Using Individual Life History Modeling To Inform Management

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Outline

Introduction and Motivation

Modeling Approach

Application To The Carmel River

Results

Conclusions

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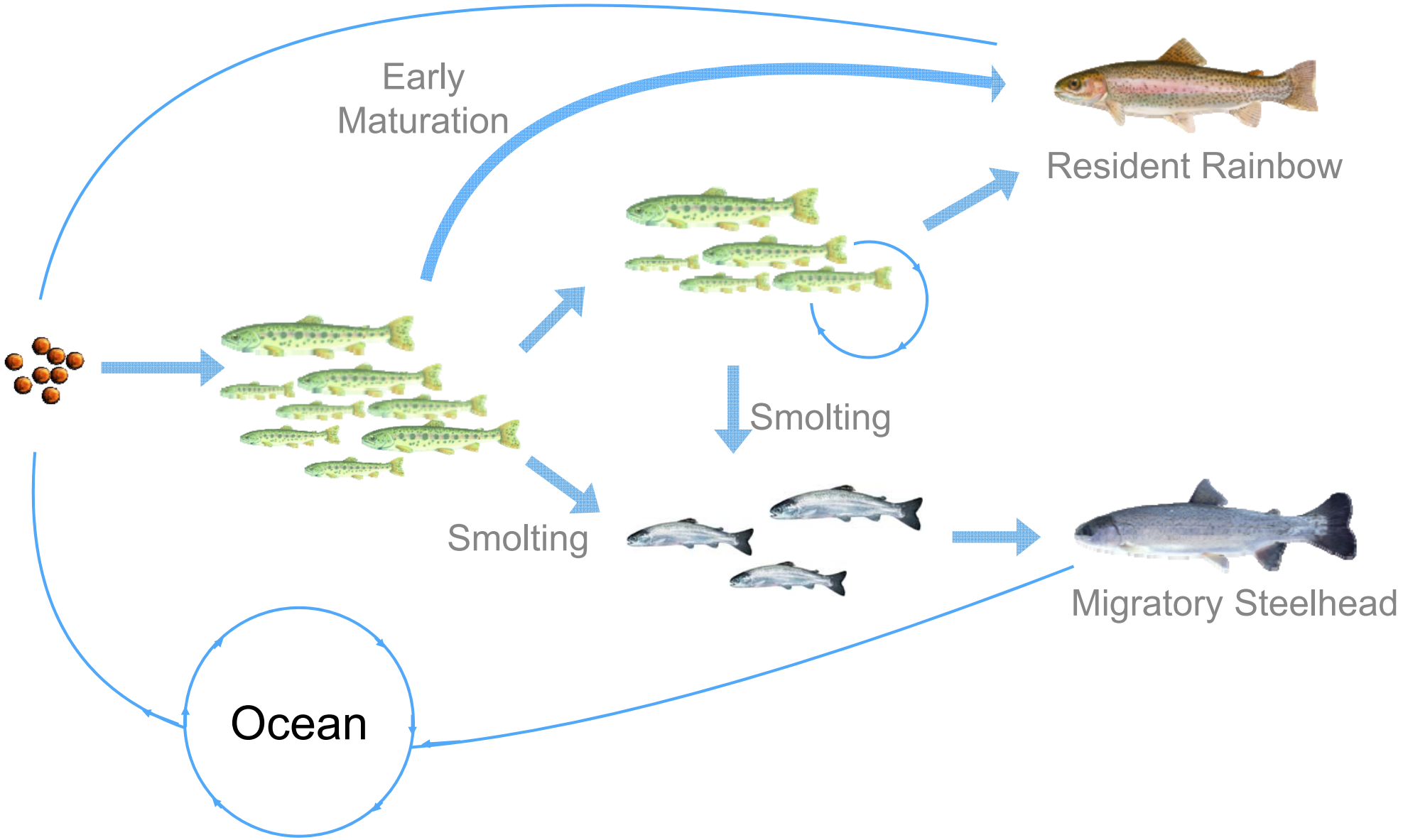
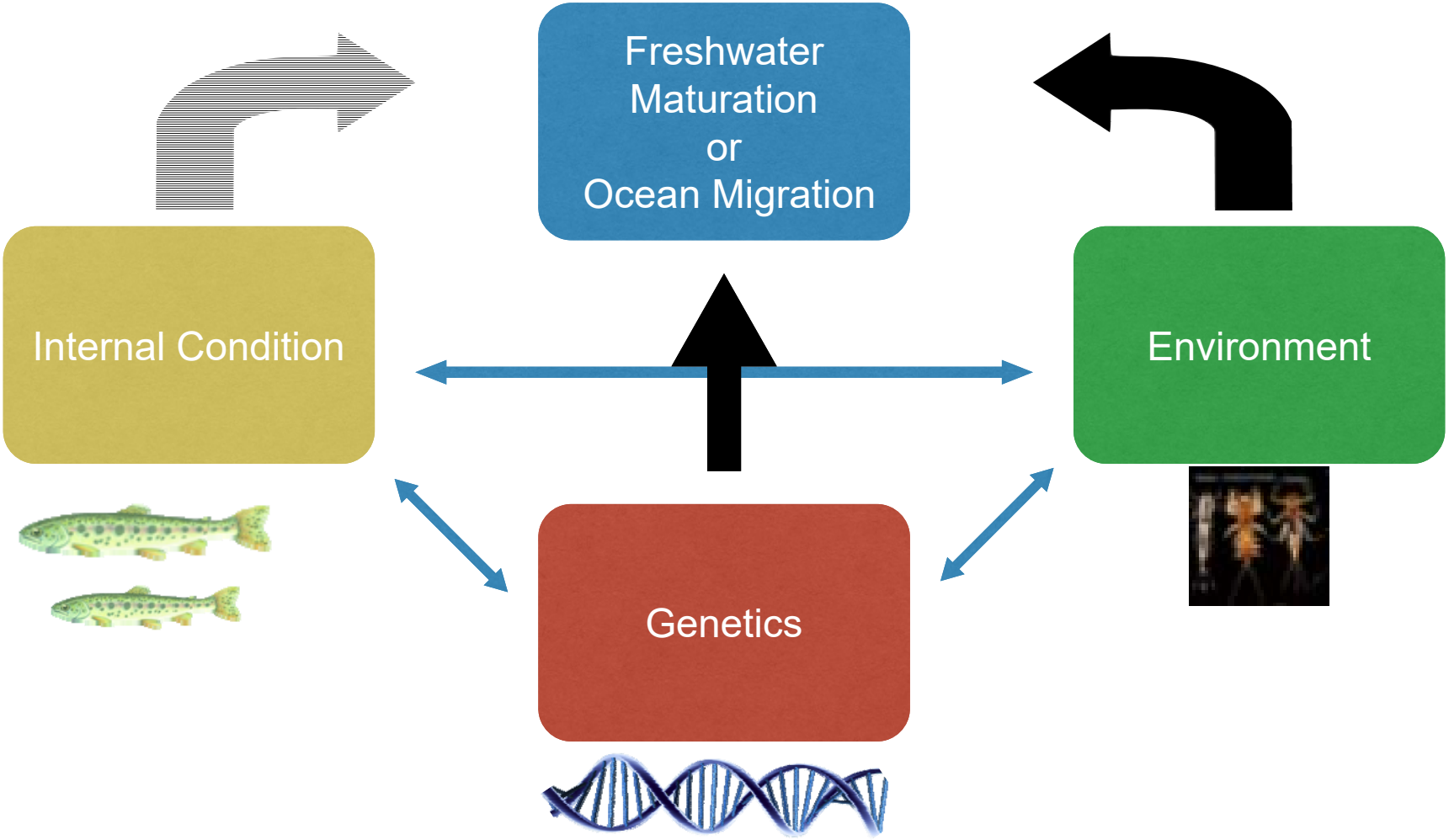
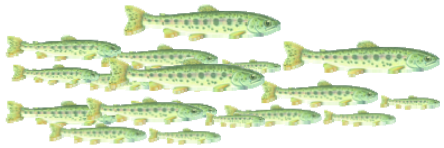
Steelhead Life Cycle



