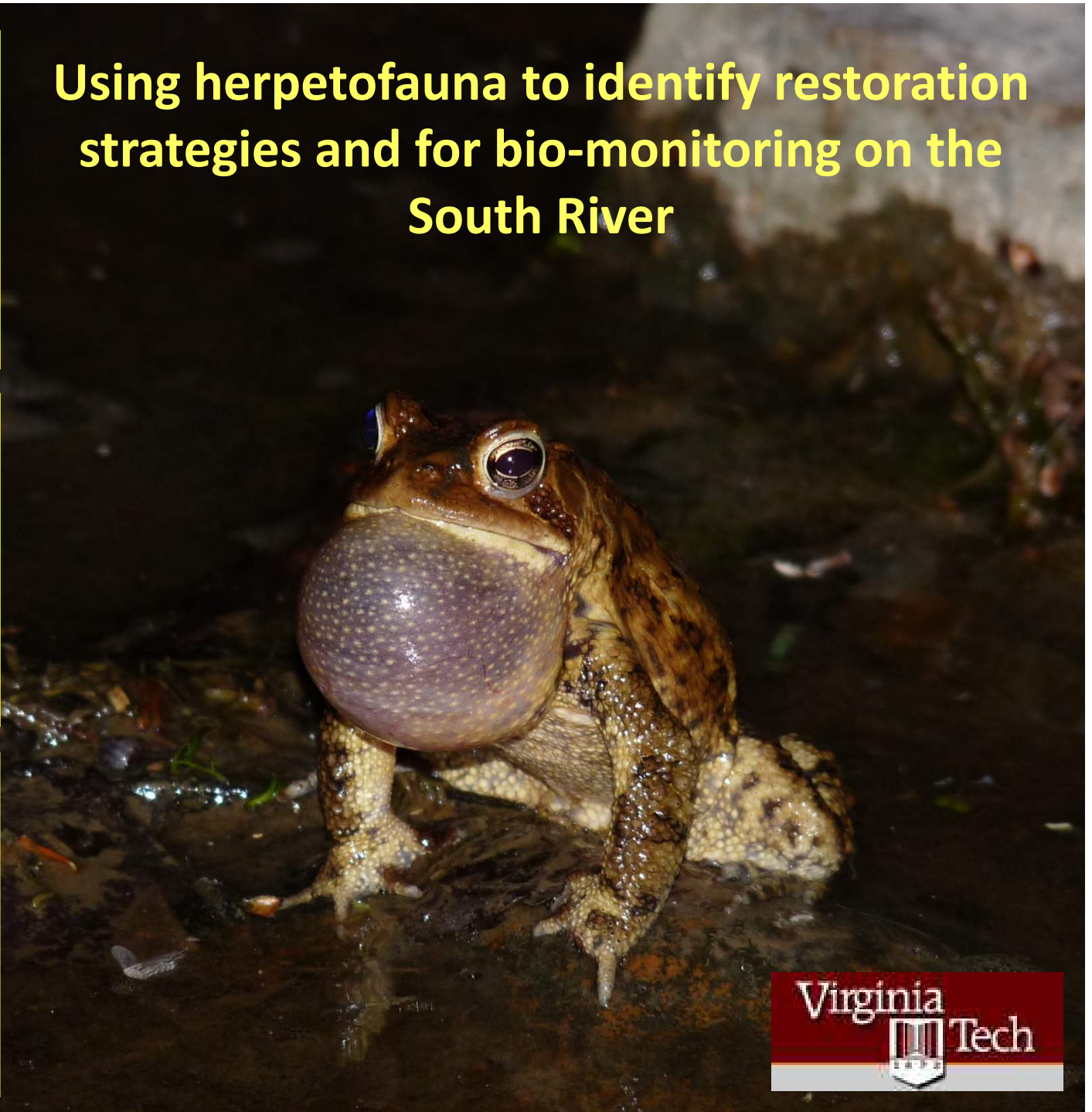
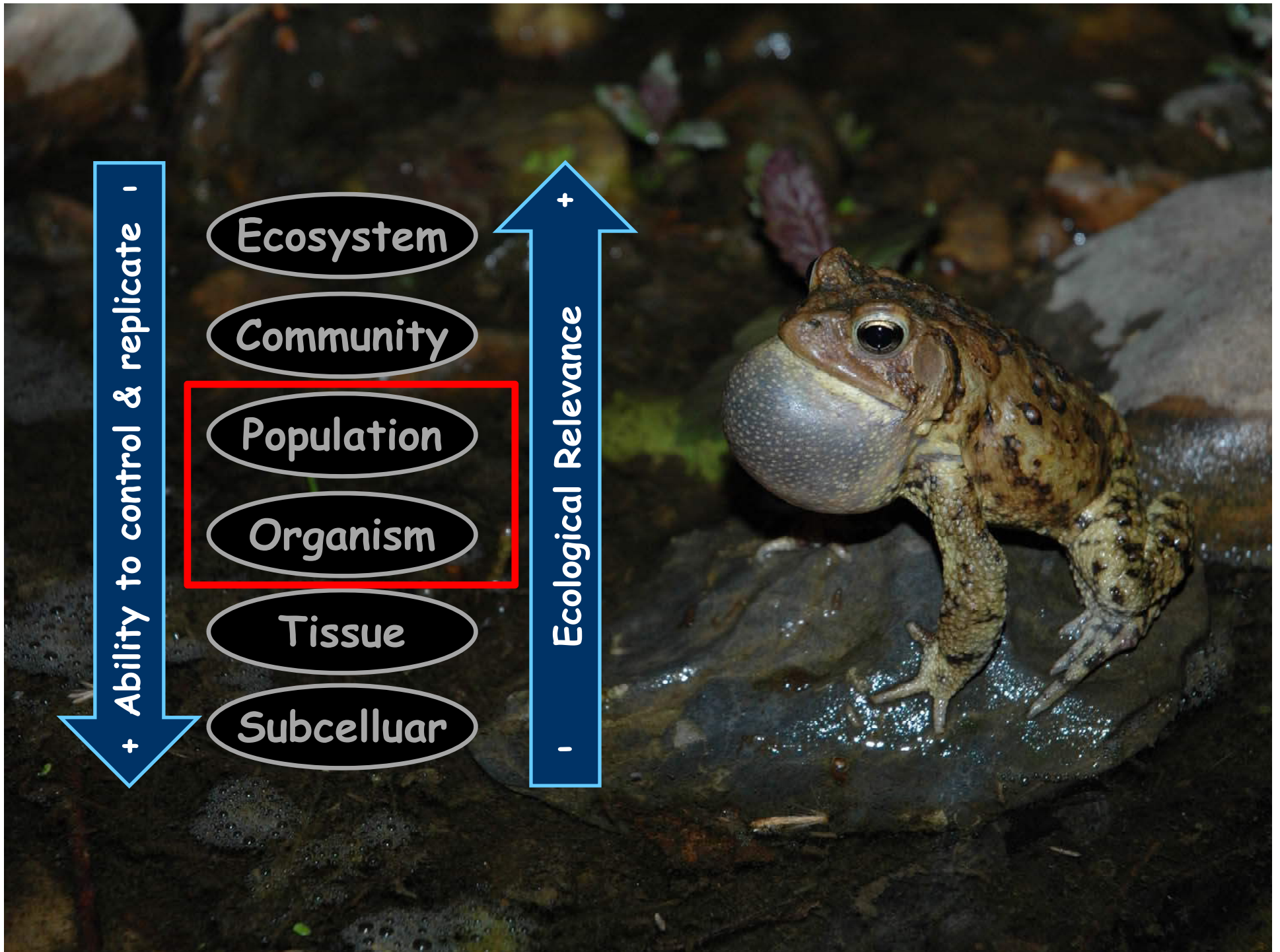


Using herpetofauna to identify restoration strategies and for bio-monitoring on the South River

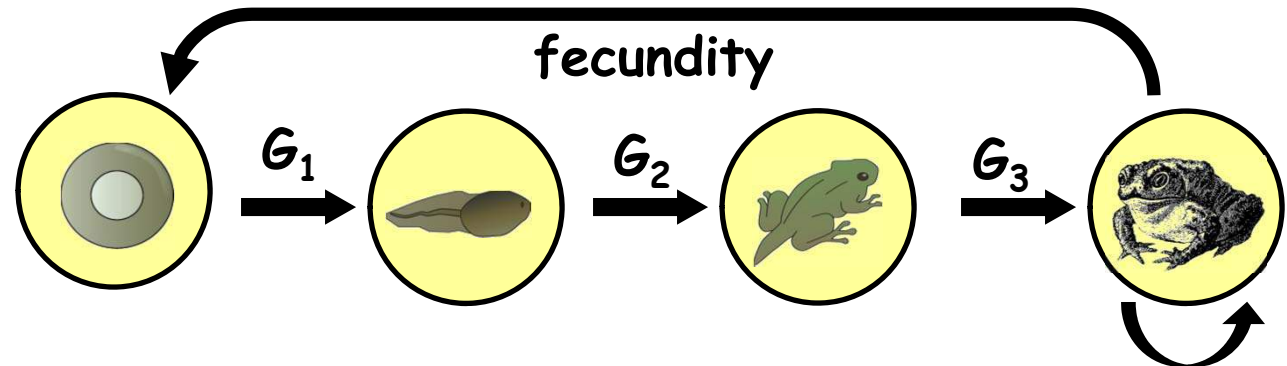


a lot of
With a ~~little~~ help from my friends...

