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An Evaluation of Downstream Dispersal of Veliger Larvae as a Mechanism for Spread of Zebra Mussels between Inland Water Bodies in Minnesota

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Mechanisms (vectors) of zebra mussel spread to inland lakes

- Overland via recreational boating
  - Veligers in water (in hulls, live wells, etc.)
  - Mussels attached to vegetation (entangled on trailers, motors, etc.) or to docks, lifts, boat hulls
- "Natural" spread through interconnected waterways
  - Downstream dispersal of veliger larvae or other life stages (e.g. rafting juveniles)

Studies of downstream spread: US lake-stream systems, 1988-2003

TABLE II. All lakes (> 25 ha) that are within 1 km of zebra-mussel–invaded lakes in the US. Each lake was classified as either "not connected" (*i.e.*, the lake was less than 1 km from an invaded lake but did not have a stream connection to that particular lake), "downstream" of an invaded lake, or "upstream" of an invaded lake. The proportion of lakes in each category known to be invaded with zebra mussels was also calculated.

Lake category	Total	Proportion with zebra mussels (%)
All	194	32.0
Not connected	84	7.1
Upstream	70	32.8
Downstream	43	79.1

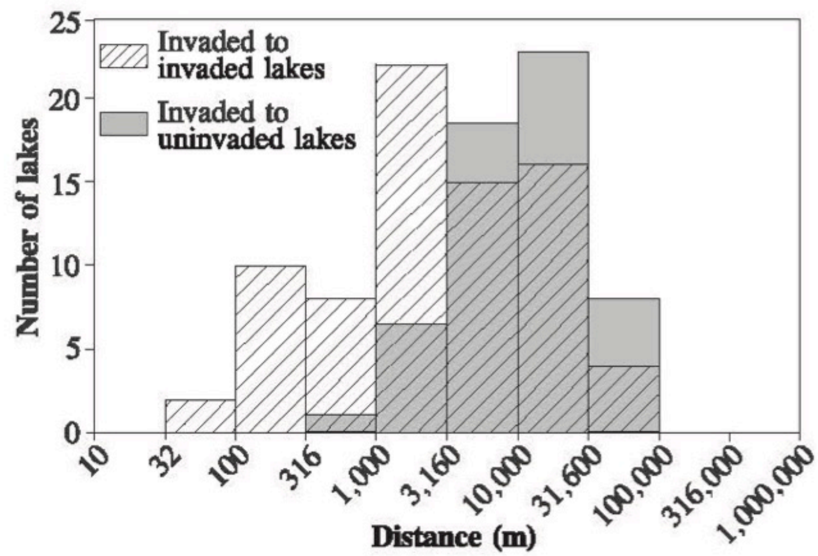
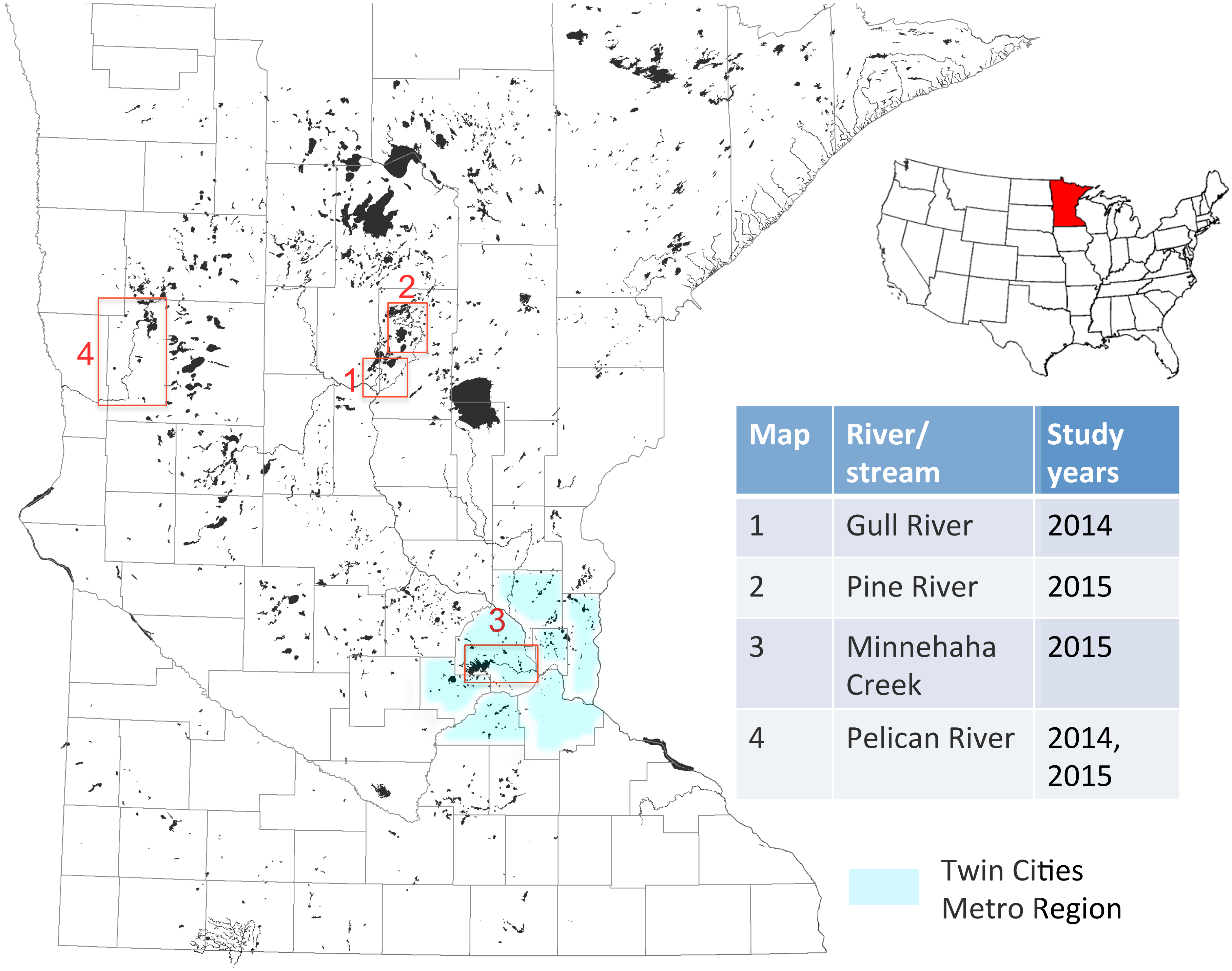


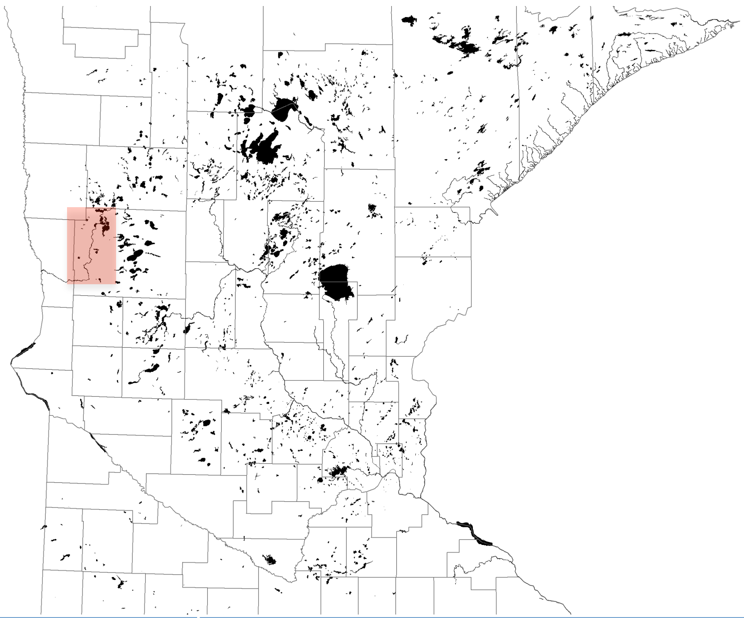
FIGURE 4. Two overlapping-frequency histograms of zebra-mussel–invaded lakes showing stream distances to downstream lakes (invaded or uninvaded). For each invaded lake in the US, the distance to the next lake was measured as well as the invasion status of each lake.

From Bobeldyk et al. (2005)

