within class X that all internal surfaces of the holding tank need to be washed.

A prewash must also be carried out if unloading has not followed the procedures detailed in the P&A manual (MARPOL Annex II, Reg. 13.7.1.2). The ship may seek exemption from prewash requirements if the holding tank will be loaded with cargo that is compatible with the previous cargo; if the vessel ensures that no tank cleaning will take place at sea but in the next port; or if it is possible for the final cargo residues to be ventilated out (MARPOL Annex II, Reg. 13.4).

Table 2. Permitted strip volume per holding tank and any prewash requirements depending on the year of construction and the cargo category. Information from MARPOL Annex II.

CATEGORIES MARPOL ANNEX II	SHIPS CONSTRUCTED PRIOR TO JULY 1ST 1986	SHIPS CONSTRUCTED BETWEEN JULY 1ST 1986 AND JANUARY 1ST 2007	SHIPS CONSTRUCTED PAST JANUARY 1ST 1986
X	300 L (+50 L) strip per tank. Prewash mandatory; max 0.1% (weight) remaining after prewash.	100 L (+50 L) strip per tank. Prewash mandatory; max 0.1% (weight) remaining after prewash.	75 l strip per tank. Prewash mandatory; max 0.1% (weight) remaining after prewash.
Y SOLIDIFYING/ HIGH VISCOSITY	300 L (+50 L) strip per tank. Prewash mandatory.	100 L (+50 L) strip per tank. Prewash mandatory.	75 L strip per tank. Prewash mandatory.
Y	300 L (+50 L) strip per tank. Prewash NOT mandatory.	100 L (+50 L) strip per tank. Prewash NOT mandatory.	75 L strip per tank. Prewash NOT mandatory.
Z	900 L (+50 L) strip per tank. Prewash NOT mandatory.	300 L (+50 L) strip per tank. Prewash NOT mandatory.	- Prewash NOT mandatory.

New regulations for persistent floaters

New regulations, which have been added to Annex II of MARPOL and the IBC Code, and which come into force in 2021, define an additional group of class Y substances covered by the prewash requirement. These substances are defined as persistent floaters (F_p) with a density ≤ seawater (1025 kg/m^3 at 20°C), vapour pressure ≤ 0.3 kPa, solubility ≤ 0.1% (for liquids) or ≤ 10% (for solids), and kinematic viscosity > 10 cSt at 20°C. Holding tanks containing persistent floaters must undergo a prewash, if the viscosity of the substance is ≥ 50 mPa at 20°C and/or the melting point is ≥ 0°C.

Washing and rinsing taking place after an approved prewash, or immediately in cases where prewash is not mandatory, may be carried out at sea and the slop may be discharged into the sea. According to MARPOL Annex II, Reg. 13.1.1, the discharge of class X, Y or Z substances is prohibited unless the discharge takes place in accordance with the guidelines of MARPOL Annex II (Reg. 13.2.1): the discharge must take place while en-route at a minimum speed of 7 knots and must take place below the water line, the water depth must be at least 25 metres, and the distance from the nearest land must be at least 12 Nm.

1.6.4 Detergents and solvents used during tank cleaning

Water is the most common medium used for tank cleaning, but addition of detergents and solvents is sometimes required. These are also regulated by MARPOL Annex II and the IBC Code. Additives, in the form of detergents and solvents, may contain up to 10% of class X substances in total, provided that they degrade immediately in the environment. No additional restrictions apply to this wash water (MARPOL Annex II, Reg. 13.5.2). If something other than water is used as the main washing medium, the washing residues shall be handled as cargo and regulated in accordance with Annex I or II, depending on the substance used (MARPOL Annex II, Reg. 13.5.1).

After a vessel has performed any prewash, followed by operational tank cleaning and completed inspection, the holding tank is deemed to be clean and ready for reloading. However, certain organisations (such as the Federation of Oils, Seeds and Fats Associations (FOSFA) and the National Institute of Oilseed Products (NOIP)) have restrictions whereby certain products, such as foodstuffs, must never be transported in holding tanks where the previous cargo consisted of benzene or phenols, for example, regardless of the degree of cleaning (Honkanen et al., 2012).

1.6.5 Regional regulations, EU, HELCOM and OSPAR

In addition to the global regulations and guidelines, regional directives also apply within the EU. All waters within the EU are regulated through the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD). These two directives overlap to some extent in the coastal zone, and both have the overall objective of reducing discharges of hazardous substances to water and achieving Good Environmental Status. The EU has also issued a directive on reporting formalities for ships (2010/65/EU), and from 1 October 2015 all ship calls must be reported via the Maritime Single Window (MSW). In Sweden, the MSW is a collaboration between the Swedish Coast Guard, Swedish Customs, the Swedish Transport Agency, and the Swedish Maritime Administration, who is responsible for its administration. All vessels – regardless of their size – carrying hazardous and/or polluting goods and leaving a Swedish port or anchorage must notify this via the MSW.

Vessels en-route for a Swedish port or anchorage site from a destination outside the EU must also report hazardous goods to the MSW. Waste is also reported via the MSW, and this must be done 24 hours before arrival at the port. This applies to sludge, oily bilge water, oil residues, cargo residues of hazardous liquid substances in bulk or packaged form, and sewage.

In parallel with the WFD and the MSFD, two commissions – the Helsinki Commission (HELCOM) and the Oslo-Paris Commission (OSPAR) – are working to improve the marine environment in the Baltic Sea (HELCOM) and the North-East Atlantic (OSPAR). Some parts of the geographical scope of these conventions overlap in the sea basin between Sweden and Denmark, and Sweden is an active member of both organisations (Figure 3). All member states undertake to follow the recommendations decided by the commissions, but there are no legal sanctions for failing to comply with the guidelines.

HELCOM's own policies and guidelines state that it is compulsory to leave ship-generated waste in port, if possible, and that incineration of waste on board is prohibited throughout the Baltic Sea Area (HELCOM (2014) Annex IV, Reg. 6B). There is also an agreement between the HELCOM nations that all vessels carrying hazardous goods and arriving at or departing from ports belonging to a Baltic Sea state must report their cargo to the appropriate authority in that state (HELCOM, 2017).

One working group within OSPAR focuses on hazardous substances and eutrophication. One of the target strategies is that various types of discharges of hazardous substances should cease by 2020 (OSPAR Convention (1992), OSPAR Agreement 2010-3). OSPAR's Hazardous Substances Strategy also includes mixtures substances that may have synergistic adverse effects on the marine environment.

1.6.6 Swedish legislation

Sweden has two laws governing the reception and handling of waste from ships (Swedish Environmental Protection Agency, 2003). The Waste Ordinance (2001:1063) describes how waste should be handled and received in port, while Chapter 15 of the Swedish Environmental Code (1980:424), the Act on Prevention of Pollution from Ships, deals with the issue of pollution. The latter is also the regulatory framework whereby MARPOL is incorporated into Swedish law. The port's responsibilities are described in documents including the Swedish Maritime Administration's regulations and general advice (SJÖFS 2001:12) on the reception of waste from ships.

Figure 3. The boundary of the Swedish economic zone is shown with a solid dark blue line. The dashed lines across the Åland Sea (on the east coast) and the Sound (on the west coast) mark the boundaries between Sweden's marine planning areas, and the colours indicate which convention applies in each area. The OSPAR Convention applies in the green area, the HELCOM Convention applies in the orange area, and the two conventions overlap in the purple area.

1.6.7 The oil and chemical industry's self-regulation system – vetting

The oil and chemical industry have largely developed a self-monitoring system including so called vetting programmes. Vetting is carried out in agreement with the shipping line alongside port state controls. During vetting, a thorough check is carried out of the certificates obtained, other documents, and the management and operation of the vessel to ensure compliance with regulations and to minimise the risk of incidents. The Oil Companies International Marine Forum (OCIMF) and the Chemical Distribution Institute (CDI) are two of the main organisations that carry out vetting inspections for liquid bulk carriers handling Annex II products.

1.6.8 The HNS Convention

Another – and potentially important – governing instrument is the HNS Convention and its associated fund (the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea, 1996, and the 2010 Protocol). Only five states (South Africa, Norway, Turkey, Canada and Denmark) have currently ratified the Convention (https://www.hnsconvention.org/). In Sweden, a draft law – the Act (2018:1854) on the International Hazardous and Noxious Substances Fund – has been formulated. The law will come into force 18 months after the Convention has been adopted, which will take place on the date when enough states (at least 12 states, corresponding to a certain tonnage of the total fleet) have ratified the Convention. As well as ensuring compensation and regulating liability in the event of discharges and accidents, the ratification of the Convention will also involve higher reporting requirements for each nation's handling of hazardous cargos.

1.7 PREVIOUS INDICATIONS THAT TANK CLEANING IS AN ENVIRONMENTAL PROBLEM

Very few scientific articles and reports address the problems of legal operational tank cleaning and the potential chronic effects it can cause in the marine environment. Şanlıer (2018) calls for a re-examination of the rules on the discharge of tank cleaning wash water into the marine environment. Şanlıer (2018) argues that decisionmakers, such as the IMO, and maritime authorities have only considered the low concentrations released during tank cleaning, without taking into consideration the development and growth of transportation of chemicals by ships.

According to HELCOM (2018b), there are now indications that ships that unload and load in the same port go offshore to carry out tank cleaning and discharge the wash water, before returning to load new cargo. There are a number of examples of fats and paraffin wax being washed ashore in Sweden and other European countries, and these are suspected to come from wash water discharges (Honkanen et al., 2012; Larsson, 2019; Roose et al., 2011). Although these discharges consist of non-fossil oils, they can still cause increased mortality in birds, with major consequences for the marine environment (Honkanen et al., 2012). For example, 1200 oiled birds were found along the southern tip of Gotland in 2013, despite the Swedish Coast Guard not having received any reports or observing any discharges (Larsson, 2019). In 2007, dead birds and a green substance were found washed up on Dutch beaches. The birds that had encountered these substances had begun to dissolve. The blend turned out to be a mixture of several chemicals including sulphur, arsenic and copper, and also contained traces of phenols (Roose et al., 2011). The source could not be traced.

1.7.1 Aerial and satellite surveillance observations

According to information from the Swedish Coast Guard, 43 discharges of unknown substances or other chemicals occurred between 2017 and 2019. In 2019, eleven specific cases were reported to the Swedish Coast Guard were lumps of unknown substances had been washed ashore. Each year, aerial surveillance is carried out on behalf of HELCOM, as part of the collaboration between the HELCOM member states. The aim of these flights is to detect discharges and to work to prevent infringements and violations (HELCOM, 2018a). Satellite monitoring has been expanded via the EU Clean Sea Net project since 2007. In 2018, 155 spills were observed in the HELCOM area, of which approximately 40% were identified as mineral oil, while the rest remained unidentified. Since it is only possible to detect oil-like substances on the surface through aerial monitoring, and since there is a wide variation in temporal and spatial monitoring, these statistics should be seen as an indication that discharges are occurring, but that the extent may be much greater than the figures suggest. Safe Sea Net (SSN), in cooperation with Clean Sea Net, also publishes real-time satellite images of potential discharges, with 17 observations noted in January and February 2020 either in or adjacent to Swedish waters.

1.1.1 Large operational discharges versus accidental discharges

Despite intensive traffic, accidents involving chemical tankers are rare (Honkanen et al., 2013). This, in addition to the fact that operational discharges are significantly more likely than major accidents, means that operational tank cleaning discharges should be considered a more pronounced threat to the marine environment (Honkanen et al., 2012, 2013). The total quantity of liquid chemicals released in accidents in European waters between 1970 and 2011 has been estimated at approximately 170 000 tonnes (Cunha et al., 2015). This compares to annual discharges of around 7 000 000 tonnes that can be attributed to operational tank cleaning globally (Honkanen et al., 2012).

2 METHOD

The aim was to gather as much information as possible over a six-month period (from October 2019 to March 2020) on the transport of liquid bulk, and to link this to potential risks in the marine environment. The information was then used to identify potential conflicts of interest between tank cleaning operations and impacts on the marine environment.

2.1 DATA COLLECTION – BULK CHEMICALS

As there is currently no overall database for reporting chemicals transported as liquid bulk, regulated by MARPOL Annex II, several strategies – such as searching databases, reviewing existing literature, and conducting interviews and study visits – were applied in parallel to gather information. The ambition was to obtain statistics being as accurate and comprehensive as possible. The sources of information used, and how the data was collected, analysed, and compiled to create a comprehensive and up-to-date overview, are described below.

2.1.1 Swedish ports and industries

The selection of ports contacted was based on the Swedish Maritime Administration's statistics on reported calls of chemical liquid bulk carriers at Swedish ports during a six-year period (2014–2019). This included all vessels carrying liquid bulk, including those transporting oil and petroleum products. Various staff members (e.g. CEOs, environmental officers, administrators, supply chain managers, terminal managers and port managers) at the selected ports and industries were contacted by email (see Annex D), and were asked which liquid bulk products (in accordance with MARPOL Annex II) were handled within their operations. Statistics on the quantities of each product were also requested. Finally, they were asked to report – if possible – how many vessels were used to transport the stated quantities, and which chemicals, if any, were transported together. The responses were received primarily by email, or by telephone if preferred by the respondent.

2.1.2 Government agencies and public databases

Vessels operating in Sweden and calling at Swedish ports must report to the MSW, also referred to as the MSW Reportal. All public agencies involved in the portal (Swedish Maritime Administration, Swedish Coast Guard, Swedish Customs, the Swedish Maritime Administration, and the Swedish Transport Agency) were contacted, and they have all contributed to various parts of the information, which were combined with information from other sources.

All goods imported/exported outside the EU and Sweden are reported to Swedish Customs. Swedish Customs was thus able to provide certain statistics on liquid bulk transported via shipping in 2017 and 2018.

Statistics Sweden (SCB) registers all goods imported/exported to/from Sweden and manages an open database containing statistics based on the name or group of such goods. In accordance with the foreign trade statistics for all EU countries, the most detailed classification of goods is in accordance with the Combined Nomenclature (CN) number. According to SCB, the reliability of its published statistics is considered to be high at overall level, but there is some uncertainty at more detailed levels. No general indication of the extent of this uncertainty is provided, but SCB considers the main source of uncertainty to be measurement errors, as well as estimates made for businesses that are not obliged to provide information. The difficulty involved in selecting the correct CN number is also mentioned as a contributing factor behind uncertainty in the statistics (SCB, 2017).

