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Abstract

Over the last decade, more than 500 maritime accidents have been reported in the Arctic, and the political will of the Russian government to develop the Northern Sea Route (NSR) for the exportation of raw materials may lead to a rise of such events. However, data on insurance claims in the Russian Arctic are rather sketchy and not up-dated which has hindered accurate analysis so far.

Based on empirical data collection throughout the period 2004-2017, the study gathers, classifies and maps certain 'marine casualties' and 'incidents' that occurred along the NSR until the Polar Code enforcement. Three maritime events are scrutinized through the lens of the Polar Code risk mitigation tools and POLARIS system in order to determine if the joint use of these new prophylactic instruments would have prevented their occurrence.

As preliminary results, the research identifies the primary causes of identified maritime accidents that occurred in the Russian Arctic and provides their categorization in accordance with IMO standards. It appears that serious 'marine casualties' represent the greatest number of insurance claims. Shedding light on the type of risk occurrence a ship may face along the NSR, it brings valuable implications for maritime operators who are still awaiting historical data for more realistic risk assessment. Finally, it demonstrates that the combination of the Polar Code and POLARIS system is an appropriate tool for risk mitigation and encourages stakeholders to implement best practices for Arctic shipping in their common interest.

Keywords: *Arctic, risk analysis, risk mapping, maritime claims, Polar Code, POLARIS*

1. Introduction

Due to global warming, sea ice coverage and ice thickness in the Arctic Ocean have progressively decreased in recent decades (IPCC, 2018; Serreze and Stroeve, 2015; Corbett et al., 2010). This offers new economic opportunities in particular for the shipping industry (Lasserre et al., 2020; Eguíliz et al., 2016; Melia et al., 2016; Kum and Sahin, 2015) both for the Northwest Passage (NWP) and the Northern Sea Route (NSR). The construction of a new Liquid Natural Gas (LNG) plant in the Yamal Peninsula (Russia), allowed the first operations through the Bering Strait in July 2018. Furthermore, even if the target of the Russian Federation was to export between around 130 and 150 million tons by 2030 (Ministry of Energy of the Russian Federation, 2010), figures were revised to 80 million tons by 2024 (Staalesen, 2019b) which is still considered as highly ambitious (Staalesen, 2019a). The NSR gives the opportunity to reduce distances (Zhang et al., 2016), and fuel consumption thereby lowering carbon emissions (Kitagawa, 2008). Although the use of the NSR is questioning notably for international transit between non-Russian ports in Europe and Asia (Lasserre, 2016; Faury and Cariou, 2016; Cariou and Faury, 2019), this route crystallizes both greater maritime actors' interests, among which oil and gas producers that represent the lion's share of the goods shipped along the NSR but also cruise companies (Cajaiba et al., 2020) and container shipping lines such as Maersk and Cosco.

Nevertheless, a high level of risk in particular as regards ice characterizes the NSR and the Russian Arctic as a whole (ABS, 2014) despite limited statistics on shipping accidents (AMSA, 2009; Goerlandt et al., 2017). Yet, the number of insurance claims doubled in Arctic Circle waters throughout the period 2007-2017 (ALLIANZ, 2018) thus highlighting an opposite trend compared to global safety improvements justifying the adoption by the International Maritime Organization (IMO) of the Polar Code (PC) (IMO, 2014a) designed to reduce operational risks in Polar waters via safety and environmental prevention measures (Fedi et al., 2018; Dalaklis et al., 2018).

The aim of this paper is twofold. First, it carries out an in-depth analysis of certain maritime accidents that occurred in the Russian Arctic, identifying their root causes, level of seriousness and locations. The analysis enables a taxonomy of these events in accordance with the Casualty Investigation Code (IMO, 2008). It seems that existing literature does not provide this categorization. Secondly, three specific maritime claims linked to the ice risk are analyzed through the lens of the "Polar Operational Limit Assessment Risk Indexing System" (POLARIS) in order to verify if their occurrence would have been prevented. Even though IMO promotes POLARIS as well as classification societies, so far, little research has been carried out on this valuable system for decision-making of Polar navigation. The contribution of this paper is to highlight the relevance of the combination of PC provisions with POLARIS instrument in formal risk mitigation for the NSR and particularly in ice-covered areas.

After this introduction, Section 2 reviews current literature on Arctic shipping risks with a particular focus on the NSR. Section 3 deals with the methodology. The analysis of maritime accidents occurring in the Russian Arctic and the case studies are contemplated in Section 4 while Section 5 provides a discussion and managerial implications. Finally, some concluding remarks are addressed in Section 6.

2. Literature review

As illustrated by the recent adoption of the PC, the safe navigation in Arctic waters has become a pressing issue of concern. The ice presence, remoteness (Haavik, 2017; Lasserre et al., 2016), lack of search and rescue (SAR) infrastructures (SARC, 2017), low temperatures, drifting icebergs - over 1,000 icebergs drifted into North Atlantic shipping lanes in 2017

(ALLIANZ, 2018) -, rapidly changing and severe weather conditions and extended period of darkness represent considerable hazards for ships complicated by the lack of experience of crew (Fu et al., 2016; Montewka et al., 2015; Tikka et al., 2008). Moreover, as predicted by some scholars (Borgerson, 2008; Balto, 2014), the number of maritime accidents has recently increased. Although in 2006 there were only eight, they reached 71 in 2017 (ALLIANZ, 2018), meaning that accidents skyrocketed within one-decade contrary to the long-term downward trend of worldwide losses (IUMI, 2018; ALLIANZ, 2017). Accordingly, this specifically raises the question for the NSR in light of the hazardous goods carried (oil and gas) and a greater traffic likelihood in coming years.

2.1 Russian Arctic shipping risks and accidentology

Located in the Russian Federation Exclusive Economic Zone (EEZ), the NSR represents several navigational routes. Pursuant to the Northern Sea Route Administration (NSRA, 2012), the NSR is “a water area adjoining the northern coast of the Russian Federation, including internal sea waters, territorial sea, contiguous zone and EEZ [...], and limited in the East by the line delimitating the sea areas with the USA and by the parallel of the Dezhnev Cape in the Bering Strait; in the West, by the meridian of the Cape Zhelanie to the Novaya Zemlya archipelago, by the east coastal line of the Novaya Zemlya archipelago and the western limits of the Matochkin Shar, Kara Gates, Yugorski Shar Straits”. The NSR is described as running through four main zones: the Kara, Laptev, East-Siberian and Chukchi Seas. The NSR extends for around 3,000 miles and its navigation must comply with Russian legislation. Connecting Asian and European ports, annual navigation along the NSR is feasible depending on the ice or polar class of the vessel. From 2010 to 2017, 302 vessels performed along the NSR between European and Asian ports, between Russian and European or Asian ports and between Arctic ports themselves with a significant 40% increase in 2017 (NSRA, 2018). The main ports in the Russian Arctic saw a 40% rise in goods handled in 2016 compared to 2015 (SARC, 2017). In 2018, roughly 20 million tons (Staalesen, 2019c) passed through Russian Arctic seaports and was made up mostly of LNG. Thanks to the opening of production at the Yamal LNG plant, traffic is forecasted to grow even more rapidly over the coming years (Iudin and Petrov, 2016) while container shipping lines show little interest in this route (Lasserre, 2016).