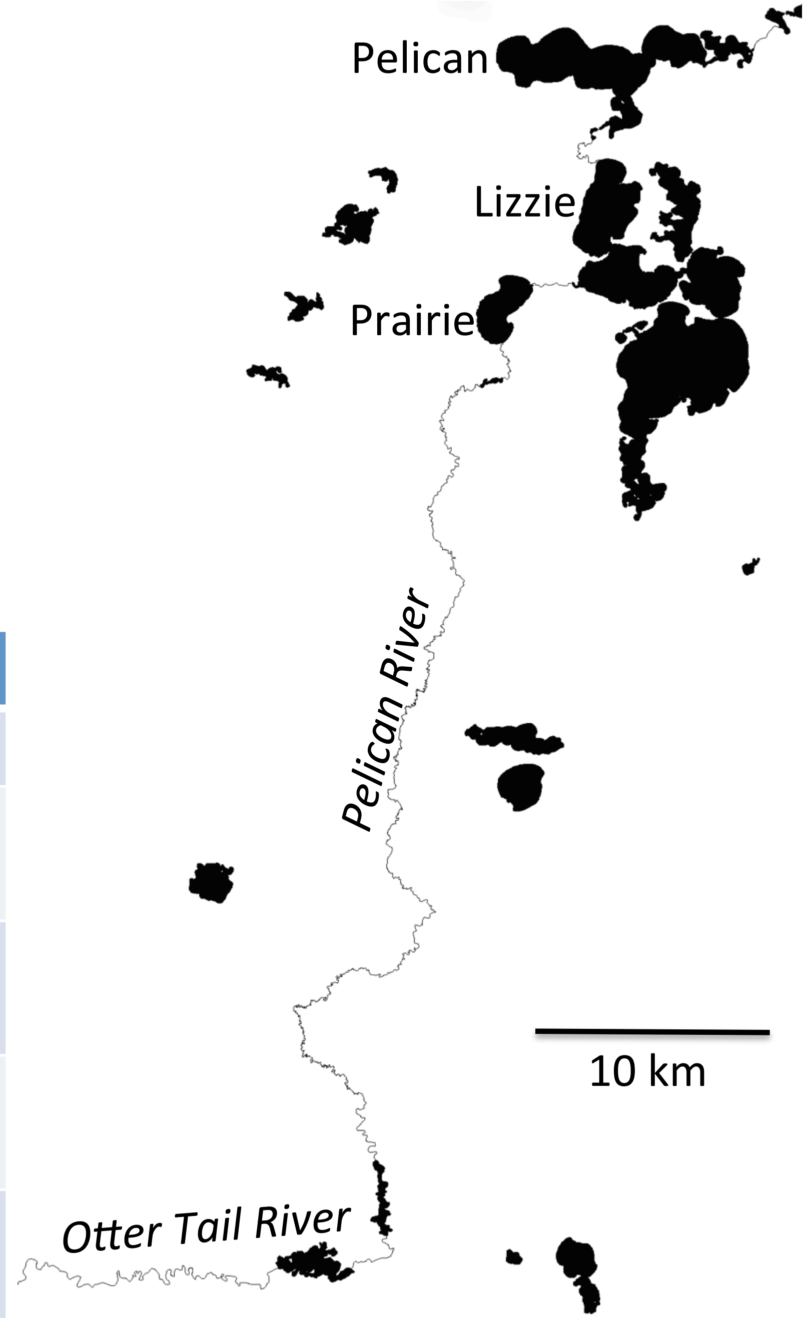


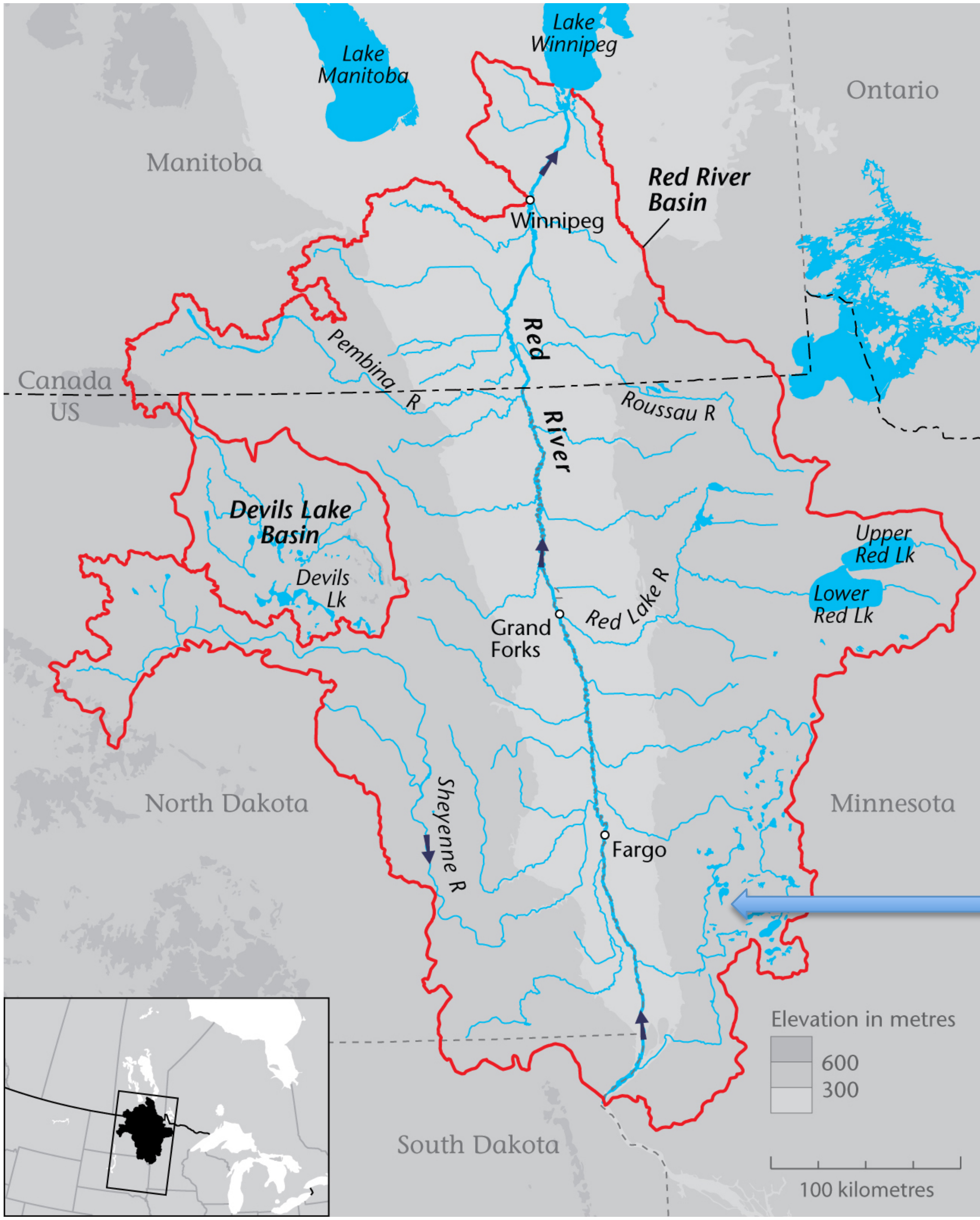
Map	River/ stream	Study years
1	Gull River	2014
2	Pine River	2015
3	Minnehaha Creek	2015
4	Pelican River	2014, 2015

Criteria for selecting systems: downstream water bodies



Pelican River	Otter Tail County, MN
Watershed	1,249,541 acres (Otter Tail)
Discharge (2015 summer average)	123 cfs (upper river), 218 cfs (lower river)
Upstream infested lakes	6864 acres
Downstream water bodies	Otter Tail River, Reservoirs
Distance downstream	80 km

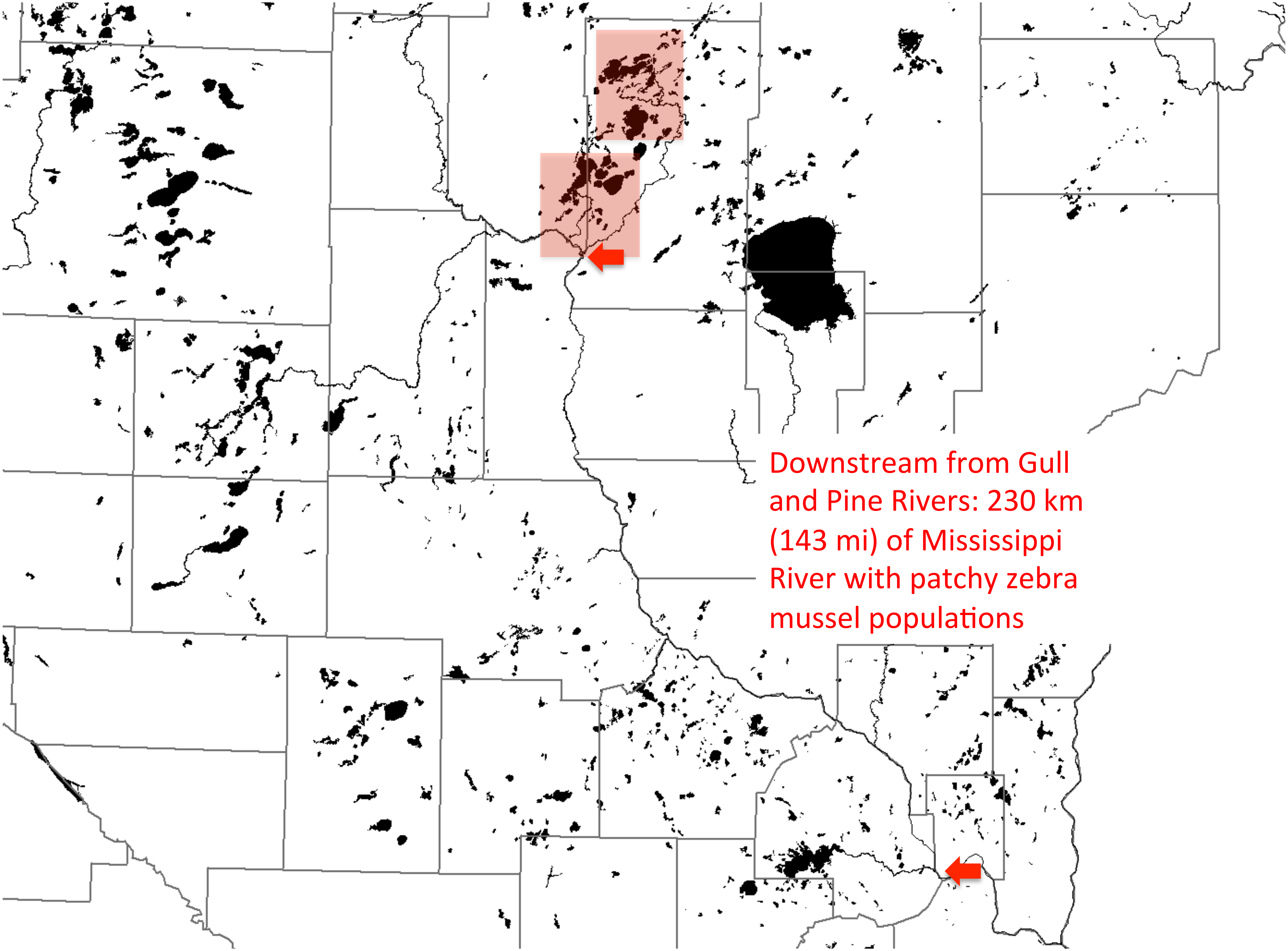




Map from watergovernance.ca

900 km (560 miles) of the Red River

Downstream of the Pelican and Otter Tail?


