Probability of Asian carps establishment in the Great Lakes predicted by a stage-structured model

Low propagule pressure will not prevent establishment, but changes to life history could

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Barriers to establishment for non-native species

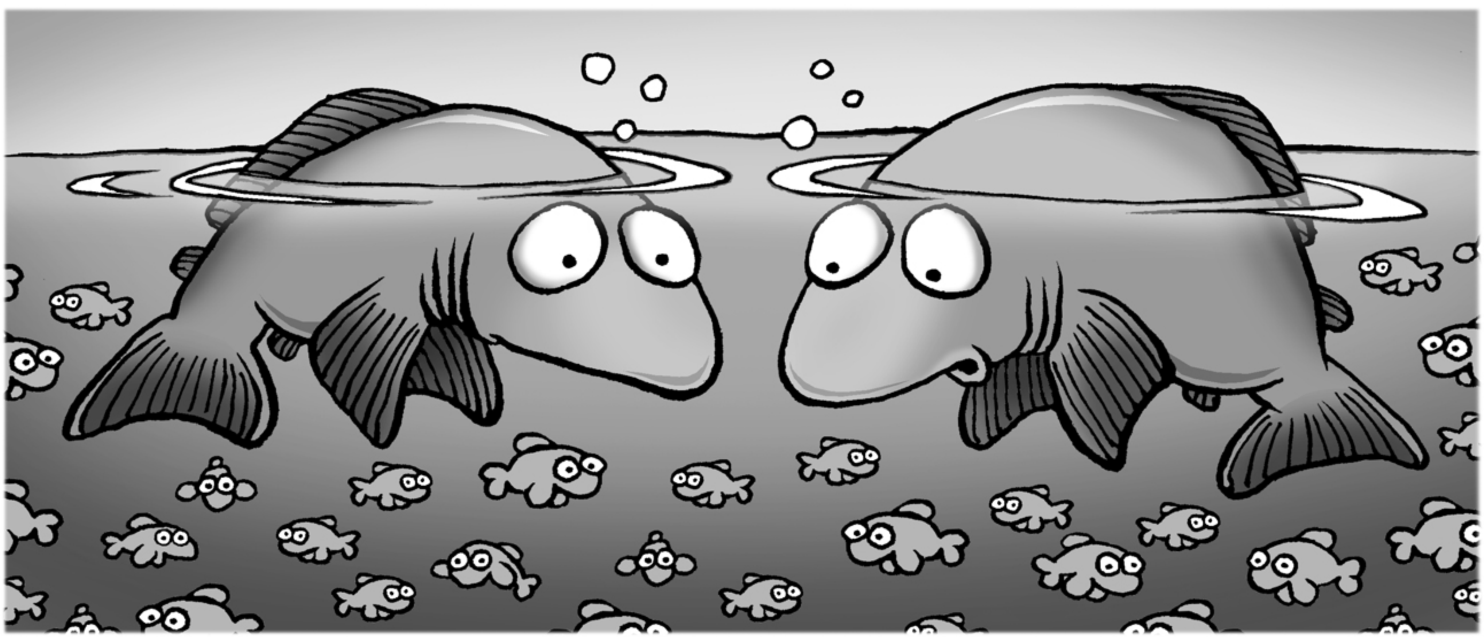
1. Detrimental changes in life history

2. Little/no suitable habitat

3. Small population numbers

1. Detrimental changes in life history

Hypothesis: Population growth will be low because colder waters and lower food levels will reduce growth rate, increase development time, and decrease fecundity



Data for Asian carps (overlaps for Bighead and Silver)

- **Fecundity:** 15000-1500000 eggs/female
- **Growth rates:** get really big really fast!
- **Age at first reproduction:** 2-5 years
- **Survivorship:** little or no data

Reported parameters for the von Bertalanffy growth curve

$$L_t = L_{\inf}\left(1 - e^{-K(t-t_0)}\right)$$

Species	$L_{\inf}$	K	t_0	Description	Reference
Bighead	702	0.234	0.156	Amur river	Nikolskii (1961)
	1127	0.179	0.271	Gobindsager Resevoir	Tandon et al. (1993)
	1044	0.35	0.14	middle Mississippi	Nuevo et al. (2004)
	778	0.629	0.161	middle Mississippi	Williamson & Garvey (2005)
	1242	0.24	0.1585	middle Mississippi	Garvey et al. (2007)
Silver	867	0.41	N/A	middle Mississipp	Garvey et al. (2007)
Median	955	0.3	0.16		

Prediction for Asian carps

- **Fecundity:** 15000, 150000 & 1500000 eggs
- **Growth rates:** von Bertalanffy equation from lit
- **Age at first reproduction:** Range from 2-5
- **Survivorship:** no data
  - use Lorenzen's equations for survivorship for adult and subadult fish ($P_x = 1 - (1 - e^{(a_x * Weight^{-b_x})})$), and
  - reported weight-length relations

Suboptimal scenario

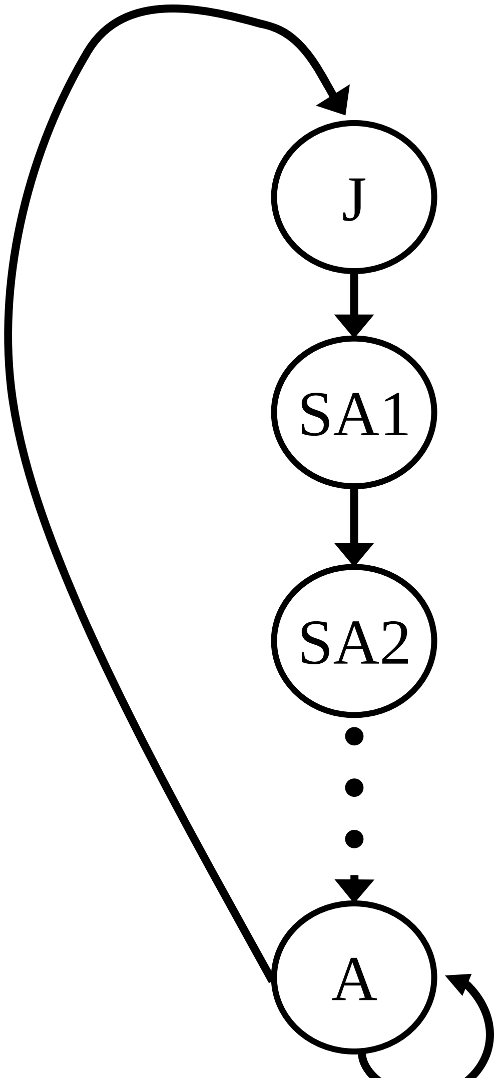
Suboptimal conditions (colder, lower food) lead to slower growth, and therefore:

