SVALBARDS
MILJØVERNFOND

Ships as potential dispersal vectors of invasive marine organisms into high-Arctic Svalbard

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SUMMARY

In 2011, a Svalbard Environmental Protection Fund project began work assessing the risk of non-native species introduction to Svalbard in association with shipping. During 2011, environmental sampling took place, details of which were made available in a previous project report (http://www.sysselmannen.no/Svalbards-miljovernfond/Nyhetsarkiv/Arktiske-blindpassasjerer-/). These samples and associated data were collected in order to determine the diversity and composition of species transported with vessels, and by doing so evaluate associated potential hazards and risks.

Sample and data analysis that has followed now permits identification of bioinvasion hazards. By employing a pathway analysis based on the regional shipping network and climate similarity we have identified a number of vessel types and pathways with the potential to transfer suitably adapted non-native organisms. We find that vessel traffic to Svalbard is highly connected to worldwide ports, many with similar environmental conditions to Svalbard. Moreover, our analysis indicates predicted ocean warming will serve to increase the similarity to over 100 ports world-wide, paving the way for increased non-native species establishment. This is the first assessment of the potential for increased species introduction under the effects of climate change coupled with vessel traffic patterns. The hazards identified are similar to other Arctic regions which have been the focus of increasing research and management. Increasing traffic in Arctic regions, such as along the Northern Sea Routes, may further strengthen the connectivity of Svalbard to source pools of potentially invasive species.

The potential for vessels to transfer non-native organisms to Svalbard was evidenced in samples collected from the ballast water tanks of coal ships arriving to Svalbard. Regulations require ships to exchange ballast water in an oceanic region prior to discharging ballast water in Svalbard to reduce the potential for transferring invasive organisms. The logic of this measure is three-fold: firstly, organisms collected from ports are likely to be flushed out; secondly, remaining organisms survive poorly in the comparatively high salinity oceanic water; and, thirdly, oceanic organisms collected pose less of an invasion risk to coastal, often brackish waters. Around 80 % of all ships discharging ballast in Svalbard first conduct ballast water exchange. We find that non-native organisms can remain alive in both exchanged and unexchanged ballast water, although abundances appear to be lower in unexchanged water. When tested experimentally, some non-native organisms collected were able to tolerate local summer Svalbard fjord conditions. Furthermore, underwater surveys of ship hulls demonstrated that biofouling was being transported on ships to Svalbard. Evaluation of vessel histories revealed that it is likely that many of the vessels accrued biofouling in high-latitude regions.

Eradication of non-native marine organisms is problematic and often unsuccessful. Prevention of introduction therefore exists as the most effective management measure. *The increasing threat associated with bioinvasion hazards outlined in this report warrant management attention*.

1. BACKGROUND

The introduction of invasive species to novel habitats is now a principal form of global change. Invasive alien species are profoundly altering communities and ecosystems (Bergstrom et al. 2009, Falk-Petersen 2011), contributing to species extinctions (Gurevitch and Padilla 2004), and impacting on commerce and human health (Pyšek and Richardson 2010). Longstanding environmental or geographic barriers to species introduction have been gradually eroded by the accidental or deliberate transport of organisms in association with increasing tourism, travel or trade (Tatum and Hay 2007). Reducing risks associated with species introductions requires examination of the pathways and mechanisms facilitating species transport.

Svalbard remains one of the least invaded marine environments in the world: no introduced marine species are known from the archipelago. Consistent with other polar regions, shipping to the archipelago of Svalbard has increased markedly over the past 40 years (Governor of Svalbard 2007) In combination, the most marked climate changes occurring worldwide (IPCC 2007) are reducing transport and establishment barriers to species invasion in the Arctic, and high-latitude species invasion is becoming a real threat (de Rivera et al. 2011). A number of pathways of terrestrial species introduction have been shown to be transferring high propagule loads into the Antarctic (Chown et al. 2012), and to high-Arctic Svalbard (Ware et al. 2011). Meanwhile, impacts from invasive species have already been widely documented from sub-Arctic (Carlson et al. 2007) and sub-Antarctic (Bergstrom et al. 2009) regions, and the first established alien species are appearing around the Antarctic continent (Tavares and de Melo 2004). To-date, just two studies have investigated shipping pathways of species introduction to the Arctic, both of which focussed on the North American Arctic (Hines at el. 2000, Chan et al. 2012). As such, there is a real need for studies focussed on the European Arctic.