Downstream from Gull and Pine Rivers: 230 km (143 mi) of Mississippi River with patchy zebra mussel populations

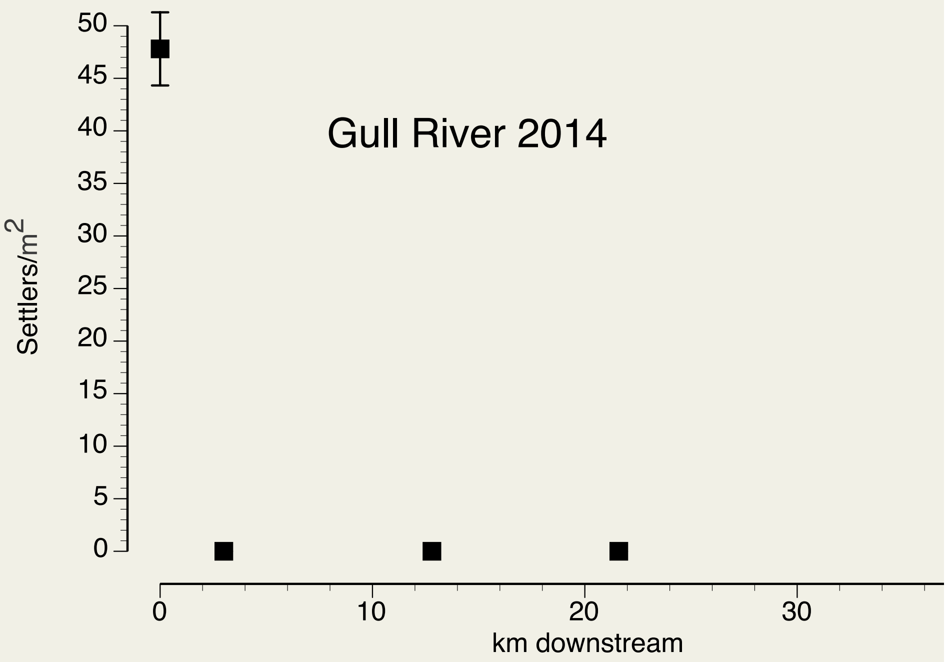
Downstream drift studies in Minnesota

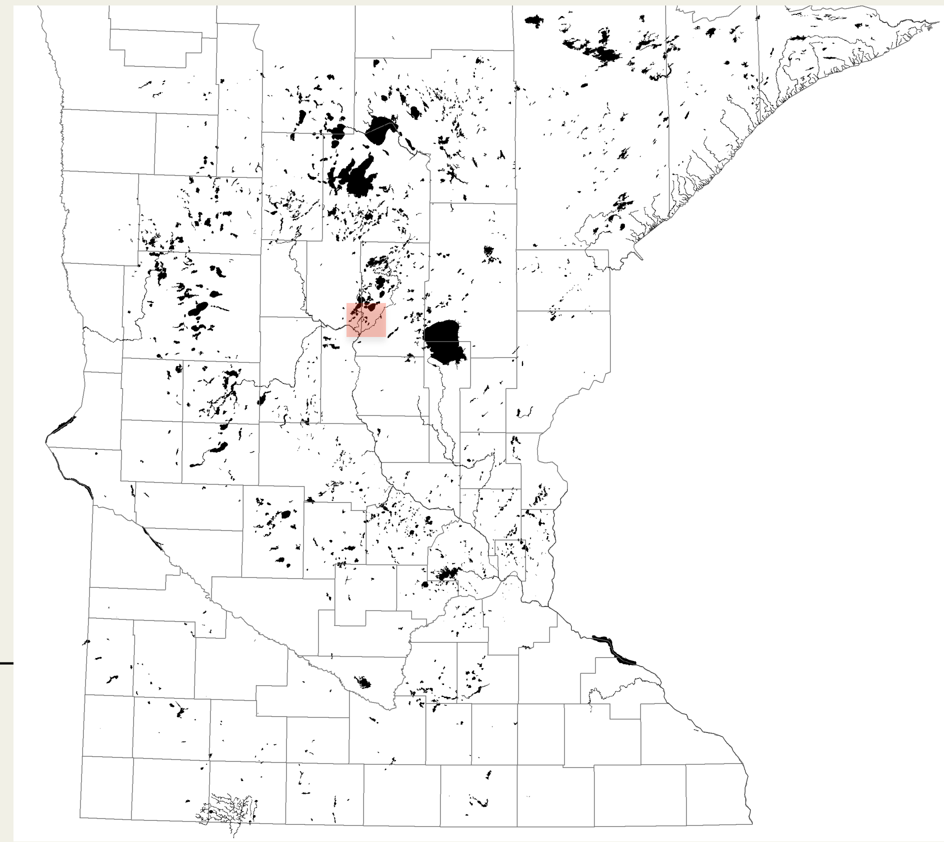
- Samples, at increasing distances downstream from the infested lake, ending near the inlet:
  - **Settlement** of juvenile mussels; reproductive season (June-October)
  - **Veliger** concentrations (June-October); 150 L water pumped and 50-micron filtered

Cinder block samplers for settlement

Pelican Brook below Lake Ossawinamakee, 06/24/2015.
Photos by Dan Swanson

Settlement in streams is highly localized near the upstream lake





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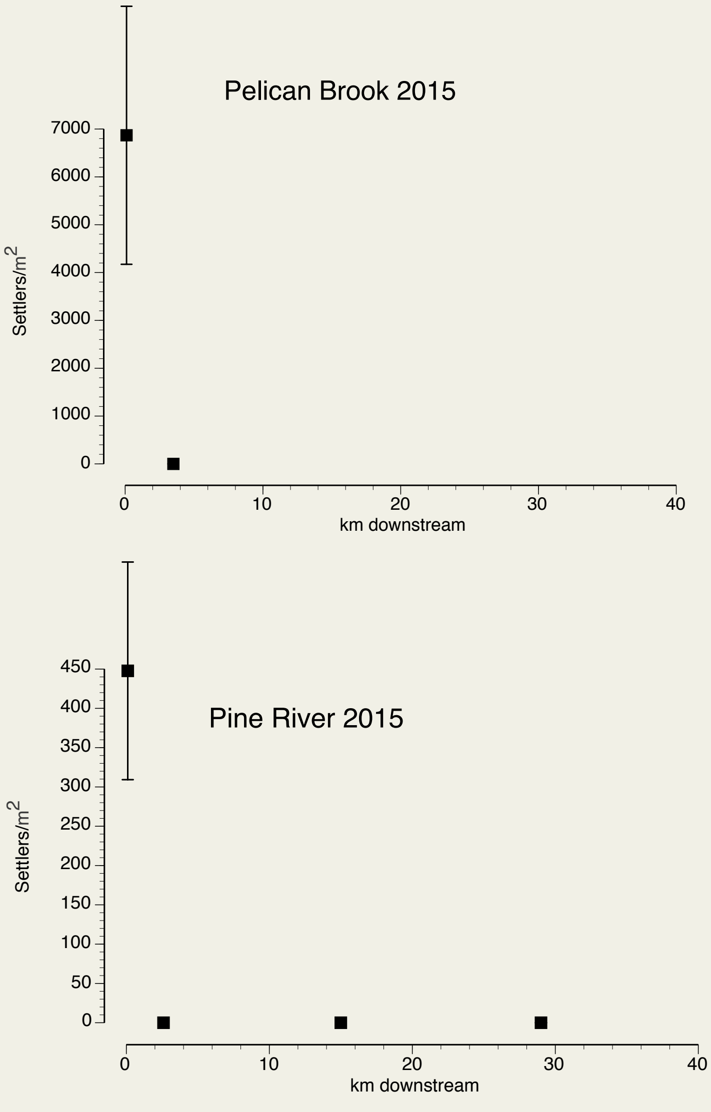