- **Lower survivorship** for longer periods of time ($P_x = 1 - (1 - e^{(a_x * Weight^{-b_x})})$)
- **Later age at first reproduction** (i.e., not mature until 400 mm, a conservative lower bound on size at 2 years from the NA literature)

Average size (mm) at stage calculated using the von Bertalanffy growth equation

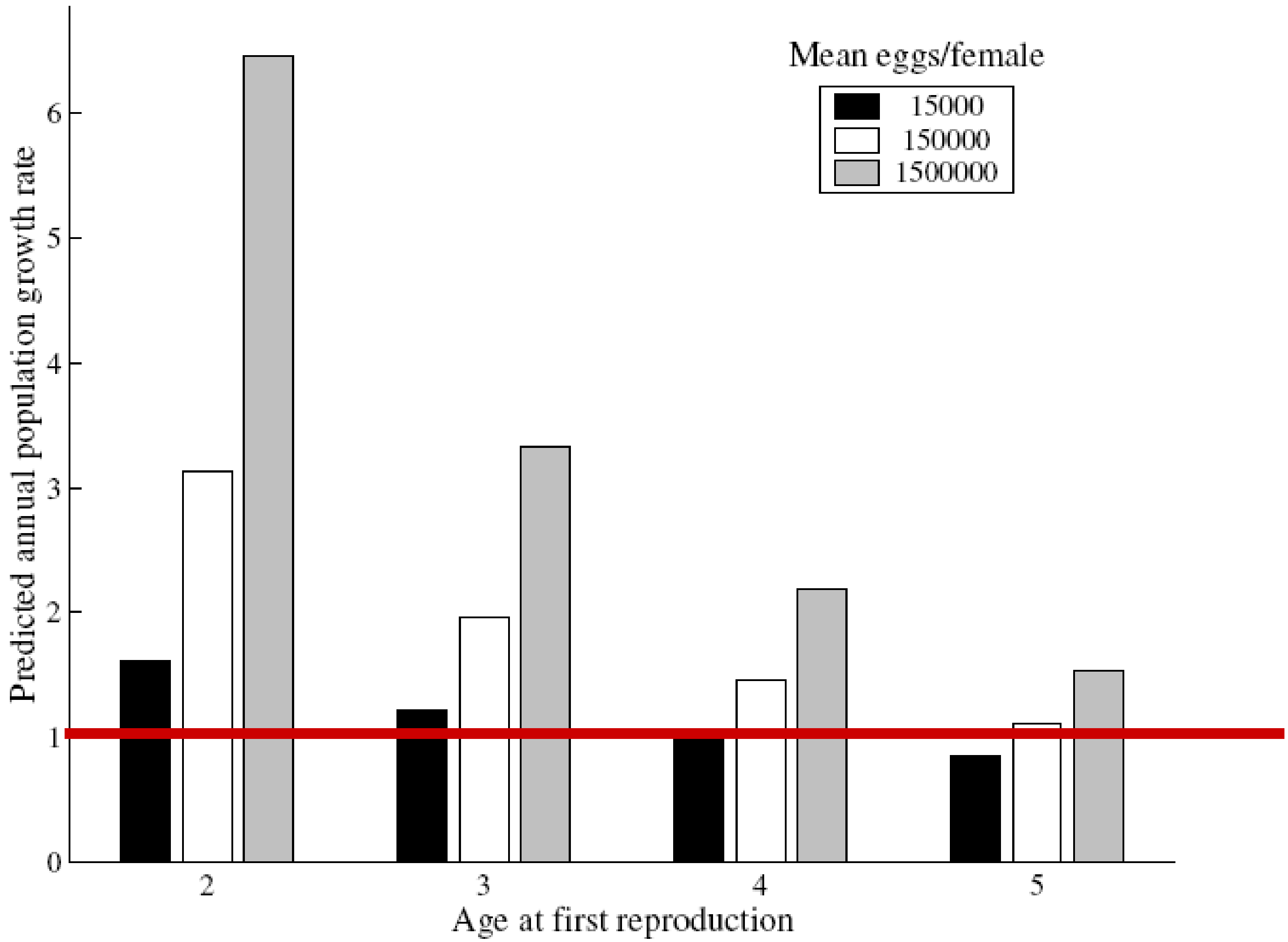
	Age at first reproduction (K)			
	2 (0.4)	3 (0.3)	4 (0.2)	5 (0.15)
J	20	20	20	20
$SA1$	300	200	150	100
$SA2$	-	400	300	200
$SA3$	-	-	400	300
$SA4$	-	-	-	400
A	700	700	700	700

Asian carp stage-structured population model with variable age at first reproduction



$$\begin{bmatrix} J(t+1) \\ SA1(t+1) \\ SA2(t+1) \\ \vdots \\ SAn(t+1) \\ A(t+1) \end{bmatrix} = \begin{bmatrix} 0 & 0 & \cdots & 0 & 0 & F/2 * P_J \\ P_{SA1} & 0 & \dots & 0 & 0 & 0 \\ 0 & P_{SA2} & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \dots & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & P_{SAn} & 0 & 0 \\ 0 & 0 & \dots & 0 & P_A & P_A \end{bmatrix} \times \begin{bmatrix} J(t) \\ SA1(t) \\ SA2(t) \\ \vdots \\ SAn(t) \\ A(t) \end{bmatrix},$$