The harsh and variable conditions along the NSR “challenge mariners, technology and systems” even when the NSR is open (AMSA, 2009; ABS, 2014). The main factor influencing the choice of the NSR is the distribution of ice (Liu and Kronbak, 2010) and ice may be encountered at any time including summer where ice massifs are frequent (ABS, 2014). Despite a longer seafaring season, waters are infested by floating ice and ice conditions are still extremely challenging for crew members, vessels (Marchenko, 2012a) and make the seafaring conditions somewhat unpredictable (Abbassi et al., 2017). The ice floes or ice drift may put a considerable pressure against the ships’ hulls. Vessels must adapt their route, trying to sail a way of “least resistance through the ice mass” to avoid the risk of being stuck or limit any risk of incident whatsoever, let alone accident (Vihanninjoki, 2014). Consequently, officers face difficulties to stick to the planned route chosen before the vessel’s departure. Additionally, the lack of infrastructures and the remoteness of the NSR render environmental conditions more challenging for seafarers, especially in case of unexpected events (Marchenko, 2014a; FoU Rapport, 2016). The NSR counts only eight major ports (Gritsenko and Efimova, 2017) subject to hard conditions and entering or operating in their facilities is often impossible.

On another note, few weighty studies reported the root causes of marine accidents in Arctic waters and in particular in the Russian Arctic. Although the Arctic Marine Shipping

Assessment (AMSA) report identified more than 290 accidents over the period 1995-2004 (2009), there was a ‘complete absence’ of reported events in the Russian Arctic. The AMSA thereby recommended the development of an accurate database. Notwithstanding the existence of the IMO GISIS, the European EMCIP or the Lloyd’s Marine Intelligence Unit database, numerous ‘weaknesses’ characterize these databases (Luo and Shin, 2019) on the Arctic region due to underreporting (Goerlandt et al., 2017) as well as different information and taxonomy applied to the same maritime events (Ladan and Hänninen, 2012). According to Goerlandt et al. (2017) limited and incorrect data lead to gaps in the analysis and may distort results. Furthermore, these databases are not often publicly accessible. Hence, providing an accurate statement on an accident in a given area is still a difficult task (Grabowski et al., 2009).

With the exception of Marchenko (2012b; 2015) who listed 90 accidents in the Russian Arctic between 1990 and 2010, few studies have been carried out up to now in particular with a global approach including identification, categorization and mapping of claims that occurred along the NSR. Most current reports use the notions of ‘incident’, ‘accident’ and ‘casualty’ alternatively and concurrently. This lack of data combined with approximate classification constitutes a significant gap in the existing literature insofar as it hinders stakeholders from precisely assessing the actual level of accidentology in the Russian Arctic and then implementing adapted responses. It is recognized that this sketchy statistical data complicates the shipowners’ and underwriters’ decision-making (Fedi et al., 2018a; Kiiski, 2017; Sarrabezoles et al., 2014) on appropriate price quotations and operations.

2.2 The prophylactic responses: the PC and the POLARIS system

The new PC aims to respond to increased maritime activities in Polar Regions (Fedi et al., 2018; Dalaklis et al., 2018; Fedi and Faury, 2016). Following a ‘risk-based approach’, the code pinpoints the main hazards in these zones, their likely impacts and provides appropriate measures to mitigate them in a prophylactic way (Fedi et al., 2018a; 2018b; Fedi, 2020). Fedi, Faury and Gritsenko (2018a) demonstrated that the PC eased risk appraisal and could be a response to lack of data through mandatory safety and environmental standards. Defined as a ‘toolbox’ reinforcing polarseaworthiness (Cullen, 2015), they demonstrated that the PC, in codifying risk assessment, represented a key determinant of marine insurance through ‘proceduralization of risk’. This proceduralization lies in three main tools (PC, Part I-A): the ‘Polar Ship Certificate’ (PSC) attesting the ship’s ice class (A, B, C) depending on her capabilities to operate in polar waters and the ‘Polar Water Operational Manual’ (PWOM) establishing detailed safety requirements pursuant to design capabilities and limitations that the master and crew must comply with in order to take “sound operational decisions” (DNV-GL, 2017). Finally, ‘voyage planning’ must be defined that encompasses nine requirement categories including hydrographic information, extent and type of sea ice, presence of icebergs, temperatures, aids to navigation, places of refuge or SAR capabilities along the chosen route.

In conjunction with the PC, one observes the POLARIS system developed by the International Association of Classification Societies (IACS) and some Arctic countries (IMO, 2014b, 2014c) that defines a methodology aiming at evaluating the ship’s operational capabilities in ice (IMO, 2016). POLARIS compares the different ice types to the vessel class with the aim of choosing the safest navigation route and ‘the optimal class of the vessel willing to sail within the polar waters’ (Fedi et al., 2018b). Based on ice conditions, POLARIS may be useful for classification and insurance companies according to Kujala et al. (2016) and Fedi et al. (2018b). For the latter, POLARIS constitutes “a fairly complex and multipurpose tool” both upstream and downstream of the shipowner’s decision process for

safer Arctic navigation. Building on this basis, it is assumed that POLARIS system combined with the PC's tools can reduce risk occurrence along the NSR where ice is predominant and would have prevented some accidents from occurring prior to the complete enforcement of the PC.

3. Methodology

This paper takes a multi-method approach with a qualitative and quantitative research design. The qualitative part firstly deals with the data collection of shipping accidents in different sources such as the International Union of Marine Insurance (IUMI), accident archives especially from the Protection of the Arctic Marine Environment (PAME), marine investigation reports from CLARKSONS, IHS Markit database (2019), the IMO GISIS, a recent study on Russian Arctic claims (Fedi et al., 2019), and the trade press between 2004 and 2017. One justifies this period since the 2009 AMSA report provided a global analysis up to 2004 and the entry into force of the latest provisions of the PC was effective in July 2018 for manning and training requirements whereas safety and environmental obligations were implemented in January 2017 (DNV-GL, 2017).

We secondly categorized the accidents in accordance with the appropriate terminology based on the IMO Casualty Investigation Code (IMO, 2008) and effective from 1st January 2010 as explained in Table 1.

Insert Table 1 here

The third stage was to map maritime events in order to provide their location along the NSR, to verify if certain areas and periods are riskier than others and what key or aggravating factors could be identified.

The quantitative part of the methodology is focused on the analysis of vessels that faced an accident or incident related to navigation in dangerous areas for which we contemplate their Risk Index Outcome (RIO) as defined by POLARIS. The RIO is a value designed to assess operating limitations in ice depending on three levels: 'normal operation', 'elevated operational risk' and 'operation subject to special consideration'. This RIO can be computed using a risk index table as defined in (IMO, 2016). When the ice thickness is above the ship ice class capability, the risk index is negative. Respectively, if the ship has the ability to sail through an ice thickness, then the risk index is positive. This risk index is then multiplied by the sea ice concentration to compute the POLARIS RIO.

To define the RIO in this paper, ice conditions statistics (thickness and concentration) were extracted over a period of 28 years on a daily basis from Copernicus database (2019) and aggregated in a grid of 12.5 km cells. As the European Union's Earth Observation Program, Copernicus provides open real-time data especially on atmosphere, land and marine environments (EU Commission, 2015). Based on Faury et al. (2019), we defined the level of risk of each case, the day of the accident and seven days before and after to determine whether the situation could have been anticipated or not. Ice conditions were evaluated in the area of the event according to three scenarios: worst case, median and best case based on POLARIS system. These three scenarios are aligned with the observed descriptive statistics (worst case = 25% lower values, median case = 50%, best case = 75% upper values) of the aggregated POLARIS RIO values within each grid cells for each day of year (1 to 365) over 28 years.

Pursuant to the IMO *Guidance*, three out of the five elements characterizing POLARIS deal with ice: the ice type definitions pursuant to the World Meteorological Organization (WMO), the different ice regimes such as partial ice concentrations or ice-free waters and ice decay in warmer temperatures (Fedi et al., 2018b). We considered POLARIS as a decision tool through risk classification and proceduralization (Fedi et al., 2018b) since it provides the RIO index that represents the cornerstone of the decision to fully operate or to limit shipping operations as shown in Table 2.

