Justiina Halonen & Lauri Hanski (eds.)

PREPARING FOR OIL AND CHEMICAL SPILLS IN THE CHANGING OPERATING ENVIRONMENT OF THE BALTIC SEA

Results and recommendations of the MARISEC project

XAMK
South-Eastern Finland University of Applied Sciences

Kymenlaakso Rescue Services
Wellbeing services county of Kymenlaakso

MERIKOTKA
KOTKA MARITIME RESEARCH CENTRE

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Ministry for Foreign Affairs of Finland

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MARISEC NOTES

Changes in the operating environment of the Baltic Sea affect the risk of oil and chemical spills, requiring urgent updates to response equipment, situational awareness tools, expertise and operating practices.

Climate change, geopolitical tensions, digitalisation and the green transition are all key drivers of change in this environment. In an increasingly complex risk landscape, it is impossible to prepare for everything in advance, which highlights the importance of being prepared to act in unpredictable situations.

Traditional statistical data is insufficient for anticipating the complex and novel risks of the future; active identification of new threats and more dynamic tools for maintaining situational awareness are necessary.

In the current situation, the lack of large recovery systems suitable for light fuel oils limits response capabilities, as current technology is primarily designed for heavy fuels.

Methods for managing large amounts of water must be developed for low-sulphur heavy oils, or investments must be made in state-of-the-art skimmers. The compatibility of new investments with the need to develop collection capacity in cold conditions must be investigated.

The systematic development of response capabilities requires continuous testing with different fuel types and under different conditions. Testing conditions must be diversified.

Maintaining readiness requires sufficiently frequent and varied training, as well as uniform competence requirements for those involved in oil spill response. International co-operation and utilising expert organisations are also essential, since experience is accumulated slowly in individual countries.

The traditional division of response systems into oil and chemicals is no longer necessarily appropriate, as the distinction between the controllability of different substance groups will become less clear in future. A more comprehensive approach with more frequent updates to the knowledge base is the solution.

Funding must be secured for the development of up-to-date response equipment, training activities, situational awareness tools and contingency planning. This can also be viewed as an investment in leadership, intellectual capital, and performance that are in demand internationally.

ABSTRACT

This publication compiles the key findings of the IBA MARISEC project and the resulting recommendations for action related to maintaining the level of preparedness for oil and chemical spills in the changing operating environment of the Baltic Sea. The publication combines research data on changes in risks in the Baltic Sea region, the effectiveness of response equipment, and response practices. The publication consists of five articles aimed specifically at authorities, decision-makers, and other stakeholders involved in oil spill response.

The risks of oil and chemical spills in the Baltic Sea are examined on the basis of a systematic literature review and expert workshops. The literature review focuses on the approaches used in previous risk assessments, their limitations, and changes in the operating environment. The results indicate that the complexity of the risk landscape and uncertainty have increased, which highlight the importance of an up-to-date knowledge base, updated risk assessments, and preparedness. A systematic literature review showed that, in previous risk analyses, the eastern Gulf of Finland consistently emerges as the area with the highest probability of an oil spill. The results of the risk landscape change analysis, in turn, illustrate the many types of changes that response measures will need to adapt to in the near future.

Practical equipment tests were utilised to assess the applicability of oil recovery equipment for responding to low-emission marine fuels. The tests evaluated the recovery efficiency of current oil recovery equipment for removing marine diesel oil and low-sulphur heavy fuel oil from water. The results show that the properties of fuels have a significant impact on their collectability and that the effectiveness of current recovery solutions should not be taken at face value. This highlights the necessity of testing and diversification of equipment to maintain response readiness.

Oil spill response exercises and shoreline response practices were examined on the basis of a survey for authorities, expert workshops, and international benchmarks. The results propose that a reduction in training activities weakens personnel preparedness and narrows the range of available methods. In addition, needs to define a minimum level of training, develop cost-effective training models, and strengthen national and international cooperation were identified.

The concluding article of the publication summarises and compiles the key recommendations derived from the results of updating the level of preparedness in a changing risk landscape. The recommendations are aimed at political decision-makers, strategy-level authorities, and authorities responsible for the operational response to marine oil and chemical spills.

Keywords:
oil spill, oil spill response, preparedness, rescue operations, testing, Baltic Sea, risk landscape, maritime transport, hazardous and noxious substances

FOREWORD

MARISEC … Check!

In a rapidly changing operational environment, it is easy to get swept away by events, causing direction and purpose to become blurred and the original reason for action to fade from view. It was, therefore, a pleasure to be a member of the MARISEC project steering group and to observe a well-planned and executed project with a real impact on advancing preparedness and readiness for marine incidents.

Project activities quickly became a significant means of promoting development and cooperation, both nationally and internationally. Projects implemented under the national IBA funding programme, which is administered by the Ministry for Foreign Affairs, have supported regional development and cooperation across the Baltic, Barents and Arctic regions. In addition to our Finnish project partners, the funding enabled the participation of foreign experts in events. These events were designed to enable regional experts to attend and develop networks of subject matter specialists, particularly within the Nordic countries, but also across the wider Baltic Sea region. The operational model supported by IBA funding enabled faster implementation of EU programmes, which has proven extremely useful in our constantly changing security environment.

The MARISEC project aims to enhance the preparedness, expertise, and equipment of rescue services and their partners in the coastal regions of the Gulf of Finland, enabling them to respond effectively to maritime incidents involving hazardous substances. Our fragmented coastline dotted with archipelagos is ecologically sensitive and challenging for marine operations. In emergency situations, it is essential that the correct procedures are in place, to have competent personnel, and that multiple rescue and support operators are involved in a coordinated manner.

During the MARISEC project, development needs relating to competence, cooperation, equipment and tools were identified. The participation of foreign experts in events, as well as visits by the project group to observe colleagues' work in Norway, increased understanding of practices in neighbouring countries. International experts also enhanced the professional knowledge and perspectives of project participants, identifying areas for future development to help rescue professionals and partner organisations prevent accidents and respond quickly when incidents occur.

The operating environment for rescue personnel is constantly changing due to new fuels, energy sources, and technical applications. Preparedness for these changes is essential, and close cooperation between different stakeholders must continue — preparedness ensures improved outcomes!

Project work is an integral part of the development process. Projects bring together networks of experts with different perspectives and needs, allowing them to focus on a common objective. Projects generate new expertise, knowledge, and innovations, as well as their novel applications. One of the great advantages of project work is workload sharing: each participant contributes their specialised knowledge, as demonstrated in this project. The Rescue Department of the Ministry of the Interior supports projects across all areas of comprehensive security within its mandate, ensuring that Finland remains one of the safest countries in the world and that we are prepared for various incident and disruption scenarios.

The work in your hands is a concise publication summarising the 15-month efforts of the MARISEC project. The project demonstrates that, with clear objectives, well-planned and properly managed activities, motivated participants and sufficient resources, a significant initiative can be realised even with relatively modest funding.

Special thanks go to the Kymenlaakso Rescue Services for its innovative leadership in developing maritime safety achieved through its collaboration with the South-Eastern Finland University of Applied Sciences (Xamk) and the Kotka Maritime Research Centre (Merikotka).

My deepest gratitude to the Ministry for Foreign Affairs for recognising the importance of the project proposal. Furthermore, I would like to thank all members of the steering group. Special thanks to project leader Lauri Hanski and to the project team led by Merisade Kuusela, Annukka Lehikoinen, and Justiina Halonen!

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CONTENTS

MARISEC PROJECT: STRENGTHENING OIL SPILL PREPAREDNESS ALONG THE BALTIC SEA COAST THROUGH A SHARED KNOWLEDGE BASE

Lauri Hanski, Justiina Halonen, Annukka Lehikoinen, Patrik Kauppi & José E. Cano Bernal

In recent years, the operating environment for maritime traffic in the Baltic Sea has experienced significant changes. Even though the overall number of ships has remained on a similar level, changes in the fleet, new lower-emission marine fuels, and rising geopolitical tensions directly affect both the likelihood of oil or chemical spills at sea and the requirements for spill response preparedness.

Authorities must be ready for a variety of spill situations that are harder to predict. Developing practical solutions and adopting response methods that work for new substances necessitate not only a broad review of response capacity and readiness, but also close cooperation and information exchange between authorities to keep the situational picture up to date.

The MARISEC project addresses these challenges by producing new information on the current performance of oil spill response equipment used by rescue authorities and on the changes in the operating environment, and by strengthening information exchange among authorities in the Baltic Sea region. With this process, the project aims to support authorities in improving oil spill response preparedness in a changing environment. Ultimately, the forecast improvement in performance aims to reduce knock-on impacts on the safety and health of coastal residents, the environment, as well as the security of supply and economy of coastal states. [1; 2.]

Why is MARISEC needed?

Changes in maritime traffic

The operating environment for maritime traffic has become diversified, which often also means that sea areas become more crowded. Alongside shipping and logistics, the variety of other activities taking place at sea is increasing. These activities include offshore wind power and fish farming. In addition, pressure to expand protected areas has increased [3]. These factors limit the available space and increase interaction between different users. In more crowded sea areas, safe navigation, traffic management, and coordination between activities become all the more important, as accident risks increase. If a sensitive marine area is located close to a crowded area, even a small oil or chemical spill can cause serious impacts.

Changes in maritime traffic are not only about ship size and traffic volumes: digitalisation has also changed the nature of risks. Navigation, machinery, cargo handling, communication, and traffic management increasingly rely on digital systems and data connections. Digitalisation can make operations more efficient, but it also increases dependence on technical systems and their reliable functioning.

As conditions change, it becomes even more important to understand the risks of maritime traffic as part of bigger picture, where technical, operational, environmental, and safety factors are closely linked.

Digitalisation also introduces new types of vulnerabilities, such as cyber disruptions and intentional interference. At the same time, geopolitical tensions and the changing security situation in the Baltic Sea have become all the more important factors affecting maritime traffic. These tensions can affect traffic volumes, shipping routes, vessel behaviour, and the predictability of risks in ways that earlier assessments and models, mostly focused on unintentional accidents, have not covered. As a result, there is a growing need to understand maritime risks as part of a broader picture where technical, operational, environmental, and security-related factors are closely connected.

New marine fuels are here, with more to come
In Finland, most oil recovery equipment is designed for heavier oil types, since ships operating in the Baltic Sea used to run mainly on heavy fuel oil. However, the introduction of the Sulphur Directive has completely changed the type of fuel used by ships, with over 80% of fuel consumption now being made up of marine distillates, i.e. marine gas oil (MGO DMA) or marine diesel oil (MDO DMB) [4; 5].

At the European level, the use of marine distillates has remained stable over the last decade, at around 20 percent. From the beginning of 2019, a new fuel product group entered the market: low sulphur fuel oils (LSFOs). After a high initial market share (just under 70 percent), the share of LSFOs in Europe has stabilised at around 50 percent. This decline can be attributed to the more comprehensive use of scrubbers, which has led, again, to the increased use of high-sulphur heavy fuel oil. Furthermore, the market share of bio-based fuels has also experienced a steady increase, reaching about 2–4 percent by the end of 2024 [6]. In addition, alternative fuels such as methanol and ammonia are becoming more common [7].

The used marine fuels, and thus potential pollutants, pose a particular challenge during the transition period, as the authorities must develop response and recovery capabilities for a number of different new fuel options while maintaining the ability to respond to conventional ones. Not only is assessing whether response capacity matches the risks complicated by the significant heterogeneity of substances, but the information on the capability of existing response and recovery equipment to cope with new substances is also only available for some fuels. Even then, the information mainly concerns the performance of small stationary skimmers [8; 9; 10]. Therefore, it was decided that the recoverability of these substances using large-scale recovery equipment and recovery systems on response vessels were to be examined through practical equipment tests.

Maritime fuel changes require updated recovery equipment.

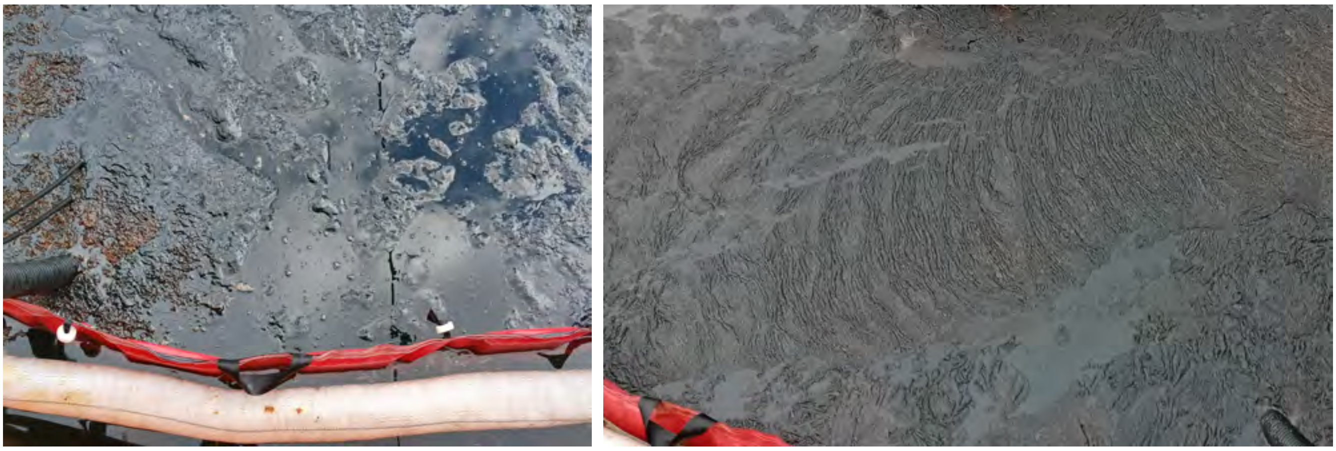

Figure 1. Ultra-low-sulphur marine fuel (RMD80) that has spilled into water begins to solidify at relatively high temperatures, posing challenges for its removal. Photos: Justiina Halonen and Manu Kettunen, 2025.

Trends in oil and chemical spills in the Baltic Sea

Most oil and chemical spills observed in the Baltic Sea occur on shipping routes. This includes unintentional incidents during normal operations of ships, such as spills during bunkering, engine faults, and leaks during loading and unloading. Major accidents, which typically lead to larger spills, are more evenly spread across the area and often occur in shallower coastal waters. [11.]

EUROSTAT statistics show that during the last ten consecutive years with available data (2014–2023), the number of visits by different types of tankers to the Baltic Sea ports (excluding Russian ports) has varied between 18,000 and 20,000 port calls per year. The time period portrays a slight upward trend, but this may also be explained by random variation. Over the same period, the total number of port calls by all vessel types has ranged from 640,000 (2014) to 550,000 (2016), with an average of 580,000 calls (excluding Russian ports). However, no clear overall trend for the period can be discerned. [12.]