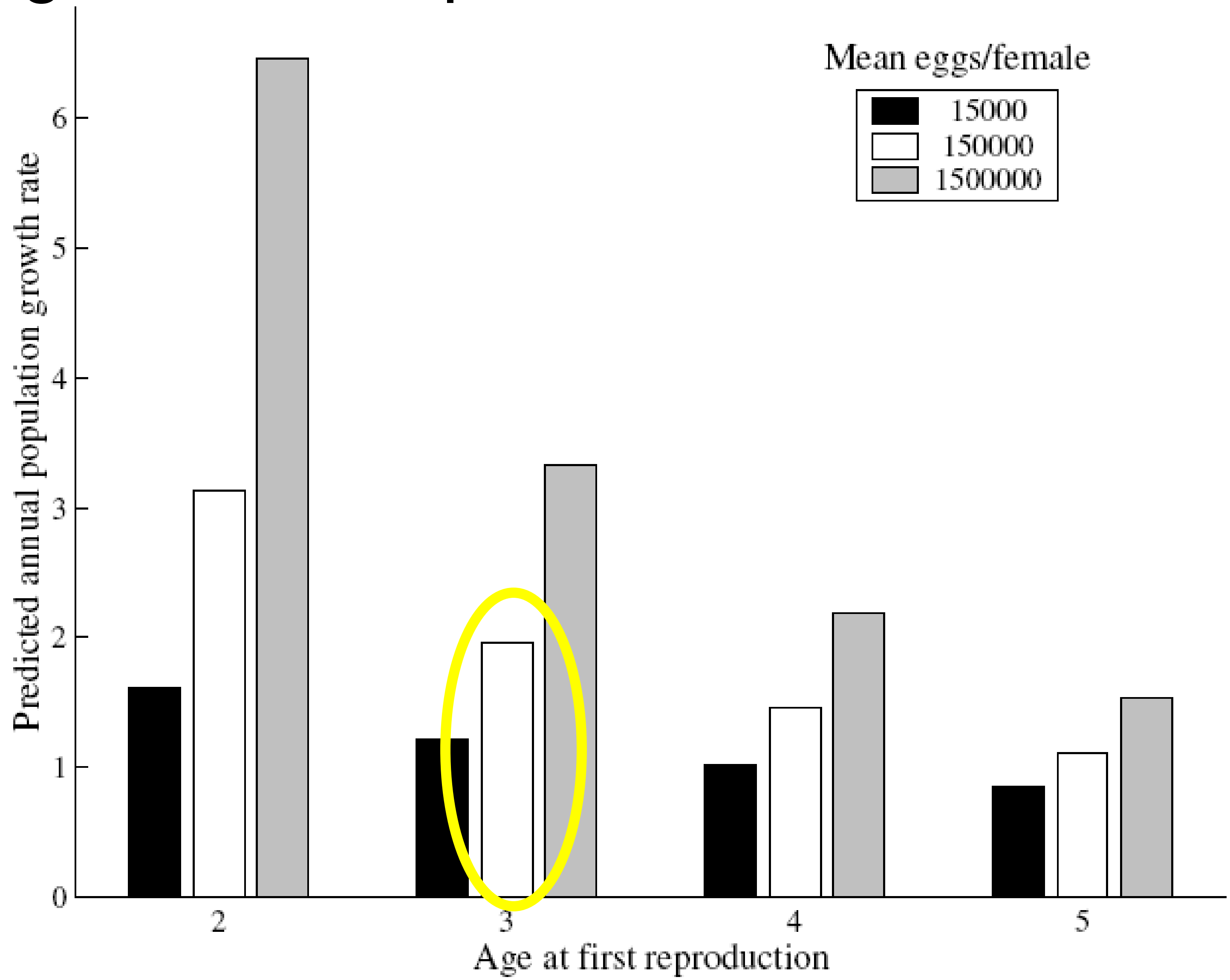
Predicted population growth rate for various ages at first reproduction and fecundities



Conclusion 1:
Detrimental changes to life history

- A wide range of suboptimal life history conditions still lead to a prediction of positive population growth in a stage-structured model
- but maturity delayed to age 5 may prevent population growth when combined with low fecundity

Predicted population growth rate for various ages at first reproduction and fecundities

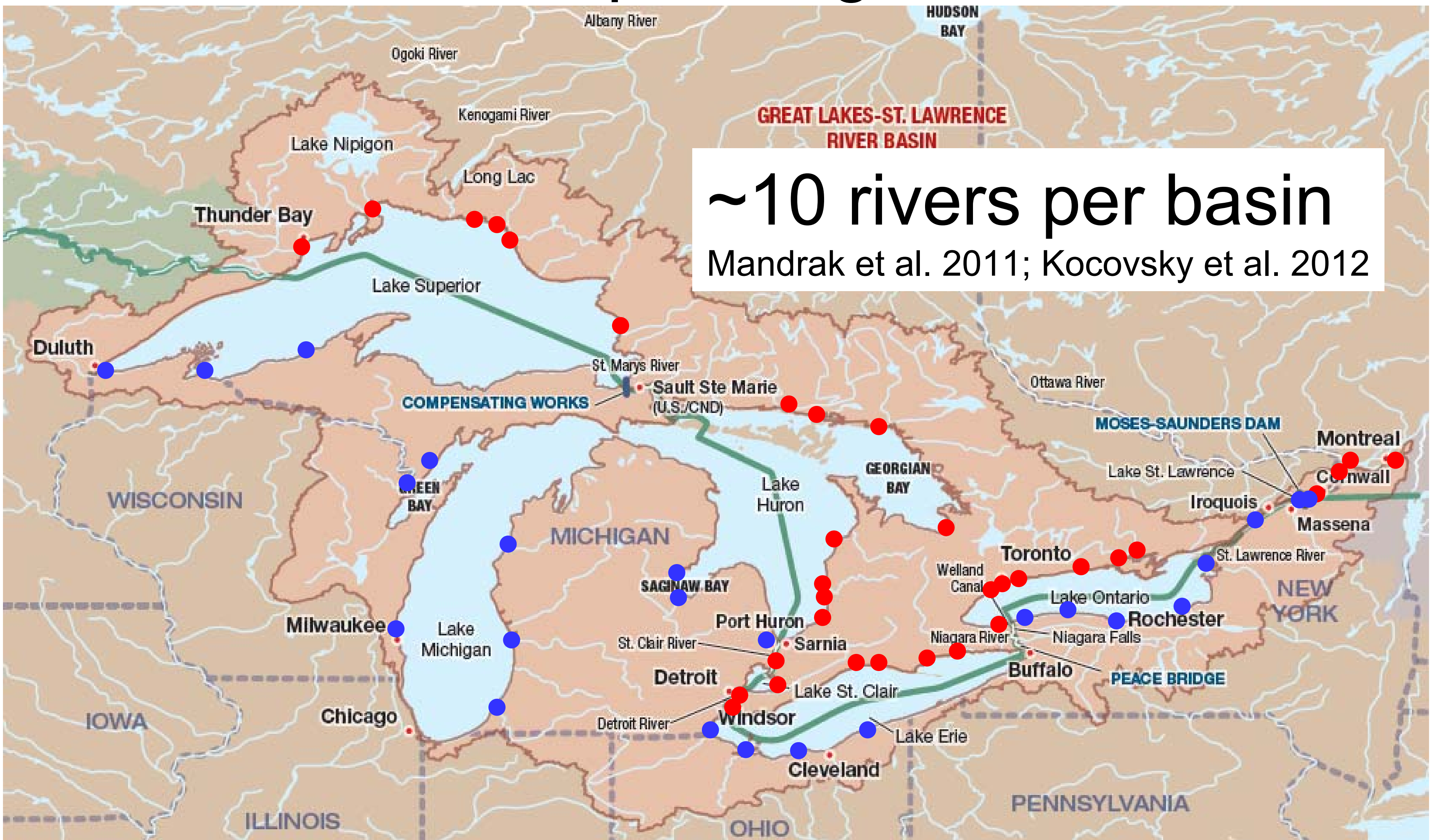


2. Little suitable habitat

Hypothesis: the small number of suitable spawning rivers will really restrict mating success, and therefore reduce probability of establishment

"I'm looking for something in a small pond."

