"Navigare necesse est" – a PhD project on bio-environmental implications of shipping in the European Arctic

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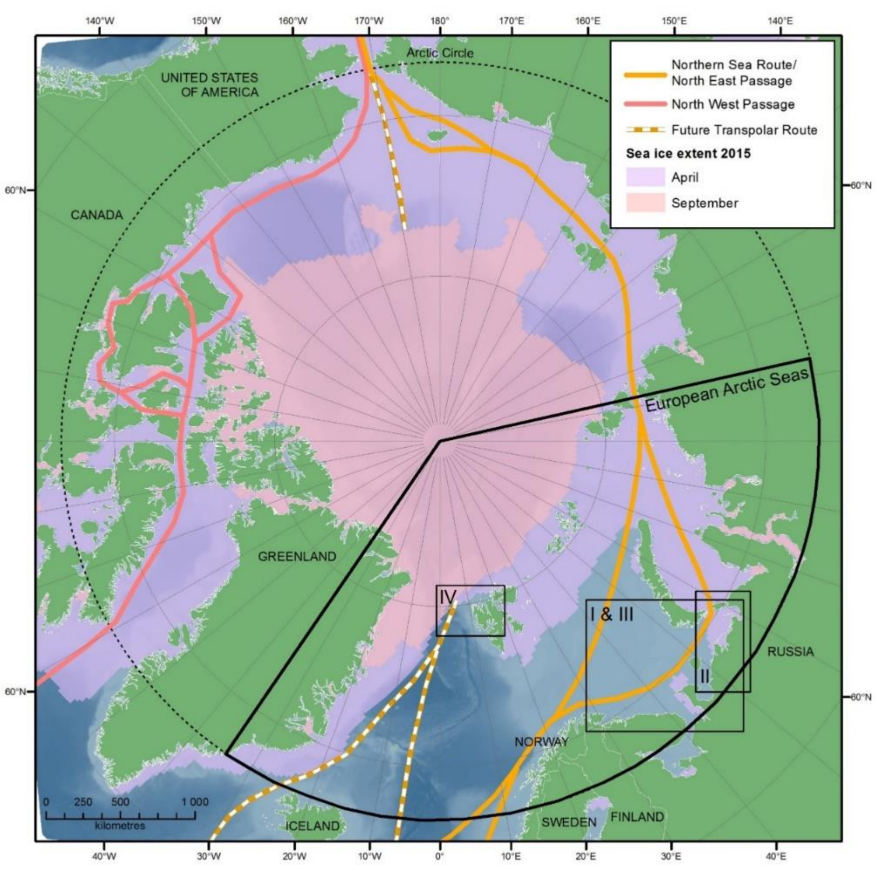
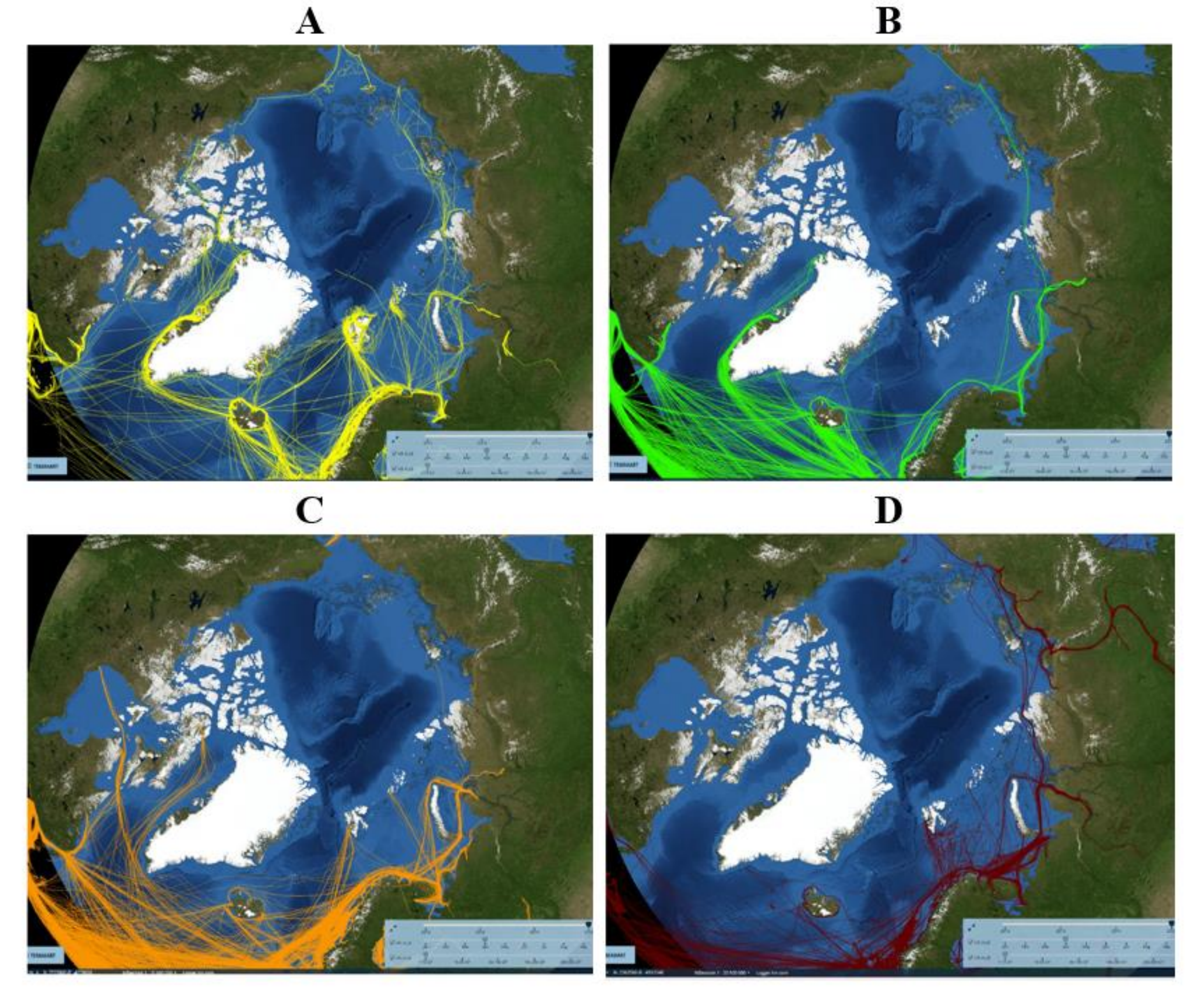
Arctic shipping background