Long-term accident data from HELCOM's map service shows that the number of maritime accidents in the Baltic Sea has increased, especially since the early 2000s. In particular, groundings and collisions portray an upward trend, although changes in reporting practices over the years create a level of uncertainty for interpreting the data. Even so, accidents that lead to pollution have remained rare and vary from year to year, with no clear long-term increase.

In recent years, the portion of accidents causing water pollution has been below five percent. This indicates improved ship safety and better environmental protection practices. However, oil and chemical spills still occur at random and appear case specific. The outcome of each accident depends on many factors, some outside human control, such as location, timing, and weather conditions. For this reason, every ship operating in the Baltic Sea should be considered as a potential accident, and as a possible source of a fuel spill or another unintentional operational incident. In addition, every tanker should be seen as a possible source of an environmental pollution caused by a cargo spill.

Photo: Kymenlaakso Rescue Services.

What did MARISEC achieve?

The risk landscape change analysis carried out in the project generates up-to-date and well-structured information on changes in the Baltic Sea operating environment and their effects on the risk of marine oil and chemical incidents and on response preparedness. The analysis highlights the factors related to preparedness and contingency planning that authorities should focus on in the coming years. As part of this work, the review of earlier risk analyses assist in clarifying what kinds of updates and possible methodological approaches are needed to maintain a strategic situational picture in a rapidly changing operating environment. The risk landscape change analysis is described in the second article of this publication, *Oil and Chemical Spills in the Baltic Sea: Situational Overview and Preparedness in a Changing Operating Environment (Lehikoinen, Kauppi & Cano Bernal).*

Recovery equipment testing highlights the current state of readiness of equipment for marine incidents involving marine distillates and low-sulphur fuel oils. The tests assessed the recovery efficiency of the most common skimmers and vessel-mounted recovery systems, which are classified as either heavy- or medium-recovery equipment and are currently deployed by rescue authorities (Figure 2). The results of these tests are presented in the article *Oil recovery efficiency tests with low-sulphur marine fuels (Halonen, Kettunen & Myrén)*.

Figure 2. The performance of the tested recovery devices was demonstrated to national and international oil spill response experts at the MARISEC seminar in September 2025. Photo: Ksenia Vihrina, 2025.

Oil spill response capabilities depend on more than just equipment and technical solutions. Smooth cooperation between authorities, consistent operating models and competent staff, maintained through regular training and exercises, play a key role. The third article of this publication describes the importance of cooperation, training activities, and the sharing of best practices: *Best Practices in Oil Spill Response and Training (Hanski*).

Figure 3. Exchanging information on best practices and fostering cooperation are considered important when preparing for oil and chemical spills. During the MARISEC project, visits were made to coastal rescue services both at home and abroad. Photos: Merisade Kuusela, 2024.

The project's primary objective is to assist authorities in enhancing their preparedness for oil and chemical spills within the evolving operational landscape of the Baltic Sea. The project's research results and recommendations should be put to versatile use in the future, guiding political and social discussion, supporting strategic planning, regulatory and investment decisions, and promoting multidisciplinary and international cooperation in these areas. The concluding article of this publication, Development Needs and Recommendations for Preparedness for *Oil and Chemical Spills in the Baltic Sea (Lehikoinen, Halonen, Hanski, Kauppi & Cano Bernal)*, summarises the project's findings and lessons, and proposes steps for the near future.

Summary

The MARISEC project produced new information on the performance of the existing oil spill response equipment used by rescue authorities and on changes in the Baltic Sea operating environment. The results of the project support the adoption of risk-based contingency planning and decision-making. As part of the project's research and interaction activities, the shared situational awareness and mutual exchange of information between the network of authorities and key actors in the Baltic Sea region was strengthened to promote coastal response preparedness. During the project, cooperation between domestic and international authorities, experts, and companies involved in oil and chemical spill response activities was enhanced, and new connections were established. Close cooperation laid the foundation for developing response capabilities across organisational and national borders, which will also enable smoother information exchange, monitoring of technological developments, and the formation of a common perspective on future oil spill response needs.

The results support decision-making and risk-based contingency planning.

Photo: Kymenlaakso Rescue Services.

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OIL AND CHEMICAL SPILLS IN THE BALTIC SEA: SITUATIONAL OVERVIEW AND PREPAREDNESS IN A CHANGING OPERATING ENVIRONMENT

Annukka Lehikoinen, Patrik Kauppi & José E. Cano Bernal

The maritime operating environment in the Baltic Sea is changing rapidly. Cargo types, ships, and technologies are evolving, while climate conditions and geopolitics affect the operating environment in their own ways. These concurring forces of change impact the risk of marine environmental incidents. They add uncertainty to the system and complicate the anticipation of future challenges. In this situation, it is difficult to assess and maintain the right level of preparedness.

Recent discussions between researchers and authorities in the region have unveiled an emerging need to examine possible changes not only in day-to-day response practices for marine environmental incidents, but also more broadly in the comprehension and development of the concept of preparedness.

In this article, we examine how the changing operating environment and the associated evolving risk landscape shape the risk of releases of substances harmful to the environment and hazardous to people in the Baltic Sea region. Our approach is qualitative and systems based, which allows us to observe the bigger picture and its complexity. We aim to improve understanding of the changes that should be considered when preventing future emission/ discharge releases and strengthening preparedness.

The article is based on research carried out in 2025 within the MARISEC project. The work aimed to (a) build an overall picture of previously published risk analyses related to oil and chemical accidents in the Baltic Sea, and (b) identify changes that have occurred, and are still occurring, in the risk landscape. Using this information, we assessed (a) how useful earlier risk assessments are today and possible necessary updates, and (b) which short-term needs related to maintaining and improving the capability to respond to environmental incidents can be identified.

Materials and Methods

The study consisted of two complementary parts: a systematic literature review and a risk landscape change analysis.

Systematic literature review

In the first phase, we mapped published accident and spill risk assessments related to the transport of oil and hazardous and noxious substances (HNS) in the Baltic Sea region, following the principles of a systematic literature review [1]. The analysis included peer-reviewed scientific publications as well as selected grey literature. In total, 51 publications were included in the final evaluation.

To ensure consistent content analysis across publications, we developed an Excel-based analysis form. The form recorded, for example:

- The study area within the Baltic Sea,
- The time period covered by the analysis,
- The data and methods used,
- The risk, substances, and impacts examined, and
- The main results and their relevance to the current situation.

The results of the literature review were used as material for the next phase, especially for identifying the factors and mechanisms that influence the formation of risks.

Risk landscape change analysis
In the second phase, we examined how the formation of oil and chemical spill risks in the Baltic Sea has changed in recent years and what changes can be expected in the near future. Methodologically, this work had three parts:

1. Workshop (May 2025):
We organised an expert workshop using the World Café method [2]. The workshop brought together 25 authorities and representatives of research organizations in Finland and Estonia. Participants rotated in small groups between themed tables based on key elements of the risk chain:

a) The likelihood of tanker accidents,
b) The size and likelihood of a spill if an accident occurs,
c) The effectiveness of response operations, and
d) The environmental impacts of spills.

At each table, participants discussed ongoing social, environmental, and technological changes in the Baltic Sea region and how these changes may affect each element. Following the discussion, moderators compiled the main observations.

2. Scoping review:
The drivers and mechanisms of change identified in the workshop were complemented with a scoping review [1]. The material included scientific publications, reports, expert statements, and other online sources. Based on this material, the identified impacts were compiled into change tables for each element of the risk chain. These tables describe how each driver is expected to influence the risk chain, and the likely direction of its effect.

3. Overall synthesis:
In the synthesis, we aimed to create a coherent overall picture of the changing risk landscape for oil and chemical spill risks in the Baltic Sea. We examined the impact of different change drivers on the overall picture and considered the possible significance of the results for managing environmental risks, focusing especially on preparedness measures, as well as current and near future needs.

Results

Systematic literature review
The systematic literature review showed that earlier risk analyses consistently identify the eastern Gulf of Finland as the area with the highest likelihood for an oil spill to occur. Several modelling studies suggest that, in the event of an accident, spilled oil would mainly drift north and north-east. Therefore, a successful response would depend strongly on Finland's national equipment and response capacity.

While earlier research has highlighted the ecological vulnerability of the western Gulf of Finland in particular, a more recent assessment of ecologically vulnerable marine areas based on VELMU data[1] [3] identifies the eastern Gulf of Finland as a key area in terms of the sensitivity of underwater biodiversity. This strengthens the knowledge base and confirms that ecological sensitivity is not limited to the western Gulf of Finland.

Although many publications emphasise the importance of cooperation and defined roles, concrete division of tasks and practical coordination are only mentioned, and often at a general level.

Most of the reviewed studies were based on numerical modelling, which is used both for risk assessment and for response planning. However, the reliability of modelling is diminished by possible under-reporting of accidents and, especially, close call events, which increases uncertainty in the input data.

Our keywords did not yield peer-reviewed scientific research focused specifically on chemical accidents. The only source directly touching on the subject was a 2012 report, which highlighted that the available respond methods to spills of soluble hazardous chemicals are very limited [4]. Based on expert advice, we complemented the material with one additional article that did not appear in our searches [5]. This article discusses the general toxicity and hazards of chemicals in the marine environ-

1 https://velmu.syke.fi/

ment and identifies areas that are more prone to collisions involving chemical tankers.

Studies that address risk management measures most often focus on individual parts of risk management, such as the effectiveness of response equipment, maritime traffic monitoring systems, or administrative control measures. Only a few studies [4; 6; 7; 8] provide more comprehensive analyses that cover the full risk management chain, from accident prevention to responding to resulting damage.

Although many publications emphasise the importance of cooperation and defined roles, concrete division of tasks and practical coordination are only mentioned, and often at a general level. Some articles do present risk management actions or tools, but they are not discussed in detail. Scenario analyses and GIS-based or environmental sensitivity maps are mentioned, but descriptions of how these are systematically linked to decision-making (for example, decision points, responsibilities, and data updates) are often broad and non-specific.

The reviewed articles included relatively thorough critical self-assessments. The most common issue concerns the limitations of applied data: outdated data, lack of precision, or geographically limited datasets reduce the reliability of models, especially statistical ones. Identifying uncertainties as part of risk analyses or when discussing results was a common occurrence in the articles, but communicating uncertainty to decision-makers was often described as a challenge or insufficient. This suggests that more attention is needed on both ends of the information chain.

In previous decades, computational limits of modelling tools, such as available computing power, significantly restricted the analysis of complex scenarios. Many articles, particularly in sections on limitations and future research needs, highlighted the need to expand the analytical framework to include ecological and socio-economic impacts (for example, improved species-specific sensitivity data, assessment of long-term ecological impacts, and consideration of societal consequences). The needs for international cooperation and to standardise analytical methods were mentioned in some publications, typically in connection with risk management and recommendations.

Change in risk landscape

When oil and HNS spill risks are discussed at a general level, the practical focus is placed on a chain of events where one step leads to the next. This way of thinking is typical in accident risk analysis, often illustrated through the 'Swiss Cheese Model' developed by James Reason (1997) [9] (Figure 1). The purpose of this conceptual model is to help explain how the outcome we are ultimately concerned about, in such as the environmental and societal impacts of spills in this case, is preceded by several stages and defence failures. These steps include: a vessel accident and the events leading up to it; damage to the ship's hull that allows oil or HNS chemicals to leak into the sea; the movement of the spilled substance in the water; and its eventual behaviour and impacts on marine and coastal ecosystems.

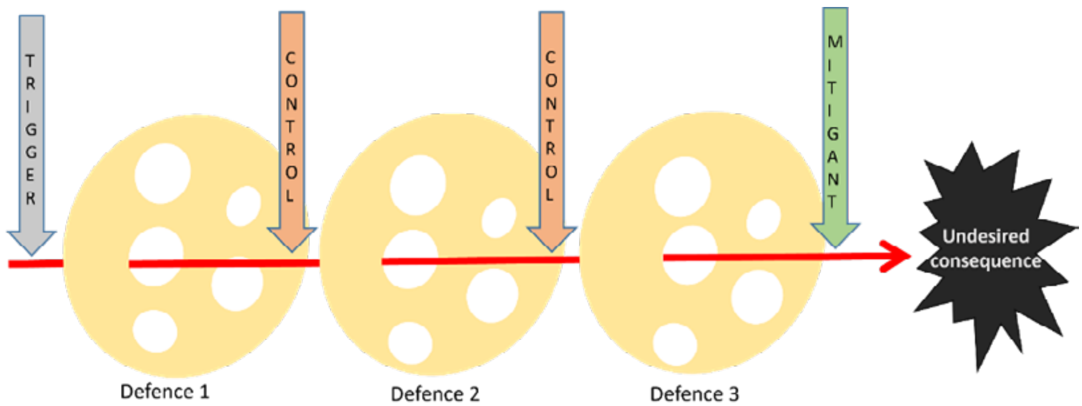

Figure 1. 'Swiss Cheese Model' developed by James Reason (1997) to illustrate accident risk chains. Illustration adapted from the cited source.

Each stage of the risk chain is affected by different external factors that cannot be fully controlled (depicted as '*trigger*' in Figure 1). These factors can either increase or reduce the likelihood of events progressing to the next stage.

For example, weather conditions (waves, wind) and seasonal factors (water temperature, ice cover, darkness, and the location and life stages of organisms) have a strong effect on the behaviour of a spilled substance, the extend of its spreading, and the potential severity of the environmental damage. Similarly, vessels that are do not appear on traffic monitoring systems or disruptions in data collections can create dangerous situations at sea and increase accident risk.

Furthermore, it is possible to actively manage risks at each stage of the chain or to reduce the harm they cause. This can be achieved through diverse solutions and measures ('*defence*' and '*control*' in Figure 1) that lower the likelihood of accidents, improve ship safety and resistance to collisions, or limit the size of a potential spill. If a spill does occur, its negative impacts can be reduced through effective response actions, such as recovery, cleanup, and restoration ('*mitigant*' in Figure 1).