Insert Table 2 here

Vessels under PC1-PC7 categories (corresponding to the A and B categories of the PC) are designed for operations in polar waters under certain ice conditions (DNG-GL, 2017). For RIOs ≥ 0 , there are no specific requirements, sailing is allowed as ‘normal operation’. For other RIOs between ≥ 0 and -10, sailing is ‘subject to special consideration’ that is to say with icebreaker assistance for instance and will depend on the vessel ice class since operational risk is elevated. Finally, if the RIO is below -10 , no navigation must be undertaken. However, the final decision will belong to the master and whatever the ice class of the ship (Fedi et al., 2018b).

4. Analysis of maritime claims occurring in the Russian Arctic

4.1 Risk categories

Sailing within the Russian Arctic implies dealing with numerous risks mostly identified within the PC and that can be organized in four main categories: climate, technical, human and geographic. Yet looking at parameters that directly impact navigation, climate appears as one of the major risks, ice having a strong impact on navigation within polar waters (Cariou et al., 2020; Faury and Cariou, 2016; Lasserre, 2014). Floating ice has been identified as the key factor of most maritime casualties (Marchenko, 2012b, 2014b). Depending on ice thickness and concentration a vessel may not be able to sail (Löptien and Axell, 2014). However, numerous measures exist to prevent these risks such as the use of polar-class vessels with reinforced hull and a more powerful main engine or the assistance of icebreaker made sometimes compulsory by underwriters (Fedi et al., 2018a) and NSR requirements (NSRA, 2012).

With regard to the current literature ice appears as the main risk weighing upon ships. Besides, the fast-changing conditions due to freezing and thawing of the ice blanket can position the vessel in unexpected situations. The ice extent changes on a yearly basis and the months with the smallest and largest areas of ice are respectively September and March (Figure 1). A considerable variability in the ice expanses can be noticed between May and August and between October through December while the ice extent amplitude is less extensive during the rest of the year.

Insert Figure 1 here

Fedi et al. (2018a) highlighted that if the melting ice provides a larger period of navigation, it also generates an increase of ice drifting which can be a source of accidents (Faury, 2015; Dalaklis et al., 2018) and thereby an unsuitable speed with such ice conditions (Marchenko, 2014b). Consequently, the ice and fast-changing climate conditions can block a vessel and impact the integrity of the hull or other parts such as propellers. Furthermore, the risks related to the dangerous and polluting nature of hydrocarbons and mineral products mainly carried

along the NSR cannot be occulted in light of their potential environmental impacts in case of accident.

4.2 Data collection and mapping on maritime claims along the NSR

Based on multi-source databases already mentioned and Fedi et al. (2019), we identified 36 events involving SOLAS vessels that occurred along the NSR from 2004 to 2017. The ship's name, its type, its ice class, year of event, and factor, that is to say the root cause of these events were collected. We classified them either as 'Marine Incident' (MI), 'Marine Casualty' (MC), 'Serious Casualty' (SC) or 'Very Serious Casualty' (VSC), depending on their respective consequences pursuant to the Casualty Investigation Code (IMO, 2018).

SC represented 75% of the claims leading to 14 collisions while MI only concerned 8 events (19%) mainly involving ships stuck in ice (85%) and 2 VSC (sinking and death) were reported.

Looking at the factors, climate conditions were dominant and at the origin of 85% of MI, 44.4% of SC and 100% of VSC respectively. In most cases, ice represented 65% of claims. Ice impacts were not homogeneous leading either to MI without detrimental consequences for ship and crew such as drift, ship stuck or to SC involving grounding and collision. The other key factor was human for 22 % of the cases and responsible for SC such as injury (2), fire (2) and collision (4). Mechanical issues accounted for 13% of MI (1) and SC (4) contributing to vessel's drift (MI), fire, mechanical damage and miscellaneous issues (SC).

Insert Figure 2 here

As illustrated in Figure 2, the claims are progressively fewer in the northern part of the NSR during the period 2004-2017. The Barents Sea concentrated the highest number of claims with a total of 13 out of 36 representing 36% of events and can be considered as the most significant accidental area along the NSR. Five claims were due to climate conditions and 5 to human error. The Kara Sea can be analyzed as the second most dangerous area with 6 claims accounting for 20% of the total. This sea is made up of several straights through isles and archipelagoes creating difficult sailing conditions especially when ice is present. Climate remained the determining factor in the Kara Sea (for 3 claims out of 7). Ice was also involved in three claims in the Pechora Sea (1) and the White Sea (2). As regards the Chukchi Sea, only three claims are recorded and worth 8.3% of the total. Nevertheless, SC systematically occurred in this area, mainly collisions, ice factor contributing to two thirds of events.

The fact that most of the casualties occurred in the Western part of the NSR (24 out of 36) makes sense since the main oil and gas fields are exploited in this area. Indeed, we could cite the shuttle tankers between Prirazlomnoye in Pechora Sea and Murmansk or sailing of tankers between Novy Port (Yamal Peninsula) and Murmansk. Moreover, if navigation in convoy with an icebreaker mitigates the risk represented by ice, it may be at the origin of collisions (Zhang et al., 2017)¹.

4.3 Case studies: evaluation analysis and discussion

As explained previously, tankers, general cargo and dry bulk represent the largest share of accidents faced by SOLAS vessels in the Arctic. We analyzed three cases: *Sinegorsk* (bulk carrier), *Inger* (general cargo), and *Chukotka* + (tanker). Insofar as ice and human error are the two main factors of risk occurrence, these cases are analyzed through the scope of

¹ http://arctic-lio.com/wp-content/uploads/2018/05/news_2017-04-25_Helsinki.pdf

POLARIS in order to determine if they could have been avoided and to evaluate the potential limits of this system as a decision tool for deck officers in light of PC provisions.

Table 3 summarizes the RIO of each vessel pursuant to its ice class and the ice conditions encountered when the accident occurred. To define the predictability of the event, we computed the RIO one week before and after the event, and the probability of ice conditions. We assessed the RIO according to worst, median and best-case scenario.

Insert Table 3 here

4.3.1 Case analysis

4.3.1.1 Inger case

On 19 March 2006, the general cargo *Inger* was sailing in the White Sea while it sustained damage following contact with ice. According to the POLARIS RIO, the *Inger* should have experienced favorable operating conditions as shown in Figure 3. However, its 11.83 RIO (Table 4) means that ice drifting may have existed. Indeed, the vessel collided with drifting ice that seriously impacted the hull and the propeller shaft. The ship was stopped for two months in a shipyard and returned to service on 17 May with detrimental economic consequences.

As previously explained, this event puts emphasis on the importance of voyage planning as imposed by the new PC and indirectly raises the question of officers' experience in polar navigation that is now framed by the said PC.

Insert Figure 3 here

4.3.1.2 Sinegorsk case

The M/V *Sinegorsk* was sailing from Arkhangelsk to Pevek in convoy with the M/V *Johann Mahmastal* assisted by the diesel icebreaker *Admiral Makarov* in order to supply cargo. While the goods were supposed to be delivered on 30 December 2016, they arrived on 7 January 2017.

The *Sinegorsk* is an ice-class 1AS vessel meaning that according to Konygin et al. (2015), it shall not be able to sail in ice with a thickness above 0.8 meters. Table 3 stresses that the situation faced by the vessel could have been anticipated. In fact, one week before and after the RIO is below -10, which is its maximum limit. Moreover, based on ice conditions over the last 28 years, one notices that the area is barely navigable for an ice class 1AS in two scenarios out of three (Table 3).

Figure 4a highlights that the vessel is surrounded by ice conditions representing a direct danger. In other words the 7.44 RIO has to be put in perspective with the RIO in the vicinity. This approach is confirmed by Figure 4b and 4c that show the existence of red zone remaining close to the bay entrance. Indeed, ice conditions changed and the ice thickness reached 1m with ridges at 2.5 meters, blocking the convoy at the entrance to Chaunskaya Bay, 24 miles from Pevek² and leading to an eight-day delivery delay. In such circumstances, if the PC had been in force, the mandatory PWOM would have required anticipated scenarios of operating and environmental conditions.

