Hotspots of vulnerability to marine invasive species introductions: Insights from habitat suitability modelling under current and projected climate change scenarios

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Changing ice conditions and shipping activity in Canadian Arctic

Average Monthly Arctic Sea Ice Extent
March 1979 - 2016

↑ accessibility & length of shipping season

NSDC 2016

Guy and Lasserre 2017, *Polar Record*

Coastal impacts:
• oil, spills
• noise, strikes
• species introductions

Increasing awareness in Arctic:

**HOW THE POLAR CODE PROTECTS THE ENVIRONMENT**

**Implemented 2017**

**OIL**
- Discharges: Discharge into the sea of oil or oily mixtures from any ship is prohibited.
- Structure: Double hull and double bottom required for all oil tankers, including those less than 5,000 GT (VLSFO ships constructed on or after 1 January 2017).
- Heavy fuel oil: Heavy fuel oil is banned in the Antarctic (under MARPOL). Ships are encouraged not to use or carry heavy fuel oil in the Arctic.

**LUBRICANTS**
- Consider using non-toxic biodegradable lubricants or water-based systems in lubricated components outside the underwater hull with direct seawater interfaces.

**GARBAGE**
- Plastics: All disposal of plastics prohibited (under MARPOL).
- Food wastes: Discharge of food wastes onto the ice is prohibited.
- Animal carcasses: Discharge of animal carcasses is prohibited.
- Cargo residues: Cargo residues, cleaning agents or additives in hold washing water may only be discharged if they are not harmful to the marine environment, both departure and destination ports are within Arctic waters, and there are no adequate reception facilities at those ports. The same requirements apply to Antarctic areas under MARPOL.

**SEWAGE**
- Discharges I: No discharge of sewage in polar waters allowed (except under specific circumstances).
- Treatment plants: Discharge is permitted if the ship has an approved sewage treatment plant, and discharges of treated sewage as far as practicable from the nearest land, any fast ice, ice shelf, or areas of specified ice concentration.
- Discharges II: Sewage not comminuted or disinfected can be discharged at a distance of more than 12 nm from any ice shelf or fast ice. Comminuted and disinfected sewage can be discharged more than 3 nm from any ice shelf or fast ice.

**INVASIVE SPECIES**
- Invasive aquatic species: Measures to be taken to minimize the risk of invasive aquatic species through ships' ballast water and biofouling.

**BACKGROUND INFO**
- The International Code for Ships Operating in Polar Waters will enter into force on 1 January 2017.
- It applies to ships operating in Arctic and Antarctic waters, additional to existing MARPOL requirements.
- It provides for safe ship operation and protects the environment by addressing the unique risks presented in polar waters but not covered by other instruments.

**DEFINITIONS**
- **Ship categories**:
  - Category A: Three categories of ships designed to operate in polar waters in:
    - A1: at least medium first-year ice
    - A2: at least thin first-year ice
    - A3: open waters/ice conditions less severe than A and B
- **Fast ice**: Sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs.
- **Ice shelf**: A floating ice sheet of considerable thickness showing 2 to 50 m or more above sea-level, attached to the coast.

**CHEMICALS**
- Discharges: Discharge of noxious liquid substances (NLS) or mixtures containing NLS is prohibited in polar waters.
Arctic Invasive Alien Species

Strategy and Action Plan 2017

- Prevention
- Early Detection*
- Rapid Response
- Eradication or Control
Aquatic Introductions

Commercial shipping: main vector for aquatic introductions in coastal waters and of greatest concern in Arctic

Changes in vessel traffic in Canadian Arctic 1990-2015

How to predict future effects?

Dawson et al. 2018, Arctic; Smith and Stephenson 2013, PNAS
Species distribution models (SDM)

Tool to predict potential suitable habitat for invasive species of concern

To assess relative risk

MaxEnt
(Phillips et al 2006)

Likelihood of suitable habitat across an area of interest by relating species occurrence information & environmental data

- High predictive accuracy
- Performs well under climate change scenarios

Elith & Leathwick, 2009
• SDM - 8 NIS found in ballast water of vessels arriving to Svalbard, Norway
• Based on temperature and salinity requirements for reproduction

Ware et al. 2015
Goal of current study

Species distribution modelling:
- More diverse taxa
- Global scale, pan-Arctic focus
- Current and projected (2050 / 2100)
  Intermediate (RCP 4.5, IPCC)
Questions

What are the potential high risk invaders?

What areas of the Arctic will have higher invasion risk?

How many potential invaders have suitable habitat in Arctic under present environmental conditions?

How many will have suitable habitat in the future?

Are there taxa specific patterns in risk?

Direct future monitoring/research efforts
Which species to model?

100 species **pre-screened**
AIS Databases/Publications, which could arrive/survive?
Pre-screening analysis

Does the species have biological/ecological features that allow survival in Arctic conditions?

- Species with invasive potential.
- AIS reported in other Arctic regions.
- Temperature and salinity tolerances (all marine species).

Can the species be transported through ballast water and/or hull fouling?

Species of high impact ballast-mediated: NIS established at ports connected to major Arctic ports (Chan et al. 2012).
Which species to model?

100 species pre-screened
AIS Databases/Publications, which could arrive/survive?