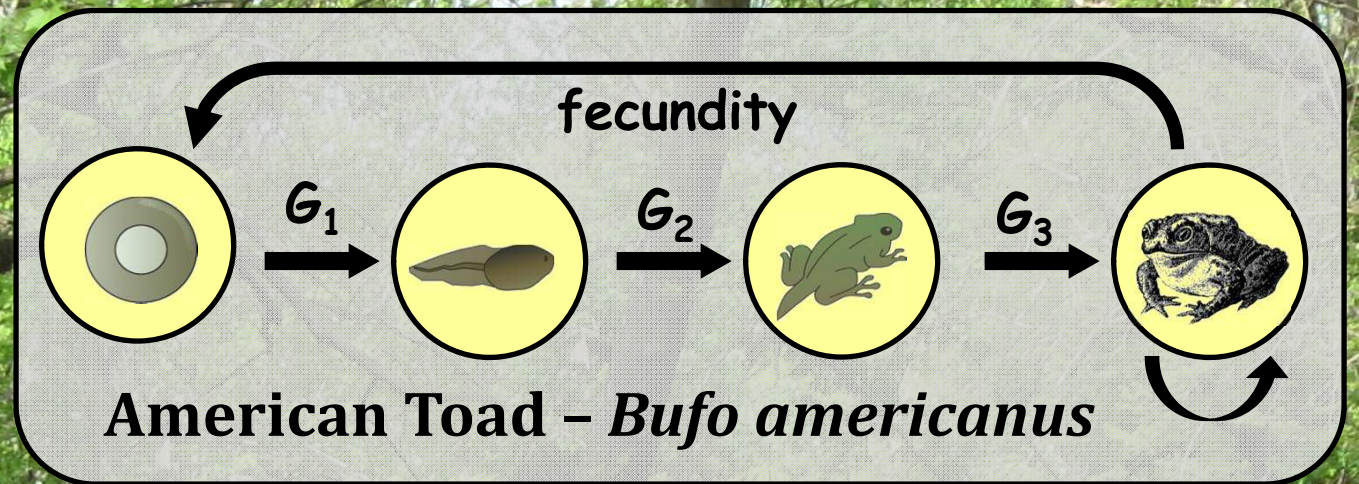




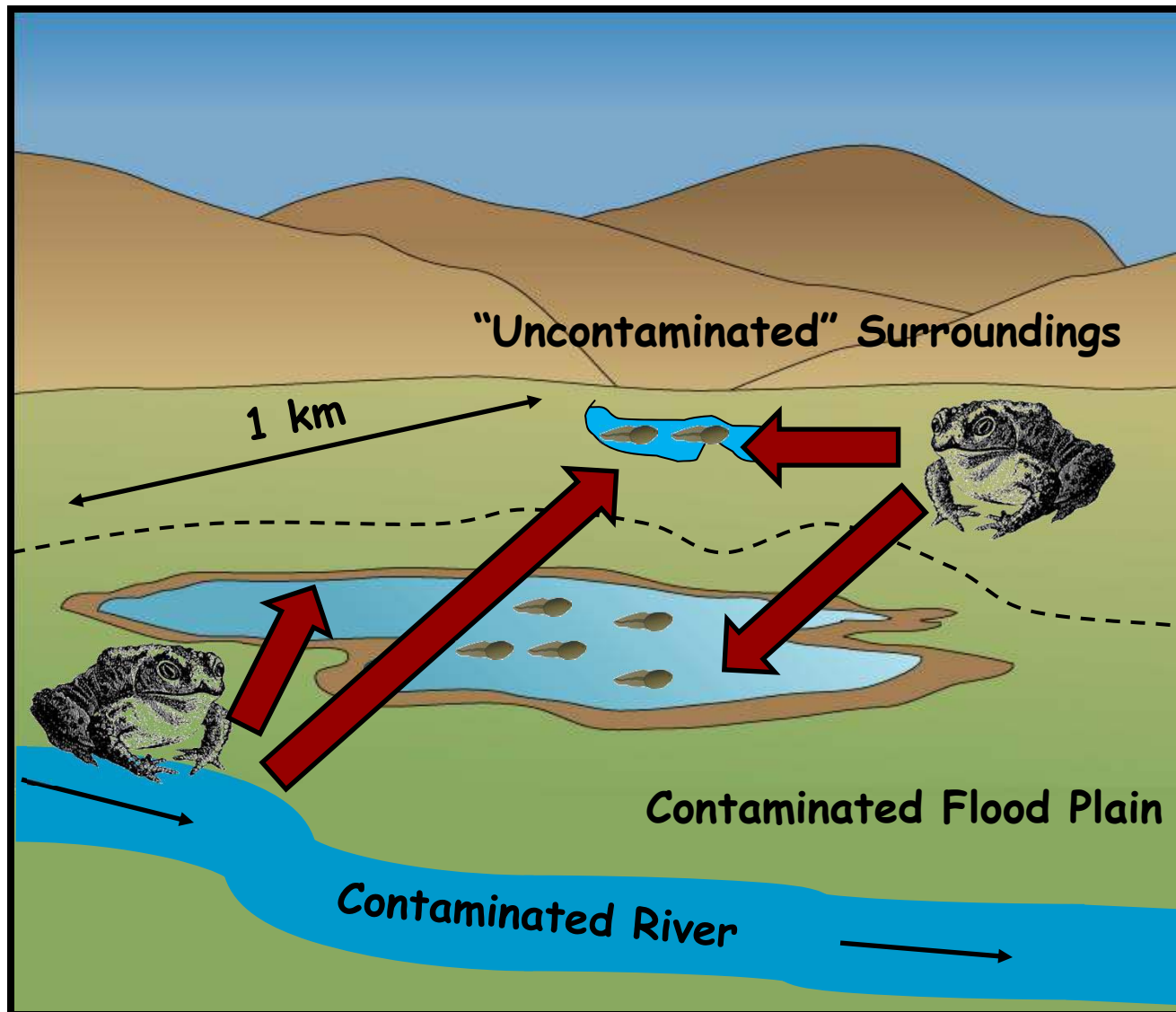
Pluralistic Approach



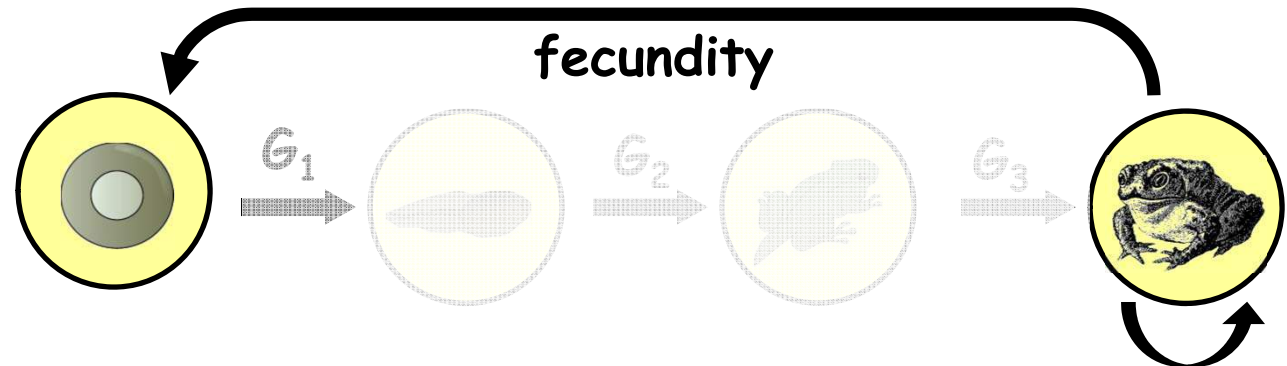
$$\begin{bmatrix} J1 \\ J2 \\ A \end{bmatrix}_{t+1} = \begin{bmatrix} 0 & 0 & (f\sigma_E Hg_m) \left(\frac{\sigma_{Tmax}}{(1+d_{stoc.} L_t)^\gamma} Hg_m Hg_d \right) (\sigma_M Hg_m Hg_d) \\ \sigma_{J1} Hg_m & 0 & 0 \\ 0 & \sigma_{J2} Hg_m & \sigma_A \end{bmatrix} \times \begin{bmatrix} J1 \\ J2 \\ A \end{bmatrix}_t$$



Complex Life Cycles & Multiple Exposure Routes



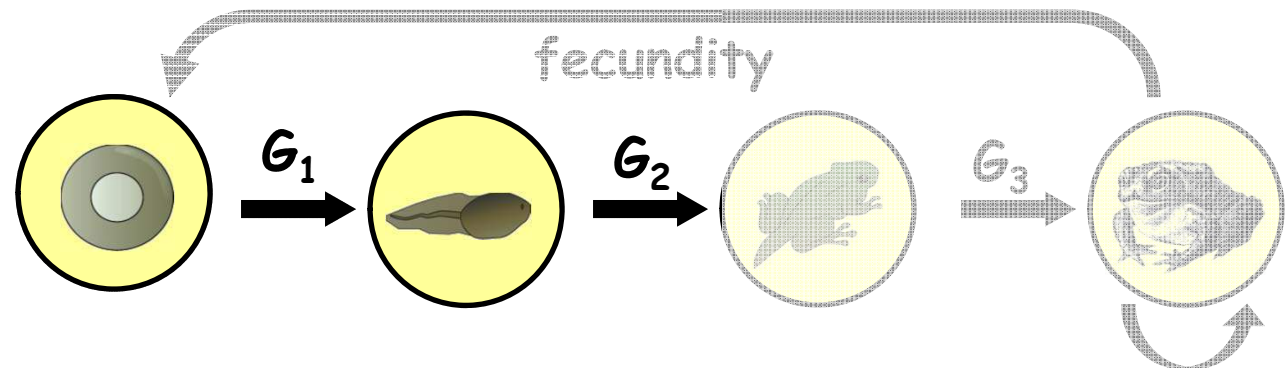
Individual - Level Effects



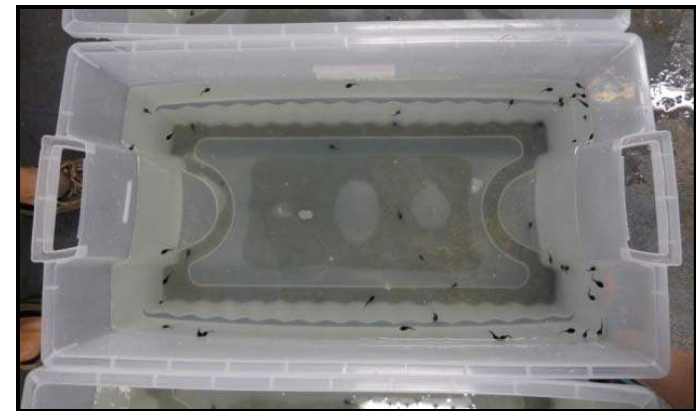
- Effects of maternal Hg exposure on female reproductive success



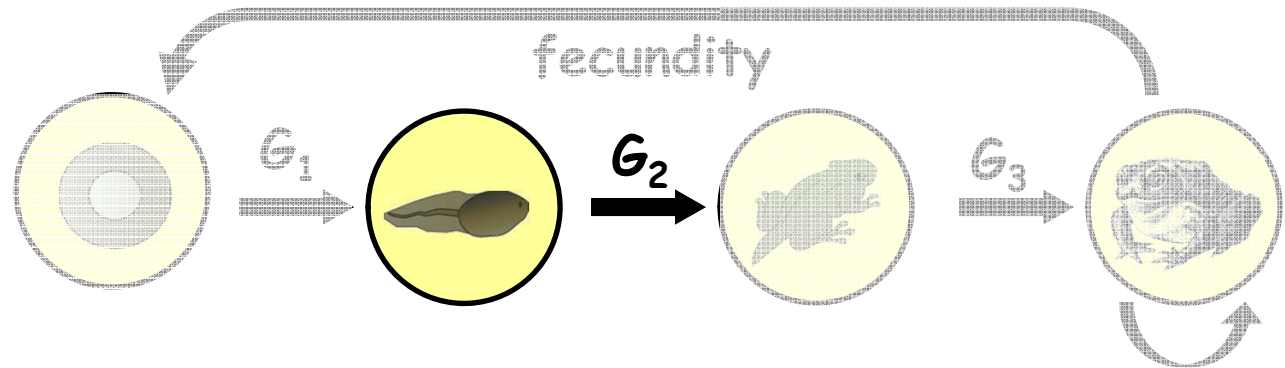
Individual - Level Effects



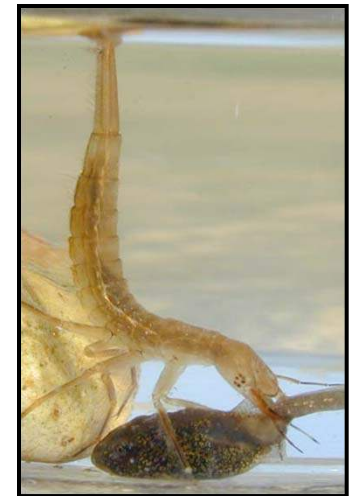
- Effects of maternal Hg exposure on female reproductive success
- Latent effects of maternal Hg



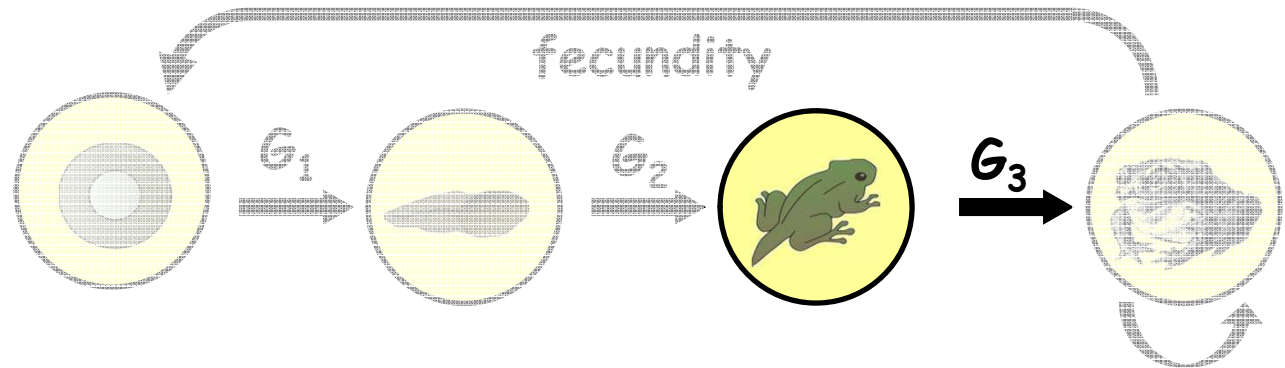
Individual - Level Effects



- Effects of maternal Hg exposure on female reproductive success
- Latent effects of maternal Hg (with and without predators)
- Individual & interactive effects of maternal and dietary Hg