To filter the data in SCB's public database, all CN numbers and names of goods (> 10,000 items) were first checked. The goods and categories deemed to be of interest for this work were then selected (approximately 750 items) based on whether they could exist in liquid form and whether they belonged to Chapters 4, 5, 13, 15, 22, 27–30, 32–35 or 38–40 of SCB's list of chapters (see Annex A). Data was then retrieved on the number of tonnes imported and exported to and from Sweden during 2014–2018 (7500 data points). The remaining items were ranked based on the quantity imported and/or exported, thus excluding certain items that were deemed too small to be shipped in bulk form. The remaining 175 items were judged to be potential products transported as liquid bulk in Swedish waters. After compilation, the statistics from Swedish Customs were also matched with the statistics received from SCB to confirm the maritime transport of certain goods.

In addition, a list based on the selection of potential liquid bulk products from the chapters of SCB, was forwarded to the Swedish Maritime Administration. The Swedish Maritime Administration was then then able to extract a comprehensive dataset that included reports of all hazardous goods notified via the Swedish MSW between 2014 and 2019. However, bulk could not be distinguished from packaged goods, meaning that these statistics also had to be compared with other sources for further analysis.

The Swedish Maritime Administration also contributed with waste reports submitted from Swedish ports during the period 2017–2019. Statistics on requests for prewash exemptions were obtained from the Swedish Transport Agency, and this information was used to supplement the information previously supplied by the ports.

In addition to the abovementioned agencies, information on imports and exports was also obtained from the Swedish Chemicals Agency and the Swedish Petroleum and Biofuels Institute (SPBI). The Swedish Chemicals Agency compiled data on the 50 largest chemical substances imported into Sweden by volume in 2017. This data does not indicate the means of transport or whether the substance in question is pure or mainly present in mixtures. SPBI produces annual statistics on imports and exports of oil-based products. Since this category of substances is mainly covered by MARPOL Annex I, no further work was carried out on these statistics.

Each year, the European Maritime Safety Agency (EMSA) publishes official statistics (Eurostat) on annual imports and exports of liquid bulk between ports. These statistics do not specify the type of liquid bulk transported, but they offer information about traffic flows in the Baltic Sea and were used to identify the main liquid bulk handling ports in the Baltic Sea Area.

Following a formal approval by all nations concerned (Sweden, Finland, Estonia, Latvia, Lithuania, Poland, Germany, and Denmark, during a high-level steering meeting in January 2020), further information, with more detailed traffic flow data, was compiled and provided by EMSA. EMSA gathers annual statistics on vessels that have reported carrying dangerous goods, in both bulk and packaged forms. The departure and arrival nation for each journey is also indicated. It is the member states' responsibility to ensure that this information reaches EMSA, and EMSA therefore does not accept liability for any reporting errors.

2.1.3 International actors

The Baltic Sea, the Kattegat and the Skagerrak border to several countries and ships transporting goods to/from these countries thus have to pass through Swedish waters. Therefore, the relevant authorities of all member states were also contacted, primarily those corresponding to the Swedish Maritime Administration. Where no response was received, individual ports were also contacted. HELCOM was contacted at an early stage to investigate whether they collected information on the transport of hazardous products in the Baltic Sea Area.

The French organization Cedre (Centre of Documentation, Research and Experimentation on Accidental Water Pollution) consists of experts from different backgrounds working on water pollution issues, mainly in France but also internationally. Cedre described difficulties in identifying and quantifying the products shipped as liquid bulk, but contributed with more general information about chemical shipments and common chemicals transported on a global scale.

2.1.4 Literature review

Only a handful of studies have investigated common chemicals transported in the Baltic Sea and the environmental impact from a potential large-scale discharge. These studies usually list the most commonly transported chemicals and select a few for further risk analysis. Many have also attempted to make priority lists of the chemicals that pose the greatest threat at local and regional levels. Early in the literature review, it became apparent that most of the works referred to the same datasets, in particular those compiled by Molitor (2006) and Häkkinen and Posti (2012), and these works have therefore formed the basis for comparison across years.

Data was also collected from projects and publications (e.g. Neuparth et al., 2011; Cunha et al., 2015, 2016) that mainly focus on accidents and accident prevention. These data often mention products which, in the event of an accident, would have a major impact on the environment but which, from a tank cleaning perspective, do not necessarily pose a major threat as they are already heavily regulated. However, these analyses were useful for identifying and evaluating products from a risk analysis perspective.

2.2 RISK ANALYSIS

The lack of detailed data on the quantities of different substances discharged into Swedish waters during operational tank cleaning, and when and where these discharges take place, makes it difficult to carry out an in-depth risk analysis. The risk analysis in this report was based on assumptions about where and how discharges of wash water occur and what the consequences might be, in terms of the concentration of pollutants in the marine environment, depending on the substance discharged.

2.2.1 Likelihood of discharges

The estimated likelihood of discharges from tank cleaning is based on the traffic intensity of liquid bulk carriers in 2018 within the HELCOM-OSPAR area, derived from EMODnet (Figure 4). Vessel intensity is based on the time spent by liquid bulk carriers within predefined 1×1 km^2 grid cells. This is expressed as a monthly average in hours/km^2/month (EMODnet, 2019). The likelihood of discharges is assumed to increase with increasing traffic intensity. The assessment of the likelihood of discharges is also based on aerial surveillance data from HELCOM where it is expected to be higher in areas where more frequent discharges have been reported.

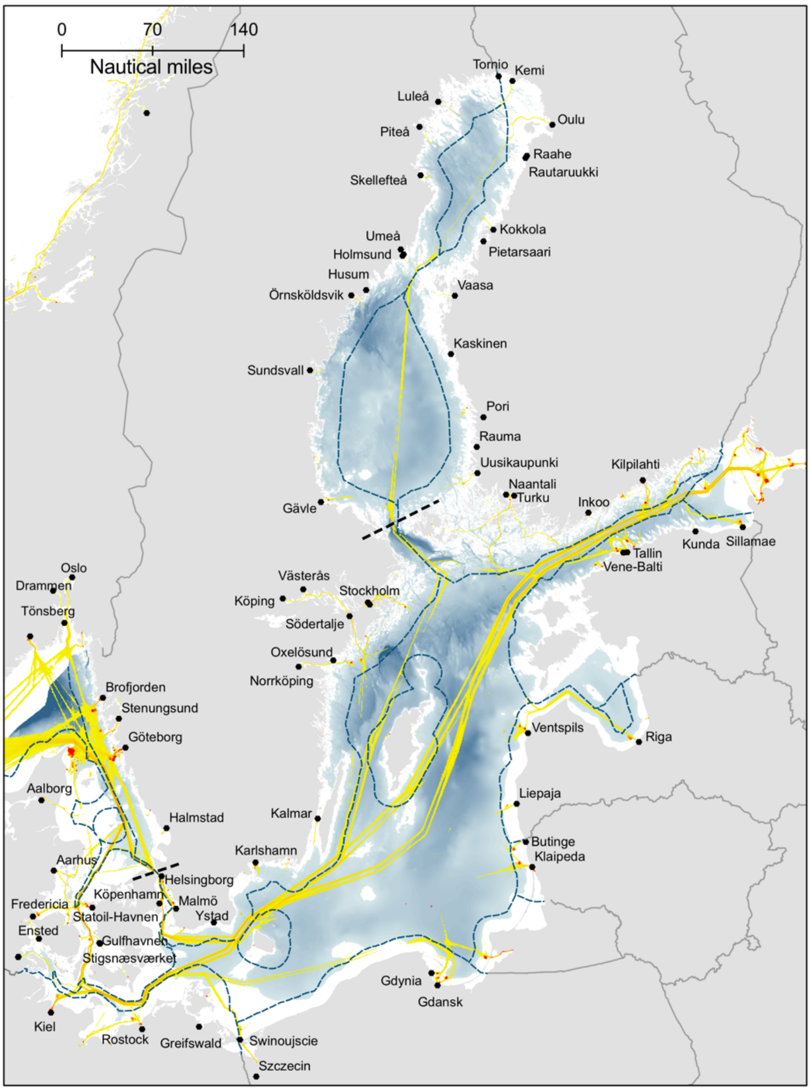

Figure 4. Traffic intensity (yellow/red scale) for liquid bulk carriers operating in Swedish waters in 2018 (EMODnet). Every vessel passing within each 1×1 km^2 grid cell is counted. The territorial boundary (dashed blue lines) is 12 Nm from land. Bathymetry is shown at all depths above 25 metres. For depths shallower than 25 metres, no bathymetry is shown.

Table 3. Calculated concentration factors (CFs) based on strip volume per holding tank, prewash and super strip.

PARAMETER	VALUE	UNIT	EXPLANATION	REFERENCES
HOLDING TANK VOLUME	1000	m^3	Exemplified in P&A Approximate average. If the tank is larger than this more butterworths are required.	Honkanen et al. (2012)
NR BUTTERWORTHS PER HOLDING TANK	1	#	Depend on tank volume according to P&A and MARPOL Annex II.	MARPOL Annex II
VOLUME WASH WATER PER WASH CYCLE	20	m^3	10-100 m^3/holding tank 18-24 m^3/holding tank	Honkanen et al. (2012) Honkanen et al. (2013)
STRIPPING VOLUME SUPERSTRIP A)	0.1	L	"only a cup left"	FRAMO
STRIPPING VOLUME B)	10	L	Common volume after unloading.	Personal communication from several sources
STRIPPING VOLUME C)	75	L	Maximum allowable volume for ships constructed after 2007 (keel laid).	MARPOL Annex II
STRIPPING VOLUME D)	150	L	Maximum allowable volume for ships constructed between (keel laid) 1st of July 1986 and 2007.	MARPOL Annex II
CF A)	5×10^{-6}	-	Concentration factor (CF) multiplied with density provides the concentration.	
CF B)	5×10^{-4}	-	Concentration factor (CF) multiplied with density provides the concentration.	
CF C)	3.75×10^{-3}	-	Concentration factor (CF) multiplied with density provides the concentration.	
CF D)	7.5×10^{-3}	-	Concentration factor (CF) multiplied with density provides the concentration.	
CONCENTRATION "SLOP B)" WITH PREWASH E)	5×10^{-4}	g/L	0.1 mass percentage prewash-concentration is equivalent to 1 g product/litre water.	MARPOL Annex II Reg. 6.1.1
CONCENTRATION "SLOP C)" WITH PREWASH F)	3.75×10^{-3}	g/L	0.1 mass percentage prewash-concentration is equivalent to 1 g product/litre water.	MARPOL Annex II Reg. 6.1.1

2.2.2 Impact analysis

The method for estimating potential concentrations in the marine environment as a consequence of slop discharges from tank cleaning operations was partly inspired by previous studies (Honkanen et al., 2012, 2013), in which concentrations from discharges were calculated based on 1) the amount of product left in the tank and 2) the volume of wash water used for tank cleaning.

The amount of product remaining in a holding tank before tank cleaning starts depends on the strip volume, whether or not a prewash was performed, and whether or not a super strip took place. The volume of wash water used depends on the size of the holding tank to be cleaned. The larger the holding tank, the more butterworths are needed.

The volume of wash water also depends on how many cleaning cycles are run per wash, and this should be done in accordance with the vessel's P&A manual. All parameters used to calculate the discharge concentrations (C_{slop}) and the justifications for determining these parameters are presented in Table 3. C_{slop} is then used to calculate the concentrations produced by the discharge in the marine environment.

This report presents a new method for determining dilution factors (DFs) that should better reflect the processes involved in a vessel's discharges while en-route. The vessel discharges a certain amount of wash water per unit time while en-route at a certain speed, and mixing takes place within the ship wake that is formed aft of the direction of travel (Figure 5).

The final concentration (PEC) is based on the concentration of the slop (C_{slop}), the flow speed of the discharge, the speed of the vessel and the size of the ship wake formed by the vessel. The size of the ship wake varies, depending on factors such as the size and shape of the vessel, and can – in very simple terms – be seen as a homogeneous water package where mixing occurs. A concentration of the discharged substances is thus maintained within the ship wake. The modified equation, based on equation 2, is shown in equation 3.

Equation 3:
$$PEC = \frac{C_{slop}}{1 + (K_{oc} \times SM \times 10^{-3})} \times \frac{V_{out}}{v_{vessel} \times w_{wake} \times d_{wake}}$$

Where v_{out} is the velocity of the outflow (m^3/h), v_{vessel} is the velocity of the vessel (m/h = knots×1852), w_{wake} is the width of the ship wake (m) and d_{wake} is the depth of the ship wake (m). The wake formation and the shape of the ship wake are very simplified, as illustrated in Figure 5, where the ship wake is assumed to take the shape of a rectangular block. Suspended material (SM) was estimated at 2.5 mg/l, but this can vary depending on the season and the specific area surveyed (Kyryliuk and Kratzer, 2019). Using Equation 3 assumes that the discharge is continuous, and it does not take into account scenarios where the slop = 0 m^3.

Figure 5. Schematic figure showing the vessel, the discharge and the ship wake formed behind the vessel. The figure is not to scale for practical reasons but is included to illustrate the simplified shape that the ship wake is assumed to take with constant depth and width.

The REACH database (REACH, 2020) and HNS-MS (Legrand et al., 2017) were mainly used to compile PNEC and/or EQS values. A number of public databases and tools that have been developed to assist in the event of an accident, sometimes also include threshold values for each substance. In Sweden, the Swedish Coast Guard's RIB data bank is used. As with Cameo Chemicals (NOAA), this can be used to get a quick overview of the properties, toxicity and compatibility of different substances.

To compare the PEC values, calculated in accordance with Equation 3, a two-dimensional hydrodynamic and chemical model (MAMPEC) was used.

Comparing the PEC and PNEC (or EQS) for individual substances only gives an indication of whether there may be a risk to surrounding environments. Gustavsson et al. (2017) and Backhaus and Faust (2012) demonstrate how several different substances can lead to an additive effect, also known as a cocktail effect, discussed in greater depth in the 'Results and discussion' section.

2.3 IDENTIFICATION OF CONFLICT AREAS

In connection with the risk analysis (section 2.2), it is important to define to whom or what the consequences apply. A phenomenon that causes major impact in one place will not necessarily give rise to the same consequences elsewhere.

The GIS tool ArcMap 10.5 was used to map and illustrate potential conflict areas. The aim was to identify likely operational discharge areas (based on MARPOL Annex II guidelines) and to investigate which of these areas that may be in conflict with other interests and environmental values. Using map layers and analyses published by HELCOM, the Swedish Agency for Marine and Water Management and the EU, areas were identified where shipping shares space with globally recognised environmental values, important industries such as fisheries and aquaculture, and spawning grounds and habitats for key species.