- Lighter Arctic navigation conditions
- Drivers for both transit and destination traffic



Ships (>5000 dwt movements in the Arctic 2015 recorded AIS (excl. fishing)

A: Passenger
B: Container
C: Bulk carriers
D: Oil tankers
(Compiled by NOR VTS Vardø)

Generic impacts of shipping

Table 2 Generic environmental impact factors related to shipping, and focus topics in the Arctic (not in prioritised order).

	Shipping activity	Environmental impact	Focus in the Arctic	Reference
Physical disturbances	Physical passage (innocent passage)	Physical disturbance	Breaking of ice. Exposure of under-ice organisms to e.g. avian predators	Divoky 1976
	Noise and vibrations	Scaring of animals	On-ice whelping grounds (seals, walrus), whales, fish spawning areas	Dooling & Therrien (2012); Erbe (2012); Mckuin, & Campbell (2016)
	Breaking of ice in shore-leads	Thinner ice, broken ice floes	Indigenous fishing and livelihoods altered (social impact)	Cameron (2012)
	Navigation in shore leads, polynya and in darkness	Collisions with marine mammals	Sluggish and slow moving Arctic marine mammals	Reeves et al. (2012) Huntington (2009)
Operational discharges and emissions	Emissions of soot, black carbon, SO_2 particles incl. on-board incineration of waste	Climate warming, smothering	Local increased melting of ice	Winther et al. (2014); Aliabadi et al. (2015)
	Emission of CO_2 and other greenhouse gases (GHG)	Climate warming Ocean acidification	Potential ecosystem level impacts	Corbett et al. (2010)
	Waste water (grey- and black water)	Nutrients, contami-nants, bacteria		Loehr et al. (2006)
	Garbage (organic/ plastic/ cardboard/ plywood/ metal)	Littering	Plastic waste in global focus. Microplastics	Wilewska-Bien et al. (2016) Lusher et al. (2015)
	Oil, operational discharge	Pollution	Smothering, accumulation in fat based food chains	Ferrano et al. (2009)
	Antifouling agents (TBT and other pesticides)	Contamination, sex change in molluscs	Mostly solved by TBT ban	Dafforn et al. (2011)
	Settling organisms on ships hulls	Introduction of alien species. Biodiversity impacts	Potential ecosystem level impacts	Chan et al. (2015)
	Ballast water	Introduction of alien species. Ecosystem level impacts	Potential ecosystem level impacts.	Scriven et al. (2015) Ware et al. (2016)
Infra-structure	Harbours, Lighthouses, navigation aids	Dredging, construction works	Local habitat modifications	
	Sea charting	Vessel traffic in uncharted waters	Risk of wreckage of charting vessels, safer post survey navigation	Borgerson (2008)
Accidents	Loss of vessel, decay of wreck	Physical decay and long time release of e.g. metals, fuel and residues	Long time emissions to e.g. coastal communities at wreckage site	Schroeder et al. 2008
	Loss of cargo (containers, liquid bulk, dry bulk) excl. petroleum	Pollution, navigational hazards (e.g. floating cargo/ containers)	Most ecosystem components influenced	Breivik et al. 2012; Neuparth et al. (2011)
	Loss of propulsion fuel and petroleum cargo	Smothering, toxicity, bioaccumulation	Most ecosystem components influenced HFO restrictions, area restrictions	Muncaster et al. (2016), Paine et al. (1996), Perez et al. (2008), Webster et al. (1997)
	Impacts related to Search and Rescue (SAR)	Helicopter traffic, ships traffic	Helo/rescue vessels in sensitive areas.	Rødseth et al. (2015)

Based on literature, eighteen impact factors identified and categorised in four groups.

Key identified impact factors researched:

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Destination traffic scenario

PERSPECTIVE

Technological and environmental challenges of Arctic shipping—a case study of a fictional voyage in the Arctic

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Arctic shipping; technology; scenario; grounding; Northern Sea Route; environmental impact.

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Abstract

Shipping in Arctic seas is challenging and poses an environmental risk. This paper presents a fictional case involving a multipurpose supply vessel transporting one large object (a 750-tonne compressor) and 24 containers loaded with chemicals and equipment for use by the petroleum industry in western Siberia. With technical details representative of vessels navigating the Arctic today, the fictitious ship *Oleum* has an ice class sufficient for navigating unaccompanied in the Barents and Kara seas, so no assistance is in range when, in late October, clogged fuel filters cause engine failure and the vessel eventually drifts ashore. Heeling over, *Oleum* loses both cargo and marine diesel oil. The scenario includes a successful helicopter rescue of the 16 crewmembers and a partial recovery of oil and chemicals by booms and skimmers. Recovery of chemicals with physical properties not allowing mechanical collection is not attempted. The scenario ends as the abandoned wreck is broken down at the stranding location, and containers rupture and discharge their cargo. The scenario postulates a moderate and short-lived environmental impact. The most visible effects of the grounding are the hull itself, the compressor and the spreading effects and degradation of oil and chemicals unmanageable for the clean-up operations.

To access the supplementary material for this article, please see the supplementary file under Article Tools, online.

Assessing the potential outcomes of a variety of options through the analysis of one or more fictitious scenarios is a valuable tool for assessing and predicting human influence on nature and ecosystems. The scenario method is a robust tool for asking "what if" questions in planning for the future (Duinker & Greig 2007). Here, a scenario approach is applied to the context of Arctic shipping, with the aim of describing a chain of events that is as realistic as possible. This involves a vessel on a realistic voyage and a set of known (planned) and unplanned events, influencing the outcome. The discussion covers technological and environmental issues of Arctic shipping as exemplified by the scenario.