Based on a systematic literature review of earlier risk analyses, we developed a risk chain for marine oil and HNS accidents. Changes in the operating environment are expected have varied effects on each part of this chain. The chain consists of four elements (Figure 2), which were used as the basis for analysing changes in the risk landscape through an expert workshop and a complementary literature review:

- 'Tanker accident': the likelihood of a vessel accident, especially tanker accidents involving large cargo spills
- 'Release of a harmful substance': the likelihood of an accident leading to damage on a cargo or fuel tank, and therefore, spill into the sea
- 'Response actions': the likelihood of the spilled substance either evaporating naturally or being successfully recovered from the sea
- 'Consequences of the spill': the likelihood of coastal areas, habitats, living organisms, or human property being exposed to the spilled substance, leading to harmful effects

The identified drivers of change affecting each element of the risk chain, as well as their possible impact mechanisms, are summarised below in element-specific tables (Tables 1-4). The tables use colour coding to indicate whether the effect of these mechanisms increases risk, reduces risk, or has unclear or neutral impacts.

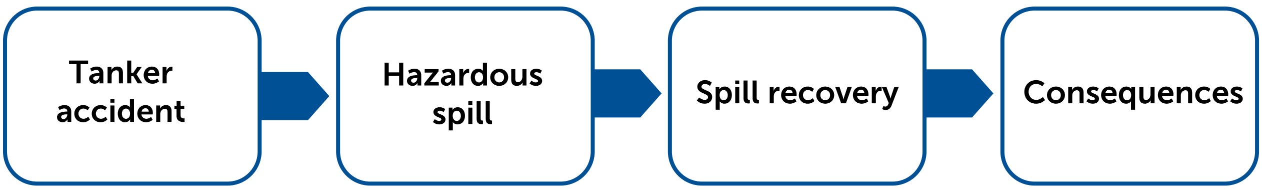

Figure 2. Elements of the oil and chemical spill risk chain used to assess changes in the risk landscape.

Table 1. Effects of key changes in the Baltic Sea operating environment on **the likelihood of tanker accidents**. Colour coding: red (-) = negative, blue (+) = positive, purple (±) = unclear or multi-dimensional impact..

Change factor	Impact mechanisms	Impact on the probability of accidents
Geopolitical tensions	*Russian shadow fleet (-), Interference (-) (AIS-spoofing, GNSS-interference, Cyber disruptions), Terrorism targeting critical infrastructure (-)*	**Increases the probability of shipping accidents.**
Digitalisation and automation	*AI-assisted operations (+), Vulnerability to cyber-security threats (-), Digital competence of crews (±)*	**Both increases and decreases the probability of shipping accidents.**
Fleet composition	*Larger vessels: fewer accident candidates vs. challenges of navigating in Baltic Sea conditions (±)*	**Uncertain, location-specific effect on the probability of shipping accidents.**
Green marine infrastructures	*Offshore windfarms: obstruct maritime traffic and complicate ice conditions in winter (-)*	**Increase the probability of shipping accidents locally.**
Climate change	*Uncertain future development of ice conditions (±)*	**Uncertain and multifaceted effect. Requires adaptation of maritime operations and icebreaking services to the evolving conditions.**

Table 2. Effects of key changes in the Baltic Sea operating environment on harmful substance spills (likelihood and severity). Spill severity depends on both the volume spilled and the substance. Colour coding follows the same principles as Table 1.

Change factor	Impact mechanisms	Impact on spills
Geopolitical tensions	*Russian shadow fleet: ageing tankers with weak collision resistance and poor condition (-)*	**Increases the likelihood of spills in accidents**
Fleet composition	*Larger tanker sizes (-)*	**Increases the potential magnitude of spills (larger volumes)**
Green transition chemicals	*Increasing chemical transports (-); New fuels and transported chemicals: wider range of substances, behaviour in the marine environment largely unknown (±)*	**Increases the probability of harmful spills. Increases uncertainty regarding spill impacts and manageability**
Climate change	*Changes in winter navigation: more vessels with lower ice class and weaker collision resistance (-)*	**Increases the likelihood of spills occurring in accidents**

Table 3. Effects of key changes in the Baltic Sea operating environment on preparedness and response capacity for oil and chemical spills. Colour coding follows the same principles as Table 1.

Change factor	Impact mechanisms	Impact on response capacity and preparedness
Geopolitical tensions	*International cooperation: the lack of cooperation with Russia may also strengthen cooperation among other Baltic Sea countries (±)*	**The impact is unclear and multifaceted.**
Fleet composition	*Larger vessels: larger potential spill volumes (-)*	**Affects response capacity negatively. Increases the need to expand response capability.**
Green transition chemicals	*New fuels and chemicals: wider range of substances, unknown behaviour and recoverability in the marine environment, safety risks for response personnel (-)*	**Complicates response and preparedness. Creates needs for research, training and equipment upgrades.**
Green marine infrastructures	*Offshore wind farms: may obstruct response operations (-)*	**Hampers local response operations.**
Climate change	*Weather and water temperature: affect the recoverability of substances (±)*	**Substance- and situation-specific. Large variability and poor predictability complicate preparedness.**
Preparedness funding and other resources	*Decreasing funding combined with changing needs (-)*	**Prevents maintaining current levels of preparedness.**
Digitalisation and automation	*Improved data availability and accessibility (+)*	**Supports both strategic situational awareness and operational decision-making and prioritisation of actions.**

Table 4. Effects of key changes in the Baltic Sea operating environment on the consequences of oil and chemical spills for people and their living environments. Colour coding follows the same principles as Table 1..

Change factor	Impact mechanisms	Impact on harmful consequences
Green transition chemicals	*New, toxic, or impact-wise uncertain substances (-)*	**Increases uncertainty regarding consequences. More potentially severe impacts on ecosystems and humans.**
Climate change	*Stress weakens the ecosystem's resistance and recovery capacity. (-)* *Behaviour of chemicals in ecosystems depends on physico-chemical conditions. (±)*	**Likely increases harmfulness but also increases uncertainty. Affects the accumulation of substances in organisms, transport pathways, and degradation.**
Marine pollution	*Other emissions and human-induced stress weaken the ecosystem's resistance and recovery capacity. (-)*	**Increases environmentally harmful consequences, adding ecosystem damage and reducing resilience.**

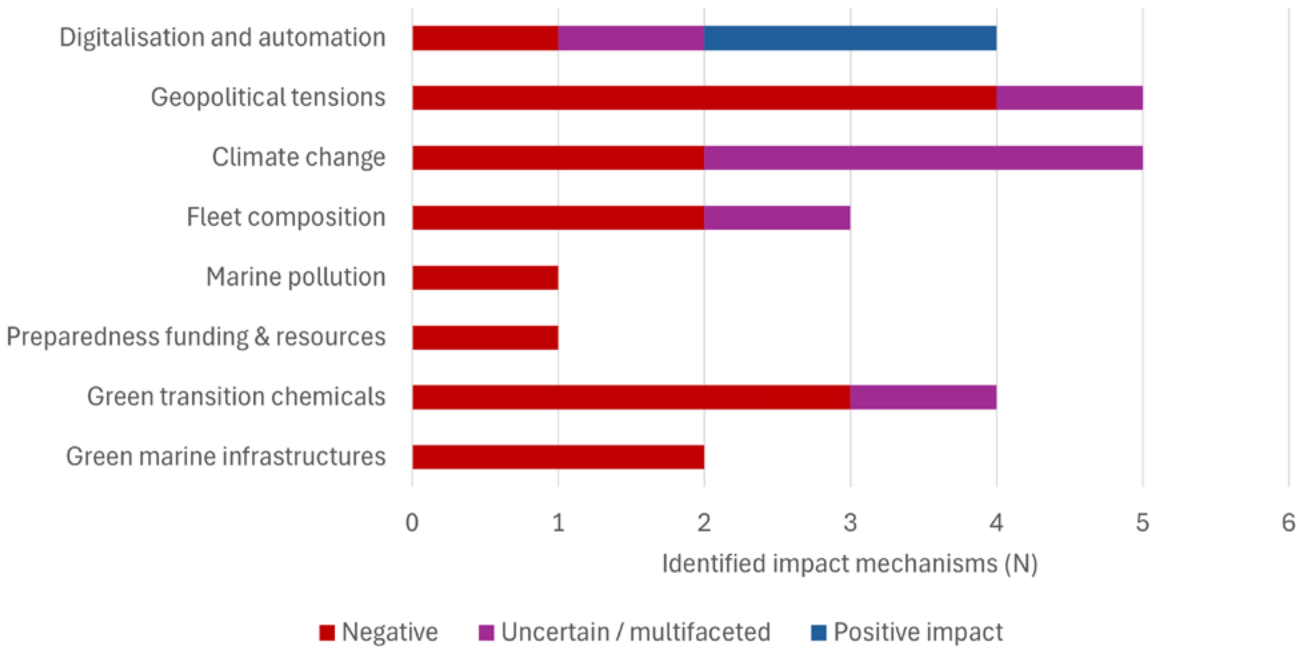

Figure 3. Influence of analysed changes in the operating environment on oil and chemical spill risks and risk management. The weighting is based on identified impact pathways, including risk-increasing (negative), risk-reducing (positive), and uncertain or complex mechanisms, as depicted in Tables 1–4.

Figure 3. Summaries the relative importance of the analysed change drivers as part of the evolving risk landscape based on the number of identified impact mechanisms. However, the scores in the figure do not directly show how strongly each driver affects risk in quantitative terms. Estimating that would require choosing measurable indicators and modelling them.

Reviewing the results

Earlier risk analyses: current relevance and the need for updates

Our process included an assessment of earlier risk analyses and their applicability to current settings. While the theoretical foundations of these models remain valid for the most part, changes in environmental conditions and the operating environment, together with new data and improved computing capacity, indicate that the analyses should be updated in order to provide an up-to-date situational picture.

New data is available on maritime transport (e.g. Eurostat[2]), vessel traffic (AIS[3]), ship accidents and spill events (e.g. HELCOM Data Service[4]), the recoverability of substances at sea (e.g. [10; 11; 12], see also Article 3 in this publication volume), and the location of ecologically sensitive areas (e.g. VELMU) is available. In addition, new or emerging tools exist for modelling spill movement, accident probabilities, environmental impacts, and overall risk in the Baltic Sea have been developed. Together, these developments offer improved opportunities to carry out more robust risk assessments using statistical and probability-based approaches (see, for example, [13], and the links below [5], [6], [7]).

2 https://ec.europa.eu/eurostat/web/main/data/database
3 https://www.marinetraffic.com/en/ais/home/centerx:18.7/centery:60.7/zoom:5
4 https://maps.helcom.fi/website/mapservice/
5 https://interreg-baltic.eu/project/openrisk-ii/
6 https://helcom.fi/helcom-at-work/projects/brisk-ii/
7 https://marine.copernicus.eu/services/use-cases/drift-modelling-investigate-stranding-vegetable-oil-hanko-peninsula-gulf-finland

As the operating environment of the Baltic Sea is undergoing rapid change, the risk landscape is continuously evolving. This makes the need for adaptive risk assessment tools, which can be updated dynamically as new observations become available, increasingly clear. Corresponding development has already begun to an extent[5].

At the same time, the growing importance of intentional security threats change the nature of risks compared to earlier assessments that focused mainly on accidental safety-related events. For risks involving deliberate harmful actions, traditional risk assessment methods based on historical statistics and probabilities are not always appropriate. Instead, analysis of current risks requires different approaches, such as scenario-based and system-oriented methods, including the identification of new threat scenarios and their impact pathways.

So far, only a small number of studies have attempted to build a comprehensive, Baltic Sea-wide picture of an oil spill risk or its key components [4; 6; 7; 8]. At present, the main limitation to producing consistent, basin-wide risk analyses and a shared situational picture is the limited availability of comparable and harmonised data. Oil and chemical spill risks in the Baltic Sea are inherently cross-border and, therefore, shared by all countries in the region. Thus, effective risk management requires close cooperation across the entire Baltic Sea area, including the development of harmonised data collection, systematic data sharing, and the joint use of common analysis methods and tools.

Change in the risk landscape: impacts on risk levels and preparedness

As presented in Tables 1–4, the social and environmental changes currently taking place in the Baltic Sea region simultaneously affect several key factors that are important for the way oil and chemical spill risks are formed and managed. These factors include the likelihood of accidents and their preventability, the type and size of possible spills, preparedness and response capacity, and the consequences of damage. Many drivers of change affect more than one of these areas simultaneously. This highlights the need to look at the overall risk chain and risk landscape as a unit, and to consider their combined effects when making decisions.

Geopolitical tensions and climate change stand out in our results as factors that increase accident and pollution risks as well as uncertainty to risk assessment and risk management. Changes related to the shipping fleet, especially the increase in vessel sizes, can increase the potential scale of damage and the need for response capacity. Chemicals linked to the green transition and new fuels increase uncertainty related to the severity of harmful spills and effectiveness of response measures. This highlights the need to improve preparedness and skills.

Green offshore infrastructure, such as wind farms, can increase local accident risks and complicate response operations. The effects of digitalisation and automation are mixed: they can improve situational awareness and decision-making, but, at the same time, they increase vulnerability to technical failures and cyber disruptions.

Based on the summary in Figure 3, geopolitical tensions in the Baltic Sea region and the impacts of climate change, including the associated high level of uncertainty, are the factors that affect the risk landscape in the most complex ways. At the same time, when the change drivers 'green transition chemicals' and 'green offshore infrastructure' are considered as a unit, green transition emerges as an equally, if not more, significant factor.

Among the analysed change drivers, digitalisation and automation are the only factors that clearly offer benefits for risk management as well (Figure 3). They create new opportunities to improve operations and situational awareness in both navigation and oil and chemical spill response.

In Figure 3, the state of the marine environment and preparedness resources receive one point each, but both are likely to have major impacts on the level of harm if a marine pollution event occurs. A healthy and diverse ecosystem is more prepared to absorb shocks and recover faster than an ecosystem in poor condition. Furthermore, the resources available for oil and chemical spill response and preparedness directly affect the ability to limit damage and reduce its spread in the environment.

Based on the visual comparison of the size of Table 4 and other tables, it is clear that changes in the risk landscape have a more comprehensive impact on the 'Response measures' than other elements of the risk chain. Almost all (7 out of 8) of the analysed environmental change drivers are included in Table 4. This portrayal highlights the numerous change trends response activities must address simultaneously.

Conclusions

This analysis provides an overall picture of how and why the risk landscape related to oil and chemical accidents in the Baltic Sea is becoming more complex and uncertain. Several social, environmental, and geopolitical changes are happening at the same time, affecting accident probabilities, the nature and scale of possible spills, response capacity, and the consequences of damages through several connected mechanisms. Together, these factors shape a dynamic risk landscape that places new demands on comprehensive risk management and preparedness.

Preparedness for oil and chemical spills must address an increasing number of situations that do not fit previously defined or practiced scenarios. A more complex risk landscape means a wider range of possible accident situations where the causes of spills, their impacts, and response conditions can differ significantly from the past. New fuels, changing weather and ice conditions, and increasing use of marine areas, in particular, create new challenges for response methods, equipment, and skills. At the same time, the opportunities offered by digitalisation and automation to improve situational awareness and prioritise actions become increasingly important, even if they also require preparedness for technical problems and cyber security threats.