Individual - Level Effects

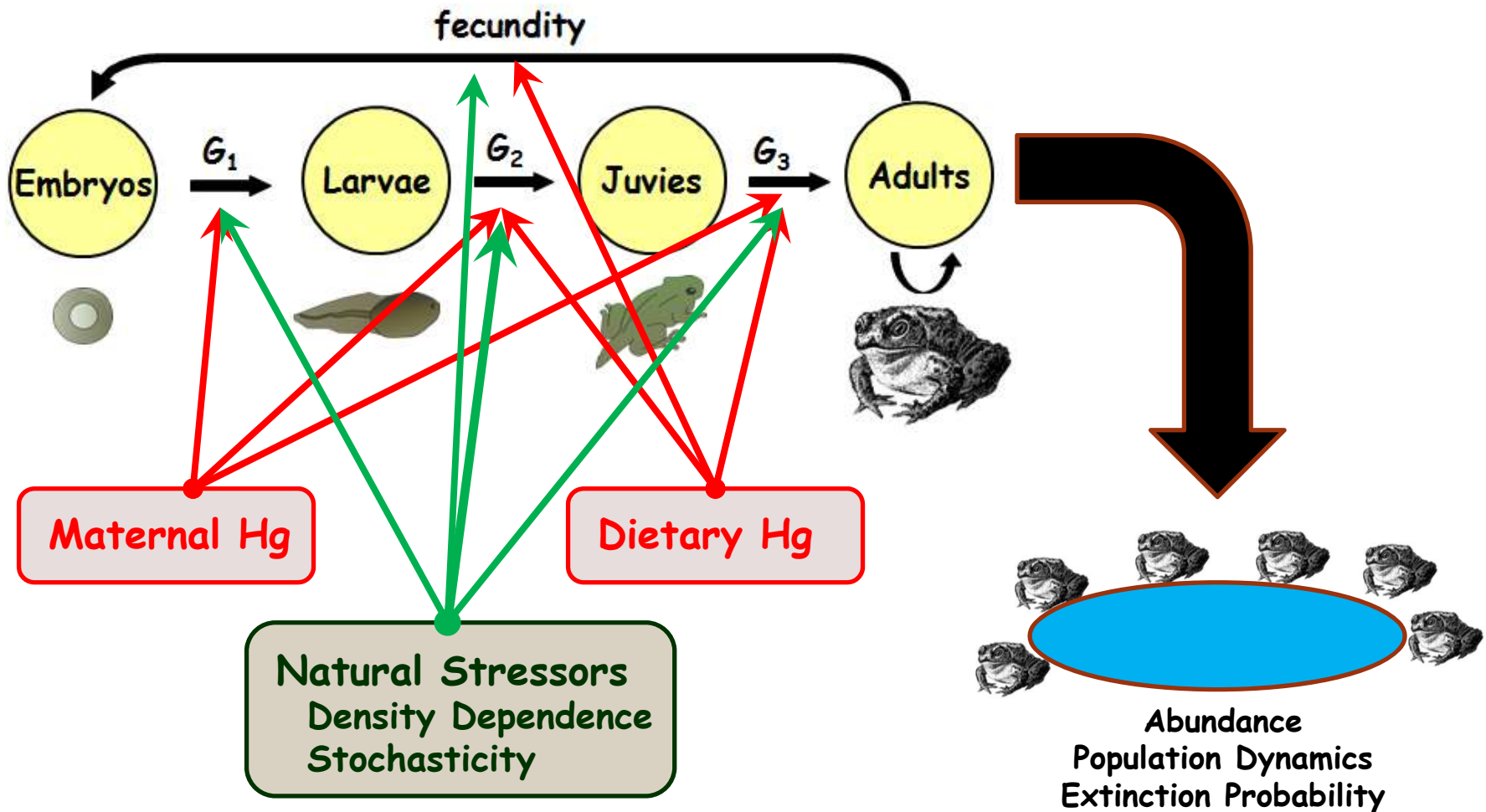


- Effects of maternal Hg exposure on female reproductive success
- Latent effects of maternal Hg (with and without predators)
- Individual & interactive effects of maternal and dietary Hg
- Even more latent effects – terrestrial enclosures



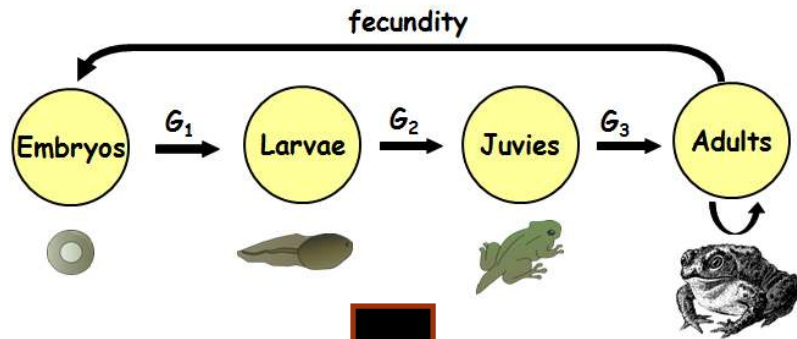
Age / Stage-based Population Model

American Toad (*Bufo americanus*)



Age / Stage-based Population Model

American Toad (*Bufo americanus*)



Sensitivity / Simulation Analyses

- Sensitivity to Hg effects
 - embryo, larval, juvenile, adult
- Simulations:
 - maternal & dietary Hg exposure
- Endpoints:
 - Quasi-extinction probability
 - Mean adult population size

Mechanistic, Discrete-Time, Matrix Model

- 4 age classes
- 1 yr. time-step
- Density-dependence in the larval stage
- Environmental stochasticity
- Hg effects based on results of lab/mesocosm experiments

Age / Stage-based Population Model

American Toad (*Bufo americanus*)

$$\begin{bmatrix} J1 \\ J2 \\ A3 \\ A \end{bmatrix}_{t+1} = \begin{bmatrix} 0 & 0 & (\phi_{A3} f \sigma_E)(\sigma_{L,t})(\sigma_M) & (f \sigma_E)(\sigma_{L,t})(\sigma_M) \\ \sigma_{J2} & 0 & 0 & 0 \\ 0 & \sigma_{J3} & 0 & 0 \\ 0 & 0 & \sigma_{A3} & \sigma_A \end{bmatrix} \times \begin{bmatrix} J1 \\ J2 \\ A3 \\ A \end{bmatrix}_t$$

$J1$ = # age 1 Juveniles

$J2$ = # age 2 Juveniles

$A3$ = # age 3 sub-adults/adults

A = # Adults

$\sigma_{E,L,M,J1,J2,A3,A}$ = survival (egg, larvae, metamorph, juvenile, adult)

f = clutch size

ϕ_{A3} = probability reproducing at age 3

$$L_t(A_t, A3_t, H_t) = \frac{(A_t + \phi_{A3} A3_t)(f \sigma_E)}{H_t}$$

$$\sigma_{L,t}(L_t) = \frac{\sigma_{L\max}}{(1 + dL_t)^\gamma}$$

H = size of breeding habitat (m of shoreline)

L = # of larvae per m of shoreline

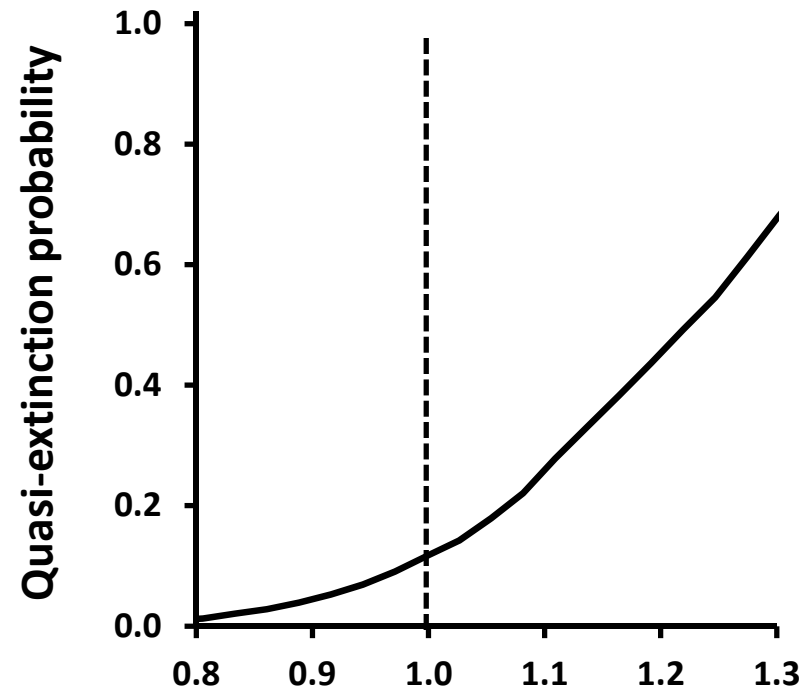
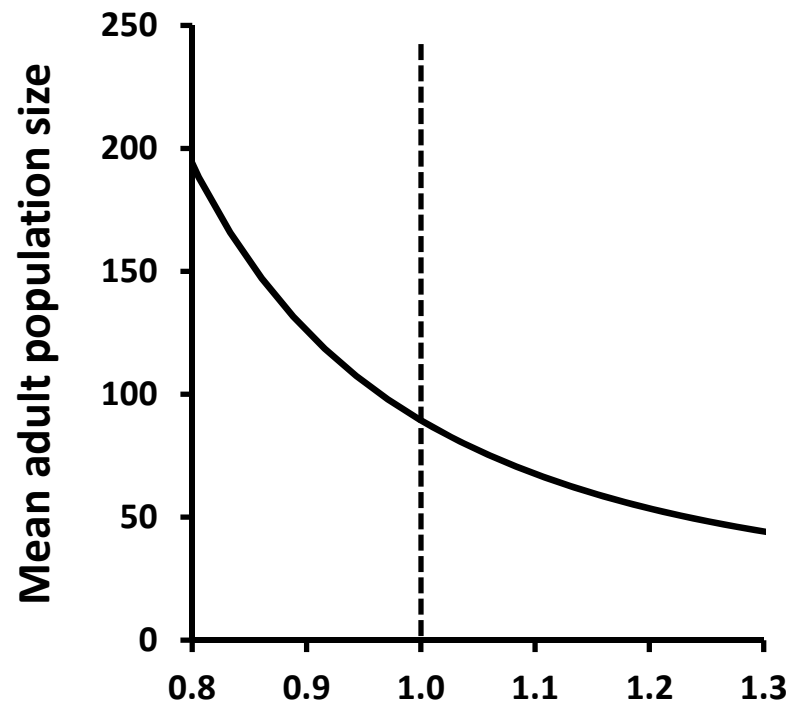
$\sigma_{L\max}$ = maximum larval survival at low density

γ = density dependence exponent

d = density dependence coefficient

Results: Simulation Analyses

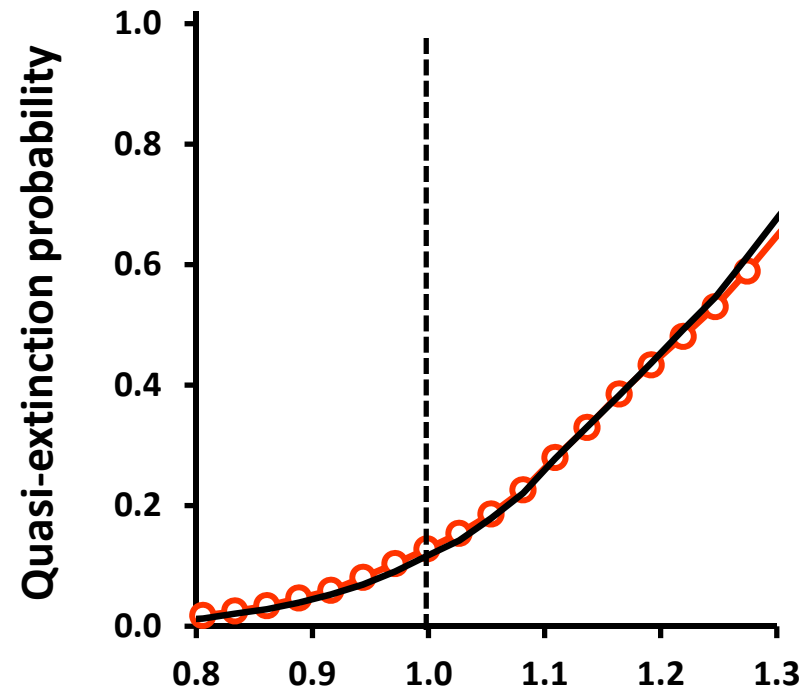
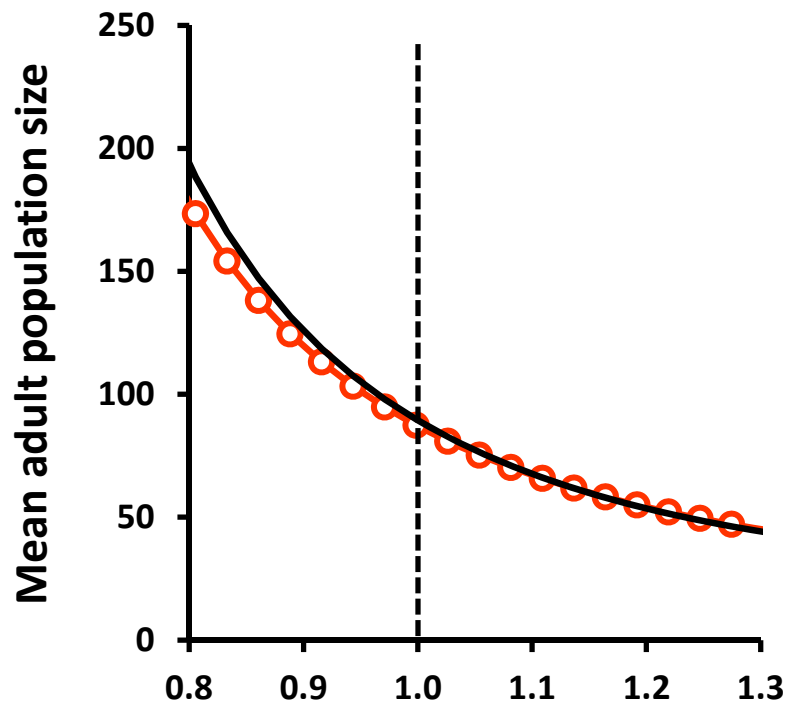
— Reference ○ Maternal Hg × Larval diet Hg - - Maternal + larval diet



