Reducing the risk of aquatic invasive species introductions and spread through vector management

Farrah Chan
Post-Doctoral Visiting Fellow
Fisheries and Oceans Canada
Email: farrah.chan@dfo-mpo.gc.ca

Photo credit: Sarah Bailey
Agenda

- Overview of the invasion process
- What are transport vectors and pathways?
- Why focus on transport vectors?
- Managing transport vectors
  - Vector-based risk assessment
    - Case study: ballast water risk assessment for the Canadian Arctic
  - Vector interruption
    - Case study: ballast water management strategies in Canada
Stages of the invasion process

Source population → Transportation → Survival → Establishment → Spread

Kolar & Lodge 2001
Colautti & MacIsaac 2004
Blackburn et al. 2011
Transport vectors and pathways

- **Vector** = the conveyance carrying species along a pathway

- **Pathway** = the geographic route between the source region and the release sites

Shipping routes
(Kaluza et al. 2010)
Globally important vectors

- Ballast water
- Hull fouling
- Aquaculture
- Aquarium trade
- Live seafood trade
- Canal construction

Molnar et al. 2008
Why focus on the vectors?

- Often impossible to predict which species may be accidentally introduced

Photo credit: International Maritime Organization

Andow 2003; Ruiz & Carlton 2003; National Research Council 2011
Why focus on the vectors?

- Often impossible to predict which species may be accidentally introduced

- Limited biological and ecological data for target species

Native range  →  Invading range

Factors:
- temperature
- salinity
- competition
- predation
Why focus on the vectors?

- Often impossible to predict which species may be accidentally introduced
- Limited biological and ecological data for target species
- Results from vector studies can be translated to vector management policies

Andow 2003; Ruiz & Carlton 2003; National Research Council 2011
Why focus on the vectors?

- Addressing the vector = managing entire assemblage of species associated with it
- Helps prevent new invasions

Source population

- Transportation

  - Survival

  - Establishment

  - Spread

Ruiz & Carlton 2003
Risk assessment (RA)

- A procedure to identify probability of threats and vulnerabilities, and analyze them to ascertain the consequence of exposures.

- Objective: “…to evaluate, order, and structure incomplete knowledge so as to allow decisions to be made with as complete an understanding as possible of the current stage of knowledge, its limitations, and its implications.” (Morgan, 1978)
Why conduct RAs?

• Not all nonindigenous species (NIS), vectors or pathways pose the same level of risk

• Important to characterize potential risk

• Undertake necessary management or mitigation measures

Green crab  Killer algae  Comb jelly  Zebra mussel

Photo credit: Smithsonian Environmental Research Centre
Risk assessment for nonindigenous species

- Invasion risk
  - \( P(\text{introduction}) \times \text{consequence} \)
    - Arrive
    - Survive
    - Establish

- Uncertainty
  - quality and quantity of available data

NRC 2001; Orr 2003; Mandrak 2012
Case study:
Ballast water risk assessment for the Canadian Arctic

Port of Churchill, Manitoba
International vessels
• Regulated and conduct mid-ocean ballast exchange

Excludes Mackenzie Bat south 69°09' N

Includes the waters of Chesterfield Inlet and Baker Lake

Includes the waters of Koksoak River to Kuujjuaq and the water of Feuilles Bay to Tasiujaq

Includes the waters of Moose River to Moosonee.
Coastal domestic vessels
- Not regulated, may or may not exchange ballast
Risk assessment framework

Pathway
- International vessels
- Coastal domestic vessels

P(arrival)
- Annual volume of ballast water discharge

P(survival and establishment)
- Environmental similarity

P(introduction)
- P(Arrival) x P(Survival & Establishment)

Magnitude of consequence
- Number of high impact ballast-mediated NIS in donor region(s)

Invasion risk
- P(Introduction) x Magnitude of consequence
Estimating $P(\text{arrival})$

- Probability that a NIS will arrive for each pathway
- Volume of ballast water discharged
- # of discharge events
Ballast water discharge pattern
Prioritized ports

Chan et al. 2012
Prioritized ports

Chan et al. 2012
Estimating $P(\text{survival and establishment})$

- Identify source-recipient port-pairs for every ship transit
- Compare environmental conditions between ports

Chan et al. 2012
Environmental similarity: Churchill

Chan et al. 2012
Estimating the magnitude of consequences

- Tabulate # of high impact NIS in connected ecoregions
- Tabulate mean # high impact NIS by all trips within a pathway

Chan et al. 2012
Combining risk ratings

- Combine $P(\text{arrival})$ and $P(\text{survival and establishment})$ using the minimum probability approach.

- Then combine $P(\text{introduction})$ and magnitude of consequences using a mixed rounding matrix.

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Lowest</th>
<th>Lower</th>
<th>Intermediate</th>
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## Summary of results

### High-risk ports and vessel pathways

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Chan et al. 2012
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Chan et al. 2012
The vector-based risk assessment framework can be applied to other regions...
Vector interruption

- Actions designed to disrupt or prevent the transfer of NIS by particular vectors

Education and outreach

Voluntary guidelines

Regulations and laws

Ruiz & Carlton 2003
Case study:
Ballast water management strategies in Canada

Photo credit: Sarah Bailey
Ballast water regulations

• Transport Canada regulates ballast water discharges

• Requires all transoceanic vessels arriving at Canadian ports to conduct **open-ocean exchange** or **salt water flushing**

• Mandatory requirements nationally since 2006, voluntary since 2000 (1989 for the Great Lakes)
Reducing the risk

Rational for mid-ocean ballast exchange/flushing:

1. Purges planktonic organisms from tanks
2. Reduces sediment accumulation (resting eggs and benthic taxa)
3. Reduces fitness of taxa remaining in tanks through salinity shock
4. Any saltwater species entrained from the ocean should have reduced fitness if released in freshwater/coastal habitats

Photo credit: Sarah Bailey; Bailey 2015
Ship-mediated non-indigenous species (NIS)

Annual # of NIS Reported

Year


*1995*

Bailey et al. 2011
Reducing the risk further

- Efficacy of ballast water exchange/flushing is mixed for marine ecosystems
- International Maritime Organization has proposed numeric discharge standards

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<th>Category</th>
<th>IMO-D2 Standard</th>
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<td>&gt;50µm (Zooplankton)</td>
<td>&lt;10 viable organisms per m3</td>
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<tr>
<td>&gt;10- &lt;50µm (Phytoplankton)</td>
<td>&lt;10 viable cells per mL</td>
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- When enter into force, the *International Convention for the Control and Management of Ships’ Ballast Water and Sediments* will require international commercial ships to treat ballast water using ballast water treatment systems

Bailey 2015
Ballast water treatment systems

- Ballast Water Treatments
  - Chemical
    - Disinfection
    - Biocides
      - Electrolysis/Electro-Chlorination
  - Mechanical
    - Filtration
      - Magnetic Separation
      - Hydrocyclone
  - Physical
    - Thermal (heat)
    - Ultraviolet Irradiation
    - Ultrasound
    - Cavitation
    - Inert Gas Deoxygenation
Acknowledgements