Maintaining and developing oil and chemical spill response capacity **will require more diverse skills and response equipment** in the future. Adapting local and regional preparedness to changing conditions requires more **testing and research, training and exercises, updates to response equipment and systems**, and close **cooperation** between different actors and countries. This, in turn, creates a need for **sufficient and long-term resources**, both financial and human.

Preparedness for oil and chemical spills must address an increasing number of situations that do not fit previously defined or practiced scenarios.

Furthermore, updated approaches are necessary for risk assessment as well. **Traditional analyses based only on statistical data are not enough** when the future risk landscape has experienced several changes when compared to the past; risks are more complex and uncertain, with some threats linked to intentionally harmful actions (security threats). Identifying **new threat scenarios and imagining unfamiliar alternative pathways** through multidisciplinary cooperation is important, as the identification of risks is a prerequisite for further assessment and for planning risk management and preparedness.

In a dynamic and increasingly complex risk landscape, it is impossible to prepare for everything in advance. This highlights the importance of **being able to improvise and act in a rational and effective way in unexpected and previously unseen situations**. In addition, our current risk landscape creates pressure to rethink preparedness training. **Alongside traditional 'proactive' scenario-based exercises, it may be useful to increase so-called 'reactive' preparedness training**. The aim of this is to strengthen the ability of organisations and individuals to operate in unexpected situations that have not been planned in advance (so-called 'black swans'). In such cases, **individual skills, tools for building and sharing situational awareness, and effective cooperation networks become especially important** (see e.g. [14]).

Finally, it is important to stress the **close link between risk analyses and decision-making in risk-based preparedness**. For analyses to effectively support preparedness, they should be designed from the outset to produce information that can be integrated into decision-making processes. At the same time, how risk analysis outputs are used in these processes should be documented transparently, to show to what extent decisions and the scale of actions are based on information and correspond to assessed risk levels. This requires **effective dialogue between those who produce risk information and those who use it**, as well as ways to communicate uncertainties clearly without oversimplification.

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OIL RECOVERY EFFICIENCY TESTS WITH LOW-SULPHUR MARINE FUELS

Justiina Halonen, Manu Kettunen & Antero Myrén

New marine fuels have emerged, yet there is limited information on the capabilities of existing spill recovery equipment when dealing with these fuels. As part of the MARISEC project, Xamk's task was to gather this information by conducting practical tests in the university's oil spill response testing and training basin. The aim of these tests was to evaluate the effectiveness of existing oil recovery equipment in incidents involving new marine fuels. The objective was either to ensure adequate performance or to identify any possible shortcomings. In the latter case, preparations were made to map out recovery technology that would complement the current capabilities. The recovery tests were carried out in May–June and October–November 2025, using two different types of marine fuel: marine diesel oil (low-sulphur marine distillate fuel) and ultra-low-sulphur heavy fuel oil. First, this article describes the fuels and oil recovery devices selected for the tests. The results of the recovery efficiency tests are presented for each fuel and recovery device. This is followed by a presentation of the most feasible options from the trials conducted to investigate the usability of different types of additional equipment. These trials were conducted alongside the recovery tests.

Fuels and oil recovery equipment to be tested

The selection of fuels used in the tests was based on expert assessment, and the following two marine fuels were selected on the basis of workshop discussions:

- Marine Diesel Oil, DMB grade (also marketed under the trade names Neste Marine 0.1 Co-processed, or Optima). Distillate fuel containing small amounts of residual oil, sulphur content less than 0.1%, density 825 kg/m^3 at 15°C, viscosity 2.0… 11.0 mm^2/s at 40°C and pour point -6…10°C.
- Ultra-low sulphur fuel oil RMD80. Blend fuel used in maritime transport with a sulphur content of less than 0.1%, density of 975 kg/m^3 at 15°C, viscosity of 80.0 mm^2/s at 50°C, and pour point of 30°C.

Following the introduction of the Sulphur Directive in 2015, the use of marine distillate fuels increased in the Baltic Sea, accounting for over 80% of fuel consumption in 2020. Prior to this, vessels mainly ran on heavy fuel oil. Marine distillate fuels include marine diesel oil (MDO) and marine gas oil (MGO), with MGO being the more common of the two. [1; 2.] Based on previous oil recovery tests, it is more challenging to recover MDO from water than MGO. Furthermore, equipment suitable for MDO recovery can be used for MGO recovery in most cases [2; 3], and for this reason, MDO was selected as the test oil. Low-sulphur heavy fuel oils (LSFOs) became more common in 2019. These fuels are further divided into Very Low Sulphur Fuel Oil (VLSFO), with a maximum sulphur content of 0.50%, and Ultra Low Sulphur Fuel Oil, with a maximum permitted sulphur content of 0.10%. The RMD80 selected for testing represents Ultra-Low-Sulphur Fuel Oils. At the European level, low-sulphur heavy fuel oils account for around 50% of marine fuels [4].

The oil recovery equipment selected for the oil recovery efficiency tests consisted of skimmers and vessel-mounted recovery systems classified as heavy or medium-duty recovery equipment commonly used by rescue services. In addition, smaller-scale trials were conducted on equipment available on the market considered to have potential. The equipment types were based on brush, disc, or drum technology, and the oil they collected was transferred mainly by either positive pumping or suction technology. In one device, the oil is drained directly into a collection container without a pump.

The following devices were selected for testing:

- **Lamor MultiSkimmer:** a floating device equipped with three interchangeable recovery units (banks) that collects oil from three directions, transferring the collected oil from the skimmer to a storage tank using a screw pump permanently installed in the skimmer. Both brush, drum, and disc modules were used as recovery units in the tests.
- **Vikoma Komara Midi 4 Skimmer:** a floating device equipped with four interchangeable recovery units that collects oil from four directions, with the collected oil being transferred using suction technology. Disc modules were used as recovery units in the tests.
- **Lamor Bow Collector:** a brush conveyor belt unit mounted on the bow of a response vessel. Gravity draws the oil into the collection tank without a transfer pump.

The trials conducted after the actual tests included the ELASTEC X30 Grooved Disc and Grooved Drum skimmers, New Naval's ScorSkim 30 skimmer, Lamor's MiniMax25 skimmer with disc and drum modules, Vikoman's Komara Midi 2 brush skimmer, and DESMI's Octopus LSFO Skimmer. The actual oil recovery efficiency tests consisted of three identical test runs, and the presented and discussed result is the average value of all three tests. The trials, on the other hand, were mainly single operating cycles, and this article describes the results of the trials for devices that proved to be applicable.

Test conditions and test procedure

Recovery tests were conducted to determine the applicability of different types of oil skimmers for recovering low-sulphur marine fuels spilled into calm waters under conditions of low current or moderate waves. A wave approximately 10 centimetres in height was produced using a 'wave machine' designed by the basin staff (Figure 1). The free-floating skimmers were tested in a 20-square-meter area boomed off the oil spill response basin. The bow skimmer was tested in a 12-square-meter test basin so that it could be attached to structures, and the flow propeller and flow-control structures could be used.

Figure 1. Prototype wave machine built for testing purposes. Photos: Manu Kettunen, 2025.

The tests focused on assessing recovery efficiency, i.e., the skimmer's ability to recover oil instead of water. Furthermore, the aim was to clean the water area as thoroughly as possible. In all tests, the oil layer thickness was set at ten millimetres, with the amount of oil released into the water varying from 100 to 200 litres depending on the surface area of the test setting. The recovery device was positioned at the centre of the test area. The rotation speed was optimised to ensure that only oil was lifted, and the amount of water was kept to a minimum. The device was then allowed to collect the material independently. If necessary, when oil uptake was impaired or had stopped, oil flow was assisted by directing oil towards the recovery unit. Recovery was stopped when the device no longer lifted oil and/or when the area was clean. The recovered material of each test run was directed into its own storage container, and the proportion of oil in the total liquid volume

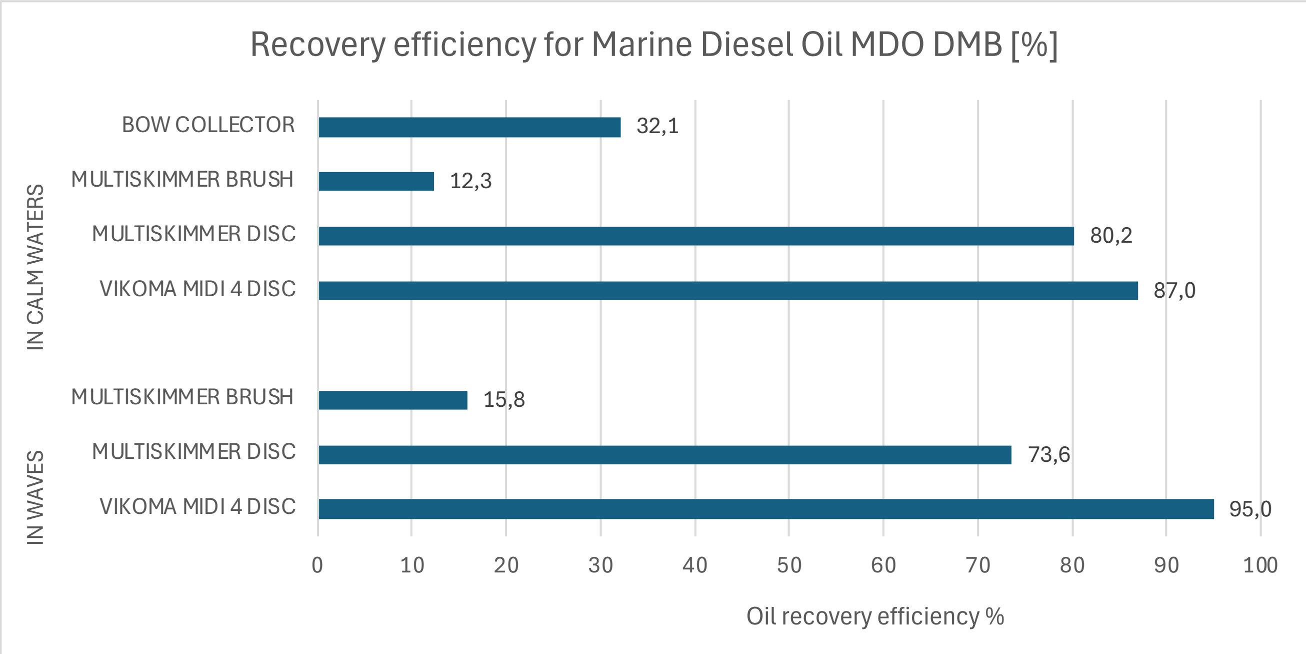

Figure 2. Recovery efficiency of the tested oil recovery equipment in calm waters and small waves when recovering Marine Diesel Oil (MDO DMB). Initial oil layer thickness of 10 millimetres. Average water of temperature 15°C. The results are presented as the average value of three test runs. Under these test conditions, the recovery efficiency of disc skimmers was established to be many times higher than that of brush skimmers.

was estimated. This ratio indicates the device's recovery efficiency: the higher the percentage, the more effective the device is at collecting oil rather than water. Furthermore, the amount of oil that was not recovered was estimated.

The recovery tests were carried out in May–June, while the trials took place in October–November. The weather conditions during the summer tests were fairly similar: the weather was dry, and air temperatures ranged from 14 to 20°C, with an average water temperature of 15°C. During the autumn trials, water temperatures were cooler, around 7–8°C.

Recoverability of marine diesel oil MDO DMB

Figure 2 shows a summary of the recovery efficiency of different skimmer models when collecting marine diesel oil (Marine Diesel Oil DMB grade, MDO DMB). The recovery efficiency achieved by each skimmer is based on an average of three test runs. Recovery efficiency was assessed in both calm waters and small waves, except for the bow collector, which was tested in a separate test tank. The initial oil layer thickness in each test was 10 millimetres.

As the graph illustrates, there is a clear difference between the types of recovery technology: under these test conditions, the recovery efficiency of disc skimmers was more than four times higher than that of brush skimmers for the type of oil in question. Furthermore, brush skimmers collected water along with oil and were prone to forming oil-in-water emulsions. However, based on these tests, no clear conclusions can be drawn about the effect of waves on recovery efficiency. In some cases, recovery efficiency improved in wavy conditions, while in others it deteriorated. While the graph does not show the amount of unrecovered oil, an estimate of this amount is provided in the results for each skimmer.

Bow Collector

Lamor Bow Collector is a brush conveyor belt system that is mounted on the bow of a rescue vessel. Its recovery principle corresponds to all fixed recovery systems currently used on rescue service vessels. During recovery operations, the recovery system advances at a slow speed. Recovery conditions were simulated using a flow propeller and deflection plates (see Figure 3). Otherwise, the test procedure followed the description discussed above.

Figure 3. The flow conditions required for the bow collector were achieved using deflection plates and a hydraulic flow propeller. Due to the structures, the oil surface area was reduced to approximately ten square meters. Photo: Justiina Halonen, 2025.

One hundred litres of oil were poured into the basin to create an oil layer 10 millimetres thick. The bow collector's brush belt rotated in both directions. Better results were achieved when the belt was rotated downwards, i.e., against the flow. When rotating upwards, a water barrier formed in front of the belt (see Figure 4), preventing the oil from reaching the brushes.

