ARCTIC PREPAREDNESS PLATFORM
FOR OIL SPILL AND OTHER ENVIRONMENTAL ACCIDENTS

Report T.1.2.1. Gap analysis and improvement suggestions for the NPA region to improve OSR infrastructure and preparedness level

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Nuclear Icebreaker Arktika sailing through the ice at the North Pole. More ice-going ships and icebreakers are needed to ensure year-round navigation and successful SAR & OSR operations. (Courtesy: Baltic Shipyard).

Finnish Environment Institute (SYKE)

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APP4SEA

The 21st century brought unprecedented interest in the Arctic's resources, turning the region from the world's unknown periphery into the center of global attention.

Within the next 50 years, local coastal communities, their habitual environment and traditional lifestyle will undergo drastic changes, starting from climatic perturbations and ending with petroleum industrial intervention and increased shipping presence.

The APP4SEA project, financed by the Northern Periphery and Arctic Programme, will contribute to environmental protection of Arctic waters and to saving the traditional lifestyle of the local communities. It will improve oil spill preparedness of local authorities and public awareness about potential oil tanker accidents at sea.

Summary

This report highlights some of the most essential challenges and gaps found for the NPA region in improving oil spill recovery (OSR) infrastructure and the preparedness level. First, important environmental factors have been highlighted which will influence the selection of OSR tools. Second, a short Arctic traffic analysis has been made due to the expectations for the rapid increase of shipping in the Polar area. Finally, the most significant gaps identified in the latest guidebooks and viability analyses for the Arctic oil spill recovery have been analyzed jointly with the lessons learned in the full scale ice trial in Oulu in 2016 and the EU-funded Arctic OSR project GRACE. Gaps related to the existing conventions concerning the safe navigation of the Arctic have been outlined mainly based on the International Maritime Organization's (IMO) Polar Code.

The technical challenges of OSR in Arctic waters have been described in this report through three main modes of the oil spill recovery: mechanical recovery, the use of dispersants and in-situ burning. Finally, the factors affecting on oil spill preparedness in the Arctic, Search and Rescue (SAR), the lack of infrastructure and communications have been discussed in more detail.

This report is part of the project APP4SEA financed by the Northern Periphery and Arctic Programme. The project will contribute to environmental protection of Arctic waters and saving the traditional lifestyle of the local communities. It will improve the oil spill preparedness of local authorities and public awareness about potential oil tanker accidents at sea.

- Share knowledge on oil's behavior on the sea, oil spill response methods, experience with tools and models;
- Introduce cutting edge technologies;
- Provide local authorities and the general public with access to the knowledge bank.

Contents

Introduction

An international literature review of geopolitical, economic, environmental, transport and other issues in the Arctic, including qualitative and quantitative parameters, has showed that the Arctic's profile will only rise in the future, turning the region from the world's periphery to a center of global attention. Depletion of traditional resource regions, an increase in globalization's processes, economic demand, development of large-scale intercontinental northern transport marine routes and activation of Arctic tourism are the reasons for the changing Arctic trends. Global warming is an accelerating factor in this situation.

Increasing oil exploration and development, an increase in shipping activities and rising turnover of goods will demand improved infrastructure and optimization of northern regions' management as well as present potential environmental, economic and social risks to residents of the NPA region, as the Arctic Ocean is one of the harshest environments in the world to operate in.

Despite the fact that the industrial development of Arctic oil and gas deposits has been ongoing for 45 years – with the amount of extracted resources in Russia and Norway equivalent to more than 20 billion tons of oil – there are currently no effective technologies for OSR in icy conditions available in the world. Thus, the drilling but also transporting of oil and oil products in the Arctic Ocean is an unsolved problem within the Arctic states and pose real risks for the vital activity of local communities and vulnerable northern ecosystems, such as that in the Barents Sea.

The most promising marine industrial regions for oil development are located in the Barents Sea, Pechora Sea, the waters of Prudhoe Bay, Yamal Peninsula, Alaska, the mouth of Mackenzie river and the Canadian Arctic Archipelago. These areas are vulnerable to potential environmental contamination with dangerous consequences. Apart from local economic players, we expect a shipping and industrial presence by non-Arctic countries such as China, Singapore, Japan and others – which are less experienced in Arctic shipping. The most wanted transport marine passages through the Arctic lie along North Sea Route and Northwest Passage along the Russian and Canadian coastlines.

In June 2016 in the Arctic Coast Guard Forum, there was a joint statement signed by representatives of all Arctic states. It states that there is a need for procedural guidelines to operate in the Arctic, a need to share information and highlight best practices, and a need to avoid duplication. The countries under the Arctic Council adopted a new agreement in Kiruna in 2013 (MOSPA) to deal with oil spills and to unite the operational preparedness and response in the Arctic. The new operational guidelines have been made under the EPPR Working Group of the Arctic Council, but guidance for proper systems and successful operational procedures is still sought. Following modern trends, APP4SEA aims to create a working platform to satisfy these needs and involve at least one coast guard service in the project. This collaboration will enable learning from each other, complement the environmental profiles of each participating country with up-to-date information about appropriate tools and methodologies, and support local authorities in decision-making process.

This report has been produced by the Finnish Environment Institute (SYKE) as a part of the project "The Arctic Preparedness Platform for Oil Spill and other Environmental Accidents (APP4SEA)", financed by the Northern Periphery and Arctic Programme (NPA) during 2014-2020. NPA is a European Regional Development Funding instrument and it involves remote communities of Northern Europe and aims to facilitate its sustainable development with related social, economic and environmental benefits (Figure 1).

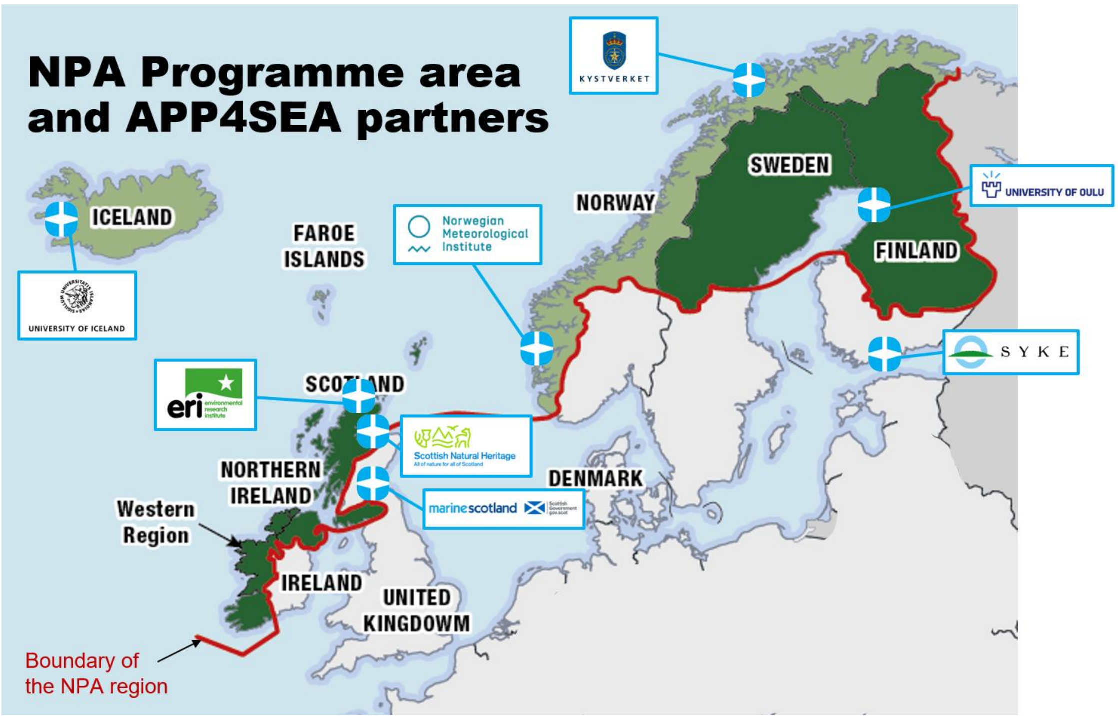

Figure 1. NPA programme area and APP4SEA project partners (Hänninen et al., 2020).

Maritime Traffic in the Arctic

The intercontinental traffic through the NRS has increased recently due to the large oil and gas projects in the Yamal peninsula and Prirazlomnaya in the Petchora Sea. The main ports in the Russian Arctic saw a more than 40% growth in goods handled in 2016 compared to the previous year. Growth has been the highest in Murmansk as well as in Sabetta which is the new port in the Yamal peninsula. It has been generally estimated that the overall traffic along the Northern Sea Route (NSR) has increased by 3% since 2015.(Humbert, 2017).

The NSR attracts also Asian shipping companies, and the transit traffic through the Bering Strait has also received more and more interest. Chinese and Korean companies have been the most interested users. Ice-going new cargo ships and LNG carriers have been used also year-round in the traffic to Sabetta port as well as to the Yamal LNG terminal (Staalesen, 2017). The transport through the NRS is thus expected also to increase during the wintertime with the help of the assisting icebreakers, while the most significant growth is expected to take place in the summer months. Figure 2 highlights the development in the last decade (UCS, 2018).