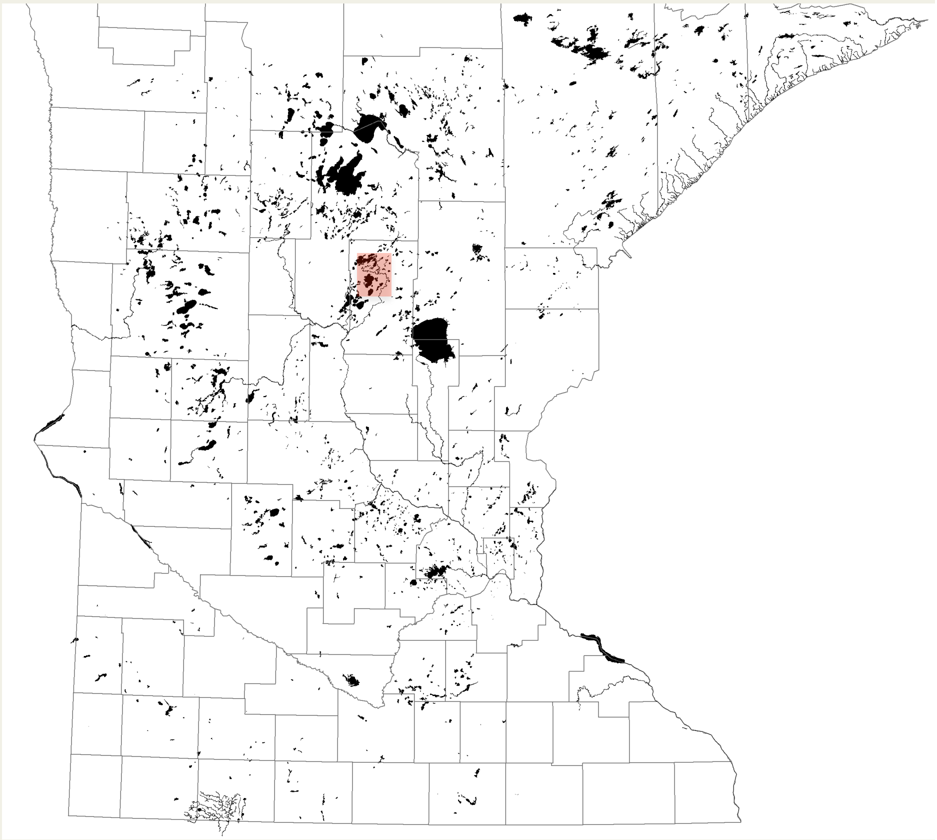

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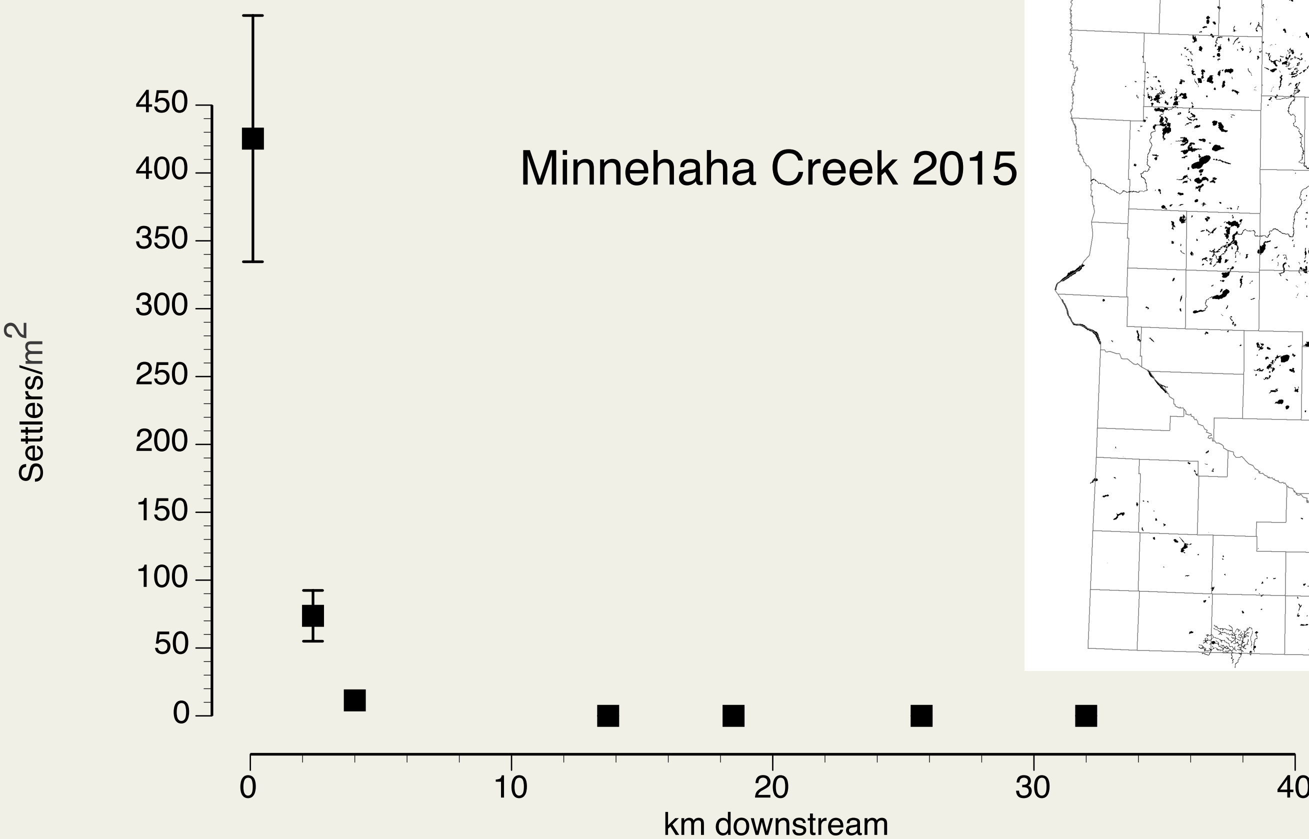

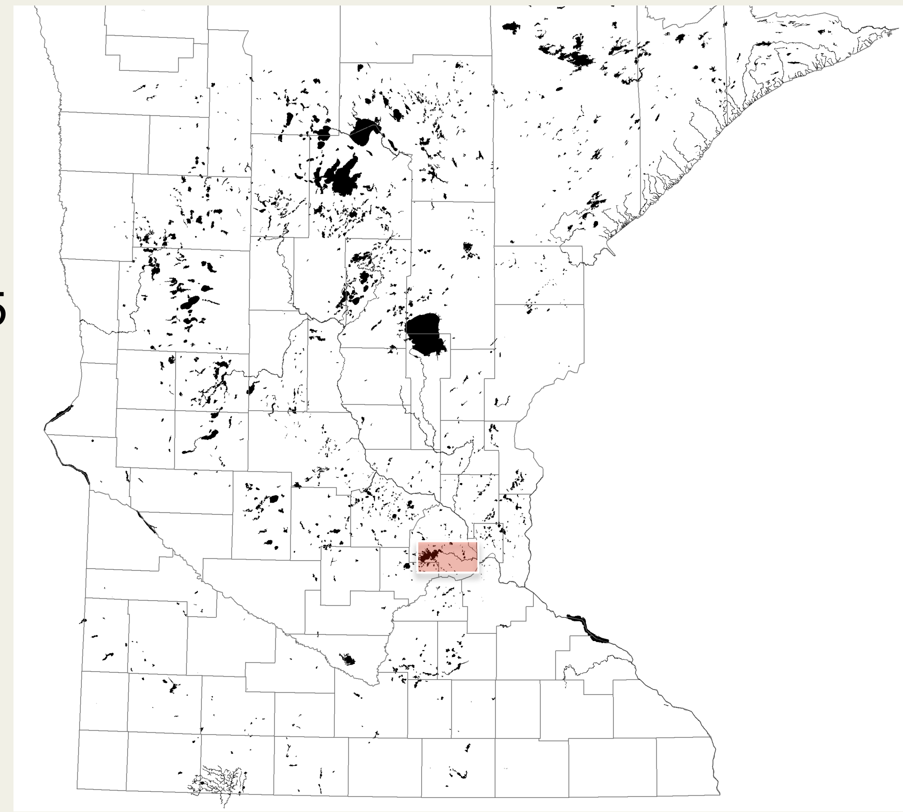

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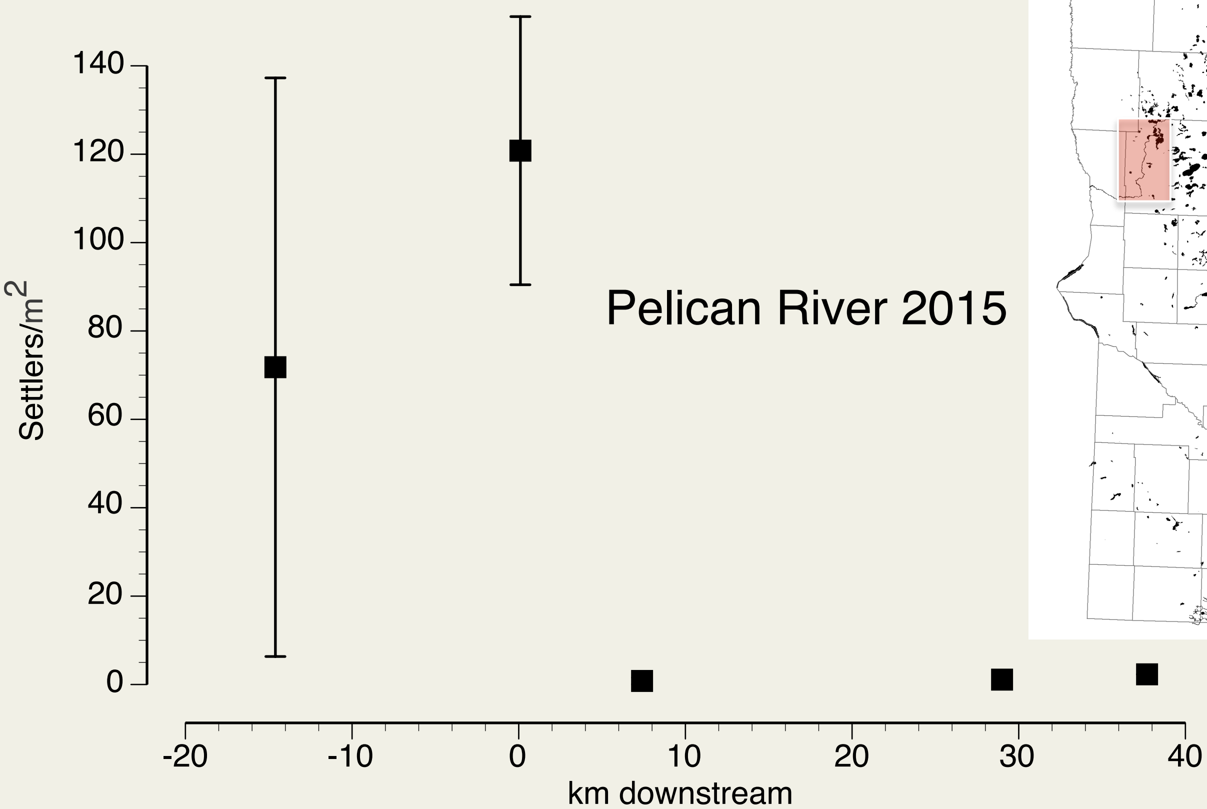
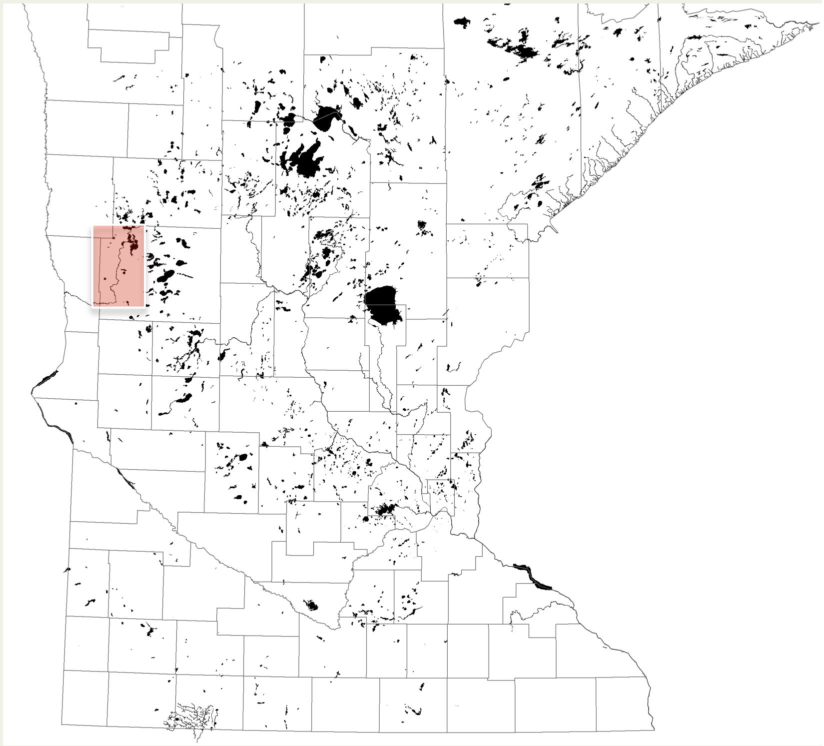
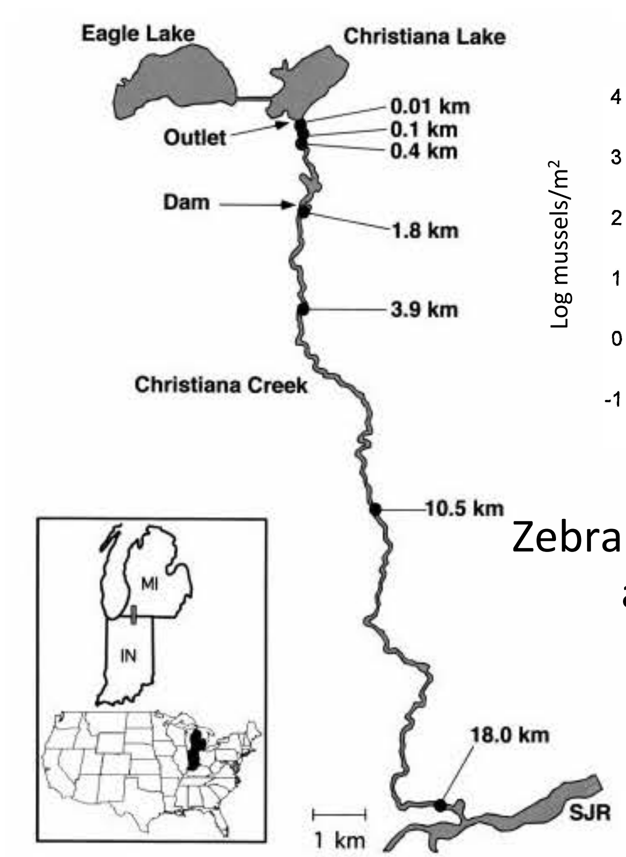
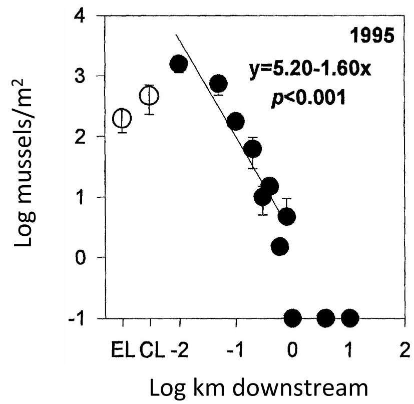