A Complex Decisions



The Question



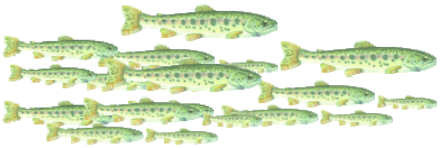
Juveniles

Resident Rainbow

Migratory Steelhead

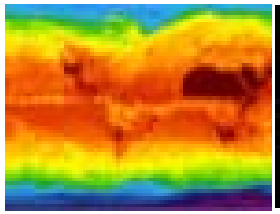
The Question

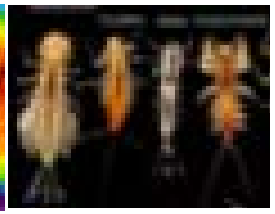
Management



Juveniles

Growth



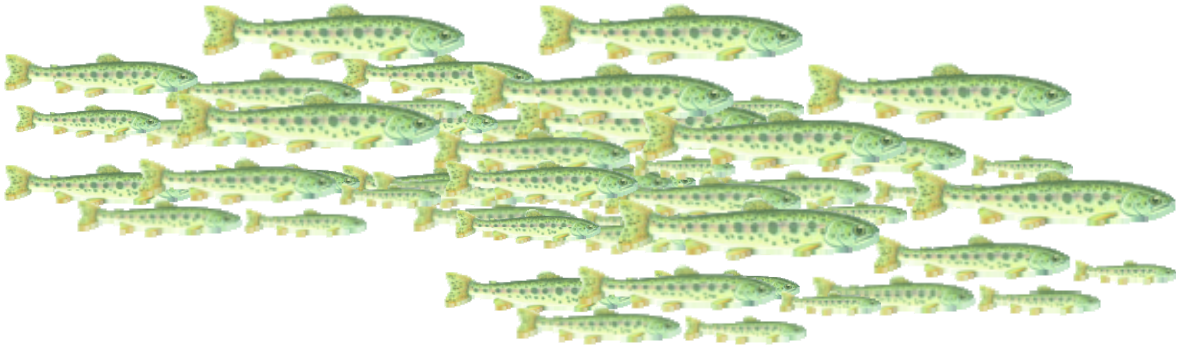


Temperature Food

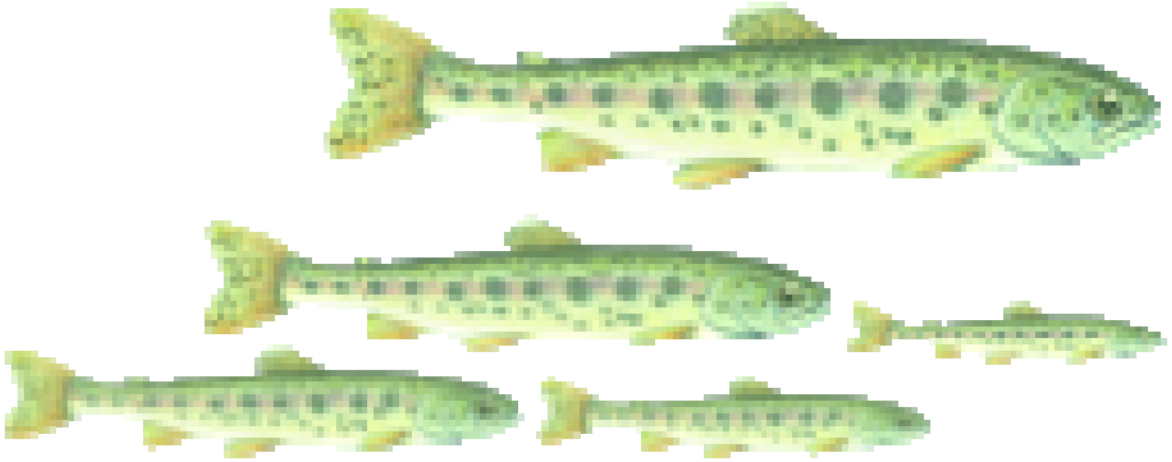
Resident Rainbow

Migratory Steelhead

What Is More Important?



Or



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Modeling Steelhead Life History

Growth

20 mm

350 mm

Smolting

Ocean Survival

+

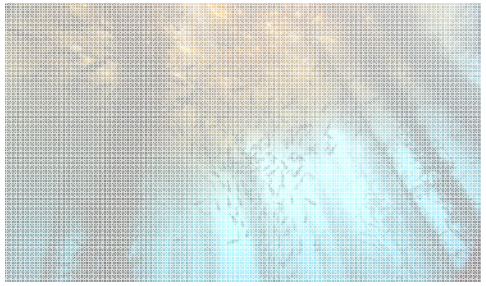
Modeling Steelhead Life History

Growth

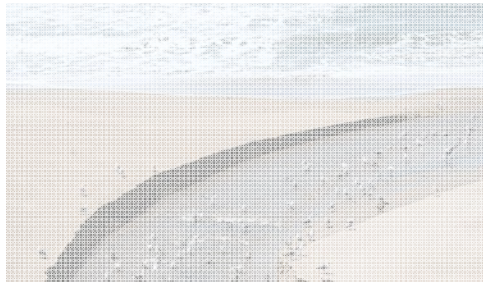
20 mm

350 mm

Smolting



Ocean Survival



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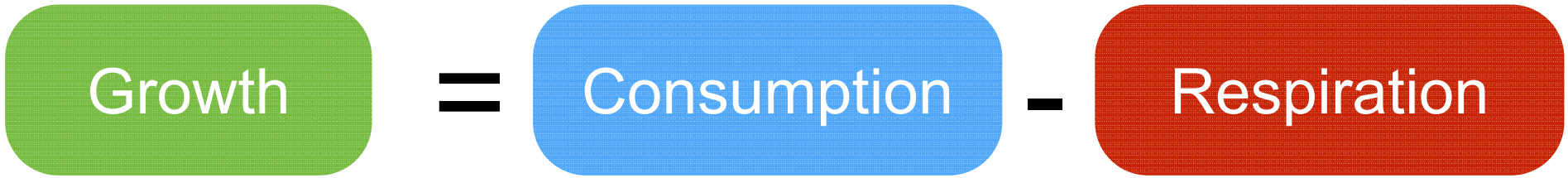
Bioenergetics Modeling



Traditional Bioenergetics Modeling

Growth = Consumption - Respiration

$$\frac{dW}{dt} = fc\Phi_c(T)W(t)^{0.86} - \alpha\Phi_m W(t)$$

f = relative energy density of food
c = maximum consumption of a 1g fish
α = weight specific catabolic cost
$\Phi_c(T)$ = temperature dependence of consumption
$\Phi_m(T)$ = temperature dependence of respiration

Individuals Compete for Resources

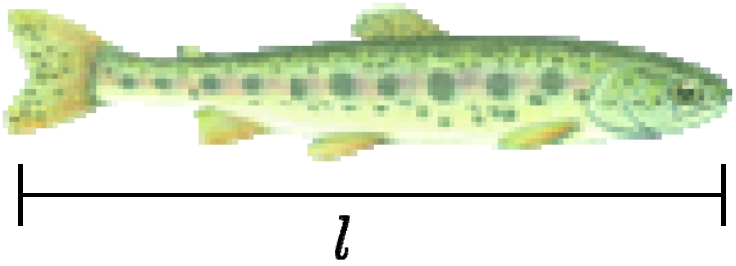
Bioenergetics Modeling With Competition

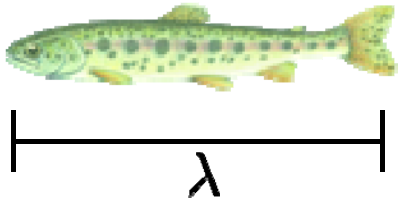
Growth = Consumption - Respiration

$$\frac{dW_i}{dt} = fc\Phi_c(T)A(t,l)W_i(t)^{0.86} - \alpha\Phi_m W_i(t)$$

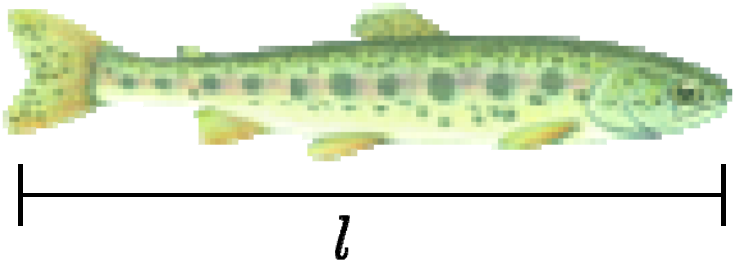
f = relative energy density of food
c = maximum consumption of a 1g fish
α = weight specific catabolic cost
$\Phi_c(T)$ = temperature dependence of consumption
$\Phi_m(T)$ = temperature dependence of respiration
$A(t,l)$ = individual access to resources