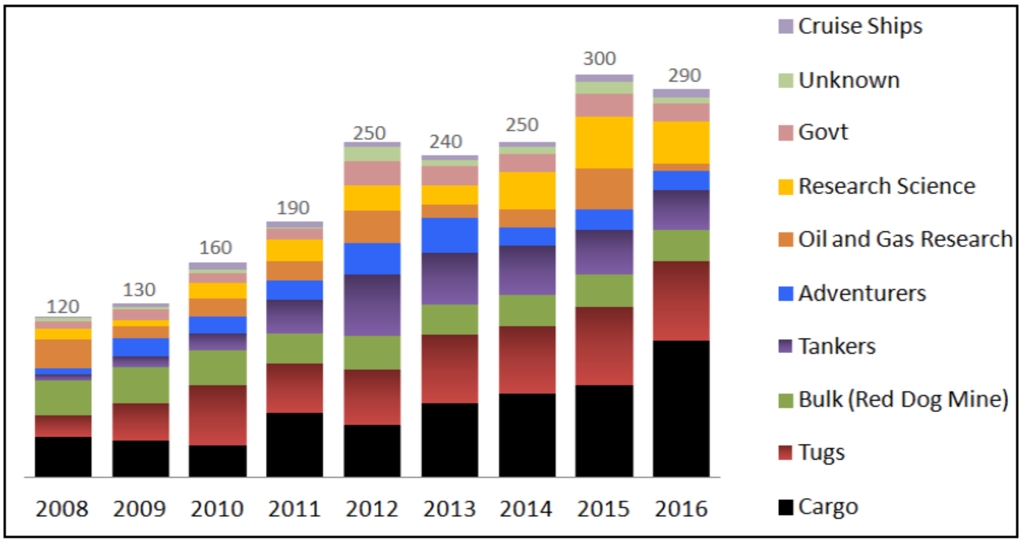

Figure 2. Total Number of Vessels in the Arctic by Activity (USCG 2018).

Marine tourist activity in the Russian Arctic has been at a relatively low level compared to some other Arctic countries. There have been some media-related efforts where Russian icebreakers have transported tourists through the NSR up to the North Pole. The Russian military has been active in the recent years, as old and new military bases have been taken into use.

The Norwegian side of the Barents Sea, Svalbard area and the Norwegian coastline have been heavily used for tourism. The Norwegian Government's Arctic Policy states that around 80% of the Arctic maritime traffic goes through Norwegian waters (Norwegian Ministry of the Foreign Affairs, 2014). From the maritime risk point of view, the Norwegian coastal waters, excluding the Svalbard area, are ice-free alternatives for the traffic, while the areas in the Barents Sea annually experiences heavier ice conditions. More risks have been taken in the areas with heavier ice conditions and harsh environmental conditions (Borch et al., 2016). Most maritime traffic in Northern Norway is concentrated on cargo transport, oil and gas industry, coastal passenger traffic, maritime tourism, research and fishery. On mainland Norway, coastal traffic is expected to increase due to goods transportation between the mainland and the offshore installations, fish farms, as well as other petroleum-related traffic. The oil and gas-related traffic prognosis is bound to the international oil market price fluctuation, well capacities and new discoveries. The general trend also in the Norwegian Artic is the increase of the vessel size, growth in the number of tourists in the passenger vessels (especially in the Svalbard) and the extension of the cruising season every year (Marchenko, 2015).

Another country linked to the Bering Strait and NSR is the United States of America via the state of Alaska (Ikonen, 2017). The U.S. Committee on the Marine Transportation System also predicts significant increase in marine traffic and transit figures in the Bering Strait area (see Figure 3). The growth will be mainly concentrated in destinational shipping, transit and container shipping to and from the North Slope companies in Alaska and NSR and ecotourism (Azzarra et al., 2015).

The traffic in Canadian Arctic waters has been mainly limited to the supply of the local communities, commercial fishing, local subsistence harvesting and as well as adventure and expedition tourism. A few cruises with larger passenger ships have been conducted. The North West Passage is not expected to see the same growth as the NSR due to the seasonal variations, ice problems, the complex archipelago, a lack of sea charts, restrictions, insurance limitations and other additional costs. Indigenous people have valuable insights and expertise to contribute to more effective response and protection of the Canadian coast including the Arctic. The Oceans Protection Plan by the Government of Canada also seeks the protection of the coastline and the enhancement of Arctic safety in the Canadian Arctic waters.

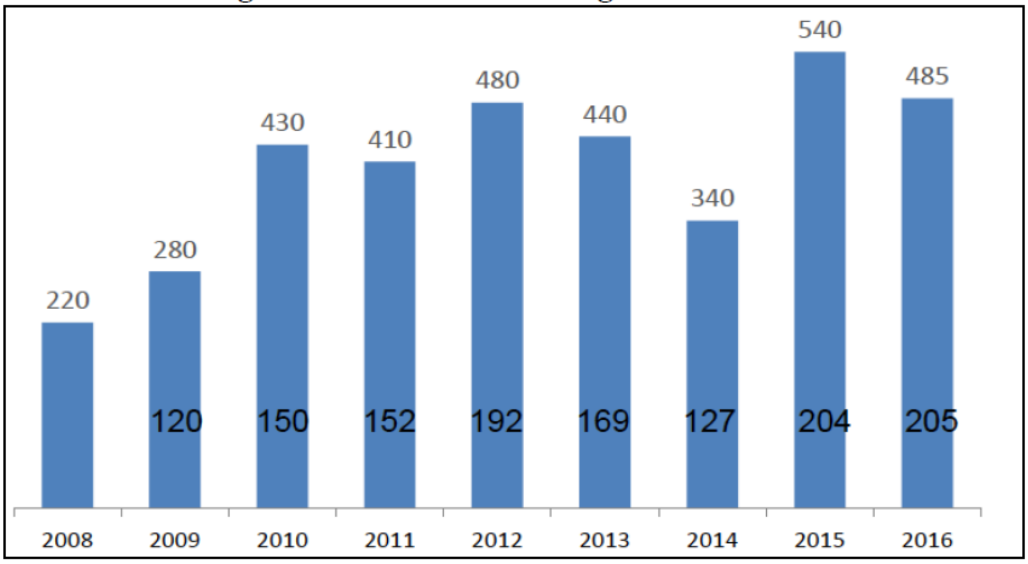

Figure 3. The development of the transit traffic through the Bering Strait. The number at the top of each bar is the total number of transits per year (USCG 2018).

Greenland has also seen some increase in maritime tourism and cruise traffic. This increase has mainly involved cruise ships for 200–500 passengers, and expedition ships. Whale observation trips, fishing and boat excursions to the glaciers have been common activities in Greenland. Small boat activity poses certain risks in terms of safety issues, thus pointing to the increasing challenges for SAR preparedness. All vessels sailing in Greenland's waters must report to the special GREENPOS vessel tracking system (Ikonen, 2017).

Besides tourism, marine traffic in Greenland mainly consists of passenger traffic on the west coast of Greenland as well as fisheries' activities, cargo transport and governmental activities. Sea transportation is crucial for the local community due to lack of roads connecting the villages and settlements. Almost all the villages and settlements are located on the coastline. It is expected that the maritime traffic in Greenland's waters will increase in the future on the fishery side and in exploration, oil and gas and mining. Maritime tourism, fisheries and governmental activities will also grow. The level of maritime passenger traffic and the transport of goods, however, is expected to stay at about the same level in the near future. The development of the Northwest Passage may have certain influence on Greenland's waters if there is a significant boost to that development in the future.

The maritime activities in the Icelandic sea areas in recent years have showed a small decline in the numbers of vessels, but the vessel size and the amount of passengers onboard have increased (Ingimundarson & Gunnarsdottir, 2016). The main forms of the maritime traffic consist of marine tourism, fisheries, coastal cargo, passenger ferries and some governmental and research activities. The fisheries have earlier been the main form of the maritime industry, but the new type of larger vessels will gradually replace the older, smaller fishing boats and trawlers. It has been estimated that both the cargo and the tanker traffic as well as cruise traffic will increase in the coming years. The oil and gas activities have more potential in the northern part of Iceland.

Like Iceland, Finland and Sweden do not border the Arctic Ocean. However, they are both Arctic States due to the fact their northern parts are within the Arctic Circle. The sea areas between Sweden and Finland, the Bothnian Sea and the Gulf of Bothnia, are frozen every year during the winter-time. Ice conditions may vary from year to year from normal to severe, even if there is no multi-year ice in the Baltic Sea area. During the winter-time, Finnish and Swedish ports in the Northern Baltic need the assistance of icebreakers. This service keeps the maritime traffic going without any delay even in severe ice conditions. The winter navigation season in the Baltic usually starts in late November and lasts up to mid-April. In addition to the cargo traffic, there is dense passenger ferry traffic between Finnish, Estonian and Swedish ports. Ice-going passenger vessels have many shifts per day even in the winter season.

The Baltic Sea is also an important route for the transport of Russian crude oil. The narrow Gulf of Finland between Finland and Estonia sees a lot of tanker traffic to and from the Russian oil terminals, which are situated at the end of the gulf. There might be up to 20 tankers sailing on this sea area on any given day. In severe winters, there can be also ice coverage in the Gulf of Finland, which increases the risk of oil spills. The Gulf of Finland is one of the most heavily trafficked sea areas, and besides the east- and westbound tanker and transport shipping, there is a lot of passenger traffic between Helsinki and Tallinn (Häkkinen et al., 2020).

Big passenger ferries, each carrying up to several thousand passengers and staff, cover this short sea trip multiple times a day. Should the paths of an oil tanker and a passenger ferry cross and lead to an accident, this could create the nightmare scenario for the rescue services: thousands of people and up to a hundred thousand tons of oil afloat.