Potentially suitable rivers for Asian carps spawning

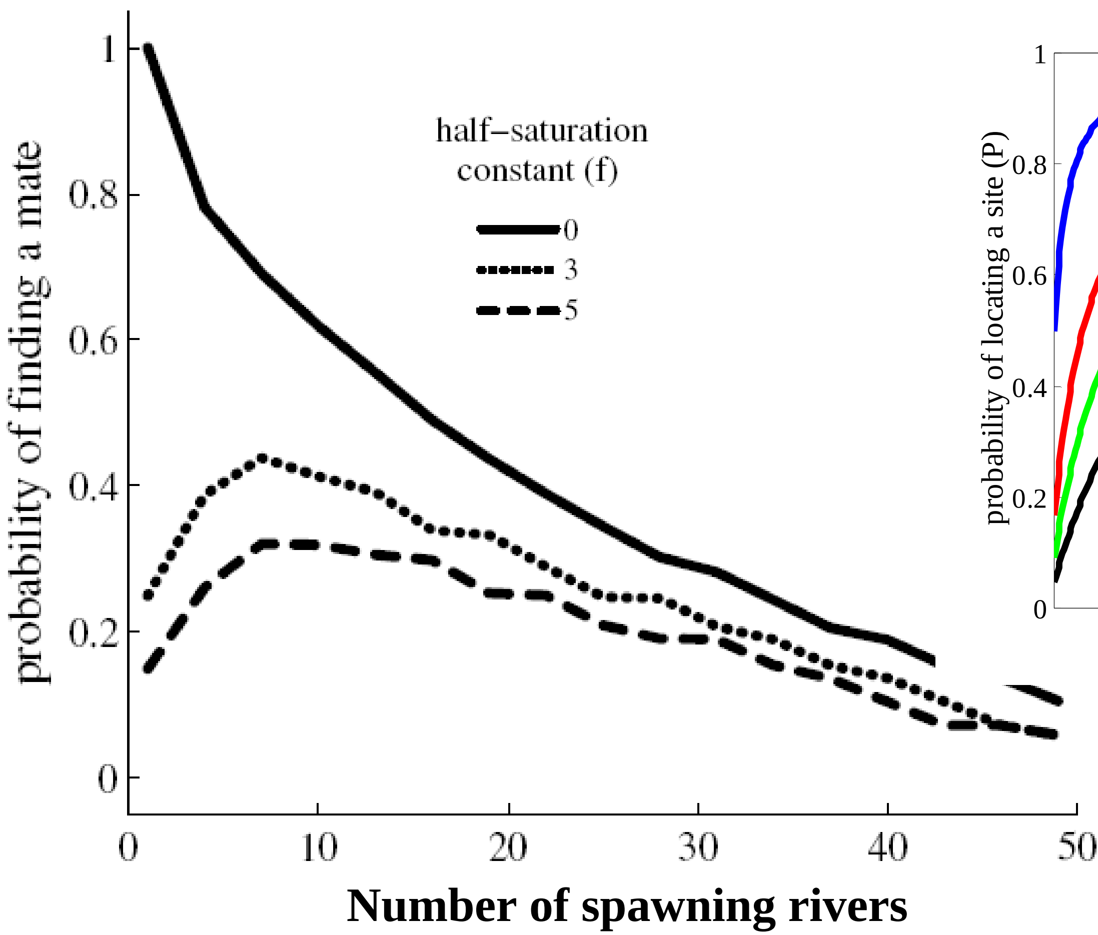


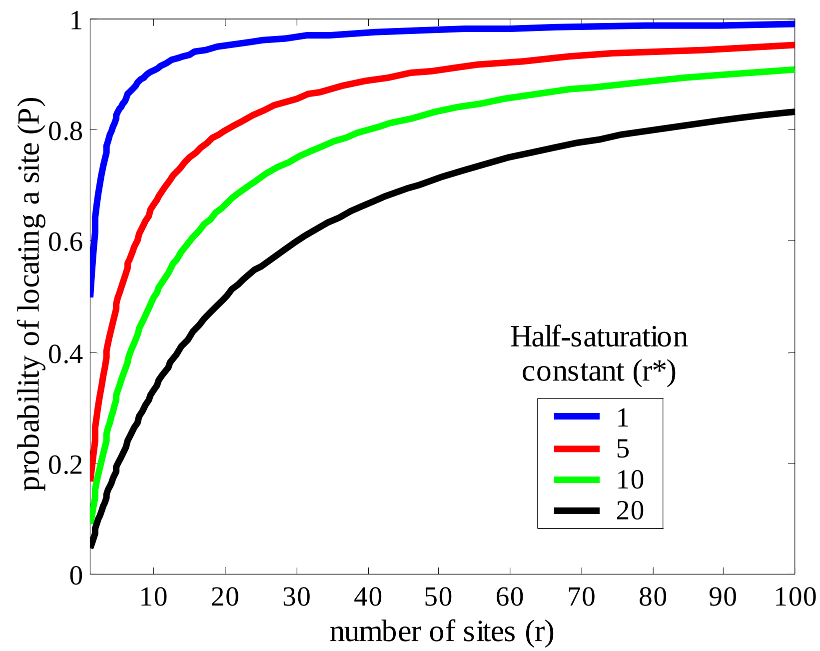
~10 rivers per basin

Mandrak et al. 2011; Kocovsky et al. 2012