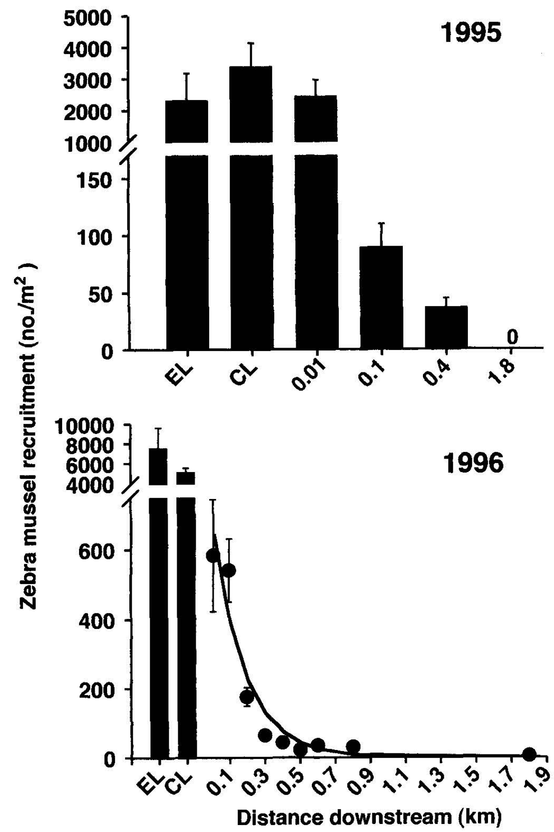


This finding is common





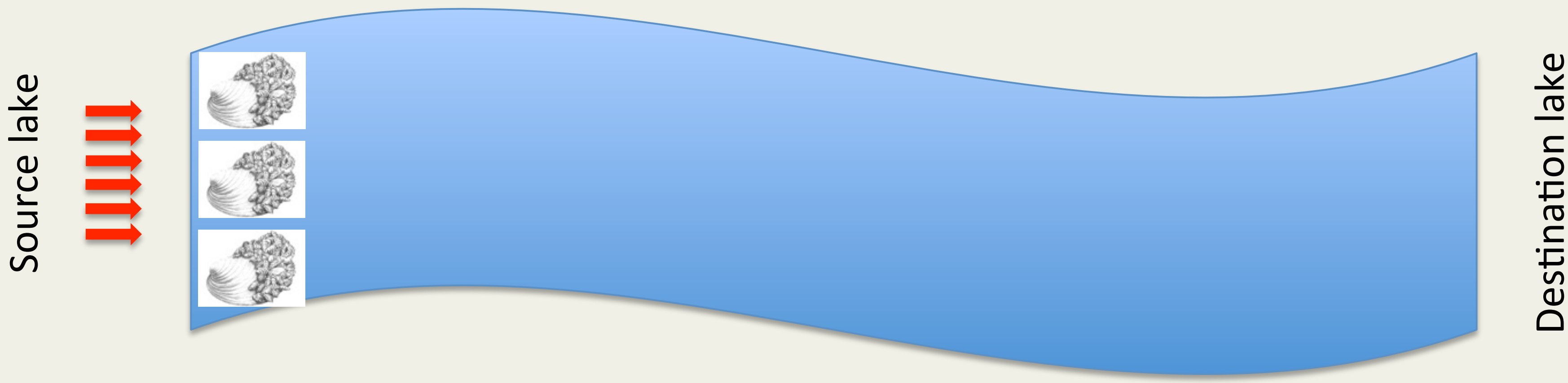
Zebra mussel densities on lake and stream bottom

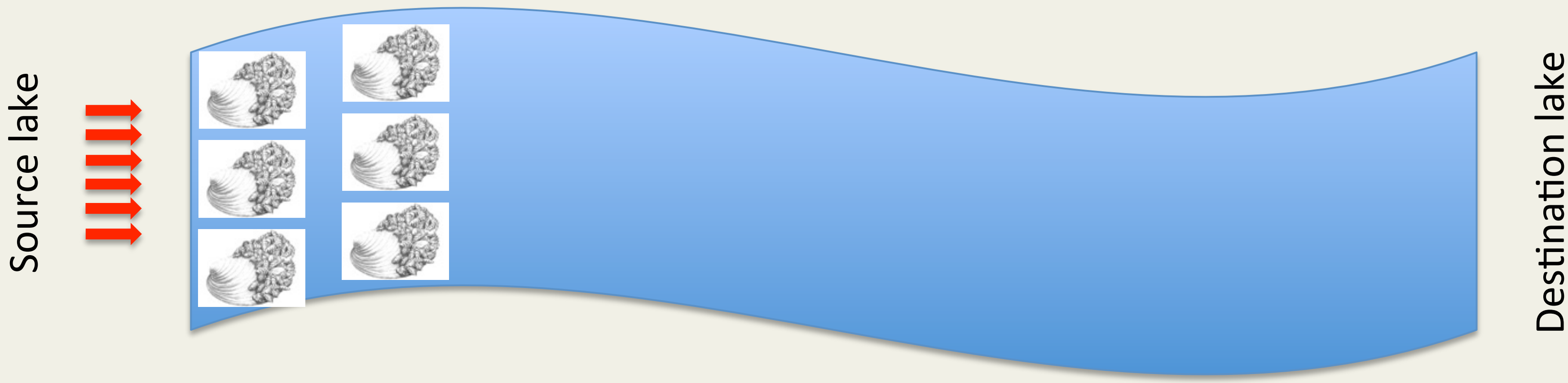


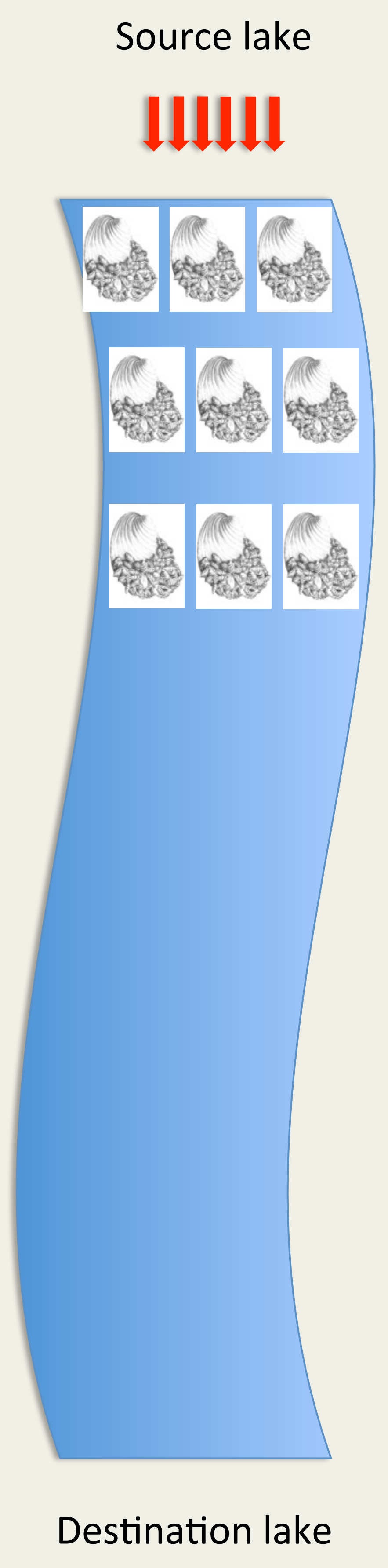
From Horvath et al. (1996); Horvath and Lamberti (1999)