Shipping is the primary pathway by which most of the world's most invasive marine species have been transferred among tropical and temperate zones (Sylvester et al. 2011). Two principal means associated with shipping facilitate species transfer. Ships may carry organisms collected in association with ballast water from the port of origin, which are then discharged at the recipient port. Secondly, vessels may transport organisms that have attached to their hull (biofouling) to new regions, a process related to number of factors including vessel speed, port layover period, and time since previous application of antifouling paint (Coutts 2004, Sylvester et al. 2011).

Much work has focused on methods to manage ballast water to limit non-native species introduction. This has culminated in the international Ballast Water Management Convention (BWM Convention), which aims to reduce bio-invasion hazards associated with ballast water principally through the regulation of ballast water discharge. Under this regulation, ballasted ships are required to undertake mid-ocean exchange of ballast water to a minimum of 95% volumetric change as a means to limit the potential for coastal organisms to be transferred between ports. At the time the BWM Convention was developed, no treatment technologies with appropriate capacity, efficacy and acceptable environmental impact was known. While treatment technologies have advanced substantially since, mid-ocean exchange of ballast water (BWE) remains the only management option for most ships. In 2008 a number of countries introduced voluntary regimes requiring, among others, all vessels sailing to the ports in the area to comply with the BWE standard (David and Gollasch, 2008). Norway has given effect to the BWM Convention through the Norwegian Ballast Water Regulation (Norwegian Ministry of the Environment 2009).

Nevertheless, a clear understanding of the efficacy of ballast water exchange, and the bio-invasion hazards that remain on a number of shipping routes, is lacking. There are some suggestions that ballast water exchange may only remove 80 % of coastal organisms, and different methods of ballast water exchange used may perform differently (Wonham et al. 2001). Moreover, the role of biofouling in species transfer is less understood, and remains unregulated. There is an urgent need to develop a better understanding of these processes in Polar Regions, where the effects of steep temperature gradients and possible ice scouring are presumed to largely mitigate invasion risk. The opening of Polar Sea Routes for large scale transportation presents a significant new challenge to Arctic environmental managers: for the first time, merchant ships are transiting the Northeast and Northwest Passages, opening new pathways for alien species transfer. There is a pressing need for empirical data on the survival rates for shipping biota, and how ballast water exchange and eventual ballast water technologies perform under these environmental conditions.

Hazards and risk assessment is a fundamental starting point for any region attempting to better understand risks associated with movements of goods and people, or contemplating implementing a formal system to manage the transfer and introduction of alien marine species (Clarke et al. 2003). Presently there is no formal system in place to monitor and manage potential pathways of introduction to Svalbard; risk assessment therefore exists as an important initial step in the identification and investigation of potential hazards. By undertaking a marine species pathway-of-introduction analyses, we aim to describe the shipping network to Svalbard and determine its capacity to facilitate species introduction from ballast water and biofouling. Further, we use climate matching techniques to determine whether suitably adapted species could be introduced by ships under present and future climatic conditions. In doing so, the project provides a comprehensive statement on existing and predicted threats to the integrity of Polar biodiversity posed by invasive species.

2. DATA COLLECTION

2.1 BALLAST WATER

Coal ships travelling to collect coal from Svea, Barentsburg, and Longyearbyen in 2011 came from the Netherlands, Portugal, and the United Kingdom. Vessels travelled fully ballasted to Svalbard, collecting ballast in the port of origin. When taking on ballast water, any organisms in the water column may be taken on board as well. This can include organisms as small as viruses, bacteria and phytoplankton, through to fish. By taking samples of ballast water from the ballast water tanks of coal ships arriving to Svea, Barentsburg and Longyearbyen (Table 1), we were able to assess the number of organisms that can survive transport in ballast water tanks, and the type of organisms collected. We focussed on the larger zooplankton. We also collected data such as the amount of ballast water discharged, locations where ballast water sourced and exchanged (if done so), and voyage duration.