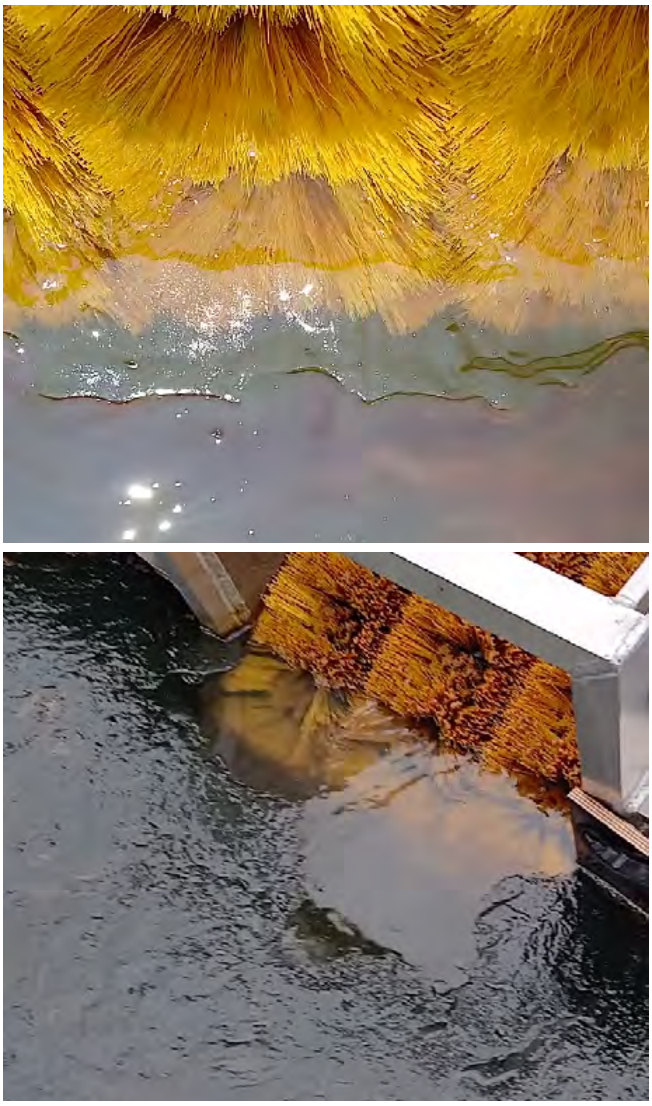

Figure 4. A stationary bow collector forms a water barrier in front of the brushes when rotated upwards. The photo above features MDO DMB marine diesel oil, and the photo below depicts RMD80 fuel. Photos: Justiina Halonen, 2025.

In order to overcome the water barrier, oil was directed towards the recovery device in order to simulate the movement of an advancing device. However, when the belt was rotated upwards, the marine diesel oil did not rise into the storage container because of its low viscosity; it did not manage to adhere to the brushes throughout the entire process. Therefore, this part of the test was terminated. When the belt was rotated downwards, the oil directed towards the belt rose with the help of the brushes and the steel plate below the belt. Nevertheless, oil still had to be supplied to the device due to the test structures hindering the free flow of oil, and to simulate forward movement.

Figure 5. The bow collector readily emulsified marine diesel oil, which in the confined space of the test tank spun back in front of the device. Photo: Manu Kettunen, 2025.

When rotated downward, the total amount of collected liquid was 280 litres, of which approximately 90 litres was oil. This resulted in a recovery efficiency of 32%. An estimated 10 litres of emulsified foam and oil that had seeped into structures remained unrecovered. The recovery took 48 minutes.

MultiSkimmer with brush modules

The Lamor MultiSkimmer features triangularly arranged recovery modules (Figure 6). The recovery efficiency of the MultiSkimmer equipped with brush modules was the lowest in the test series for marine diesel oil (Figure 2). The recovery efficiency in calm waters was 12%, and 16% in small waves. Of the 200 litres of oil poured onto a 20-square-meter area enclosed by a boom, 10 litres in calm water and 20 litres in waves remained uncollected. The recovery times were roughly the same, approximately 40 minutes. The low recovery efficiency was due to the emulsification of the oil and the large amount of free water. It should be noted that water intake was affected at the initial phase by minor challenges in optimising the hydraulic control of the model in question.

Figure 6. A foamy emulsion formed when collecting with the brush module. However, 90–95% of the oil was removed. Photos: Manu Kettunen, 2025.

MultiSkimmer with disc modules

The discs used in the tests were not in perfect condition, probably due to storage damage, and were dented and bent. After some minor repairs, however, the device was ready for testing. The test was carried out in a boomed area measuring 20 square metres with 200 litres of oil. In the recovery of marine diesel oil from calm waters, a total of 225 litres of liquid was collected, 190 litres of which was oil. This resulted in an efficiency of recovery of 84%. This process took 22 minutes, making it the fastest in this test series. In waves, only a slight change in the result was observed: the recovery time increased to 35 minutes; 20 litres of oil remained unrecovered; and the total amount of liquid was 220 litres. This resulted in a recovery efficiency of 82%. It was found that the structure of the MultiSkimmer (a curved plate just below the discs) created a counterwave, causing the oil to escape from the discs, particularly with a thin oil film.

Figure 7. The MultiSkimmer with disc modules demonstrated its recovery capabilities with light oil, in a manner similar to that of other disc skimmers. Photo: Manu Kettunen, 2025.

Komara Midi4 Skimmer with disc modules
Vikoma's Komara Midi 4 disc skimmer was tested in a 20-square-metre area surrounded by booms, into which 200 litres of marine diesel oil MDO DMB was poured (Figure 8). The skimmer was positioned in the middle of the test area, and it operated independently during the entire test. In calm waters, the area was successfully cleaned: when checked with an absorbent, virtually no oil was found. The total liquid volume was 230 litres, 200 litres of which was oil. This resulted in an efficiency of recovery of 87% (Figure 2). The average time taken was 37 minutes, with approximately 90% of the oil recovered within the first ten minutes. Recovery of the remaining oil took longer due to the device's tight positioning and lack of assistance.

The results in the waves were pretty much the same. About 10 litres of oil that had been pushed into the corner opposite the wave machine remained uncaptured, but everything that was recovered in 30 minutes was oil, not one drop of water. The recovery efficiency in waves was 95%, the best result in this test series.

Recoverability of ULSFO RMD80

The recovery of ultra-low sulphur fuel oil (ULSFO) was tested using three devices: a disc skimmer, a bow collector, and a brush skimmer. Only the latter two brush-type devices were able to lift the oil under the test conditions. During testing, the state of RMD80 varied greatly due to the effects of temperature and solar radiation, ranging from a flowing liquid to a pulp-like mass and solid lumps. This production batch was found to become fluid at around 25°C, with a pour point of 30°C, as specified in the safety data sheet. RMD80 fuel recovery tests were conducted under both sunny and cloudy weather conditions. It was observed that the floating oil became more fluid as the dark surface of the oil absorbed the sun's heat radiation, but even slight movement in the water column caused the oil to solidify again. Therefore, when reviewing the results, special attention must be paid to the ambient conditions.

Figure 8. Komara Midi 4 disc skimmer in calm waters at the beginning and end of a skimming operation. The skimmer removed virtually all of the diesel oil without having to change position or assist with the oil supply. Photos: Justiina Halonen, 2025.

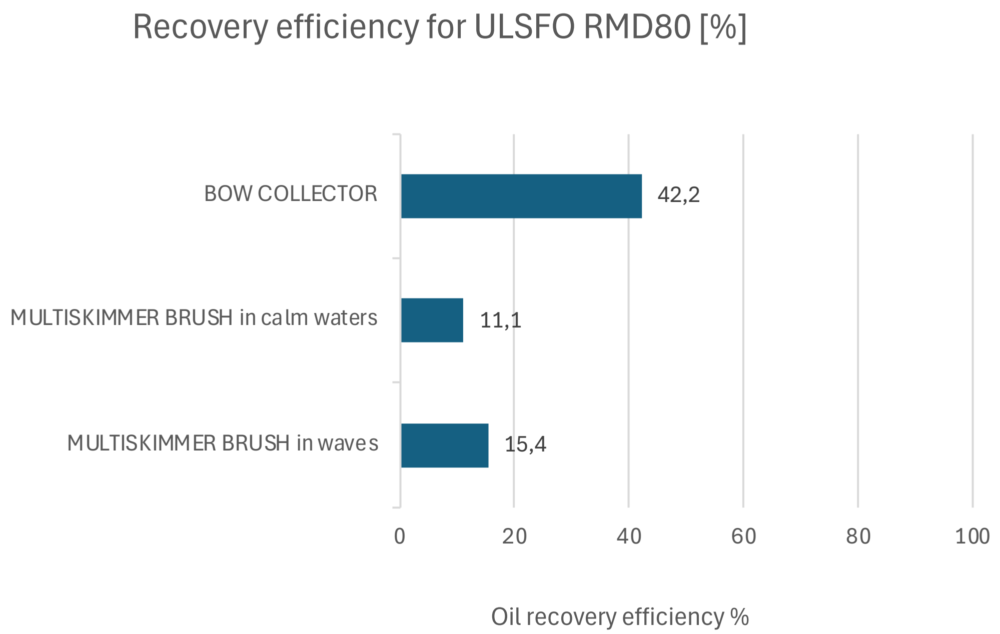

Figure 9. Recovery efficiencies of two different devices used to recover RMD80 marine fuel. The initial oil layer thickness was 10 millimetres. The water temperature was 16°C. The results are the average values of three test runs. Under these test conditions, the bow collector achieved the highest recovery efficiency when rotated downwards.

Figure 9 shows the recovery efficiency of two devices capable of collecting RMD80, calculated as the average value of three tests. The test protocol was similar to that used for diesel oil: an initial 10-millimetre layer of oil was applied, and the device was allowed to operate independently for as long as possible or until the area was clean. Assistance was provided only if necessary. As the figure depicts, the bow collector achieved the highest recovery efficiency of the two devices. The effect of waves on recovery efficiency could only be tested with one of the skimmers; however, no significant effect was observed. Moreover, it was found that waves slightly sped up the recovery process, possibly making otherwise very viscous oil more accessible to the skimmer.

Photo: Justiina Halonen.

Bow Collector

The RMD80 recovery tests for the bow collector were conducted at a water temperature of 16°C, which kept the oil in a grape-like state in the shade, but in the sun, the oil became more fluid (Figure 10). RMD80 formed an uneven, pulp or porridge-like raft and had to be assisted onto the conveyor from the start of the tests.

The average result of the recovery tests was 230 litres collected in 36 minutes, of which 95 litres was oil, yielding a recovery efficiency of 42% (Figure 9). This result is better than that previously achieved with light MDO, since the brush technique is generally more suitable for high-viscosity substances. Even variations in cloud cover highlighted the effect of oil viscosity on the brushes' recovery efficiency with this substance: in cloudy weather, the recovery efficiency was more than 40% higher than with oil that had been warmed by the sun, as the oil remained more viscous.

Figure 10. In the shaded area, the ultra-low-sulphur fuel oil (RMD80) remained fairly thick. The part of the oil slick exposed to sunlight warmed up and thinned out. This difference is visible in the portion of the oil slick partially shaded by the boom. Water temperature: 16°C. Photos: Justiina Halonen, 2025.

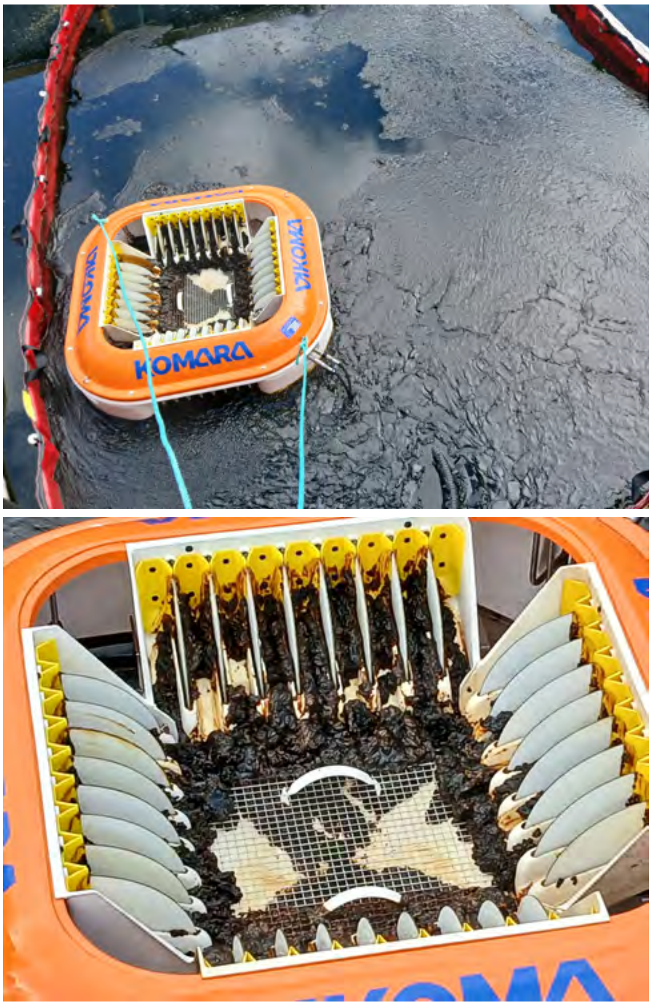

Figure 11. The Komara Midi 4 disc skimmer recovered only the amount of heavy RMD80 oil shown in the photo. Water temperature was 12°C. Photos: Manu Kettunen and Justiina Halonen, 2025.

Komara Midi4 Skimmer with disc modules
With the Vikoma's Komara Midi4 disc skimmer, the recovery of RMD80 fuel remained just an attempt. After ten minutes, only a few oil clumps had risen to the rim of the sump (see Figure 11), and therefore, the test was terminated. In practice, only the oil that was in direct contact with the skimmer was actually removed. The surrounding oil did not flow towards the skimmer, but appeared as a non-uniform, loose, porridge-like mass lacking the viscoelasticity characteristic for oils. The water temperature was 12°C. The composition of the collected oil was so viscous that it would not have moved forward without the help of water – and the discs do not pick up water. The same applied to the Lamor's MultiSkimmer with disc recovery modules (Figure 7).

Figure 12. The RMD80 was in a fairly viscous state and adhered well to the brushes once drawn to the device. The oil was recovered, but it was accompanied by a large amount of water. The water temperature was 16°C. Photo: Manu Kettunen, 2025.

MultiSkimmer with brush modules
Equipped with brush modules, the MultiSkimmer worked for 50 minutes in calm, 16°C water to recover 200 litres of RMD80 oil. The total amount of liquid collected was 1,800 litres on average, of which 200 litres was oil, resulting in a recovery efficiency of 11%. In small waves, the corresponding figures were an average of 1,300 litres with a recovery time of 38 minutes, leading to a recovery efficiency of 15% (Figure 9). Once the oil had reached the recovery device, it was recovered, albeit accompanied by a large amount of water: the skimmer's suction captured the oil bit by bit. This clearly demonstrated how the operator's technique can impact the recovery result. The hydraulics of this skimmer are designed so that adjusting one component affects the other, making it difficult to find the optimal rotation speeds and necessitating practice.

Summary of the usability of the current equipment

Based on the tests described above, Marine Diesel Oil (DMB grade) can be removed effectively using the disc skimmers currently in use, regardless of the manufacturer. Disc skimmers achieved three to seven times higher recovery efficiency compared to brush skimmers (Figure 2). Furthermore, previous tests evaluating the recovery efficiency of lightweight skimmers have yielded similar results [see, e.g., 2; 3]. However, rescue services do not currently utilise disc skimmers as higher-capacity skimmers or as collection systems installed on response vessels. The disc skimmers did not remove any ultra-low-sulphur fuel oil under the test conditions, unlike the brush skimmers. Of the brush skimmers, the brush belt conveyor type achieved better efficiency than the brush wheel type (MultiSkimmer) (Figure 9). However, the bow collector's recovery results contained a significant proportion of water (almost 60%), which could present challenges in terms of intermediate storage capacity during a response operation. In addition, the formation of emulsion was identified as a potential issue. For this reason, it was deemed necessary to survey other devices on the market and invite manufacturers to demonstrate their products at the test facility. The following chapter describes the results of demonstrations involving suitable devices.