The vessel, voyage, time of the year and cargo were chosen to represent a type of well-established navigation expected to increase in the Barents and Kara seas, as the industry of petroleum exploration and raw material extraction evolves (Arctic Council 2009). Oil and gas operations will move northwards along the coast of Arctic Europe and Asia and the need for seaborne supplies will increase as production grows; the export of oil, gas and other raw materials by ship will increase. As the Arctic Sea ice cover recedes, both new and existing shipping routes will become ice-free and expectations for increased transport along the North-east Passage, among other routes, are high (Schoyen & Brathen 2011; Smith

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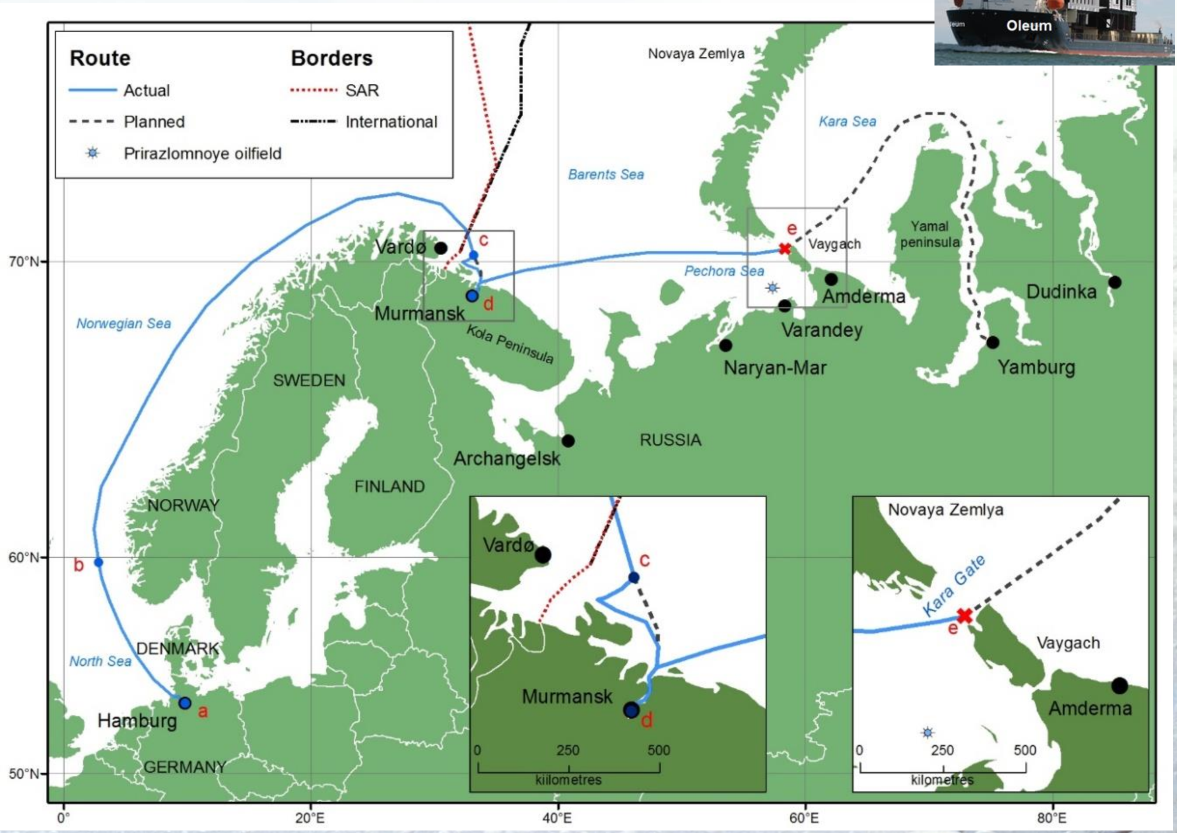
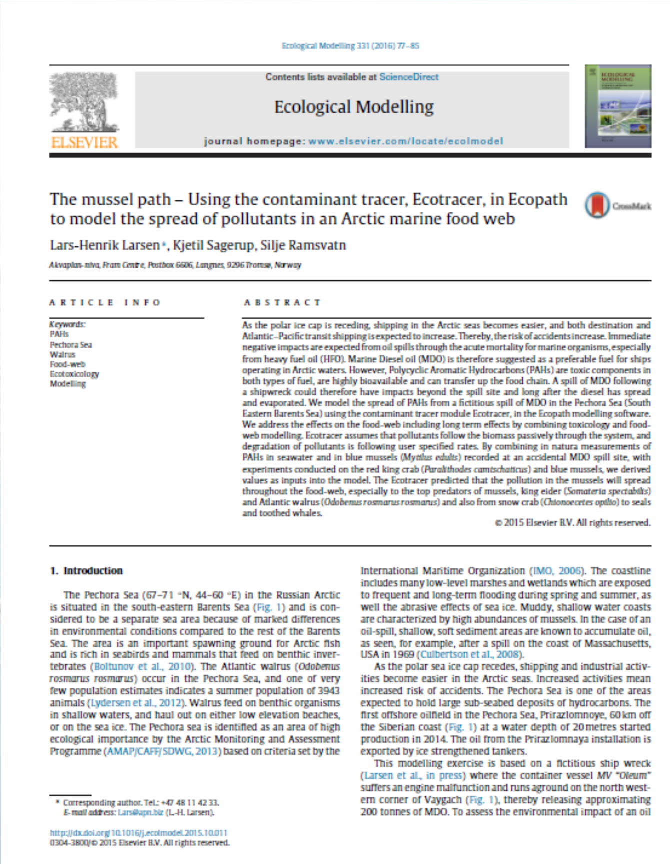


