A RISK ASSESSMENT OF GOLDEN MUSSEL (*LIMNOPERNA FORTUNEI*) FOR ONTARIO

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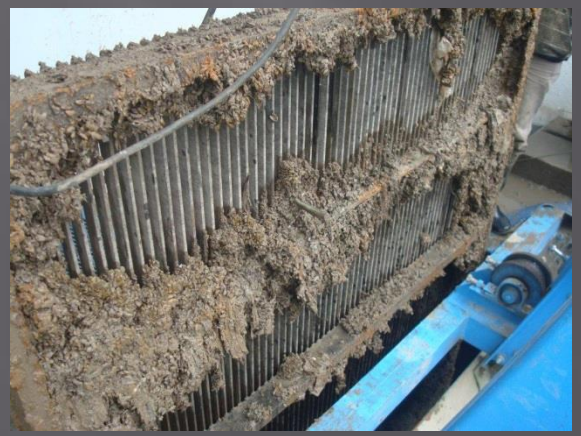
Invasion History

- **An invasive epibenthic mytilid in freshwater and brackish water habitats in Asia (China, Japan, Vietnam,Taiwan) and South America**
- **The Golden Mussel was introduced to South America in 1991 through ballast water discharge into La Plata River basin at Argentina. Now in Bolivia, Paraguay, Uruguay, Brazil.**
- ***The Golden Mussel is not YET present in North America.***

Provided by Dr. Gustavo Darrigran

Habitat Characteristics

- Same as dreissenids
- e.g. on solid substrates including rocks, roots, driftwood, concrete walls, docks, piers, gastropods, crayfish, clams, etc.
- Found as druses on loose silt or mud substrates
- Has similar high reproductive capacities and same nuisance characteristics and dispersal mechanisms as dreissenids
- Differences:
- Has wider environmental tolerances to pH and calcium and temperatures from 4-32^{o} C



All photos provided by Gustavo Darrigran

Ontario Invasive Species Strategic Plan

- Developed by the Ontario Ministry of Natural Resources and Forestry in partnership with OMAFRA, MOE, and MTO (OMNR 2013).
- The plan is a method for conducting a risk assessment for the purposes of a rapid (1-2 weeks) response
- The over-riding objective is to prevent new invaders from arriving and surviving in Ontario.

Risk Assessment Process – A four-step process

Step 1 –

Probability of invasion by Golden Mussel:

- Assessed by estimating probabilities of 4 stages:
- Arrival – assessing likelihood of arrival through primary pathways
- Survival – assuming it has arrived, what is likelihood of its survival?
- Establishment – likelihood of not only surviving but reproducing and maintaining a population
- Spread – the likelihood of Golden Mussel to spread

Stages of Invasion	
Category	**Definition**
Very High	Probability estimated to be 96-100%.
High	Probability estimated to be 61-95%.
Moderate	Probability estimated to be 41-60%.
Low	Probability estimated to be 6-40%.
Very Low	Probability estimated to be 0-5%.

The probability of invasion is then determined by using the lowest of the scores for the four stages of invasion.

Risk Assessment Process – A four-step process

Step 2 –

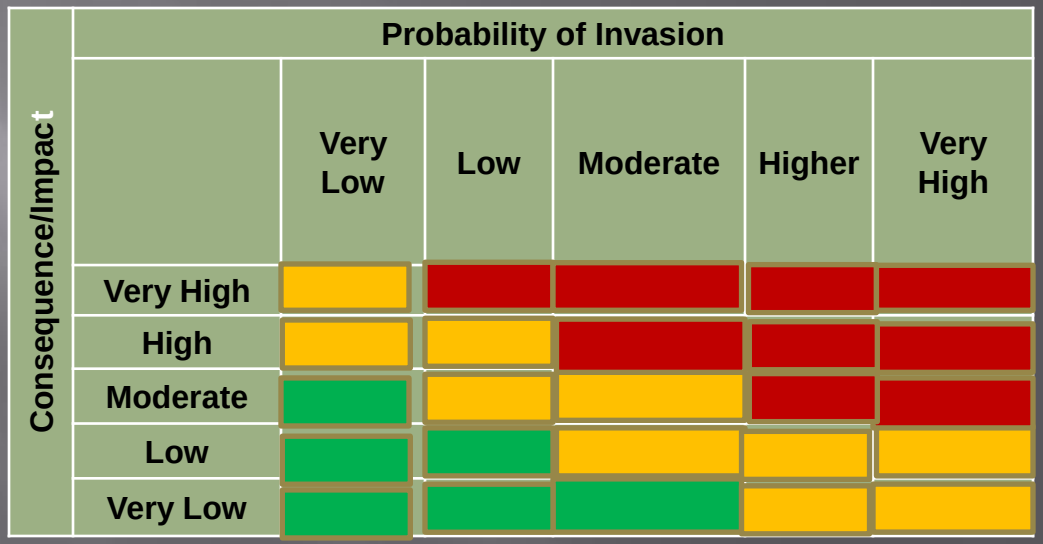
Predicted Impacts of Golden Mussel

By estimating potential impacts at several levels, including biodiversity, natural resources, chemical and physical parameters, and any other impacts based on the literature reviewed

Impacts	
Category	**Definition**
Very High Negative	A critical impact; extensive disruption to the factor in question that is irreversible.
High Negative	A significant impact; widespread disruption to the factor in question that persists over time or is likely not reversible.
Moderate Negative	A measurable widespread impact; widespread disruption to the factor in question but reversible or of limited severity or duration.
Low Negative	A measurable limited impact; disruption to the factor in question but reversible or limited in time, space or severity.
Very Low Negative	Little measurable impact; consequences can be absorbed without additional management action.
Positive or neutral	A positive impact; improvement of the factor in question or no discernible impact.

Risk Assessment Process – A four-step process

- **Step 3 - Potential Risk**
- **The impact rankings from Step 2 can be combined with the probabilities in Step 1 using a risk matrix to produce a final potential risk ranking of invasion. This is a risk matrix that ranks the potential risk as high (red), moderate (yellow) or low (green).**



Estimating certainty

Step 4 - An estimation of uncertainty for each probability and estimated impact.