Surveying alternative recovery techniques

When searching for solutions for the large-scale recovery of marine diesel oil (MDO DMB), the ELASTEC X30 Grooved Disc (Figure 13), developed as an alternative to brush recovery systems on response vessels, came to the fore. The X30 could recover marine diesel oil from water at a temperature of 8°C with the same efficiency as other disc skimmers. The skimmer differs from other disc skimmers not only by its structure but also in the design of the disc: the discs are grooved, which increases the adhesion area, thus increasing the recovery capacity. The skimmer is available as bow collectors, side recovery systems, and inbuilt systems.

Figure 13. In the ELASTEC X30 Grooved Disc skimmer, the discs are grooved to improve collection capacity by increasing the adhesion area for oil. Photo: Manu Kettunen, 2025.

Similar recovery efficiencies were also achieved in the recovery of marine diesel oil using Lamor's MiniMax25 disc and drum skimmers and New Naval's ScorSkim 30 equipped with a disc module (Figure 14).

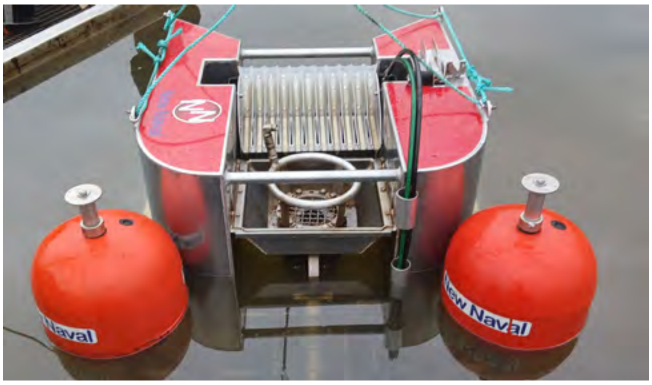

Figure 14. ScorSkim 30 equipped with a disc module. Photo: Justiina Halonen, 2025.

Furthermore, the large volume of water produced when collecting ultra-low-sulphur fuel (RMD80) prompted a search for new solutions. As low-sulphur heavy fuels have only been on the market for a few years, the number of established recovery methods is still very limited. The Norwegian Coastal Administration (Kystverket), for example, provided support in identifying new technologies through tests carried out in its IMAROS projects.

The DESMI Octopus LSFO Skimmer (Figure 15) was demonstrated as one of the devices that proved to be usable in Norway. When recovering ultra-low-sulphur fuel, the Octopus achieved an average recovery efficiency three times higher than other brush skimmers. The water was eight degrees cooler than in the previous in tests. The skimmer's manoeuvrability, thanks to its own thrusters, also contributed to its higher recovery rate.

Figure 15. Octopus proved to be an efficient recovery device thanks to its thrusters. The photo clearly illustrates the porridge-like consistency of RMD80 fuel in water at a temperature of 8°C. Photo: Manu Kettunen, 2025.

Discussion

The results from marine diesel oil confirmed the findings of previous tests. However, the generalisability of the test results for low-sulphur fuels is affected by the fact that the tests were conducted on only one LSFO grade, while the range of product properties in this category is very extensive. According to the MAROS project, low-sulphur fuels are, to an extent, manufacturer-specific products: their composition, including additives, paraffin content, viscosity, and pour point, varies even between production batches. This, in turn, affects differences in their spill behaviour and has led to significant and even unexpected differences in their recoverability. [4; 5; 6.] Due to the properties of LSFOs, and thus their spill behaviour and recoverability, depend heavily on temperature, low-sulphur fuel recovery tests should be conducted on several fuel types and grades under varying conditions to gain a more comprehensive understanding.

On the other hand, the interpretability of the results obtained with low-viscosity oil is enhanced by their consistency with the findings of the IMAROS2 project on oil behaviour and recoverability. Despite technical differences between the IMAROS and MARISEC tests8, observations on the effectiveness of mechanical recovery correspond with those recorded by the Norwegian Coastal Administration. As observed in the aforementioned tests, low-sulphur heavy fuel oil presented as an uneven, loose mass that did not move independently towards the recovery device. Instead, a water barrier formed between the oil and the recovery surface, interrupting the flow. Moreover, similar properties were observed in the oil grades used in Norwegian tests [7]. Since low-sulphur heavy oils do not flow to the recovery device, the device must be moved to the oil. In both test series, a manoeuvrable recovery device, such as one equipped with thrusters, proved to be effective. In addition, recovery can be improved through tactical measures, such as towing or directing the oil with water hoses. Water hoses were used successfully in the MARISEC tests. However, in tests conducted in Norway, feeding some of the oil towards the recovery device did not help, but instead caused the oil to accumulate in front of the device. In Norway, there were also challenges with pumping the collected oil: some of the oil stuck to the sides of the collection sump and did not flow to the pump without heating or mechanical energy. [7.] This was also apparent in MARISEC tests with a disc skimmer, and, furthermore, challenges with oil solidification were observed during the washing phase: after the tests, the equipment was successfully cleaned with 50°C water, but once the water cooled down, the oil solidified. Therefore, the pump and hoses must be rinsed thoroughly with warm water. It is likely to be difficult to remove these types of oils from the intermediate storage tanks without heating.

As low-sulphur heavy oils do not flow to the recovery unit, either the unit must be brought to the oil or the flow of oil must be accelerated.

The observations described above concerning the pumpability of solidifying low-sulphur oils can be compared to the management of heavy oils under cold conditions. Thus, solutions developed for responding to low-sulphur oil spills may also support response efforts under winter conditions, but this requires practical tests to confirm. It would be useful to test the recover-

8 In the IMAROS tests, the main objective was to evaluate the recovery rate; the oil was already formed into an oil/water emulsion, and the oil was not recovered until it formed a thin film [7], so the recovery efficiency of different skimmers cannot be directly compared with each other.

ability of viscous oils, for example, to determine heating requirements and energy consumption. The importance of increasing the collection capacity of solidifying substances is emphasised not only by the need for oil spill response capabilities under winter conditions, but also, more generally, by the average annual surface water temperature in our sea area, which even at its highest remains below the average pour point[9] of low-sulphur fuels: less than 13°C [4; 8].

The low-sulphur fuel category includes products with a variety of different properties. Their behaviour is also highly dependent on temperature. To obtain a more comprehensive picture of their recoverability, tests should be conducted with several fuel grades and under different conditions.

In addition to further research into cold conditions, the test environment should replicate elements that affect real-life recovery operations, such as the presence of debris. Furthermore, a more powerful wave generator is required for future tests. In the conducted test series, the differences between the results achieved under calm and wave conditions were unclear and ambiguous. The waves generated were very mild and dampened further by the boom. In addition, more realistic flow conditions are required. Furthermore, it would be beneficial to allow the oil to weather for a longer time before removing it.

Further research will also be necessary, as new equipment with technological advances becomes available. Development work has only just begun: in the first tests conducted in Norway in 2022, none of the tested oil skimmers performed well in recovering low-viscosity oils [5], and it was decided to support the companies' equipment development with project funding [7]. Since companies in the oil spill response sector have recognised the need for a fuel transition, it is clear that the equipment demonstrated during this project represents only a small proportion of what will be available in the near future. In addition to diversifying the equipment, testing must continue to ensure the recovery capacity of new types of fuels and liquid cargoes entering the market, as the range of substances is expected to expand further [4; 9]. Testing products before they are launched on the market or introduced on a wider scale would also enable rescue authorities to engage in safety dialogue and take proactive rather than reactive measures.

Conclusions and recommendations

Regardless of the manufacturer, disc skimmers proved effective for lighter DMB-grade marine diesel oil. However, disc skimmers are not suitable for solidifying and high-viscosity oils. Brush skimmers are ineffective for light distillate fuels, such as marine distillates, but can handle low-sulphur fuel oils. However, when using traditional brush skimmers to remove RMD80 oil, a large amount of water was produced compared to the result of a skimmer developed specifically for low-sulphur substances.

In addition to the skimmer's structure, manoeuvrability and mobility, the operator's skills significantly impact the amount of water collected. This is further emphasised when dealing with a thinning oil film. In order to improve current spill response capability to meet the risk of pollution from new types of fuels, the recovery capacity for light oil should be increased and, in the case of low-sulphur oils, either technical and skill-based methods for managing large amounts of water should be developed or investments should be made in state-of-the-art skimmers.

Particular attention should be paid to vessel-mounted recovery systems, as their current effective range is too narrow – especially in view of the ever-increasing variety of fuels and liquid cargoes. The challenge in diversifying recovery equipment is the lack of vessel-based or otherwise higher-capacity multi-purpose recovery systems, which seems to necessitate an increased range of equipment. However, from the perspective of multifunctionality, technology designed for low-sulphur fuels also has potential for addressing other types of solidifying and solidified oils, for example under cold conditions.

9 Most VLSFO products have a pour point of around 20–25°C. ULSFO products have a wider pour point variation, ranging from -5°C to over 30°C, but most fall between 25–30°C. [4.]

The risk-performance trade-off could be improved by increasing the total recovery capacity for light oil; developing methods for managing large volumes of excess water for low-sulphur heavy oils; or investing in in state-of-the-art recovery systems.

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BEST PRACTICES IN OIL SPILL RESPONSE AND TRAINING

Lauri Hanski

One of the objectives of the MARISEC project was to compile best practices related to oil and chemical spill response in the Baltic Sea region. The compilation drew on national and international networks, depot visits, workshops, surveys, and study visits. The identified key themes were related to preparedness and the organisation of exercises, competence objectives, and the broader potential use of new technologies and various shoreline response methods.

The Role of Training in Maintaining Operational Capability

Oil spill response capability is based not only on equipment, but also on personnel competence and regular training. In connection with the project, a need to define a minimum level for training activities to harmonise training across different rescue service regions was identified. The Regional State Administrative Agency has also highlighted deficiencies related to training when assessing the response preparedness of the rescue services [1].

According to a Webropol survey conducted within the project (2025), the number of exercises carried out by coastal rescue services has decreased in recent years, by up to 75%, as a result of funding and resource pressures. This has weakened the ability to maintain basic training and response preparedness, even though changing chemical and fuel profiles in maritime traffic would necessitate broader competence. The changing operating environment places new requirements on rescue service equipment and operational models.

A reduced number of exercises leads to lower preparedness – maintaining operational readiness requires harmonized competence requirements for oil spill response personnel.

International recommendations, such as the HELCOM Response Manual [2], emphasise the importance of systematic training and versatile methodological competence in shoreline response. The HELCOM Manual recommends regular exercises that combine different response methods, cooperation between personnel groups, and inter-authority coordination [2]. These principles can be applied in Finland to support the definition of a minimum training level and cost-effective training activities. Norway can also be used as a point of reference, with the Norwegian Coastal Administration shoreline response units conduct oil spill response exercises approximately 5–10 times per year. Regular training maintains personnel competence and enables mastery of different response methods. Furthermore, public actors have portrayed a broader commitment to the task: approximately 185 individuals, including teachers and police officers, have received training to support authorities in the use of oil spill response depots. In addition to these basic depots, so-called ‘rapid response stations’ managed by pilots and maritime rescue authorities are utilised in Norway; however, an Oil Spill Response Certificate is required for actual response operations on oil spill response vessels [3]. A similar corresponding certificate demonstrating the fulfilment of minimum competence requirements could be a practice worth considering also in Finland as well.

During the project, a workshop aimed at developing training activities for rescue services in the Gulf of Finland region (November 2025) highlighted the need to define a common minimum level of competence for personnel involved in oil spill response. The minimum level of annual exercises could include equipment operation and maintenance training, role-specific training for different operational levels, as well as regular joint exercises with different authorities and stakeholders. Regular exercises ensure that the level of competence remains consistent across all rescue service regions.

Task-specific competence profiles are in use at the Helsinki Rescue Department. In the workshop, the competence profiles were considered as great models for maintaining

Annual Cycle of Joint Training Activities 2026–2023	2026	2027	2028	2029	2030
Eastern Uusimaa Rescue Department	Lead responsibility	Participant	Participant	Support	Support
Helsinki City Rescue Department	Participant	Lead responsibility	Support	Participant	Support
Kymenlaakso Rescue Department	Participant	Support	Lead responsibility	Support	Support
Western Uusimaa Rescue Department	Support	Participant	Support	Lead responsibility	Participant
Southwest Finland Rescue Department	Support	Support	Support	Participant	Lead responsibility

Figure 1. Proposal for an annual training schedule from the MARISEC project workshop.

oil spill response capability, as they clarify the responsibilities and competence requirements associated with different roles. Basic training and induction provide the foundation for oil spill response competence, while the seamanship skills training logbook used by the Eastern Uusimaa Rescue Department ensures that essential seamanship skills are practised annually. Competence is maintained and developed further through mandatory annual oil spill response exercises.

As an outcome of the workshop, joint training activities are planned to be developed in a systematic and long-term manner. The annual schedule for joint exercises for the years 2026–2030 (Figure 1) illustrates how lead responsibility, participation, and support roles would be distributed among the different rescue services. The aim of the model is to ensure that joint exercises are conducted regularly, responsibilities are rotated fairly, and training activities are predictable.

A shared annual training schedule facilitates the planning and scheduling of exercises and allows for annually changing exercise topics and themes based on regional risks. Simple, **regular** joint exercises form the foundation, which can be complemented in cooperation with the Border Guard and other partners.

Strengthening Cooperation

Several discussions voiced support for the project's objective to strengthen international cooperation. The need for cooperation is particularly evident in training activities and shoreline response of coastal authorities. In discussions with the Norwegian Coastal Administration, the possibility of establishing a cross-border cooperation group under the Copenhagen Agreement was raised, with a focus on shoreline response. The aim of the cooperation group would be to share experiences and best practices regarding, among others, equipment, cleanup methods, cleanliness criteria, organisation, GIS-based situational awareness, SCAT methods (shoreline cleanup assessment technique), as well as the utilisation of new technologies, such as unmanned aerial vehicles and artificial intelligence. The cooperation would also support the cost-effective development of training and exercises. In addition, members of the CTIF Dangerous Goods Commission, who visited the oil spill response basin, expressed interest in joint exercises and testing, for example, to address risks related to static electricity in maritime recovery operations.