Insert Figure 4a here

Insert Figure 4b, 4c, 4d here

² <https://gcaptain.com/russian-vessel-convoy-beset-ice-northeast-passage/>

4.3.1.3 *Chukotka +*

On 30 October 2017, as it was sailing, the tanker *Chukotka +* became stuck in the ice close to the Sannikov Strait. Regarding POLARIS RIO (Figure 5), the vessel was sailing in a safe area and the ice conditions that day were median (10.10). A 45 cm ice thickness covered 99% of the area. As explained by Faury and Givry, (2017), a 1A should not be able to sail on its own with a thickness above 30 cm. Even though the tanker was not damaged nor did an oil spill occur, the vessel had to wait 12 days for the assistance of the nuclear icebreaker *Yamal*³ and faced related unexpected expenses.

Consequently, this claim stresses the importance of the captain's ability to assess the ship's capabilities. If the PC had been in force, the master would have defined voyage planning beforehand and respected the PWOM with related operational limitations.

Insert Figure 5

5. *Discussion and managerial implications*

Whereas the recorded shipping accidents do not pretend to constitute an exhaustive database, their analysis provides a basis on NSR accidentology pursuant to the IMO taxonomy during the 2004-2017 period. Obviously, most of these events are 'casualties' illustrating their seriousness. With regard to accident factors, our assessment highlights that climatic conditions and ice remain key determining causes of risk occurrence (AMSA, 2009; Marchenko, 2012a; ABS, 2014; Abassi et al., 2017). Collisions represent the most frequent SC while ships stuck and drifts constitute the common MI showing that ice conditions along NSR are still challenging for ships (Vihanninjoki, 2014; Marchenko, 2014a, 2014b). Moreover, human factor is identified as the second cause of claims in the Russian Arctic and emphasizes the importance of training and experience in Polar areas (Tikka et al, 2008; Kum and Sahin, 2015) as currently required by the PC (Fedi et al., 2018a).

With regard to the typology of vessels, our analysis shows that 25% of events involve tankers, 19.4% general cargo and 16.7% bulk carriers. Insofar as raw materials are mainly carried along the NSR (Faury and Cariou, 2016), this statement is hardly surprising. Nevertheless, tankers face most SC in particular collisions. It raises the topical issue of oil spills and their environmental impact in fragile Arctic eco-systems (AMSA, 2009; 2017). Considering the strategic role of the NSR in the exportation of Russian oil products, this traffic is expected to grow while related risks shall proportionally increase. A worst-case scenario cannot be excluded (Fedi et al., 2018a; Johannsdottir and Cook, 2019) and the low density of SAR infrastructure heightens the threat of oil spills (Vihanninjoki, 2014). Finally, one observes the absence of passenger vessel claims along the NSR with contrast to the 27 events recorded by AMSA (2009).

Through the case studies, we underlined the potential contribution of POLARIS as a risk mitigation tool for ice-covered areas and the importance of officers' competencies and experience. POLARIS implementation prior to 2018 would certainly have prevented accidents occurring along the NSR where ice still involves huge risks. Nevertheless, as the cases implicitly revealed, this system shows some limitations and requires complementary measures for an appropriate decision-making. POLARIS is not self-sufficient since it only covers ice conditions which constitute a sole parameter of ship's operational limitations (Fedi et al., 2018b). Whereas the human factor is particularly important, it is not included in

³ <https://thebarentsobserver.com/en/arctic/2017/12/emergency-arctic-waters-oil-tanker-gets-stuck-ice-drifts-ashore>

POLARIS. The AMSA report (2009) highlighted the determining role of human factor with 76.7% of the total number of accidents in Arctic waters. That is why POLARIS needs to be apprehended and completed by PC tools. According to the PC, officers must indeed consider the vessel's capabilities to sail through or in ice-covered areas thanks to the PSC in particular and also evaluate a wide range of operating and environmental conditions beyond ice. This relates to low air temperature, high latitude, remoteness or weather conditions. In addition, appropriate voyage planning must be conducted and officers shall respect the PWOM and related procedures on operational limitations based on anticipated scenarios addressing key risks and normal and emergency conditions (DNV-GL, 2017). If the worst-case scenario was further envisaged by officers, it would allow different decisions such as the choice of different routes or the recourse to icebreaker assistance. Here, the PC requirements on specific polar crew's certification compensates for the POLARIS shortage on human element. Accordingly, this system cannot be 'disconnected' from the key PC provisions such as PSC, PWOM, voyage planning, experienced and trained crew members in treacherous waters still poorly or uncharted (hydrography and bathymetry) with frequent fogs, icy blizzards, and blocks of drifting ice (ABS, 2014). Thus, the implementation of POLARIS combined with the PC enable operators to adopt a proper formal risk assessment for undertaking a journey via the NSR and to prevent risk occurrence in a prophylactic way.

Furthermore, the beneficial impacts of POLARIS system must be evaluated in the medium and long-run and especially in light of greater maritime activities in the Russian Arctic. As a modern methodology for assessing ship's operational capabilities, the benefits of POLARIS must be promoted by Arctic stakeholders, classification societies, shipowners and underwriters in particular. This promotion seems necessary insofar as POLARIS is not mandatory. As stated in the PC Recommendations Part-I-B (IMO, 2014), other methodologies can be used. The Arctic Shipping Best Practice Information Forum that aims to promote the PC and to support some form of good practice for Arctic shipping (AMSA 2017; Fedi et al., 2018a) provides a relevant setting for this promotion.

These preliminary results should allow Arctic states, maritime operators such as shipowners, classification societies and underwriters who need statistics in particular (Kiiski, 2017; Fedi et al., 2018a) to have a better operational knowledge on past claims that occurred along the NSR (Schmied et al., 2016). Nevertheless, if universal regulation such as the PC and more realistic operational risk appraisal as POLARIS are necessary, they are not sufficient to holistically manage Arctic shipping risk. Through a general examination, one should not overlook potential severe accidents (Marchenko et al., 2015; Fedi et al., 2018a) and notably underestimate the dangers of some bulks (e.g. oil products and minerals) to the environment in case of accident. It is not necessary to wait for a second Exxon Valdez or Titanic before making changes. Public and private stakeholders must proactively work in close collaboration not only for prevent and reduce current casualty rates in the coming years but also to provide the required responses to emergency preparedness with adequate places of refuge and SAR infrastructures (Gritsenko and Efimova, 2017).

Finally, pursuant to the PAME 2019-2021 Work Plan (PAME, 2019), the Compendium of Arctic Shipping Accidents (CASA) should be created with the purpose of providing up-dated data on the Arctic Ocean. It should constitute a valuable source of information for more exhaustive analysis on the nature of accidents, their location, their impacts and contemplating measures that might be pursued to reduce their occurrence. If Russia participated in this database, it would allow an accurate identification and mapping of shipping accidentology along the NSR with a greater transparency.

6. Concluding remarks

So far, few works of research have been carried out following the IMO Casualty Investigation Code and providing a global approach of accidents in the Russian Arctic. The analysis gave an overall picture of the situation and underlined that serious casualties represented the largest number of events. Our results confirmed the role of ice as determining factor in marine casualties during the 2004-2017 period. In light of growing traffic along the NSR, these preliminary results allow stakeholders to have a better knowledge on past accidents and to carry out a better formal risk assessment for undertaking a journey via the NSR. This risk evaluation must not be neglected considering that the NSRA has recently observed numerous violations of rules (NSRA, 2017).

The second contribution of the research was to highlight the relevance of the POLARIS instrument combined with the PC in the shipping risk mitigation for the NSR ice-covered areas. Through the case studies, we have shown that the couple POLARIS – PC constituted a valuable decision support tool and an appropriate mitigation response to ice risk which remains one of the greater hazards in the Russian Arctic. Yet we also emphasized the importance of the officers' skills and actual experience to assess situations properly and the capacity of their vessel to sail in risky areas. Moreover, sailing in apparent safe areas does not mean that there is no danger as the *Inger* and *Chukotka* + cases pointed out.