Juvenile recruitment, cement blocks in Christiana Creek

The scenario for spread down streams, often assumed




Source lake
Destination lake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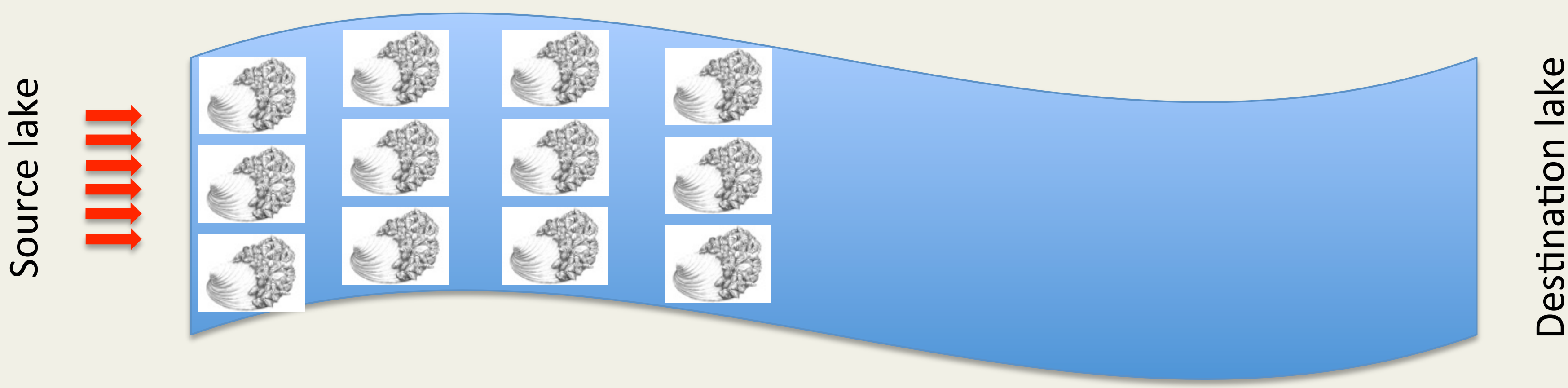
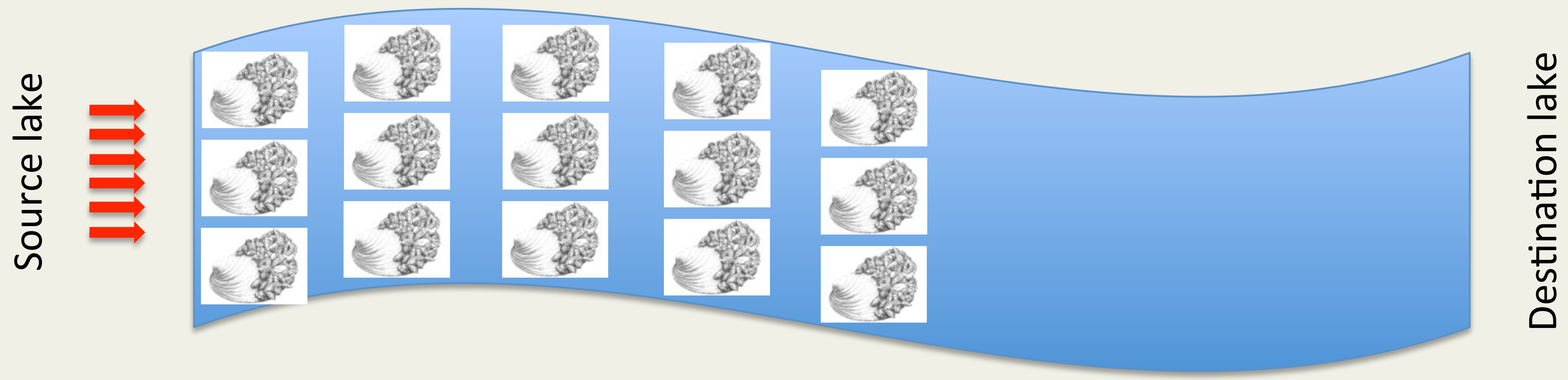
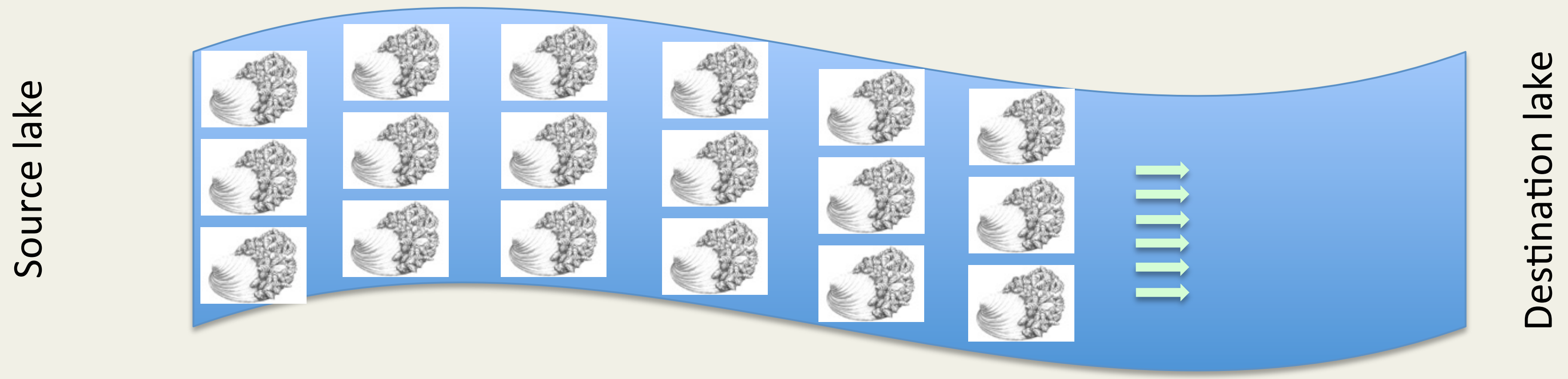
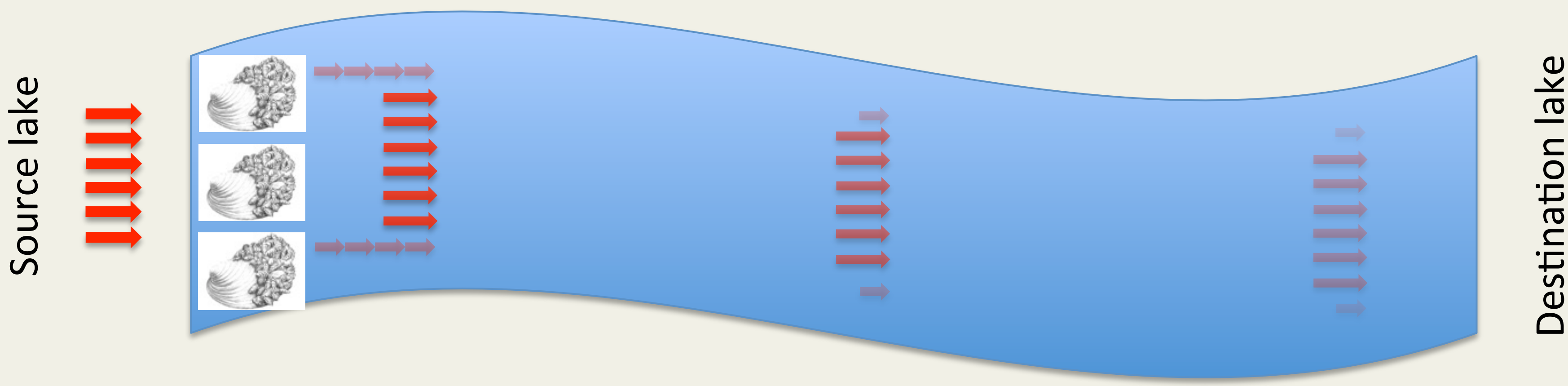

