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Optimal Planning of Invasive Species Surveillance Campaigns

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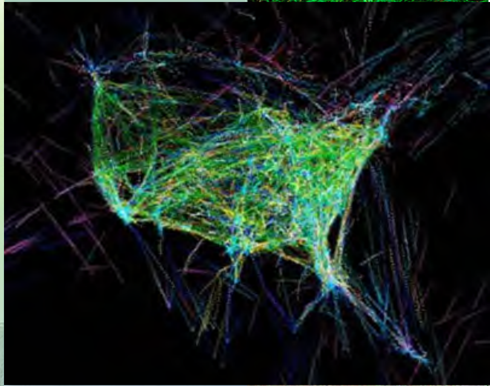
International Conference on Aquatic Invasive Species (ICAIS) 2019
Special Session "Integrating Invasion Science and Management Across Realms:
Learning from Terrestrial, Marine and Freshwater Experiences

October 27-31, 2019, Le Centre Sheraton, Montreal, QC



Minnesota Aquatic Invasive Species Research Center, University of Minnesota, Driven to Discover

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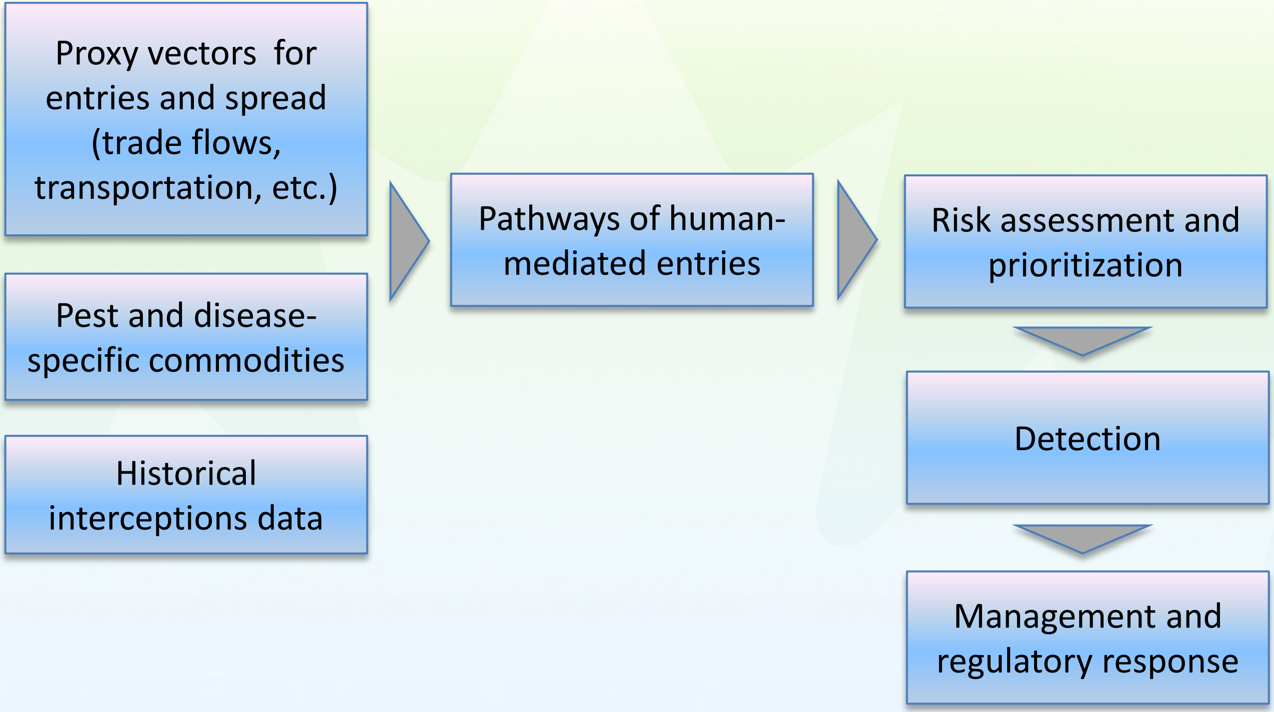
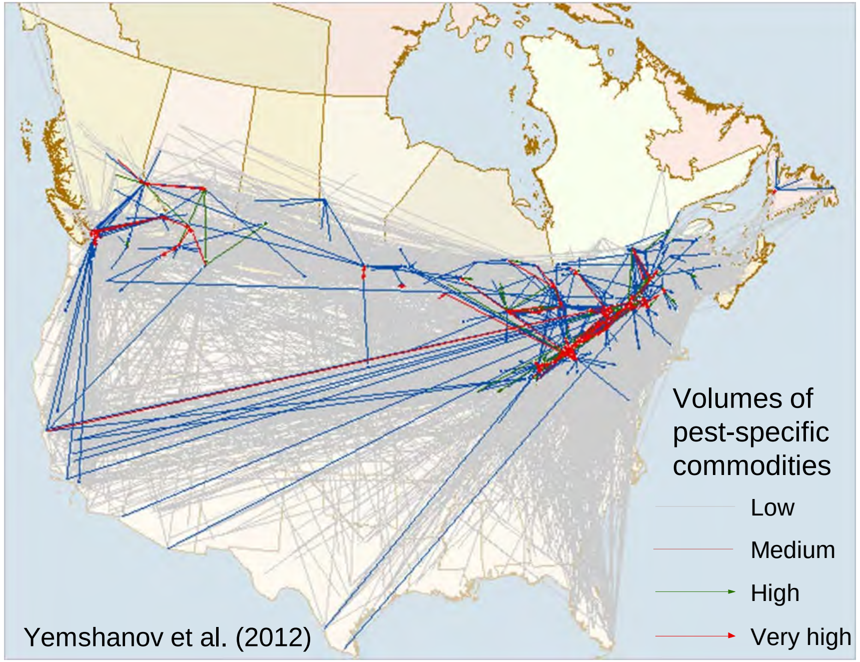
Detecting and managing biological invasions – basic analysis flow