Figure 2. Shoreline cleanup training environment of the Norwegian Coastal Administration. Photos: Kystverket, s.a.

The Importance of Method Selection in Shoreline Response

Effective oil spill response requires the planning of shoreline response as systematically as offshore response. Statistics from the International Tanker Owners Pollution Federation (ITOPF) indicate that oil spills from ships often occur close to the coast. When oil reaches the shore, recovery operations frequently require significant resources and effort. Shoreline recovery methods, equipment, and training form a comprehensive system in which the choice of recovery technique is based on coastal characteristics, oil type, and the accessibility of the area. Furthermore, response effectiveness decreases if the range of methods is limited or if personnel has not received sufficient training for the task [4].

During a visit to the Norwegian Coastal Administration in Horten, a container-based training environment (Figure 2) was observed. In this environment, shoreline cleanup can be practised using different methods, including high-pressure water washing. The shoreline training environment supports systematic competence development and allows for the acquisition of operational experience under realistic conditions across different types of shorelines. Similar training can be carried out at the Xamk oil spill response basin.

In addition to the training environment, a soil protection and oil absorption method used in shoreline response was demonstrated, in which a bark-based absorbent was applied to the shore using a dedicated blower. The bark is used to protect the worksite itself, or to shield the shoreline against the arrival of an oil slick. The Norwegian Coastal Administration has several blower units for applying absorbent material (Foxblower), as well as devices that mechanically mix and work the absorbent into the oil to ensure adhesion (Foxmix) [5].

The Foxblower unit uses pine bark granules as the absorbent material, marketed under the brand name Zugol. Zugol is suitable for shoreline oil response due to its hydrophobic properties. The material repels water while effectively binding oil and other non-polar liquids. For this reason, Zugol remains buoyant even at the waterline and functions as an oil absorbent without significant water uptake. The Foxblower allows rapid application of the absorbent material. However, the use of absorbent material should be considered on a case-by-case basis, as it significantly increases the amount of waste generated [4]. When used correctly, the application of absorbent material facilitates oil recovery, especially in locations where oil removal would otherwise be challenging [6], such as areas difficult to access on foot, but reachable by boat.

Figure 3. Application of absorbent material as a part of shoreline response. The material is applied to rocky areas before the arrival of oil or as a protective mat in case of spills during operations. Photos: Henriksen, s.a.

The use of natural materials in shoreline response requires a more extensive exploration. Both synthetic and natural absorbent materials, or sorbents, are used in shoreline response; however, locally available natural materials are often more cost-effective than synthetic alternatives [4]. Utilising local and natural materials in shoreline response could offer significant development opportunities in Finland as well as in other eutrophicated areas of the Baltic Sea. For example, common reed (*Phragmites australis*), which is widespread in Finland, is in many places associated with eutrophication problems, but its use as an absorbent material could provide benefits for both oil spill response and the environment. Cutting the reed should take place during winter, when it is naturally dry and easy to handle. While the reed could be suitable as a sorbent material for oil spill response, harvesting it would also remove harmful nutrients from the water. However, further investigations are needed regarding its suitability, particularly in terms of absorbency and practical handling.

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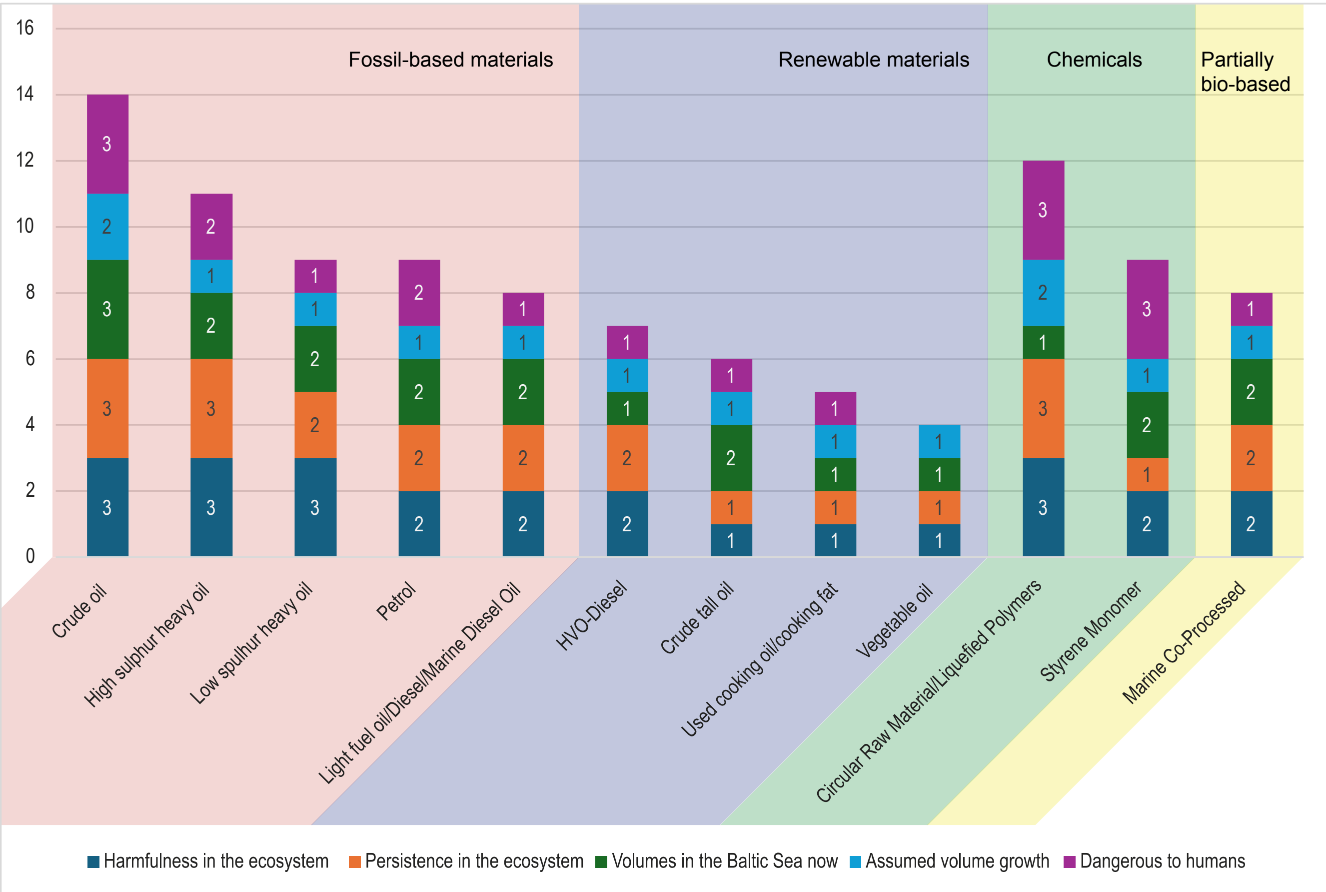

Figure 4. Expert assessment of the environmental hazard and volume trends of different substances. New types of liquefied polymers raise concern, while traditional fossil products continue to pose a significant risk. Chart compiled from workshop results by P. Kauppi.

Shared Future Challenges and Development Needs

Based on the results of the survey conducted within the project, authorities appear to believe traditional oil spill response methods and equipment may not necessarily cover all future needs. Responses to the Webropol survey were received from rescue services along the coast of the Gulf of Finland, the Finnish Border Guard, the Swedish Coast Guard, the Norwegian Coastal Administration, and an expert from Oil Spill Response Limited (n=8). However, systematic monitoring of the development of hazardous substances is not yet in place. There is a strong need for such monitoring, as the changing maritime operating environment creates challenges for authorities by complicating response operations and imposing new requirements on response equipment, methods, and surveillance.

Changes in maritime traffic patterns and a growing diversity of hazardous substances challenge preparedness – highlighting the need for proactive monitoring and versatile response capability.

The project organised an expert workshop on Recovery Equipment Technology and Hazardous Substances in February 2025. At the workshop, the overall risk of substances transported in the Gulf of Finland was assessed based on five criteria: 1) environmental hazard, 2) persistence in the environment, 3) current volume in the Baltic Sea, 4) estimated volume growth, and 5) human hazard. Each criterion was scored from 0 to 3, and based on the total scores, the substances were ranked according to overall risk (Figure 4). According to the scoring, the most concerning substances were crude oil and liquefied polymers. The hazard properties of the substances with the highest scores, combined with the quantity required for the selected equipment size in testing, led to the choice of low-sulphur fuels for the recovery tests. The results, however, confirm that we should be prepared for multiple types of hazardous substances.

The workshop revealed that comprehensive statistics on fuels used by ships are not available, and as a result, uncertainty in volume data complicated the risk assessment. More resources for monitoring and risk analysis practices at both national and international levels should, therefore, be allocated to ensure preparedness for emerging risks in a changing operational environment. Furthermore, the workshop results highlight the need to develop response equipment and methods to address the evolving range of hazardous substances. In addition, the safety of the testing environment should be improved for substances with more challenging hazardous properties. Alongside representatives from the MARISEC consortium, experts from the Finnish Transport and Communications Agency Traficom, the rescue services of Southwest Finland, Helsinki, Western Uusimaa, and Eastern Uusimaa, the Border Guard, Neste Oyj, the University of Helsinki, the Finnish Environment Institute, and the Southeast Finland ELY Centre participated in the workshop.

Conclusions

Oil spill response capability in Finland is primarily limited by the lack of training and the constraints of available resources. Insufficient training reduces the range of applicable methods and weakens personnel readiness to apply alternative response techniques. Training activities are currently constrained both by financial factors and by challenges related to relieving rescue personnel from their daily duties. This underscores the need to develop cost-effective and repeatable training models, as well as to utilise regional and international cooperation in the planning of training activities.

A clear development need identified in Finland is to define a minimum level of annual exercises. Defining a minimum training level supports the maintenance of competence, promotes regional equality, and creates the conditions for cost-effective training activities with limited resources.

As the range of potential hazardous substances in maritime traffic increases, systematic and up-to-date monitoring and risk assessment are required. These factors enable proactive preparedness, sufficient readiness, and the correct targeting of response operations. Testing activities that support preparedness, and the testing environments that make them possible, should be developed accordingly.

Methods used in shoreline recovery should be practised more extensively. In Finland, recovery methods are described in considerable detail in the SÖKÖ-Suomenlahti manual [7]. Shoreline recovery operations and cleanup techniques have also been covered extensively in the ITOPF Technical Information Paper series (TIP 7 & 8). Despite these sources, methods used in shoreline cleanup in Finland—such as washing techniques and the appropriate use of absorbent materials—have only been practised to a small extent, which may result in some response practices being unfamiliar to operational personnel. Systematic mapping and training of different methods and procedures is indisputably justified, as shoreline response is a central component of overall oil spill preparedness and readiness.

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DEVELOPMENT NEEDS AND RECOMMENDATIONS FOR PREPAREDNESS FOR OIL AND CHEMICAL SPILLS IN THE BALTIC SEA

Annukka Lehikoinen, Justiina Halonen, Lauri Hanski, Patrik Kauppi & José E. Cano Bernal

Almost all change drivers in the Baltic Sea operating environment that were identified and analysed in the MARISEC project affect preparedness and response readiness for oil and chemical spills in some way, as Lehikoinen et al. (2026) summarise earlier in this volume. Maintaining an adequate level of preparedness requires addressing most of these development paths. [1.] The benefits that digitalisation and modern technological development can offer for building situational awareness and for other operations will only be realised if there is willingness to invest in their use. For this reason, it is important to increase funding for preparedness in terms of RDI activities, equipment purchases, stakeholder networks, and the development and expansion of training and exercise activities. Otherwise, it is clear that, in the midst of ongoing change, the level of preparedness is nowhere near what was previously considered sufficient, i.e., the level of risk exceeds what is considered acceptable.

This article summarises and compiles the key recommendations derived from the MARISEC project's results for updating preparedness levels in a changing risk landscape. These recommendations are intended for political decision-makers and strategic-level authorities, as well as for those responsible for responding to marine oil and chemical spills.

Needs for rapidly updated situational picture and improvisational skills are driven by the evolving risk landscape

The Baltic Sea operating environment is changing quickly and becoming more complex. This challenges traditional risk models and preparedness exercises. As Lehikoinen et al. (2026) state earlier in this volume, risk assessment must be updated to respond to new threats and to ongoing, dynamic change [1]. Traditional analyses based mainly on past statistics are not enough when the future risk landscape differs clearly from the past, risks are more complex, and some risks are completely new and/or hard to predict, such as threats based on intentional harm. Identifying new threat scenarios and imagining situations that have not been experienced before is becoming a more important element of risk-based preparedness. For analyses to support practical preparedness work, they must be designed to produce information that can be used directly in decision-making processes. This requires continuous, smooth dialogue between analysts and authorities [1].

> ***Identifying new threats and imagining previously unseen scenarios is an increasingly important part of risk-based preparedness.***

In a strongly changing and unstable risk landscape, analysis tools that can be updated dynamically would help to maintain an up-to-date strategic, and also operational, situational picture. To make this possible, data sources that are updated frequently, even in real time, should be linked to risk models. This would require an open and accessible data policy in the Baltic Sea region. To develop tools that cover the entire region and allow regional comparison and international planning cooperation, close cross-border cooperation is necessary, not only for sharing data but also for developing joint monitoring programmes and common standards for risk calculations. In the current geopolitical situation, data exchange between Russia and other Baltic Sea coastal states has largely stopped, which creates gaps in the situational picture used for preparedness. Other Baltic Sea countries could invest in shared data collection that does not depend on Russia, using the latest remote sensing and monitoring technology and AI-based solutions [1].

Alongside traditional scenario-based exercises, it could also be worthwhile to emphasise training that strengthens operational capabilities specifically in new and unexpected situations. In a changing and more complex risk landscape, it is impossible to prepare in advance for everything. This makes the ability of operational actors to improvise, and to act in a rational and effective way in unexpected, previously unseen situations, even more important. Preparedness training could, therefore, be expanded with training in 'reactive skills', which would improve how organisations and individuals perform in situations that have not been planned in advance [1].

In an ever-changing and increasingly complex risk landscape, it is impossible to prepare for everything in advance. This highlights the importance of operational actors being able to act rationally and effectively, even in unpredictable and unprecedented situations.