Regarding the limitations of the study, the provided information is not exhaustive and does not constitute a database while different sources were used in order to optimize the statistics. Besides, our analysis is mainly based on three case studies. Consequently, future research should evaluate if the same results can be duplicated in other case studies with similar contexts. In addition, considering the recent entry into force of the PC, operators are in a transition phase and a certain time is necessary to assess the long-term impacts on the NSR. Nevertheless, the new prophylactic PC provisions associated with POLARIS should contribute to a reduction of insurance claims in the long run. This analysis is a part of our research agenda and should be facilitated by the access to the promising Compendium of Arctic Shipping Accidents.

References

- ABS. 2014. "Navigating the Northern Sea Route – Status and Guidance." American Bureau of Shipping Advisory, 28 pages.
- Abbassi, R., Khan, F., Veitch, B. and Ehlers, S. 2017. "Risk analysis of offshore transportation accident in Arctic waters." *International Journal of Maritime Engineering*, Vol 159, Part A3, Jul-Sep 2017, A213-A224.
- ALLIANZ. 2018. Safety and shipping review: an annual review of trends and developments in shipping losses and safety. www.agcs.allianz.com/assets/PDFs/Reports/AGCS_Safety_Shipping_Review_2018.pdf.
- ALLIANZ. 2017. Safety and shipping review: an annual review of trends and developments in shipping losses and safety. www.agcs.allianz.com/assets/PDFs/Reports/AGCS_Safety_Shipping_Review_2017.pdf.
- AMSA. 2009. Arctic Marine Shipping Assessment 2009 Report. Arctic Council, April 2009, second printing. <http://www.arctic-council.org/index.php/en/documentarchive/category/20-main-documents-from-nuuk>
- AMSA. 2017. Status on Implementation of the AMSA 2009 Report Recommendations. May 2017. https://oaarchive.arctic-council.org/bitstream/handle/11374/1957/PAME_4th-AMSA_Implementation_Progress_Report_for_the_period_2015-2017.pdf.
- Balto, J.B.H. 2014. "Risk of Ship Collision in the Barents Sea in 2030." Department of Engineering and Safety. UiT The Arctic University of Norway, Norway, p. 60.
- Borgerson, S.G. 2008. "Arctic meltdown: the economic and security implications of global warming." *Foreign Aff.* 87, 63–77.
- Cajaiba-Santana, G., Faury, O., & Ramadan, M. 2020. "The emerging cruise shipping industry in the arctic: Institutional pressures and institutional voids." *Annals of Tourism Research*, 80, 102796.
- Cariou, P., & Faury, O. 2019. "An economic analysis on the NSR viability of an ice-class 1A oil tanker vessel." *Arctic Shipping: Climate Change, Commercial Traffic and Port Development*.
- Cariou, P., Cheaitou, A., Faury, O., & Hamdan, S. 2019. "The feasibility of Arctic container shipping: the economic and environmental impacts of ice thickness." *Maritime Economics & Logistics*, 1-17.
- Copernicus Data Base, 2018, <http://www.copernicus.eu/main/marine-monitoring>. (retrieved, 1 July 2019)
- Dalaklis, D., Baxevani, E., & Siousiouras, P. 2018. "The future of Arctic shipping business and the positive influence of the international code for ships operating in polar waters." *The Journal of Ocean Technology*, Vol 13 (4) pp 76-94.
- DNV-GL. 2017. "Maritime Polar Code. Understand the code's requirements to take the right steps for smooth compliance." 31 p., Hamburg.
- Eguíluz, V. M., Fernández-Gracia, J., Irigoien, X., & Duarte, C. M. 2016. "A quantitative assessment of Arctic shipping in 2010–2014." *Scientific Reports* , 6, 30682.
- EU Commission. 2015. "Copernicus Europe's eyes on Earth. European Commission", Directorate-General for Communication, Publications 1049, Brussels, Belgium available on line:

https://www.copernicus.eu/sites/default/files/documents/Copernicus_brochure_EN_web_Oct2017_0.pdf

Faury, O., Fedi, L., Etienne, L., Rigot-Müller, P., Stephenson, S. & Cheaitou, A. 2019, 'La Route Maritime Nord : complément ou concurrent des routes conventionnelles ?' *Baltic-Arctic: Strategic perspective*, Edition Océanides, septembre, pp. 169-190.

Faury, O., & Cariou, P. 2016. "The Northern Sea Route competitiveness for oil tankers." *Transportation Research Part A: Policy and Practice*, 94, 461-469.

Faury, O. 2015. "Risk management in the Arctic from an underwriter's perspective. IAME Conference, Kuala-Lumpur, 24-26 August 2015.

Fedi, L. 2020. "Arctic Shipping Law From Atomised Legislations to Integrated Regulatory Framework: The Polar Code (R)Evolution?" In Lasserre, F. and Faury, O. Arctic Shipping, Climate Change, Commercial Traffic and Port Development, 117-136, *Routledge Oxon*, New York.

Fedi, L. & Faury, O. 2016. "Les Principaux Enjeux et Impacts du Code Polaire OMI." ["The main stakes and impacts of the IMO Polar Code"], *Le Droit Maritime Français* 779: 323-337.

Fedi, L., Faury, O., & Gritsenko, D. 2018a. "The impact of the Polar Code on risk mitigation in Arctic waters: a 'toolbox' for underwriters?" *Maritime Policy and Management*, Vol. 45, No. 4, pp. 478-49. doi.10.1080/03088839.2018.1443227.

Fedi, L., Etienne, L., Faury, O., Rigot-Müller, P. Stephenson, S. & Cheaitou, A. 2018b. "Arctic Navigation; Stakes, Benefits, Limits of the Polaris System." *The Journal of Ocean Technology*, Vol. 13, No. 4, 2018, 54-67.

Fedi, L., Faury, O., Etienne, E., & de Ferrière le Vayer, A. 2019. "Mapping and analysis of maritime claims in the Russian Arctic based on POLARIS System." IAME Conference, Athens, June 25th – 28th 2019.

FoU-RAPPORT. 2016. Borch, O.J., Andreassen, N., Marchenko, N., Ingimundarson, V., Gunnarsdóttir, H., Jakobsen, U., Kern, B. Iudin, U., Petrov, S., Markov, S. and Kuznetsova, S. "Maritime activity and risk patterns in the High North MARPART Project Report 2. " Nord universitet, FoU-rapport nr. 4, 133 pp.

Fu, S., Zhang, D., Montewka, J., Yan, X., & Zio, E. 2016. "Towards a Probabilistic Model for Predicting Ship Besetting ice in Arctic Waters." *Reliability Engineering & System Safety* 155: 124-136.

Goerlandt, F., Goite, H., Valdez Banda, O., Höglund, A., Ahonen-Rainio, P., & Lensu, M. 2017. "An analysis of wintertime navigational accidents in the Northern Baltic Sea," *Safety Science* 92, 66–84.

Grabowski, M., You, Z., Zhou, Z., Song, H., Steward, M., & Stewards, B. 2009. Human and organizational error data challenges in complex, large-scale systems. *Safety Science* 47, 1185–1194.

Gritsenko, D. & Efimova, E. 2017. "Policy environment analysis for Arctic seaport development: the case of Sabetta (Russia)." *Polar Geography* Vol. 40, 186-207, <http://doi.org/10.1080/1088937X.2017.1328466>

Gritsenko, D. & Kiiski, T. 2016. "A review of Russian ice-breaking tariff policy on the northern sea route 1991–2014." *Polar Record* Vol. 52(2) 144-158. .DOI: <http://dx.doi.org/10.1017/S0032247415000479>.