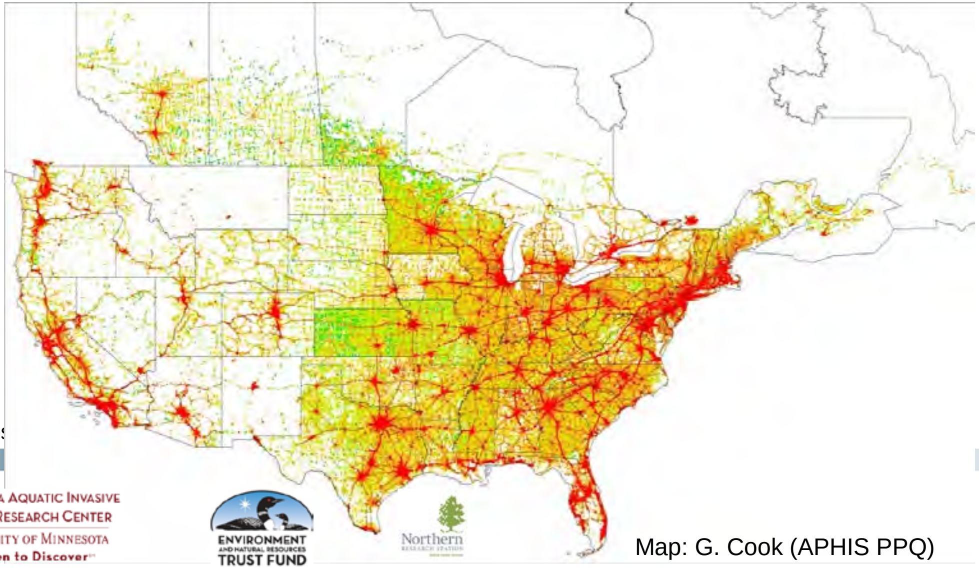
Examples of pathway-related data: Road transportation

Movement of pest-specific commodities across Canada and the U.S.A. (“origin-destination” routes based on Canadian Roadside Survey)