Modelling of fate of a contaminant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The mussel path – Using the contaminant tracer, Ecotracer, in Ecopath to model the spread of pollutants in an Arctic marine food web

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ABSTRACT

As the polar ice cap is receding, shipping in the Arctic seas becomes easier, and both destination and Atlantic–Pacific transit shipping is expected to increase. Thereby, the risk of accidents increase. Immediate negative impacts are expected from oil spills through the acute mortality for marine organisms, especially from heavy fuel oil (HFO). Marine Diesel oil (MDO) is therefore suggested as a preferable fuel for ships operating in Arctic waters. However, Polycyclic Aromatic Hydrocarbons (PAHs) are toxic components in both types of fuel, are highly bioavailable and can transfer up the food chain. A spill of MDO following a shipwreck could therefore have impacts beyond the spill site and long after the diesel has spread and evaporated. We model the spread of PAHs from a fictitious spill of MDO in the Pechora Sea (South Eastern Barents Sea) using the contaminant tracer module Ecotracer, in the Ecopath modelling software. We address the effects on the food-web including long term effects by combining toxicology and food-web modelling. Ecotracer assumes that pollutants follow the biomass passively through the system, and degradation of pollutants is following user specified rates. By combining in natura measurements of PAHs in seawater and in blue mussels (*Mytilus edulis*) recorded at an accidental MDO spill site, with experiments conducted on the red king crab (*Paralithodes camtschaticus*) and blue mussels, we derived values as inputs into the model. The Ecotracer predicted that the pollution in the mussels will spread throughout the food-web, especially to the top predators of mussels, king eider (*Somateria spectabilis*) and Atlantic walrus (*Odobenus rosmarus rosmarus*) and also from snow crab (*Chionoecetes opilio*) to seals and toothed whales.