Strength of larval density-dependence

Results: Simulation Analyses

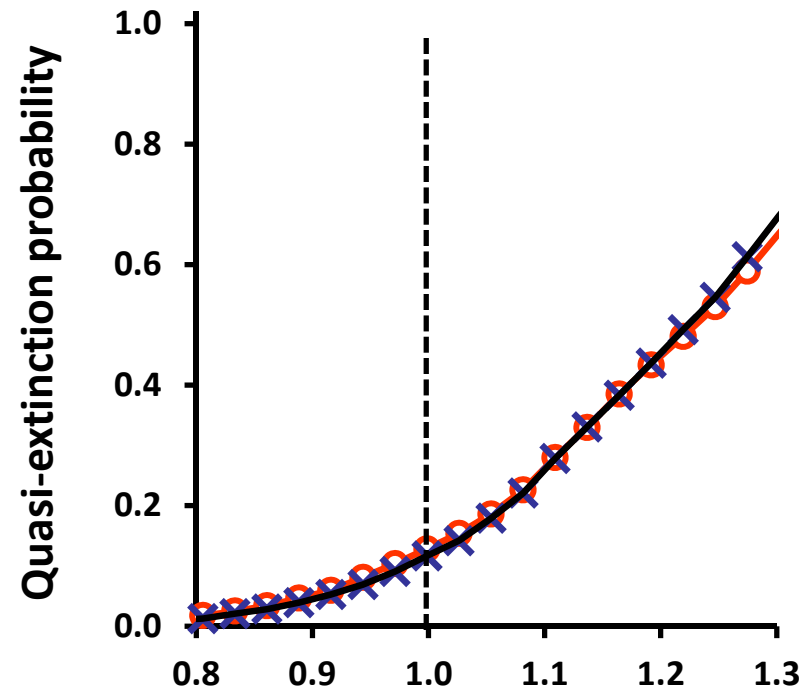
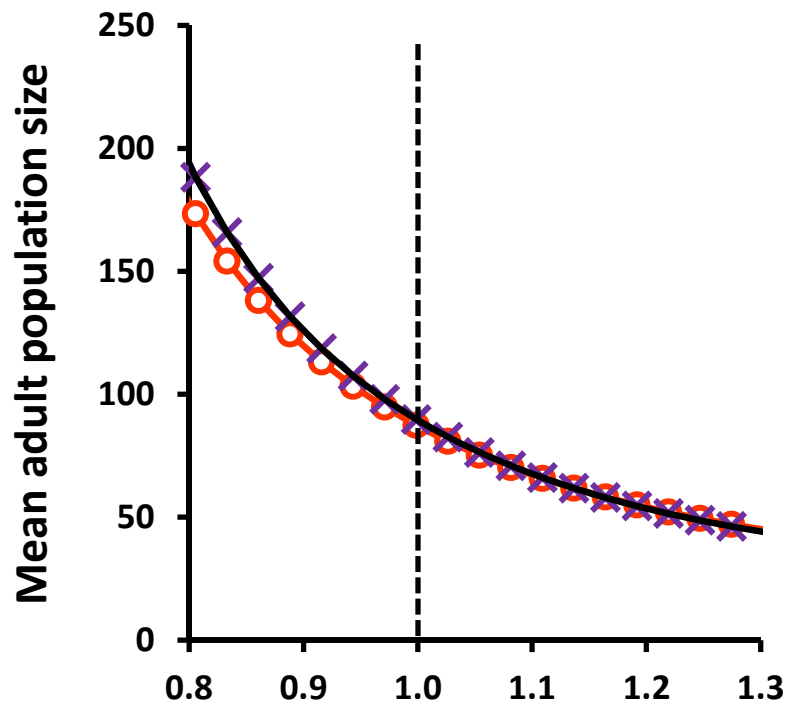
— Reference ○ Maternal Hg × Larval diet Hg - - Maternal + larval diet



Strength of larval density-dependence

Results: Simulation Analyses

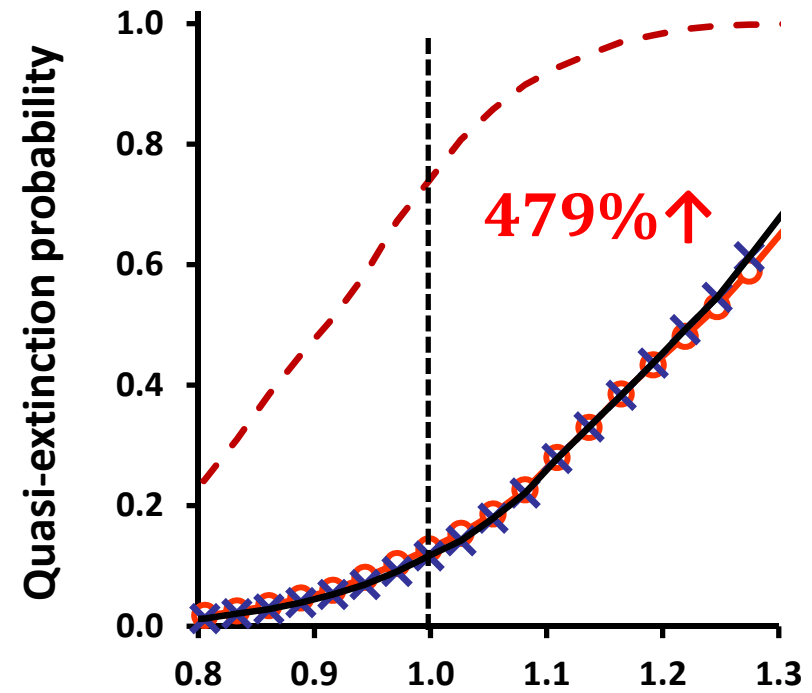
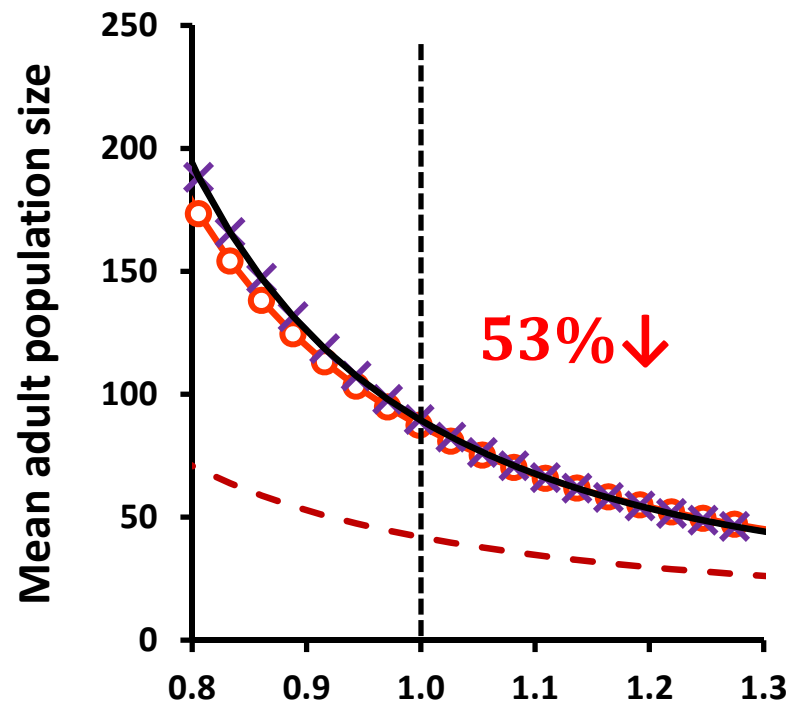
— Reference ○ Maternal Hg × Larval diet Hg - - Maternal + larval diet



Strength of larval density-dependence

Results: Simulation Analyses

— Reference ○ Maternal Hg × Larval diet Hg - - Maternal + larval diet



Strength of larval density-dependence

Conclusions

- Embryonic effects and delayed maturity have minor population-level effects
- Late-larval and post-metamorphic effects have serious consequences
- Maternal and dietary Hg *alone*
minor effects on population dynamics
- Maternal and dietary Hg *together*
↓ adult density
↑ local extinction

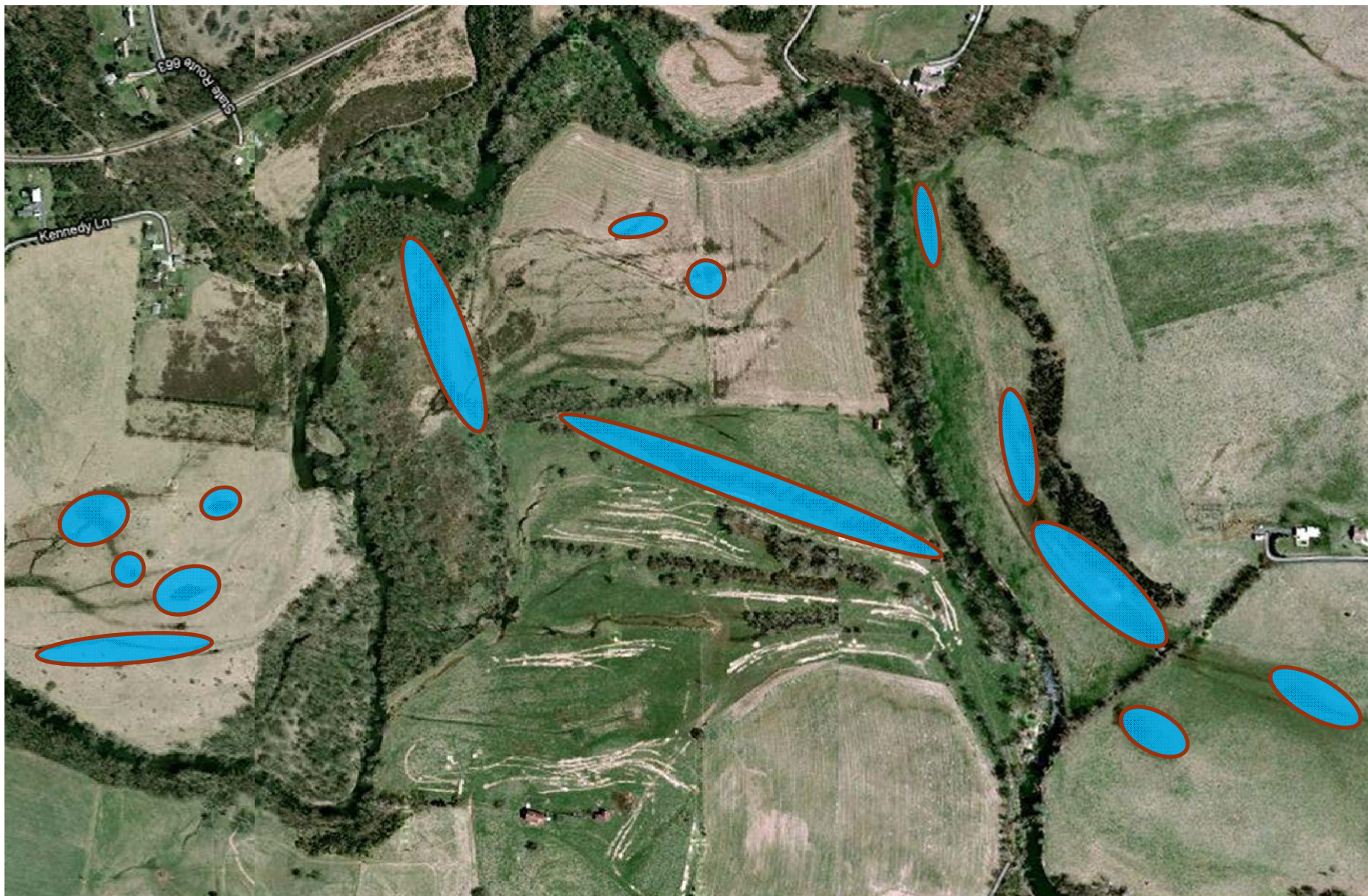


The Path Forward: Implications for Restoration

- Larval stage is a good target for restoration
- Reduce Hg exposure through larval diet
- Residual maternal effects have minor effects on abundance or extinction rate