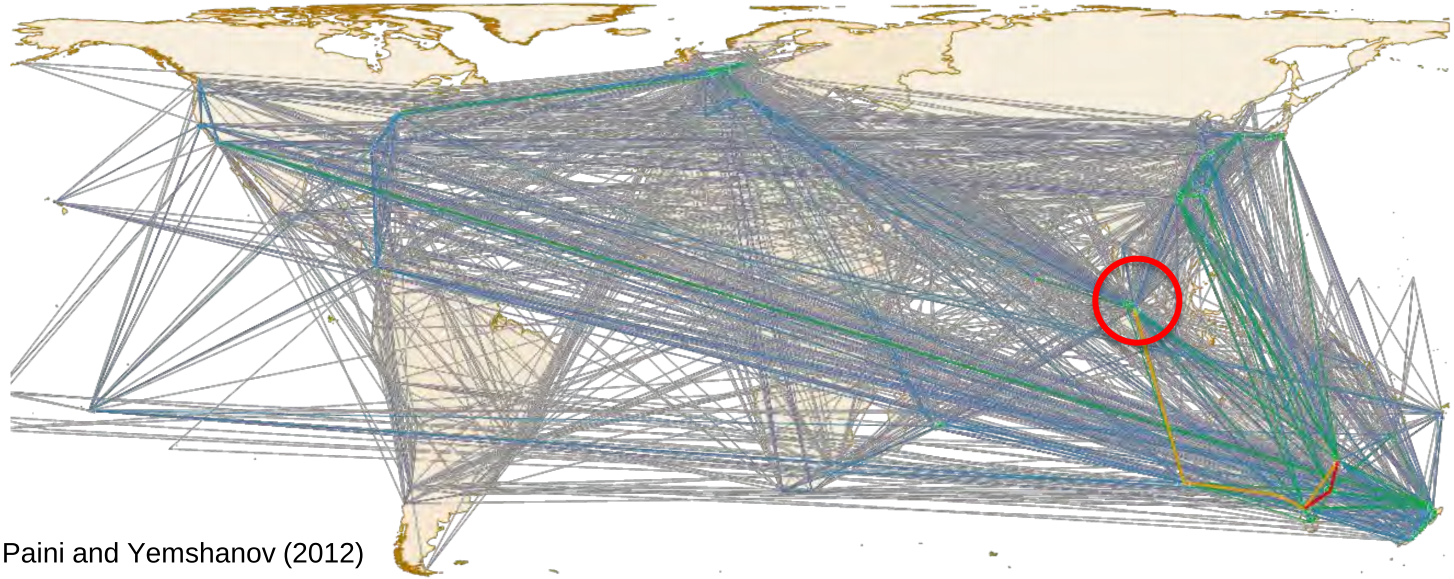
- Recorded at <u>Canadian</u> highway weigh stations
- 15 000 summary records for forest pest-associated SCTG commodities
- Covers Canada and cross-border trips to and from the U.S.

The North-American road traffic volumes



Examples of pathway-related data: International marine trade

Pathways of marine vessels that have unloaded cargo at Australian ports (based on Lloyd's marine vessel database)



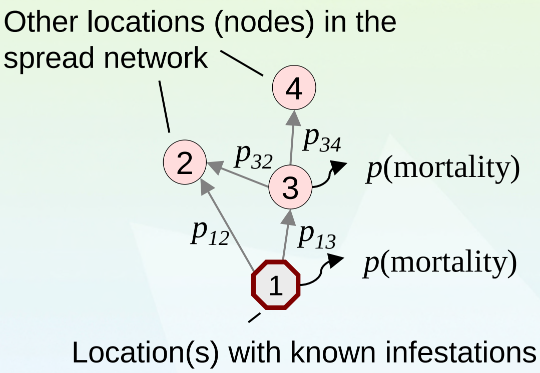
Number of ships per route over five years:

- < 50
- 50 - 200
- 200 - 1000
- 1000 - 1500
- >1500

Paini and Yemshanov (2012)

Network-based approach to assess invasion risks

Pathway-related data can be used to estimate the rates of entry and optimal detection strategies using the network-based approach