Expert taxonomists are currently further identifying all organisms collected so we can determine which species are being introduced to Svalbard. Furthermore, we will use DNA barcoding methods to help identify many of the larval forms found in the samples. These are vital steps: if we know what non-native species are arriving, we can better determine the threat they pose to the Svalbard environment.

2.2 BIOFOULING

Vessel hulls were inspected at the Longyearbyen port (bykaia). We used an underwater remotely operated vehicle (ROV) with a mounted video camera to get an underwater view of these parts of vessel hulls. The ROV proved to be a useful tool for rapid inspection in an environment where SCUBA diving is logistically prohibitive. We surveyed a range of cruise and expedition ships, research and cargo vessels, and private yachts. Unseasonal sea ice and sedimentation of the port environment limited our opportunities for more extensive survey work. The model ROV we used did not permit adequate inspection of the flattened sections of hulls at depth. The collected footage permitted the identification of organisms to higher taxonomic units (i.e. barnacle, algae, bryozoan etc). Based on this, vessel footage was classified into broad categories of biofouling (*sensu* Floerl et al. 2005).

In addition, for each surveyed vessel we identified the age of antifouling paint, the duration of previous port layovers, and the average speed. These were used to explore which factors may be associated with higher densities of fouling.

2.3 PORT AND VESSEL DATA

We obtained data describing vessel traffic patterns to Svalbard from the shipping data provider FleetMon (www.fleetmon.com). For all ports visited by ships within the previous 12 months to visiting Svalbard, we obtained port environmental data (salinity and three temperature variables) from Keller et al. (2011). We then calculated environmental similarity between ports as the Euclidean distance. In addition, we also examined how environmental similarity might change as a consequence of climate change between Svalbard and global ports. For this, we obtained projected mean zonal ocean surface temperature increases for 2080–2099 relative to 1980–1999 determined by Intergovernmental Panel on Climate Change (IPCC) models under the A2 scenario (Meehl et al., 2007). Port temperature values were then adjusted according to these predictions. This was performed for more than 6000 global ports.

3. BIOINVASION HAZARDS

3.1 BALLAST WATER

In 2011 a total of 13 ships discharging ballast water made 30 visits to Svalbard discharging ballast at each arrival. We identified ballast water source origins for 28 of these arrivals, all being from European ports (Fig. 1). In addition, we obtained ballast water records and samples from eight vessels discharging ballast in Svalbard (representing 25 % of the fleet). Based on these eight records we estimate the volume of ballast water discharged by the entire fleet to be 624,000 m3. Five of the eight ships that we obtained records for reported having exchanged ballast water mid-ocean, while three (37 %) reported no form of exchange. Ballasting regimes across vessels arriving in Svalbard were inconsistent, resulting in spatially differentiated hazards. Both Longyearbyen and Barentsburg ports received modest quantities of un-exchanged ballast water, while the port of Svea received substantial quantities of exchanged ballast water (Fig 1). Thus, coastal organisms are being transferred to Longyearbyen and Barentsburg, whereas predominately oceanic organisms are likely being transferred to Svea. This trend is likely to continue into the foreseeable future.

While the amount of ballast water transferred to Svalbard is low in comparison to many temperate ports, the volume discharged is high for an Arctic region, being close to double that discharged in Arctic Canada (Chan et al. 2012). The density of organisms can also be very high in ballast water, ranging in our study from 5-3000 organisms per cubic metre. Thus, large numbers of organisms can be introduced in every discharge event. Species composition of the ballast water samples revealed that ballast water exchange replaced a large portion of the port-of-origin biota with oceanic organisms; therefore many of the taxa discharged in Svalbard are present already around the region. However, a number of surviving coastal organisms highlights the limitation of ballast water exchange between higher salinity and marine ports. Ballast water exchange has been shown experimentally to be up to 99 % effective between freshwater ports, and somewhere between 60 – 100 % effective between marine ports. Furthermore, it has been shown that ballast water exchange may even promote the survival of coastal taxa through the addition of nutrients, oxygen and prey (Briski et al. 2012). The presence of coastal taxa in our samples indicates that the effect of ballast water exchange was limited. Therefore, the rationale for ballast water exchange to be undertaken between all ports and Svalbard should be explicitly evaluated.