3 RESULTS AND DISCUSSION

This section presents the data collected, as well as some of the risks posed by discharges of the liquid bulk products. Four geographical areas identified as being particularly interesting from a tank cleaning perspective are also presented. Finally, problems are discussed, and possible measures are suggested.

3.1 CHEMICALS TRANSPORTED AS LIQUID BULK BY SHIP

It is clear from the 'Methodology' section of this report that collecting data on the liquid bulk products transported in Swedish waters is not a simple task and requires active searches among many different sources (Table 4). The resulting statistics presented below (Table 5) are therefore derived from a combination of several sources such as agencies, ports, and industries, both within and outside Sweden. 'Within Sweden' includes cargo either loaded or unloaded at a Swedish port, while 'Outside Sweden' consists of aggregated statistics from liquid bulk being unloaded and loaded at a port outside Sweden but within the Baltic Sea countries or countries bordering Sweden. None of the sources could provide all the information required, and some of the uncertainties are therefore discussed in parallel to the presentation of the results.

According to the report by Transport Analysis, which includes statistics on shipping traffic in Sweden in 2018, the total amount of liquid bulk handled in Swedish ports is about 65 million tonnes. This is consistent with the figures obtained from Eurostat. The total amount of crude oil and refined petroleum products handled in Swedish ports in 2018 was approximately 60 million tonnes (TRAFA (2018), Table 3B), indicating that the remaining liquid bulk amounted at least 5 million tonnes in 2018. The total amount of liquid bulk regulated under MARPOL Annex II and reported to us by surveyed ports and industries totalled 2.8 million tonnes, representing only 56% of the estimated 5 million tonnes based on Transport Analysis' statistics.

One reason that only 56% of the total 5 million tonnes were identified might be that not all ports responded to the questions sent out. The ports that did not respond accounted for 15% of the total number of chemical and oil tanker port calls in 2018. Due to variations in factors such as vessel size and port capacity, it is not possible to say what volume this represents. Also, it is not certain that the responding ports and terminals accounted for all terminals within the official port area. This may be particularly problematic if port operations are leased to industries or other stakeholders. A few ports replied about the products handled, but only gave the total amount for all products. These represented about 690,000 tonnes, or close to 14% of the total 2.8 million tonnes identified during the project.

Two other possible reasons for the statistical discrepancies regarding the amount of liquid bulk from different sources of information were identified through the statistics on prewash exemptions. For one of the ports that reported that it did not receive liquid bulk other than oil and petroleum products, exemptions to carry out prewash have been requested on two occasions, which is only done if the cargo is covered by MARPOL Annex II. If the exemptions are also compared with statistics from the ports that submitted reports, it is obvious that products are sometimes missing from these reports. In all identified cases, where reporting did not correspond with the exemption request, the cargo consisted of biofuels ('biofuel blends' under the IBC Code). Here, it seems that the regulations are not clear enough. The definitions in the IMO are based on the percentage of petroleum oil contained in the mixture. If the mixture contains > 75% petroleum oil, it is regulated under MARPOL Annex I. Otherwise, it is regulated under MARPOL Annex II (MEPC.1/Circ.761/Rev.1 (2013)). If, at the time of reporting, it is not clear how much of the mixture consists of bio-based and/or fossil fuel, it is not possible to determine the Annex under which the cargo should be regulated.

The substances and quantities reported by the ports were also compared with the statistics from Swedish Customs. It became clear that nine substances were not included in the port statistics. Another four substances (sodium hydroxide, methanol, potassium hydroxide and ethyl acetate) were reported by the ports, but higher quantities were received according to Swedish Customs. Of the total 1.21 million tonnes of products reported to Swedish Customs, just over 400,000 tonnes (401,772 tonnes) were not accounted for in the port statistics. Adding the port statistics to the non-included statistics from Swedish Customs results in potentially existing data for 3.15 million tonnes of goods, corresponding to 63% of the 5 million tonnes previously reported in TRAFA.

The same comparison was also made between statistics received from the Swedish Maritime Administration for those items where no IMDG code was stated and statistics from ports and Swedish Customs. Once again, substances (11) were identified that were not represented in either the port statistics or Swedish Customs' statistics, as well as a number of substances which, when added together, exceeded the quantities previously reported by ports and Swedish Customs. In total, these items corresponded to 703,499 tonnes, meaning that the total amount of data collected from ports/industries, Swedish Customs and the Swedish Maritime Administration adds up to 3.86 million tonnes (= 77% of 5 million tonnes).

Table 4. Overview of sources used to obtain information about products shipped as liquid bulk. N ('No') and Y ('Yes') indicate which data is presented from each source, the geographical coverage indicates where the products come from, and the comments column contains a brief explanation (including identified significant gaps) of each source.

SOURCE	CARGO TYPE	PRODUCT SPECIFIED	PHASE	GEOGRAFICAL COVERAGE	MODE OF TRANS-PORTATION	COMMENTS
Swedish Maritime Administration Hazardous Cargo MSW	N	Y	N	National	Y	Bulk and packaged goods are not separated. Units are not always indicated, hard to separate kg and tonnes.
Swedish Customs	Y	Y	Y	Only outside EU	Y	Some cargo might be solids, i.e. should not be included in the liquid bulk statistics
Swedish Transport Agency	N	N	N	National	N	Only approved exemptions of prewash
Eurostat	Y	N	Y	Within EU	Y	Overview of liquid bulk statistics, no details.
SCB	N	Y	N	International trade	N	Domestic trade not included. Mode of transport is not indicated.
Swedish Chemicals Agency	N	Y	Y	International trade	N	Domestic trade not included. Mode of transport is not indicated.
SPBI	-	Y	Y	National	N	Domestic trade not included. Only petroleum products.
Swedish Maritime Administration Waste reports	-	-	-	National	Y	Reports on waste receptions.
Ports and industries in Sweden	Y	Y	Y	Only local	Y	84% of the total amounts of ship calls during 2018. Detail in reporting varies.
Other countries	Y	Y	Y	International (Not Sweden)	Y	Inadequate response. Varied resolution.
Transport Analysis (TRAFA)	Y	N	Y	National	Y	Overview of liquid bulk statistics, no details.
EMSA	Y	N	N	International (HELCOM)	Y	Overview traffic flow liquid bulk carriers. Hazardous/dangerous goods might be incorrectly reported. Formal application is required.

Table 5 shows all substances reported by Swedish ports and industries, the Swedish Customs and selected data from the Swedish Maritime Administration. The table also details substances reported by international actors with a connection to Swedish waters. All quantities have been rounded to the nearest thousand and should be interpreted as a minimum number of tonnes per year as, in certain cases, handled products have been reported without stating quantities. The total amount of liquid bulk for which both the product name and the quantity have been reported, within and outside Sweden, totals approximately 12 million tonnes. The majority of these products – 7.8 million tonnes (approximately 65%) – are categorised as class Y products in accordance with MARPOL Annex II. 25% are class Z products, and only 3% are class X products.

Based on data produced by EMSA, traffic flows for chemical tankers, based on port calls, in and around Swedish waters were estimated for 2019 (Figure 6). The selection was based on vessels declaring that they had carried hazardous goods regulated under the IBC Code. During 2019, 510 port calls meeting these criteria arrived in Sweden. Fifty-eight (58) of them came from another Swedish port, 125 came from a port within the Baltic Sea Area (Finland, Russia, Estonia, Latvia, Lithuania, Poland, Germany, or Denmark), and the remaining port calls (327) originated from vessels arriving from a port other than the abovementioned alternatives. In addition to calls to Sweden, 291 port calls were reported as both arriving and departing within the Baltic Sea Area. One hundred and fifty-three (153) port calls originated from vessels that reported to have departed from Sweden with dangerous cargo. Seventy-five (75) of these unloaded at a port in the Baltic Sea Area, while the remaining vessels (78) left the area.

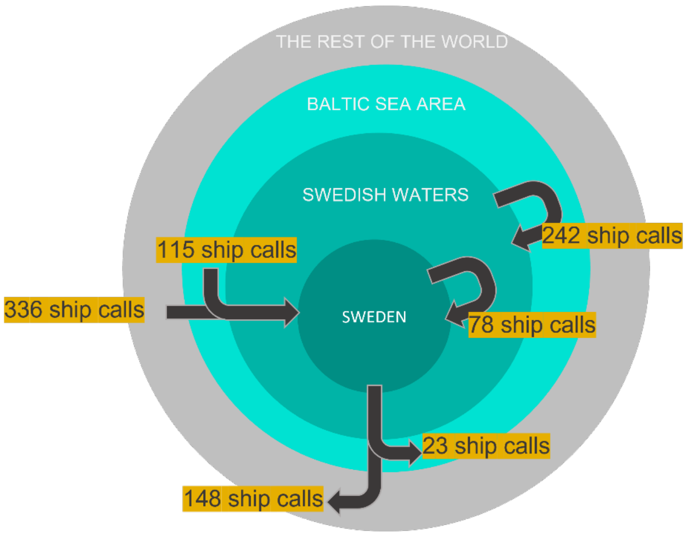

Figure 6. Traffic flow of chemical liquid bulk carriers in and around Swedish waters in 2019. The values correspond to the number of vessels carrying cargo regulated under the IBC Code that declared departure from or arrival in Sweden or within the Baltic Sea Area in 2019. Reports are submitted to EMSA by the member states based on what each vessel has declared, and there is a risk of inaccurate data being reported to EMSA.

3.1.1 Product groups with different environmental consequences

Based on the data collected for all products transported as liquid bulk, five different groups were identified. These were based mainly on the distribution of the respective substances in the marine environment, as well as on the potential consequences of discharges. The five selected groups are:

1. *Acids and bases, and alcohols*
2. *Potential fertilisers*
3. *Benzene and other aromatic hydrocarbons*
4. *Persistent floaters that remain at the surface of the water*
5. *Other products*

Descriptions of the five groups are given below, together with a justification for the grouping. Table 5 shows which products – of those currently shipped – that have been included in which group(s). Since some products have characteristics that match more than one of the selected groups, they are included more than once.

Table 5. Summary of all chemicals and chemical-like products reported as products transported as liquid bulk by ship in 2017/2018. The products are presented with a CAS number if available, MARPOL class according to the IBC Code and grouping based on the classification in section 3.1.1. The quantity of goods handled is presented in number of tonnes handled (loaded/unloaded) per year in Sweden, and goods loaded/unloaded outside Sweden, i.e. all Baltic Sea nations plus Norway are included. Dashes show that 1) the substance has not been reported or 2) the substance has been reported as having been handled, but no quantities have been specified.

**Includes hexane and alkanes (C10–C26), linear and branched.*
***Includes hexene and propylene trimer.*

PRODUCT NAME	CAS	MARPOL CLASS	GROUP	SWEDEN	OUTSIDE SWEDEN
		X, Y, Z, O.S.	1,2,3,4,5	Tonnes/year	Tonnes/year
1-hexadecylnaphthalene/1,4-bis(hexadecylnaphtalene) mixture	-	Y	5	7000	-
Acetaldehyde	75-07-0	Y	5	33 000	-
Acetic acid	64-19-7	Z	1	9000	-
Acetone	67-64-1	Z	5	-	126 000
Acetone cyanohydrine	75-86-5	Y	5	-	9000
Alkylated(c5-c8) benzene	-	X	3	-	2000
Ammonia	-	Y	1,2	-	208 000
Ammonium polyphosphate (solution)	-	Z	2	-	69 000
Ammonium sulphate (solution)	-	Z	2	-	76 000
Aniline	62-53-3	Y	5	-	22 000
Aviation alkylates (c8 paraffin)	-	X	5	5000	8000
Base oils	-	-	5	-	306 000
Benzene	71-43-2	Y	3	3000	10 000
Biofuels (inc. mixtures)	-	X	4	143 000	75 000
Bis(2-propylheptyl) phthalate	533-54-0	X	5	15 000	-
Butyl acrylate	141-32-2	Y	5	<1000	-
Carbon tetrachloride	56-23-5	Y	5	-	2000
Chloroform	67-66-3	Y	5	-	5000
Cumene	98-82-8	Y	3	-	5000
Cyclohexane	110-82-7	Y	5	-	5000
Cymene	99-87-6	Y	3	-	3000
Dibutyl ether	142-96-1	Y	5	-	122 000

Dichloroethane (ethylene dichloride)	107-06-2	Y	5	7000	213 000
Diethylenetriaminepentaacetic acid	67-43-6	Z	5	-	<1000
Dichlorobutene	760-23-6	Y	5	1000	-
Dichloropropane	78-87-5	Y	5	-	33 000
Epichlorohydrine	106-89-8	Y	5	-	2000
ETBE	637-92-3	Y	5	37 000	-
Ethanol	64-17-5	Z	1	176 000	118 000
Ethyl acetate	141-78-6	Z	5	21 000	4000
Ethylenedinitrilotetraacetic acid	60-00-4	Y	5	-	<1000
Ethylene glycol	107-21-1	Z	5	1000	-
Ethylhexanoic acid	149-57-5	Y	5	44 000	-
Ethylhexanol	104-76-7	Y	5	69 000	-
Fatty acid methyl ester/rapeseed methyl ester*	-	Y	4	365 000	-
Formalin	50-00-0	Y	5	-	59 000
Formic acid	64-18-6	Y	1	-	11 000
Glycerol	58-81-5	Z	5	<1000	-
Hydrated vegetable oils (HVO)	-	Y	4	99 000	-
Hydrocarbons, acyclic, saturated*	-	Y	5	178 000	677 000
Hydrocarbons, acyclic, unsaturated	-	Y	5	2000	5000
Hydrochloric acid	7647-01-0	Z	1	<1000	-
Iso- and cycloalkanes	-	Y	4	10 000	-
Isobutanol	78-83-1	Y	1	-	-
Isoprene	78-79-5	Y	5	-	3000
Kaolinite slurry	-	O.S.	5	413 000	-
Lard	-	Y	4	-	347 000
MTBE	1634-04-4	Z	5	-	272 000
Methanol*	67-56-1	Y	1	7000	1 025 000
Methylnaphthalene	90-12-0	X	3	46 000	-
Nitric acid	7697-37-2	Y	1	35 000	-
Octanol	111-87-5	Y	5	1000	-
Orthophosphoric acid	7664-38-2	Z	1	<1000	83 000
Palm fatty acid distillate	-	Y	4	-	89 000
Phenol	108-95-2	Y	3	-	316 000
Pitch oil	-	X	4	83 000	-

Potassium hydroxide	1310-58-3	Y	1	3000	-
Propionic acid	79-09-4	Y	5	15 000	-
Propylene glycol	57-55-6	Z	5	-	633 000
Propylene oxide	75-56-9	Y	5	-	215 000
Propylheptanol	10042-59-8	Y	5	6000	-
Pyrgas (containing benzene)	-	Y	3	161 000	12 000
Rapeseed methyl ester	-	Y	4	29 000	-
Rapeseed oil	-	Y	4	75 000	-
Sodium hydroxide*	1310-73-2	Y	1	326 000	1 499 000
Sodium chlorate (solution)	7775-09-9	Z	5	35 000	-
Styrene	100-42-5	Y	3	-	89 000
Sulphuric acid*	7664-93-9	Y	1	475 000	250 000
Tallow	-	Y	4	4000	-
Tallow, fatty acid	-	Y	4	6000	-
Tall oil, crude	-	Y	4,2	110 000	110 000
Tall oil, fatty acid	-	Y	4,2	14 000	6000
Tall oil, pitch	-	Y	4,2	8000	-
Tar	-	X	5	8000	-
Tetrachloroethylene	127-18-4	Y	5	-	81 000
Toluene	108-88-3	Y	3	-	25 000
Turpentine	-	X	5	7000	-
Urea/ammonium nitrate solution	-	Z	2	-	1 456 000
Urea/ammonium phosphate solution	-	Y	2	-	54 000
Vegetable oils	-	Y	4,2	24 000	-
Wax from hydrocarbons	-	X	4	-	13 000
Xylene	1330-20-7	Y	3	3000	152 000

1. Acids and bases and water-soluble alcohols

This group includes substances that are not necessarily directly toxic to the environment, but which – in combination with other chemicals – could contribute to additional pressure on the environment. These are often the products that are transported in the highest volumes at both national and international levels (Table 5). Substances in this group include sulphuric acid, acetic acid, ammonia, sodium hydroxide, ethanol, and methanol.