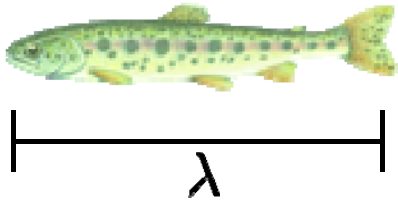
Competition





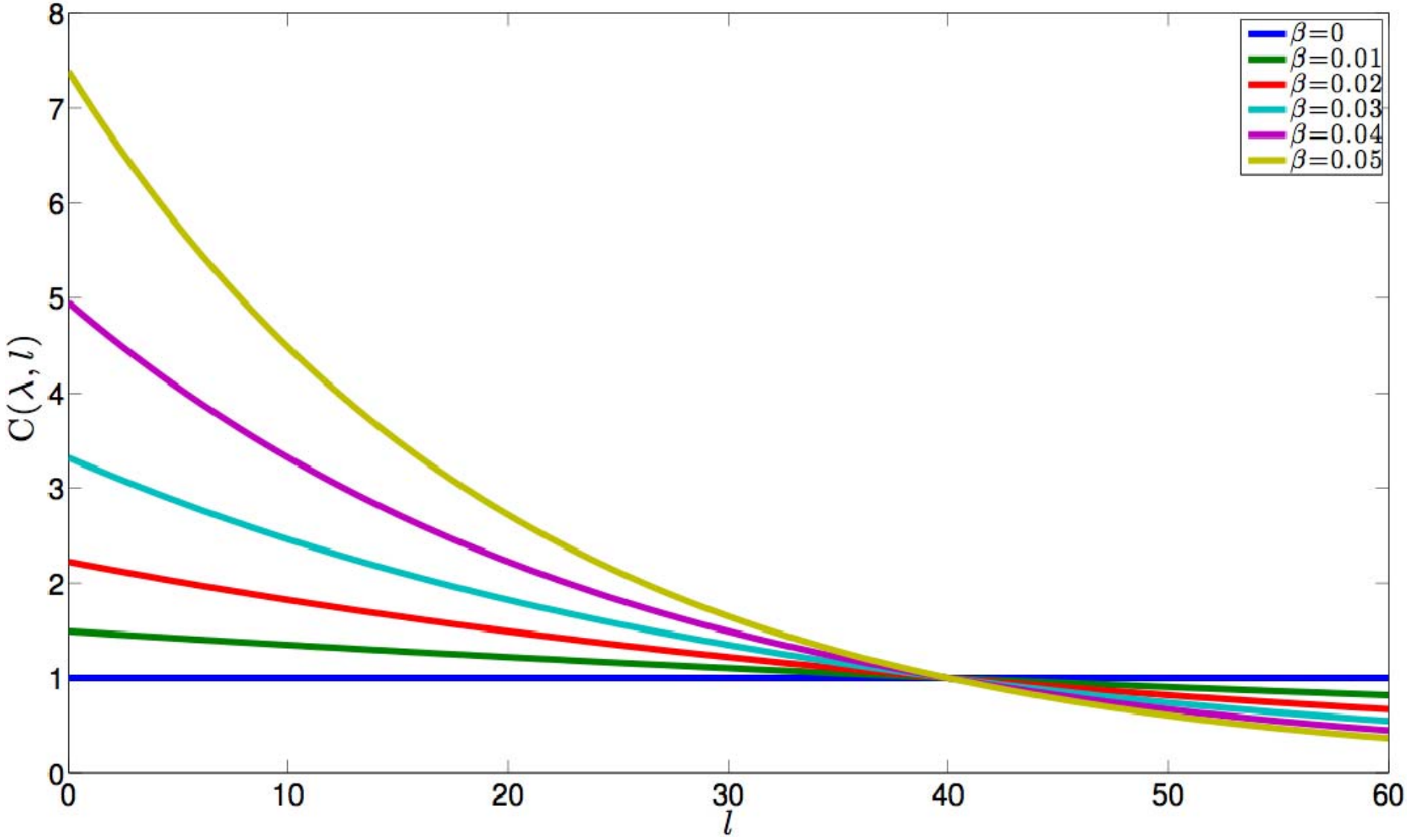
Competition

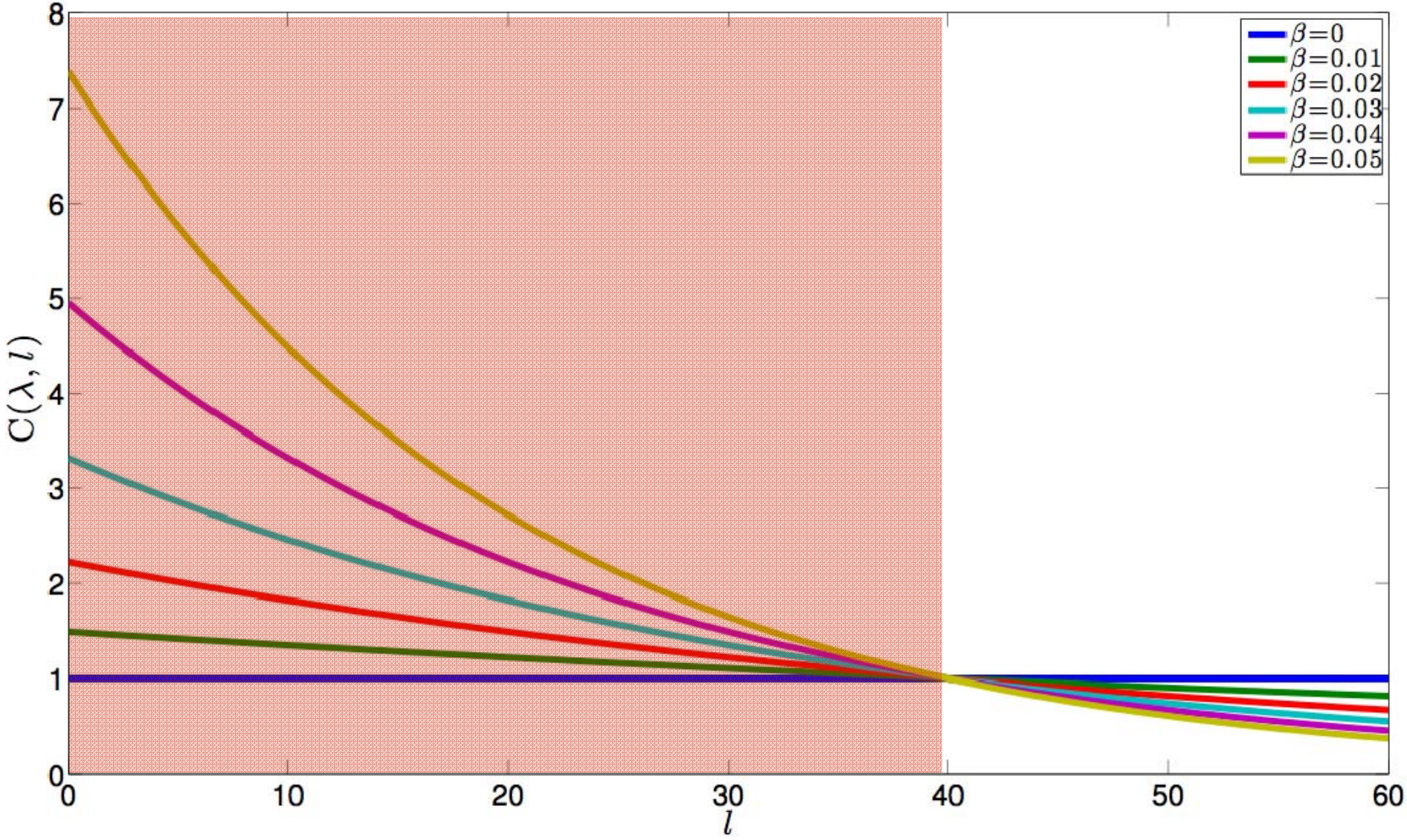




$$C(l,\lambda) = e^{\beta(\lambda - l)}$$

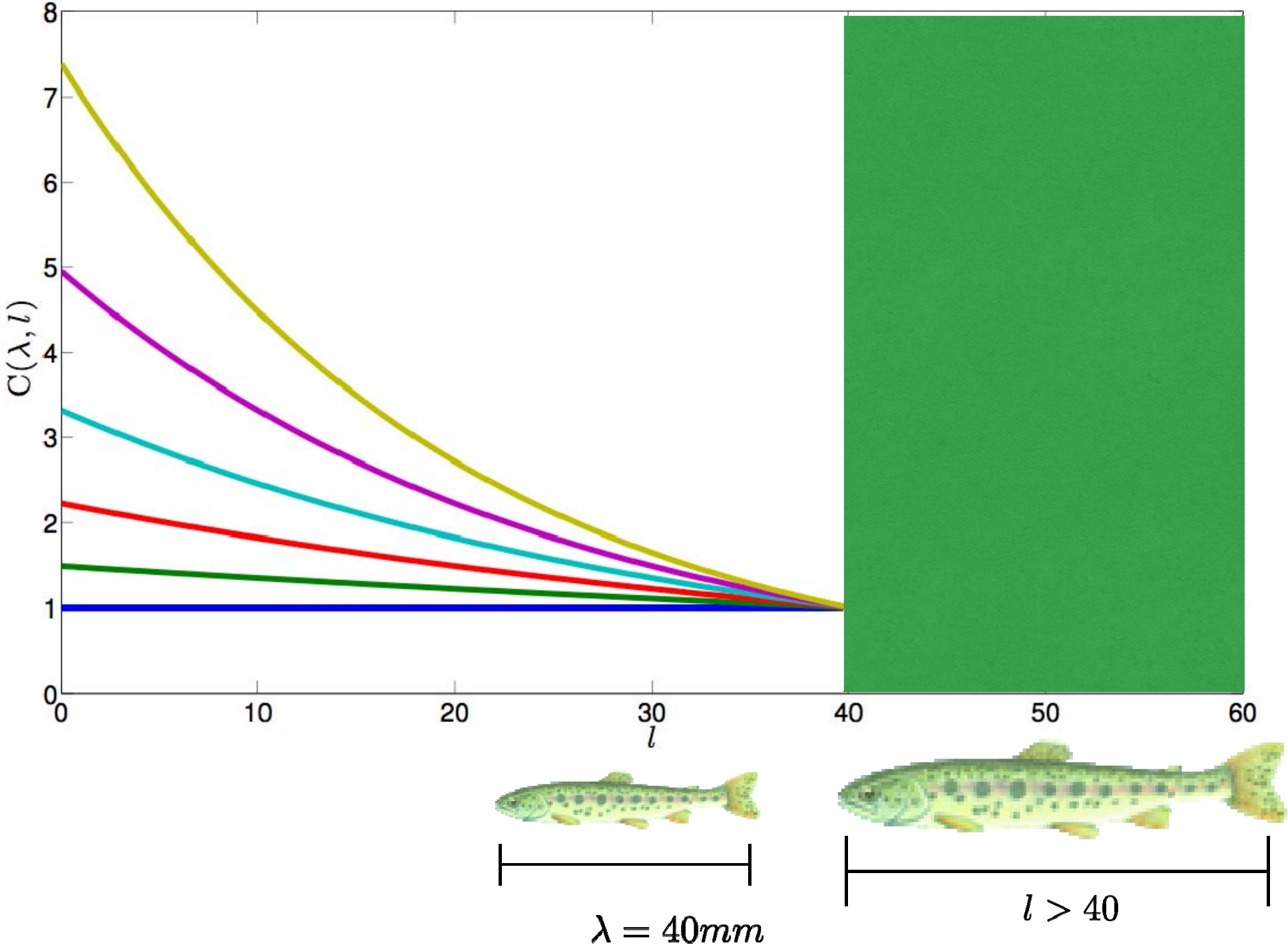
$$C(l, \lambda) = e^{\beta(\lambda - l)}$$