From the collected ballast water samples, we have to-date identified 40 species, many of which are non-native to Svalbard. While the low temperatures experienced around Svalbard would preclude survival and/or reproduction of many organisms introduced, where suitably adapted organisms are introduced they are done so in large number, and as such may exert strong propagule pressure. As propagule pressure is a strong correlate of establishment and invasion success (Lockwood et al. 2009), the potential for ballast water discharge to facilitate species invasion will likely increase in Svalbard.

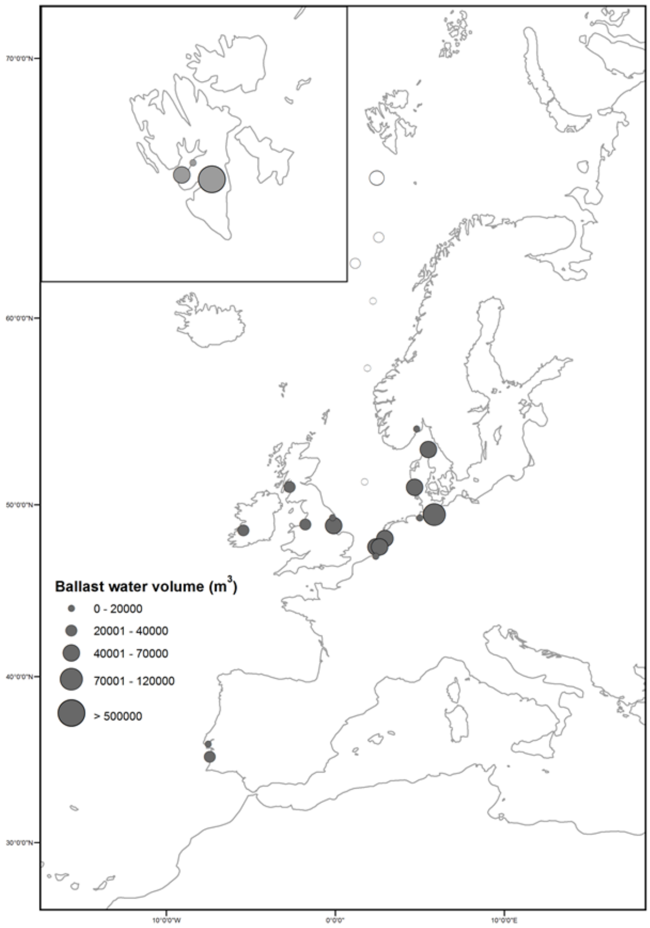

Fig 1. Regions from which ballast water was sourced for the eight sampled vessels in 2011: grey circles – original ballast water sourced; open circles – mid-ocean exchanged ballast water. Inset: ballast water discharged in Svalbard.

3.2 BIOFOULING

During 2011, we identified 155 vessels making 215 visits to Svalbard, each representing a possible dispersal vector. The majority of these visits were to the largest settlement on the archipelago, Longyearbyen (Fig. 2a). The tourism sector accounted for the majority of vessel visits, but when only vessel types are considered, recreational vessels were the most common class to visit Svalbard (Fig. 2b). The composition of vessel types at any port was strongly spatially dependent: the port of

Longyearbyen received the full range of vessel types visiting Svalbard, while no cruise, tourist, or recreational vessels visited the port of Svea. There was a strong seasonal component associated with vessel arrivals, with 77 % of vessel arrivals occurring between June and September.

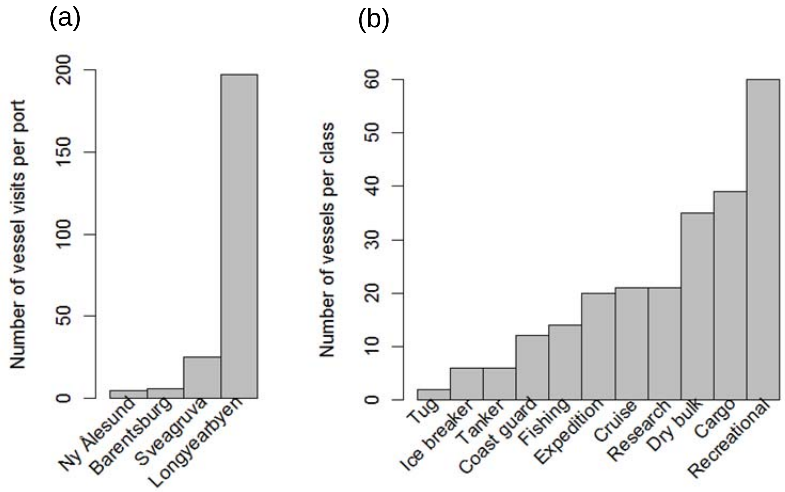

Fig 2. (a) Number of vessels making first port of call at each of Svalbard's ports; (b) number of vessels per vessel class visiting Svalbard during 2011.