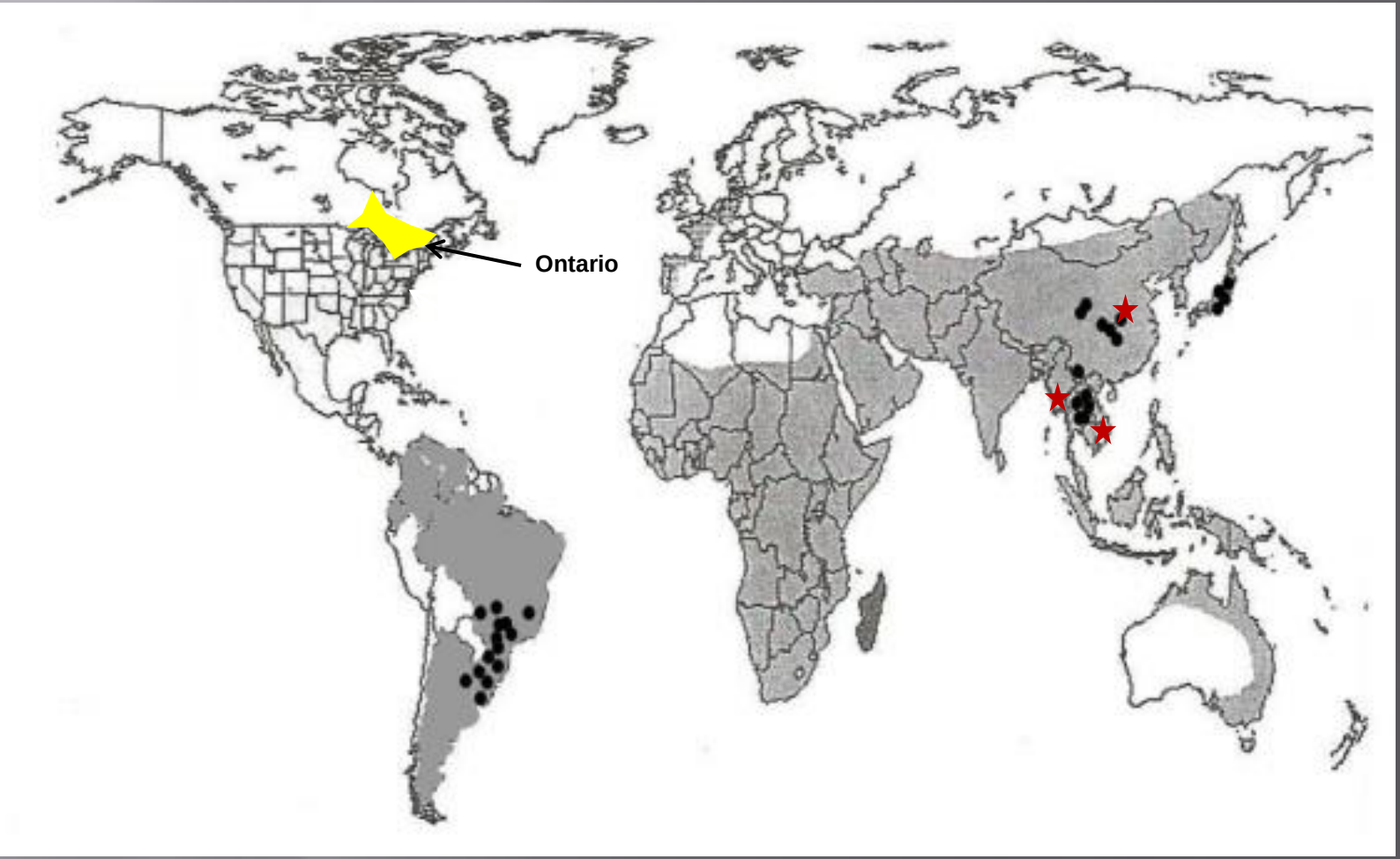
- **The definitions of certainty of probabilities of each stage of invasion and level of impact used in the following risk assessment, are provided in this Table.**

Uncertainty	
Category	**Definition**
Very High	**Little or no scientific information; no supporting data.**
High	**Limited scientific information; circumstantial evidence.**
Moderate	**Moderate level of scientific information; first hand, unsystematic observations.**
Low	**Substantial scientific information; expert opinion.**
Very Low	**Extensive scientific/systematic information; peer-reviewed data sources/information.**

1. Probability of Invasion of Golden Mussel

Probability of invasion of GM was assessed by estimating the probability of:

- **Arrival**
- **Survival**
- **Establishment**
- **Spread.**



Global distribution of Asian Clam (shaded area) often associated with Golden Mussel, shown with closed circles. Asian Clam is also established in isolated areas of Ontario in Lake Erie and Lake St. Clair. Red stars are native ranges of Golden Mussel (China, Taiwan, Cambodia, Vietnam).

Probability of Invasion by Golden Mussel

Stage 1 - Probability of Arrival

- The potential donor regions are:
  - South America (Argentina, Uruguay, Paraguay, Bolivia, and Brazil).
  - Southeast Asia where it is native to China, Thailand, Vietnam and Cambodia, introduced to Japan.
- For Ontario most likely receptor region is the Great Lakes basin.
- Examined primary & secondary pathways
- The most likely source is ballast water from South America but depends on efficacy of ballast water exchange & other variables
- Summary of analyses is the level of probability of survival is low with low certainty

Probability of Invasion by Golden Mussel

Probability of Arrival

- For Ontario most likely receptor region is the Great Lakes basin.
- The potential donor regions are:
  - South America (Argentina, Uruguay, Paraguay, Bolivia, and Brazil).
  - Southeast Asia where it is native to China, Thailand, Vietnam and Cambodia, introduced to Japan .

Probability of Invasion

Probability of Arrival

- ***Primary pathways*** **from which Golden Mussel could enter Ontario waters are:**
- **Ballast water in transoceanic vessels entering the Great Lakes**
- **Trailered boats if the species is introduced into other provinces or USA before Ontario**

Probability of Invasion

Probability of Arrival

- ***Secondary pathways*** **from which Golden Mussel could enter Ontario waters are:**
- **Ballast water or hulls of coastal and inland ships**
- **Trailered boats from lakes/rivers already infested with Golden Mussel**
- **Unauthorized release of freshwater plants and animals with mussels attached, as in the aquarium trade (highly unlikely).**

Probability of Invasion

Probability of Arrival

- **Ballast water:**
  - **Probability depends on:**
    - **Frequency of transoceanic vessels from donor regions (all operate outside of the Canadian and U.S. EEZs and all are currently foreign flagged).**
    - **NOBOBS vs BOBs.**
    - **Efficacy of ballast water exchange (BWE) or treatment.**

Probability of Arrival/Survival

Ballast water (continued):

Estimating potential for introduction and magnitude of consequences of introduction:

- ballast volume discharged
- propagule pressure (based on biological sampling surveys),
- environmental similarity between donor and recipient ports (based on salinity and climate),
- number of high impact NIS in donor ecoregions,
- Effects of mitigation strategies

Country	Ports present	Freshwater ports
Asia		
China	401	99
Japan	325	11
Vietnam	63	9
Thailand	37	4
Cambodia	6	1
South America		
Argentina	112	30
Brazil	88	16
Uruguay	14	3
Paraguay	10	3
Bolivia	1	1

DONOR REGIONS

Of the 2 most likely donor regions, SA is the most likely because:

- **It is closer to Great Lakes via the Atlantic Ocean than Asia via the Pacific Ocean.**
- **Two primary pathways from SA: (1) A single ship could transport GM from SA to Great Lakes (2) Overland transport from a port in USA to Great Lakes**
- **A single ship could transport GM to west coast of Canada but a "back door" entry via overland transport is needed to enter the Great Lakes.**