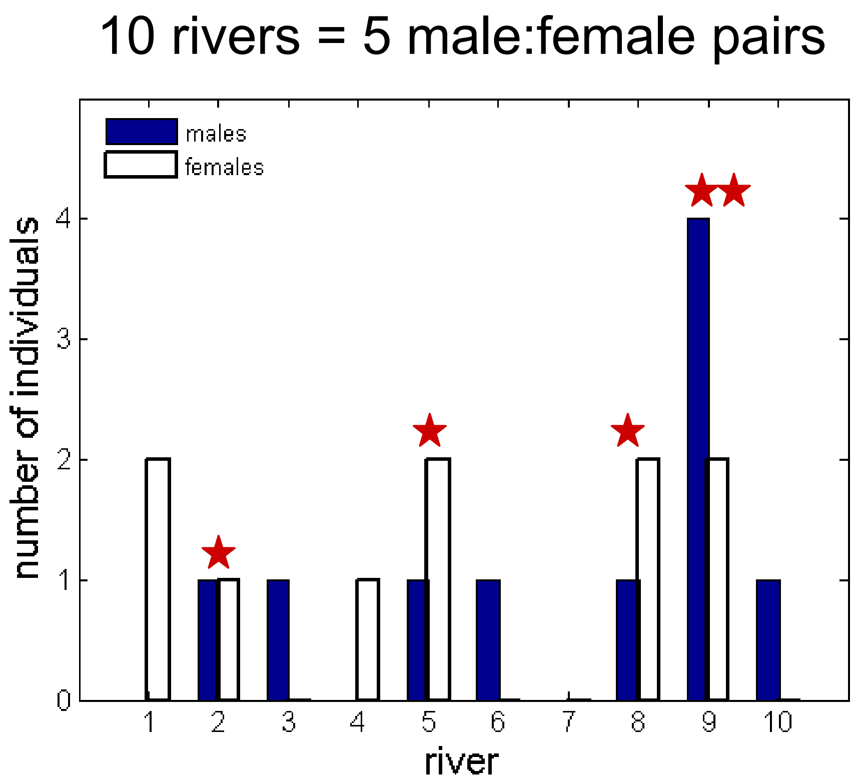
Life history ● ● ● ● ● ● ● ● ●   Habitat ● ● ○ ○ ○ ○ ○ ○ ○   Numbers ○ ○ ○ ○

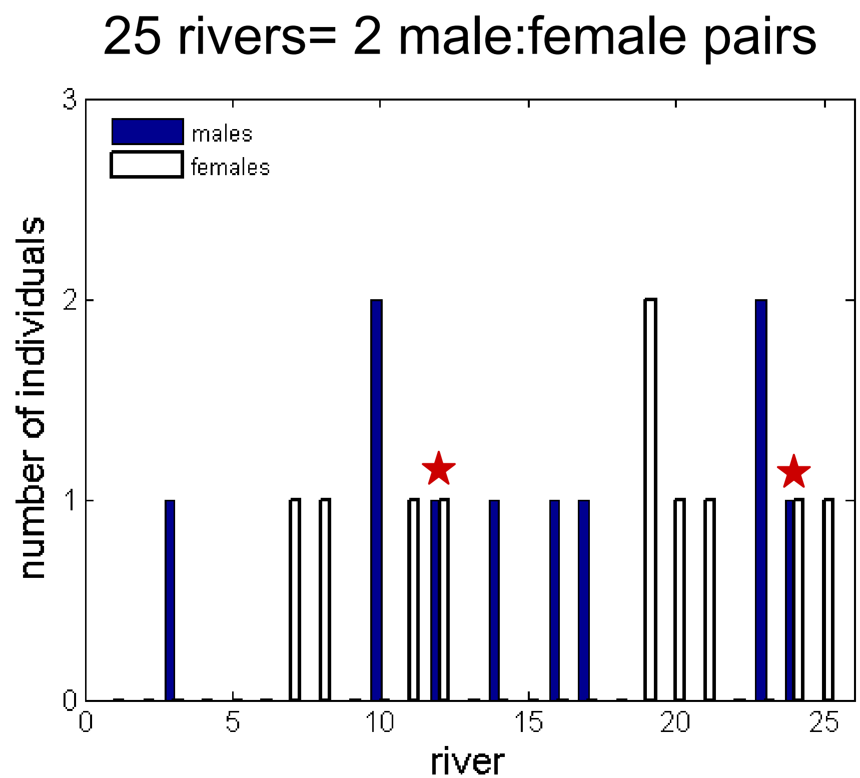
Mating probability decreases as # of suitable rivers increases