We obtained hull surveys of 12 vessels arriving to Svalbard over the year of study, recording biofouling on all but two of the vessels. Consistent with the results of other work (e.g. Coutts and Taylor 2004, Sylvester et al. 2011) we found a positive association of biofouling with older antifouling paint, slower vessel speeds, and longer layover periods in ports. This operational profile suggests that cruise and expedition vessel traffic are generally less likely to support substantial biofouling based on their more regular dry-docking, and shorter layover periods (although individual exceptions exist: e.g. this study).

The one recreational vessel surveyed in this study had an extensive level of biofouling. Having overlaid the previous winter in a mainland Norwegian port, biofouling taxa were likely collected from this region. As the type of vessel that most visits Svalbard, and considering the propensity for recreational vessels to visit many locations around Svalbard beyond the main ports, their potential to introduce species to Svalbard is high.

4. ENVIRONMENTAL SIMILARITY

Environmental similarity calculations revealed biofouling to be a substantial present and future bioinvasion hazard. The concentration of northern European ports with low environmental distances to Svalbard presently, together with the density of shipping operating from these ports – and especially that operating in the narrow window of environmental conditions between Svalbard and northern Norwegian ports – indicates a greater potential for the transport of suitably adapted organisms (Fig 3). Moreover, the number of global ports with predicted low (e.g. <1) environmental similarity to Svalbard in coming years is extensive (Fig 4).

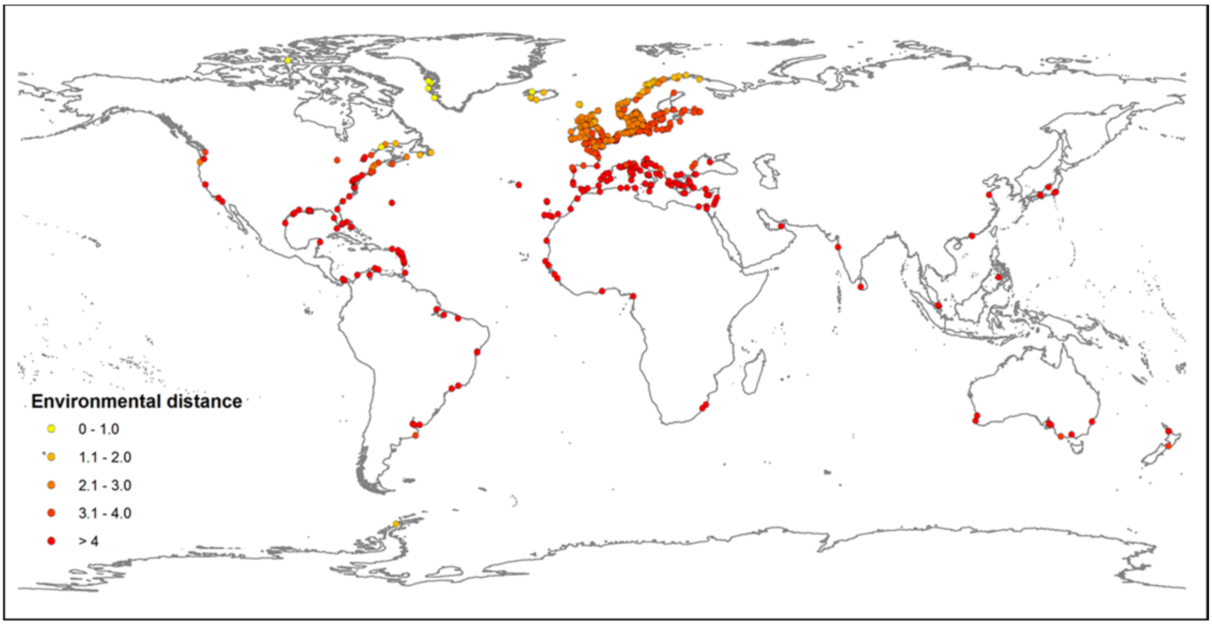

Fig 3. Environmental distance between global ports and Svalbard for the current shipping network (2011). Lower values of environmental distance mean salinity and temperature parameters are more similar (i.e., 0-1), and organisms present at one region are more likely to be able to survive in another.