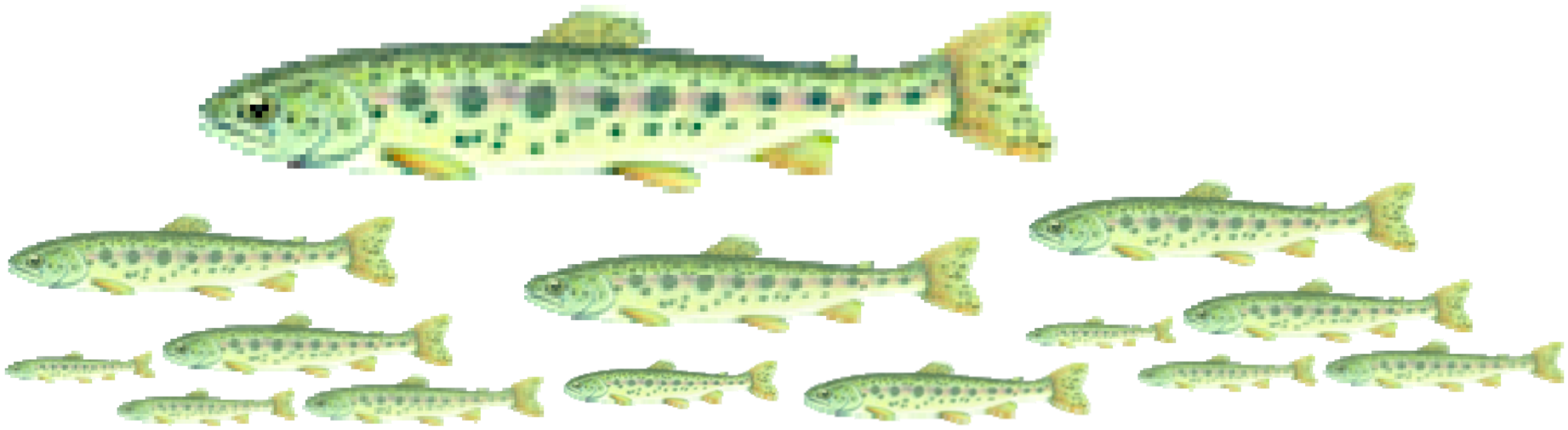


$l < 40$

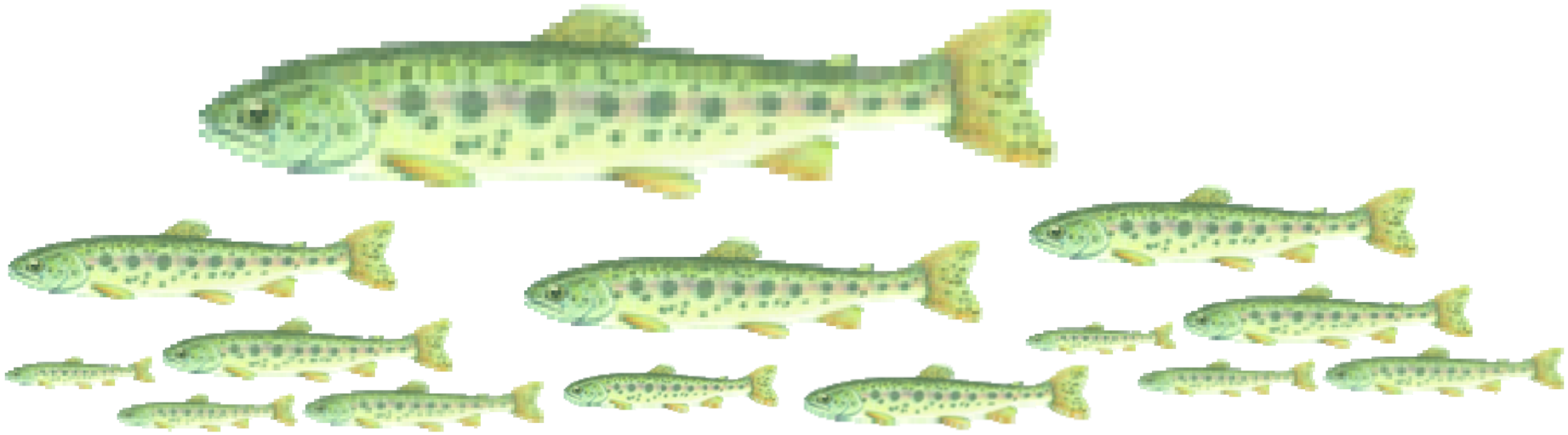
$\lambda = 40mm$


8
7
6
5
4
3
2
1
0
$C(\lambda, l)$
0
10
20
30
40
50
60
l
$\lambda = 40mm$
$l > 40$

Entire Population

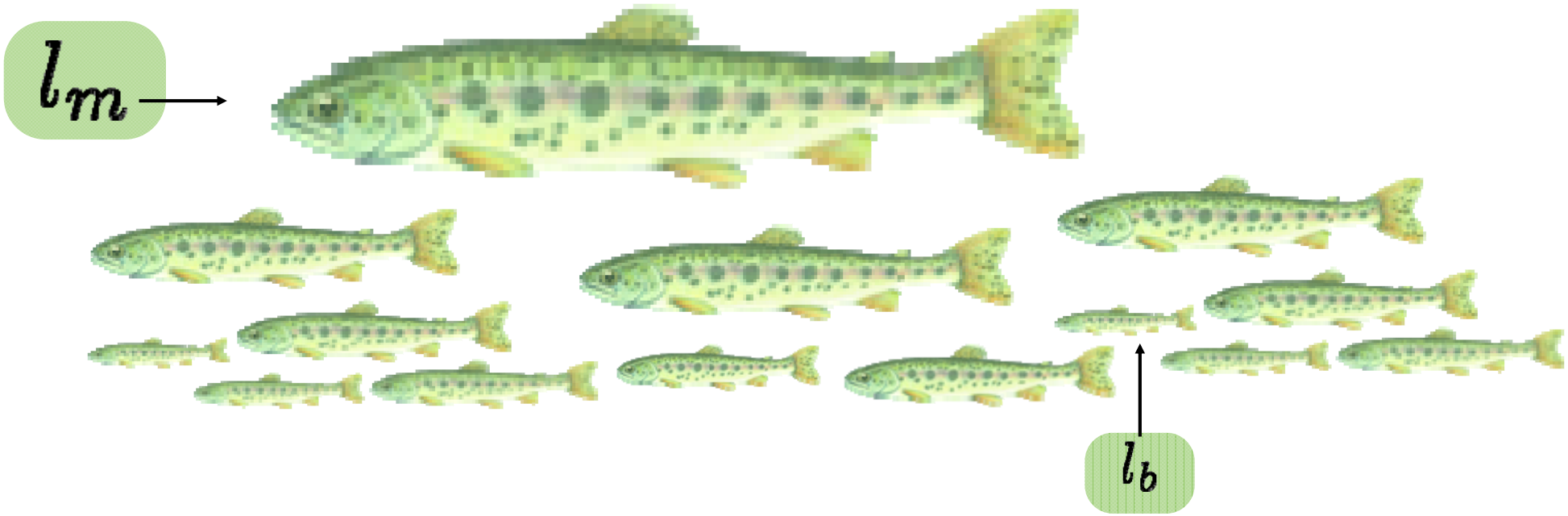


Effective Population Density



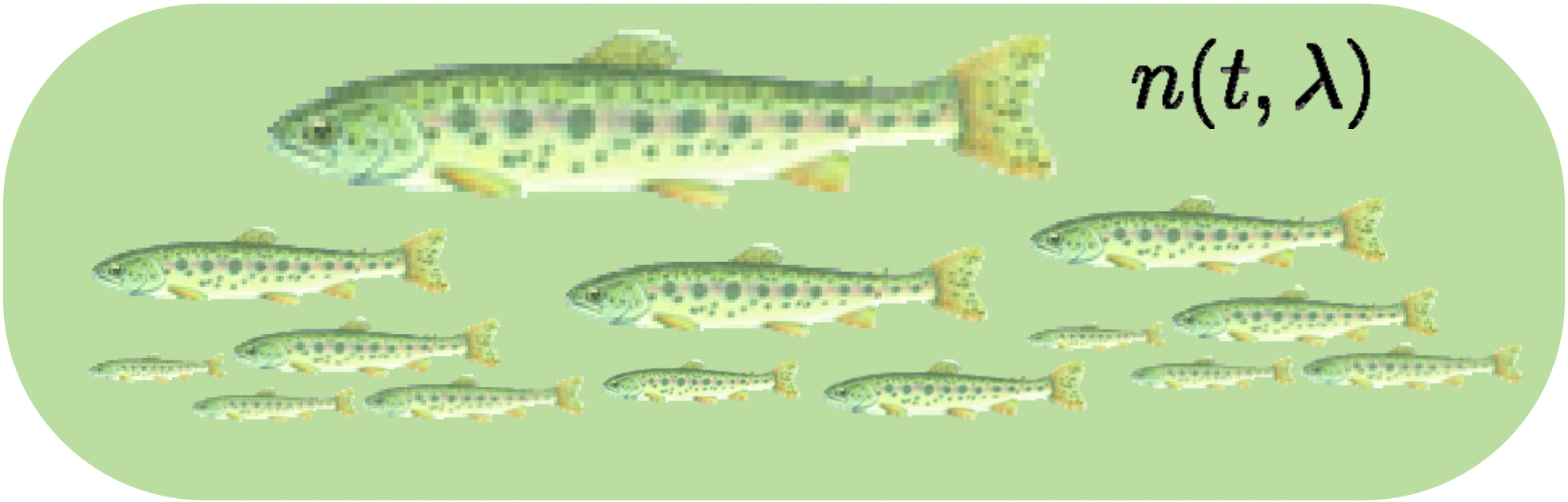
$$\eta(t,l) = \int_{l_b}^{l_m} C(l,\lambda) n(t,\lambda) \lambda^2 d\lambda$$