Selected Guidelines and Lessons Learned

Main gaps defined in the guidebooks

Currently there are two main guidelines available for oil spill response (OSR) created especially for the Arctic conditions: The Field Guide Response in Arctic Waters (hereafter, "Field Guide") was recently updated (EPPR, 2017a) and mainly focuses on supporting the response and operations. The other guidebook, "Guide to Oil Spill Response in Snow and Ice Conditions" (EPPR, 2015), in turn focuses on planning and decision-making processes. The EPPR 2015 version was also later published by the IMO in 2017 for more global usage. This guidebook has generic, strategic and global objectives and focuses on ice and snow oiled from potential marine sources as well as ice and snow in the marine coastal environment oiled from potential terrestrial sources. The key areas here are planning and preparation and response and implementation.

The updated Field Guide contains updated material and is reorganized to remove some repetition in the first edition from 1998. It focuses on practical OSR strategies and tools for application in open water, ice and snow conditions in remote areas during cold weather. It also provides information relevant to the marine offshore and coastal environments, and to large rivers and lakes, where oil is transported and where spills pose a threat to the environment and public health.

Some of the baseline lessons learned from these two guidebooks for oil spill recovery in the Arctic have been reviewed and the challenges and gaps identified have been discussed in this report, too.

The updated Field Guide also suits any cold regions with ice and snow and not only the Arctic. The Field Guide also has a large application range with the oil types: oil types have been grouped in three main categories, which makes the application easier. Globally there are numerous crude oil types, various refined oils and the behavior of all these oil types differ a lot. Here the oil types have been mainly characterized by viscosity, which from the recovery ability point of view is perhaps the most critical feature of oil in ice and cold conditions.

One of the latest guidelines for the best practices and selection of the optimal oil spill recovery means in the Arctic is the Circumpolar Oil Spill Viability Analyses (COSRVA), prepared by the EPPR Working Group of the Arctic Council (EPPR, 2017b). It gives estimates for the percentage of time the environmental conditions may be favorable, marginal or not favorable for a selected oil spill countermeasure. Generally, the open water season in the Arctic offers more favorable conditions for OSR than in the winter-time.

The response viable analyses do not include the overall operational picture or data on particular response tools available in the area. For example, if the conditions have been analyzed to be favorable for a certain response tool, the lack of the relevant equipment in the response area is not included into the analysis. Also, the possible deployment time from the depots or any transport time is not included and needs to be planned separately. The same holds for other resources supporting the operations like crew onboard, necessary service or logistic solutions.

COSRVA analyses use a 25 x 25 km^2 grid, which may not be suitable for coastal areas with a lot of shallow embankments, rocks, islands and curvy coastal lines. For a closer look at certain restricted areas, other means are needed for surveillance and final analysis of the recovery options. For some restricted sheltered areas, the overall analysis may provide a false estimation as not favorable or marginal, when in fact due to the good shelter or micro climate of the area under surveillance, the selected countermeasure would fit this area well.

Thus, there is a need for parallel tools in addition to the COSRVA tool to use all available surveillance means to get a fresh situational awareness view over the target area. Satellite pictures and SAR images taken from the surveillance air crafts are needed to ensure the viability of the tactics to be used. Novel drone concepts, especially fixed wing aircrafts, have a long range and can be used as a support tools for the surveillance team trying to map the oil-infected area and ascertain whether certain areas can be protected by booms, or whether certain recovery tools could be directed to the focus areas.

In a remote area which involves long distances, the local environmental conditions may vary a lot from the original time at which a decision was made until the final environmental conditions encountered when the recovery tools have been transported to the site. Even if the COSRVA analyses would give an estimate that a certain primary option would be favorable or not favorable, there could still be a window of opportunity to use certain tools or tactics.

IMO Polar Code

The Polar Code includes mandatory measures covering a safety section and pollution prevention section, and recommended provisions for both. From a past set of voluntary safety guidelines of the IMO, the Code gradually developed into today's sophisticated, legally binding catalogue of rules whose stated objective is not only to make shipping in polar waters safer, but also to mitigate its impacts on Arctic and Antarctic environments. https://www.thearcticinstitute.org/revisiting-polar-code/

Ships aiming to sail through Arctic (or Antarctic) waters need to have Polar Ship Certificates introducing their suitability for certain ice conditions. The Polar Code has been discussed earlier in the App4SEA project report (Rytkönen & Santasalo, 2020). The most promising development in this context has been the momentum building towards a ban on the use of heavy fuel oil (HFO) in Arctic waters.

When studying the Polar Code's provision in greater detail, one soon discovers that notable gaps remain. Perhaps the most glaring omission comes with regard to HFO. In the Arctic, however, the Polar Code only recommends that shipmasters refrain from using or transporting what has been described as "the world's dirtiest fuel". Given that HFO represented nearly 57% of total fuel consumed by ships in the Arctic in 2015, it is questionable at best whether this recommendation will be observed in practice. https://www.thearcticinstitute.org/revisiting-polar-code/

Similarly, measures aimed at preventing ships from transporting non-native species to polar regions are also non-binding, leaving Arctic ecosystems exposed to the introduction of potentially harmful invasive species. According to a 2016 study submitted to the IMO by Friends of the Earth International, eight cases of human-caused, marine bio invasions – ranging from algae and molluscs to different types of crustaceans – have been reported in waters north of the Arctic Circle (Cohen, 2016). While the Polar Code recognizes the danger of "harmful aquatic species" introduced to the Arctic through ships' ballast water or hull fouling, it fails to introduce mandatory measures that could effectively counter this threat.

Other sources of pollution have been omitted from the Polar Code entirely, underwater noise being one example. Produced by propeller movement and on-board machinery, ship-generated noise can disturb marine mammals by masking sounds vital for communication, reproduction, and orientation (WWF, 2017).

Similarly, options to regulate so-called "grey water" discharges – that is, water from sinks and showers aboard ships – were widely discussed during the Polar Code negotiations, but not incorporated into the final document. A further notable gap comes with regard to emissions. While the IMO recently pledged to curb CO_2 emissions in the shipping sector by 50% by 2050, the Polar Code does not cover airborne pollutants.

A final issue concerns the Polar Code's safety provisions. The Code's novel requirements in this respect do not apply to all ship types, notably sparing fishing vessels, private yachts, and smaller cargo ships. While accidents involving these kinds of vessels might not be as damaging to the environment as, say, those involving cruise ships or oil tankers, the lack of Arctic-specific safety provisions is concerning nonetheless (Sun & Beckman, 2018).

Project GRACE – Main findings

The project GRACE ("Integrated oil spill response actions and environmental effects"), funded by the EU Horizon 2020 programme 2016-2019 (Jørgensen et al., 2019), shed new light on many aspects of different OSR technologies in Arctic areas (www.grace-oil-project.eu).

The objectives of the project were:

- to improve the observation and predictions of oil spill distribution and fate in the sea using novel on-line sensors on vessels, fixed structures or gliders, and smart data transfer to operational awareness systems;
- to explore the true environmental impacts and benefits of a suite of marine oil spill response technologies in cold climates and ice-infested areas in the northern Atlantic Ocean and the Baltic Sea. The response methods include mechanical collection of oil in water and below ice, in-situ burning, use of chemical dispersants, natural biodegradation and combinations of these;
- to assess in particular the impacts of naturally and chemically dispersed oil, in-situ burning residues and non-collected oil, on fish, mussels, crustaceans and macro algae, using highly sensitive biomarker methods, and to develop specific methods for the rapid detection of the effects of oil pollution on biota;
- to develop a strategic Net Environmental Benefit Analysis tool (sNEBA) (later published as EOS tool) for OSR strategy decision making in cold climates and ice-infested areas.

Findings

The results of GRACE are reported in the 58 reports (deliverables) and they are all available here https://www.grace-oil-project.eu/en-US/About/Deliverables

On-line monitoring of oil in the water column

The GRACE project performed unique field tests for on-line monitoring of oil under water including satellite communication of the data streams. Oil sensors installed in SmartBuoys, FerryBox and underwater (autonomous) vehicles such as gliders were tested. On-line data transfer worked well and no deviating observations indicating an oil spill were observed. Comparison to laboratory analyses showed that signals from interfering compounds should be corrected for, and that the calibration of instruments in a harmonized way is desirable. FerryBox data is available on http://on-line.msi.ttu.ee/GRACEferry/. Developed systems for on-line monitoring on different platforms of oil in the water phase are thus on levels that are ready to be implemented and marketed.

Biodegradation

Biodegradation of oil and dispersed oil in ice, water and sediment was studied in laboratory scale. The results showed that oil in the water phase and in ice can be degraded somewhat by the natural population at low temperatures, and the limiting factor is the accommodation of oil into the water phase. The use of dispersants did not enhance the biodegradation rate. The key microbial species and metabolic pathways which are associated with oil biodegradation were studied by sequencing of the DNA in the samples and by comparing to relevant databases. New information on the genetic level of the microbial communities' ability to degrade oil compounds has been obtained. The microbial communities differ greatly between the North Atlantic and the more brackish Baltic Sea. The communities also differ greatly between coastal areas and offshore areas. The application of dispersants for enhancing oil removal from seawater by biodegradation provided contradictory results, and more research is needed.

A pilot scale test with novel electrokinetic treatment of petroleum hydrocarbon contaminated sediment was performed in a coastal bay of the Baltic Sea. Based on the obtained results, it is difficult to make clear conclusions on the overall effect of the treatment, due to the large variation in the sediment properties between the test plots. However, valuable experiences for further exploitation of this method were obtained.