Probability of Invasion by Golden Mussel

Stage 2 – Probability of Survival

According to matching climate in donor and recipient regions

	Donor Region			
Recipient Region	**Arctic & Antarctic**	**Cold-temperate**	**Warm-temperate**	**Tropics**
Arctic & Antarctic	**High**	**Medium**	**Low**	**Low**
Cold-temperate	**Medium**	**High**	**Medium**	**Low**
Warm-temperate	**Low**	**Medium**	**High**	**Medium**
Tropics	**Low**	**Low**	**Medium**	**High**

According to matching salinity in donor and recipient regions

Recipient Region	**Donor Region**		
	Freshwater	**Brackish water**	**Salt water**
Freshwater	**High**	**Medium**	**Low**
Brackish water	**Medium**	**High**	**High**
Salt water	**Low**	**High**	**High**

Ecological & Physiological Tolerances & Requirements

Stage 2 – Probability of Survival

Examined GM known ranges

pH (5.4-10.0)

[Ca] (1-50 mg/L)

[D.O.] (0.2-12.7 mg/L)

Conductivity (14-1470 µS/cm)

Temperature (4-32ºC)

Ecological & Physiological Tolerances & Requirements

pH, [Ca], [D.O], Conductivity in Ontario

Ecological & Physiological Tolerances & Requirements

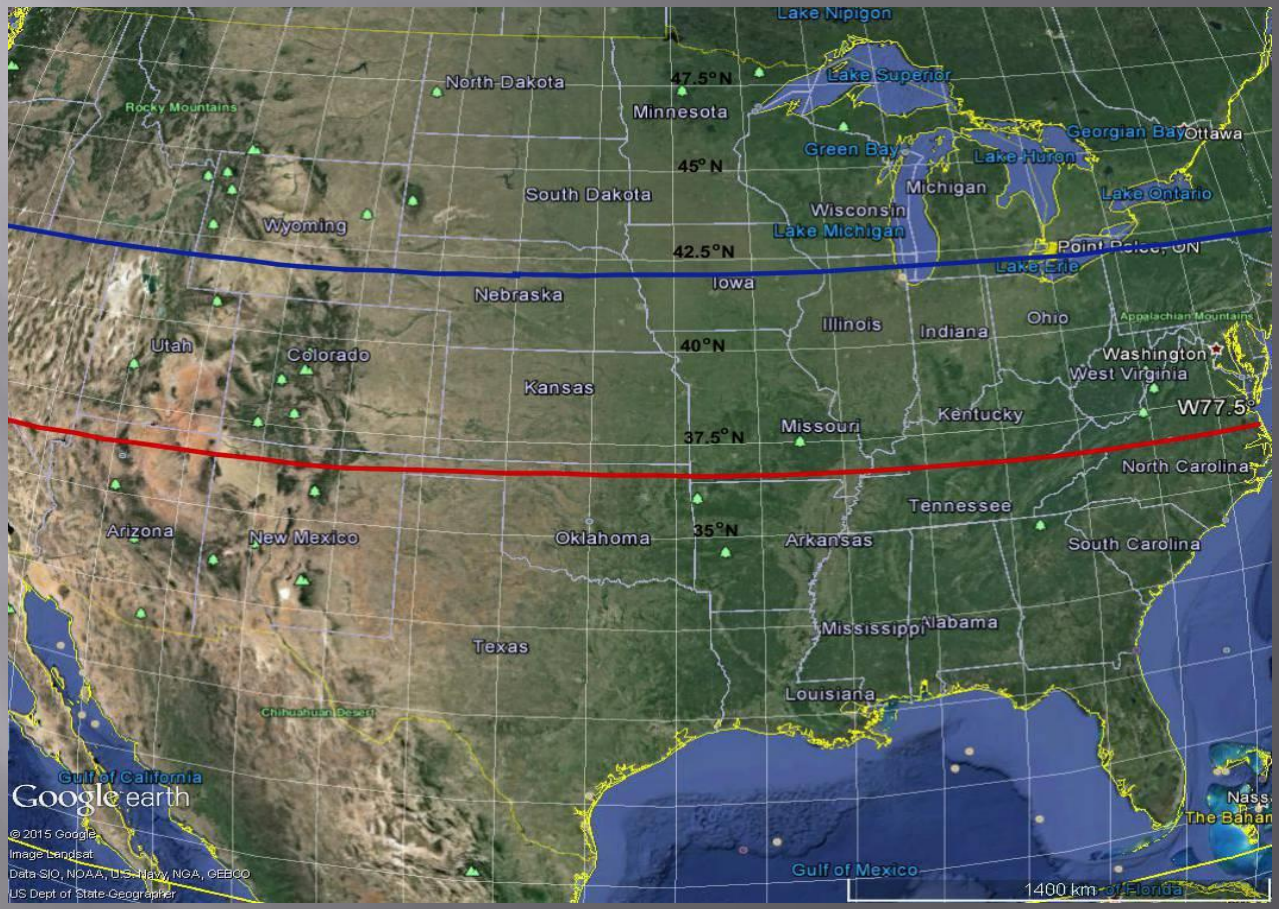
Winter temperature (not known from <4^{o}C)

Ecological & Physiological Tolerances & Requirements

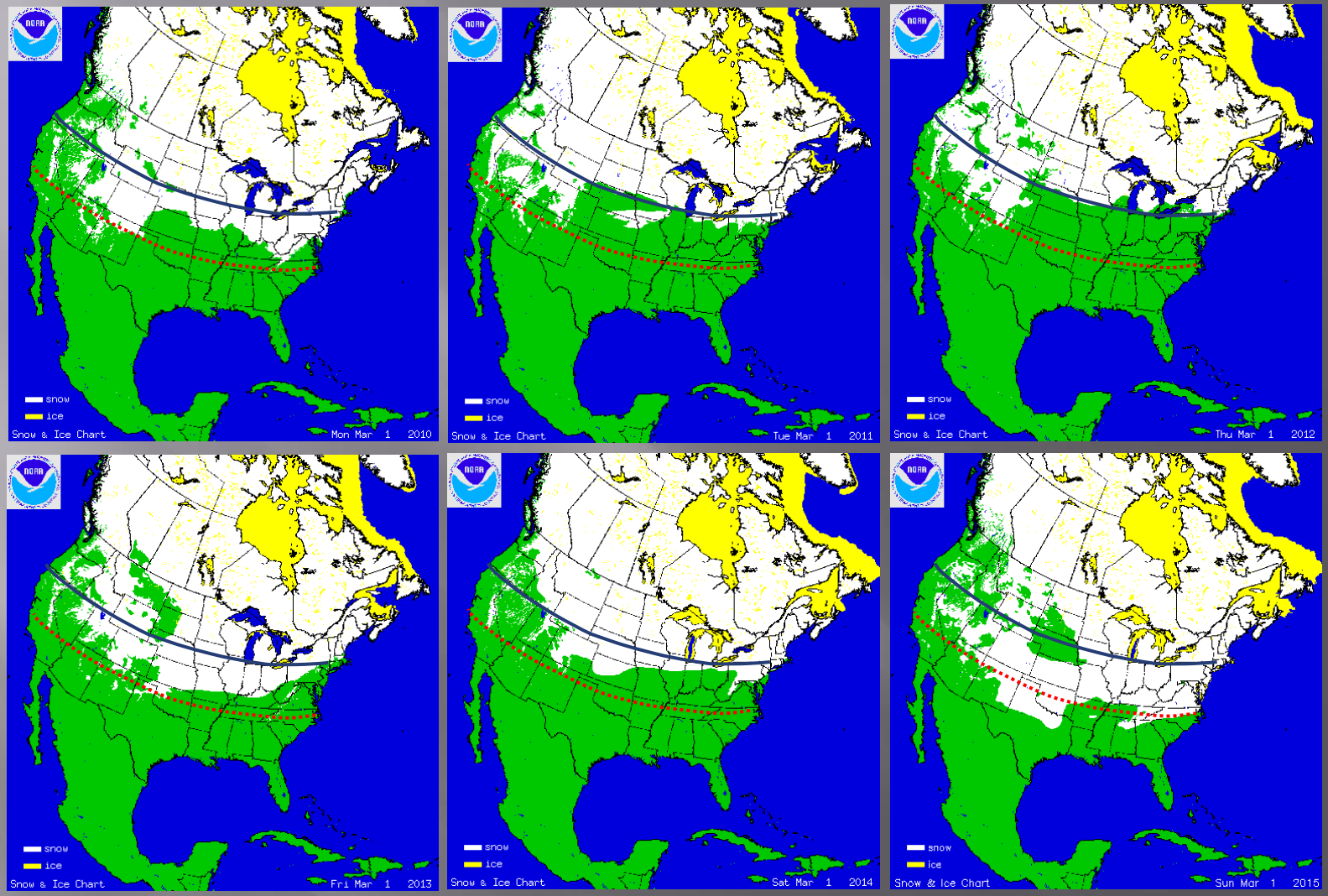
Summer temperature (21- 36ºC)