The Path Forward: Landscape Scale Dynamics

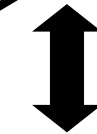




2010- '11 Research Objectives

**Bioaccumulation &
Non-destructive
Techniques**

Blood/Nail



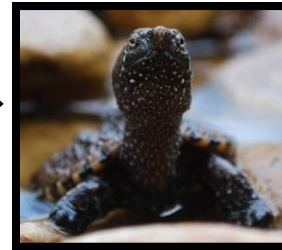
Eggs



Muscle



**Current Exposure
& Food Web Models**

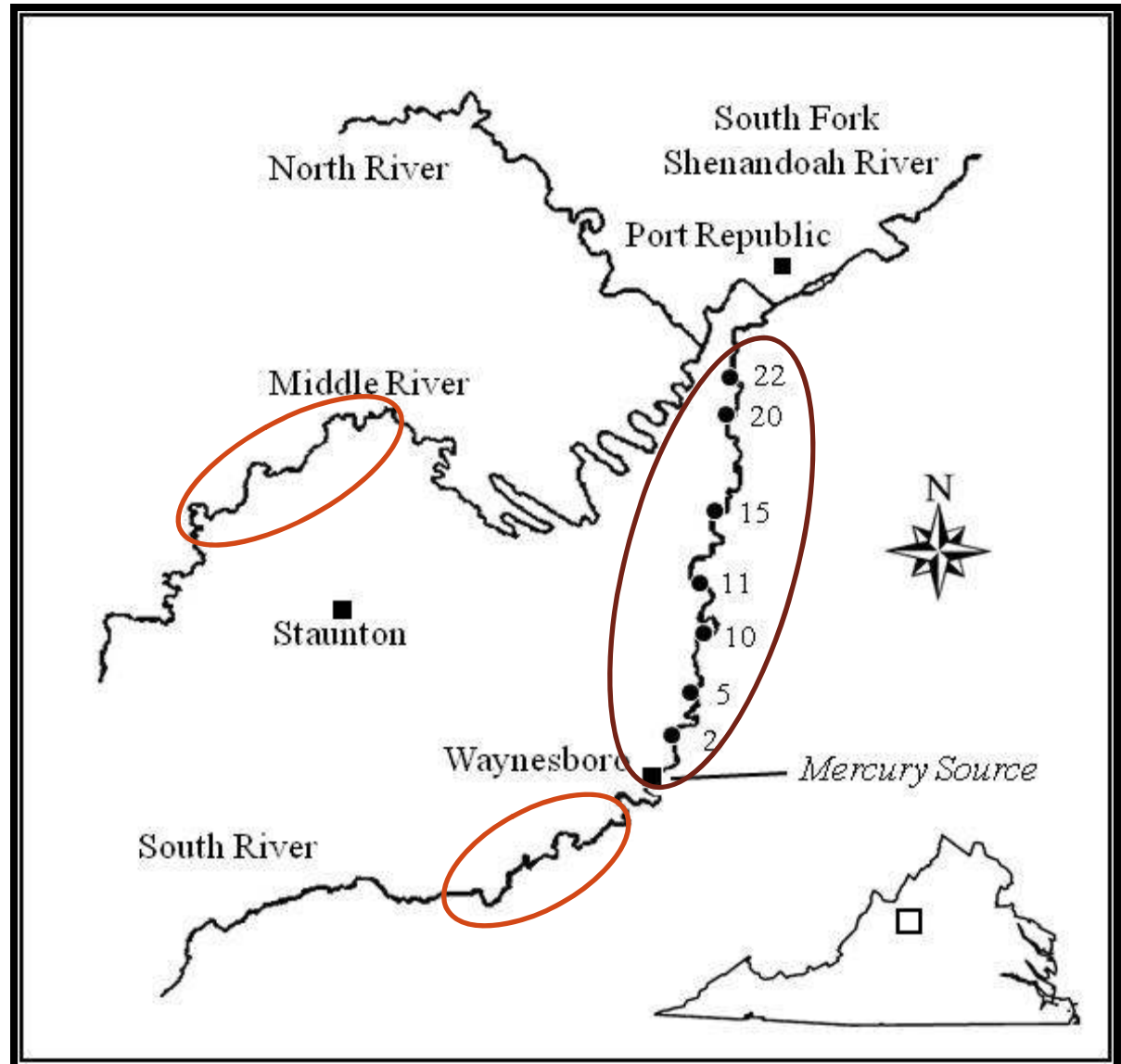


**Reproductive
Effects
& Eco-risk**



**Human
Risk
Assessment
& Eco-risk**

2010- '11 Sampling Sites



Total Captures (2010- '11)

		Female	Gravid	Eggs
	728 →	324	98	2,579
	847 →	360	96	644
	385 →	162	76	298
	161 →	64	13	123

'10-'11
Marked
1,748



'06
Marked
552

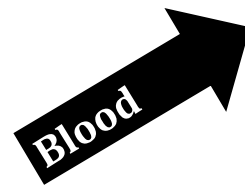


Marked
Hatchlings
~1,200

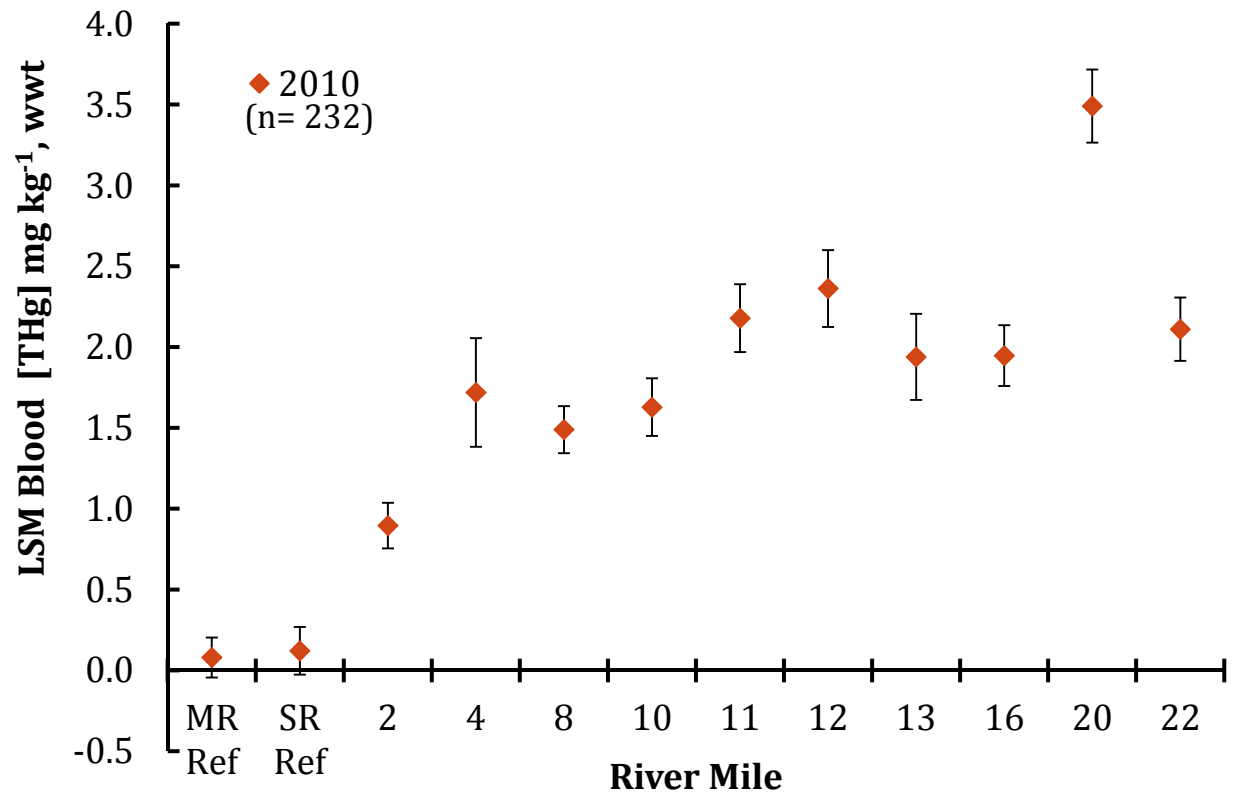


~3,500

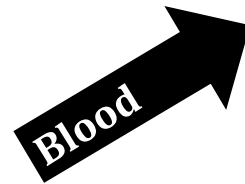
Current Exposure



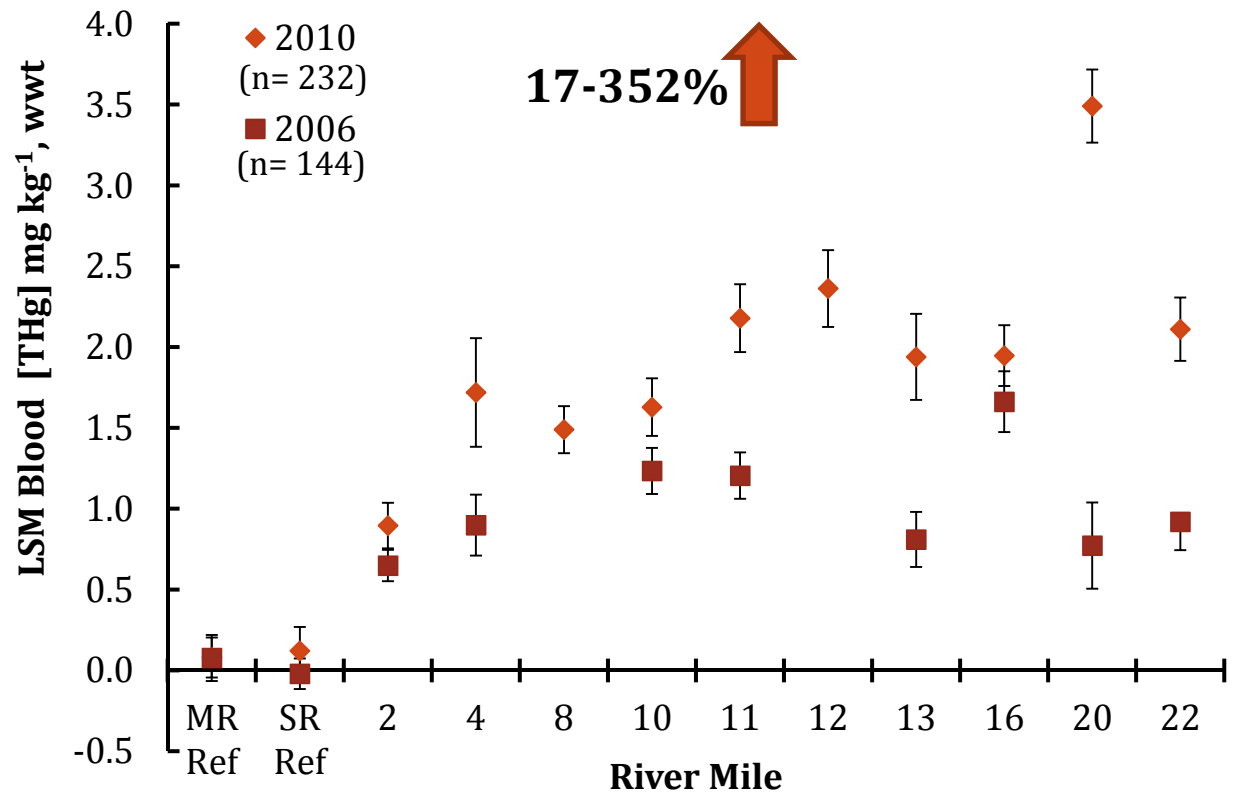
**Current
Exposure in
Adult Snapping
Turtles**