Response capability would benefit from complementary recovery technology

Field testing showed that oil skimmers based on disc technology are effective at removing marine distillates, the fuels typically used by merchant ships in the Baltic Sea [2; 3]. However, of the total recovery equipment, only around 35% is dedicated to light fuels, primarily in the form of small, portable skimmers[10]. High-capacity skimmers suitable for light fuels are practically non-existent. Therefore, performance should be improved by increasing the recovery capacity for light oil to match the current risk. This could be achieved by purchasing skimmers with greater capacity, known as offshore skimmers, or by diversifying the technology of integrated recovery systems on response vessels. [4 Halonen et al., 2026, earlier in this volume.]

In Finland, there are hardly any high-capacity skimmers or vessel-mounted recovery systems that are suitable for light fuel oils. All of the recovery systems currently integrated into response vessels are based on brush recovery technology designed for heavy fuels.

To assess the feasibility of retrofitting, the Kymenlaakso Rescue Services investigated the possibility of installing a disc-based recovery system alongside their in-built brush belt skimmers without having to completely replace the existing system. The review focused on the X45 Disc Cassettes, which are similar to the

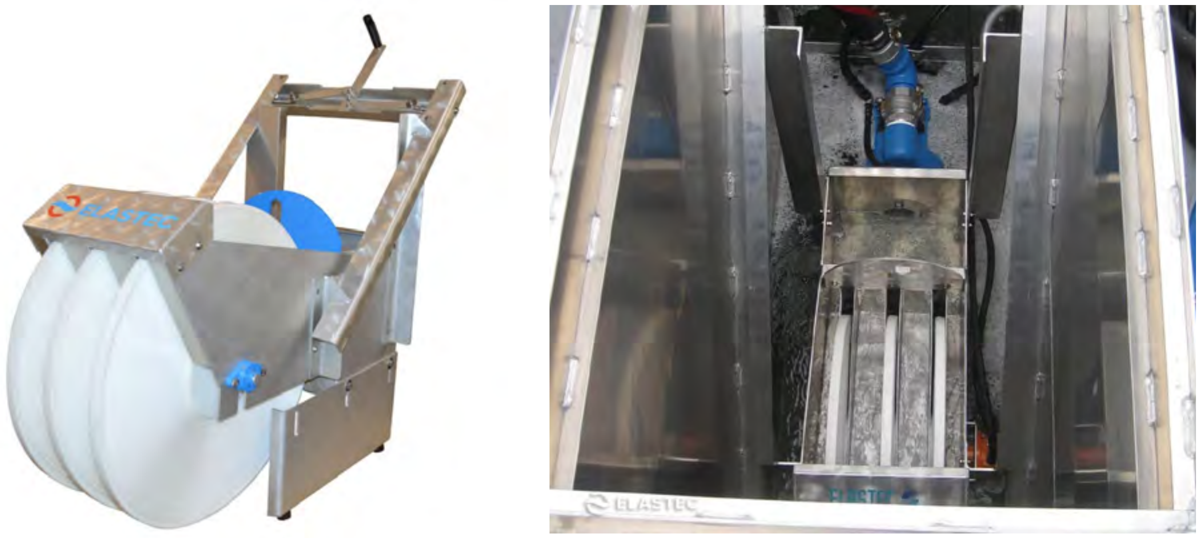

Figure 1. ELASTEC X45 grooved disc type recovery system installed in the vessel's recovery compartment. Photos: Elastec, s.a.

10 Based on the MARISEC project's Webropol survey, 2025. There have been no changes in the situation since the previous survey in March 2023 [3].

X30 system showcased in the recovery demonstration, but equipped with three grooved discs instead of two (Figure 1). Based on the review, the disc type system is suitable in terms of size and shape for replacing or supplementing existing fixed brush systems with relatively minor modifications to the vessel's structure. As rescue services in Finland operate a significant number of F-class oil spill response vessels with integrated brush systems, this type of alternative would offer a concrete solution for improving performance. Therefore, similar systems should be investigated further.

The brush technology-based recovery devices, which currently account for 100% of the systems on response vessels, are not suitable for marine distillate fuels. However, brush skimmers were able to recover ultra-low-sulphur heavy fuel oil, albeit with a large amount of water. [4.] Low-sulphur marine fuels (VLSFO and ULSFO) accounted for just under half (48.8%) of marine bunker fuel deliveries in Europe at the end of 2024. This figure has fallen from its highest level (68% at the beginning of 2020), as the use of traditional high-sulphur heavy fuel oil has started to rise again. [5.]

However, according to expert estimates, low-sulphur products are not just an intermediate stage in the transition to new marine transport fuels; they are here to stay [6]. Therefore, it is essential to develop response and recovery capabilities to deal with the consequences of spills involving these fuels. During the warmer seasons, the solution may be to use existing equipment with improved water management capabilities alongside tactics to improve oil encounter rate. In cooler conditions, however, new technology is required to recover solidifying oils. Improving the performance of equipment in this respect would also support the development of overall response capabilities in cold conditions. [4.] It is proposed that high-capacity skimmers, or devices designed for specific groups of substances, be included in the equipment selection at the European Maritime Safety Agency's (EMSA) Northern Baltic Sea warehouse, or that they be invested in as national capacity. If the combination of Arctic and low-sulphur oil response capabilities is realised, this capacity could have potential as a formation to be included in the European Civil Protection Pool (ECPP).

Developing the capacity to respond to and recover new types of substances is essential. This requires more detailed information on the evolution of substance quantities, spill behaviour, and the suitability of different types of equipment.

Preparing for new types of incidents and the long-term development of recovery technologies has been hindered by uncertainty regarding which low-emission marine fuels will ultimately become the most common [7]. It is still expected that fuels and their properties will change, so diversity will likely have to be tolerated for a long time to come [6]. In order to direct the development of recovery capacity, regularly updated statistical data should be obtained on the fuels used by ships and on the development process of the quantities of various fuels. This would be supported by amending the Vessel Monitoring Directive to require ships entering reporting zones to report not only dangerous and environmentally harmful cargoes, but also their onboard fuel. Similarly, spill response testing and training activities must keep pace with developments in fuel and recovery technology. New products must undergo testing to determine their spill behaviour and establish safe operating models, in order to develop response and recovery techniques in advance.

Towards more comprehensive preparedness

In Finland, oil spill response and chemical spill response have previously been treated as conceptually and operationally separate entities. However, substances currently classified as oil may have hazardous properties typically associated with chemicals, and they may not behave in the same way as traditional oils when spilled into water. At the same time, the use of chemicals as marine fuels is increasing. The reasons for maintaining separate approaches to these two areas have also weakened, as earlier differences relating to funding and compensation processes have been erased.

Integrating response systems into a comprehensive response and preparedness framework would strengthen the ability to deal with a changing operating environment. In practical terms, this would mean combining oil spill response (OSR) contingency plans with operational guidelines for hazardous and noxious substances (HNS, CBRNE). [8.] Integration would bring immediate synergy benefits, for example, for protection against health and safety hazards. However, it alone would not solve the development needs related to expertise or the lack of knowledge about the features of new products – not to mention the shortage of proven response techniques and tactics. This highlights the importance of research and experimental testing.

The traditional division of response systems into oil and chemicals may no longer be appropriate, as the distinction between the controllability of different substance groups will become less clear in future. A more comprehensive approach involving more frequent updates to the knowledge base may be the solution.

Unutilised potential for cross-organisational and cross-regional cooperation

The project's findings show a clear need, as well as genuine willingness, to improve international cooperation in information exchange, training, and exercising. A need for cross-border cooperation was identified especially in shoreline response, for example within the framework of the Copenhagen Agreement. Oil and chemical spill incidents are rare, and therefore, it takes a long time for up-to-date practical experience to build up within a single country. This makes it even more important to draw more widely on international experience and expertise, especially from real response operations and the lessons learned from them.

Since oil and chemical spills are rare, collaboration with authorities and international experts is essential for building practical experience.

During the project, it also became clear that in Finland, the expertise of international specialist organisations, such as ITOPF, is still applied only in limited sense, even though they take an active role in response work and preparedness planning around the world. The knowledge available from these actors could provide strong support for developing national response capacity. Information exchange should not depend solely on the occasional seminar; instead, cooperation should be regular. This view was supported by feedback from the international seminar organised during the project. Participants expressed interest in holding a similar event every year to facilitate the direct sharing of current knowledge and experience among operational actors. Concurrently, seminars provide an important forum for strengthening stakeholder contacts. Regular dialogue

Figure 2. The study trip to the Norwegian Coastal Administration's premises and familiarization with its operating methods provided much food for thought. Photos: Justiina Halonen, 2025.

would foster deeper cooperation through activities, such as joint planning and exercises, and would also facilitate the practical adoption of knowledge within organisations involved in oil spill response.

Every country has valuable practices and solutions that can be learnt from. For instance, Norway's long-term research and development work in oil spill response has built up expertise which was openly shared in connection with the project. The idea that environmental protection is a shared responsibility and that good practices should be shared for the benefit of the whole region emerged as a key principle for supporting cooperation.

While international dialogue and cooperation between research organisations seems fairly close based on the project, international cooperation between practical authority actors appears more fragmented and less systematic.

In order to make informed decisions about investments, it is crucial for authorities to have a thorough understanding of how the equipment performs in real response situations and the types of incidents for which it is suitable. This requires close cooperation between research institutes and the authorities, systematic testing of recovery equipment, and an active exchange of practical lessons learned from oil spill response operations. This ensures that decisions on equipment procurement are based on shared knowledge and experience rather than external references alone. Through international information exchange and the sharing of practical experiences, future equipment investments can be targeted more effectively to meet the evolving needs of changing risk situations.

Training activities must be developed

There is a need to increase training and exercises in the Baltic Sea region, especially with regard to shoreline response. Practices differ across the region, which yields many opportunities to learn from each other through information exchange. Different response methods and ways of working are best learned through joint exercises. Joint training and the sharing of best practices improve readiness and ensure more consistent operations. This ensures that equipment and staff skills develop in line with changing risks. In addition to practising response actions for new substances, some aspects of traditional shoreline response measures are not practised enough. In particular, shoreline clean-up methods involving washing (rinsing, low-pressure washing and high-pressure washing) should be studied further and practised more. [9.]

Conclusion

The Baltic Sea's combined social, environmental, technological, and economic system, and the operating environment it creates for shipping and rescue services, is going through major and complex change. This system-level change affects the risk of oil and chemical spills in many ways. It increases the likelihood of incidents and spills, expands the range of possible spill substances, makes response and advance preparedness more difficult, and raises the potential severity of impacts on the environment and people. As the risk landscape changes rapidly, new needs will inevitably arise for response and recovery equipment, situational awareness tools, skills, and operating practices. The importance of collecting, processing, and using information is even further emphasised. Information must flow effectively through the whole chain, from researchers to practical operators, so that both the strategic and operational situational picture can be kept up to date. Smooth and trusted information exchange between actors is, therefore, more important than ever.

As the green transition advances, chemical incidents will become a growing area of response and preparedness, new in many respects and more challenging than oil spills.

There is a need for more knowledge on how to respond to marine chemical spills, such as the usability of oil spill response equipment for chemical spill containment and recovery. This work should begin immediately. Knowledge of the behaviour of new potential pollutants in water and their consequences for the marine ecosystem, as well as their effects on humans, is also largely incomplete or non-existent, so there is an urgent need for more information in this area as well. To maintain an up-to-date situational picture, the increasing use of alternative fuels in shipping and the changing range of chemicals and other substances that could potentially be spilled must be continuously monitored and assessed. This information should be easily accessible and cover all Baltic Sea shipping routes and ports.

So far, no single multi-purpose recovery device that works for all spill substances has been developed. Because of this, authorities must be able to use several different types of recovery devices and systems. Additional equipment also creates new demands for skills and for keeping skills up to date. This applies both to practical equipment use and to decision-making, command, and situational awareness management during an incident. For this reason, improving training and exercises is essential, and funding must be available both for training and for new types of equipment, so that the changing risk landscape can be addressed properly. Without equipment, we do not have the tools—and without skilled personnel, the tools cannot be used effectively.

Addressing all identified gaps and meeting the needs will require broad cooperation across organisations, regions, and even national borders. Cooperation also offers ways to use resources more efficiently, for example through joint development and organisation of databases, systems, equipment, training, joint procurement, and effective joint planning. Good communication and a shared situational picture at political, strategic, and operational levels are also essential for enabling the desired progress. The project's action recommendations, targeted at political, strategic, and operational levels, are included as an annex to this article (ANNEX 1).

The investments being made now and the pioneering role in responding to and preparing for new types of marine oil and chemical spills can not only save the Baltic Sea coastal states from losses and costs of many kinds but also bring new capital to the region.

The list of investment needs outlined in this article based on the MARISEC project results is long. It is worth remembering that similar drivers of change are at work worldwide, and that risks and the need for managing them are in many ways similar elsewhere as well. This means that the results of research, development, and innovation cooperation in the Baltic Sea region also have strong export potential. Investments made now, and taking a leading role in modern marine oil and chemical spill response and preparedness, can not only help Baltic Sea coastal states avoid losses and costs in an even of an incident, but also bring new value and capital to the region.

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ANNEX 1

MARISEC project implementation recommendations

	Political decision-making	Regulatory and strategy authorities	Oil and chemical spill response authorities
Funding	Ensure sustained and sufficient funding for the development of preparedness for oil and chemical spill response in an evolving risk landscape.	Funding should be targeted at the development of up-to-date oil spill response equipment, training activities, situational awareness tools, and preparedness planning.	Capability requirements should be identified and communicated to maintain and develop response readiness.
Research and innovation	Research and development should be enabled to support risk management that is future-oriented, systemic, and considers a safety perspective.	Risk assessment methods that combine statistical data with scenario-based and systemic analyses should be developed, taking uncertainties into account.	Participation in research and development activities should include incorporating the experience of authorities responsible for oil and chemical spill response into risk analyses and method development.
Equipment preparedness	Strategic investments should be guided to strengthen response and recovery capabilities as well as critical infrastructure.	Efforts should be made to promote compatible systems, databases, and analytical tools to create a comprehensive situational picture across the entire Baltic Sea.	Response and recovery equipment should be maintained and updated to meet evolving hazardous substances and operational environments.
Training and exercise activities	Resources should be secured for long-term training and exercises, including both proactive and reactive preparedness drills.	Training exercises should be directed and promoted to strengthen both proactive and reactive operational capabilities.	Competence and training should be developed to support both incident command and practical equipment-handling skills, as well as decision-making, situational awareness, and improvisation in unprecedented situations.
Cooperation and networks	Cross-governmental and international cooperation should be promoted to strengthen shared situational awareness and operational capabilities.	Permanent structures should be created for information exchange, joint analyses, and shared resources at both national and international levels.	Information exchange and other forms of cooperation with other authorities and neighbouring countries should be strengthened.

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