- Haavik, T.K. 2017. "Remoteness and Sensework in Harsh Environment." *Safety science* 95: 150-158. doi:10.1016/j.ssci.2016.03.020.
- IHS Markit, 2019. <https://ihsmarkit.com/index.html>.
- IMO. 2008. Resolution MSC.255(84) adopted on 16 May 2008 adoption of the Code of the international standards and recommended practices for a safety investigation into a marine casualty or marine incident (Casualty Investigation Code).
- IMO. 2014a. Resolution MSC 385 (94) of November 21, 2014 and Resolution MEPC 264 (68) of May 15, 2015. International Code for Ships Operating in Polar Waters (Polar Code).
- IMO. 2014b. Maritime Safety Committee POLARIS – proposed system for determining operational limitations in ice. Submitted by the International Association of Classification Societies, MSC 94/3/7, 9th Session, Agenda 3, September 12, 2014.
- IMO. 2014c. Maritime Safety Committee – technical background to POLARIS. Submitted by Canada, Finland, Sweden, and the International Association of Classification Societies, MSC 94/INF13, 9th Session, Agenda 3, September 12, 2014.
- IMO. 2016. "MSC. 1/Circ 1519, 6 June 2016, Guidance on Methodologies for Assessing Operational Capabilities and Limitations in Ice." [https://docs.imo.org/Final Documents/English/MSC.1-CIRC.1519\(E\).docx](https://docs.imo.org/Final Documents/English/MSC.1-CIRC.1519(E).docx).
- IPCC. 2018. Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]
- Johannsdottir, L. & Cook, D. 2019. "Systemic risk of maritime-related oil spills viewed from an Arctic and insurance perspective." *Ocean and Coastal Management*: 179 (2019) 104853
- Iudin, I. & Petrov, S. 2016. "The Russian Sea Areas and Activity Level Up to 2025." From the report: Maritime activity in the High North - current and estimated level up to 2025, MARPART Project Report 1. Nord Universitet, No 7. Bodø 2016.
- IUMI, 2018. Global marine insurance report 2018. Cape-Town, 16-19 September 2018. https://cefor.no/globalassets/documents/statistics/iumi-statistics/2018/monday-1155-seltmann_final.pdf.
- Kiiski, T. 2017. "Feasibility of Commercial Cargo Shipping along the Northern Sea Route." *Annales Universitatis Turkuensis*, University of Turku.
- Kitagawa, H. 2008. "Arctic routing: challenges and opportunities." *WMU Journal of Maritime Affairs* 7, 485–503.
- Konygin, A., Nekhaev, S., Dmitruk, D., Sevastyanova, K., Kovalek, D., & Cherenko, V. 2015. "Oil Tanker Transportation." In: The Russian Arctic. *International Journal of scientific & technology. Research volume* 4(03): 27-33.
- Kujala, P., Kämäinen, J., & Suominen, M. 2016. "Challenges for Application of Risk Based Design Approaches for Arctic and Antarctic Operations." 6th International Maritime Conference on Design for Safety, Hamburg, Germany, 28-30.11.2016.

- Kum, S. & Sahin, B. 2015. "A root cause analysis for Arctic marine accidents from 1993 to 2011." *Safety Science*, Vol. 74, pp. 206-220. doi:10.1016/j.ssci.2014.12.010
- Ladan, M., & Hänninen, M. 2012. "Data Sources for Quantitative Marine Traffic Accident Modeling." *Science + Technology* No. 11/2012. Aalto University publication series Science + Technology. Aalto University, Department of Applied Mechanics, Helsinki, Finland.
- Lasserre, F. 2016. "Polar seaways? Maritime transport in the Arctic: an analysis of shipowners' intentions II." *Journal of Transport Geography*, 57
- Lasserre, F. 2014. "Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector." *Transp. Res. Part A* 66, 144– 161.
- Lasserre, F. Meng, Q. Zhou, C. Têtu, P.-L. & Alexeeva, O. 2020. Compared transit traffic analysis along the NSR and the NWP, in F. Lasserre and O. Faury (Eds): *Arctic Shipping. Climate Change, Commercial Traffic and Port Development*, 71-93. Routledge: Oxon, New York.
- Löptien, U., & Axell, L. 2014. "Ice and AIS : Ship speed data and sea ice forecast in the Baltic Sea." *The Cryosphere*, 8, 2409-2418, 2014 <www.the-cryosphere.net/8/2409/2014/> doi:10.5194/tc-8, 2409-2014.
- Liu, M. & Kronbak, J. 2010. "The potential economic viability of using the Northern Sea Route as an alternative route between Asia and Europe." *Journal of Transport Geography*, Vol. 18, Issue 3, p 434-444.
- Luo, M. & Shin, S.H. 2019. "Half-century research developments in maritime accidents: Future directions", *Accident Analysis and Prevention* 123 (2019) 448–460.
- Marchenko, N. 2012a. "Ice Conditions and Human Factors in Marine Accidents at the Arctic." The University Centre in Svalbard, Longyearbyen, Norway.
- Marchenko, N. 2012b. "Russian Arctic Seas: navigational conditions and accidents." Heidelberg: Springer.
- Marchenko, N., 2014a. "Northern Sea Route: Modern state and challenges." Proceedings of the 33rd International conference on ocean, offshore and arctic engineering. OMAE2014. June 8-13, San Francisco, CA.
- Marchenko, N., 2014b. "Floating Ice Induced Ship Casualties." In *22nd IAHR International Symposium on Ice, Singapore*.
- Marchenko, N., Borch, O., Markov, S., & Andreassen, N. 2015. "Maritime activity in the high North – the range of unwanted incidents and risk patterns." Proceedings of the 23rd International conference on port and ocean engineering under Arctic conditions (June 14–18, 2016)
- Melia, N. Haines, K., & Hawkins, E. 2016. "Sea ice decline and 21st century trans-Arctic shipping routes." *Geographical Research Letters* 43:9720-9728.
- MINISTRY OF ENERGY OF THE RUSSIAN FEDERATION. 2010. "Energy Strategy of Russia for the period up to 2030." Decree N°1715-r of the Government of the Russian Federation dated 13 November 2009, 174 pages.
- Montewka, J., Goerlandt, F., Kujala, P., & Lensu, M. 2015. "Towards a Probabilistic Model of a Ship Performance in Dynamic Ice." *Cold Regions Science Technology* 112: 14-28.
- National Snow & Ice Data Center (NSIDC). 2014. http://nsidc.org/data/docs/noaa/g02135_seaice_index/index.html#processingstep.