Impacts of oil and dispersants on biota below the water surface

GRACE also studied how dissolved oil components can affect marine fauna, like copepods, and mussels in the Northern Atlantic and the Baltic Sea. The establishment of latitudinal and seasonal baselines of the biomarkers allows distinguishing contaminant effects from a healthy state. Important differences were found between the sampling locations that will help future investigations to account for natural variability (Benito et al., 2019). Experiments where biota was exposed to oil were performed at either high concentration for acute toxicity tests or at sub-lethal concentrations in order to study measurable effects on the different biomarkers in these organisms and in laboratory model organisms. We were interested in the soluble oil components dissolved in the water phase under an oil slick, because this is more relevant for the studying the effect of the exposure in the field. Therefore, we used the so-called water-accommodated fractions, which means water overlaid with oil, stirring for about 2 days, and testing of the water phase, not the floating oil (Figure 4).

Fig 4. Non- dispersed and dispersed oil during the preparation of the water-accommodated fraction of oil for experiments with biodegradation and effects on biota in the GRACE project. (Photo K. Jørgensen).

The impact of naturally and chemically dispersed oil on different relevant trophic levels of biota has shown that dispersants and oil dispersion can increase toxicity (Katsumiti et al., 2019). The toxicity of the dispersant alone is negligible in many cases compared to the toxicity of the dispersed oil (GRACE, 2019). More refined oil seems to be more toxic than the crude oil. The oil contamination had an impact on eye development of zebrafish embryos, and this could be observed from the gene level to eye size and behavioral changes. This work has led towards a novel establishment of adverse outcome links that should report an exposure and possible adverse outcome already on a molecular basis in biota. Toxicity tests showed that dispersed oils can be more acutely toxic than oil and therefore dispersants should be used with caution in sensitive areas such as the Arctic and the Baltic Sea.

Oil spill response in coastal Arctic water

GRACE obtained permission from the authorities in Greenland to perform controlled pilot tests on in-situ burning and field experiments with mimicked stranded oil on tiles placed in the tidal zone in the coastal waters of Greenland. After the pilot scale oil spill field experiment and subsequent in-situ burning, the burn residues were collected. Environmental effects and exposure of the marine environment was monitored using blue mussels. A transient effect in some biological parameters was found in the water column below the burning. In vitro assays gave no elevated toxicity. Also short-term effects on tidal macro-algae were observed (Wegeberg et al., 2020). Results from this unique in-situ burning experiment showed that this is a method that can be used in remote areas under suitable conditions. A novel under-ice oil recovery device, which can be attached to already existing remotely operated vehicles (ROVs), has been tested in a test tank and will be launched to the market.

Strategic decision tool

A strategic Net Environmental Benefit Analysis (sNEBA) decision tool was developed and it was decided to launch the tool under the name Environmental & Oil Spill Response (EOS). This novel EOS analytical tool for environmental assessment to support OSR design is freely available at http://bios.au.dk/index.php?id=128153&L=1 .

GRACE – Discussions and Conclusions

Dispersants

When dispersants are considered as an OSR method, the whole environmental issue and evaluations change due to concern the underwater marine life. After deploying dispersants, the oil is not /cannot be collected, and all oil will remain in the environment. Therefore, the biodegradation and effects of dispersed oil is very important to study and to know (National Academies of Sciences, Engineering, and Medicine, 2020) both in the water column and in the sediment (Miettinen et al., 2019). Currently the use of dispersants is not recommended by HELCOM in the Baltic Sea.

Chemical analysis of oil concentrations in the environment is challenging and the choice of methods needs more harmonization. In order to obtain environmentally relevant concentrations and conditions, dilutions of the water-accommodated fraction of oil and dispersed oil should be used in laboratory experiments assessing this.

Biodegradation

Natural biodegradation in the Arctic is slow (Fritt-Rasmussen, 2018) and the natural microbes prevailing at different locations in the oceans varies much (Reunamo et al., 2014). The activity can be enhanced by different means. However, there are hardly any large-scale studies in sea water that have included e.g. the addition of microbes. Estimates of biodegradation are quite uncertain because each case is different.

Risks and Emergency Preparedness

Maritime activity in the Arctic area differs a lot depending on the specific sea area or by the certain development and business interest of the surrounding countries. In certain cases, it is the accessibility of the area which determines the fleet to be used. More often the types of activities is the key factor which defines the fleet, cruising schedules and the related activities for the Arctic navigation. In the Russian Arctic, it is mainly oil and gas which are the drivers for the maritime industry. Increasing interest in getting transit sailing along the NSR is also forming up ways to keep the navigation open year-round with the assistance of icebreakers.

In Norwegian Arctic waters in Svalbard, the focus is more directed toward tourism, and in the Canadian Arctic, key activities are concern the ensuring of supplies to the local communities, fishing and hunting. Tourism is also seen here as of growing importance, however.

The limiting factors of vessel traffic and maritime activities in the Arctic include climatic factors, ice and weather conditions affecting accessibility and sailing schedules, geopolitical and governance factors, environmental protection factors such as the recent ban of offshore oil and gas development in the Arctic by Canada, infrastructure factors, economic factors and the profitability factors depending on the market situation globally (Ikonen, 2017).

Offshore oil and gas production platforms form one set of constructions with certain risks for fire, explosion and oil spills. Failures within the offshore structures may pose serious consequences for both humans and the environment (Staalesen, 2017). Increasing tourism will also bring larger cruise vessels to the Arctic area, with an increasing amount of people onboard. Besides cruise vessels, the Arctic has been a popular destination for adventure tourists and leisure boaters without any AIS systems onboard or which are not subjected to any Polar Pilot requirements (McKenzie et al., 2016; Marchenko, 2015).

Global warming will also cause the extension of the open water season, which in turn will increase tourism. New innovations in ship design, and ice strengthened ships offer ice breaking capacity for cargo ships, tankers, LNG ships and cruise ships. This also means that authorities must extend their existence over the typical summer periods, thus having means for emergency operations also in serious weather conditions and in the presence of ice.

Emergency Preparedness

Contingency planning, monitoring and risk assessments are key elements of preparedness and awareness in terms of maritime safety in the Arctic. From the responder's point of view, most of the challenges related to OSR or SAR operations are due to the long distances and severe environmental conditions, which may rapidly vary and negatively affect the emergency actions. Response actions are also difficult and laborious due to the lack of resources and manpower. Even though responders have been trained in their operations in the Arctic conditions and recognize the risks, there is a lack of knowledge on the local conditions and risks for the people who sail in Arctic waters. In order to mitigate risks related to unknown areas or local conditions, authorities must work closely with the industries in the Arctic as well as with non-Arctic countries in order to share information on the possible risks related to operating in the Arctic and also challenges on the emergency preparedness required (Ikonen, 2017).

The Arctic SAR challenges center on the authorities' responsibilities to assist people, vessels and aircrafts in distress. In the Arctic region, responsible SAR authorities belong to the eight Arctic Council Nations, with their responsible border shown in Figure 5. Specific obligations can be found from several international agreements and conventions such as:

- International Civil Aviation Organisation (ICAO) Convention on International Civil Aviation,
- International Convention on Maritime Search and Rescue,
- International Convention for the Safety of Life at Sea and
- United Nations Convention on the Law of the Sea.

If the Artic sea routes get more ships from non-Arctic countries, the most problematic phenomena causing risks would be the presence of ice, cold air causing freezing and icing problems increasing the threat of ships capsizing. Personnel's competence and the experience is a key value when meeting difficult weather conditions, even when the ship is assisted by the icebreaker. A ship's technical capabilities, maintenance and housekeeping procedures need to be at a high level to face Arctic conditions. The safety management of the fleet has a significant role in mitigating risks.

The basic maritime transport risks from the shipping companies' point of view are:

- capsizing, sinking. This mode of accident may originate in heavy wave patterns which may cause the movement of the cargo and increasing instability of the ship resulting in the vessel capsizing. Another typical mode of failure in the cold climate is icing, which will also increase instability resulting in capsizing;

- grounding. The ship's safe position along the shipping channels ensures the safe navigation without the danger of grounding. Navigation failures or electrical failures resulting in a black out situation may lead to grounding. In ice-infested waters, moving ice can cause a ship to deviate from a safe course and lead grounding. If the ship gets stuck in the ice, the ship may move with the ice and be shoaled to the rocks and embankments nearby. Lack of proper navigational charts in the Arctic may also result in grounding accidents. Perhaps the most common failure here is a gap between a ship's true position and the suggested position due to the failures made in navigation.
- fire onboard which may result in the total loss of the ship, and where any countermeasures by emergency units may be very challenging due to the long distances.
- risk of pollution as a result of the above-mentioned hazards and failures and
- unsafe behavior and work practices, which point to the importance of the safety management structure of the shipping company and the integration of the safety aspects into the company's overall management policy.

