Biological introduction risks from shipping in a warming Arctic

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Several decades of research on marine invasive species have yielded a broad understanding of the patterns of species transfer associated with shipping. This has enabled the implementation of management measures designed to limit non-indigenous marine species transfer. However, whether this understanding translates to the Arctic context, and whether the same management approaches are effective, has been little studied. I will discuss research performed in the high Arctic archipelago, Svalbard, which evaluated pathways of marine species transport and associated invasion risks, and the efficacy of measures currently used to limit species transfer. Samples of ships’ ballast water revealed large propagule loads are being transferred to the region annually. Known invasive species were among the non-indigenous species recorded and were present in both unexchanged ballast water and also ballast water which had been exchanged mid-ocean. Samples were too few to draw robust conclusions about the efficacy of ballast water exchange, but our data suggest that ballast water exchange may promote survivorship of some non-indigenous species during transit. Ecophysiological models for known invasive species present in samples suggest present-day conditions are unfavourable for most species; however, under a future climate scenario, conditions will steadily favour colonization. Consequences of ship-mediated species introductions, therefore, will likely magnify over time with implications for the management of shipping across the Arctic. While managing for this scenario requires improvements to existing approaches, management frameworks must take into account the natural poleward expansion of species’ ranges as climates continue to warm. Impacts of range-shifting species may be as great as those from introduced non-indigenous species, and in such a scenario managing sources of anthropogenic species introduction may be of little consequence. Greater effort must be given to understanding the potential consequences of different sources and patterns of species translocations.
Biological introduction risks from shipping in a warming Arctic

Chris Ware
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Overview

• Study site

• Vector assessment

• Vector sampling

• Establishment modelling

• Svalbard management

• Arctic management
Arctic marine invasive species

Latitudinal pattern of invasion (Ruiz and Hewitt 2009)
Study site: Svalbard
Study site: Svalbard

Study site: Svalbard
Study site: Svalbard
Study site: environment

- Archipelago spans 74-81° latitude.
- Mean July temperature: 6° C / 40° F.
- Mean January temperature: -15 °C / 0 ° F.
- Seasonal sea ice around main port environments
- Summer sea temperatures ~2 ° C / 35 ° F
Study site: environment

Study site: environment
Study site: invasive species

Study site: invasive species

Ballast water and biofouling

Photo: New York working harbour committee

Photo: International Paint
Ballast water
What do we know about marine invasion risks?

• Ship ballast water
  – Port environments key to invasion threat
  – Ballast water exchange/treatment

• Ship biofouling
  – Port environments key to invasion threat
  – Vessel operation profile
  – Industry managed/unregulated

• Invasions occur where new marine regions are connected

• Propagule and colonisation pressure correlate with invasion
Study site: vectors
Study site: management frameworks

- Norwegian ballast water regulation:

- Biofouling regulations:

Norwegian ballast water exchange zones
Species introduction: vector assessment

Wonham et al. 2013 Modelling the relationship between propagule pressure and invasion risk to inform policy and management. Ecological Applications.
Species introduction: vector assessment

- Proxies of propagule pressure
- Relative risk informed using qualitative model of propagule pressure

\[ \text{Propagule pressure} = P_{\text{Entrain}} \times S_{\text{Season}} \times P_{\text{Survival}} \times S_{\text{Mngmt}} \times P_{\text{Release}} \times P_{\text{RepeatVisit}} \]

<table>
<thead>
<tr>
<th>Ballast water?</th>
<th>Meroplankton settling?</th>
<th>How long was the voyage?</th>
<th>BWE? Antifouling paint age?</th>
<th>BW? Port duration?</th>
<th>Number port calls?</th>
</tr>
</thead>
<tbody>
<tr>
<td>How long in port?</td>
<td>Abundant?</td>
<td>How long was the voyage?</td>
<td>BWE? Antifouling paint age?</td>
<td>BW? Port duration?</td>
<td>Number port calls?</td>
</tr>
</tbody>
</table>

- Identify NIS in ecoregions (Molnar et al. 2008) connected by high risk vectors
Species introduction: vector assessment
Species introduction: vector assessment

Ware et al. 2014. Climate change, non-indigenous species and shipping: assessing the risk of species introduction to a high-Arctic archipelago. Diversity and Distributions.
Species introduction: vector sampling

Samples collected through inspection hatches quantitatively, and qualitatively (fishing).

Focus on zooplankton (60µm net)

Pump used where no hatches existed. All organisms transferred to ethanol immediately.
Species introduction: specimen identification
Species introduction: specimen identification
Species introduction: specimen identification

• From zooplankton larvae sampled from ballast water...