Ecological & Physiological Tolerances & Requirements

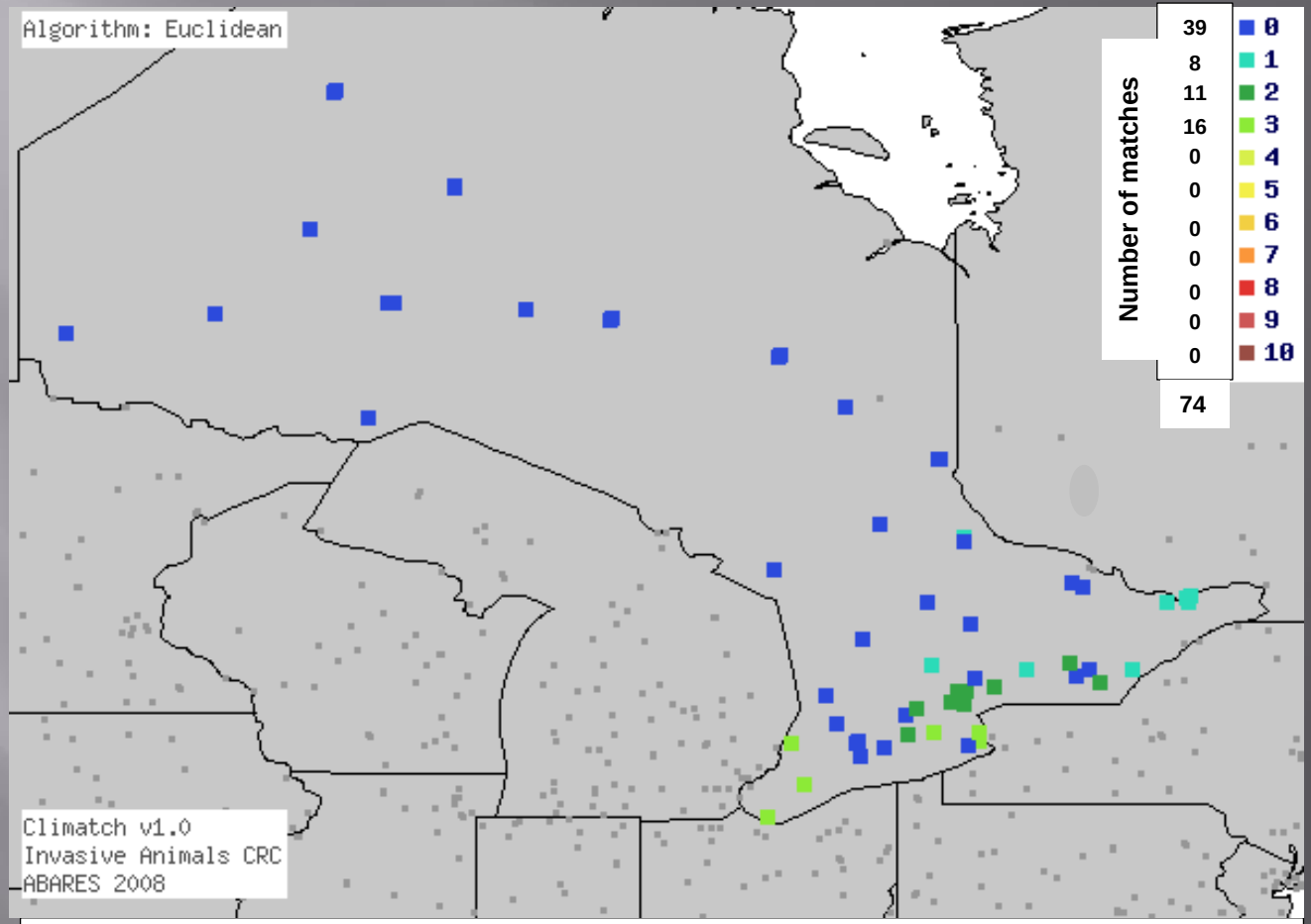
Summer temperature (21-36ºC)