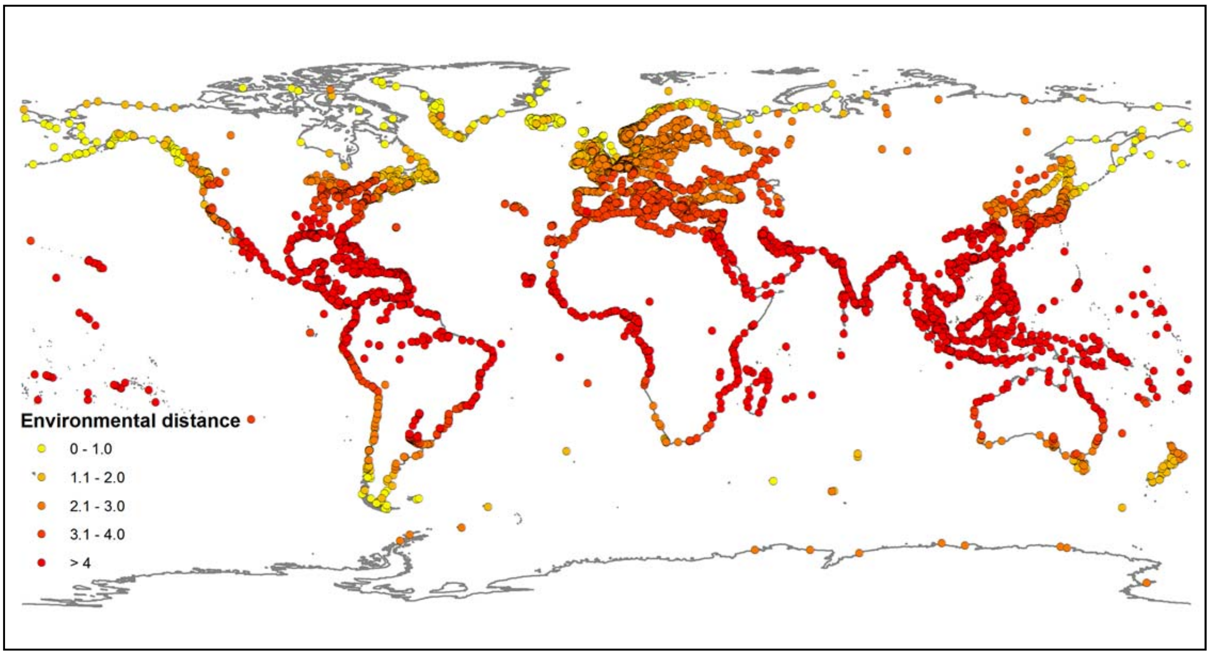

Fig 4. Environmental distance between global ports and Svalbard predicted for the year 2099. Temperature values are based on predictions under the A2 scenario (Meehl et al. 2007).

While a number of Southern hemisphere ports are also environmentally similar to Svalbard, transport of organisms collected from these ports through tropical and northern temperate regions to Svalbard would likely be beyond the tolerance of most organisms (e.g. MacIsaac 2002). More worrying are the high concentration of ports with similar environment around northern latitudes that ships already travel to Svalbard from. Should shipping patterns change and new routes connect Svalbard to a broader range of these ports, the potential for non-native species introduction and establishment will increase.

Environmental similarity between ballast water source ports and Svalbard is currently low to moderate (compare Fig. 1 and 3), but not necessarily beyond the tolerances of some organisms. Many invasive species, in particular, show wide levels of tolerance across temperature and salinity levels. Figure 4 demonstrates that environmental similarity between those ports from which ballast water is sourced and Svalbard will be higher towards the end of this century under predicted climate changes. High propagule pressure associated with ballast water discharge under these conditions means large numbers of suitably adapted organisms may then be transferred to Svalbard.