More rivers = fewer mated females

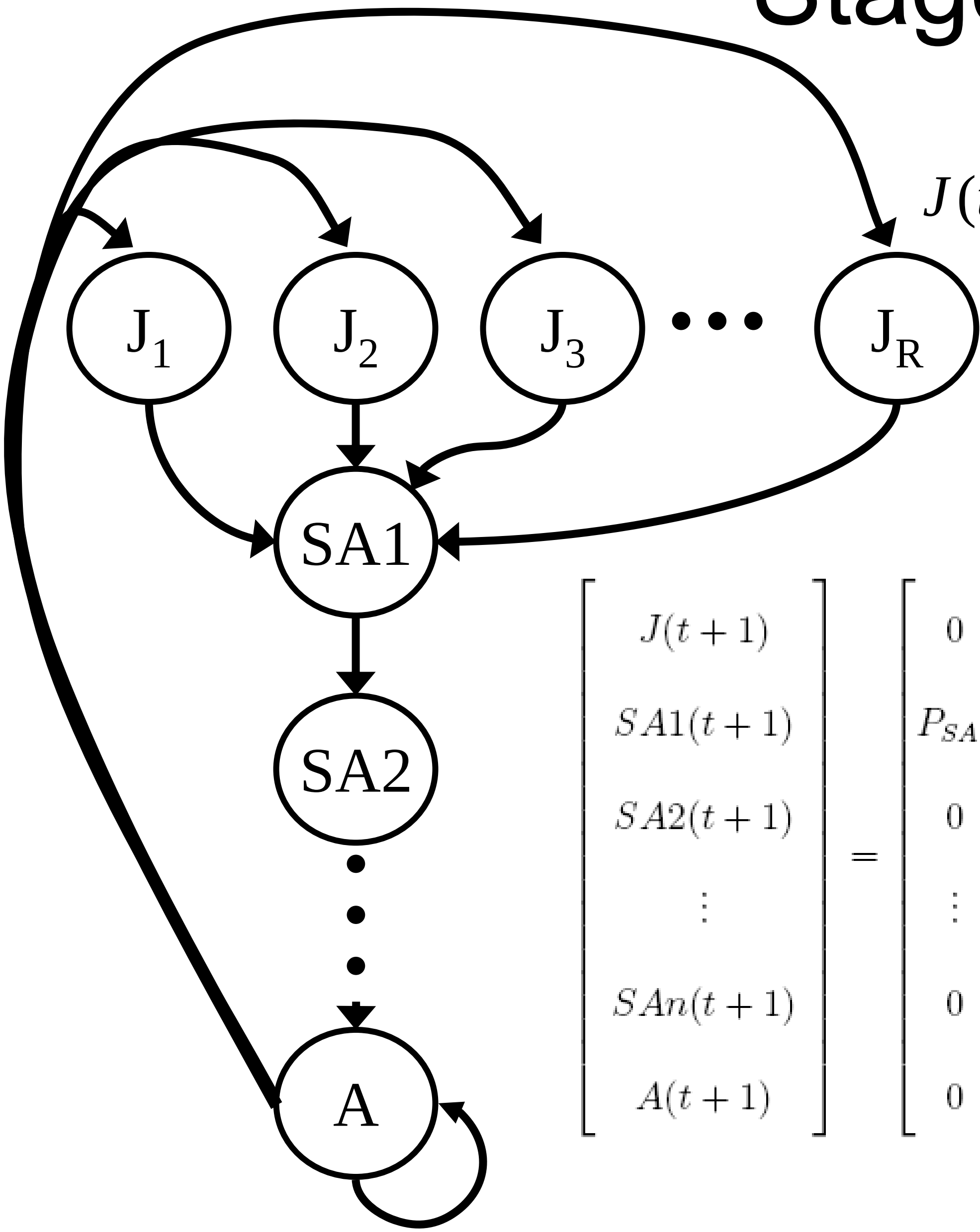




Life history ● ● ● ● ● ● ● ● ● Habitat ● ● ● ● ○ ○ ○ ○ Numbers ○ ○ ○ ○

Spawning river (R) subdivided

Stage-structured model



$$J(t+1) = \sum_{i=1}^{R} J_i(t+1) = \sum_{i=1}^{R} \left(M_i * F_i / 2 * P_J\right)$$

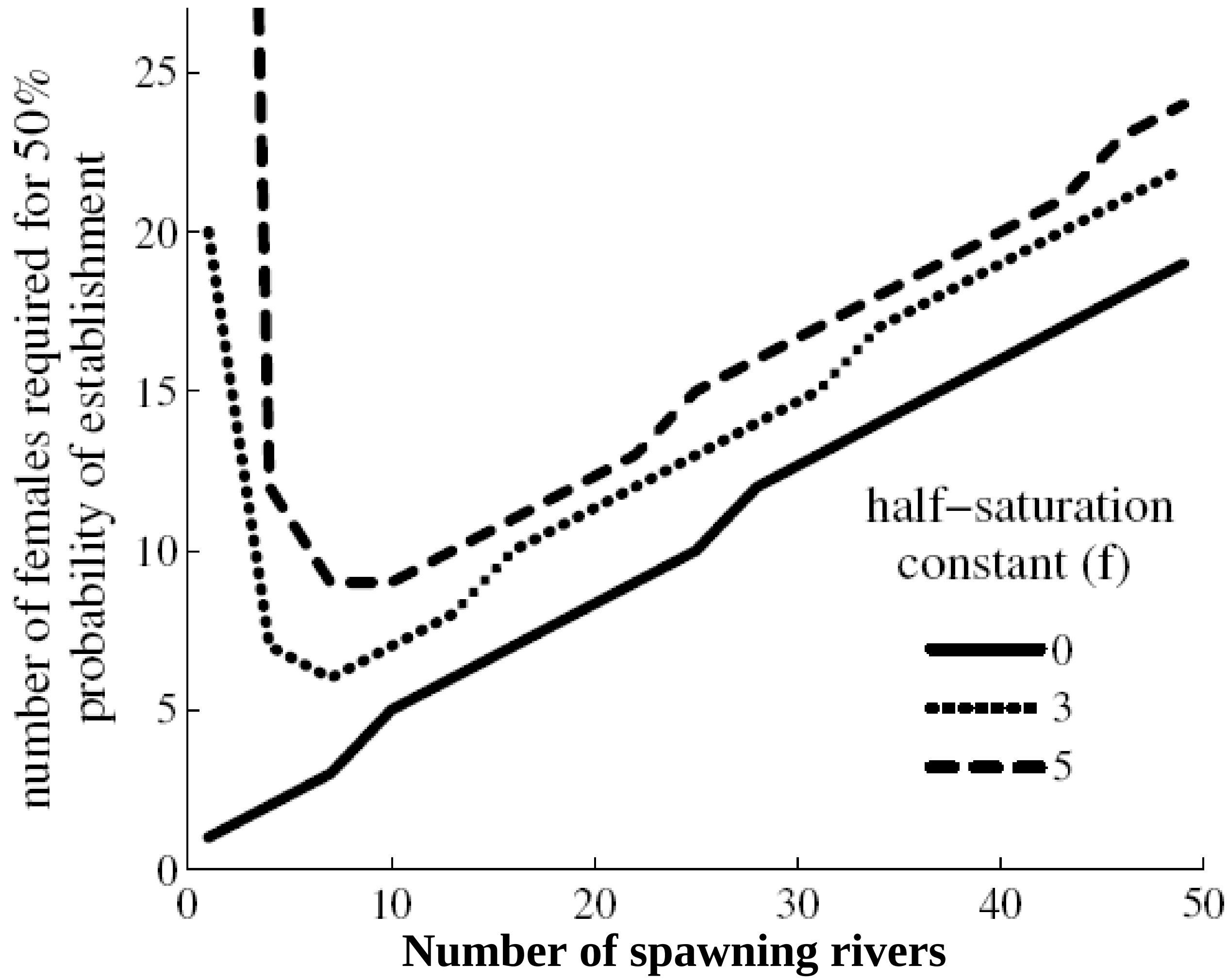
Number of mated females in river *i*

$$\begin{bmatrix} J(t+1) \\ SA1(t+1) \\ SA2(t+1) \\ \vdots \\ SAn(t+1) \\ A(t+1) \end{bmatrix} = \begin{bmatrix} 0 & 0 & \cdots & 0 & 0 & F/2 * P_J \\ P_{SA1} & 0 & \dots & 0 & 0 & 0 \\ 0 & P_{SA2} & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \dots & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & P_{SAn} & 0 & 0 \\ 0 & 0 & \dots & 0 & P_A & P_A \end{bmatrix} \times \begin{bmatrix} J(t) \\ SA1(t) \\ SA2(t) \\ \vdots \\ SAn(t) \\ A(t) \end{bmatrix},$$

Define “Probability of Establishment”

Probability of a population of 1000 female fish in a single basin in 20 years

Number of female fish required for 50% probability (~10 fish for 10 rivers)