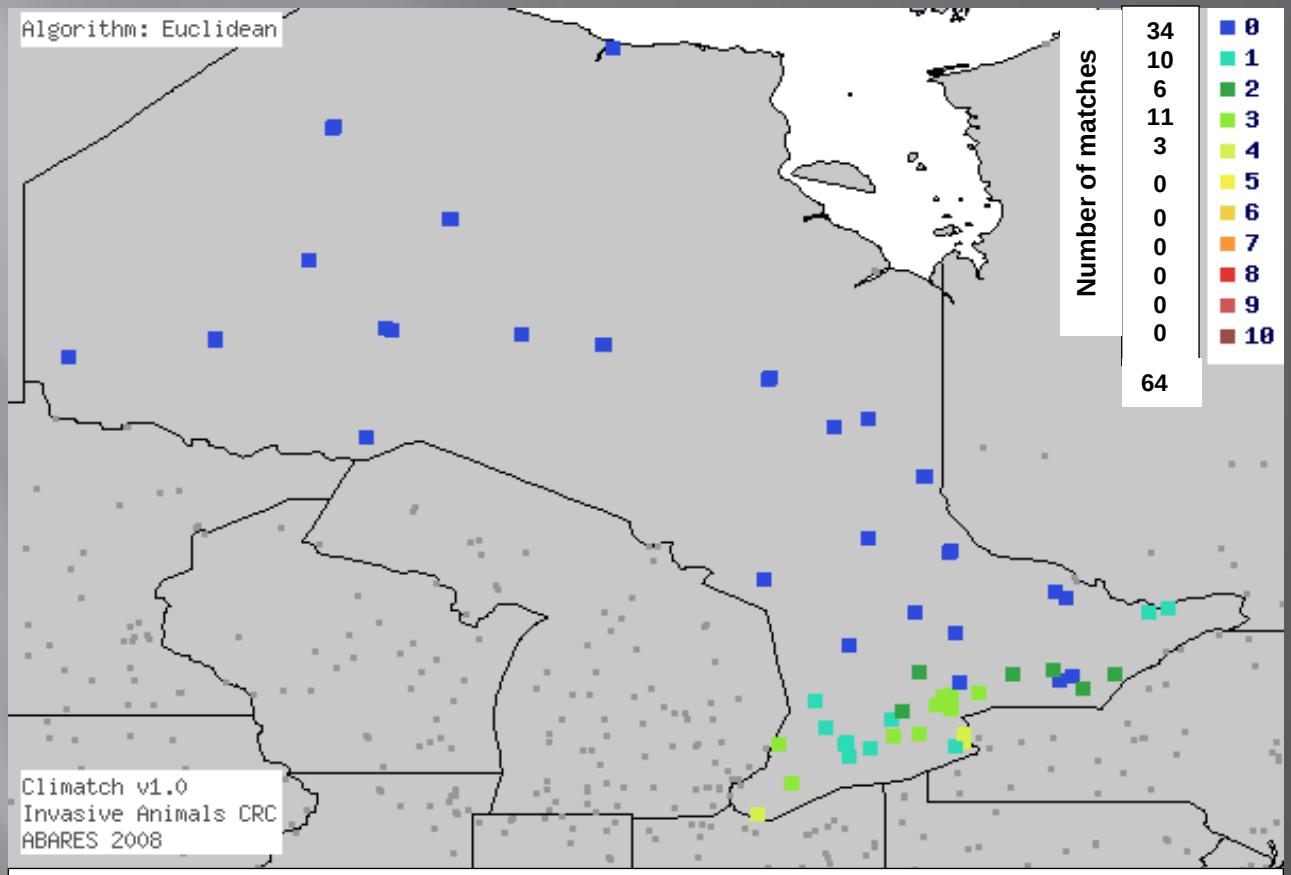
Potential northern limits of distribution of *Limnoperna fortunei* in NA is somewhere between 36º N (red line) and 41º N (blue line, Point Pelee, Western Lake Erie).



Snow cover in North America on March 1, 2010 to 2015.
Blue solid line at 41ºN (Point Peelee), red dotted line at 36ºN.



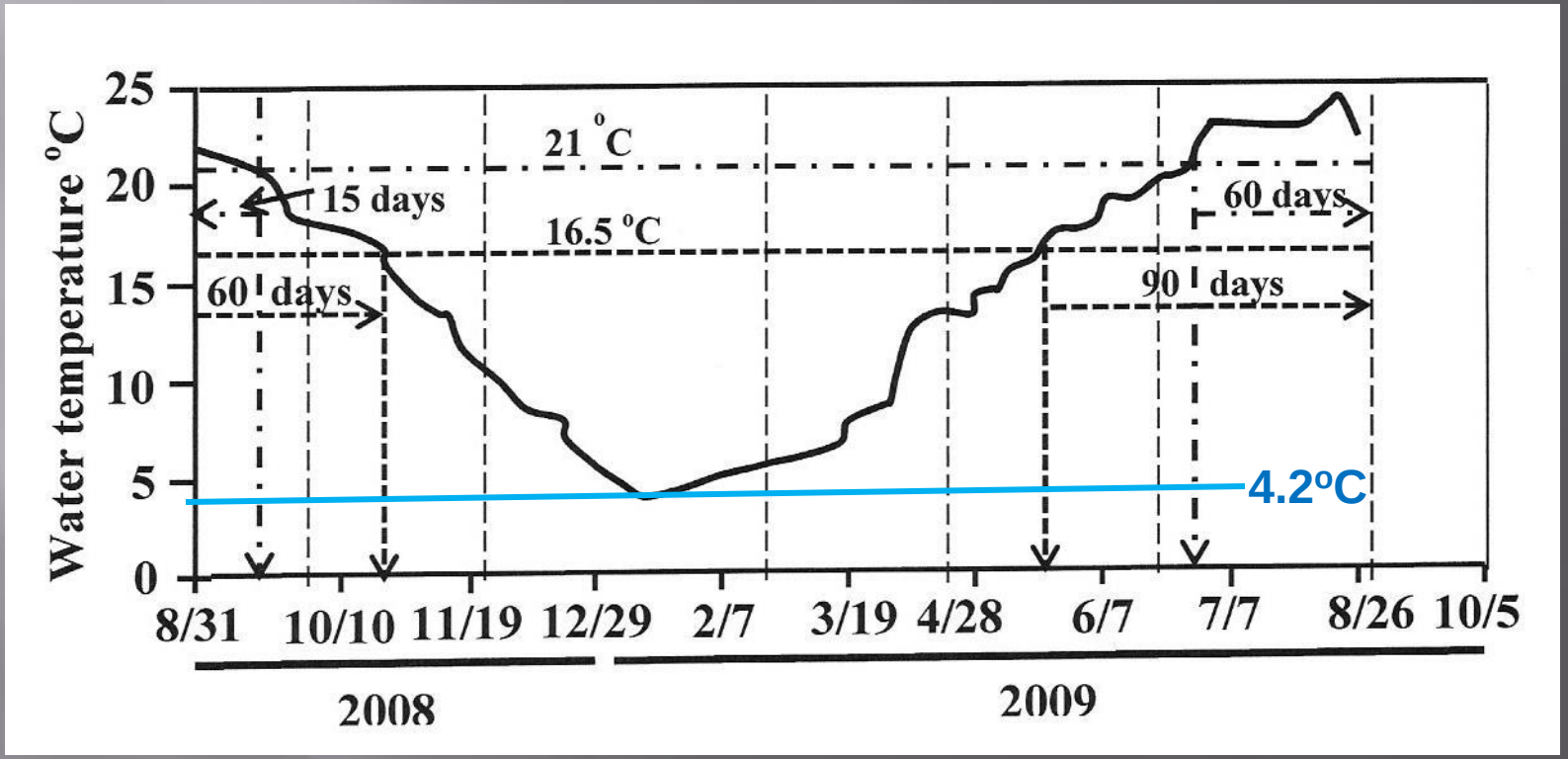
Climatch results for *Limnoperna fortunei* in Ontario based on Climatch stations in Japan. The number of matches for each climate symbol (0 to 10, 10 being most similar climates) shown in legend.