Sub-set ranked: **Canadian Marine Invasive Screening Tool (CMIST, Drolet et al. 2015)**

**Rapid Screening tool** can be applied quickly with available data

17 questions on invasion process (introduction, impact)

**Global risk** = Avg. intro X Avg. impact

Low = 1  Moderate = 2  High = 3

**Final list of higher risk species for modeling**
Ranking of 31 potential species (Canadian Marine Invasive Screening Tool (CMIST); Drolet et al. 2015) from initial list of 100

Benthic Invertebrates: 21
Amphibalanus improvisus
Amphibalanus amphitrite
Amphibalanus eburneus
Austrominius modestus
Aurelia limbata
Botrylloides violaceus
Botryllus schlosseri
Caprella mutica
Carcinus maenas
Chionoecetes opilio
Ciona intestinalis
Cordylophora caspia
Eriocheir sinesis
Gammarus tigrinus
Littorina littorea
Marenzelleria viridis
Membranipora membranacea
Molgula manhattensis
Mya arenaria
Paralithodes camtschaticus
Pontogammarus robustoides
Styela clava

Zooplankton: 6
Acartia tonsa
Aurelia limbata
Centropages typicus
Eurytemora affinis
Eurytemora carolleeae
Mnemiopsis leidy

Macroalgae: 4
Codium fragile spp. tomentosoides
Dumontia contorta
Sargassum muticum
Undaria pinnatifida

Most known introduced marine species are benthic (Streftaris et al. 2005)
Species selection

Mean risk scores in a gradient heat matrix

Mean risk scores

Likelhood of invasion

Impact of invasion

Mean risk scores in a gradient heat matrix

Species selection
Species selection

**Benthic Invertebrates: 11 modeled**
- Amphibalanus improvisus
- Amphibalanus amphitrite
- Amphibalanus eburneus
- Austrominius modestus
- Aurelia limbata
- Botrylloides violaceus
- Botryllus schlosseri
- Caprella mutica
- Carcinus maenas
- Chionoecetes opilio
- Ciona intestinalis
- Cordylophora caspia
- Eriocheir sinensis
- Gammarus tigrinus
- Littorina littorea
- Marenzelleria viridis
- Membranipora membranacea
- Molgula manhattensis
- Mya arenaria
- Paralithodes camtschaticus
- Pontogammarus robustoides
- Styela clava

**Zooplankton: 3 modeled**
- Acartia tonsa
- Aurelia limbata
- Centropages typicus
- Eurytemora affinis
- Eurytemora carolleeae
- Mnemiopsis leidyi

**Macroalgae: 4 modeled**
- Codium fragile spp. tomentosoides
- Dumontia contorta
- Sargassum muticum
- Undaria pinnatifida
Phytoplankton species added

Chosen according to species that are known to produce harmful toxins and that have been found in ballast water of ships transiting to the Canadian Arctic (Laget 2017).

- Alexandrium tamarense
- Dinophysis caudata
- Dinophysis dens
- Gonyaulax polygramma
- Heterocapsa triquetra
Species Distribution Modeling (SDM)

23 species:

11 Benthic invertebrates (4 Crustacea, 4 Tunicata, 2 Mollusca, 1 Bryozoa)

4 Macroalgae (1 Green Algae, 2 Brown Algae, 1 Red Algae)

3 Zooplankton (1 Copepoda, 1 Ctenophora, 1 Cnidaria)

5 Phytoplankton (5 Dinoflagellata)
Known Species Occurrence

Native

Introduced

Input

SDM - Methods

Maxent (Philipps et al., 2006)

Biodiversity & Invasive Species Databases/Lists

Literature
**SDM - Methods**

**Maxent (Philipps et al., 2006)**

**Known Species Occurrence**

- Native
- Introduced

**Input**

**Environmental variables**

- Temperature
- Salinity
- Ice concentration
- Bathymetry

39 environmental layers

- Chlorophyll
- pH
- Dissolved oxygen
- Light
- Minerals and nutrients
- Land distance

see Goldsmit et al. 2018
Projected suitable habitat change – Arctic & Global (all species)

SDM Results

Poleward shift (mainly north)

Global

Present vs 2050

HS: -4.0%

Arctic

Present vs 2050

HS: +5.8%

Present vs 2100

HS: -4.2%

Present vs 2100

HS: +14.1%
Projected suitable habitat change - Arctic (by taxa)

SDM - Results

Present vs 2050

Loss
Increase
No change

Present vs 2100

Benthos
Macroalgae
Phytoplankton
Zooplankton

HS: +54.9
HS: +39.8
HS: +2.4
HS: +15.3

HS: +74.1
HS: +68.6
HS: +12.8
HS: +0.7
**SDM - Results**

Hotspots of suitable habitat for AIS

**Arctic 2100**

- Chukchi/Bering Sea
- White/Barents Sea
- Northern Labrador

*Global hotspots include native/invaded ranges of species*
Environmental variables

SDM - Results

Benthos

Macroalgae

Zooplankton

Phytoplankton

Temperature  Salinity  Sea ice  Depth  Land distance  pH  Dissolved oxygen  Nutrients and minerals
Summary

- Regions of greater vulnerability in the Arctic; taxa-specific responses to climate change

- Limitations: doesn’t include fundamental niche, ecological interactions in receiving habitat, quantitative shipping information

But.....

- First step in identifying focal areas, species for monitoring
  - e.g., Northern Labrador, Canada

- Development of “watch” lists for screening (e.g., eDNA), regulations

- Citizen Science – education, outreach
Thank You! ᐊᖃᑲᓐᓇᒦᒃ
Merci!

Polar Knowledge
Savoir polaire
Canada
Canada

Fisheries and Oceans
Pêchés et Oceans
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Questions?

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