1. Introduction

The Pechora Sea (67–71 °N, 44–60 °E) in the Russian Arctic is situated in the south-eastern Barents Sea (Fig. 1) and is considered to be a separate sea area because of marked differences in environmental conditions compared to the rest of the Barents Sea. The area is an important spawning ground for Arctic fish and is rich in seabirds and mammals that feed on benthic invertebrates (Boltunov et al., 2010). The Atlantic walrus (*Odobenus rosmarus rosmarus*) occur in the Pechora Sea, and one of very few population estimates indicates a summer population of 3943 animals (Lydersen et al., 2012). Walrus feed on benthic organisms in shallow waters, and haul out on either low elevation beaches, or on the sea ice. The Pechora sea is identified as an area of high ecological importance by the Arctic Monitoring and Assessment Programme (AMAP/CAFF/SDWG, 2013) based on criteria set by the International Maritime Organization (IMO, 2006). The coastline includes many low-level marshes and wetlands which are exposed to frequent and long-term flooding during spring and summer, as well the abrasive effects of sea ice. Muddy, shallow water coasts are characterized by high abundances of mussels. In the case of an oil-spill, shallow, soft sediment areas are known to accumulate oil, as seen, for example, after a spill on the coast of Massachusetts, USA in 1969 (Culbertson et al., 2008).

As the polar sea ice cap recedes, shipping and industrial activities become easier in the Arctic seas. Increased activities mean increased risk of accidents. The Pechora Sea is one of the areas expected to hold large sub-seabed deposits of hydrocarbons. The first offshore oilfield in the Pechora Sea, Prirazlomnoye, 60 km off the Siberian coast (Fig. 1) at a water depth of 20 metres started production in 2014. The oil from the Prirazlomnaya installation is exported by ice strengthened tankers.

This modelling exercise is based on a fictitious ship wreck (Larsen et al., in press) where the container vessel *MV "Oleum"* suffers an engine malfunction and runs aground on the north western corner of Vaygach (Fig. 1), thereby releasing approximating 200 tonnes of MDO. To assess the environmental impact of an oil

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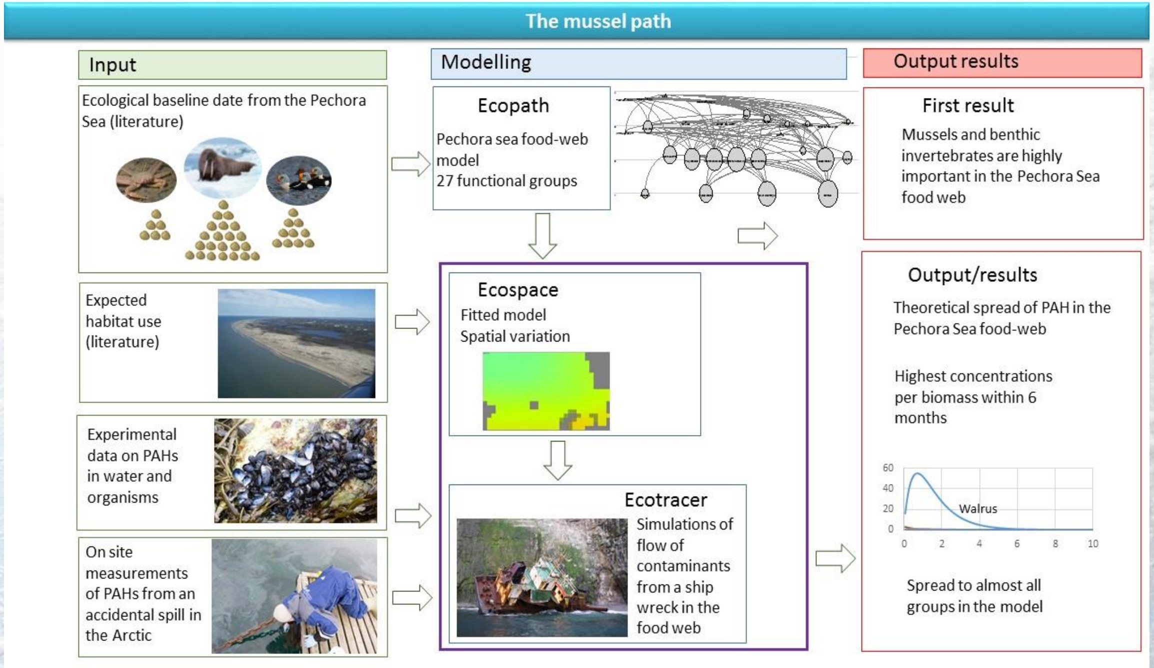
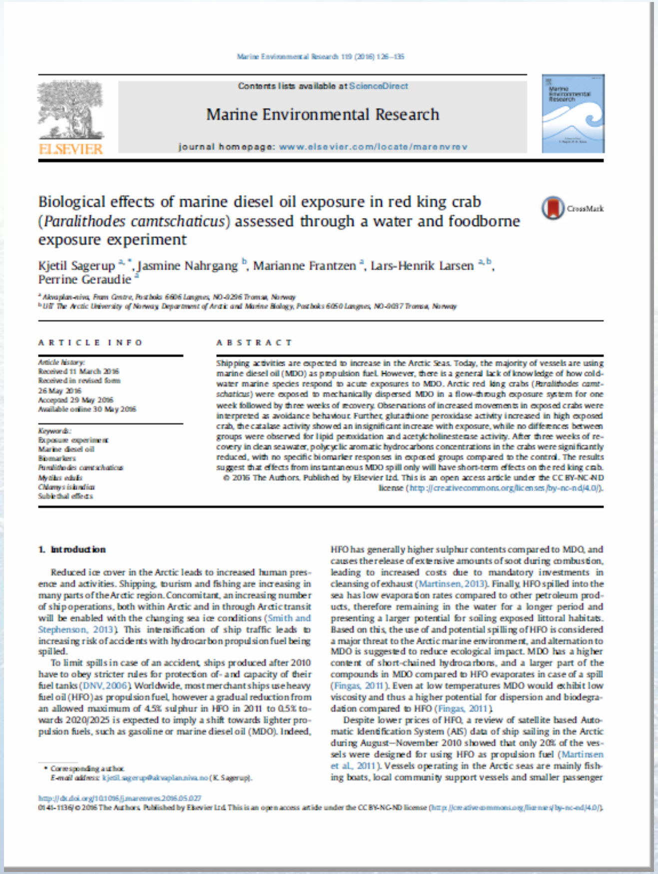