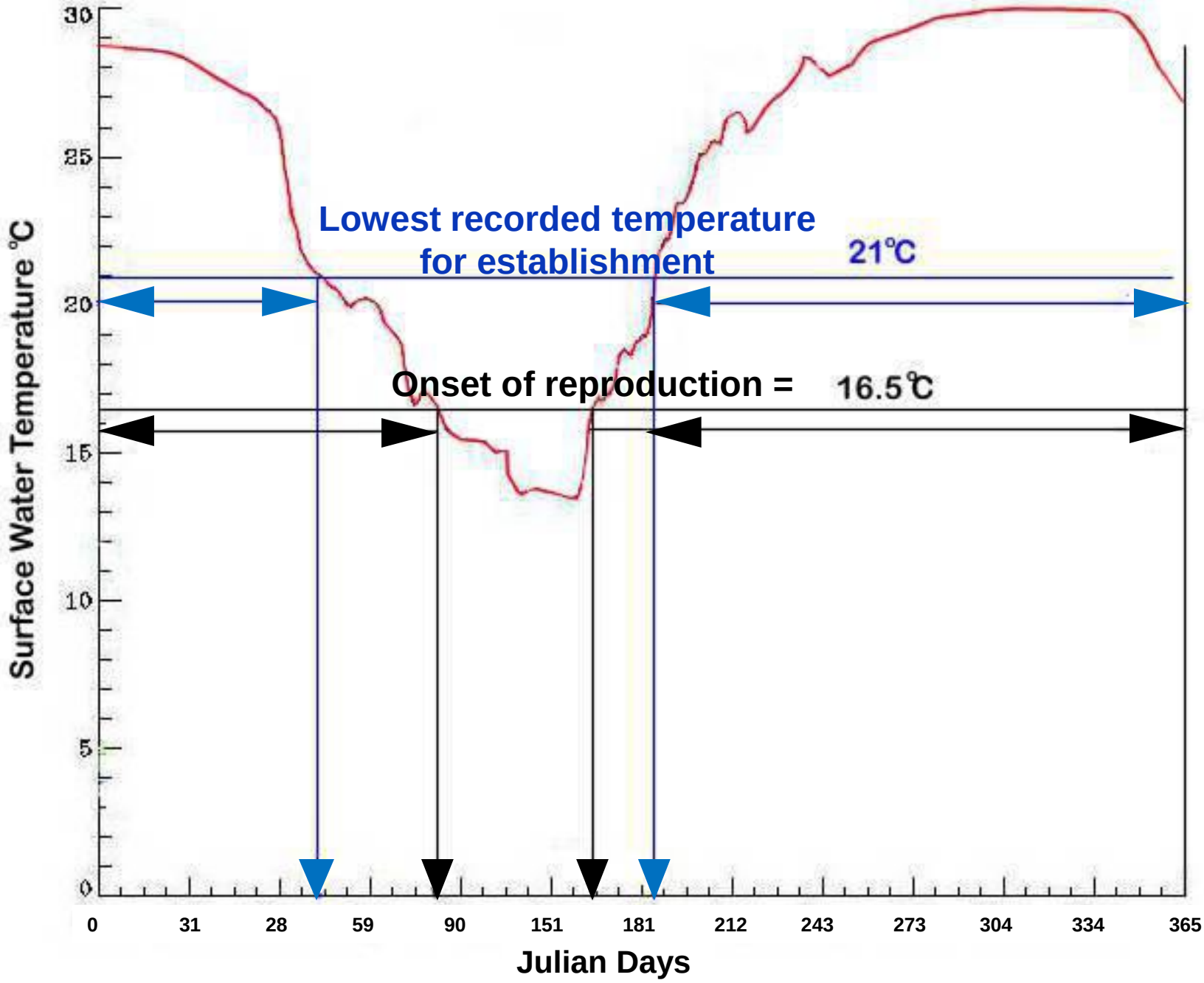
Climatch results for *Limnoperna fortunei* in Ontario based on Climatch stations in South America. The number of matches for each climate symbol (0 to 10, 10 being most similar climates) shown in legend.