Acids (and bases) can affect the pH locally, but the alkalinity of seawater – the overall buffering capacity – acts to stabilise and reduce these effects. Discharges of strong acids that dissociate completely in water will contribute to a lower pH and a consumption and reduction of the total alkalinity (Turner et al., 2018). Similarly, the addition of weak acids ($pK_a > 4.5$), will lead to lower pH. However, as the release of protons simultaneously involves the formation of a base, which contributes to increased alkalinity, the overall alkalinity will remain unchanged (Kuliński et al., 2014). The water-soluble alcohols, methanol and ethanol, are effectively diluted, and as individual substances are expected to have little or no impact on the marine environment.

Sulphuric acid – a strong acid – is one of the substances that is transported in large volumes in the Baltic Sea Area (Table 5). Several previous publications have reported sulphuric acid to be a high-risk substance, especially in the context of major accidents (Honkanen Häkkinen, 2012; Häkkinen Posti, 2014). When calculating operational discharges, it has also been reported that PECs often exceed PNECs. However, it is unclear whether the alkalinity of seawater – the buffering capacity – is included in the risk analysis.

All strong acids will have an acidifying effect, and although this effect is small on a regional scale, it can affect the mobility of metals, for example, on a local scale. Increased pressure on the environment due to cocktail effects can have major impacts on areas with intensive traffic.

2. Potential fertilisers

This group includes substances that may have a direct or indirect effect on the eutrophication of the Baltic Sea Area, where the eutrophication problem has been known for a long time. Solutions containing ammonia/ammonium nitrate and phosphate can have a direct fertilising effect if discharged into the marine environment. Other substances include urea solutions, phosphoric acid, and nitric acid, which are also part of the acid/base group above and thus have different effects depending on what is being investigated.

Discharges of organic matter can also contribute to an increased biochemical oxygen demand (BOD) as a result of decomposition. High oxygen consumption and poor water exchange result in the proliferation of anoxic bottoms in the Baltic Sea, leading to further phosphate release. Discharges of organic substances can thereby also indirectly affect the eutrophication of the Baltic Sea.

This group does not pose major risks from a toxic perspective but can nevertheless have a significant impact on the marine environment and contribute to potential cocktail effects. As shown in Table 5, several of the substances in this group are categorised as class Z substances under MARPOL Annex II. This group therefore consists of substances that are not strictly regulated, but that are transported in large quantities and can have a major impact on the marine environment, especially in areas that are sensitive to eutrophication.

3. Benzene and other aromatic hydrocarbons

Many monoaromatic hydrocarbons are volatile, meaning that they evaporate under normal conditions. They are therefore not necessarily considered a major threat to the marine environment. However, it is important to note that, according to MARPOL Annex II guidelines, wash water should be discharged en route and below the waterline. When benzene and other volatile aromatic hydrocarbons are discharged below the waterline, a larger proportion will dissolve in the water column and this will have significant effects on dispersion, as well as consequences in the marine environment (French McCay et al., 2006).

Benzene is on the EU priority list of substances to be monitored in accordance with the WFD. Benzene is carcinogenic, and exposure involves a heightened risk of leukaemia (Soares et al., 2018). Xylenes are monoaromatic hydrocarbons with two methyl groups attached to a benzene ring. There are three different isomers used for different purposes, but mixtures of these isomers are often shipped (Honkanen et al., 2012; Duan et al., 2017b). Xylenes have a low bioaccumulation potential but demonstrate direct toxic effects on exposed organisms (Duan et al., 2017b). Styrene is mainly handled in Baltic countries other than Sweden and is mentioned here primarily because it illustrates how stakeholders can be involved in controlling how handling takes place. In Finland, cargo owners have taken the initiative to request that prewash should be carried out after unloading styrene, even though this is not a legal requirement under MARPOL Annex II (Honkanen et al., 2012). Phenol is not handled in large quantities in bulk in Sweden, but other Baltic countries have reported its presence. Even very low concentrations of phenol have been shown to have a major impact on the growth of algae and other organisms (Duan et al., 2017a).

4. Persistent floaters on the surface of the water

These substances consist of biological oils and fats that are often used as a raw material for the biofuel industry (Cunha et al., 2015). When discharged, these products often form layers (‘slicks’) that float on the surface of the water. As temperatures drop, these substances can also solidify and form hard or gelatinous lumps that float ashore (Cunha et al., 2015).

Other, more or less toxic organic compounds can be adsorbed (attach to the surface) on these accumulations in accordance with the ‘like dissolves like’ principle. A harmless product can thereby acquire toxic properties based on which other substances are present in the surrounding environment.

If the products polymerise or form complexes with sand, for example, they can sink to the bottom and create impermeable aggregates that choke burrowing species in the sediments (Cunha et al., 2015). Oxygen consumption also increases when organic matter decomposes, contributing to a more reduced environment (Cunha et al., 2015, 2013). In addition, degradation products – such as diglycerides and triglycerides of palm oil that are formed after exposure to the marine environment – are potentially hazardous (Roose et al., 2011).

5. Other products

'Other products' are those which do not fit into any of the other categories, and include chlorinated hydrocarbons, ethers, alkanes, and alkenes. Many of these are raw materials, or, are used as solvents within industry. Some examples of these products are listed below. Halogenated hydrocarbons are often highly toxic with potentially carcinogenic properties, even at low concentrations. Ethylene dichloride is a volatile organic compound that is both toxic and carcinogenic. It is mainly used in the production of vinyl chloride, which is used for further plastic production. Ethylene dichloride is included in the Water Framework Directive's list of prioritised substances (EC, 2000).

Ethyl tert-butyl ether (ETBE), as well as methyl tert-butyl ether (MTBE), is used to increase the octane number of petrol. Recognition of the negative effects of MTBE has resulted in ETBE rising in the market (Yee et al., 2013). Both MTBE and ETBE have relatively high solubility in water while decomposing slowly, meaning that they can remain in the marine environment for a long time (Yee et al., 2013).

Acetone cyanohydrin is often used as a raw material in the chemical industry and in products such as plexiglass (NRC US, 2009). When it comes into contact with water, acetone cyanohydrin rapidly degrades into hydrogen cyanide, which is highly toxic even at very low concentrations (NRC US, 2009).

3.1.2 Comparison with earlier studies

According to Molitor (2006), the most common chemicals handled in Swedish ports were sulphuric acid, sodium hydroxide, ammonia, and ethanol. According to Häkkinen and Posti (2012) – whose statistics most recent publications refer to – the most common substances transported as liquid bulk in the Baltic Sea Area in 2010 were methanol, sodium hydroxide, ammonia, sulphuric acid, phosphoric acid, pentane, aromatic hydrocarbons, xylenes, MTBE and ethanol. Fertilisers and vegetable oils were also mentioned as products transported in large volumes. All substances reported from previous studies by Molitor (2006) and Häkkinen and Posti (2012) are among the most common substances presented in this report. The total amounts transported appear to have increased, but since all data sets are subject to considerable uncertainty, no more in-depth trend analysis has been carried out.

3.2 CONSEQUENCES OF DISCHARGES

Substances that are highly soluble in seawater are often considered more toxic, but it is also important to consider mixing, turbulence and currents that can potentially dilute the substance rapidly to concentrations below those deemed to be toxic (Cunha et al., 2013). Toxicity can be of acute and chronic nature, both of which can be difficult to assess, and often several different species must be studied in ecotoxicological tests. Many products shipped as liquid bulk have low solubility, and it can therefore be difficult to measure acute toxicity within the threshold value of the substance's solubility (Cunha et al., 2013). Based on the statistics in Table 5, PNEC values were collected for those substances where values were available. For some products and chemicals with very low solubility, it is not possible to obtain PNEC values for aquatic environments experimentally as they exceed the product's solubility in water. For those substances where PNEC values could be obtained (table in Annex B), eight substances were selected for further calculation of PEC and R (Equation 1 and 3 and Table 6).

The calculations of PEC in accordance with Equation 3, where the discharge flow rate =200 m^3/h and the vessel speed= 7 knots, result in a dilution factor of about 80000:1. This dilution factor is considerably higher than the 1000–3000:1 used by Honkanen et al. (2012), for discharges that have not undergone prewash, but is also significantly lower than the factors reported by the US's EPA (2002) of 195 000–660 000:1. The results in Table 6, are based on assumptions on wake formation and the magnitude of the discharge, which have a direct impact on the dilution factor. The speed is defined as 7 knots, as this is the minimum permitted vessel speed for discharging wash water. Increasing the speed of the vessel also increases the dilution factor. The vessels surveyed by the US's EPA (2002) were travelling at speeds of between 9 and 19 knots. If the vessel speed in Equation 3 is defined as 15 knots instead of 7 knots, this means that the dilution factor is 166000:1. The wake is also assumed to have a constant width (100 m) and a constant depth (12 m), based on the mean values presented by Nylund et al. (2020). This simplification is deemed sufficient for the scope of this report, but a more detailed description of wake formation and shape can be found in Voropayev et al. (2012). Equation 3 is a simplification of reality, but still takes into account the effect of discharge flow, vessel speed and wake formation, which have been shown to be highly significant in terms of the resulting concentration in the environment (US EPA, 2002; Nylund et al., 2020).

PEC values calculated using Equation 3 were also compared with the PEC values calculated via the MAMPEC software. Although this software is considerably more sophisticated than the equations presented in this work, it turned out to be less appropriate for making comparisons in this case, since the calculations are based on the steady state assumption where the load is a constant. Similar PECs were obtained in where a comparison was made, but this could be directly attributed to the choice of parameters such as discharge rate, daily load, and total water volumes. As tank cleaning discharges are rather intermittent, higher resolution data is required to carry out accurate calculations in a specific area.

Calculated PEC values and risks associated with discharges should primarily be interpreted as indications that discharges involve a risk rather than being treated as absolute values. Table 6 shows that most of the investigated products exceed the PNEC threshold values, despite the strip volumes being kept below 75 litres per tank, which is the permitted strip volume according to MARPOL Annex II (Table 2). Tables 3 and 6 also show that both super strip and prewash, if carried out correctly, are effective methods for minimising discharges to the marine environment. These conclusions are fully in line with earlier publications (Honkanen et al., 2013, 2012), which concluded that the PEC is reduced by a factor of 1000 provided that the prewash is carried out and remains below the PNEC value for the relevant product if the strip volume does not subsequently exceed 50 litres. Without prewash, PEC exceeded PNEC regardless of strip volume.

Table 6. Overview of calculated PEC/PNEC ratios for a selection of substances shipped around Sweden. PEC was calculated using the methodology described in section 2.2.2. containing Equation 3, and the respective ratios were calculated using Equation 2. If the ratio exceeds 1 (marked in yellow), this means that there is a risk for the marine environment. PNEC values and densities are taken from the table in Annex B and KOC were taken from REACH (2020).

COMPOUND	PNEC mg/l	DENSITY kg/m³	K_{OC} l/kg	PEC/PNEC based on stripping volume per holdingtank			
				0.1 l	**10 l**	**75 l**	**150 l**
Sulphuric acid	2.5×10^{-4}	1830	-	<1	>10	>100	>100
Methanol	2.08	790	0.18	<1	<1	<1	<1
Benzene	8×10^{-3}	876	59	<1	<1	>1	>1
Xylene	3.3×10^{-1}	861	407	<1	<1	<1	<1
Ethylhexanol	1.7×10^{-3}	830	35	<1	>1	>10	>10
ETBE	1.7×10^{-2}	736	160	<1	>1	>10	>10
Dichloroethane	1.1×10^{-1}	1250	33	<1	<1	<1	>1
Phenol	1×10^{-3}	1070	33	<1	>1	>10	>10

The PEC/PNEC ratios are calculated for one substance at a time. If the discharged slop contains several different types of substance or if solvents are used during tank cleaning, this may affect the overall toxicity of the solution. To investigate this, the effects of mixtures of substances must also be examined, not just the effects of individual substances. It is generally accepted to assume that mixtures of chemical substances result in an additive effect, and that this should be included in the risk analysis (Backhaus and Faust, 2012; Gustavsson et al., 2017).

Although many parameters differ between large spills (in the case of accidents) and operational discharges (which occur more continuously), some common strategies can be applied when investigating the effects. Important examples that will have a significant impact on the significance of a discharge, are the location of the discharge, the prevailing weather conditions, the physical and chemical properties of the product discharged and whether multiple products are released at the same time (Cunha et al., 2013, 2015). All in all, this results in an impact assessment that is complex and often incomplete in one or more respects.