Entire Population



$$\eta(t,l) = \int_{l_b}^{l_m} C(l,\lambda) n(t,\lambda) \lambda^2 d\lambda$$

Entire Population



$$\eta(t, l) = \int_{l_b}^{l_m} C(l, \lambda) n(t, \lambda) \lambda^2 d\lambda$$

Access to Resources

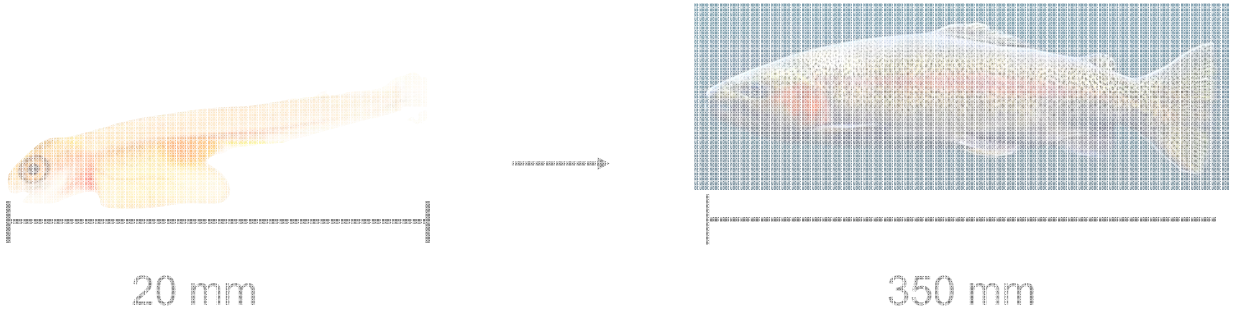
$$A(t,l) = \frac{\eta_H}{\eta_H + \eta(t,l)}$$