... to identification *Homo sapiens*... x 16 genotypes... ???
Species introduction: vector sampling

• Sampled ~ 1/3 of the annual bulk carrier fleet.
• Some ships exchanged ballast water; some didn’t.
• Live non-indigenous species present in both management and un-managed ballast water.
• Well known invasive species present.
Species introduction: establishment models

Climate thresholds

Physiological performance

Cold          Warm
Species introduction: tolerance experiments

Proportion survived:

- Isopods
- Crabs
- Shrimps
### Species introduction: establishment models

<table>
<thead>
<tr>
<th></th>
<th>Present</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. improvisus</td>
<td>![Map of A. improvisus]</td>
<td>![Map of A. improvisus]</td>
<td>![Map of A. improvisus]</td>
</tr>
<tr>
<td>A. modestus</td>
<td>![Map of A. modestus]</td>
<td>![Map of A. modestus]</td>
<td>![Map of A. modestus]</td>
</tr>
<tr>
<td>A. tonsa</td>
<td>![Map of A. tonsa]</td>
<td>![Map of A. tonsa]</td>
<td>![Map of A. tonsa]</td>
</tr>
<tr>
<td>C. crangon</td>
<td>![Map of C. crangon]</td>
<td>![Map of C. crangon]</td>
<td>![Map of C. crangon]</td>
</tr>
</tbody>
</table>

Species introduction: establishment models

Species introduction: biofouling
Species introduction: biofouling

Species introduction: biofouling

• Most vessels free of substantial fouling, maintaining a hull with ‘only light slime’

• ~ one third of surveyed hulls had substantial fouling (macrofouling and biofilm > 40% hull)

• Only broad taxonomic composition known (algae and barnacles dominant)
Where to next: management for Svalbard

- Svalbard will become increasingly vulnerable to marine NIS establishment.
- Research, fishing, and recreational vessels pose the highest risk through biofouling.
- Ballast water discharge is estimated to pose an increased risk over the coming century.
- Ballast water management requires further investigation.
Mitigation options? Impacts?
Ballast water management implications
Biofouling management implications

Table 1: Biofouling Threshold for Long-Stay Vessels

<table>
<thead>
<tr>
<th>Hull part</th>
<th>Allowable biofouling</th>
</tr>
</thead>
<tbody>
<tr>
<td>All hull surfaces</td>
<td>Slime layer; Goose barnacles</td>
</tr>
</tbody>
</table>

Table 2: Biofouling Threshold for Short-Stay Vessels

<table>
<thead>
<tr>
<th>Hull part</th>
<th>Allowable biofouling</th>
</tr>
</thead>
<tbody>
<tr>
<td>All hull surfaces</td>
<td>Slime layer; Goose barnacles</td>
</tr>
<tr>
<td>Wind and water line</td>
<td>Green algae growth of unrestricted cover and no more than 50 mm in front, filament or beard length; Brown and red algal growth of no more than 4 mm in length; Incidental (maximum of 1%) coverage of one organism type of either tubeworms, bryozoans or barnacles, occurring as:  - isolated individuals or small clusters; and  - a single species, or what appears to be the same species.</td>
</tr>
<tr>
<td>Hull area</td>
<td>Algal growth occurring as:  - no more than 4 mm in length; and  - continuous strips and/or patches of no more than 50 mm in width. Incidental (maximum of 1%) coverage of one organism type of either tubeworms, bryozoans or barnacles, occurring as:  - isolated individuals or small clusters that have no algal overgrowth; and  - a single species, or what appears to be the same species.</td>
</tr>
<tr>
<td>Niche areas</td>
<td>Algal growth occurring as:  - no more than 4 mm in length; and  - continuous strips and/or patches of no more than 50 mm in width. Scattered (maximum of 8%) coverage of one organism type of either tubeworms, bryozoans or barnacles, occurring as:  - widely spaced individuals and/or infrequent, patchy clusters that have no algal overgrowth; and  - a single species, or what appears to be the same species; and Incidental (maximum of 1%) coverage of a second organism type of either tubeworms, bryozoans or barnacles, occurring as:  - isolated individuals or small clusters that have no algal overgrowth; and  - a single species, or what appears to be the same species.</td>
</tr>
</tbody>
</table>

Biofouling on vessels arriving to New Zealand (2014) Ministry for Primary Industries, Wellington, New Zealand
Management implications

but...
Beyond Svalbard: northern sea routes

Smith and Stephenson 2013 New Trans-Arctic shipping routes navigable by mid-century. PNAS
Beyond Svalbard: northern sea routes

- Evaluating risks dependent on projections of shipping (marine craft) patterns.
- Through traffic versus destination traffic.
- Relative risk of ballast water versus biofouling.
- Drilling and rig equipment.
Beyond Svalbard: northern sea routes

Smith and Stephenson 2013 New Trans-Arctic shipping routes navigable by mid-century. PNAS
Things to do list

• Research.
• Research aligned with identified management scenarios.
• Empirical data.
• Experimental / simulation studies.
• Species based, and vector-scale models.
Thank you

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