3.3 LIKELIHOOD OF DISCHARGES IN DIFFERENT AREAS

Every year, several discharges of suspected oil or other unknown substances are recorded by HELCOM's aerial surveillance programme, to which the Swedish Coast Guard also reports its data (Figure 7). When summing up the data from the last five years, it appears that discharges occur more frequently in certain areas. It is important to stress that aerial surveys are not scheduled randomly and are mainly focused on areas with the highest ship traffic intensity in order to have a preventive effect (HELCOM, 2018a). This implies that there is a degree of bias in the results, where detected discharges are prone to being concentrated around the ship lanes.

Additionally, Russia has not reported any aerial surveillance data to HELCOM since the 1990s and Latvia has only carried out a few flight hours, leaving large areas unmonitored. All in all, this results in some uncertainty regarding the identified discharges (HELCOM, 2018a). HELCOM's report on aerial surveillance (2018b) also mentions that there is a risk of intentional dumping occurring at night and in bad weather, since the risk of detection is significantly reduced.

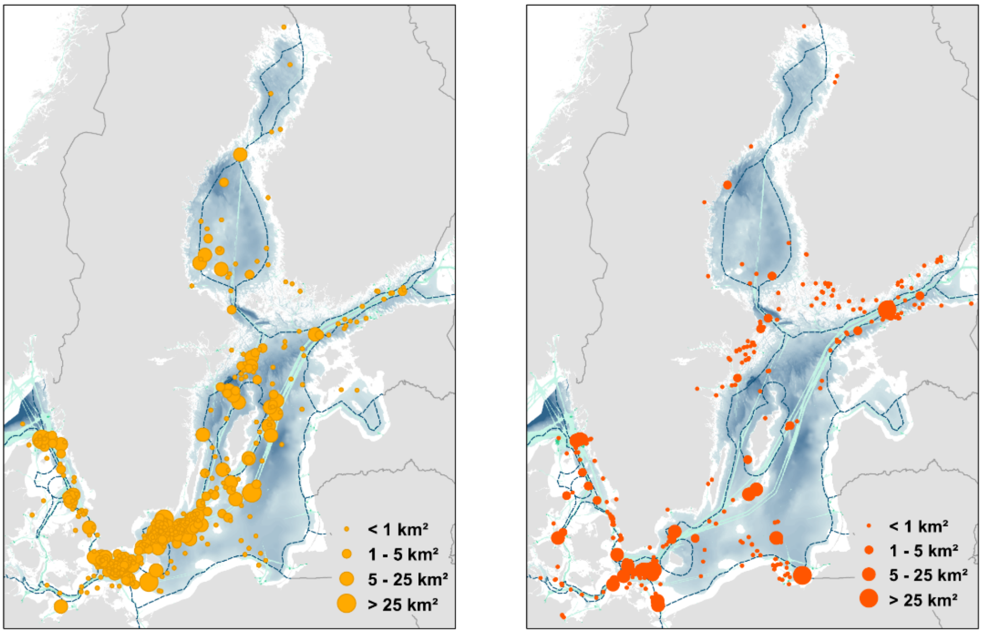

Figure 7. Overview maps illustrating discharges of oil (right, red circles) and unidentified substances (left, orange circles) as observed by HELCOM's aerial surveillance programme between 2014 and 2018. The size of the circles corresponds to the size of the discharges in km^2. The traffic intensity of liquid bulk carriers operating in Swedish waters in 2018 has been coloured light blue, the territorial limit (dashed blue lines) coincides with 12 Nm from land and the bathymetry is shown at all depths above 25 metres.

Based on strict self-regulation via vetting, combined with widespread aerial surveillance of the HELCOM area, the likelihood of illegal discharges can be estimated to be lower than the likelihood of discharges attributable to legal activities. Areas of higher likelihood to be exposed to operational legal discharges of wash water follow the traffic-intensive ship lanes that are outside the territorial zone (> 12 Nm from land) and where the water depth is greater than 25 m (Figure 4). Several studies also show that concentrations of discharged substances within a ship wake are not homogeneous, but rather follow a gradient with higher concentrations closer to the source, i.e. the vessel (US EPA, 2002). These studies were carried out on discharges that occurred on the surface of the water, so mixing can be deemed to be limited. It is likely that discharges in ship wakes are better modelled with a concentration gradient rather than a homogeneous cuboid, but more research and more advanced models are needed. Based on HELCOM's aerial surveillance data (Figure 7) and assumptions that most vessels comply with IMO regulations, it seems likely that most discharges occur in the vicinity of the busiest ship lanes, outside the territorial limit and at sufficient depth (> 25 m). Another argument supporting the theory of tank cleaning and emptying of cargo tanks (either to a slop tank or at sea) taking place while en-route is that tank cleaning requires large quantities of water and, in those cases where the wash water will be heated, large amounts of energy, i.e. engine power. Venting the tanks after cleaning often takes several hours and is rarely done at berth since ports do not want venting of potentially hazardous gases to take place close to port personnel, supporting the argument that at least part of the cleaning process takes place at sea.

Since prewash is mandatory for class X substances as well as class Y substances that are defined as highly viscous or solidifying, the likelihood of operational discharges of these substances is lower than for those substances for which prewash is not stipulated by regulations. However, highly viscous, and solidifying substances are defined based on handling temperature, which in theory may mean that the prewash requirement can be bypassed by heating a substance to a temperature so that it complies to the threshold values prescribed in MARPOL Annex II.

According to data compiled by the Swedish Transport Agency, more than seventy exemptions for prewash were issued in 2018. According to an inspection company that checks and monitors aspects such as prewash procedures, there are about four or five exemptions approved per prewash performed, indicating that prewash is something that is avoided, if possible – potentially for economic reasons, as it involves more time and higher costs for berthing.

3.4 HIGH RISK AREAS AND CONFLICTS OF INTEREST

Based on the consequences of chronic discharges (Section 3.2) and the likelihood of discharges occurring (Section 3.3), four areas were identified as being at particularly high risks with respect to tank cleaning discharges (Figure 8). The four areas are: the Swedish West Coast; the Arkona and Bornholm Basin; the Hoburg Shoal and the Mid-Sea Banks; and the areas around Kvarken and the Åland Sea. This was determined based on high traffic intensity in the selected areas, but also with respect to the proximity to the territorial boundary – which also corresponds to 12 Nm from land – and the proximity to other natural environmental values such as fishing and protected areas. The next sections describe the unique problems of each area and uses GIS (ArcMap 10.5) as a tool to illustrate this, comparing map layers from EMODnet, HELCOM and the Swedish Agency for Marine and Water Management (see Annex C) with the areas defined as potential discharge areas.

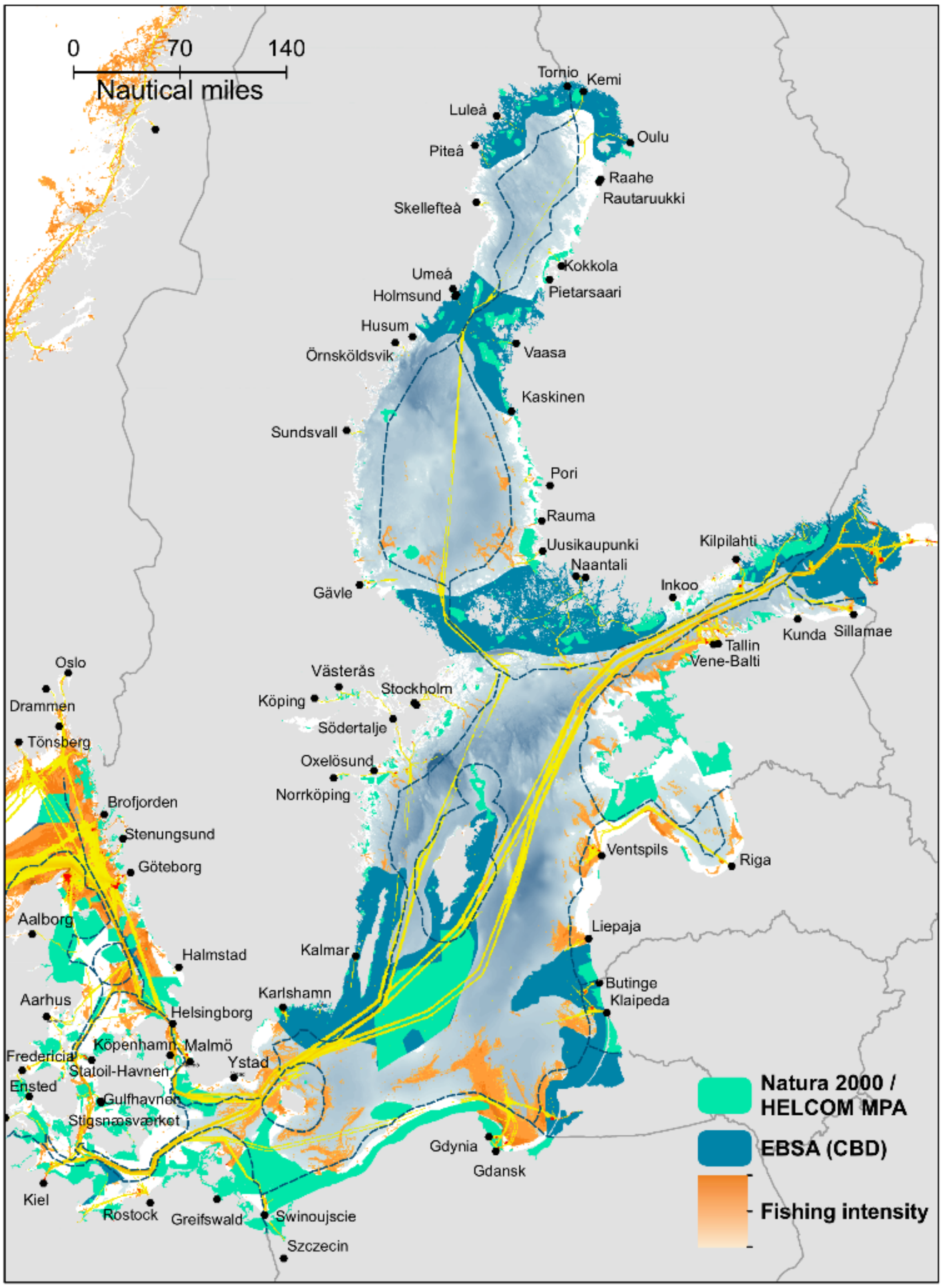

Figure 8. Overview map illustrating different areas of interest in Swedish marine areas. Traffic intensity of liquid bulk carriers in 2018 is illustrated by a yellow/red gradient, turquoise areas mark EBSA and green areas show Natura 2000 areas with different environmental values. The traffic intensity of the fishing fleet in 2018 is shown in orange.

3.4.1 The Swedish West Coast

There is a high intensity of liquid bulk carrier traffic along the West Coast of Sweden, as the route is lined with major oil and industrial ports. It is the ship route that link the Baltic Sea with the North Sea and the Atlantic Ocean. In addition to high liquid bulk carrier traffic intensity, a large fishing fleet operates regularly in the vicinity (Figure 9). If discharges of hazardous substances affect fisheries, either directly or indirectly, this creates a conflict between stakeholders.

The territorial boundaries of Sweden and Denmark limit the area where discharges from operational tank cleaning can legally take place. Only one narrow passage with a width of less than 3 Nm is located at a distance from land exceeding 12 Nm where the depth is greater than 25 metres (Figure 9). There is therefore a relatively small area where discharges can legally take place, which may impose a major burden locally. The lane is also bordered by Natura 2000 areas, and by Fladen, Stora Middelgrund and Lilla Middelgrund, which according to the UN Convention on Biological Diversity have been classified as Ecologically or Biologically Significant Marine Areas (EBSAs), based on their unique habitats and rich wildlife.

From the 1st of July 2020, the route system in the Kattegat and the northern Sound was partly redesigned to reduce traffic intensity along the current route. North-going vessels bound travelling from the Sound are thus using a ship lane closer to the Swedish coast, also known as Route S, passing directly through Natura 2000 areas. The Swedish Maritime Administration estimated a significant increase in merchant vessel traffic closer to the West Coast of Sweden. More ships thereby enter the Swedish territorial boundary, which may affect their operational activities since, for example, wash water discharges will no longer be allowed under MARPOL regulations.

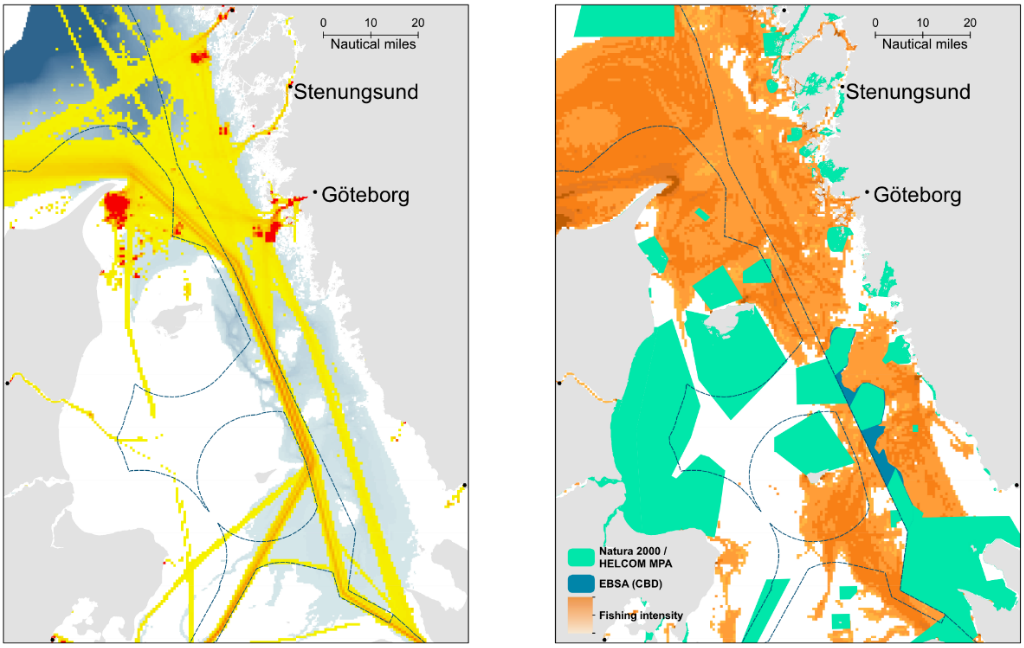

Figure 9. Maps of the Kattegat. Grey areas are land, and the blue lines mark the territorial boundary drawn about 12 Nm from land. Left: Blue coverage illustrates sea areas where the depth is >25 m. Traffic intensity of liquid bulk carriers in 2018 is shown with a scale from yellow to red. Right: Green fields indicate Natura 2000 areas and marine protected areas issued by HELCOM. Orange colour shows the traffic intensity of the fishing fleet according to EMODnet, and the turquoise fields mark EBSA areas.