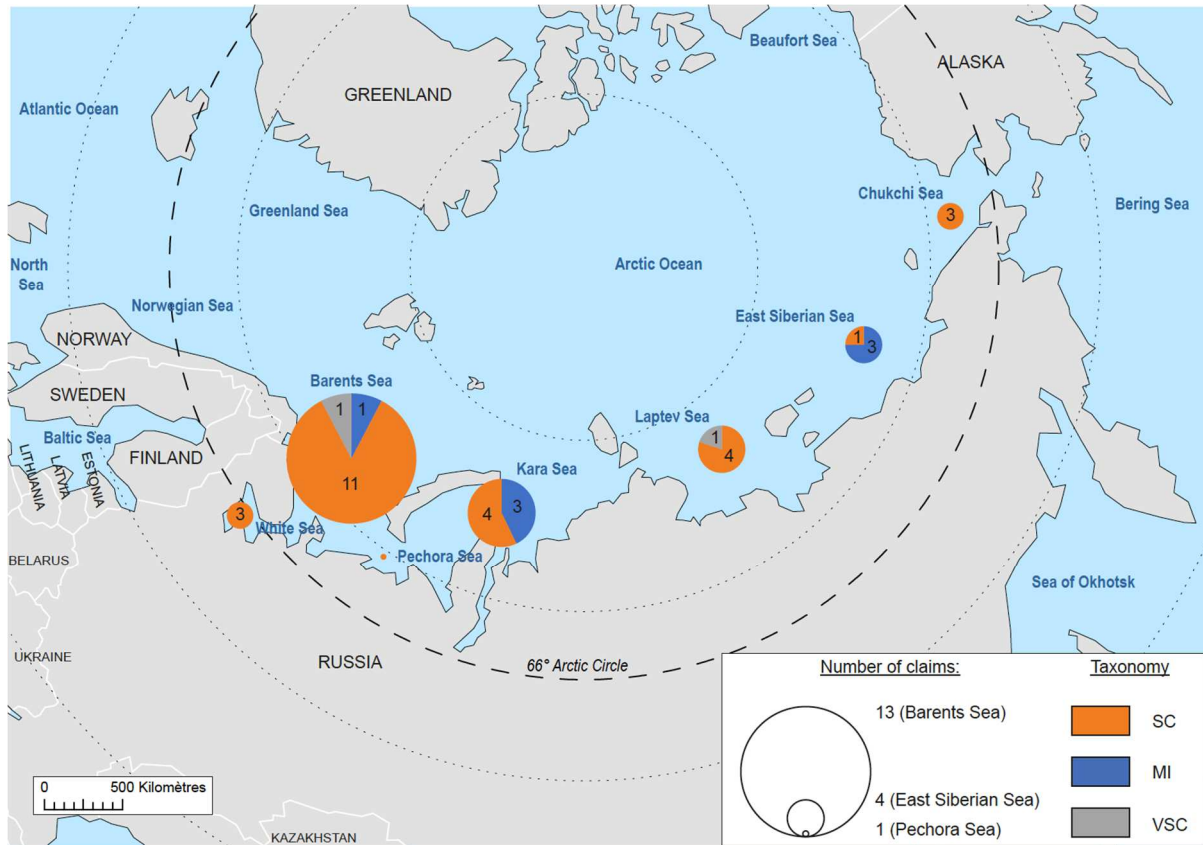
- NSRA (Northern Sea Route Administration), 2012. The Federal Law of Shipping on the Water Area of the Northern Sea Route July 28, 2012, N 132-FZ. http://www.nsra.ru/en/ofitsialnaya_informatsiya/zakon_o_smp.html.
- NSRA 2017. Violation of the Navigation Rules on the NSR. Accessed 5 January 2019. <http://www.arctic-lio.com/node/2777>.
- NSRA 2018. Northern Sea Route Administration. http://www.nsra.ru/en/glavnaya/ceci_funktsii.html.
- PAME, 2019. PAME work plan 2019-2021. <https://www.pame.is/index.php/document-library/pame-reports-new/pame-ministerial-deliverables/2019-11th-arctic-council-ministerial-meeting-rovaniemi-finland/426-pame-2019-2021-work-plan/file>.
- Sarrabezoles, A., Lasserre, F., & Hagouagn'rin, Z. 2014. "Arctic shipping insurance: towards a harmonisation of practices and costs?" *Polar Record* 52(04): 393-398.
- SARC, 2017. "Arctic Search and Rescue Capabilities Survey. Enhancing International Cooperation." 56 Pp.
- Serreze, M.C. and J. Stroeve. 2015. "Arctic sea ice trends, variability and implications for seasonal ice forecasting." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 373(2045), 20140159.
- Staalesen, A. 2019a. "Ministry hints Putin's Arctic ambitions are not realistic." *The Barents Observer*. January 18, 2019. <https://thebarentsobserver.com/en/arctic-industry-and-energy/2019/01/ministry-hints-putins-arctic-ambitions-are-not-realistic>.
- Staalesen, A. 2019b. "Shipping on Northern Sea Route up 40%." *The Barents Observer*. October 04, 2019 <https://thebarentsobserver.com/en/arctic-industry-and-energy/2019/10/shipping-northern-sea-route-40>.
- Staalesen, A. 2019c. "Shipping on Northern Sea Route up 63 percent." *The Barents Observer*. November 15, 2019. <https://thebarentsobserver.com/en/industry-and-energy/2019/11/shipping-northern-sea-route-63-percent>.
- Tikka, K., Riska, K., & S. Liu. 2008. "Tanker Design Considerations for Safety and Environmental Protection of Arctic Waters: Learning from Past Experience." *WMU Journal of Maritime Affairs* Vol. 7 (1): 189–204.
- Vihanninjoki, V. 2014. "Arctic Shipping Emission in the Changing Climate." Finnish Environment Institute 41.
- Zhang, Y., Meng Q., & Zhange L. 2016. "Is the Northern Sea Route attractive to shipping companies? Some insights from recent ship traffic data." *Marine Policy*, Volume 73, 53-60.
- Zhang, M., Zhang, D., Fu, S., Yan, X., & Goncharov, V. 2017. "Safety distance modeling for ship escort operations in Arctic ice-covered waters". *Ocean Engineering*, 146, 202-216.

Figure 1: Arctic ice extent in 1996, 2006 and 2012



Source: Authors based on NSIDC (2014)

Figure 2. Accident representation along the Northern Sea Route



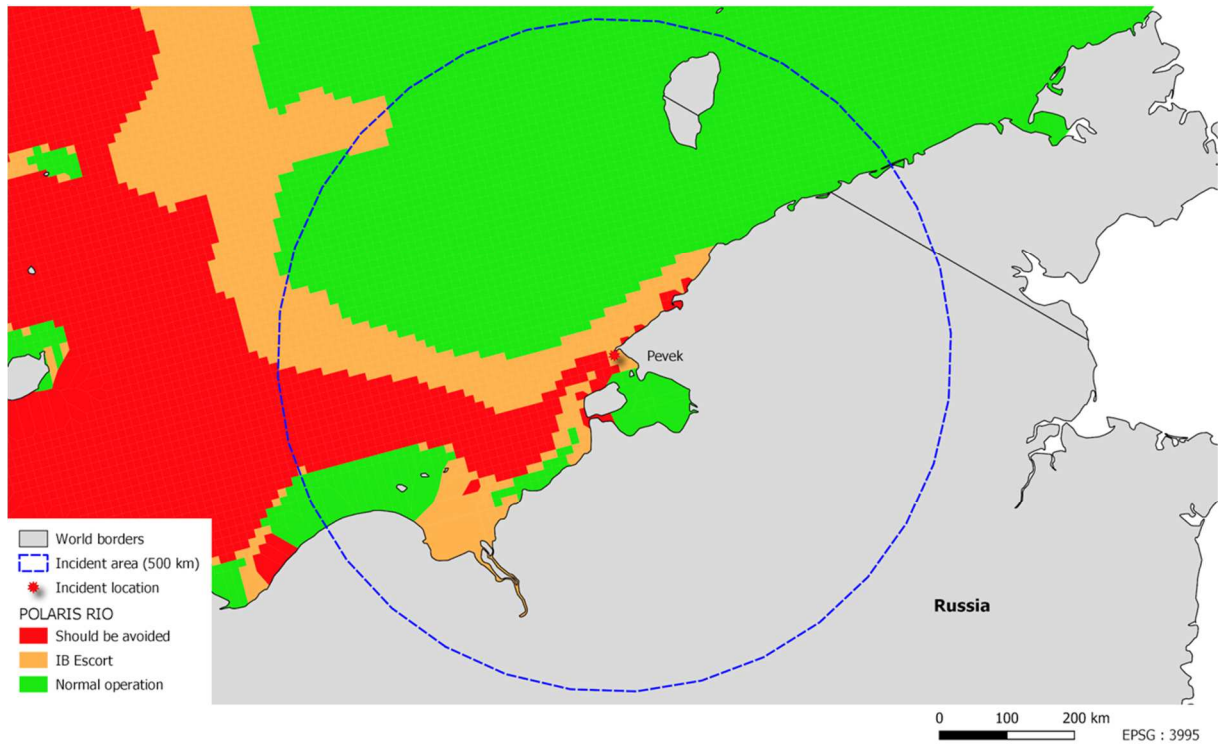
Source: Authors based on ABS (2014)