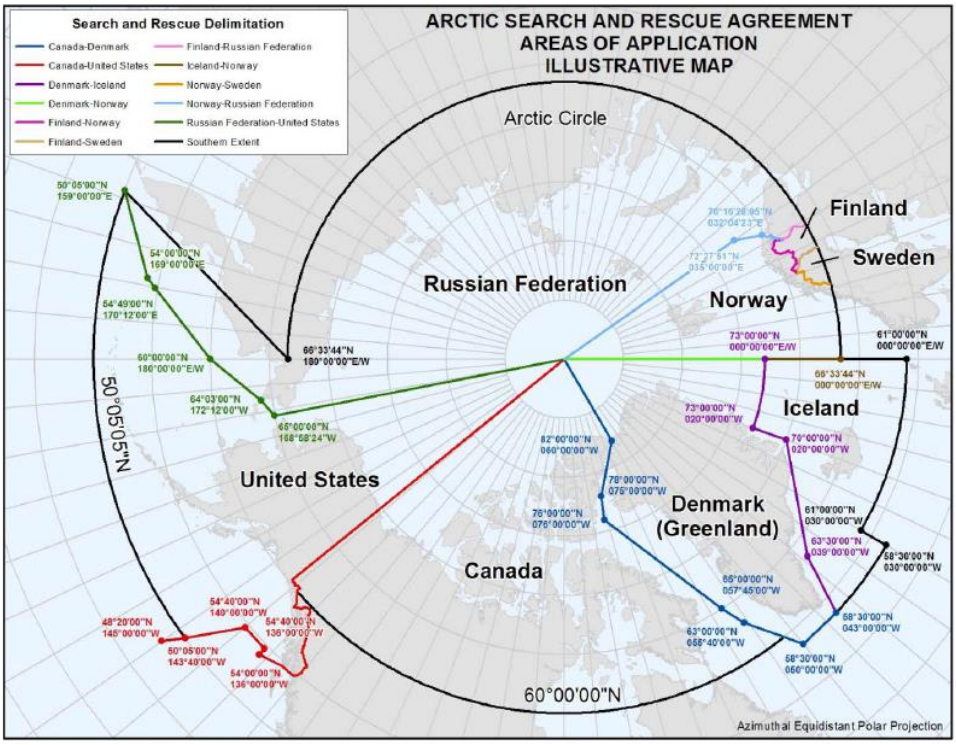

Figure 5. Arctic operations area (USCG, 2018).

Challenges in Emergency and SAR Operations

The current search and rescue, or SAR, infrastructure in the Arctic, while varying between regions, is limited. Preparedness for SAR activities exists in certain areas around the Arctic area, but generally speaking, large gaps exist. There is little to no infrastructure along the coast of Greenland to respond to a passenger ship in distress. A survey of SAR resources among Arctic states indicates limited availability of fixed wing aircraft and helicopters in most of the region. Some survey responses included icebreakers and seasonal patrol vessels that can be used for SAR when near enough to an incident.
http://www.arctis-search.com/Search+and+Rescue+%28SAR%29+in+the+Arctic .

Usually the lack of any emergency response means in the Arctic is closely linked with the lack of decent logistics or support stations. The existing ports and offshore production platforms, however, are usually the natural “contact point of emergency actions”. Due to their original tasks, however, the devices and manpower for any larger scale SAR activity may be very limited.

The future increase in human activity in the Arctic, including Arctic marine shipping and the continued overflight of the Arctic region by commercial aircraft, will place increasing demands on the SAR infrastructure. Many of the infrastructure deficiencies, such as the insufficient number of accurate charts or the need for better real-time information concerning the operational environment and communications difficulties, will also impact search and rescue efforts (AMSA, 2009). Partly of the above mentioned reasons, the Arctic countries made a joint agreement on the SAR activities in 2008 in Ilulissat (Ilulissat agreement, 2008) and further agreed on the geographical response areas, and defined responsible organizations and certain support activities in Nuuk 2011 (SAR agreement, 2011). IMO has also pointed out the concern of the maritime industry on the passenger ships in the Arctic area in IMO (2006) to define contingency plans for passenger ships operating in areas considered to be remote from SAR facilities. This annex includes detailed information on emergency drills and inspections, and contains additional requirements for lifeboats, life rafts and survival kits that would allow passengers and crew to better survive the harsh Arctic environment until SAR response arrived on scene (AMSA, 2009).

Amver system, originally known as the Atlantic Merchant Vessel Emergency Reporting (Amver) System, became operational on July 18, 1958. Amver began as an experiment, confined to waters of the North Atlantic Ocean, notorious for icebergs, fog and winter storms. Amver’s mission is to quickly provide SAR authorities, on demand, accurate information on the positions and characteristics of vessels near a reported distress. Any merchant vessel anywhere on the globe, on a voyage of greater than 24 hours duration, is welcome in the Amver system and family. International participation is voluntary regardless of the vessel's flag of registry, the nationality of the owner or company, or ports of call (USCG, 2020). The system consists of a communication network by internet, Inmarsat type of compressed messages, radiotelex, radio, telex, telefax and instructions on why and what to report to the system. Approximately 450 lives were saved in 2007 because of Amver.

Today, over 22,000 ships from hundreds of nations participate in Amver. An average of 4,000 ships are on the Amver plot each day and those numbers continue to increase, The Amver Center computer receives over 14,000 Amver messages a day. Over 2,800 lives have been saved by Amver-participating ships since 2000. The success of Amver is directly related to the extraordinary cooperation of ships, companies, SAR authorities, communication service providers and governments in supporting this international humanitarian program to protect life and property at sea. Amver will also act as a resource for SAR authorities managing maritime incidents in the navigable waters of the Arctic.
https://www.amver.com/Home/AmverHistory

Table 1. Amver summary statistics. https://www.amver.com/Home/Statistics .

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Average Daily Plot	3618	3780	4634	5305	5474	7623	7776	7699	7850	7260	7315
Max Vessels On Plot	3809	4092	5218	5461	7650	8094	8083	8089	8340	8543	7683
Award Eligibles	5549	5742	6963	7501	7613	9101	9067	9264	8453	8453	7957
Ships Added	1448	1760	2313	1614	1241	905	818	676	635	628	541
SAR SURPICs	1146	1980	2229	2465	2748	1652	1084	1634	1465	1455	1318

- *Average Daily Plot: shows the average number of vessels that actively participated in the Amver system for the year.*
- *Max Vessels On Plot: shows the highest number of vessels that were on plot for any given day for the year*
- *Award Eligibles: shows the number of vessels that were eligible for an Amver award for the year*
- *Ships Added: shows how many new Amver participants there were for the year*
- *SAR SURPICS: shows how many SAR SURPICS were used for the year (only SURPIC requests - previous years included training/test surpics) .*

Another example is the Russian Vessel Monitoring System, referred to as VMS Victoria. The system is intended for near real-time automated monitoring of vessels positions provided vessels are fitted with the ship satellite communication systems INMARSAT-C or INMARSAT-D+, and for delivering the collected position reports data via internet to remote users. VMS Victoria caters to the shipowners, operators and organizations responsible for control and surveillance of maritime vessels, as well as for search and rescue at sea. There are more than 1,200 vessels enrolled in the system, among them more than 600 foreign flag-state vessels. Promoting the use of mutual vessel assistance systems such as AMVER or VMS Victoria would serve to supplement the extremely limited search and rescue resources and improve SAR capacity in the Arctic.

http://www.arctis-search.com/Search+and+Rescue+%28SAR%29+in+the+Arctic .

Oil Spill Recovery

Environmental factors limiting the use of certain OSR tools

From the environmental point of view, the Arctic forms a unique and sensitive environment, where any oil spill may cause severe damage. A typical feature for the Arctic is the extreme seasonal variations which in turn reflects the ecological sensitivity of the area. The short summer season is also an important mating season for many waterfowls and other animals, and certain Arctic areas are crowded with various species during the short summer seasons. Cold water forms a rich environment for aquatic life where whales and other mammals can feed and have certain areas as their playground. Fish species are numerous, and there are important spawning areas where any oil spill may endanger fish stocks and cause long-term decline. Bottom animals and all species living close the coastlines and in shallow water are the kind of the target animals to be protected.

The Arctic area is also a very large area with different geological formations, islands and rocks and deep-water basins. Shore line types are numerous, which in turn greatly affect oil recovery options or coastal protection operations against drifting oil slick. Oceanographic and coastal seasonal variations have a significant impact on the nature and the air temperature variations and winds create rapidly changing conditions where all operations could be difficult and time consuming.

Ice is one of the most dominant forms of water in the area and a key feature of Arctic conditions. Open water conditions have a freezing phase with different ice forms all having their own behavior with spilled oil. Once the sea area is frozen, conditions can be characterized as stable, but winds may cause the formation of ice ridges, and form dynamic drifting ice conditions. Operations can be carried out on the ice in winter. Finally, the spring induces the melting season with the ice breakup, after which the sea area in question will be characterized as an open water area.

The cold climate also means that the spilled oil will usually have a slower oil alteration process with slower weathering and persistence of spilled oil. Cold air temperature in turn affects the personnel and all equipment. Coldness, high wind and poor visibility are risk factors affecting safety. The high viscosity of oil, for example, may block pumps and hoses and stop recovery operations.

From the operational point of view, perhaps the main challenge for OSR operations is the long distances and remoteness of the Arctic area. There is no infrastructure or logistical support to conduct operations. In the case of an oil spill, the resources to deal with the oil may be very limited and the deployment time to get necessary equipment and other resources may be long. It is very likely that the first responders are forced to improvise countermeasures. There might also be environmental conditions in which any operation would be too risky for the responders or equipment, and even to ascertain information on the oil's location could be a challenge, especially in severe ice conditions.

Seasonal daylight variability is also a special feature in the High North. The long dark season during the winter-time affects safety issues and also makes it difficult even to locate the oil to be collected. There are also many days when fog will reduce the visibility and produce extra difficulties for responders. Poor visibility or the icing phenomenon may endanger the aircraft operations and affect marine operations significantly.