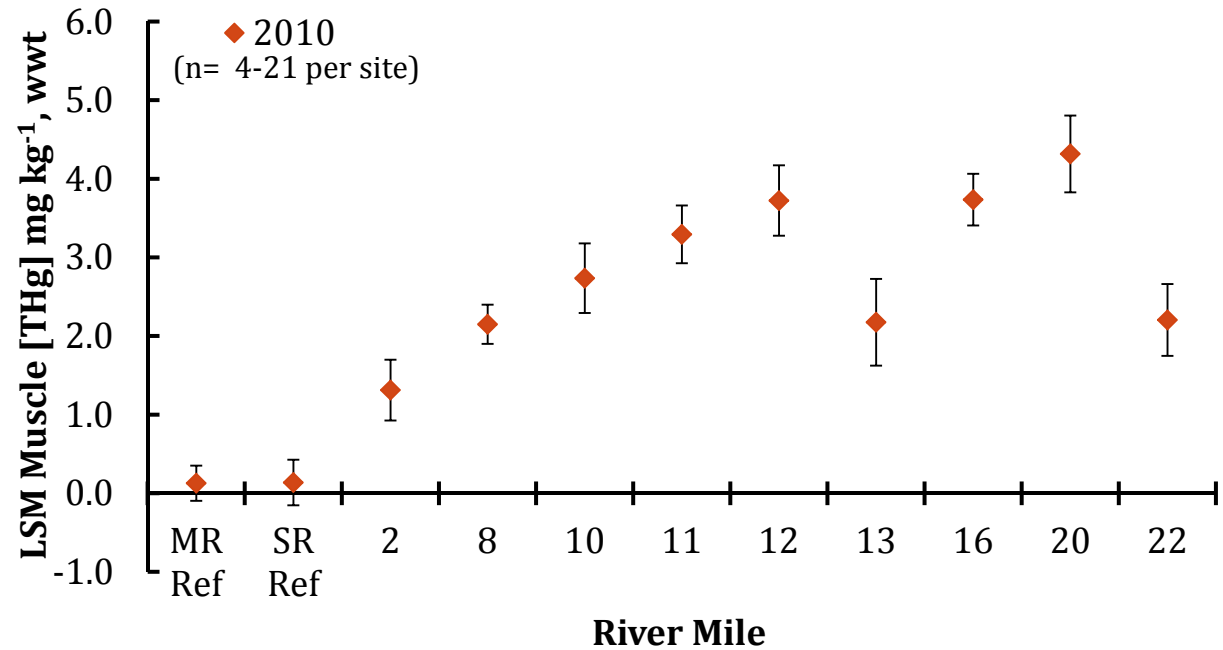
Current Exposure



**Current
Exposure in
Adult Snapping
Turtles**

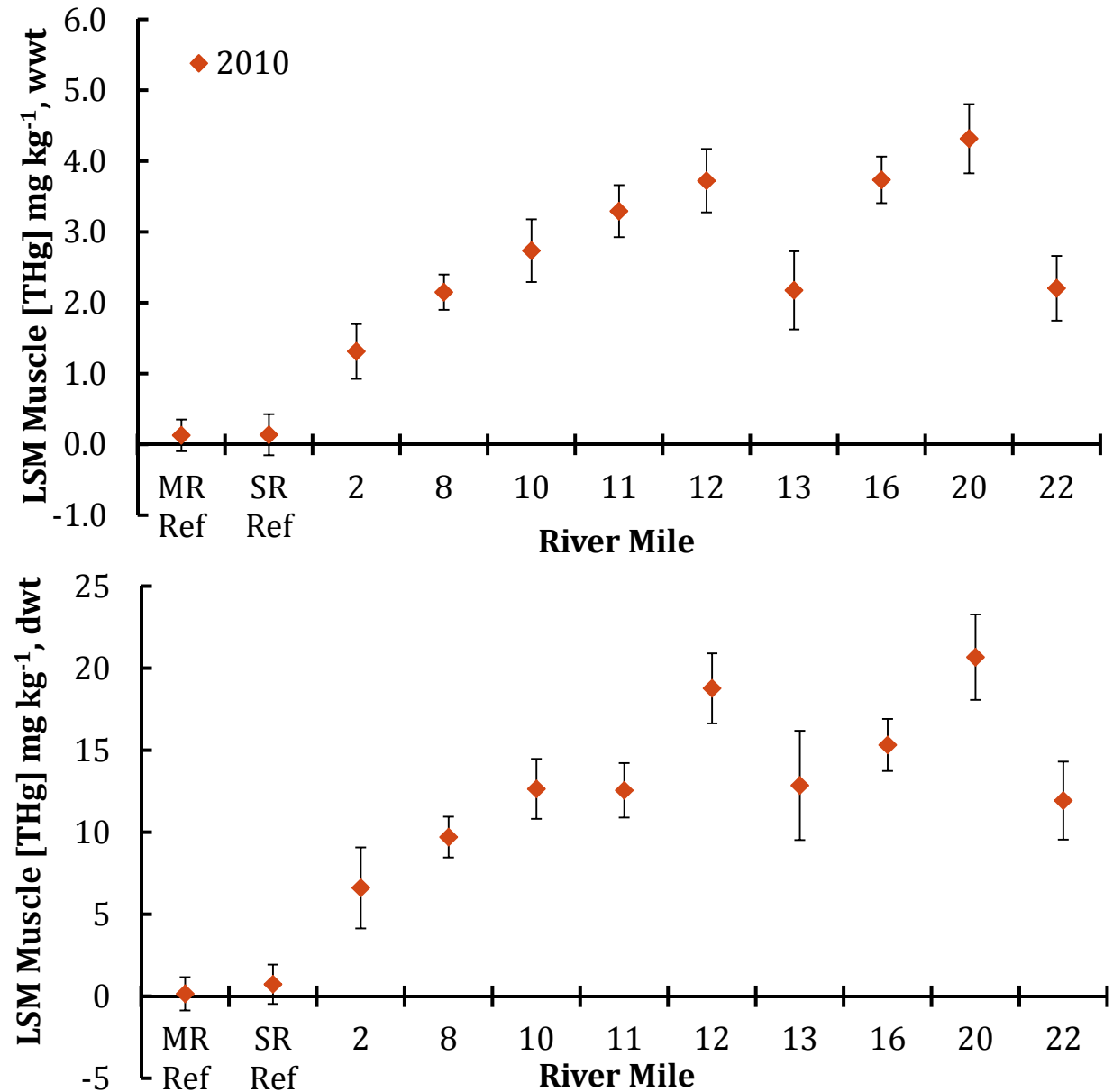


Spatial Patterns in Bioaccumulation

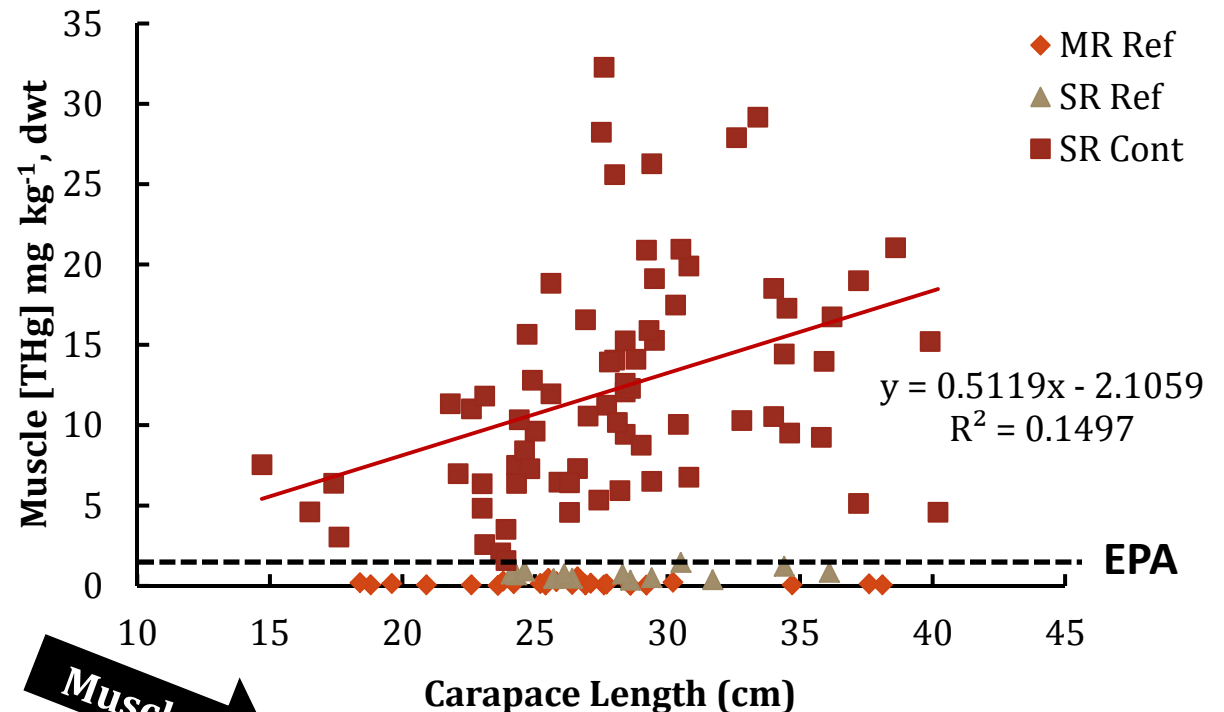


**Adult Bioaccumulation
& Human Exposure?**

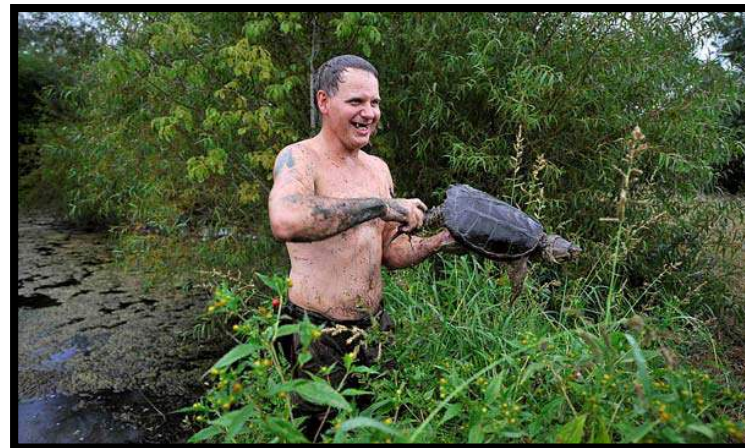
Spatial Patterns in Bioaccumulation



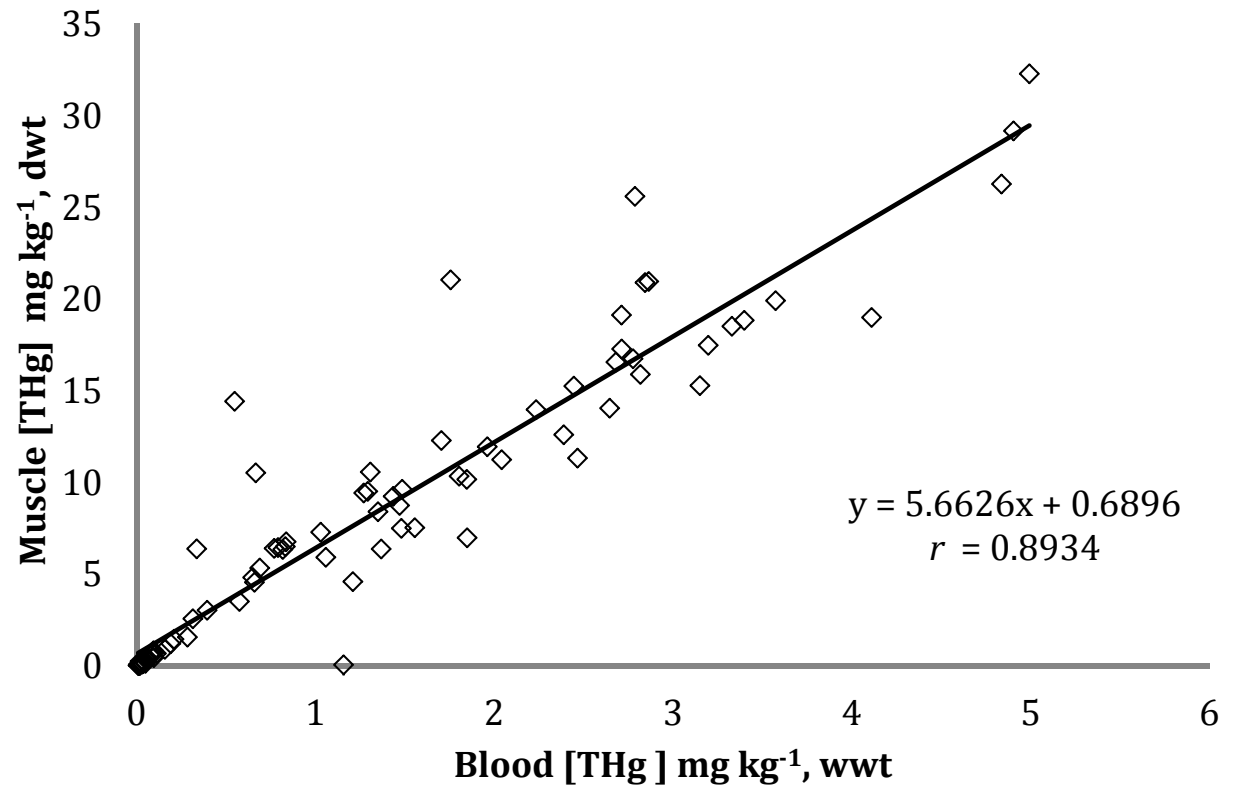
Demographic Patterns in Bioaccumulation



Human Exposure?