$$\eta(t,l) >>> \eta_H \quad \Longrightarrow \quad A(t,l) \sim 0$$

$$\eta(t,l) <<< \eta_H \quad \Longrightarrow \quad A(t,l) \sim 1$$

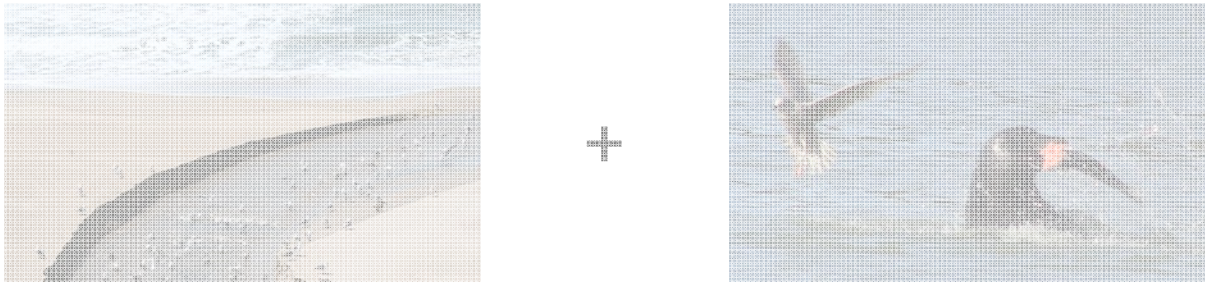
Modeling Steelhead Life History

Growth

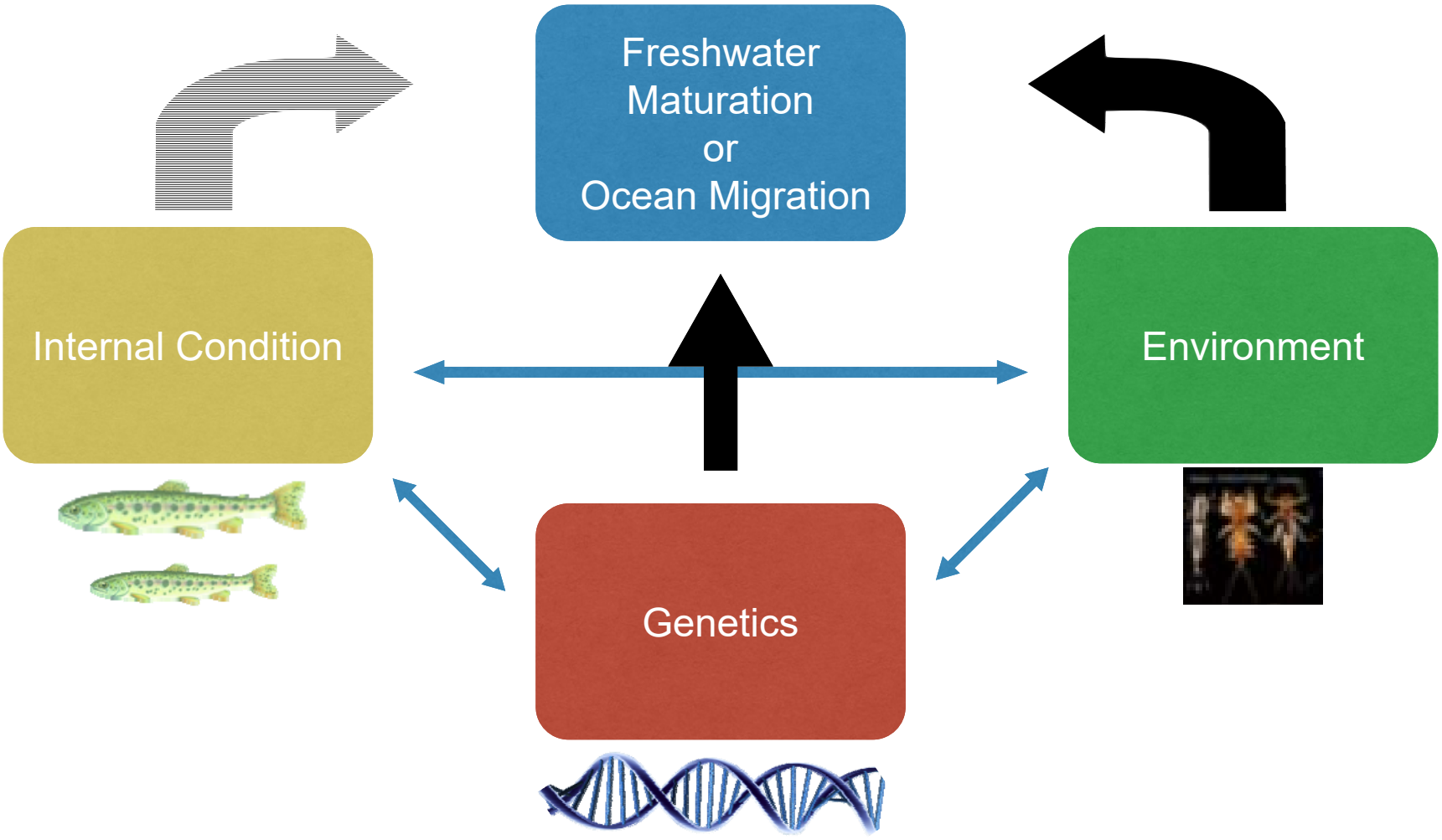


Smolting

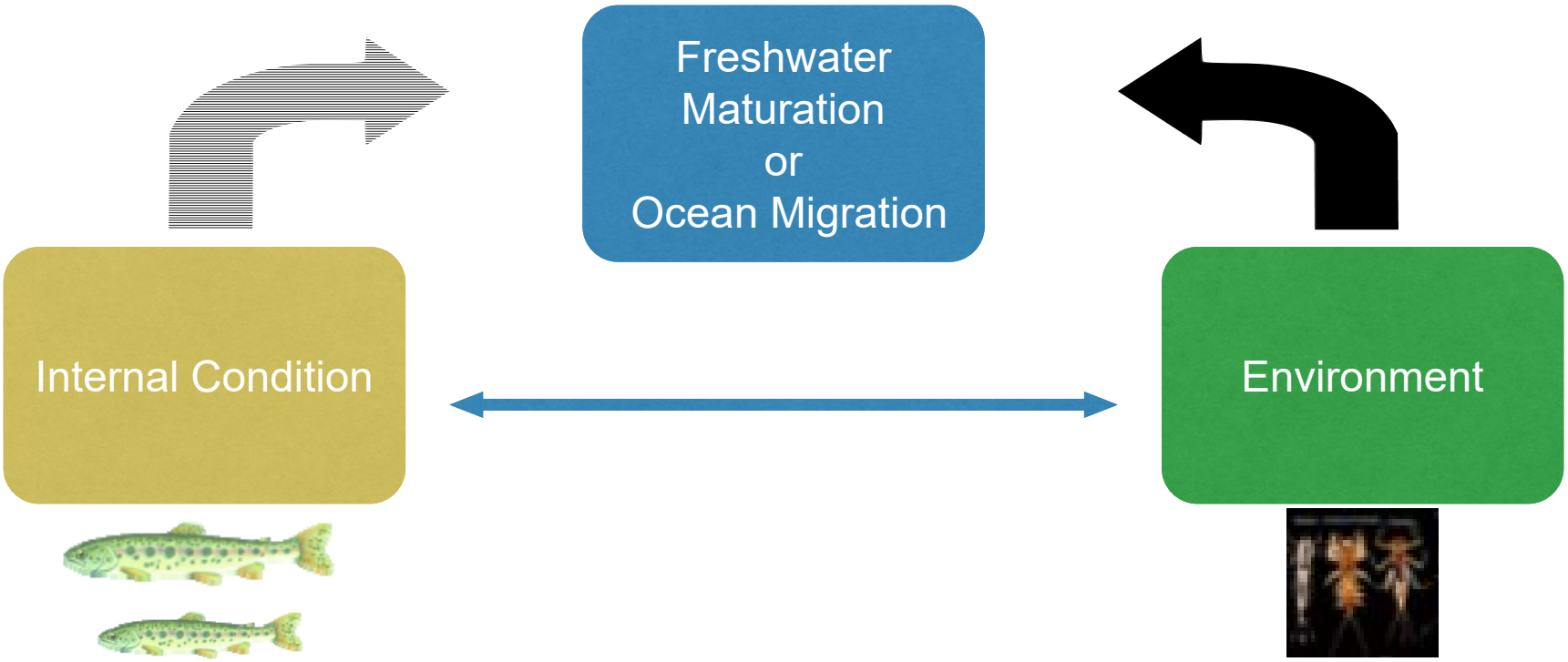
Ocean Survival



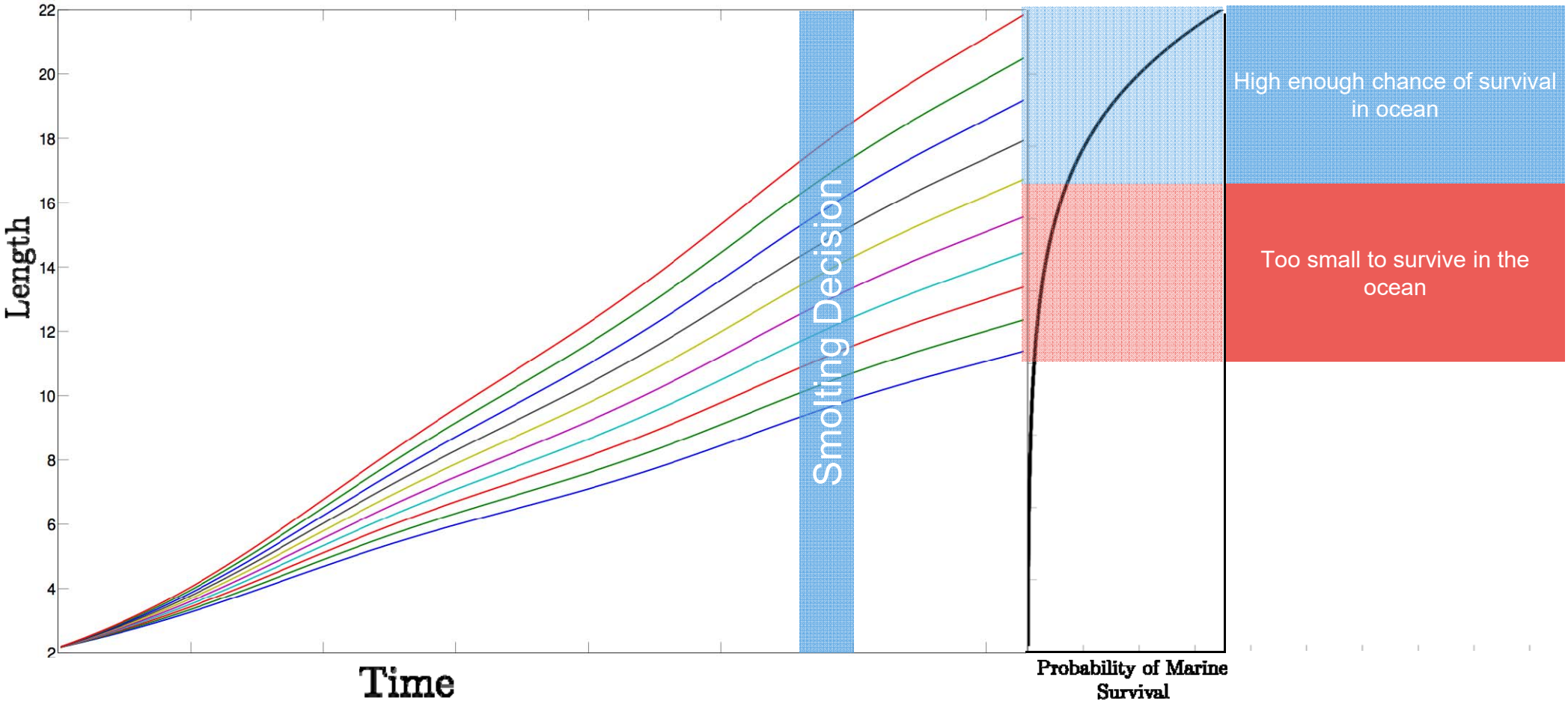
Migration Decision



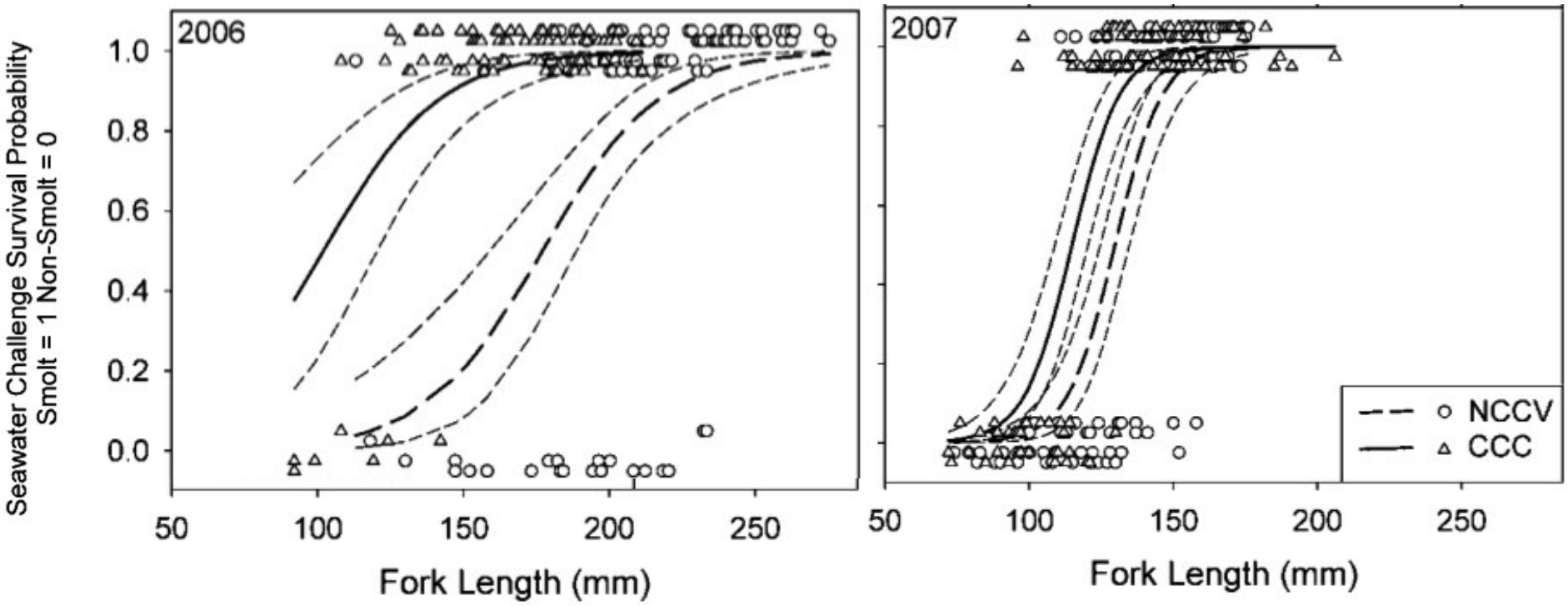
Migration Decision



Smolting Decision



Smolting Decision



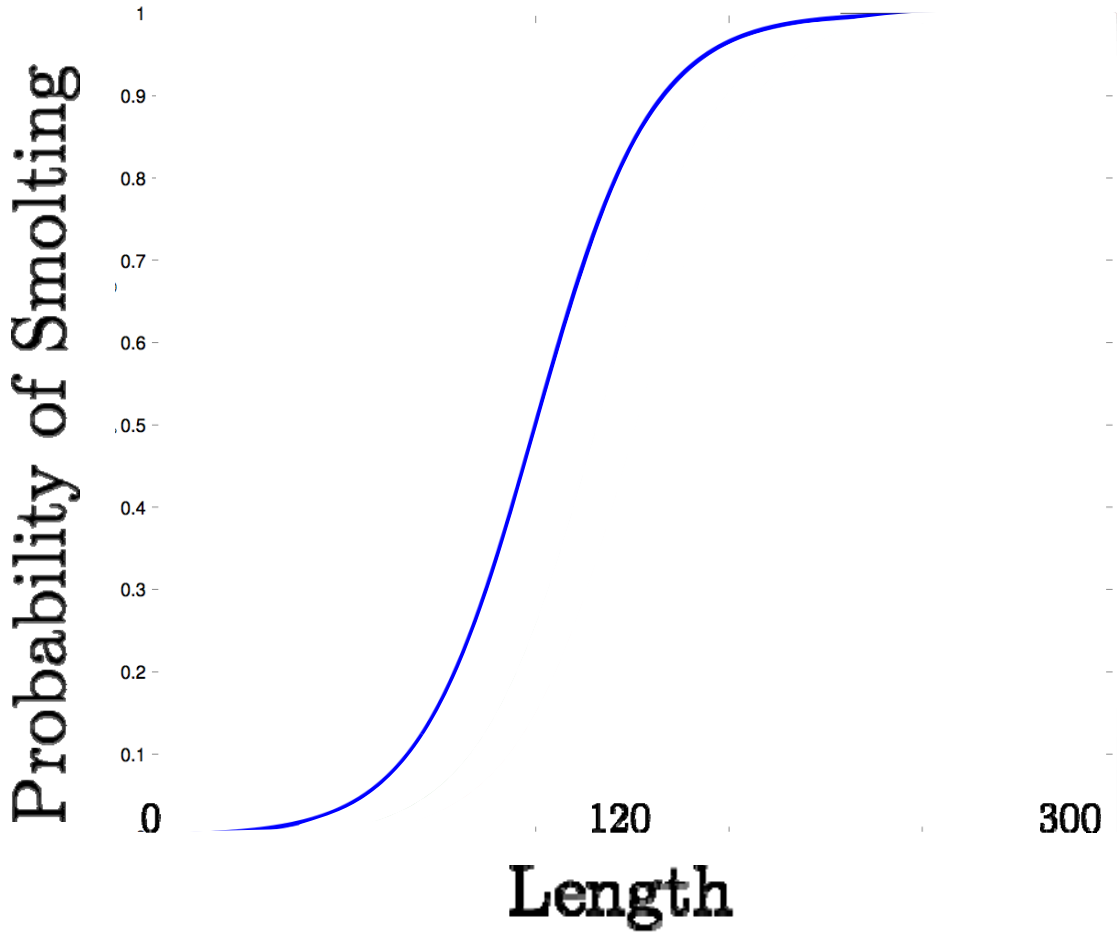
Beakes et al. 2010

Smolting Decision

$$P_s(l,a) = \frac{1}{1+\exp\left(-\frac{l-l_s(a)}{\sigma_s}\right)}$$

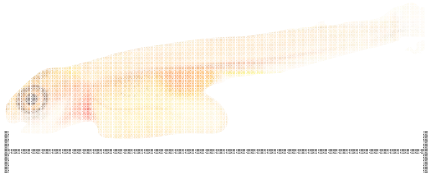
$l_s(a)$: Critical smolting length for an individual of length a