Clean-up operations in shallow water and close to the shorelines also depend on the season. There are a lot of different shore types, some open and some covered by ice where certain recovery tools will not be favorable. Seasonal variation will significantly influence the conditions encountered at a certain shoreline. There are also land areas where permafrost is an issue and needs to be considered, especially if support stations or logistic centers are to be established in summer-time.

The protection of responders and other staff is a key issue of Arctic OSR operations. Guidelines and occupational heathy concerns have been listed for example in EPPR (2017a) and in many guidelines made for personnel working within the oil & gas industry In the Arctic area (https://www.seapro.org/toolbox.html).

Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils (EPPR, 2017a). It is likely, however, that in the case of a remote oil spill in the Arctic, significant parts of the volatile compounds will have evaporated before any significant countermeasures or equipment are transported to the area under operation. This occupational health concern is anyhow an important tissue for first responders and for crews surveying the area to build up the situational awareness view for the command center.

It is primarily the cold weather and extreme weather conditions which are of concern for responders in the Arctic. Seasonal daylight variations may also bring additional concerns especially in winter when the length of the day light is at a minimum. Wind chill effect is also a factor which points to the importance of good clothing and support stations. It is likely that the extreme environmental conditions greatly reduce operational efficiency: icing of the equipment, failures due to the extreme coldness and problems of water and food supplies are typical failures which accompany the typical hazards of electric supplies and batteries in cold temperatures.

For the coastal protection work, cleaning efforts and when working on the ice, another precautionary concern is caused by bears. Sea mammals and their feeding and reproduction sites are those special areas to be taken into account, too.

Essential Challenges in OSR Preparedness

Remote surveillance and detection technologies (i.e., satellite communications, GPS availability, weather stations) are critical for establishing situational awareness for both preventive and response issues. This overall capability is limited in the Arctic due to a lack of coverage and the availability of real-time weather information. http://www.arctis-search.com/Search+and+Rescue+%28SAR%29+in+the+Arctic . However, numerical weather prediction analyses and predictions are available for the Arctic from all of the major meteorological centers using global weather models. Countries with the need for more detailed information for Arctic areas have developed high-resolution models covering the Arctic region according to their needs.

Although weather forecasts for the Arctic are based on the same tools and techniques as other areas of the world, the scarcity of observations in the Arctic makes the monitoring of the weather more difficult than in areas with more observations. The forecast of the weather data, however, is a rapidly developing mode of service in the Arctic area, where modern satellites and their new sensor systems will produce better forecasts in real time (for example, INMARSAT Global Maritime Distress Safety System (GMDSS)).

While all Arctic states individually support the overall strategic goal of limiting negative environmental impact and establishing sustainable development, the potential for increased shipping has led to increased concern for threats, risk and evaluation of potential consequences worldwide. This leads to a high expectation by public and environmental groups for adoption of stringent preventive measures, as well as thorough mitigation and restoration measures in the event of an incident. This has also contributed to an increasing gap in maintaining realistic response expectations (AMSA, 2009).

If a vessel sinks or is stranded in shallow water in Arctic, the moving ice and harsh environmental conditions may block any successful oil removal operation. Even if these kind of operations are normally conducted by special salvage companies, there is a need for specialized contingency plans related to the reduction of the oil spill in various environmental conditions supported by a certain cross-border preparedness to cope with the specified need in different scenarios.

Mechanical Recovery

From the environmental point of view, mechanical recovery is usually considered the most favorable oil spill combating method with the following advantages and disadvantages:

Advantages:

- It is environmentally friendly.
- The oil is removed from nature.

Disadvantages:

- It is often ineffective.
- There are logistical difficulties.
- It is time-consuming, laborious, and costly.
- It demands special equipment and vessels.

There are two main principles for mechanical recovery in icy conditions:

- Lift the oily ice blocks from the surface water and clean them with a specially developed cleaning device.
- Separate the oil from ice in the water.

Several devices have been developed and then tested at laboratory scale and in real-world conditions over the years. Many Nordic manufacturers of response equipment have developed special skimmers for response in icy conditions, such as self-floating ice skimmers and hanging rope mop skimmers. These are usable when the ice concentration is clearly less than 100% but can be rather difficult and ineffective in cases with a high ice concentration. In very light ice conditions, skimmers designed for open water can also be used effectively. Typical mechanical recovery units for ice conditions include the following:

- Rope Mop skimmers;
- Arctic skimmer (LAMOR LtD);
- Polar Bear skimmer;
- Polaris Ice skimmer;
- Lori Ice Cleaner;
- Oil Ice Separator, LOIS;
- Oil recovery bucket.

More detailed descriptions of these devices is given in Lampela & Rytkönen (2012).

Most of the equipment is designed to be used in connection with specialized response vessels, but some can be used also from a vessel of opportunity thus enlarging the usable response vessel fleet. Brush technology is the most common response method in ice conditions in the Baltic Sea states: mechanically separating oil from water and from ice, provided that the oil is floating on the water's surface or is stuck to the ice.

Figure 6. Oil recovery bucket and sweeping arms mounted onboard a Swedish Coast guard vessel (Photo: Lamor LtD).

Depending on the ice coverage, different methods can be used (Lampela & Rytkönen, 2012):

- If the ice coverage is 0–30%, normal open-sea skimmers can be used, keeping in mind that there is always a risk of damage to the skimmer due to the pressure of moving ice and also that, even in favourable conditions, 100% recovery cannot be expected.
- If the ice coverage is between 30% and 70%, special ice skimmers are needed. If self-floating skimmers are used, they must be specially built to withstand the ice pressure. To facilitate movement among ice blocks, these skimmers should have their own propulsion system or the possibility to enhance movements by the crane of the supporting vessel.
- If ice coverage is 70% or more, specialized robust ice skimmers are needed. They must be operated by ice-going response vessels or integrated directly to the vessel. Often there is also need of special cranes or an excavator onboard the vessel to be operated effectively. Some skimmers can be used also from a vessel of opportunity thus enlarging the usable response vessel fleet.

Figure 7. Naval Oil Recovery vessel LOUHI in Ice (photo: SYKE).

Part of any OSR countermeasures in the Arctic is first ensuring that the origin of the spill can be blocked and isolated, and confirming that the original source of the spill would not cause a continuous oil spill trajectory. In the case of a ship grounding or a hull that has suffered significant damage due to the ice forces, one of the methods is a lightering operation. Lightering normally means the ship's cargo or oil will be transferred to another vessel resulting in the grounded ship being towed away from the rock, or the ruptured cargo hold/oil tank being emptied, thus resulting in stopping the leakage. Lightering in emergency situations and salvage typically represent two distinct marine activities that may be used in whole or in part to prevent and/or recover pollutants, which are considered in many cases synonymous with mechanical response capacities (AMSA, 2009).

The effectiveness of mechanical containment and recovery at sea largely depends on the sea and wind conditions at the spill site. Containment and recovery are likely not possible, and are probably unsafe to attempt, in wave heights exceeding 2 m or in winds of more than 10 m/s. Many recovery ships have their practical wave height limitation already at a wave height of 0.5 m, but there are ships with inbuilt wave dampening systems which may still recover oil with wave heights of 2.1 m; in practice, this means a sea state where the maximum wave height can be close to 4 to 4.5 m (Häkkinen & Rytkönen, 2020).

Due to these restrictions, Arctic oil recovery ships should all be equipped with inbuilt dampening systems similar to those built in the Finnish oil recovery vessels Louhi and Turva. Due to the patented dampening system onboard the ship, the ship will maintain quite stable movement (mainly rolling and pitching) in significantly heavier sea states, and still continue oil recovery with the sweeping arm system. Also, the separate oil recovery buckets can be used in the presence of ice to clean oily ice floes or to lift oil among the ice floes more effectively.

Figure 8. The large oil brush systems of the oil recovery ship Louhi. Each unit has a 4-m-wide brush system which can lift oil from ice-covered waters effectively (photo: SYKE).

Figure 9. Finnish oil recovery vessel TURVA (left) and the Swedish oil recovery vessel (right) during the joint full-scale MOSPA trial outside of the city of Oulu in Finland in 2016 (Photo: SYKE).

Ice forms many problems for mechanical recovery, and depending on the ice form encountered, the main problems can be summarized as follows:

- limited access to oil: ice slush or small ice cubicles may block the system's input channels or belts;
- reduced oil flow to the skimmer: the mixture of oil and ice bristles will decrease the total oil pick up ratio. The water/ice content of the recovery tank will be significant;
- icing/freezing/jamming of equipment: moving parts of the system will be stopped due to the freezing. Pumps and hoses will be blocked by the high viscosity of the oil. Ice and possible debris will boost the formation of blockages;
- separation of oil from ice is difficult: Excess hot water or steam is required, causing the water /oil pick up ratio to be higher;
- oiling/cleaning of ice: part of the oil is touched by ice blocks and will remain in the sea. Some modern ice brush skimmers can be used to loosen and recover oil from the surfaces of the ice blocks;
- deflection of oil together with ice: ice and slush will form a kind of barrier between the skimmer and oil to be recovered;

- strength and durability considerations: special high durable steel, and materials tested in cold environments need to be used here;
- detection, monitoring of slick: detection of oil among ice or under ice is difficult (Häkkinen & Rytkönen, 2020).