5. CONCLUSIONS

In this work, we characterise potential pathways of marine species introduction to high-Arctic Svalbard, the first such assessment for the European Arctic. Spatial and temporal dimensions of ship arrivals and ballast water discharge to Svalbard illustrate a high degree of connectivity to temperate and Arctic coastal regions. Two distinct hazards exist in association with this connectivity: 1) ballasted vessels travel to Svalbard with untreated, un-exchanged ballast water, and; 2) vessels can transfer extensive biofouling communities to Svalbard. Furthermore, coastal European organisms are discharged in Svalbard waters through ballast water discharge despite ships managing ballast water through ballast water exchange. Risks associated with these hazards may increase as environmental similarity between Svalbard and mainland European ports will likely decrease towards the end of this century as the Arctic Ocean warms.

By undertaking an analysis of the near-complete shipping network to Svalbard, we present data indicating effective propagule transport occurs with a number of vessel classes to Svalbard, which may give rise to new species establishment. Vessel traffic to Svalbard in 2011 included movement that could be expected to differ little from year to year (e.g. cargo shipping and some tourism associated shipping) and highly dynamic movement which may change from year to year (e.g. bulk carrier shipping, recreational vessel traffic). Hazard management need account for this variation, and also increasing severity of hazards associated with climate change.

5.1 FUTURE PERSPECTIVES

The project documented here forms part of a larger project funded by the Svalbard environmental protection fund, the Fram Centre, and Tromsø University Museum. Work under the broader project has investigated the potential for terrestrial plant introduction and establishment on Svalbard (Ware et al. 2012), the transportation of organism by cruise passengers and the efficacy of management techniques used by expedition cruise ship operators (Svalbard environmental protection fund 12/91), and will continue with a focus on marine pathways of introduction (Fram Centre). A previous report of the project can be found at http://www.sysselmannen.no/Svalbards-miljovernfond/Nyhetsarkiv/Arktiske-blindpassasjerer-/). The objectives for the ongoing marine work include the identification of the remaining organisms collected in ballast water samples using DNA barcoding techniques; modelling of potential environmental niches of collected organisms to determine whether they could establish in Svalbard currently, or under future environmental conditions; evaluation of ongoing management techniques; and analysis of bioinvasion hazards associated with shipping along the Northern Sea Routes. This work will provide information to better evaluate risk of species invasion in Svalbard and the wider Arctic, and in addition help develop tools to be used in the management of introduction vectors.

REFERENCES

Ashton, G., K. Boos, R. Shucksmith, and E. Cook. 2006. Risk assessment of hull fouling as a vector for marine non-natives in Scotland. Aquatic Invasions 1:214-218.

Barry SC, Hayes KR, Hewitt CL, Behrens HL, Dragsund E, Bakke SM (2008) Ballast water risk assessment: principles, processes, and methods. J Mar Sci 65: 121-131

Bergstrom DM, Lucieer A, Kiefer K, Wasley J, Belbin L, Pedersen TK, Chown SL. 2009. Indirect effects of invasive species removal devastate World Heritage Island. Journal of Applied

Carlson ML, Shephard M (2007) Is the spread of non-native plants in Alaska accelerating? Meeting the challenge: invasive plants in Pacific Northwest ecosystems. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Chown SL, Huiskes AHL, Gremmen NJM, Lee JE, Terauds A, Crosbie K, Frenot Y, Hughes KA, Imura S, Kiefer K, Lebouvier M, Raymond B, Tsujimoto M, Ware C, Van de Vijver B, Bergstrom DM (2012). A continent wide risk assessment for the establishment of alien species in Antarctica. PNAS, 109 (13): 4938-4943

Clarke C, Hayes T, Hilliard R, Kayvanrad N, Taymourtash H, Parhizi A, Yavari V, Raaymakers S (2003) Ballast Water Risk Assessment, Port of Khark Island, Islamic Republic of Iran. GloBallast Monograph 8, International Maritime Organisation London

Clarke M, Pakhomov CEA, and Therriault TW (2011). Recreational boating: a large unregulated vector transporting marine invasive species. Diversity and Distributions.