3.4.2 The Arkona and Bornholm Basin

In order to carry out legal discharging of wash water, the depth must be greater than 25 metres and, as the Arkona and Bornholm Basin borders several shallow areas with high traffic intensity, this could mean that holding tanks are emptied in this area. All traffic from southwest Sweden, southeast Denmark and the northern coast of Germany that are travelling further north in the Baltic Sea Area (or in the opposite direction) passes through this area, which is also the first (or last) port of call where the criteria for legal tank discharge is met, in accordance with Annex II of MARPOL. HELCOM aerial surveillance data is showing that the highest number of discharges of both oil products and unknown substances were recorded in this area between 2014 and 2018 which further supports the theory that the area is a strategic location for discharges od tank cleaning residues (Figure 10).

Commercial fishing is also widespread in this area, and close to the ship lanes there are also designated protected areas such as Natura 2000 areas and the EBSA area Southern Gotland Harbour Porpoise Area. These are described in greater detail in the next section, 3.4.3 The Hoburg Shoal and the Mid-Sea Banks.

A report from the Baltic Sea Centre at Stockholm University (Viklund, 2018) also notes that, since the late 1980s, the Bornholm Basin has been virtually the only area where the endangered Baltic cod spawns. This has been confirmed by other studies (Hinrichsen et al., 2016), and is another strong argument for better protection of this area. The Arkona and Bornholm Basin has also been deemed particularly vulnerable to changes in pH and alkalinity when modelling the effects of large-scale discharges of wash water from scrubbers (for exhaust gas cleaning on board ships) (Turner et al., 2018).

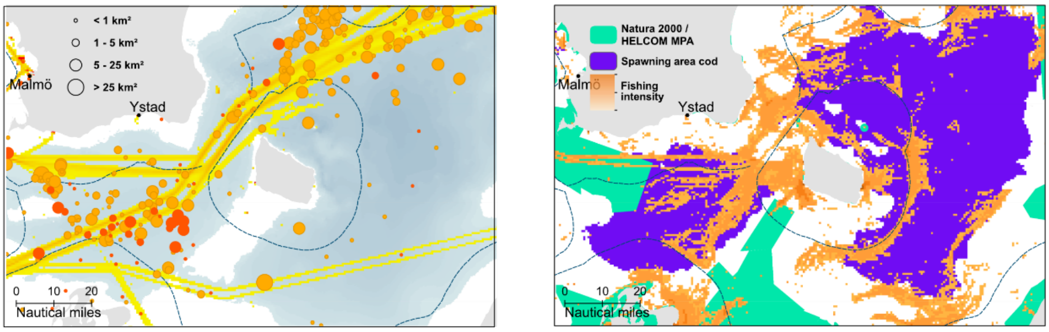

Figure 10. Maps of the area around the Arkona and Bornholm Basin. Grey areas are land and the blue lines mark the territorial boundary corresponding to approximately 12 Nm from land. Left: Blue coverage illustrates sea areas where the depth is > 25 m. Traffic intensity of liquid bulk carriers in 2018 is shown on a yellow to orange scale, and the filled circles show oil discharges (red) and discharges of unknown substances (orange) recorded via aerial surveillance by HELCOM in 2014–2018. Right: Green fields indicate Natura 2000 areas and marine protected areas issued by HELCOM. Orange colour illustrates the traffic intensity of the fishing fleet and purple fields mark spawning areas for Baltic cod according to HELCOM.

3.4.3 The Hoburg Shoal and the Mid-Sea Banks

The need for greater environmental protection of the Hoburg Shoal and the Mid-Sea Banks has been reported several times (Larsson and Karlsson, 2018; Larsson, 2019). Here, too, shipping is intensive, both in the deep ship lane south of the AtbA (Areas to be Avoided) areas and in the ship lane passing north of the AtbA areas (Figure 11) (Larsson and Karlsson, 2018). The northern ship lane is considered to be at particularly high risk due to the proximity to the shallower banks and to land (Figure 11). In this area, Larsson and Karlsson (2018) identified more than 400 passages per year of liquid bulk carriers carrying class X goods and more than 700 passages per year of liquid bulk carriers carrying class Y goods. Compliance with the recommendation on AtbA is voluntary for vessels.

Both the Northern Mid-Sea Bank and the Hoburg Shoal are part of a Natura 2000 area and are also part of a larger EBSA area (the Southern Gotland Harbour Porpoise Area). The shallower areas provide a favourable environment for filtering blue mussels, which then provide a food base for threatened bird species such as the long-tailed duck (*Clangula hyemalis*). Wintering birds also represent significant environmental values (Larsson and Karlsson, 2018), and it has been estimated that these have declined by almost 80% since the 1990s (Larsson, 2019). In addition, as the name of the EBSA area suggests, the outlying banks are a habitat for the endangered harbour porpoise (*Phocoena phocoena*) and are thought to be an important calving ground (Larsson, 2019). Potential chronic discharges of chemicals in an area where filter feeders, such as the blue mussels, are an important food base for the ecosystem may be particularly problematic, as substances with bioaccumulation potential are effectively moved to higher trophic levels.

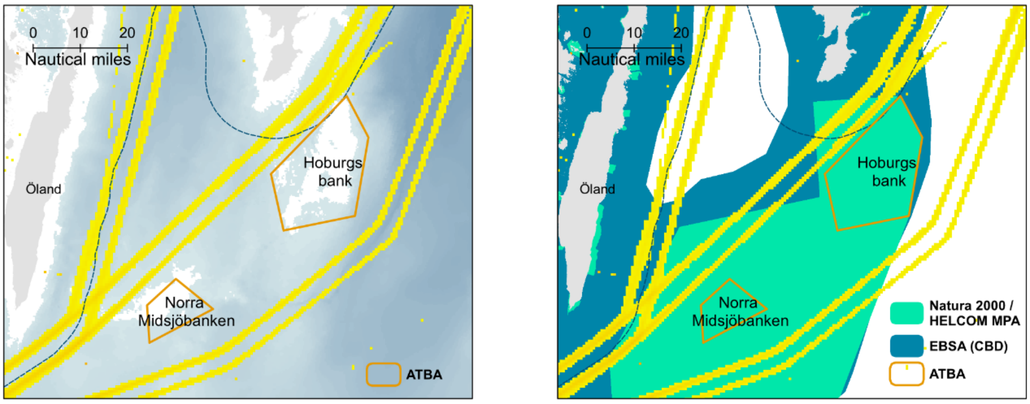

Figure 11. Maps showing the area south of Gotland. Grey areas are land, and the blue lines mark the territorial boundary drawn about 12 Nm from land. Areas to be avoided (AtbA) are marked with an orange line. Left: Blue coverage illustrates sea areas where the depth is > 25 m. Traffic intensity of liquid bulk carriers in 2018 is shown with a scale from yellow to orange. Right: Green fields indicate Natura 2000 areas and marine protected areas issued by HELCOM, and turquoise fields indicate EBSA areas.

3.4.4 The Bothnian Sea and the Bothnian Bay

In the northern parts of Sweden's eastern coast, the traffic intensity of liquid bulk carriers is generally not as high as in the southern and western coast. However, due to the hydrographic conditions with narrow, deep channels which then flow into more open basins, the traffic intensity in a few areas may be as high as in the southern Baltic Sea and on the west coast. Due to these narrow channels (the Kvarken and Southern Kvarken areas), water exchange is also reduced which can result in poorer water circulation and less effective dilution. The Bothnian Sea and the Bothnian Bay also have much lower alkalinity – or buffering capacity – than the rest of the Baltic Sea and these areas may be more sensitive to inputs of strong acids (Kuliński et al., 2014). Three specific EBSA areas have been issued within the Bothnian Bay and the Bothnian Sea, two of which are illustrated in Figure 12. In the area around the Åland Sea, especially along the Finnish coast, there is extensive aquaculture activity such as fish and mussel farms.

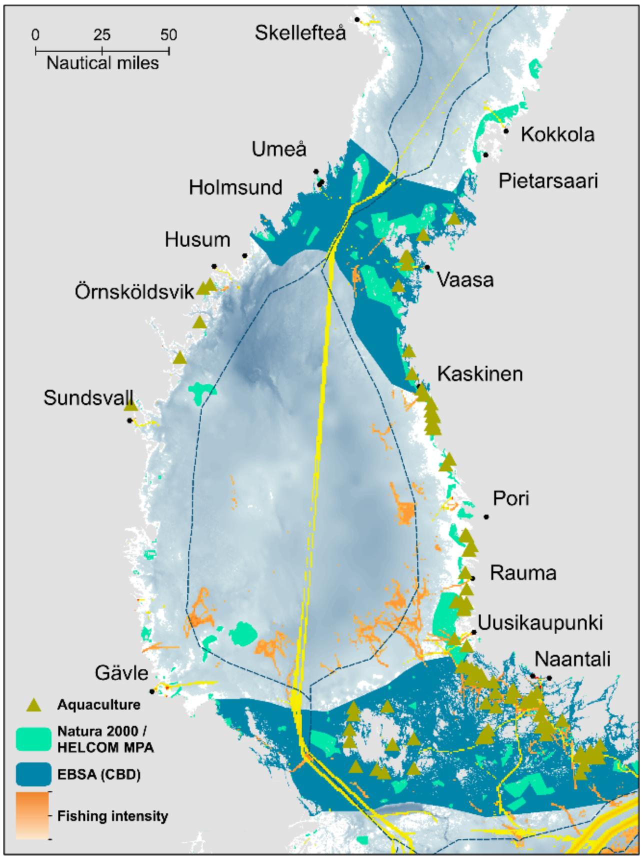

Figure 12. General map of the Åland Sea and Kvarken. Blue coverage marks sea areas where the depth is >25 m, grey areas are land, and the blue lines mark the territorial boundary drawn about 12 Nm from land. Traffic intensity of tankers in 2018 is illustrated by a yellow-orange gradient, the turquoise and green areas mark EBSA as well as Natura 2000 areas with different nature values, and green triangles show areas with aquaculture.

3.5 IDENTIFIED PROBLEMS AND PROPOSED ACTIONS

There is room for improvement when it comes to the future management of tank cleaning related issues, especially in terms of data management, environmental monitoring, and regulations. This section lists some of the problems identified during the study and suggests potential measures and how the regulations can be adapted to minimise discharges into the marine environment.

3.5.1 Data management and analysis

The reports and decision-making documentation that are currently used are based on work carried out between 2004 and 2012 (Häkkinen and Posti, 2012; Molitor, 2006; Hänninen and Rytkönen, 2006). The most recent officially available detailed compilation of chemicals handled in Swedish ports is taken from a thesis written in 2006 (Molitor, 2006). Based on the fact that the volumes transported are increasing (UNCTAD, 2019) and that the content has changed (for example, new raw materials are emerging as a result of the shift towards biofuels), there is an urgent need for updated statistics.

The data collection within the scope of this study proved to be a major challenge, both in terms of accessing real-time data and of finding historical data on liquid bulk other than mineral oils and other petroleum products. There is currently no designated authority with the responsibility for collecting general statistics on liquid bulk, let alone statistics on tank cleaning operations, and several different authorities have a shared mandate. As a result, reporting and access to reported materials appear to be incomplete. Similar conclusions on the challenges of data collection were drawn by Häkkinen and Posti (2012), who also noted that it is hard to distinguish between chemicals and liquid bulk in the existing reporting system. They also identified that differences in terms of classification systems, use of names, reporting requirements, et cetera make it hard to compare studies.

In connection with this study, there were several cases where chemical designations, names, UN numbers, Swedish and English language, etcetera were mixed in the cargo reports submitted to authorities. Product names are sometimes also misspelled, listed with several different names or mentioned in a different order. Reporting may also be done using different units (kg, tonne, cc) without specifying which unit is used in which instance. All in all, this makes the data difficult to manage and sorting all the records manually is an extremely time-consuming process.

There is currently no common platform for collecting statistics on products transported as liquid bulk. In spite of great efforts from authorities, significant help from port staff and industries, and assistance from both EMSA and other Baltic Sea countries, the data presented in this report is incomplete. There is also a lack of official figures quantifying the uncertainty in the statistics, which may be due to reporting errors or a lack of relevant data. For example, data from Russia is missing from EMSA statistics. The data made available for this case study has lacked various elements, making it incomplete (Table 4).

It would be desirable if the Swedish Maritime Administration, as the responsible authority for the MSW Reportal, could lead the work forward, to complete and improve the conditions for future reporting. For example, it would be possible to add a description of goods where it is defined whether the cargo is in bulk or packaged form. A simple solution would be to add an extra column where this can be indicated. A general harmonisation would be desirable to ensure that correct substances and quantities are reported by establishing a system that encourages continuity, for example by using drop-down lists instead of text and requiring the reporter to fill in the unit used when reporting quantities.

It is also clear from the statistics made available that imports and exports of goods can vary greatly from year to year. For example, SCB reported that no acetaldehyde was imported or exported in 2018, but that in 2017 it totalled 33000 tonnes. This underlines the importance of gathering statistics from several years to get a better overall picture. Several ports, and SCB, also mention that certain substances and chemicals are subject to confidentiality, and therefore could not be reported in the context of this study. In some cases, the data was missing altogether, while in other cases it was reported which substances were handled in port but not how much, adding further uncertainty to the data as these quantities were not included.

There is also uncertainty about how vessels are presented on different AIS platforms such as Marine Traffic and SafeSeaNet, as it has been noted on several occasions that vessel types are defined in different ways. If a liquid bulk carrier is defined as ‘other’ on one platform and as a ‘tanker’ on another, this introduces unnecessary uncertainty into the presented data. In order to accurately assess the environmental impact of a particular category of fleet (e.g. liquid bulk carriers, passenger vessels, RoRo, etc.), access to statistics on vessel intensity, the number of vessels and common routes is needed. Again, harmonisation and clear guidelines are required in terms of how vessels are categorised, and here, international cooperation is required.

3.5.2 Risk assessment and environmental monitoring

The reports and publications that deal with risk analysis, referred to in this report, all address the current lack of information, especially when it comes to chronic toxicity and long-term effects (Tornero and Hanke, 2016; Cunha et al., 2015, 2016; Neuparth et al., 2012; Häkkinen and Posti, 2014; Honkanen et al., 2012). This makes it difficult both to compare substances with each other, and to evaluate the effects of individual substances, which in many cases may result in underestimations of the effects. If the potential synergistic effects are also considered, this adds more uncertainty.