Figure 3: POLARIS Map – 1A vessel – *Inger* 03/19/2006



Source : Authors (2020)

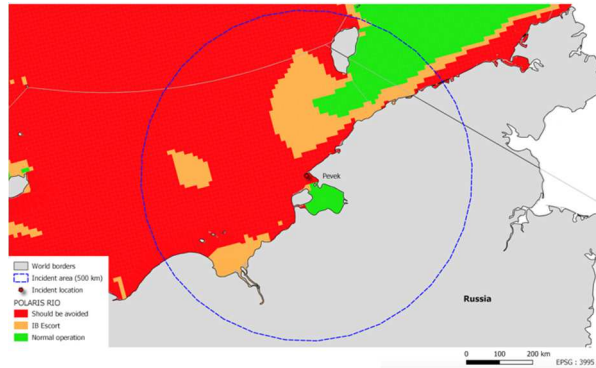
Figure 4a: POLARIS Map – 1AS vessel – *Sinegorsk* – 12/28/2016



Source: Authors (2020)

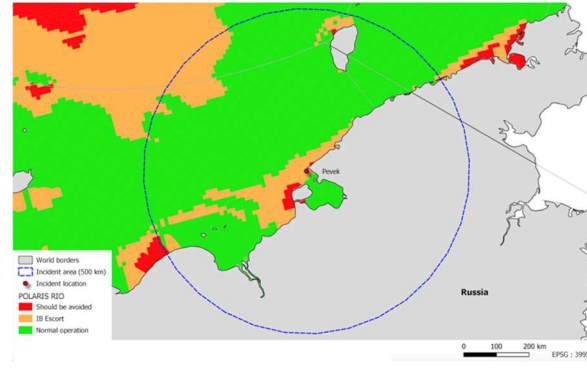
Figure 4b, 4b, 4c: POLARIS Statistics Map – *Sinegorsk* – 12/28/2016

Figure 4b: POLARIS Statistics Map – 1AS Vessel – *Sinegorsk* – December 28th – Bad Case Scenario



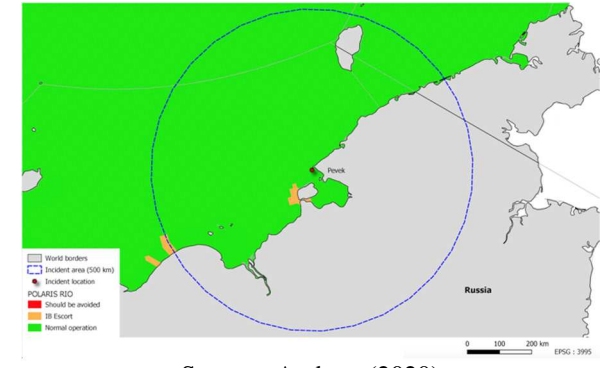
Source : Authors (2020)

Figure 4c: POLARIS Statistics Map – 1AS Vessel – *Sinegorsk* – December 28th – Median Case Scenario



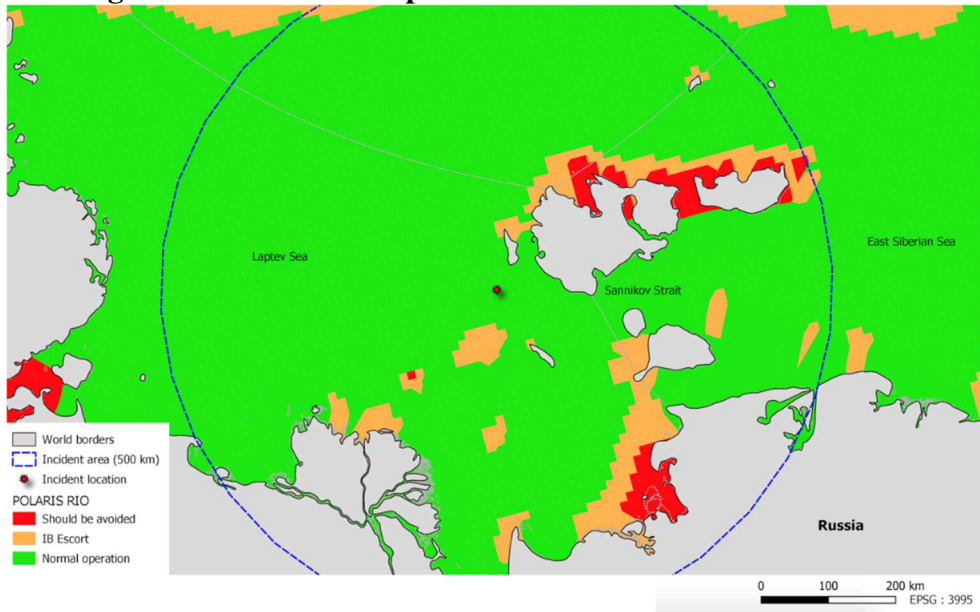
Source : Authors (2020)

Figure 4d: POLARIS Statistics Map – 1AS Vessel – *Sinegorsk* – December 28th – Best Case Scenario



Source : Authors (2020)

Figure 5: POLARIS map – 1A vessel *Chukotka* +- 30/10/2017



Source: Authors (2020)

Table 1. Taxonomy of marine incidents and casualties

Taxonomy	Marine incident	Marine casualty	
		Serious casualty	Very serious casualty
Definition	- Endangers the safety of the ship, its occupants or any other person or the environment	<ul style="list-style-type: none"> - Fire - Explosion - Collision - Grounding - Contact - Heavy weather damage - Ice damage - Hull cracking - Suspected hull defect - Material damage to a ship - Stranding or disabling of a ship - Material damage to marine infrastructure - Severe damage to the environment 	<ul style="list-style-type: none"> - Total loss of the ship - Death - Severe damage to the environment - Loss, presumed loss or abandonment of a ship

Source: Authors based on IMO Resolution MSC.255(84) 16 May 2008

Table 2. Risk Index Outcome Criteria

<i>RIO_{SHIP}</i>	<i>Ice classes PC1-PC7</i>	<i>Ice classes below PC 7 and ships not assigned an ice class</i>
$RIO \geq 0$	Normal operation	Normal operation
$-10 \leq RIO < 0$	Elevated operational risk*	Operation subject to special consideration**
$RIO < -10$	Operation subject to special consideration**	Operation subject to special consideration**

Source: IMO (2016)

Table 3: POLARIS RIO per vessel according to the three scenarios and the RIO encountered

Ship Name	Ship Ice Class	Zone	Sea	Longitude	Latitude	Date	POLARIS RIO			
							COPERNICUS	25%	50%	75%
INGER	IA	Arkhangelsk	White Sea	40.55	64.53	2006-03-12	11.54	10.61	20.49	23.53
						2006-03-18	11.09	11.51	21.82	24.65
						2006-03-19	11.83	12.18	22.30	25.04
						2006-03-20	14.09	13.08	22.10	24.99
						2006-03-26	11.62	18.14	22.36	25.93
SINEGORSK	IAS	Pevek	East Siberian Sea	170.23	70.09	2016-12-21	-19.62	-18.59	-8.20	2.16
						2016-12-27	-18.68	-19.67	-8.59	2.92
						2016-12-28	-7.44	-19.67	-9.37	0.17
						2016-12-29	-9.06	-19.57	-9.67	1.24
						2017-01-04	-19.66	-19.58	-9.53	1.38
CHUKOTKA +	IA	Sannikov Strait	Laptev Sea	134.46	75.09	2017-11-03	10.23	10.35	20.10	21.03
						2017-11-09	10.17	10.10	10.45	20.19
						2017-11-10	10.10	7.76	10.45	20.07
						2017-11-11	10.10	7.89	10.38	14.07
						2017-11-17	10.18	0.15	10.17	10.79

Source: Authors (2020)