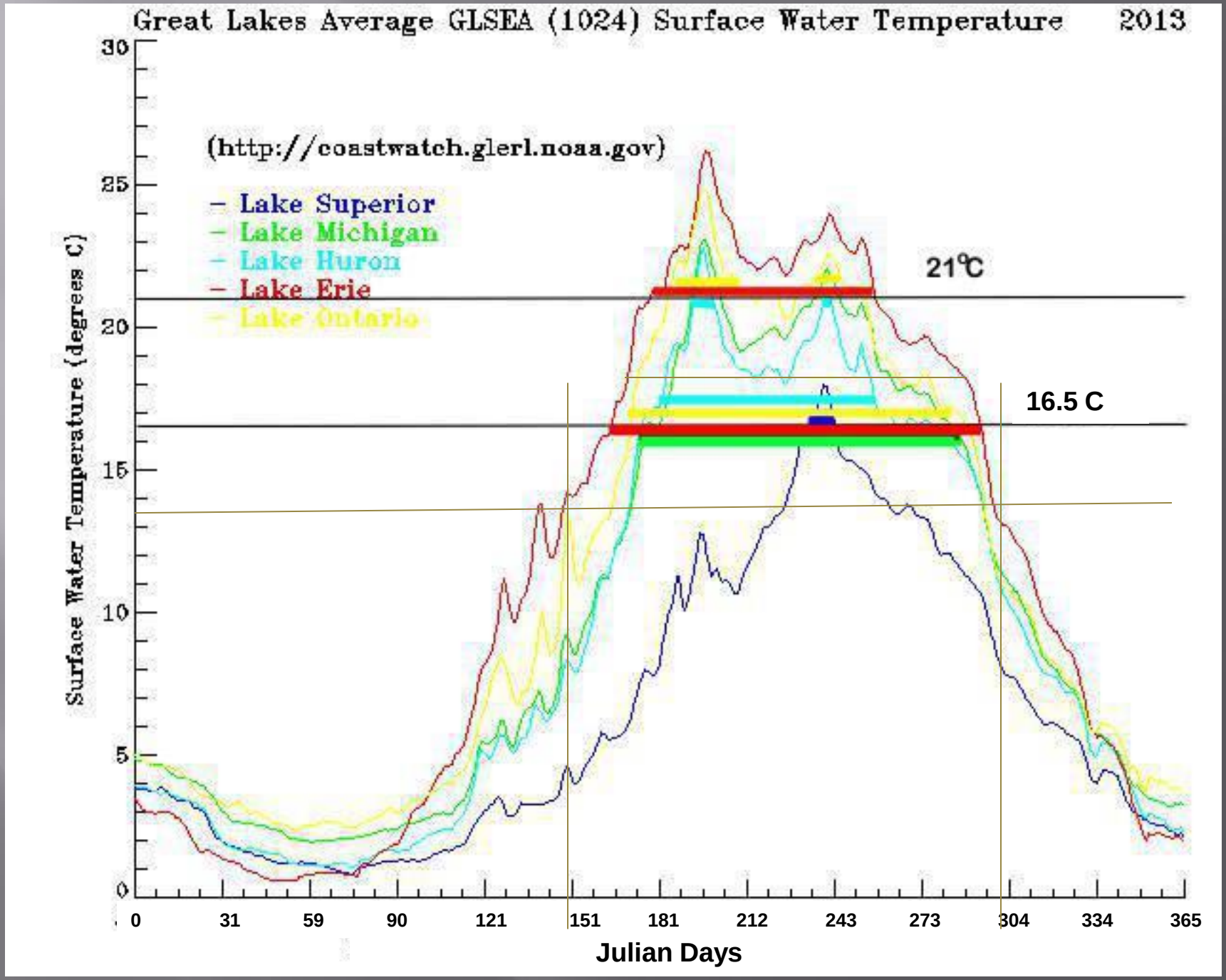
Stage 3 – Probability of establishment

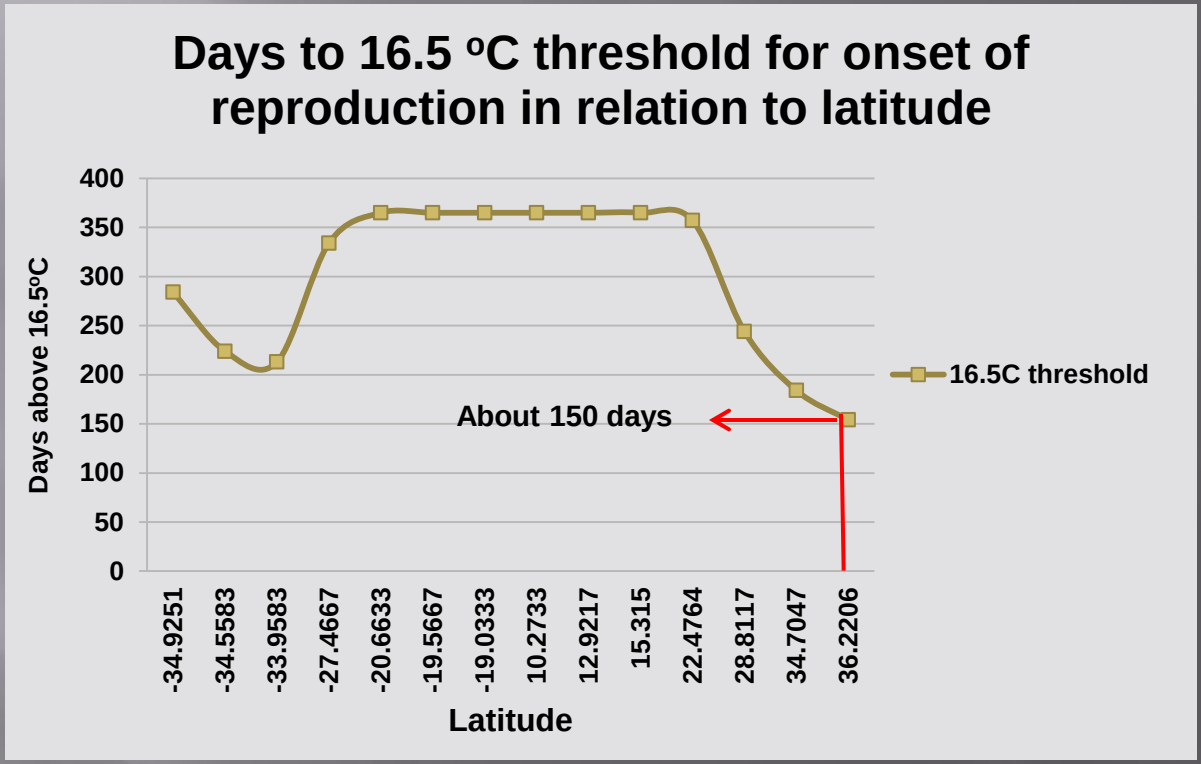
Degree days at threshold of reproduction & establishment

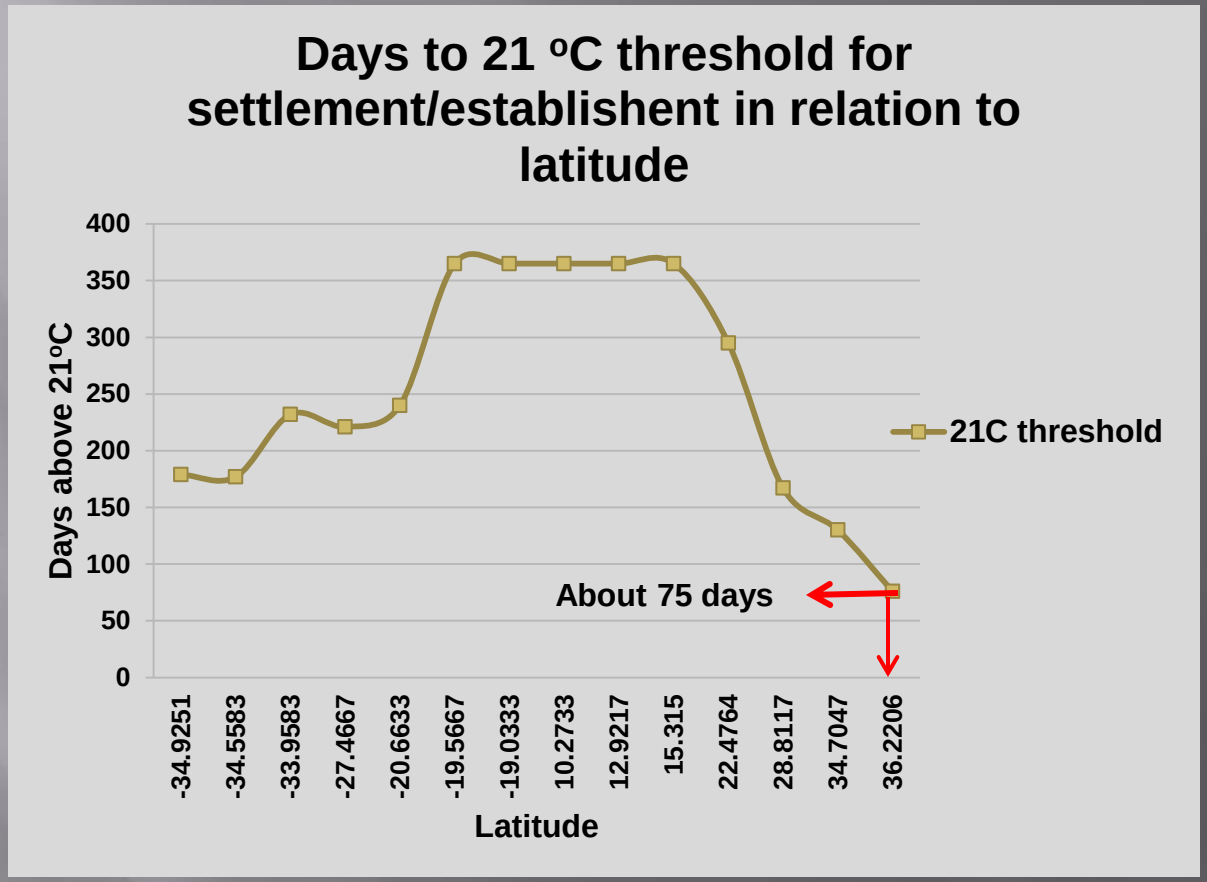


Lake Ohshio, Japan, seasonal water temperature variation. From Nakano et al (2011).