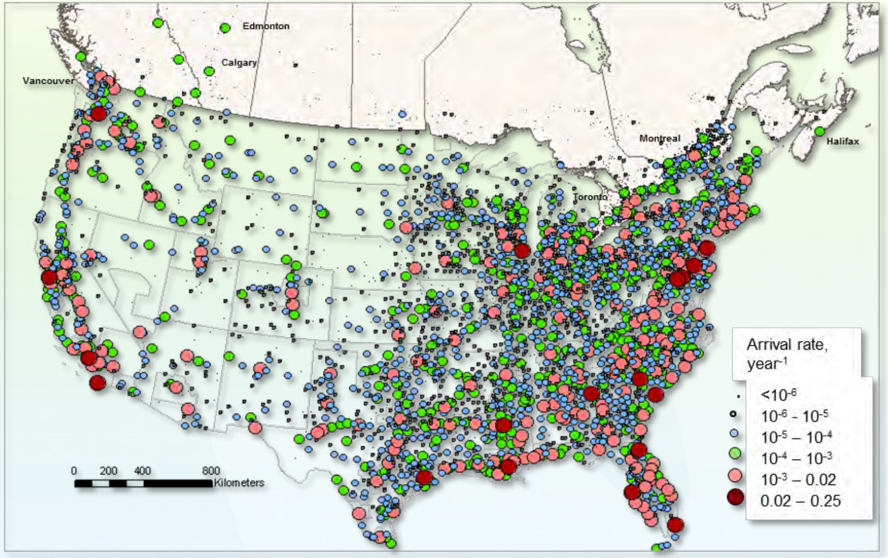
- Convert the data on movement of invasive organisms to a spatial network
- For each location in the network (e.g., city, forest site, lake, etc.):

  Estimate the likelihood of "spread" to other locations

  Use the estimated likelihoods of spread to find optimal strategies to detect and control the spread of an outbreak

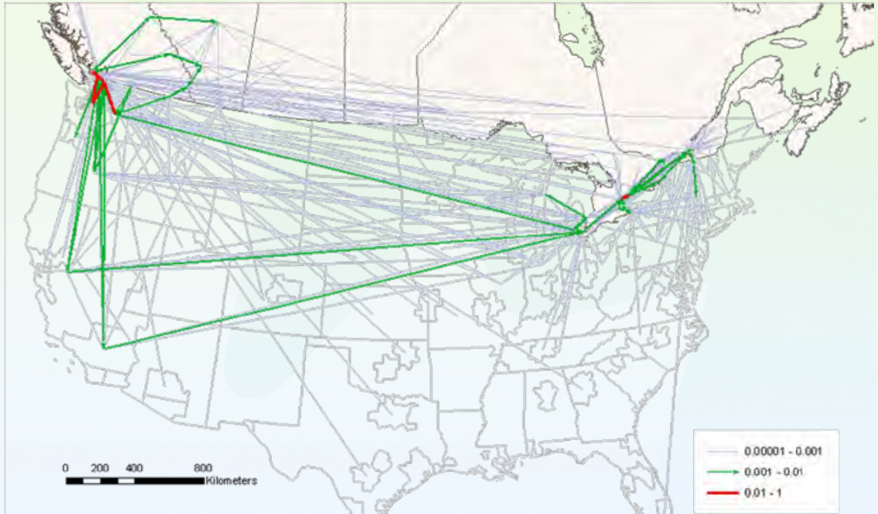
Using pathway data to estimate invasive species entry rates

Arrival rates of invasive forest pests entries to ports and major cities in Canada and U.S.



U.S. entries - Koch et al. 2010
Canadian entries - Yemshanov et al. 2012

Major gateways of invasive forest pests entries with foreign imports to Canada



Yemshanov et al. 2012

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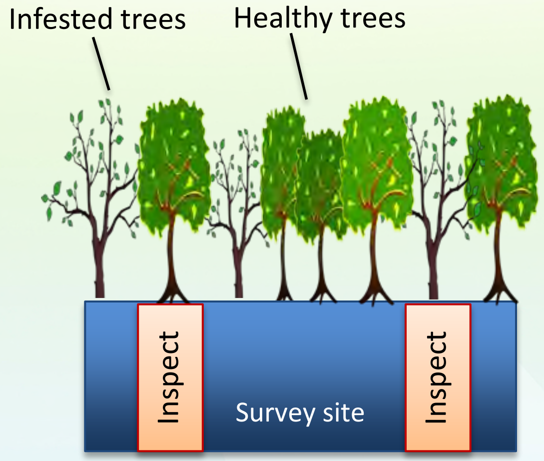
Delimiting surveys