Non-destructive Sampling



**Blood serves as great non-destructive
parameter for monitoring
accumulation!**

Maternal Transfer



Eggs

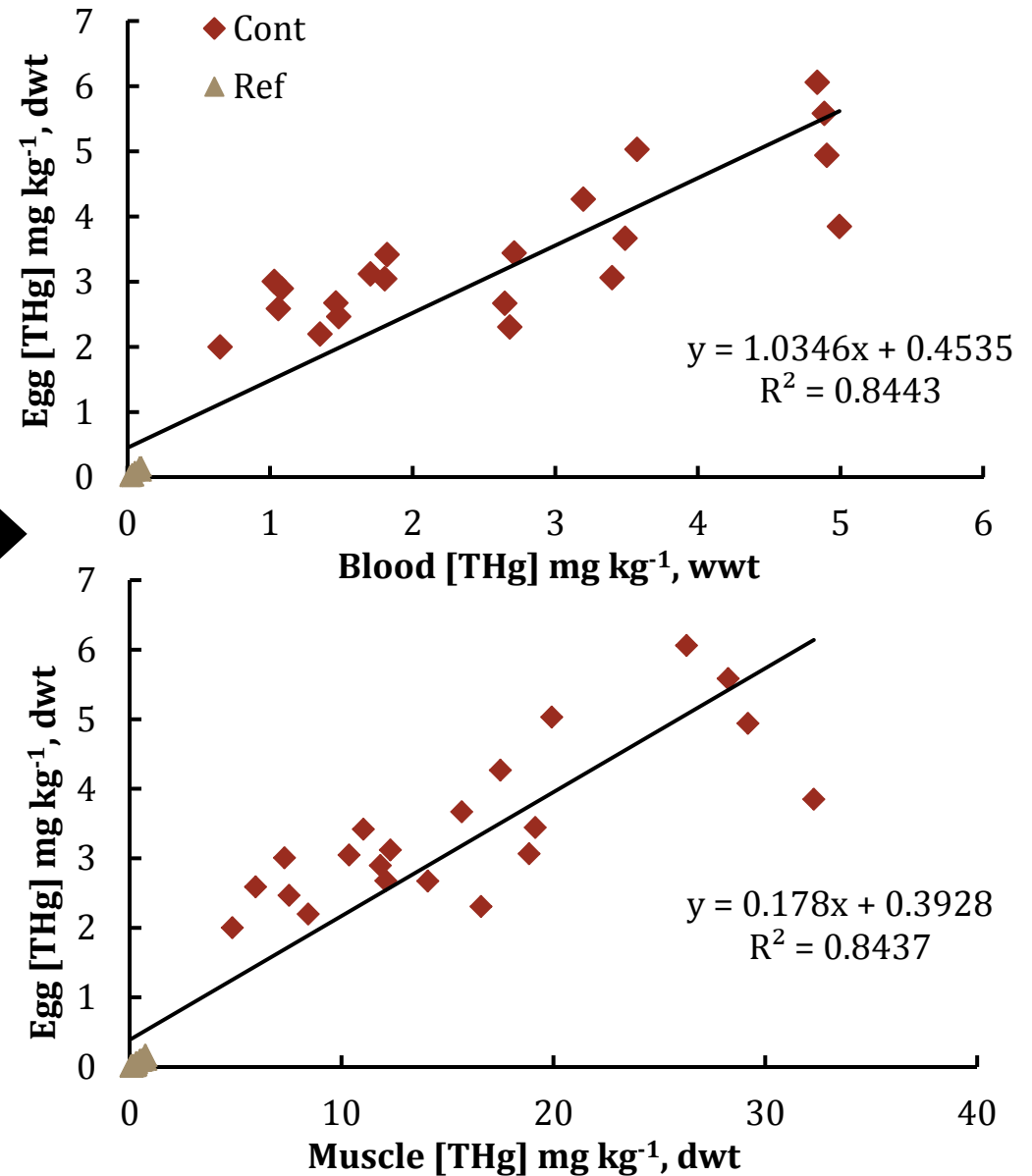


**Embryo Exposure
Predator Exposure**

Maternal Transfer



Eggs



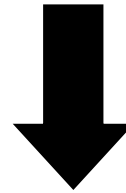
Research Objectives in Progress



Eggs



Embryo Exposure



**Relationships between Hg &
Hatching Success,
Malformation Rates,
& Overwintering Survival??**



Biomonitoring

❖ Human Health

- Aid in assessing risk

❖ Wildlife Health

- Implications for predatory wildlife

❖ Turtle Health

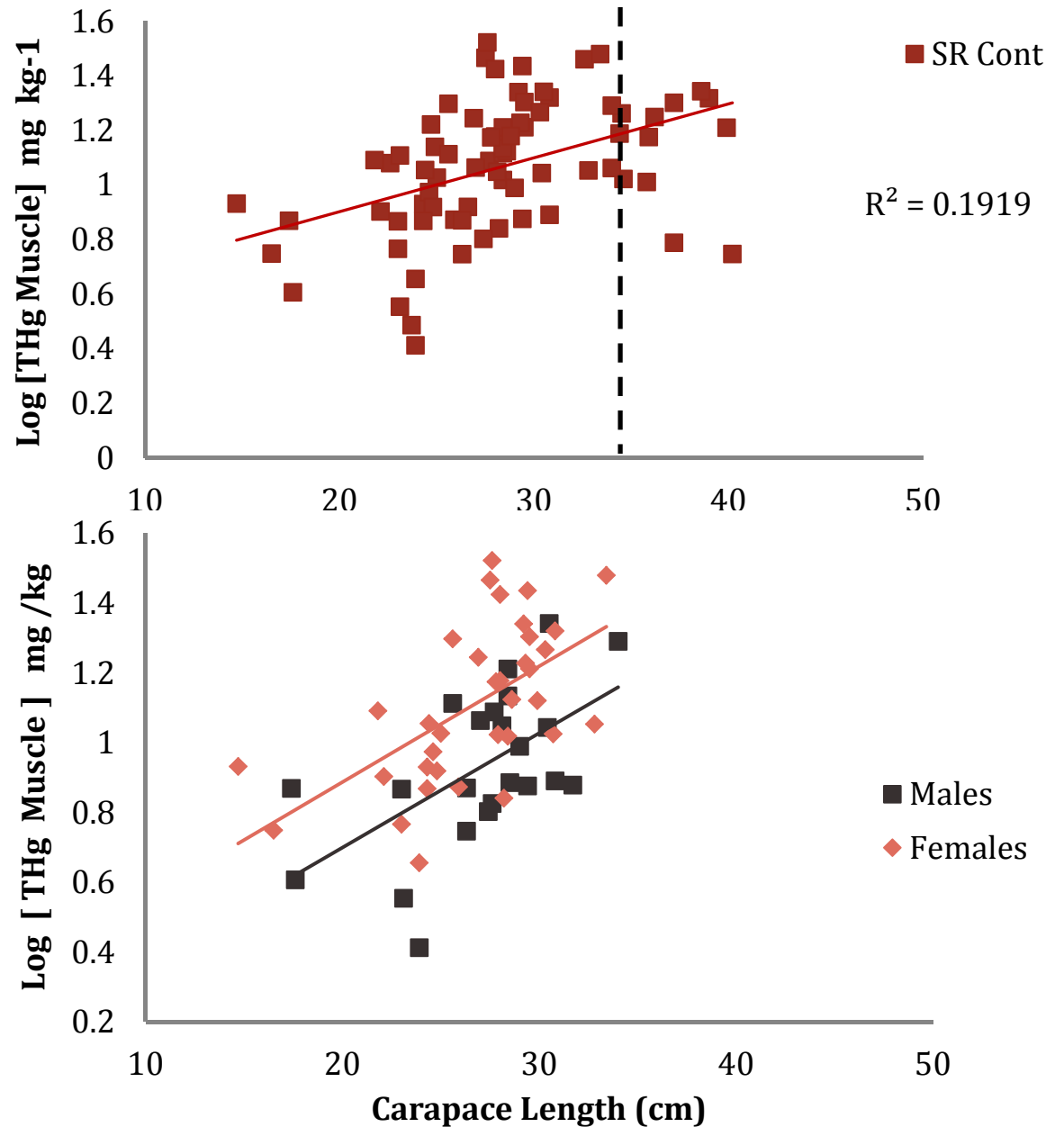
- Current exposure
- Reproductive effects



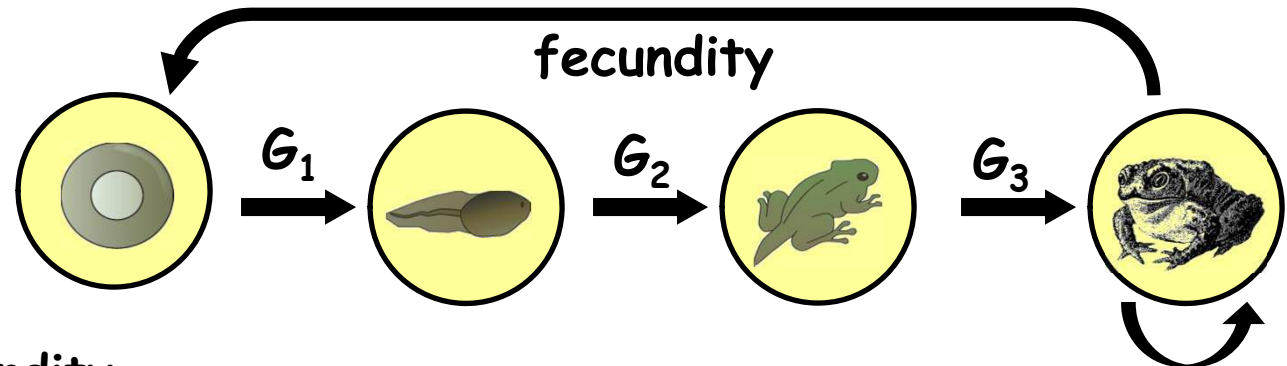
Riverfest 2011



Muscle Bioaccumulation



Individual-Level Effects

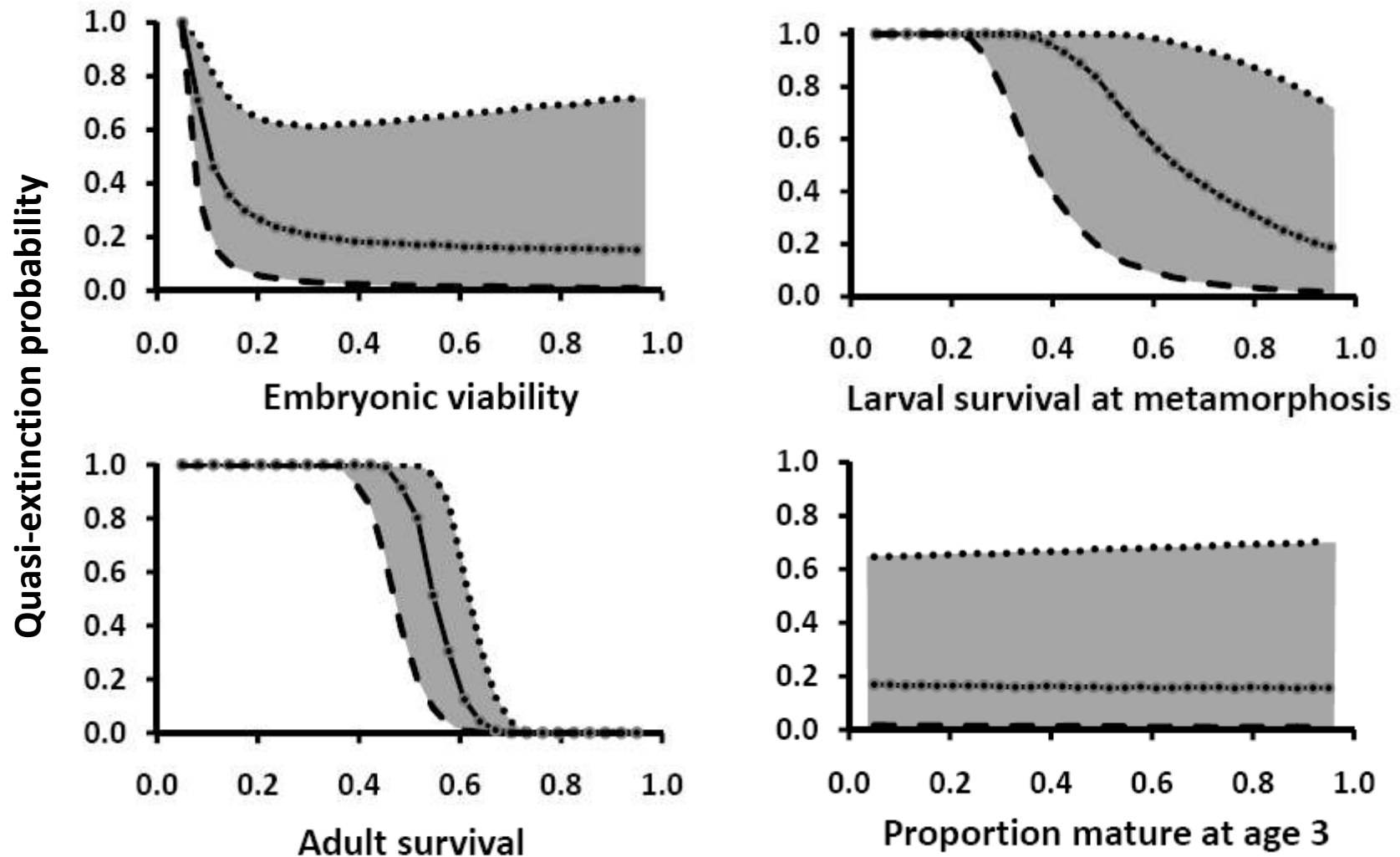


- No effects on fecundity
- Dietary Hg alone = minor growth effects
- Maternal Hg alone = growth effects = delayed maturity
- Maternal + Diet Hg + limited food = **↓50% larval survival**

	Clutch Size	Embryonic Viability	Larval Growth	Larval Survival	Juvenile Survival	Juvenile Growth
Maternal	NE	-4% to -39% (annual variation)	-18% (ample food)	+16% to -17% (annual variation)	NE	-8%
Larval Diet	NA	NA	-26% (limited food)	NE	NE	NE
Maternal + Larval Diet	NE	-4% to -39% (annual variation)	-20% to -27% (food-dependent)	-50% (limited food)	NE	-8%