Source lake
Destination lake


Source lake
Destination lake

Is incorrect…

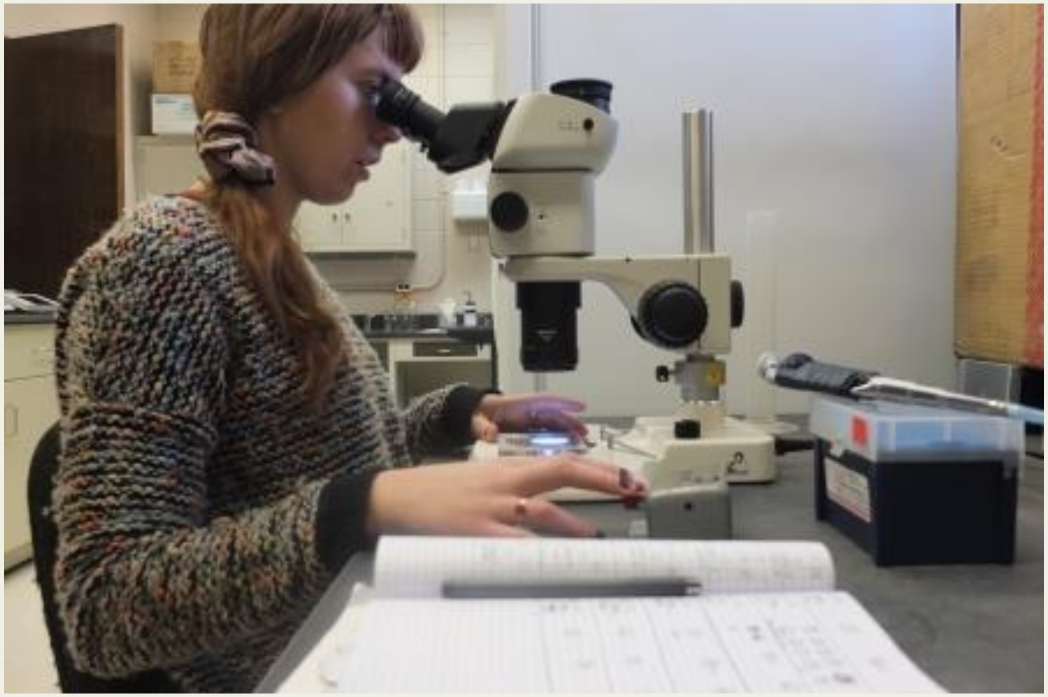
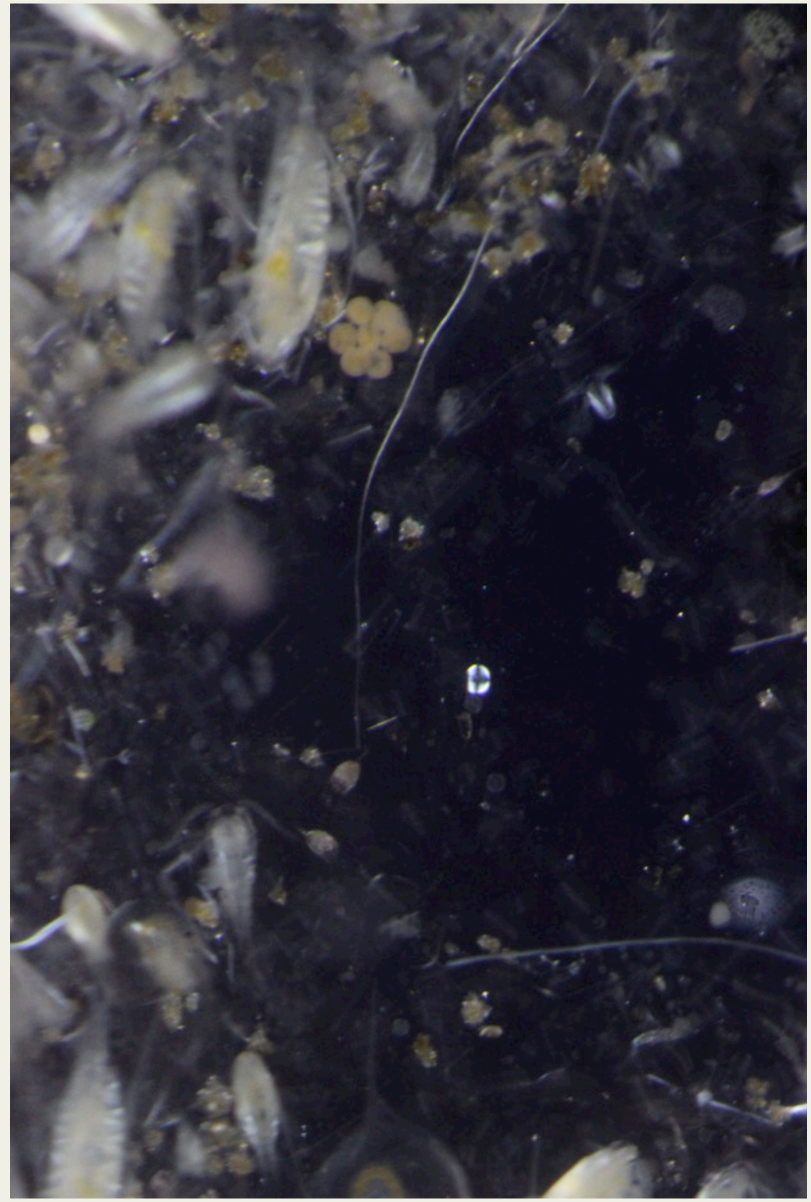


This is closer to correct



Veliger pump-sampling, Gray's Bay Dam, Minnehaha Creek 06/16/2015

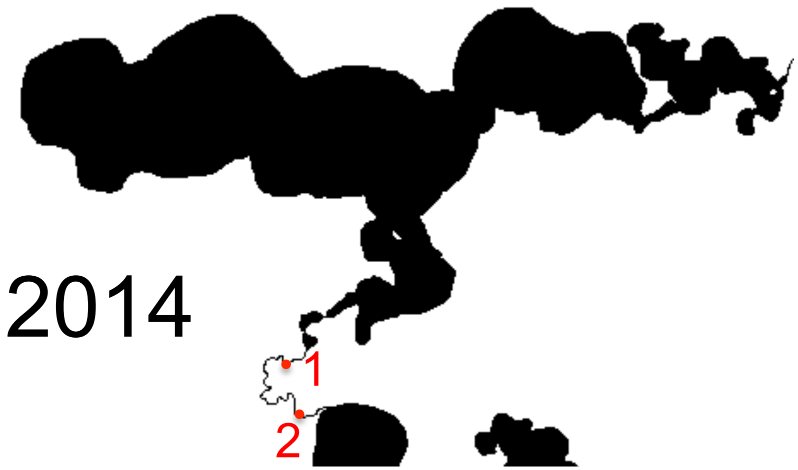
Stream discharge measurement, Pelican River 06/11/2015