- Use invasion risk or entry rate estimates
- Aim to uncover full spatial extent of invasion
- Subdivide area into sites
  - Number of host trees / carrying capacity
  - Tree infestation rate
  - Inspection cost
  - Detection rate
- Determine the number of trees to inspect in each site to maximize the expected area (or number of sites) with successful detections, subject to an inspection budget

Survey problem example

Maximize the expected number of sites with successful detections

Parameters[*]

N_j = number of trees (host density)

γ_j = tree infestation rate

e_j = pest detection rate

c_j = tree inspection cost

Decision variables

n_j = number of trees to inspect

P(detecting one or more infested trees at a survey site)

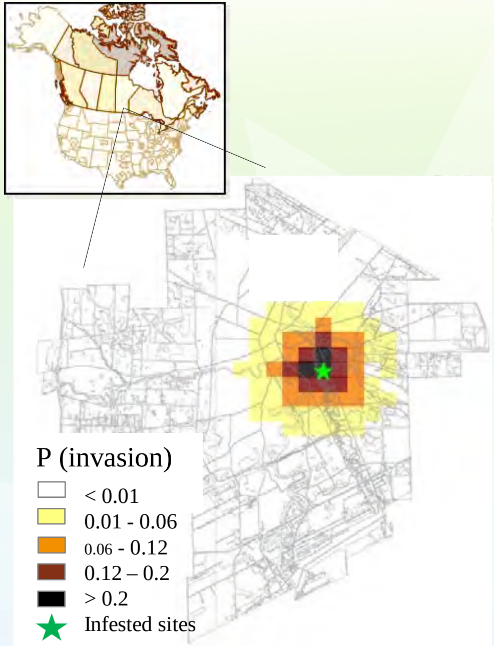
$$\max \sum_{j=1}^{J} \left(1-(1-\gamma_j e_j)^{n_j}\right)$$

Subject to:

$$\sum_{j=1}^{J} c_j n_j \le B$$

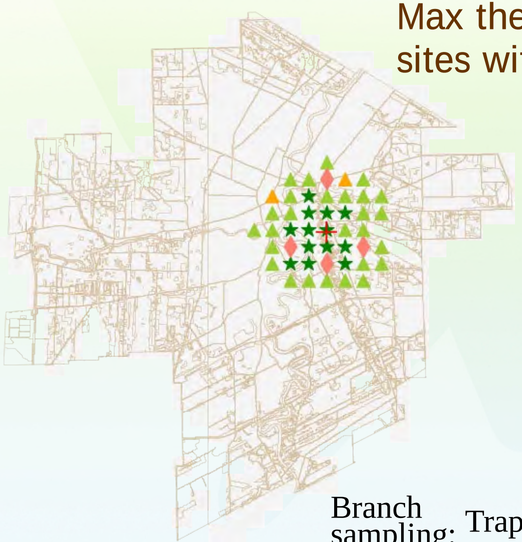
[*]See Yemshanov et al. 2019

Survey problem example: Delimiting surveys of Emerald Ash Borer (EAB) in Winnipeg, MB



Likelihoods of EAB invasion in Winnipeg, MB

Max the expected number of sites with successful detections



Sampling rate, trees per site:	Branch sampling:	Trapping:
	1-5	1-5
	6-15	6-15
	16-25	16-25
	26-50	26-50
	>50	>50

$25 000 survey budget example

See Yemshanov et al. 2019

Aquatic species surveillance planning example:
Locating boat inspection stations to prevent spread of zebra mussel (ZM)