The response effectiveness of certain response tools may differ significantly from those given in the literature or in the sales catalog. Most of the mechanical recovery tools have been tested in laboratory conditions, and often the stated oil pick up ratios describe theoretical maximum recovery capacities for a given system. Mechanical means have been used a long time, and there is a certain understanding of their limitations for given wave and wind conditions. Cold air temperatures, however, will often pose additional difficulties for the systems. For example, some mechanical skimmers may still work well partly submerged in the water, but the cold air may easily freeze the hoses or oil scraping systems which in turn will block the work of the whole system. Cold temperatures may also move the oil from the Newtonian fluid more toward a pseodoplastic type, increasing the viscosity so much that conventional pumping systems will no longer work without any additional heating by hot water or steam. There are mechanical recovery systems available designed for winter conditions with modern heating systems for the key parts of the systems. However, if one component of these system fails due to freezing, usually it means the whole oil recovery efficiency will remain practically close to zero.

In-situ Burning

In-situ burning (ISB) is one of the countermeasures available for responding to oil spills in marine but also in ice and snow conditions. Actually, ISB in oil spill response has been utilized since the 1960s and it is the oldest response method. ISB involves the controlled burning of oil that has spilled from a vessel or a facility, at the location of the spill. The main purpose is to reduce the amount of oil beaching and the burning rate of thick (1 cm or more), large (3 m diameter or more) slicks of relatively fresh oil has been measured to be in the range of 3 mm/minute (Buist et al., 2013).

There is a limited “window of opportunity” for using ISB and this window is defined by the time it takes the oil slick to emulsify. While most oils are suitable for removal by ISB, there is a limited timeframe after the initial spill in which ISB will be effective. As oil weathers over time, it becomes emulsified with water, and suffers evaporative losses of its volatile compounds. Both emulsification and evaporative loss increase with time and decrease the efficiency of ISB (Häkkinen & Rytkönen, 2020).

Almost all ISB tests conducted in cold and ice conditions have been carried out as small-scale or intermediate tests, thus the results may not to be used directly in the case of a large-scale oil spill. However, the tests provide a general idea of ISB as a tool in the oil-combating tool box. Tests conducted also provide a sense of the feasibility of ISB's burning efficiency and mass loss rate. Very little has been done to understand the heat transfer mechanism between the burn and the ice.

Most important for the actual response work is the guidelines on the correct use of the ignition and optimal time when ISB should be used as a part of oil recovery efforts. Also, if the oil will be trapped among and under ice and stay for a longer period of time, the important question is how effective ISB will be once exposed again for the combating operations. Also, the link between the oil release rate and the burn rate is not known.

More research is needed on igniters, fire-resistant booms, floating burners and additional supporting techniques such as ignition and burn promoters, smoke suppressors and herding agents.

More research is needed on the health or environmental effects from burning in actual spills in full-scale conditions. It is also unclear how the environmental impacts caused by the oil itself or burning residues should be evaluated as part of the NEBA process.

Dispersants

Chemical dispersants enhance natural dispersion by reducing the surface tension at the oil/water interface, making it easier for waves to create small oil droplets that remain in suspension for long periods and are rapidly diluted in the water column. The main reason to use dispersants is to reduce the amount of oil drifting to shorelines in the case of a very large oil spill. In addition, the aim is to reduce the exposure of birds and mammals to oil on the water surface (e.g. Prince 2015). Furthermore, it has been thought that use of dispersants may increase the biodegradation of oil in the water column (e.g. Brakstad et al., 2017).

Cold temperatures do not reduce the dispersability of most of the oils, thus the use of dispersants is a secure method even in ice-infested waters. Limitations may arise due to the attenuation effect of ice floes, due to the fact that they block the wave energy which is required for mixing of the oil and dispersant in a proper manner. If the open water and ice ratio is suitable, the small ice floes have been observed even to stimulate the dispersing reaction. In a dense ice field, however, the use of dispersants is ineffective.

Most of the modern chemical dispersants are less toxic than older ones in the concentration used in the environment.. The dispersed oil is however causing toxicity depending on the dilution (GRACE deliverable 3.16, 2019). In shallow water conditions, or in the areas having a rich underwater or near-bottom marine habitat, the small oil droplets may have severe impacts once dispersed into the water column. There are observations in the literature pointing out that the impacts in the water mass usually are insignificant due to dilution, but more research is needed to define the limits of their usage. Dispersants are not recommended for use in the Baltic Sea area, mainly due to the limited data on the expected impacts on nature. Testing protocols and data on the impacts to the oxygen level near the bottom or impacts to the food web is scarce.

In extreme weather and sea conditions, it is unlikely that dispersants would be applied to a spill because natural dispersion occurs readily under these conditions without the need to add chemicals.

Even if the use of dispersants appears initially to be favorable, the sudden change of the air temperatures or wind velocities will endanger their success. An overly calm water surface will not produce enough energy for dispersants to expedite the oil dispersion unless some energy using ships' wake water cannons can be used. If the distance of the oil spill site is too far to be reached by ships with dispersant spraying units, the use of aircrafts requires sufficient wave energy in the operation site.

Oil Biodegradation

Biodegradation after oil spills occurs when micro-organisms that are capable of degrading oil compounds consume the oil compound and uses it as a carbon source. A wide range of micro-organisms (bacteria, fungi, yeast, unicellular algae and protozoa) have been found to be capable of degrading oil compounds, and they are distributed widely in different oceans around the world. Oil biodegradation rate after oil spills is affected by several factors (Figure 10), for example environmental (e.g. seawater temperature, presence of ice, nutrient and oxygen concentrations and local microbial community composition) and oil property factors (oil type and composition, concentration and level of weathering).

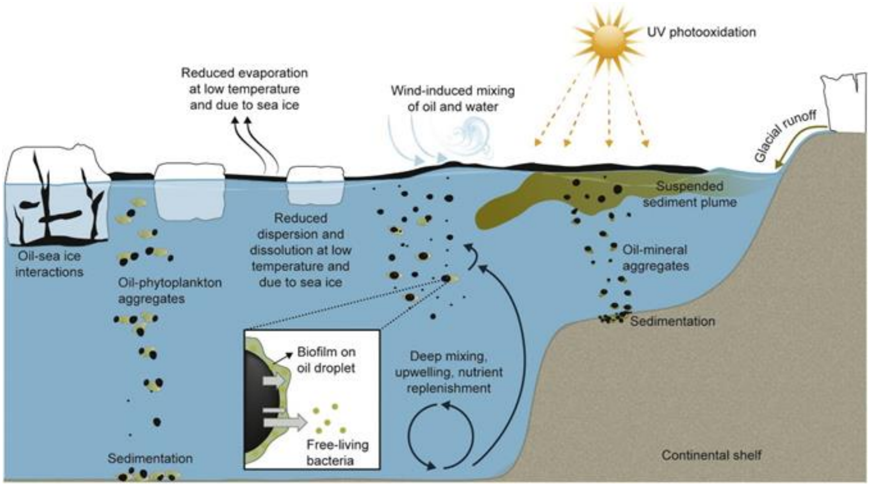

Figure 10. Schematic diagram of Arctic-specific conditions that affect oil biodegradation (Vergeynst et al., 2018).

Effect of oil type

One of the biggest factors affecting the biodegradation rate is the type and composition of the spilled oil. Some petroleum hydrocarbon compounds degrade easier than others, and the susceptibility of hydrocarbons to microbial degradation can be generally ranked as follows: linear alkanes > branched alkanes > small aromatics > cyclic alkanes (Leahy & Colwell, 1990). Some compounds may not degrade at all, for example PAHs (polycyclic aromatic hydrocarbons) may not degrade at all or very slowly (Atlas & Bragg, 2009). Oil types with high viscosity, for example HFOs, have the highest persistence, while lighter oils have generally lower persistence (Fritt-Rasmussen et al., 2018; ITOPF, 2011).

Biodegradation occurs in the oil-sea interface and therefore the creation of droplets by natural or chemical dispersion can increase the interfacial area available for microbial activity. Weather and climate conditions during the spill also affect oil persistency. In calm weather the persistence of the same oil type can be much shorter compared to rough weather (ITOPF, 2011).

Environmental parameters: Oxygen

Because the microbial degradation of petroleum hydrocarbons is often an oxidative process where the initial attack is performed by oxygenases and peroxidases, oxygen can be a limiting factor for the

biodegradation (Hazen et al., 2016). Although microbes can degrade petroleum hydrocarbons anaerobically, it is generally considered slower than aerobic degradation (Widdel et al., 2010).
Oxygen can be the limiting factor in the deeper water if the oil concentration is high and there are not enough waves to keep oxygen levels high, but oil slicks remaining on the surface are most likely not oxygen-limited. If oil reaches a shoreline and sediments, the degradation can be very slow due to anaerobic conditions.

Environmental parameters: Temperature

Biodegradation is generally slower and more limited in lower temperatures. In lower temperatures oil viscosity increases, while solubility, dissolution, and volatilization decrease. These changes decrease the bioavailability of oil to microbes (Lofthus et al., 2018). Oil degradation rate is also dependant on the environmental compartment where the oil is spilled (Fritt-Rasmussen et al.2018). If the oil reaches a coastline and is deposited in the sediment, the biodegradation will be slower than in the sea water due to lower oxygen levels. Similarly, degradation is slower in the sea-ice due to colder temperatures and smaller oil-water interface.

Environmental parameters: Nutrients

Although oil-degrading microbes can use petroleum hydrocarbons as their energy and carbon source, lack of nutrients (mainly nitrogen, phosphorous and iron) can be a limiting factor for the oil-degrading community to grow and therefore it can slow the biodegradation rate. This has been observed during oil spills. For example, during the Deepwater Horizon oil spill, oil biodegradation of surface slicks was observed to be slow due to lack of nutrients (Edwards et al., 2011). In cold waters, the biodegradation rate may be lower due to low temperatures, but on other hand they commonly have higher amount of nutrients.