Coutts ADM and Taylor MD (2004) A preliminary investigation of biosecurity risks associated with biofouling on merchant vessels in New Zealand. New Zealand Journal of Marine and Freshwater Research 38: 215-229

David M, Gollasch S (2008). EU Shipping in the Dawn of Managing the Ballast Water Issue. Mar. Pollut. Bull., vol. 56, no. 12, 1966-1972.

Davidson IC, Zabin CJ, Chang AL, Brown CW, Sytsma MD, and Ruiz GM (2010). Recreational boats as potential vectors of marine organisms at an invasion hotspot. Aquatic Biology, 11:179-191.

de Rivera CE, Steves BP, Fofonoff PW, Hines AH, Ruiz GM (2011) Potential for high-latitude marine invasions along western North America. Diversity and Distributions 17: 1198-1209.

Falk-Petersen J, Renaud P, Anisimova N (2011) Establishment and ecosystem effects of the alien invasive red king crab (Paralithodes camtschaticus) in the Barents Sea—a review. ICES J. Mar. Sci. 68: 479–488. (doi:10.1093/icesjms/fsq192).

Floerl O, Inglis GJ, Hayden BJ (2005). A risk-based predictive tool to prevent accidental introductions of nonindigenous marine species. Environmental Management 35:765-778.

Floerl O, Wilkens S, Inglis GJ (2010). Development of a template for vessel hull inspections and assessment of biosecurity risks to the Kermadec and sub-Antarctic Islands regions. National Institute of Water & Atmospheric research Limited, Christchurch, New Zealand.

Gurevitch J, Padilla DK (2004) Are invasive species a major cause of extinctions? Trends in Ecology and Evolution. 19(9): 470-474

Hall CM, James M, Wilson, S (2010) Biodiversity, biosecurity, and cruising in the Arctic and sub-Arctic. Journal of Heritage Tourism 5: 351-364

Hines AH, Ruiz GM (2000) Biological invasions at cold-water coastal ecosystems: ballast- mediated introductions in Port Valdez/Prince William Sound. Final Report to Regional Citizens Advisory Council of Prince William Sound

IPCC (2007) Climate Change 2007: The physical science basis. Working Group I, Contribution to the Fourth Assessment Report of the IPCC Intergovernmental Panel on Climate Change. University Press, Cambridge.

Keller RP, Drake JM, Drew MB, Lodge DM (2011). Linking environmental conditions and ship movements to estimate invasive species transport across the global shipping network. Diversity and Distributions 17:93-102.

Lockwood JL, Cassey P, Blackburn T (2005). The role of propagule pressure in explaining species invasions. Trends in Ecology & Evolution 20:223-228.

Norwegian Ministry of Environment (2009). Regulation concerning the prevention of transfer of alien organisms via ballast water and sediments from ships (the Ballast Water Regulation). Norway. Available online at http://www.regjeringen.no

Pyšek P, Richardson DM (2010): Invasive species, environmental change and management, and health. Annual Review Environment and Resources 35: 25-55 (doi: 10.1146/annurev-environ-033009-095548).

Sylvester F, Kalaci O, Leung B, Lacoursiére-Roussel A, Clarke Murray C, Choi FM, Bravo MA, Therriault TW, MacIsaac HJ (2011) Hull fouling as an invasion vector: can simple models explain a complex problem? Journal of Applied Ecology 48: 415–423

Tavares M, De Melo GAS (2004) Discovery of the first known benthic invasive species in the Southern Ocean: the North Atlantic spider crab Hyas araneus found in the Antarctic Peninsula. Antarctic Science 16:129–31.

Tatem AJ, Hills SI (2007) Climatic similarity and biological exchange in the worldwide airline transportation network. Proc Roy Soc B, 274: 1489-1496.

Ware C, Bergstrom D, Müller E, Alsos I. (2011 early online). Humans introduce viable seeds to the Arctic on footwear. Biological Invasions DOI 10.1007/s10530-011-0098-4

Wonham MJ, Walton WC, Ruiz GM, Frese AM, Galil BS (2001) Going to the source: role of the invasion pathway in determining potential invaders. Marine Ecology Progress Series 215: 1–12.