PHOTO BY MN DNR

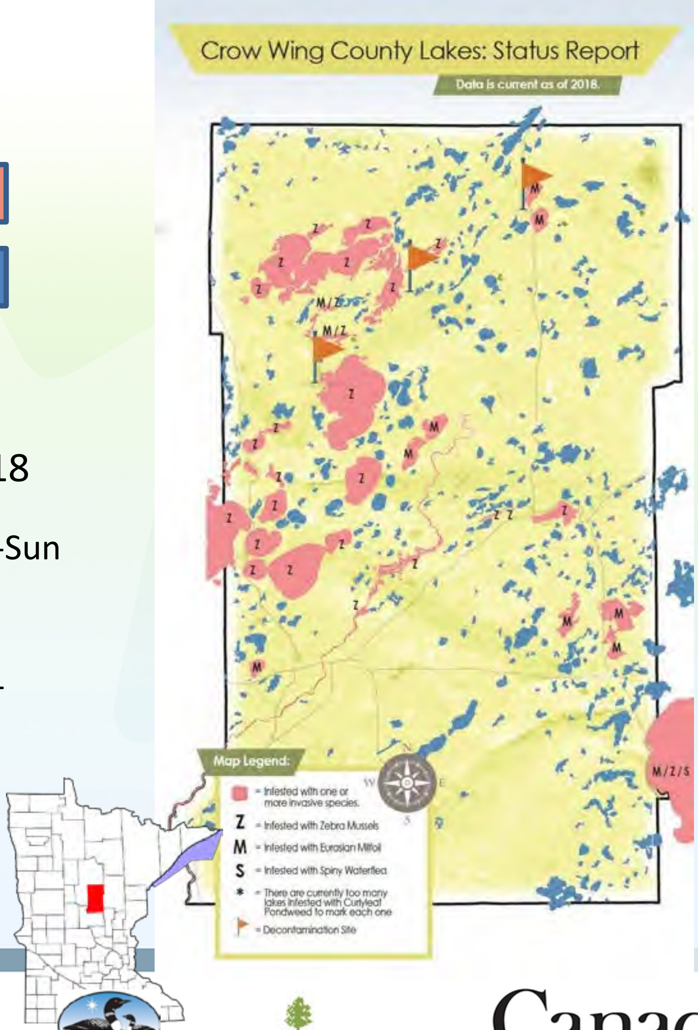
PHOTO BY BRAD HENLEY

- Where do we put inspection stations for controlling the spread of ZM?
- Location: Crow Wing Country, Minnesota, USA
- Objective: Locate a fixed number of boat inspection stations to maximize the number of inspected boats that move from infested to uninfested lakes
- Data:
  - Lists and locations of infested and uninfested lakes
  - Number of boats moving from infested to uninfested lakes annually (from Nick Phelps; MN-DNR inspection data, 2014-18)
    - Within the county
    - Within the county to outside
    - Outside the county to within the county

Crow Wing county, Minnesota

- 27 lakes infested with ZM
- 132 uninfested lakes
- Annual boat movements between individual lakes: >42k boats per year
- $370 388 spent on 2 065 8-hour inspector-days in 2018
  - 66 inspection days assuming inspections take place Fri-Sun during May-Sept
  - Dividing 2,065 inspector days by 66 - a maximum of 31 boat landings per day can have inspection stations

Z



Problem formulation

$$\max_{x_i, y_j} Z = \sum_{j \in J} \sum_{i \in I} n_{ij}(a_{ij} + b_{ij})$$

Subject to:

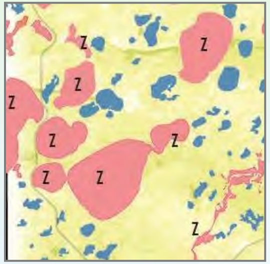
$$a_{ij} \leq x_i \qquad \forall i, j$$

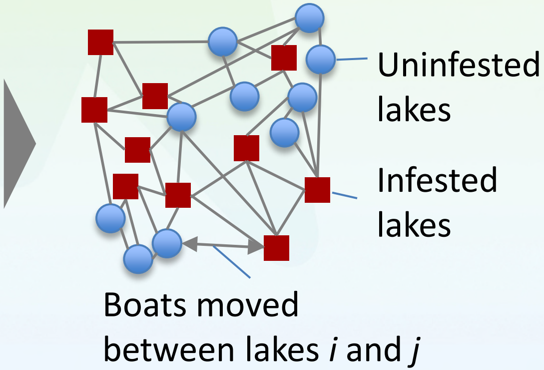
$$b_{ij} \leq y_j \qquad \forall i, j$$

$$a_{ij} + b_{ij} \leq 1 \qquad \forall i, j$$

$$\sum_{i \in I} x_i + \sum_{j \in J} y_j \leq B$$

Locate a fixed number of boat inspection stations to maximize the number of inspected boats that are moved from infested to uninfested lakes