There is also a lack of ecological and biochemical data from pristine areas, which means there is no reference to use as a starting point when investigating effects from shipping or other activities (Neuparth et al., 2012; Häkkinen et al., 2018). A reference point is extremely important when assessing changes in the marine environment, and especially when tracing the source of a discharge. The ambitions of the MSFD and the marine-related national environmental objectives are to achieve Good Environmental Status (GES), and thus try to return to pre-industrial levels, or that the marine environment receive input from natural sources only. If there is no base line to refer to, it is hard to set target values and formulate strategies on how to achieve GES. It is also difficult to link operational discharges directly to changes in environmental contaminant levels, as the specific source of the discharges can rarely be identified with a high degree of certainty (Honkanen et al., 2012; Roose et al., 2011).

Since 2003, the Geological Survey of Sweden has carried out sediment sampling campaigns at regular intervals (every 5–6 years) in the deep basins within the Swedish Economic Zone (Josefsson and Apler, 2019). As part of these campaigns, surface sediment is analysed for carbon, nitrogen, metals, and organic substances to monitor the status of Swedish sediments. This data can often be attributed to human activities such as shipping. Here, there is the potential for improvement by using existing statistics, and by reviewing possible future coordination, so that analyses in connection with new campaigns can also include additional substances and geographical sampling areas that may be of interest from a maritime point of view.

Filtering organisms such as blue mussels can also act as indicators of the environmental status of the seas around Sweden. The mussel beds around the Hoburg Shoal could serve as a natural sampling site since this has been identified as an area of intensive traffic and potential pollution. Here, blue mussels can be collected and analysed for metals, environmental toxins and other substances that may be linked to shipping. Several experiments using mussel cages have also been carried out to analyse environmental status (Dabrowska et al., 2013). Another option would be to run a campaign with blue mussels from a number of mussel cages deployed in and around Swedish ship lanes, as well as in areas with less intensive shipping, to give an indication of the impact of shipping.

Various authorities are currently responsible for environmental monitoring and measurements of chemicals in the marine environment, in the water column, in sediment and from organisms. The Swedish Agency for Marine and Water Management has the overall responsibility for the coast and the sea, but the Swedish Environmental Protection Agency is responsible for the aspects of metals and hazardous substances in the environment. In Sweden, there are also various data custodians (such as the Geological Survey of Sweden, the Swedish University of Agricultural Sciences and the Swedish Meteorological and Hydrological Institute) with responsibility for quality assuring and storing the collected data. Water Information System Sweden (WISS) is another database that holds information about Sweden's bodies of water. WISS was developed in cooperation between the Swedish water authorities, the county administrative boards and the Swedish Agency for Marine and Water Management. According to the Swedish Agency for Marine and Water Management, strategic work is being carried out to coordinate and quality assure aquatic monitoring. At the same time, as part of the Smart Environmental Information project, the Swedish Environmental Protection Agency is responsible for leading the work to digitalise environmental monitoring data. The ongoing strategy work should also include issues relating to discharges and the impact from shipping, such as tank cleaning effluent discharges.

Environmental monitoring programmes rarely study effects at the individual or community level, making it hard to identify cause and effect relationships, which thereby makes it difficult to propose actions. This monitoring usually focuses on a few selected chemicals which, in connection with bans, may be more or less relevant in today's marine environment. Here, it is important to have a dynamic list of substances to be prioritised in order to avoid chemicals being overlooked in the belief that they do not exist. There is also a need to harmonise priority lists and their design, as today's priority lists are hard to compare, and no substance appears on all the lists.

The challenge in carrying out environmental monitoring programmes is that the substance(s) to be investigated must be defined in advance. The handling of samples and the selected analytical method(s) limit the substances that can be analysed, especially when it is desirable to obtain a low limit of detection (LOD). The wide variety of substances can be discharged makes both monitoring and sampling challenging. In addition, knowledge is required about the surrounding environment and the influence of external – often seasonal – circumstances such as weather, currents, and algal blooms. An earlier study conducted in the North Sea, where concentrations of selected chemicals in the water were measured before and after the ratification of MARPOL Annex II, points to the difficulties of making comparisons when there are so many parameters involved (Hurford et al., 1990). Their study may also be hard to apply to other more enclosed areas, as the North Sea is an exposed sea with a high water-exchange rate (Honkanen et al., 2013).

There are currently few or no generic models describing the behaviour of chemicals in the marine environment. The models that exist are often limited to a particular location or a particular type of chemical, and rarely handle more than one chemical at a time. Many scenarios concern freshwater environments, and this do not reflect the higher salinity solutions. Temperature has a very significant impact on how a substance will behave (Cunha et al., 2016). In the IBC code, substances are usually classified based on their properties at a single temperature (often 20´C) (Cunha et al., 2016), which rarely corresponds to the ambient temperature at which chemicals are discharged or handled. Swedish waters experiences seasonal variations with rapid weather changes and large temperature fluctuations, making it particularly hard to predict the potential impact of a discharge on the marine environment.

When carrying out a risk assessment, it is also important to define the object(s) at risk and the timescale involved. For marine organisms, toxicity – both acute and chronic – is often an important factor, while it is often carcinogens that are considered most dangerous for human health. In the best-case scenario, PNECs can be used as a proxy for the risks associated with elevated concentrations of substances in the marine environment. Hahn et al. (2014) compared how different international actors determined PNECs based on the same dataset, and the difference could be up to a thousand times depending on how the data was interpreted and weighted.

For substances that are not directly toxic, other methods are required to define the risk associated with discharges. Some fats and oils are harmless from a biochemical perspective and are classified as non-toxic. However, given the potential physical stresses of an oil discharge on marine life and the fact that other organic toxic substances and even heavy metals present in the surrounding environment can be absorbed and accumulate in these discharges, the associated risk can significantly increase.

It is important to have clear guidelines and threshold values to enable quantitative evaluation of the risks associated with different stressors. However, it is also important to keep a broad perspective and to be critical of how data is produced and presented. It would be desirable to develop generic models that are capable of handling multiple different chemicals, processes, and stressors in order to improve the quantitative assessment of the effects of shipping and other human impacts on the marine environment.

3.5.3 Proposed policy and regulatory changes

Although the process of making changes to the maritime regulations is often difficult, as decisions require a consensus among member states within the IMO, it is stated that MARPOL Annex II, in combination with the IBC Code, should be a dynamic regulatory framework with the potential to implement changes in a relatively short space of time.

Several different levels of strengthening can be achieved with only minor changes to the regulations themselves. The Baltic Sea is currently classified as a special area under several MARPOL Annexes (I, IV, V and VI), and is also included in the areas classified as PSSAs by the IMO (IMO, 2005). If the Baltic Sea Area were to be classified as a special area under MARPOL Annex II, the Baltic Sea and the Kattegat would be included and discharges in these areas could be prohibited. Tank cleaning could then continue while the vessel is underway, but with the requirement that all waste/wash water must be collected in slop tanks and left ashore. To include the entire West Coast of Sweden, the current delineation – where what is considered the Baltic Sea Area includes the areas covered by the HELCOM Convention (Figure 3) – needs to be reformulated. Alternatively, it is proposed that the North Sea should also be included as a special area under MARPOL Annex II, which would also reduce the likelihood of contaminants being washed ashore from transboundary pollution sources.

Article 5 of the HELCOM Convention for the Protection of the Marine Environment of the Baltic Sea Area states that:

The Contracting Parties undertake to prevent and eliminate pollution of the marine environment of the Baltic Sea Area caused by harmful substances from all sources, according to the provisions of this Convention…

There is a consensus within HELCOM to prevent and eliminate all discharges of hazardous substances, which should be a driving force for designation of the Baltic Sea as a special area under MARPOL Annex II, thus banning all discharges of tank cleaning effluents.

One option would be to introduce mandatory prewash for all substances included in classes X and Y of the IBC Code. This would lead to a reduction in total discharges associated with tank cleaning, and previous studies have shown that this is an effective way to reduce the quantities of chemicals discharged into the marine environment. Today, the prewash requirement for solidifying and highly viscous substances can be circumvented if the unloading temperature is kept sufficiently high (Höfer et al., 2013; Honkanen et al., 2012). The definition in accordance with MARPOL Annex II (Reg. 1.15.1 and 1.17.1) is based on the unloading temperature, which makes the prewash regulation inconsistent.

Substances are classified by GESAMP (GESAMP, 2019; Höfer et al., 2013) based on a variety of chemical and physical properties, and on potential environmental and health impacts. This then forms the basis for how the substance is classified in accordance with MARPOL Annex II (Reg. 6.2.1). The problem with this classification system is that the same substance can have different properties depending on environmental factors such as temperature, other substances in the same solution, discharge source, etc. As the prewash requirement for certain class Y substances is defined based on a certain type of property at the unloading temperature, ships are implicitly allowed to circumvent the measures as the temperature can be changed. Even if the unloading temperature can be kept high and the wash water is heated, solidifying and highly viscous substances will solidify and form slicks when they are released into the lower temperature environment.

With the new regulations that entered into force in 2021, persistent floaters (F_p in accordance with GESAMP) are also subject to the prewash requirement (IMO, 2018). More and more substances are therefore being added to the list of substances that require mandatory prewash, which can be seen as an indication that the previous classification does not correspond to the potential environmental impact. The new proposals for the prewash of persistent floaters mean that the prewash requirement can no longer be circumvented by increasing the unloading temperature. However, it has been noted that substances such as crude tall oil, which is defined as a persistent floater by GESAMP, are not covered by the new regulation under the IBC Code, despite meeting the definitions above. It is unfortunate that only selected substances defined as persistent floaters under GESAMP are covered by the new prewash requirement.

Another clear example where the classification of chemicals can be questioned is the case of nonylphenol and nonylphenol ethoxylate. Nonylphenol – a toxic substance with high bioaccumulation potential – is considered to be so harmful to the environment that it is categorised as a class X substance. Nonylphenol ethoxylate, on the other hand, has lower toxicity and impact. It is therefore categorised as a class Y substance and is not subject to the prewash requirement provided that the unloading temperature is maintained at such a level that nonylphenol ethoxylate is not classified as highly viscous under MARPOL Annex II (Reg. i.17.1). However, several scientific publications report that nonylphenol ethoxylate rapidly degrades in the marine environment into substances such as the class X substance nonylphenol, which in this case means that the degradation products are more toxic than the source product (Häkkinen and Posti, 2014; Ying et al., 2002; Honkanen et al., 2012; Roose et al., 2011; Soares et al., 2018). Nonylphenol has been shown to have a negative effect on the oestrogen and endocrine system and may thus have significant impacts on the marine environment when discharged (Honkanen et al., 2012). This clearly illustrates how a substance's classification does not necessarily reflect the substances that are formed in – and have an effect on – the marine environment when discharged.

One suggestion to investigate is the possibility of introducing a ban on vessels loading and unloading at the same port from leaving the berth to carry out tank cleaning offshore (even if this is done in a legal area) and then returning to reload. However, such a proposal would require coordination between ports, buyers, ship owners and vessels, as well as a review of ports' capacity to accept wash water from tank cleaning. Coordination between all relevant actors and an understanding of the need to reduce pressures on the marine environment to achieve legislated environmental objectives is essential in order to establish a common vision and to ensure that as few polluting discharges as possible are released into the environment.

Another alternative to reduce the environmental impact would be to introduce a requirement to minimize the strip volume per tank, preferably to volumes equivalent to super strip, as this is already applied to some extent. By carrying out a super strip, the tank can be emptied almost completely, with less than 1 litre remaining in total. Discussions with crew on board vessels reveal that a super strip is often carried out, where possible, to maximise the amount of cargo unloaded. This benefits both the economy and the environment. However, it is also mentioned that highly viscous products can get stuck in smaller pipes, and that a super strip is not carried out for this type of products.

According to the Swedish Environmental Code, there is currently a requirement for environmentally hazardous operations to investigate the environmental impact of such operations via recipient controls. However, this does not apply to shipping. In 2015, the Swedish Agency for Marine and Water Management published a study on how self-monitoring of water-related recipients could be better coordinated with regional and national environmental monitoring programmes. Again, no mention was made of shipping (Swedish Agency for Marine and Water Management, 2015). The same regulations and guidelines that apply to land-based environmentally hazardous operations should also apply to the shipping industry in order to ensure consistency in the imposed requirements. This would improve the effectiveness when investigating the environmental impacts associated with all anthropogenic activities.

Most of the proposals described here will place stricter demands on ports, which would need to increase their capacity to receive and treat wash and rinse water and from ships. It is beyond the scope of this report to investigate the costs and opportunities involved in such a transition, but it can be concluded that an investigation of costs and opportunities should be carried out in consultation with ports throughout the Baltic Sea Area, so that these stricter rules can be complied with, and individual 'high performing' ports are not forced to take responsibility for all vessels' waste.

According to the Swedish Coast Guard's annual report, statistics from several years back clearly show that, at best, only a few per cent of confirmed discharges result in fines being imposed (Swedish Coast Guard, 2019). These fines average around SEK 100,000 per offence. Here, more resources must be devoted to gathering evidence and bringing prosecutions, and – where an offence is detected – imposing penalties that are proportional to the vessels or the shipping companies' turnover.

The ratification of the HNS Convention (Swedish Government, 2018) provides clearer regulations for discharges of hazardous substances into the marine environment, when transported in both packaged and bulk forms. With clearer regulations and a clearly defined division of responsibilities, where the shipowner is liable, stricter requirements for liability insurance are also imposed, thereby resulting in a system with greater requirements and more controls.

4 CONCLUSION

Discharges of wash water and chemicals from operational tank cleaning at sea result in increased stress on the marine environment. It is important to emphasise that this is only one of many sources of pollution that can be traced back to human activity. The aim of this study was to highlight tank cleaning from the perspective of the marine environment, and to describe the current regulations. Additional questions have arisen during the course of this work, and this should support an implementation of the precautionary principle and to consider a ban on discharges from tank cleaning at sea. There is a consensus within HELCOM that pressures on the marine environment in the Baltic Sea must be reduced. This could motivate the HELCOM member states to pursue the issue of introducing a total ban on discharges of all substances within the IMO, instead of gradually implementing stricter rules. A total ban approach could then include an opportunity to seek exemptions from the discharge ban, if scientific evidence shows that the products are completely harmless to the marine environment. Today, very few substances should be classified as totally harmless, and the regulations should therefore be reviewed. In the absence of reliable statistics and scientific evaluations, all substances discharged in connection with tank cleaning should be classified as hazardous substances.