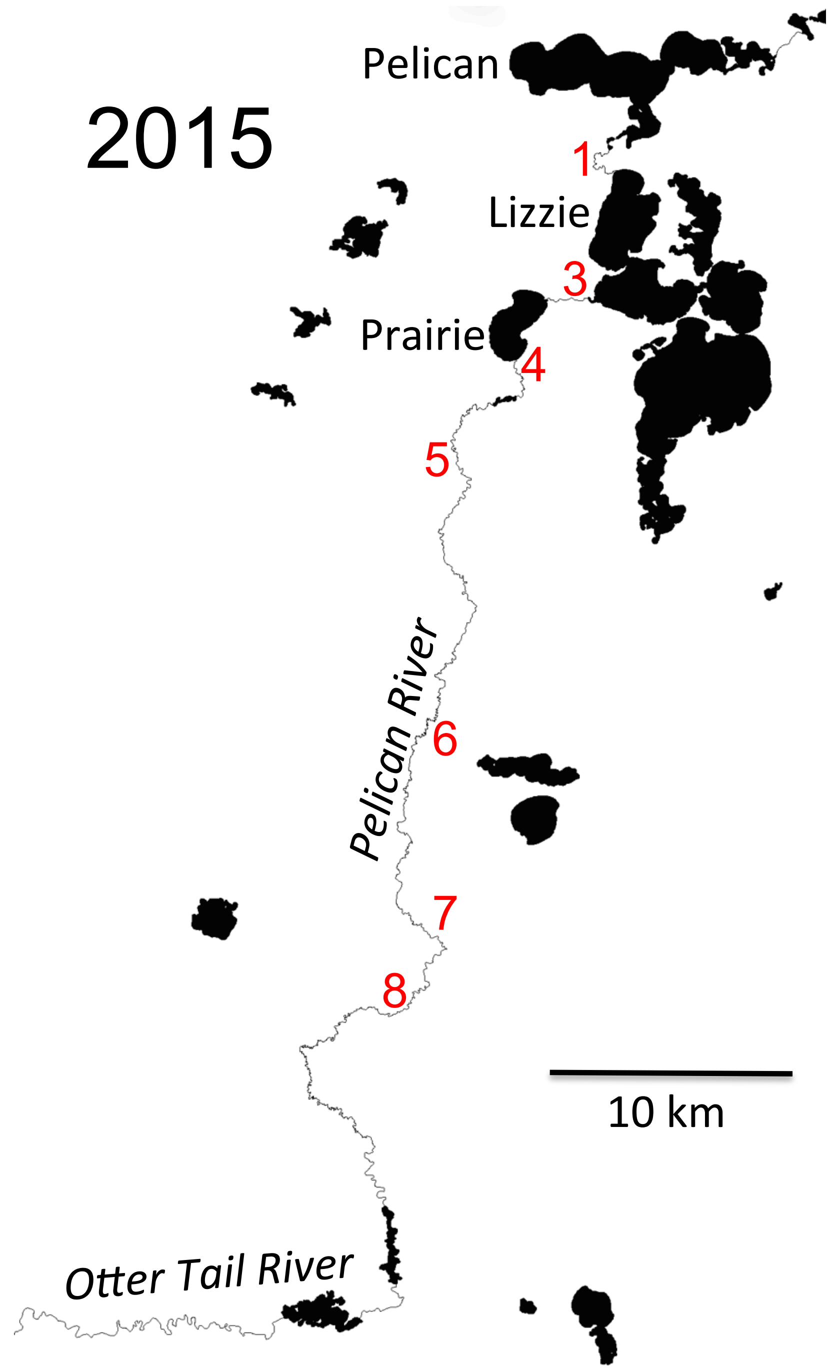



Estimating veliger "supply" to sites downstream

- Concentration (veligers/L) from counts is not sufficient

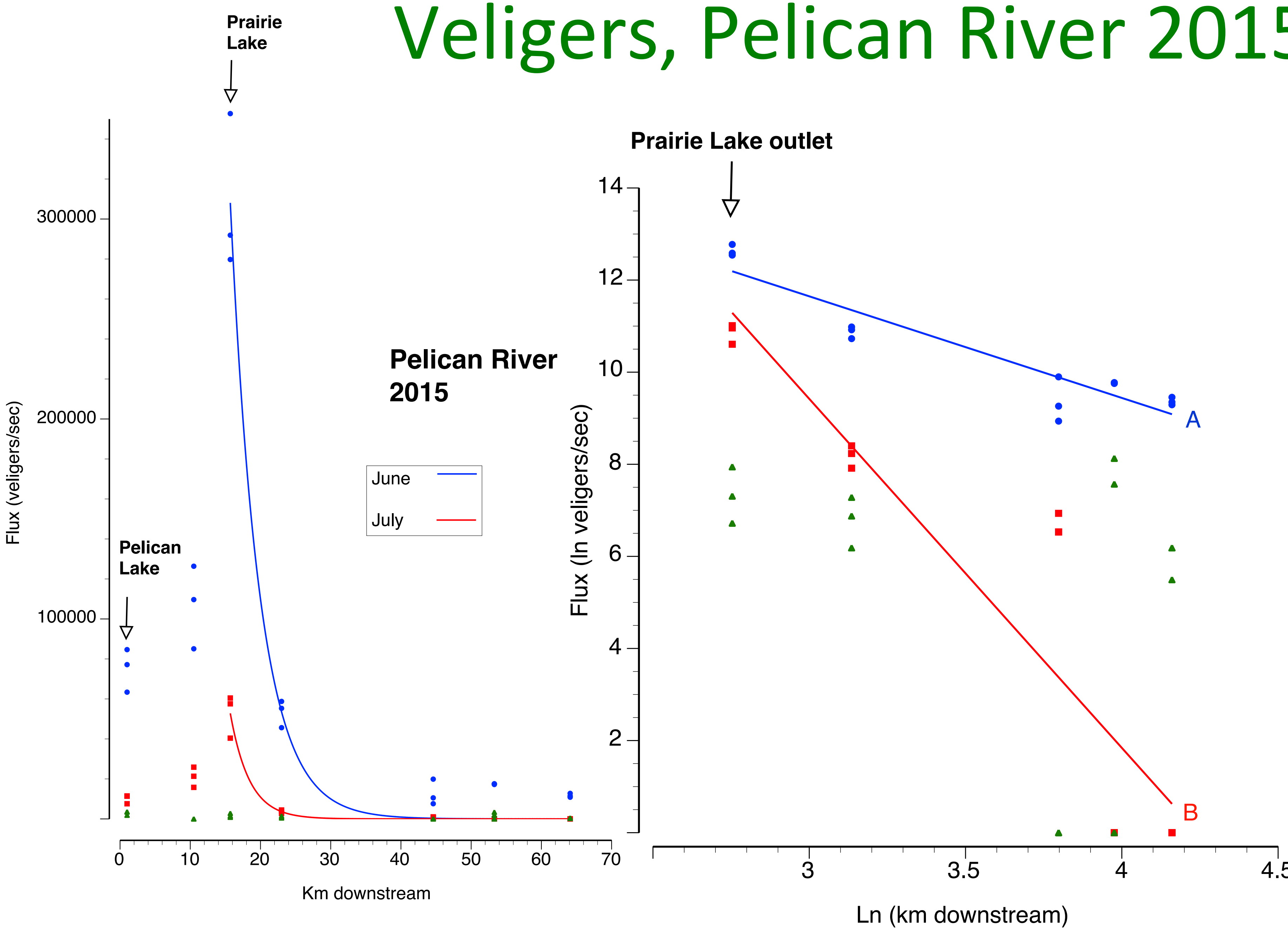
- Flux—a measure of bulk transport of larvae past a stream cross section per unit time
  - Considers stream discharge
  - Flux = (veligers/liter)(Liters/sec) = veligers/sec





Site	Distance (km)
1	1
2	3.6
3	10.5
4	15.7
5	23
6	44.6
7	53.3
8	64.1
Otter Tail River	80.2
Red River	152

Veligers, Pelican River 2015



Veligers decline downstream in all cases; strong seasonality

Site	Month	Comparison of slopes	Regression Coefficent	F (regression)
Gull River (2014)	July	July = August	-0.682	6.204*
Gull River (2014)	August		-0.867	10.423**
Pine River	June	June < (July = August)	-0.103	6.803*
Pine River	July		-0.959	10.188**
Pine River	August		-1.106	14.569**
Minnehaha Creek	June	June < July < August	-0.337	20.212***
Minnehaha Creek	July		-1.008	75.199***
Minnehaha Creek	August		-1.454	137.28***
Pelican River	June	June < July	-2.206	87.461***
Pelican River	July		-6.499	42.540***
Pelican River	August		-0.839	1.858 ns

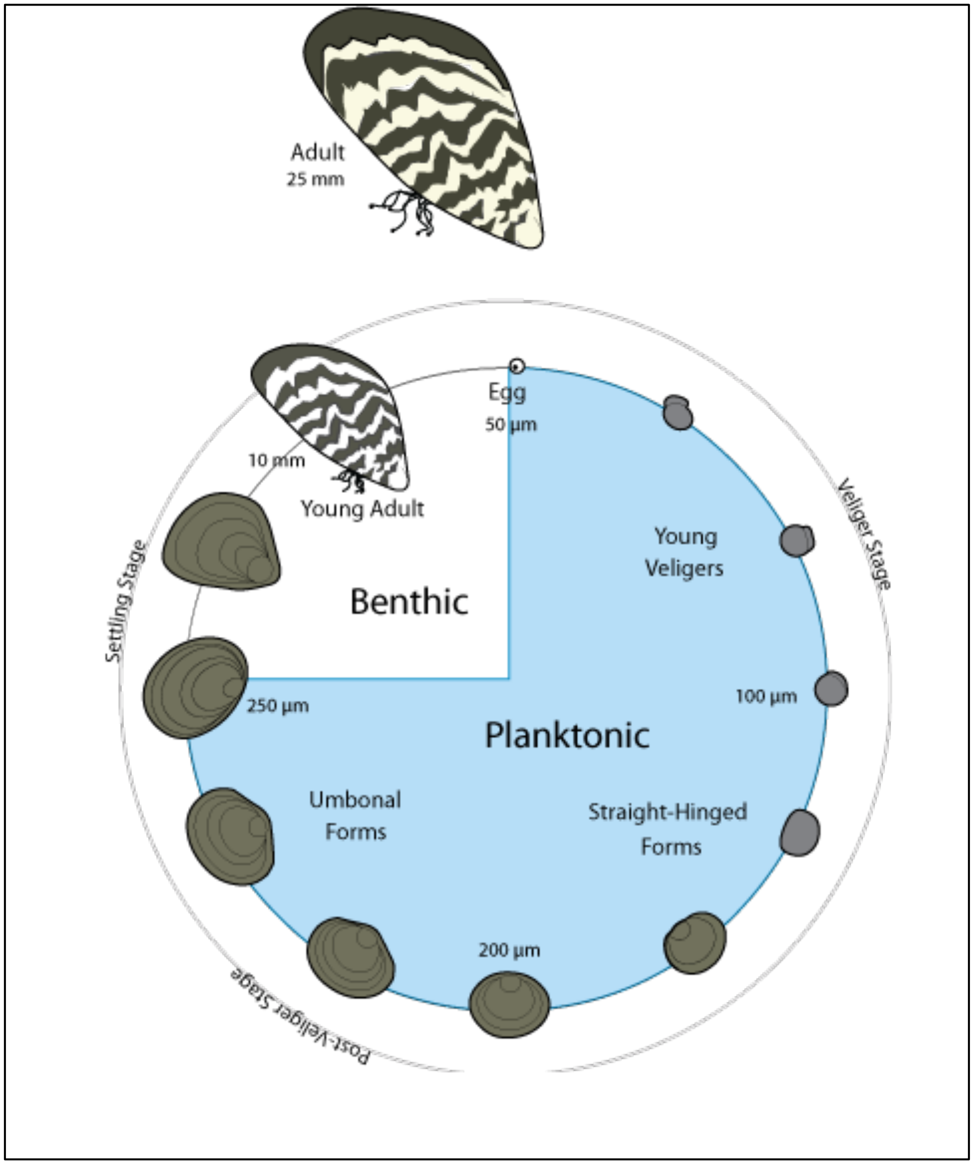
Veliger transport to downstream water bodies

			Observed at downstream inlet			Predicted* from regression			
River	Year	Month	Veligers/ day	% decline	km to inlet	km to 0	Lower 95%	Upper 95%	r^2
Gull	2014	July	2.50×10^7	89.9	22	5.4	-6.1	16.9	0.945
Gull	2014	August	0	100.0	22	41.0	5.9	76.0	0.621
Minnehaha	2015	June	1.74×10^6	90.7	32	6.1	3.3	9.0	0.872
Minnehaha	2015	July	0	100.0	32	3.5	-2.1	9.1	0.922
Minnehaha	2015	August	0	100.0	32	3.5	-2.1	9.1	0.995
Pine	2015	June	1.04×10^9	52.5	29	459.3	240.6	677.9	0.684
Pine	2015	July	6.64×10^5	99.2	29	82.1	-14.5	178.6	0.540
Pine	2015	August	1.15×10^7	93.9	29	11.0	4.8	17.3	0.894
Pelican	2015	June	1.01×10^9	92.7	64	68.4	55.8	81.1	0.975
Pelican	2015	July	1.23×10^6	99.9	64	45.4	30.6	60.2	0.964
Pelican	2015	August	3.48×10^7	61.9	64	—	—	—	0.063

Threat: High | Moderate | Zero

*2-parameter exponential

Zebra mussel veliger larvae



- Possible causes of loss during downstream transport
  - Starvation, predation
  - Abiotic factors exceed tolerance limits
  - Settlement in poor habitat
  - Physical removal: e.g. flow through wetlands
  - Turbulence

Conclusions: settlement studies

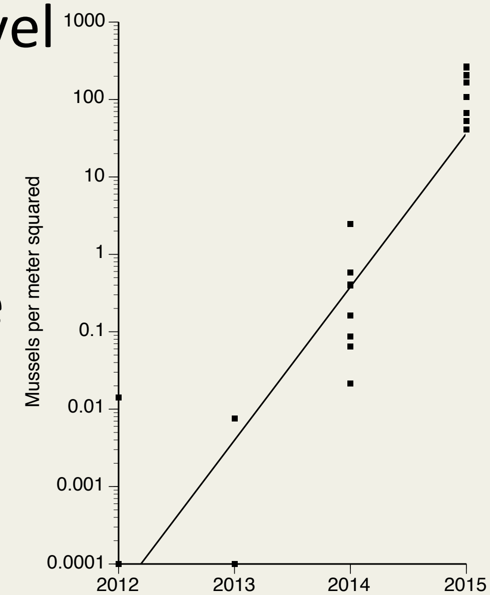
- Settlement of zebra mussels occurs only a short distance downstream of source lakes
- In small streams (< ~ 10 m wide)
  - Adult populations will not become established far downstream of source water bodies
  - Limits threat e.g. to freshwater mussel populations

Conclusions: larval drift

- Substantial, highly seasonal threat of spread to connected waterways
- Extensive (largely unexplained) variation in veliger concentration leaving lake outlets
- Strong decline with distance—why?

Some future research needs…

- Determination of survival of larvae as they travel downstream
- Research on stream reproductive ecology, lake colonization biology
- Spread modeling that considers both overland and waterway connections



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