Lowest recorded temperature
for establishment
21°C
Onset of reproduction = 16.5°C
Surface Water Temperature °C
30
25
20
15
10
5
0
0
31
28
59
90
151
181
212
243
273
304
334
365
Julian Days

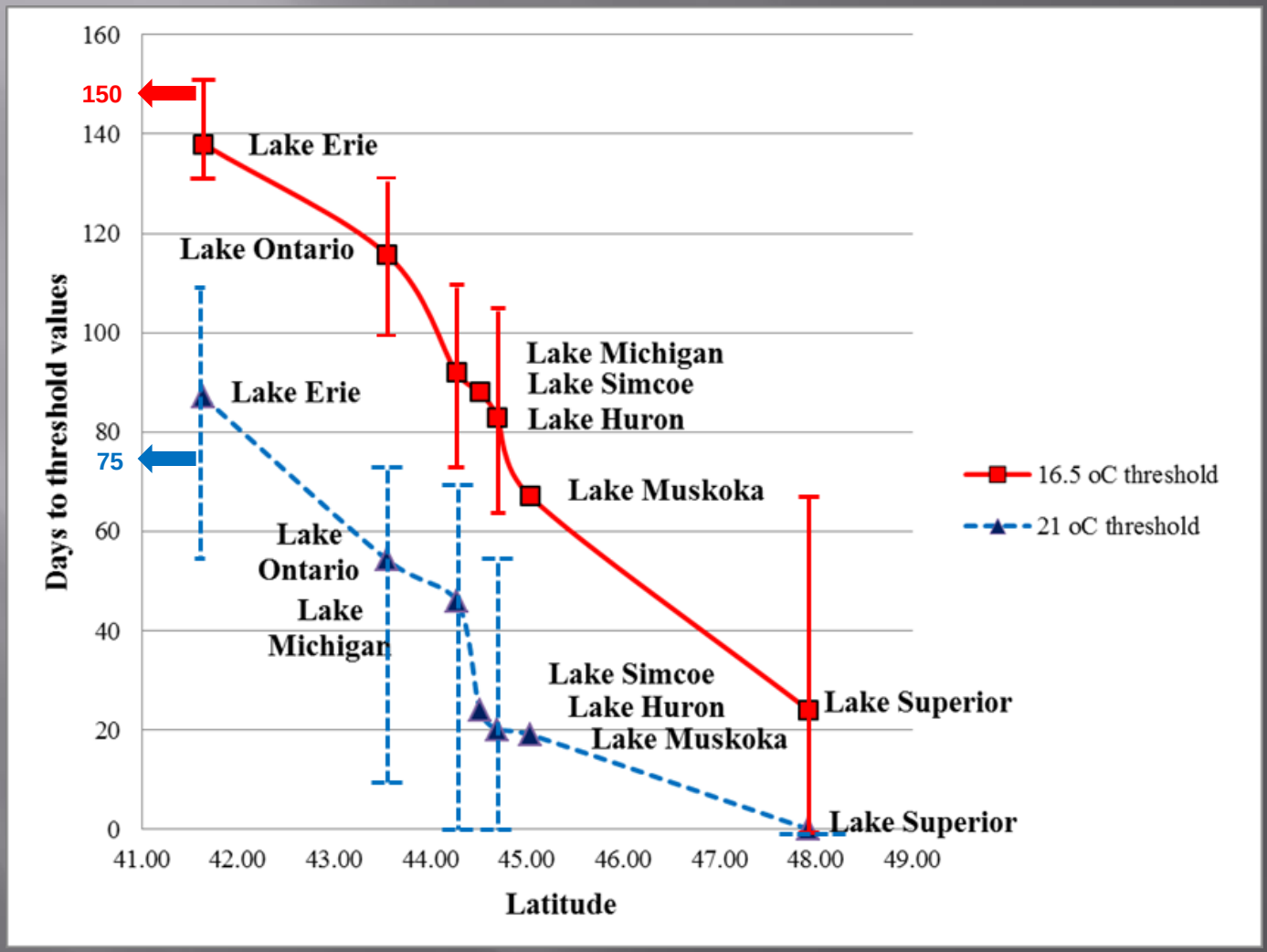

Great Lakes Average GLSEA (1024) Surface Water Temperature 2013
(http://coastwatch.glerl.noaa.gov)
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
21℃
16.5 C
Surface Water Temperature (degrees C)
30
25
20
15
10
5
0
0
31
59
90
121
151
181
212
243
273
304
334
365
Julian Days


Days to 16.5 ºC threshold for onset of reproduction in relation to latitude
Days above 16.5ºC
400
350
300
250
200
150
100
50
0
About 150 days
16.5C threshold
-34.9251
-34.5583
-33.9583
-27.4667
-20.6633
-19.5667
-19.0333
10.2733
12.9217
15.315
22.4764
28.8117
34.7047
36.2206
Latitude


Days to 21 ºC threshold for settlement/establishent in relation to latitude
Days above 21ºC
400
350
300
250
200
150
100
50
0
-34.9251
-34.5583
-33.9583
-27.4667
-20.6633
-19.5667
-19.0333
10.2733
12.9217
15.315
22.4764
28.8117
34.7047
36.2206
Latitude
21C threshold
About 75 days

Stage 3 – Probability of establishment

Degree days at threshold of reproduction & establishment



Stage 4 – Probability of spread

Maximum summer distribution

Stage 4 – Probability of spread

Winter distribution

- Currently, <4ºC will limit spread of Golden Mussel in Ontario
- At current predicted increase of 1.8ºC/30yr in Lake Erie it would take ~40 yrs for Lake Erie to reach 150 day threshold for reproduction and 5 yrs to reach 21ºC for establishment
- At current predicted time to reach 4ºC, it would take >150 yrs, and for 5ºC > 200 yrs.

CONCLUSIONS

Probability of arrival

Pathway of introduction	Probability of arrival	Level of certainty
Ballast Water	low	low
Overland Transport	low	low

Probability of survival

Ecology/Physiology	Probability of survival	Level of certainty
Chemical (pH, Ca, etc)	high	high
Physical (temperature)	low	moderate

Probability of establishment

Criteria	Probability of establishment	Level of certainty
Reproducing potential	low	low
Maintaining population	low	Moderate

Probability of spread

Pathways	Probability of spread	Level of certainty
Primary	Low	low
Secondary	Low	Moderate

Probability of Invasion is lowest of 4 scores

= LOW with LOW certainty

Uncertainty of LOW probability

Major lack of empirical data on lower threshold temperature levels. Need:

1. Survival times @ 0-10^{o}C for different size classes

If any survive, determine:

1. Rate of development from 0-16^{o}C

2. Reproductive temperature (t_{repro}) – literature 16-17^{o}C

3. Growth rates between t_{repro} & 20-27^{o}C (e.g. Lake Erie: lowest high 20^{o}C; mean high 23^{o}C; highest high 27^{o}C)

THE END