Decision variables:

x_i – 0-1 variable for locating the inspection station at lake *i*;

x_j – 0-1 variable for locating the inspection station at lake *j*;

a_{ij} – 0-1 variable for whether boats moved between lakes *i* and *j* are inspected as they leave lake *i*;

b_{ij} – 0-1 variable for whether boats moved between lakes *i* and *j* are inspected as they enter lake *j*;

Parameters:

n_{ij} – number of boats moved from lake *i* to lake *j*;

B – maximum number of inspection stations.

Optimal inspection solutions

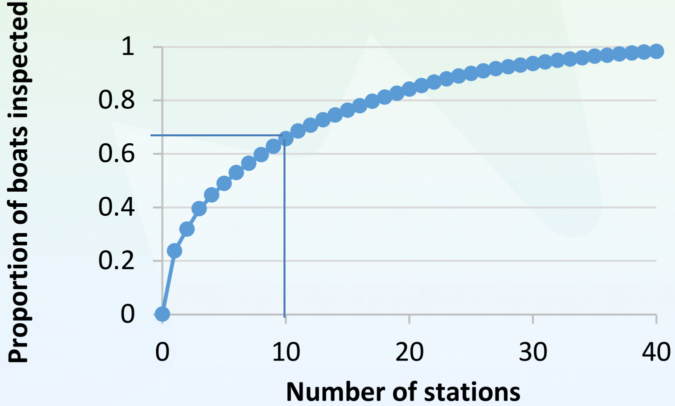
Best solution for a maximum of 10 inspection stations