σ_s : Spread of the smolting probability

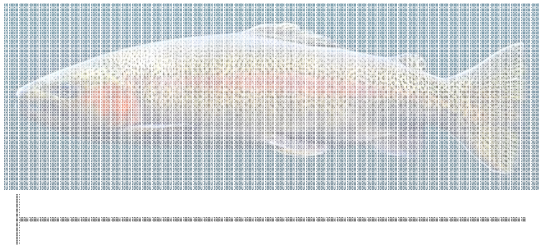


Modeling Steelhead Life History

Growth

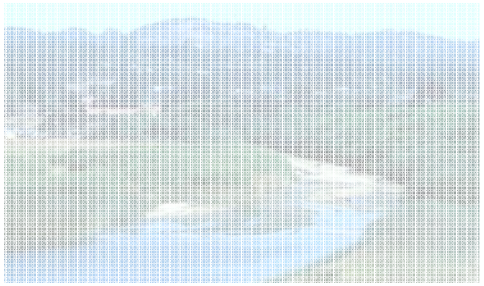


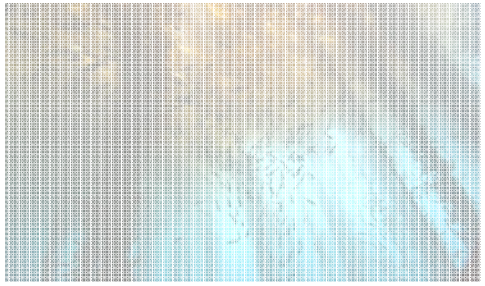
20 mm



350 mm

Smolting



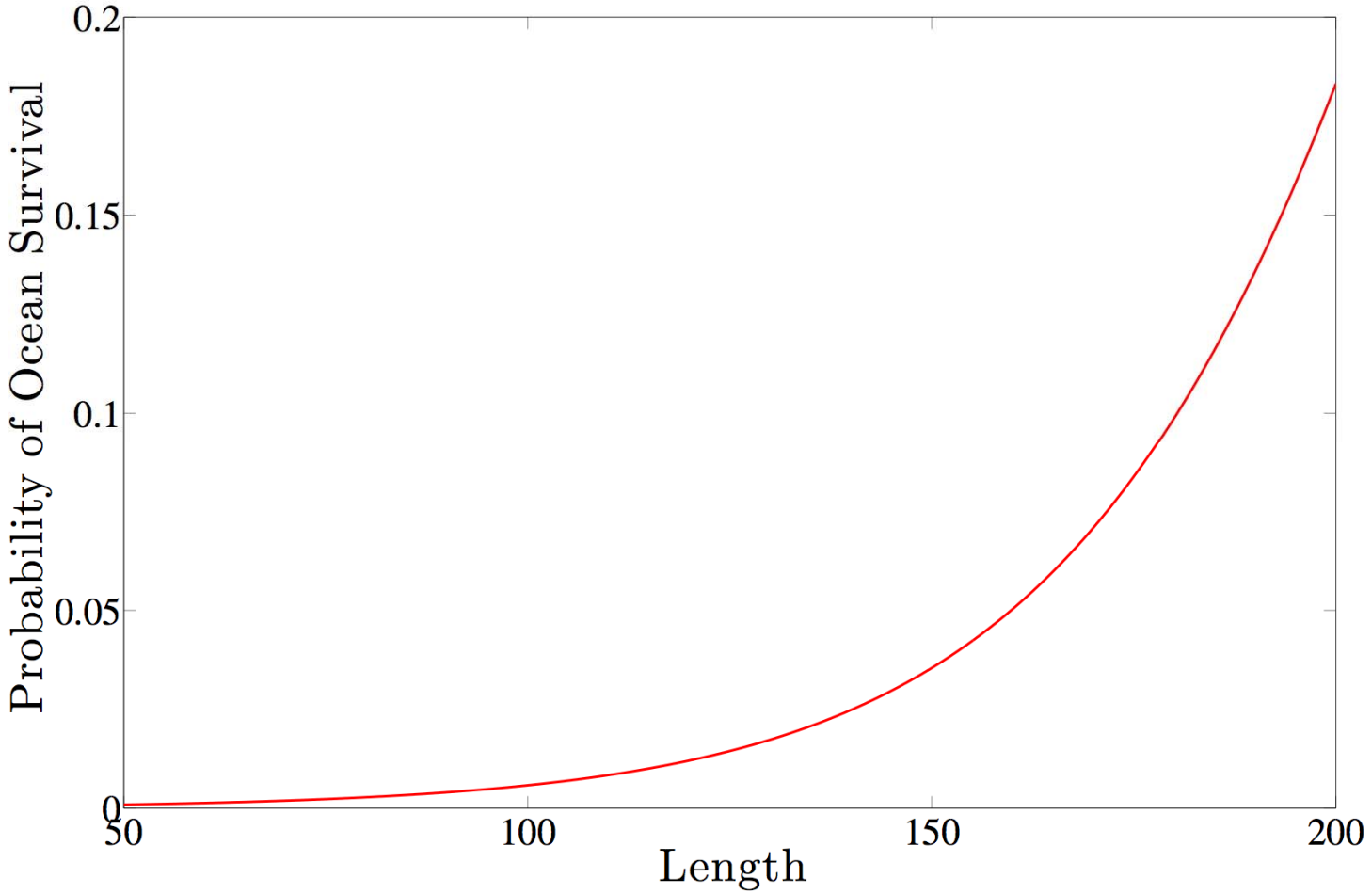


Ocean Survival

+

Expected Marine Survival

$$S_m(l) = 0.84 \frac{1}{1 + e^{(8.657 - 0.369l))}}$$



Satterthwaite et al. 2010, *Evolutionary Applications*

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Application To The Carmel River

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The Setting

The Carmel River

The Carmel River

The Carmel River

Steelhead in the Carmel River

"The Carmel River is a good example of how fast an anadromous fish population can decline to the point of near extirpation"

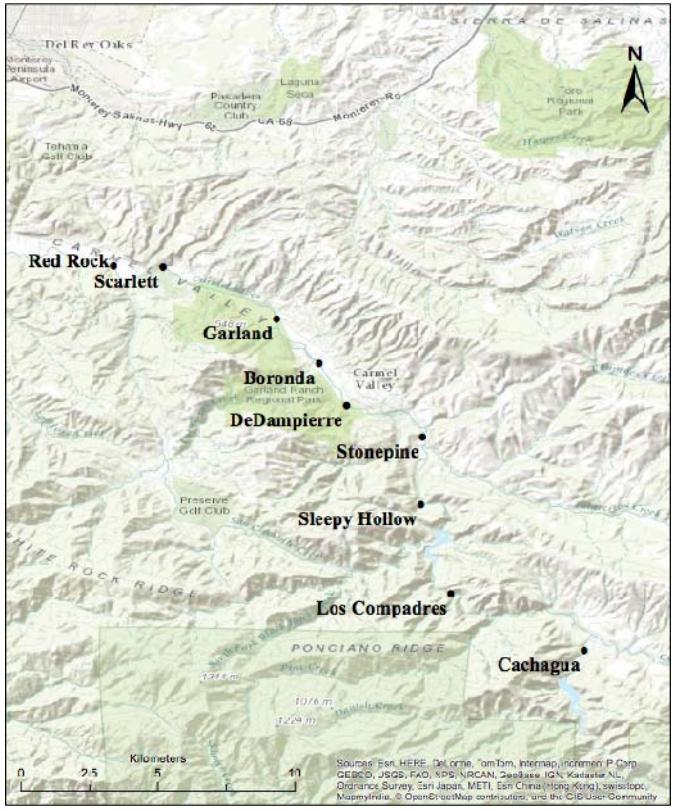
California Department of Fish and Wildlife, Steelhead Restoration and Management Plan Fo

The Data

- Fall Surveys
- Sleepy Hollow Steelhead Rearing Facility (SHSRF)
- Adult Counts
- Relocations
- In-stream Temperature

Fall Surveys

- 9 Sites
- ~ 18 Years
- 3 Pass depletion electrofishing
- Length-frequency distributions