Conclusion 2:
Little suitable habitat

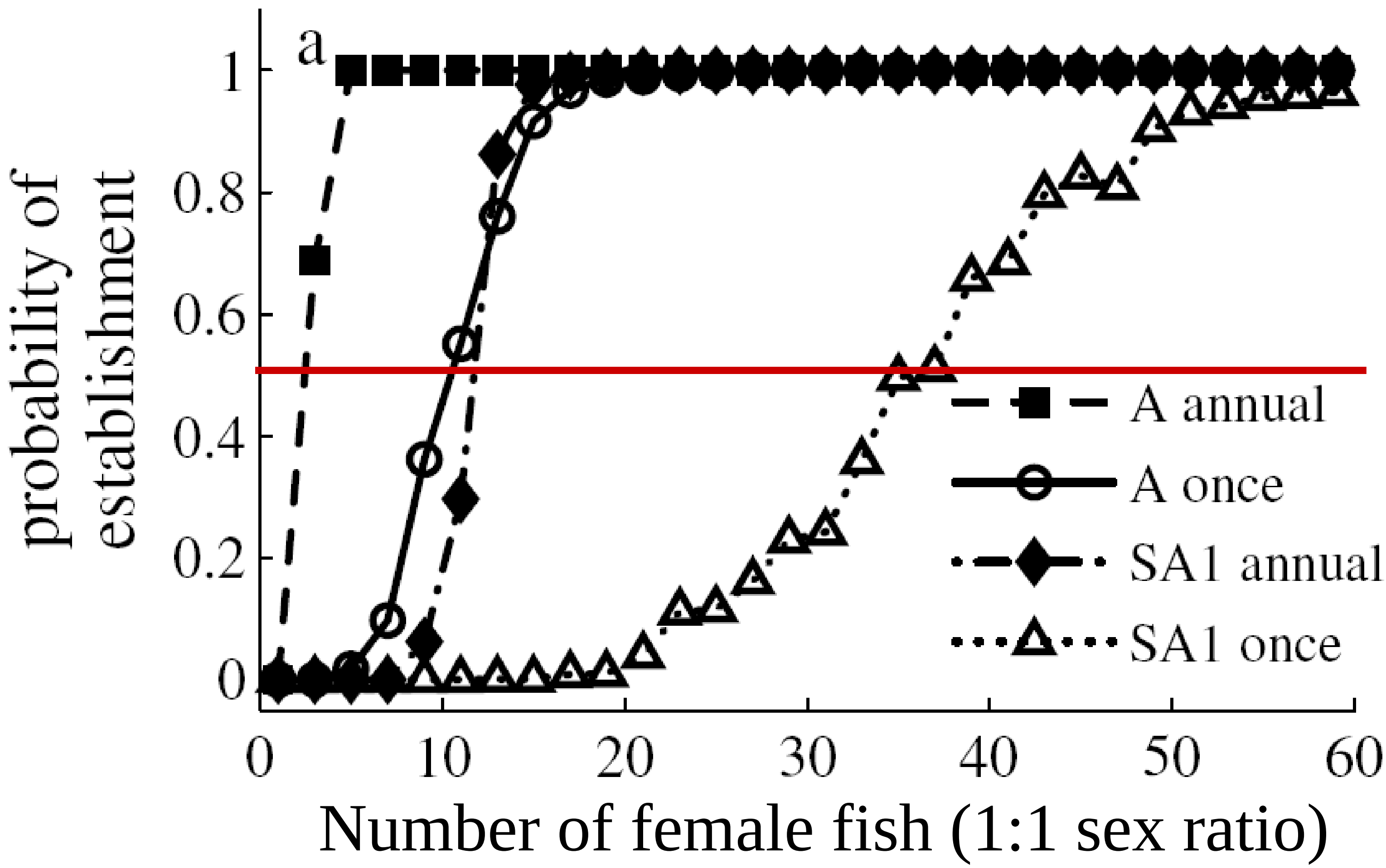
- the relatively small estimated number of suitable spawning rivers (~10) in each basin may actually facilitate mating-finding
- And therefore the small number of rivers on each basin may *increase* probability of establishment at low population density