Marine management, environmental monitoring and exploitation of marine resources should take place in consultation between the various actors involved. Although there is already extensive cooperation, there is a lack of harmonisation in terms of maritime issues between the overall regulatory framework for ships and the environmental management. Solving the problems associated with the marine environmental impact of tank cleaning discharges require coordination between ship operators, industries and – not least – ports. It has become clear that there will not be one generic solution: the relationships between vessels, industries, ports, and municipalities and/or other authorities will vary. This study presents an overview of the effects on the marine environment that may be linked to discharges of tank cleaning residues.

In order to reduce the current uncertainties and improve the conditions for mapping what is transported around Sweden, not only in terms of discharges but also from a safety point of view, a common platform or database should be established as soon as possible. In concrete terms, this means that information from all relevant authorities needs to be organised so that data on MARPOL Annex II products is held in one place. It is also essential to use a harmonised system that cannot be misinterpreted, for example by misspelling or using different names for the same substance. This will make reporting to EMSA, HNS, etc. much easier, and the Swedish Coast Guard and other environmental emergency services will find it easier to get an overview of what needs to be done in the event of an accident.

For the proposed approach to succeed, it is necessary to identify who is responsible for reporting to this database (the vessel, the shipbroker, the port, etc.). With so many different operators, there is a clear risk of confusion, which again reinforces the importance of robust systems, for example in terms of the units and designations used, in order to ensure the quality of the statistics reported. This would also be relevant for transporting other types of substances and products.

Finally, it is of the utmost importance to ensure that ports are able to handle larger quantities of wash water in the event of a ban. Authorities should be able to act as a link between vessels and ports, and to ensure that everyone can – and does – comply with the rules.

5 REFERENCES

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APPENDIX A: STATISTICS SWEDEN'S LIST OF CHAPTERS

CHAPTER	TEXT
01	Live animals
02	Meat and edible meat offal
03	Fish and crustaceans, molluscs, and other aquatic invertebrates
04	Dairy produce; birds' eggs; natural honey; edible products of animal origin, not elsewhere specified or included
05	Products of animal origin, not elsewhere specified or included
06	Live trees and other plants; bulbs, roots and the like; cut flowers and ornamental foliage
07	Edible vegetables and certain roots and tubers
08	Edible fruit and nuts; peel of citrus fruit or melons
09	Coffee, tea, mate, and spices
10	Cereals
11	Milling industry products; malt; starches; inulin; wheat gluten
12	Oil seeds and oleaginous fruits; miscellaneous grains, seeds and fruits; industrial or medicinal plants; straw and fodder
13	Lac; gums; resins and other vegetable saps and extracts
14	Vegetable plaiting materials and vegetable products, nes.
15	Animal, vegetable or microbial fats and oils and their cleavage products; prepared edible fats; animal or vegetable waxes
16	Preparations of meat, of fish, of crustaceans, molluscs, or other aquatic invertebrates, or of insects
17	Sugars and sugar confectionary
18	Cocoa and cocoa preparations
19	Preparations of cereals, flour, starch, or milk; bakers wares

20	Preparations of vegetables, fruit, nuts, or other parts of plants
21	Miscellaneous edible preparations
22	Beverages, spirits, and vinegar
23	Residues and waste from the food industries; prepared animal feed
24	Tobacco and manufactured tobacco substitutes; products, whether or not containing nicotine, intended for inhalation without combustion; other nicotine containing products intended for the intake of nicotine into the human body
25	Salt; sulfur; earths and stone; plastering materials, lime, and cement
26	Ores, slag and ash
27	Mineral fuels, mineral oils and products of their distillation; bituminous substances; mineral waxes
28	Inorganic chemicals; organic or inorganic compounds of precious metals, of rare-earth metals, of radioactive elements or of isotopes
29	Organic chemicals
30	Pharmaceutical products
31	Fertilizers
32	Tanning or dyeing extracts; tannins and derivatives; dyes, pigments, and other coloring matter; paints and varnishes; putty and other mastics; inks
33	Essential oils and resinoids; perfumery, cosmetic or toilet preparations
	Soap etc.; lubricating products; waxes, polishing or scouring products; candles etc., modeling pastes; dental waxes and dental plaster preparations
34	Albuminoidal substances; modified starches; glues; enzymes
35	Explosives; pyrotechnic products; matches; pyrophoric alloys; certain combustible preparations
36	Photographic or cinematographic goods
37	Miscellaneous chemical products
38	Plastics and articles thereof
39	Rubber and articles thereof
40	Raw hides and skins (excl. Furskins) and leather
41	Articles of leather; saddlery and harness; travel goods, handbags, and similar containers; articles of gut (other than silkworm gut)
42	Furskins and artificial fur; manufactures thereof

43	Beverages, spirits and vinegar
44	Wood and articles of wood; wood charcoal
45	Cork and articles of cork
46	Manufactures of straw, esparto, or other plaiting materials; basketware and wickerwork
47	Pulp of wood or other fibrous cellulosic material; recovered (waste and scrap) paper and paperboard
48	Paper and paperboard; articles of paper pulp, paper, or paperboard
49	Printed books, newspapers, pictures, and other printed products; manuscripts, typescripts, and plans
50	Silk, incl. Yarns and woven fabrics thereof
51	Wool and fine or coarse animal hair, incl. Yarns and woven fabrics thereof; horsehair yarn and woven fabric
52	Cotton, incl. Yarns and woven fabrics thereof
53	Vegetable textile fibers nes.; yarns and woven fabrics of vegetable textile fibers nes. And paper
54	Man-made filaments, incl. Yarns and woven fabrics thereof
55	Man-made staple fibers, incl. Yarns and woven fabrics thereof
56	Wadding, felt and nonwovens; special yarns; twine, cordage, ropes and cables and articles thereof
57	Carpets and other textile floor coverings
58	Special woven fabrics; tufted textile fabrics; lace; tapestries; trimmings; embroidery
59	Impregnated, coated, covered, or laminated textile fabrics; textile articles suitable for industrial use
60	Knitted or crocheted fabrics
61	Articles of apparel and clothing accessories, knitted or crocheted
62	Articles of apparel and clothing accessories, not knitted or crocheted
63	Made-up textile articles nes.; needlecraft sets; worn clothing and worn textile articles; rags
64	Footwear, gaiters and the like; parts of such articles
65	Headgear and parts thereof

66	Chapter 66: umbrellas, sun umbrellas, walking sticks, seat-sticks, whips, riding-crops and parts thereof
67	Prepared feathers and down and articles thereof; artificial flowers; articles of human hair
68	Articles of stone, plaster, cement, asbestos, mica or similar materials
69	Ceramic products
70	Glass and glassware
71	Natural or cultured pearls, precious or semiprecious stones, precious metals; precious metal clad metals, articles thereof; imitation jewelry; coin
72	Iron and steel
73	Articles of iron or steel
74	Copper and articles thereof
75	Nickel and articles thereof
76	Aluminium and articles thereof
78	Lead and articles thereof
79	Zinc and articles thereof
80	Tin and articles thereof
81	Base metals nes.; cermets; articles thereof
82	Tools, implements, cutlery, spoons and forks, of base metal; parts thereof of base metal
83	Miscellaneous articles of base metal
84	Nuclear reactors, boilers, machinery and mechanical appliances; parts thereof
85	Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television recorders and reproducers, parts and accessories
86	Railway or tramway locomotives, rolling stock, track fixtures and fittings, and parts thereof; mechanical etc. Traffic signal equipment of all kinds
87	Vehicles (other than railway or tramway rolling stock), and parts and accessories thereof
88	Aircraft, spacecraft, and parts thereof
89	Ships, boats and floating structures
90	Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus; parts and accessories thereof
91	Clocks and watches and parts thereof

92	Musical instruments; parts and accessories thereof
93	Arms and ammunition; parts and accessories thereof
94	Furniture; bedding, mattresses, mattress supports, cushions and similar stuffed furnishings; luminaires and lighting fittings, not elsewhere specified or included; illuminated signs, illuminated nameplates and the like; prefabricated buildings
95	Toys, games and sports equipment; parts and accessories thereof
96	Miscellaneous manufactured articles
97	Works of art, collectors pieces and antiques
98	Complete industrial plant

APPENDIX B: PNEC VALUES AND DENSITIES FOR 40 PRODUCTS

PRODUCT	PNEC	DENSITY	REFERENCE
	mg/l	kg/m^3	
Acetone cyanohydrine	0.000013	930	HNS-MS
Sodium chlorate (solution)	0.00024	-	ECHA
Aniline	0.00012	1020	ECHA
Sulphuric acid	0.00025	1830	ECHA
Cumene	0.00037	860	ECHA
Epichlorohydrine	0.001	1180	ECHA
Phenol	0.001	1070	ECHA
Ethylhexanol	0.0017	830	ECHA
Dibutyl ether	0.002	770	ECHA
Propylheptanol	0.0022	830	ECHA
Butyl acrylate	0.003	900	ECHA
Tetrachloroethylene	0.005	1610	ECHA
Benzene	0.008	876	HVMFS 2019:25 HNS-MS
Dichloropropane	0.0082	1150	ECHA
Turpentine	0.01	962	ECHA
Styrene	0.014	909	ECHA
ETBE	0.017	736	ECHA
Octanol	0.02	830	ECHA
Carbon tetrachloride	0.022	1590	ECHA
Ethyl acetate	0.024	902	ECHA
Ethylhexanoic acid	0.036	906	ECHA HNS-MS
Isobutanol	0.04	800	ECHA
Chloroform	0.048	1490	ECHA
Bis(2-propylheptyl) phthalate	0.093	962	ECHA
Dichloroethane (ethylene dichloride)	0.11	1250	ECHA
Cyclohexane	0.2	770	ECHA
Formic acid	0.2	1220	ECHA
MTBE	0.26	740	ECHA
Acetic acid	0.306	1041	ECHA

Xylene	0.327	861	ECHA
Formalin	0.44	1100	ECHA
Toluene	0.68	867	ECHA
Ethanol	0.79	790	ECHA
Isoprene	0.93	680	ECHA
Acetone	1.06	800	ECHA
Methanol	2.08	790	ECHA
Propylene glycol	26	1040	ECHA
Acetaldehyde	210	780	ECHA

APPENDIX C: SOURCES FOR GIS MAP LAYERS

NAMN	KÄLLA	ADRESS
EBSA	HELCOM	https://metadata.helcom.fi/geonetwork/srv/eng/catalog.search/metadata/828468c6-dd88-408c-97d3-ce9c926681f0
Bathymetry	Baltic Sea Hydrographic Commission	http://metadata.helcom.fi:8080/geonetwork/srv/eng/catalog.search#/metadata/8b 46e4c7-f911-44ab-89e6-2c8b8d9fa2c0 Baltic Sea Bathymetry Database version 0.9.3. Downloaded from http://data.bshc.pro/ on download date.
Base line + 1Nm	SwAM	Produced by Swedish Maritime Administration Swedish Agency for Marine and Water Management
Coastline and borders	EEA	https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-1/gis-data/europe-coastline-shapefile
BRISK Aquaculture	HELCOM	https://metadata.helcom.fi/geonetwork/srv/eng/catalog.search#/metadata/9321a816-57fb-4d71-afd8-c3ad9c548c9c
HELCOM MPAs	HELCOM	http://metadata.helcom.fi:8080/geonetwork/srv/eng/catalog.search#/metadata/d27df8c0-de86-4d13-a06d-35a8f50b16fa
Oil spill	HELCOM	https://metadata.helcom.fi/geonetwork/srv/eng/catalog.search#/metadata/345c9b95-6e9c-44a4-b02a-ee4304cccffc http://www.helcom.fi/baltic-sea-trends/maritime/illegal-spills/
Natura2000	HELCOM	http://metadata.helcom.fi:8080/geonetwork/srv/eng/catalog.search#/metadata/47a94309-c72b-4a1a-8982-ed24ae829220
Natura2000, birds directive (SPA)	Swedish EPA	https://metadatakatalogen.naturvardsverket.se/metadatakatalogen/GetMetaDataById?id=a80bf3d7-e70c-42d1-9b8d-8148e53e011d
Natura2000, The Species and Habitats Directive (SCI SAC)	Swedish EPA	https://metadatakatalogen.naturvardsverket.se/metadatakatalogen/GetMetaDataById?id=945e918f-8426-4155-8fd6-3f780a85dd8f
Other spills	HELCOM	https://metadata.helcom.fi/geonetwork/srv/eng/catalog.search#/metadata/a2dadf9a-92be-4f3e-aa00-b2802ef420b9 http://www.helcom.fi/baltic-sea-trends/maritime/illegal-spills/
Territorial waters	HELCOM	http://metadata.helcom.fi:8080/geonetwork/srv/eng/catalog.search#/metadata/8a393266-519d-4eaa-a94b-b67f9f589744
Tanker vessel density	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php
Fishing vessels density	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php

Ports	EMODnet	https://www.emodnet-humanactivities.eu/view-data.php
Cod spawn-ing area	HELCOM HOLAS II cod spawning areas	https://metadata.helcom.fi/geonetwork/srv/eng/cata-log.search#/metadata/e91d509d-bd3e-4bd8-a7c8-ac2d10bbfd1b
ATBA	HELCOM	https://metadata.helcom.fi/geonetwork/srv/eng/cata-log.search#/metadata/60712fe9-ce1b-4fc6-b0b6-46e44f9bf134

APPENDIX D: EXAMPLE OF THE REQUEST EMAILED TO PORTS AND INDUSTRIES

In order to produce a study that is as accurate and reliable as possible, I need your help in obtaining information on the chemicals handled at your port (both loading and unloading). The chemicals I am interested in are those that are transported as liquid bulk in accordance with the IBC Code and Annex II of MARPOL 73/78. I am aware that oil and petroleum products are also liquid bulk, and if it is easier for you to include information on these, I will be happy to receive it.

The main things I want to know from you are:

- Which are the most common chemicals/substances that have been/will be shipped as liquid bulk and handled at your port?
- Approximately how much of each substance is handled each year? The more recent the data the better, so if you have data from 2018 that would be ideal. If you have data for more years (2015–2017), I would also be interested in receiving it.

If you are also able to share the following information, that would be an added bonus:

- Approximately how many ships/holding tanks are used to transport the quantities referred to in question 2?
- If there are multiple different chemicals on board, do you know which chemicals are usually carried at the same time?

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