Gaps in the logistics

Perhaps the biggest bottleneck at the moment is the lack of icebreaker assistance. From the US's point of view, the US Coast Guard is unable to give any assistance for merchant ships or to maintain a persistent, year-round surface presence for SAR response in the Arctic. The situation with Russia is better due to their icebreaker fleet and the strong nuclear icebreaker capable of year-round navigation. The number of proper ice-going ships in the world is still limited and offers minimal support for Arctic transit navigation, but global warming and changes in the global trade may change this prognosis. Russia currently has roughly 40 icebreakers, while the number of Canadian icebreakers is 18. Canadian icebreakers are operated under the Canadian Coast Guard (CCG).

Russia is aiming to add three more nuclear icebreakers, two LK-60Ya class and one LK-100Ya class, in addition to the three LK-60Ya class currently under construction (Humpert, 2017). Currently Russia operates six nuclear icebreakers: two shallow-draft river icebreakers Taymyr (in service since 1989) and Vaygach (1990) and four powerful Arktika-class icebreakers, Rossiya (1985), Sovetskiy Soyuz (1990), Yamal (1993), and 50 Let Pobedy (2007). Three of the Arktika-type nuclear icebreakers have surpassed their original design limit of 100,000 hours over 26 years and need to be replaced soon. Thus, altogether five new Arktika class icebreakers were decided to be built, and the first icebreaker from this set, IB Arktika, had its ice trials in the Arctic at the end of 2020. Two additional vessels, Sibir and Ural, are expected to enter into service by 2021 (Humpert, 2020).

In addition, Russia is also in the process of finalizing design decisions for a new flagship icebreaker called the LK-110Ya class or Leader class. The new ships will escort natural gas and oil tankers through the ice along the NSR to the markets of the Asia-Pacific region.

Figure 11. The world's largest icebreaker 50 Let Pobedy (50 Years of Victory) - the last of the Arktika class of nuclear icebreakers - launched in 2007 (Source: Courtesy of Rosatomflot).

The US Coast Guard plans to close the icebreaker gap by 2026, with the delivery of a planned third heavy polar icebreaker. Currently, the Coast Guard Cutter (CGC) POLAR STAR (built in 1976) is the nation's only operational heavy icebreaker. The Coast Guard's immediate focus is on the construction of the first new heavy icebreaker since POLAR STAR entered service, followed by a second to re-establish self-rescue capability to enhance their assured access to the Arctic. The congressionally mandated 2011 High Latitude Study recommended three heavy icebreakers and three medium icebreakers to meet the Coast Guard's and the nation's mission demands in the Polar Regions until September 30, 2050 (USCG, 2018).

Figure 12. Canadian icebreaker CCGS Amundsen (Wikipedia.org)

Until that time, the US Coast Guard is mitigating risk through the mobile, scalable, and seasonal approach of Arctic Shield, and the forward deployment of air and surface assets during the times of peak maritime activity (AMSA, 2009). The Arctic Shield objectives are: (1) enhance Arctic Marine Domain Awareness, (2) broaden partnerships, (3) excel in operations, and (4) conduct Coast Guard missions to support increased Arctic maritime activities while preparing for the future (USCG, 2018).

Operation Arctic Shield is the Coast Guard's mobile and seasonal presence focused on performing the service's 11 statutory missions throughout the Arctic to ensure maritime safety, security and stewardship. It is an annual operation that began in 2009 https://www.hstoday.us/subject-matter-areas/maritime-security/coast-guard-concludes-operation-arctic-shield-2020/

Discussion

The future increase in human activity in the Arctic, including Arctic marine shipping and the continued overflight of the Arctic region by commercial aircraft, will place increasing demands on the SAR infrastructure. Even though there are agreements between some of the countries on SAR activities (for example, the Ilulissat Declaration in 2008), there are still a lot of challenges in enhancing the level of emergency actions to protect both humans and the environment.

The continuous work in the Arctic Council's EPPR Working Group led to the new SAR-related declaration in 2011 where the objective of the Agreement was to strengthen aeronautical and maritime SAR cooperation and coordination in the Arctic. This agreement defines the geographical border lines for both aeronautical and maritime SAR and defines the competent authorities of the parties with the responsible agencies to conduct any SAR activities in the areas defined. The national rescue coordination centers have also been listed in this document. The agreement also gives guidance for cross-border operations, communication and sharing information about any services requested when conducting operations (SAR agreement, 2011).

One of the ways to enhance the emergency and SAR preparedness in the Arctic areas would be the training of locals with volunteer organizations to support the authorities and to enhance the local emergency capacity. Many Arctic countries have recognized the need for local responders both in SAR and in OSR operations. For example, in Norway fishermen may use their trawlers in the case of a large-scale oil accident to transport booms and equipment. The Red Cross is a known actor in many countries, and WWF also has their own trained responders for oil spills. According to the questionnaire carried out for the Arctic SAR authorities in the Arctic (Ikonen, 2017), private assets have also been considered part of emergency preparedness. For example, private helicopter services can be used for SAR purposes. Local fishermen and their fleet may represent significant resources for OSR operations. Vessels of opportunity may also be the only means in a remote location for carrying out protective measures or for SAR operations.

Figure 13. Red Cross evacuation center during the Arctic SAR exercise Kvarken SARex (courtecy: Finnish Border Guard).

In the case of a cruise liner in distress, with a fire onboard or close to capsizing or sinking, any large-scale evacuation or protective measure will face a lot of challenges. Some of the challenges identified in this study are:

- long distances
- severe weather conditions
- poor communication network
- ice conditions
- inadequate resources in the operational area
- lack of situational awareness view of the accident
- problems related to large-scale evacuations – how to protect the victims
- lack of proper equipment and materials
- lack of aviation infrastructure.

The US Coast Guard (USCG, 2018) has listed some of the challenges for operations in the Arctic which in fact apply to all parties operating in the Arctic.

An increase in human activity in the Arctic continues to drive authorities' response preparedness activities. Internationally and nationally, maritime sovereignty claims, commercial shipping, resource exploration, and expanding military operations also are typical modes of activities increasing. Increased preparedness needs to be built to cope with an aeronautical or maritime disaster involving large numbers of persons in distress and other types of SAR including a ship or boat collision, sinking, or grounding; aircraft ditching; missing boaters; or the medical evacuation of persons requiring medical attention.

Due to the long distances, more aviation capacity has to be built to better cover the Arctic area. Aviation assets are the most probable rapid response methods for incidents in the Arctic.

The current seasonal ice edge recession rate in the Arctic allows for commercial, subsistence, and recreational maritime activity for about 3 to 5 months each year in open water conditions. Arctic marine traffic, including cargo and tanker traffic along the NSR and passenger and commercial traffic along the Northwest Passage, is projected to increase in the near and offshore Arctic waters.

VHF coverage, as of 2017, is effective over approximately only 20% of the coast of Alaska because of geography, distances from communication centers, and atmospheric interference. The majority of this coverage is centered on southern Alaska. However, some Arctic communities maintain limited VHF sites for monitoring local communications. This apparent lack of VTS coverage also characterizes the rest of the Arctic area.

Currently, the only fixed communication available to vessels operating in the Arctic are satellite communications. However, the limited satellite communications capability aboard cutters and aircraft is insufficient to support full-time response operations. Therefore, the US Coast Guard, for example, has to transport a Mobile Arctic Support System to the predefined location in Alaska from mid-June to late-October to supplement VHF and HF communications. Similar arrangements need to be considered elsewhere in the Arctic areas.

Conclusions

This report is part of the project APP4SEA focusing on the challenges and gaps affecting OSR and preparedness in the Northern Periphery and Arctic area. The focus of this work was first to study best practices and recommendations for the successful oil spill and pollution prevention operations in the Arctic. This report used data collected to analyze possible gaps and obstacles creating negative impacts for the use of certain main response tools in Arctic conditions.

In addition to the harsh environmental conditions and long distances which affect preparedness, there is a long list factors affecting emergency operations, preparedness and safe marine shipping in Arctic waters.

It is possible that global warming and the smaller scope of the ice season is increasing the attractiveness of the Polar sea routes for global navigation. Currently, Russia is perhaps the only Arctic country which really has year-round navigation through the NSR. The other Arctic countries, however, have plans to increase their awareness and competence in the Arctic and to build better ice-going ships, icebreakers, communications tools and effective SAR assets.

Generally speaking, it is the lack of infrastructure and human resources in the Arctic area which, together with the long distances and severe weather conditions, point to the need for better emergency response systems and suitable tools for environmental protection.

There are three types of oil spill recovery tools discussed in this report: mechanical recovery, dispersants and ISB. It is also likely that if any oil spill were to take place in the Arctic with the presence of ice, some amount of oil would always stay in the nature due to the limitations of the recovery tools. There should thus be an interest in studying how oil will impact the Arctic over the longer term, in addition to what kind of impact-assessment procedures need to be developed to better understand which areas near navigation channels or areas of offshore activities need to be better protected.

Surveillance and tracking are also key activities for building up a real-time situational awareness view over specific Arctic areas. Satellite images, aircrafts, and drones with modern sensor systems offer new solutions to track oil spills and collect data for the rescue and response centers for further oil-combatting measures.

Due to the fact that the transit traffic is expected to increase many times over during the coming decades, many aspects of the Polar Code need to be revisited and revised. Here cooperation between SAR authorities of the Arctic nations has an important role as part of basic preparedness against accidents and oil spill in the Arctic.

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