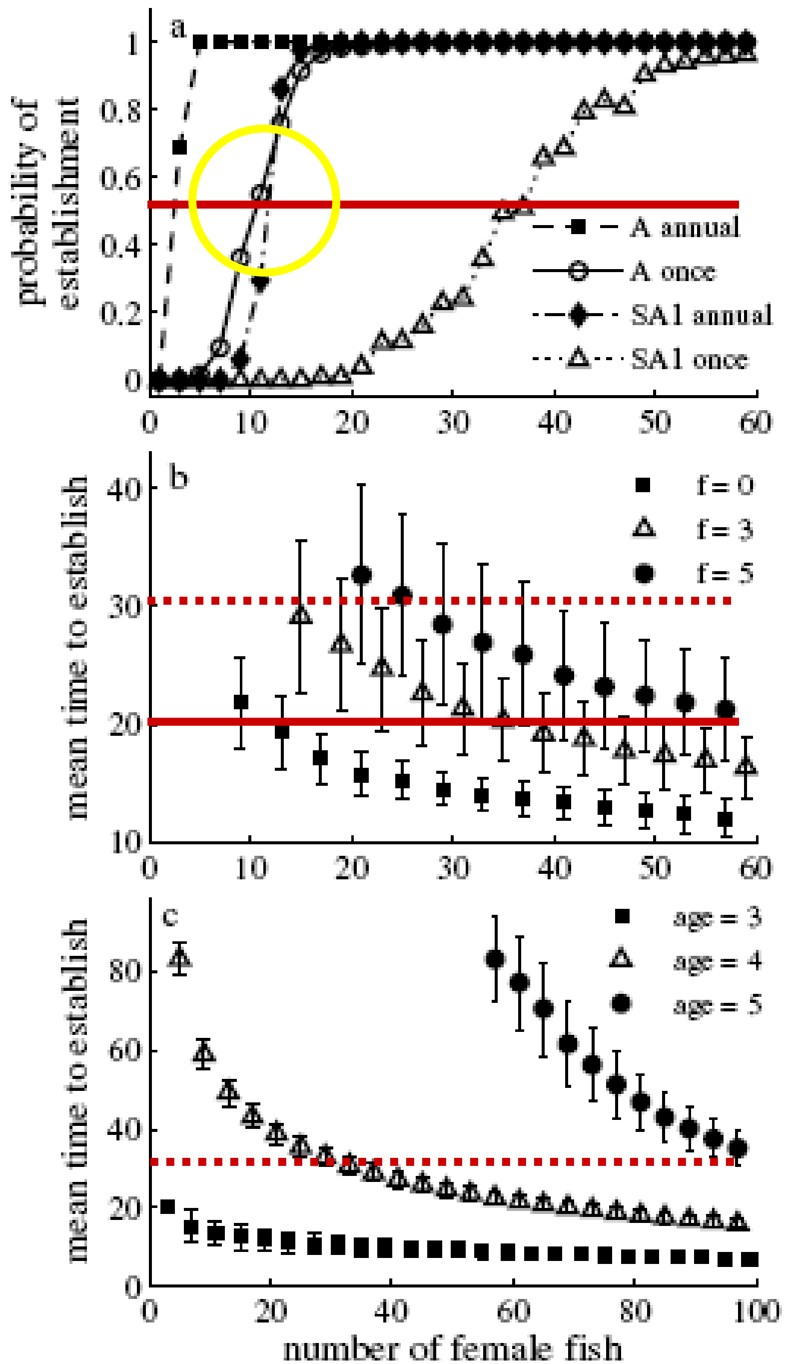
3. Small population size

Hypothesis: the small number of fish that breach containment make it unlikely, given all the other factors, that Asian carps can establish

"Lately I've been feeling so alone."

~10 female fish required for 50% probability (standard life history,10 rivers, every fish locates)





3. Various introduction scenarios (>50% in 20 years for ~10 fish)

2. Difficulty in river location decreases probability (>50% in 30 years >20 adults)

1. Slow growth and delayed reproduction significantly decrease probability (age 4: >50% in 30 years >40 adults)

Conclusion 3: Small population size

- Propagule pressure does increase risk
- But risk is very high at low population levels
- Low propagule pressure is no defense against establishment for average life history conditions

Conclusions

➔The “safe” number of introduced fish for a basin may be EXTREMELY low (<10 females)

➔We need robust predictions for effect of “lake” conditions on growth and age at maturity

Acknowledgements

- Funding provided by the Department of Fisheries and Oceans

4. Environmental stochasticity

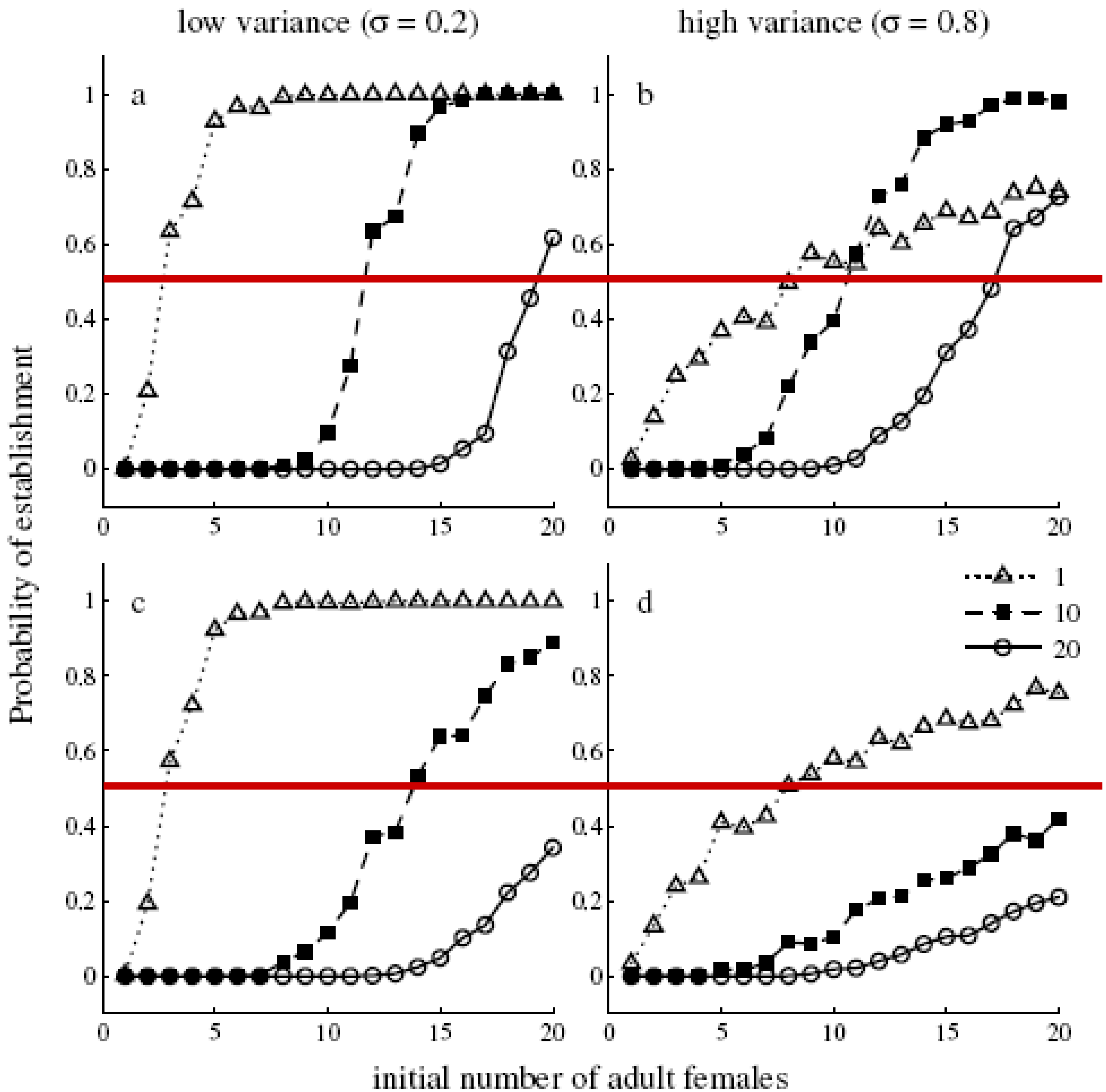
Hypothesis: Variable conditions in environmental factors such as rainfall will result in low-flow conditions which cause reproductive failure and enhanced juvenile mortality in bad years

Simulating environmental stochasticity Cold temp/Low flow/Poor food

- Bad conditions cause spawning failure:
  - environmental variability for each river using autocorrelated random series of probabilities, and standardized to have a given variance (σ^2)and mean of 0.5.
  - Spawning only $e_t > 0.05$.

- Bad conditions decrease juvenile (J) and subadult stage 1 (SA1) survivorship
  - P_J*e_t or $P_{SA1}*e_t$

Large variance decreases establishment probability



Uncorrelated between watersheds

Correlated between watersheds

Conclusion 4:
Environmental stochasticity

- will certainly decrease probability of establishment,
- but the effect is largest for basin-wide correlation of bad conditions,
- and is not very large in any of the conditions examined