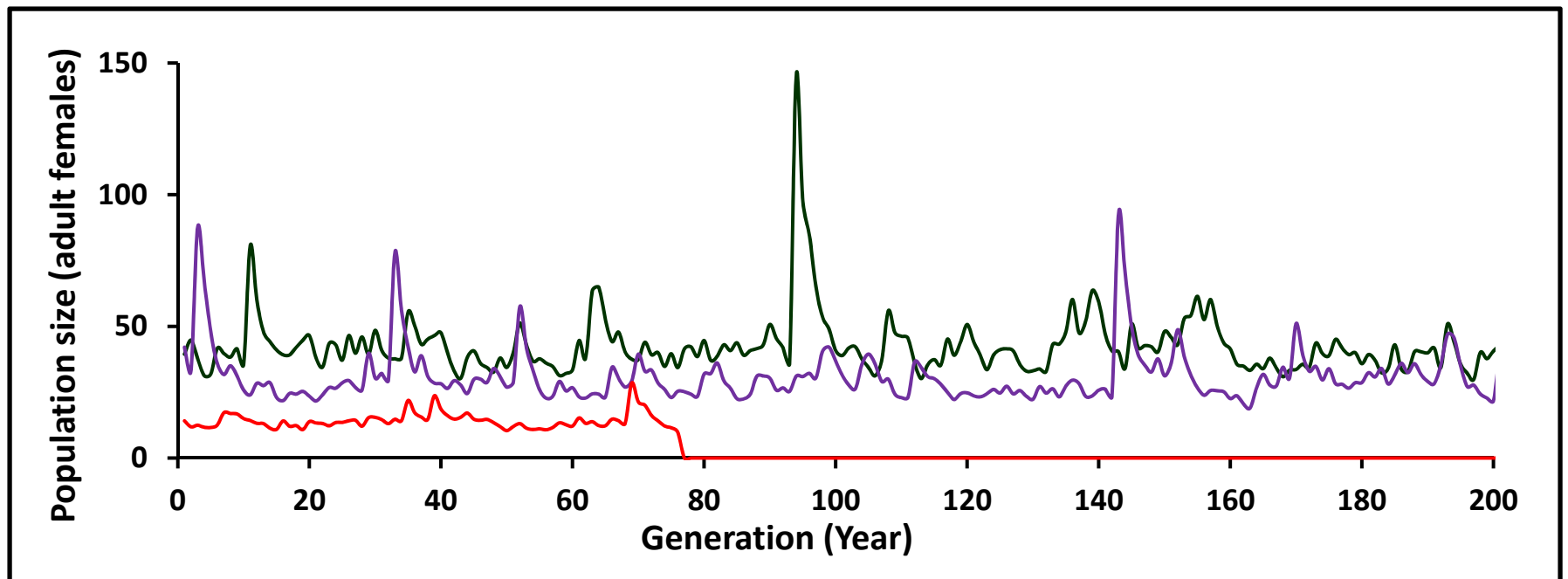
NE = no significant effect; NA = not a valid exposure route

Results: Model Sensitivity

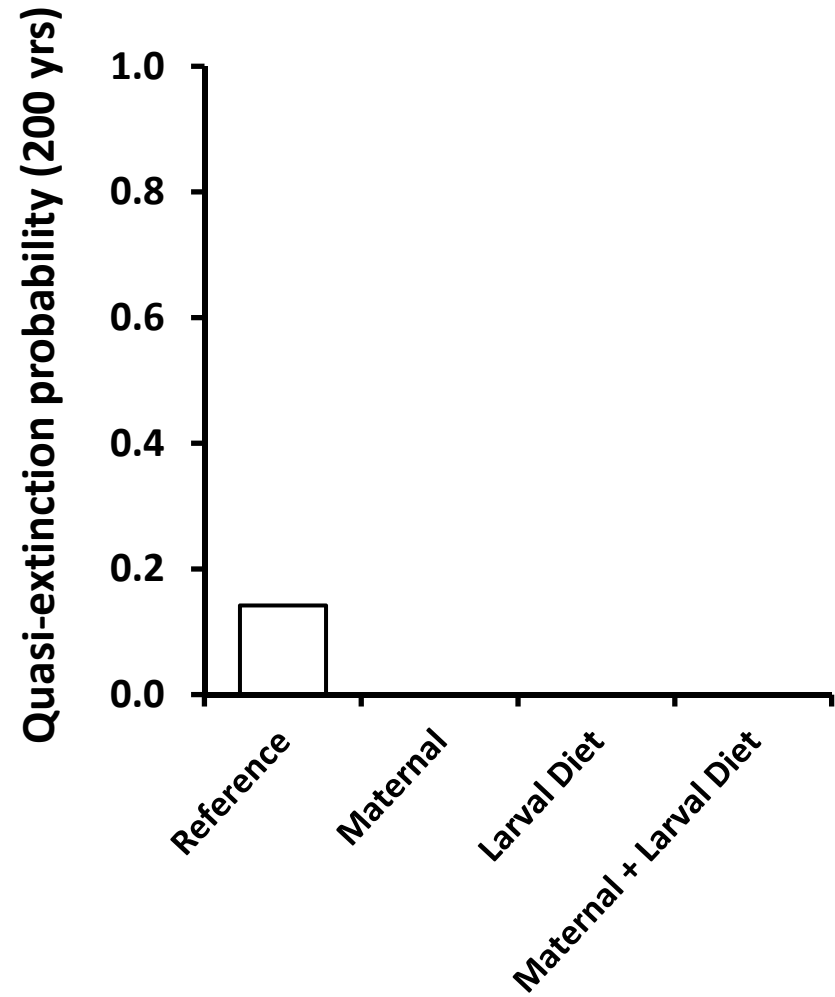
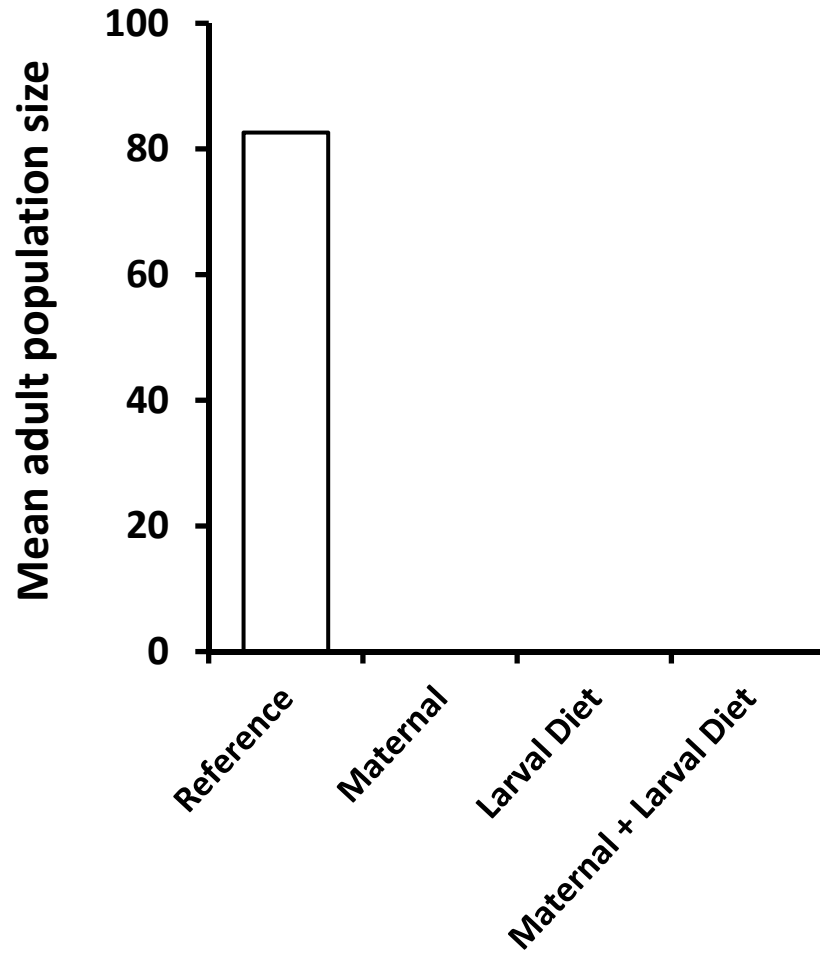


Simulation Analyses

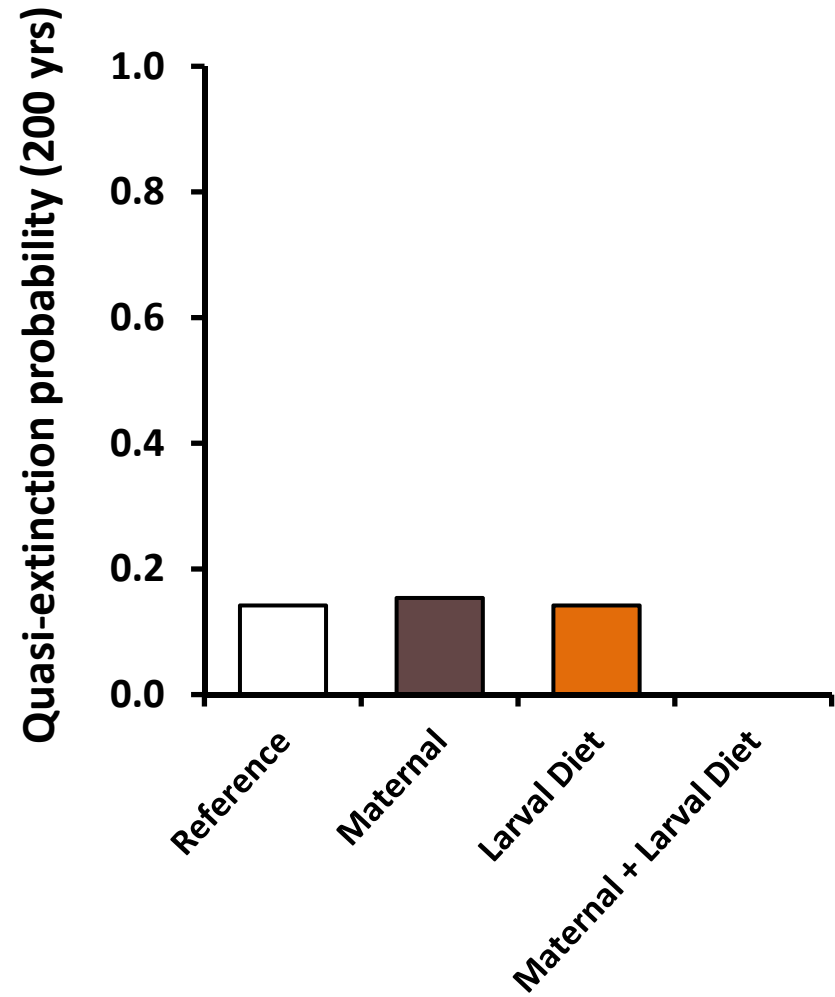
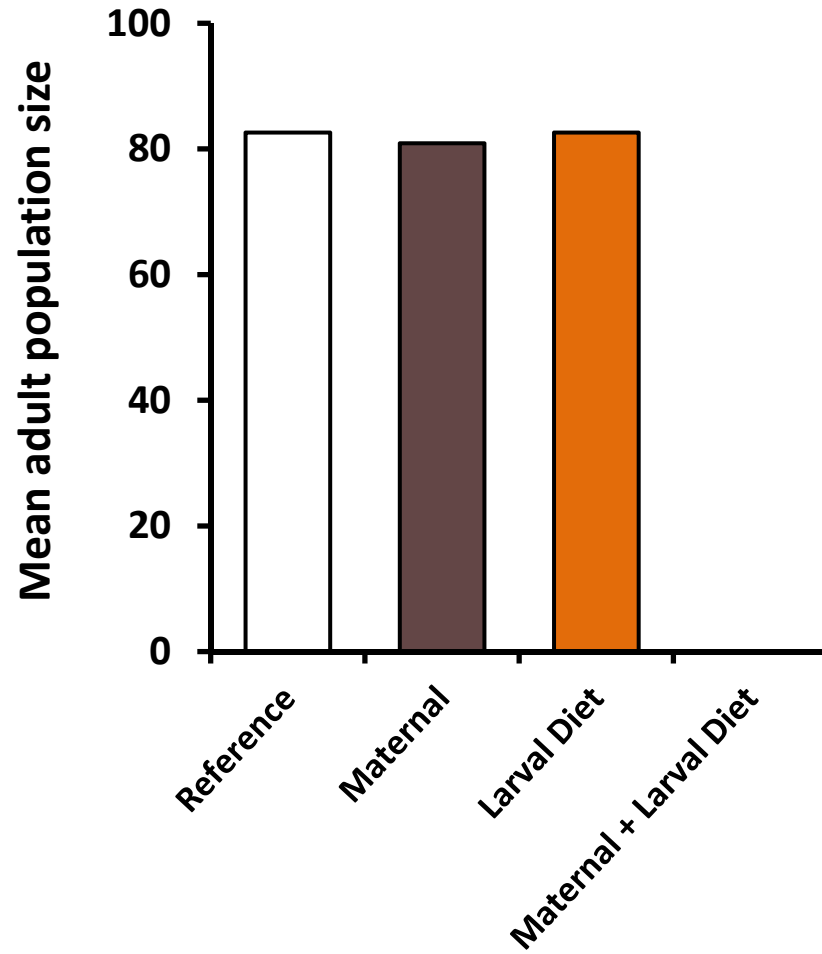
$$\begin{bmatrix} J1 \\ J2 \\ A3 \\ A \end{bmatrix}_{t+1} = \begin{bmatrix} 0 & 0 & (\phi_{A3} f \sigma_E)(\sigma_{L,t})(\sigma_M) & (f \sigma_E)(\sigma_{L,t})(\sigma_M) \\ \sigma_{J2} & 0 & 0 & 0 \\ 0 & \sigma_{J3} & 0 & 0 \\ 0 & 0 & \sigma_{A3} & \sigma_A \end{bmatrix} \times \begin{bmatrix} J1 \\ J2 \\ A3 \\ A \end{bmatrix}_t$$



Results: Simulation Analyses



Results: Simulation Analyses



Results: Simulation Analyses