Ecotox Experiments Nov–Dec 2013



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Biological effects of marine diesel oil exposure in red king crab (*Paralithodes camtschaticus*) assessed through a water and foodborne exposure experiment

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A B S T R A C T

Shipping activities are expected to increase in the Arctic Seas. Today, the majority of vessels are using marine diesel oil (MDO) as propulsion fuel. However, there is a general lack of knowledge of how cold-water marine species respond to acute exposures to MDO. Arctic red king crabs (*Paralithodes camtschaticus*) were exposed to mechanically dispersed MDO in a flow-through exposure system for one week followed by three weeks of recovery. Observations of increased movements in exposed crabs were interpreted as avoidance behaviour. Further, glutathione peroxidase activity increased in high exposed crab, the catalase activity showed an insignificant increase with exposure, while no differences between groups were observed for lipid peroxidation and acetylcholinesterase activity. After three weeks of recovery in clean seawater, polycyclic aromatic hydrocarbons concentrations in the crabs were significantly reduced, with no specific biomarker responses in exposed groups compared to the control. The results suggest that effects from instantaneous MDO spill only will have short-term effects on the red king crab.

1. Introduction

Reduced ice cover in the Arctic leads to increased human presence and activities. Shipping, tourism and fishing are increasing in many parts of the Arctic region. Concomitant, an increasing number of ship operations, both within Arctic and in through Arctic transit will be enabled with the changing sea ice conditions (Smith and Stephenson, 2013). This intensification of ship traffic leads to increasing risk of accidents with hydrocarbon propulsion fuel being spilled.