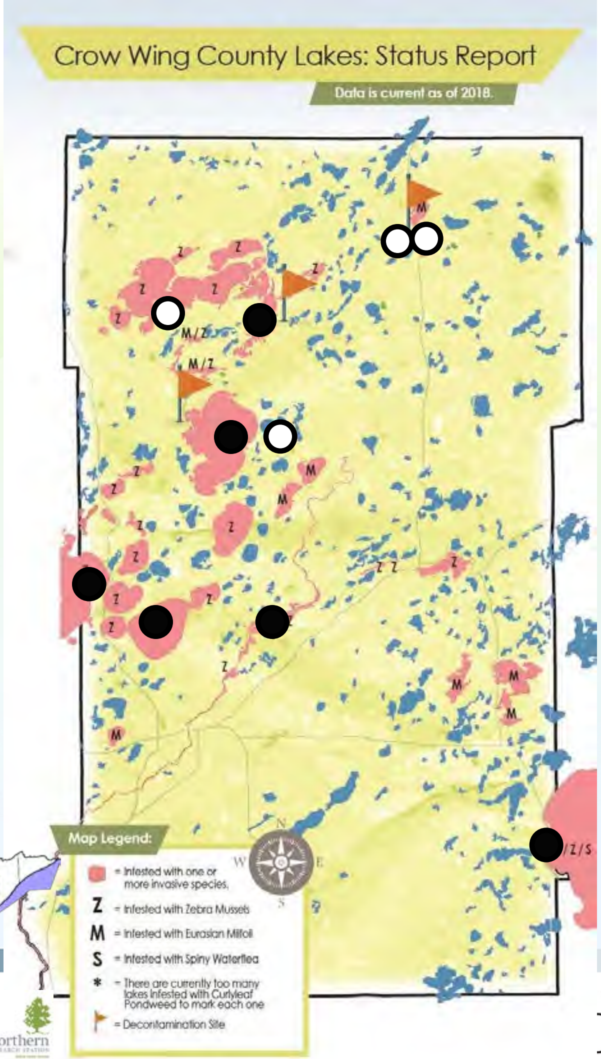
- 6 infested lakes ●

  Gull, Mille Lacs, North Long, Pelican, Little Rabbit, Cross Lake Reservoir

- 4 uninfested lakes ○

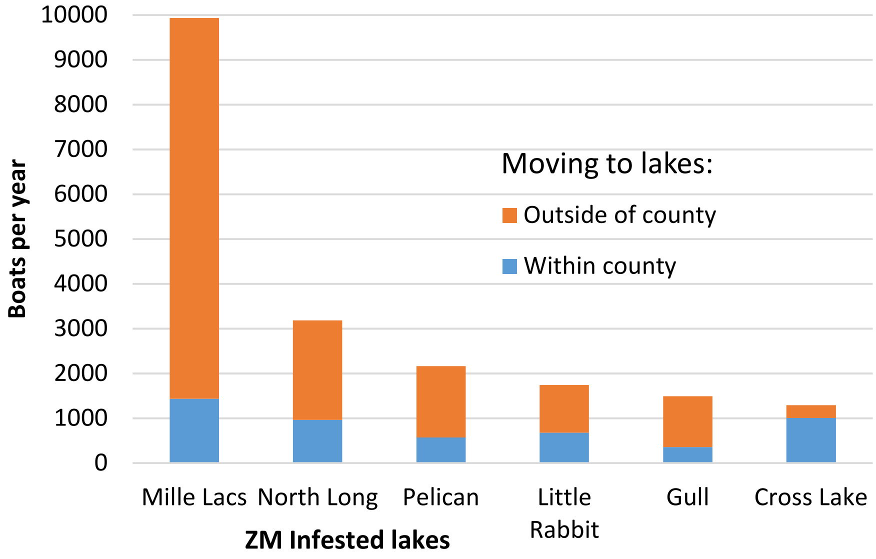
  Clamshell, Emily, Horseshoe, Trout



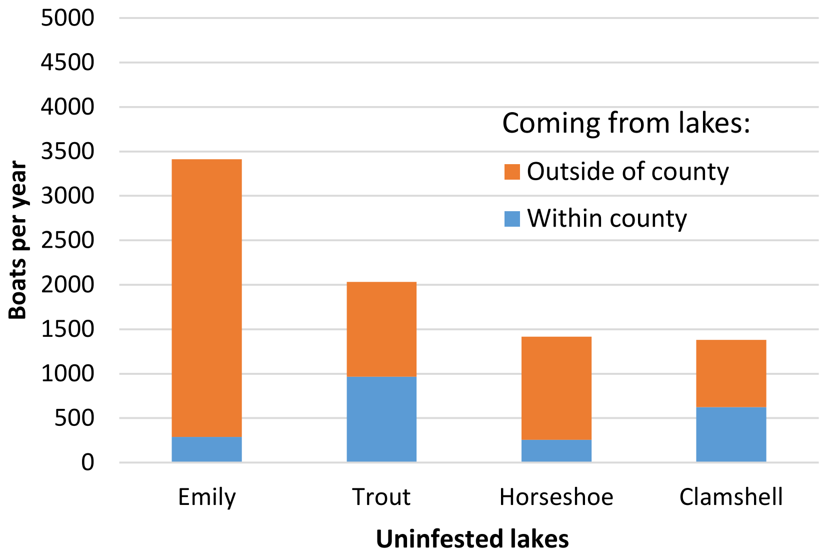


Boat movements from infested to uninfested lakes

Boats leaving infested lakes to uninfested lakes



Boats entering uninfested lakes from infested lakes



Concluding comments

Crow Wing County lakes study:

- Inspections should be placed at:
    - Lakes infested with ZM with a lot of boat traffic
    - Uninfested lakes with a lot of **incoming** boat traffic from out of county
- Consistency between the model optimal selections and the lake invasion risk ranks

Conceptual similarity in formulating optimal surveillance and control problems

Pathway assessments in conjunction with optimization-based surveillance models can help develop better surveillance strategies and general guidelines for practitioners

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