To limit spills in case of an accident, ships produced after 2010 have to obey stricter rules for protection of- and capacity of their fuel tanks (DNV, 2006). Worldwide, most merchant ships use heavy fuel oil (HFO) as propulsion fuel, however a gradual reduction from an allowed maximum of 4.5% sulphur in HFO in 2011 to 0.5% towards 2020/2025 is expected to imply a shift towards lighter propulsion fuels, such as gasoline or marine diesel oil (MDO). Indeed, HFO has generally higher sulphur contents compared to MDO, and causes the release of extensive amounts of soot during combustion, leading to increased costs due to mandatory investments in cleansing of exhaust (Martinsen, 2013). Finally, HFO spilled into the sea has low evaporation rates compared to other petroleum products, therefore remaining in the water for a longer period and presenting a larger potential for soiling exposed littoral habitats. Based on this, the use of and potential spilling of HFO is considered a major threat to the Arctic marine environment, and alternation to MDO is suggested to reduce ecological impact. MDO has a higher content of short-chained hydrocarbons, and a larger part of the compounds in MDO compared to HFO evaporates in case of a spill (Fingas, 2011). Even at low temperatures MDO would exhibit low viscosity and thus a higher potential for dispersion and biodegradation compared to HFO (Fingas, 2011).

Despite lower prices of HFO, a review of satellite based Automatic Identification System (AIS) data of ship sailing in the Arctic during August–November 2010 showed that only 20% of the vessels were designed for using HFO as propulsion fuel (Martinsen et al., 2011). Vessels operating in the Arctic seas are mainly fishing boats, local community support vessels and smaller passenger

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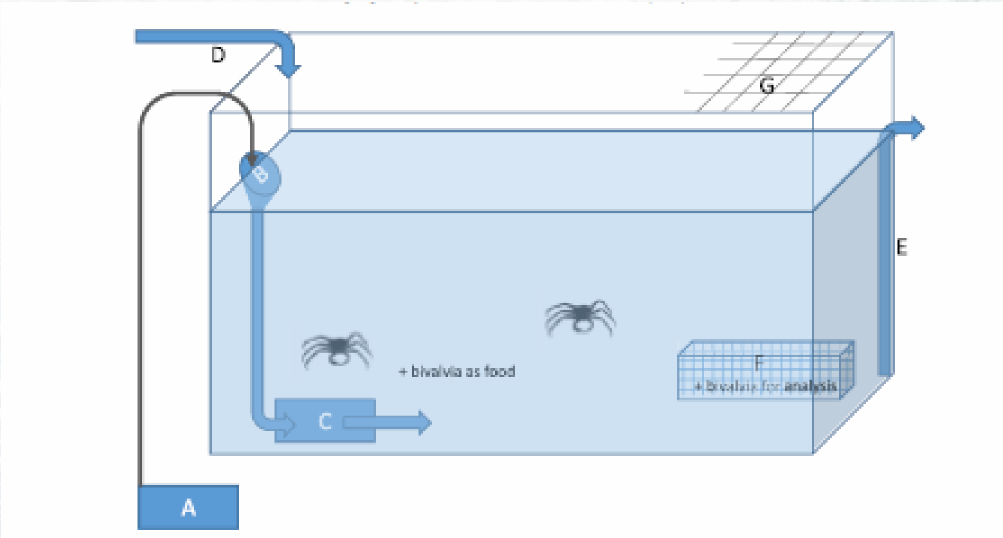

Ecosystems during polar night

Extending the autumn navigation season means increased navigation during polar night.

Paradigm: Marine ecosystems are dormant during polar night – Is this correct?

Fish feeding during polar night investigated as indicator of ecosytem activity

Scientific conclusions

- A scenario approach provides a learning example by itself, and offers a wealth of opportunities for further analyses of potential outcomes of a chain of events.
- Spatial ecosystem modelling is a useful and needed tool in remote areas with scarcity of updated environmental information. Application of *in-situ* and experimental data into the model strengthened the predictions of spread of contaminants to all trophic levels.
- Experimental ecotoxicology provides useful data on accumulation and excretion of PAH in Arctic species. Design of experimental conditions are of outmost importance.
- Fish play an important role in a biologically active polar night ecosystem. Any perturbations may prove as environmentally significant during January as during July.

"Supplementary observations"

- No conclusive documentation has been discovered on shipping in the European Arctic causing perturbations to marine ecosystems
- Impacts of shipping are and will be masked by impacts of GW
- A ships wreck will most likely be left to decay on site due to economic, safety or practical issues

- Limited, if any, confidence by stakeholders, managers or policy makers in the Paris agreement on limiting GW

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