Fall Surveys

- 9 Sites
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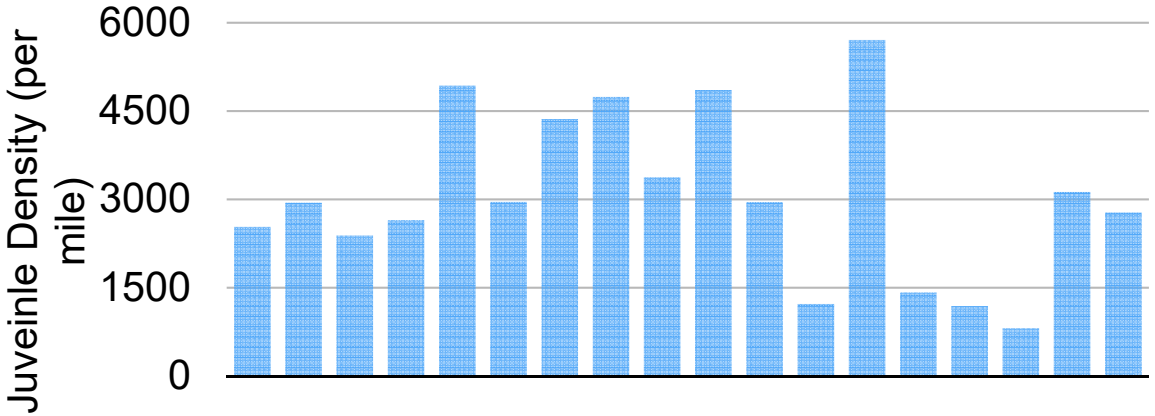
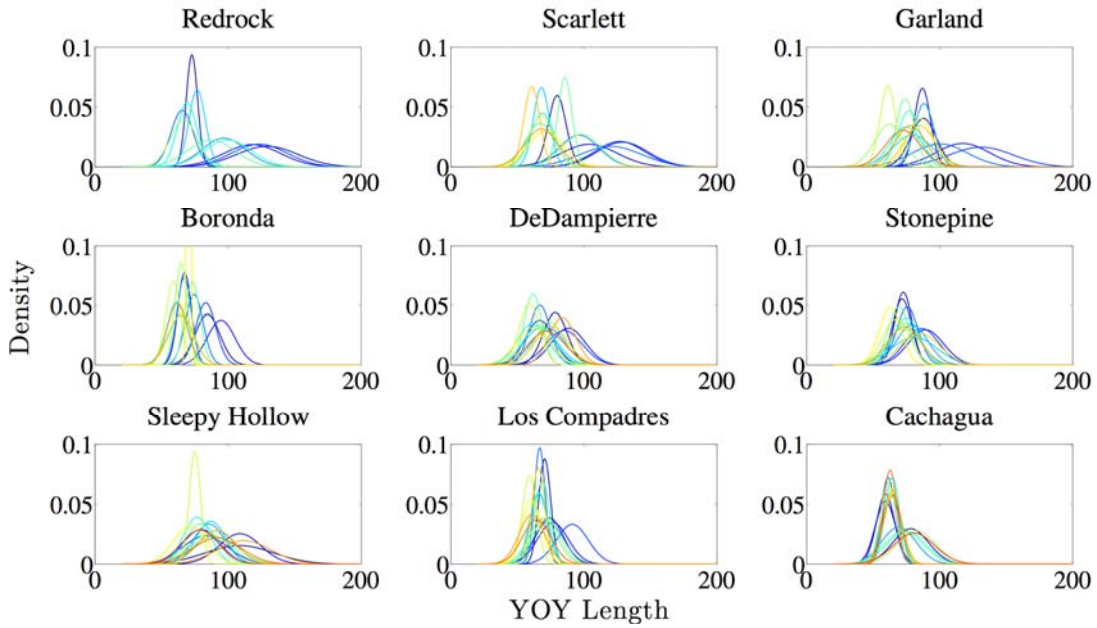
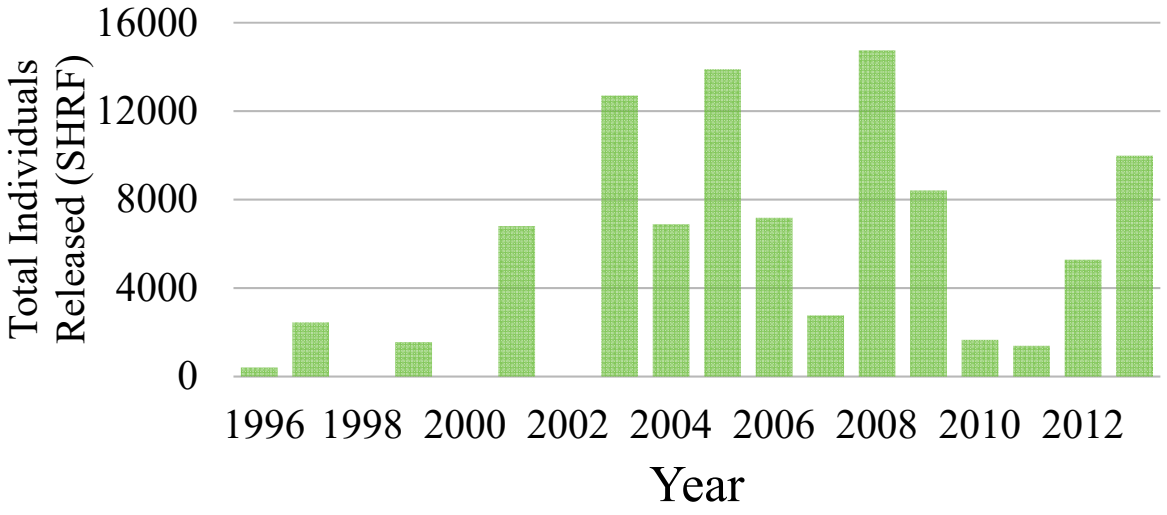


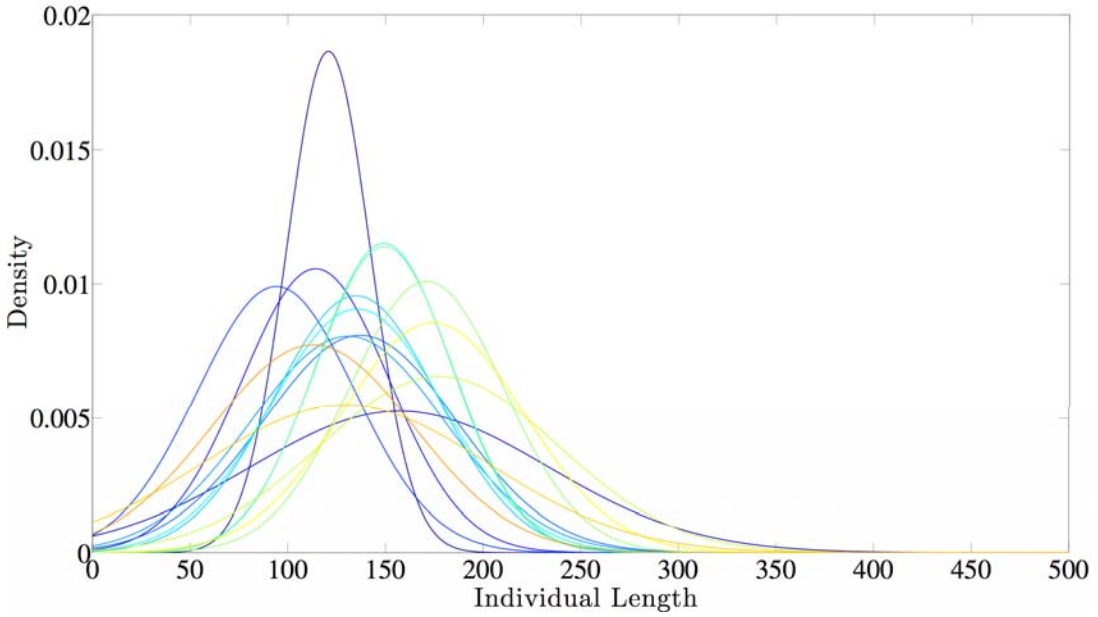


Sleepy Hollow Rearing Facility

Sleepy Hollow Rearing Facility

- Total number released
- Length-frequency distributions



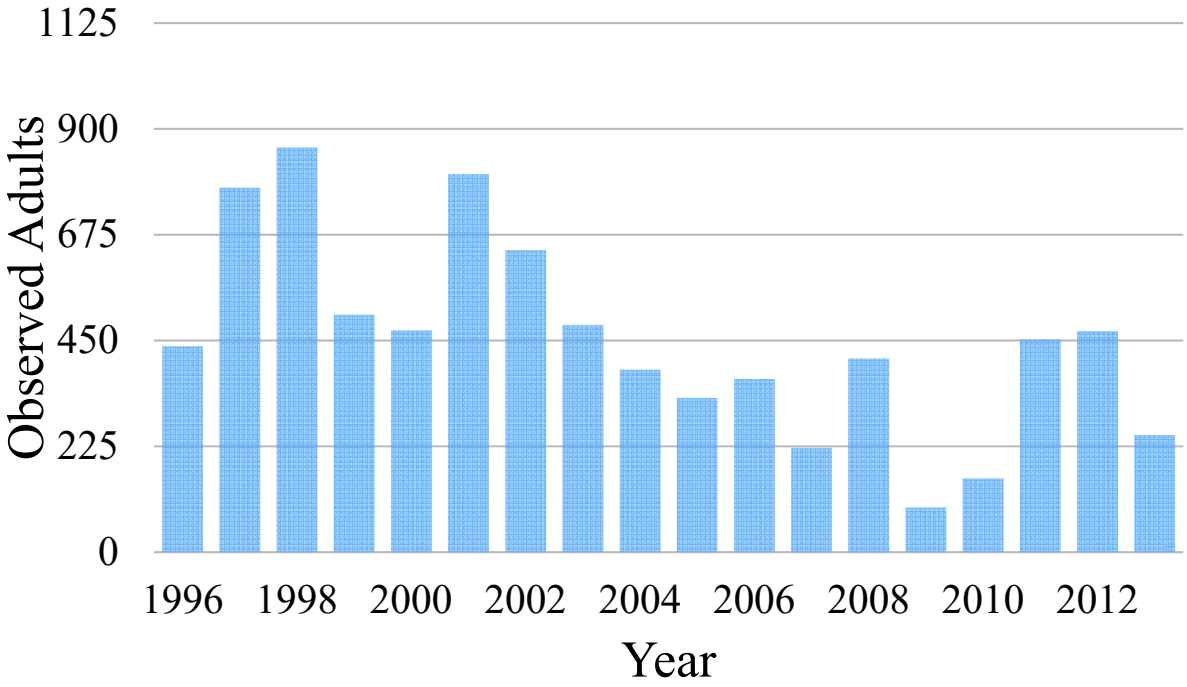


Adult Counts

- Yearly counts at the San Clemente Dam

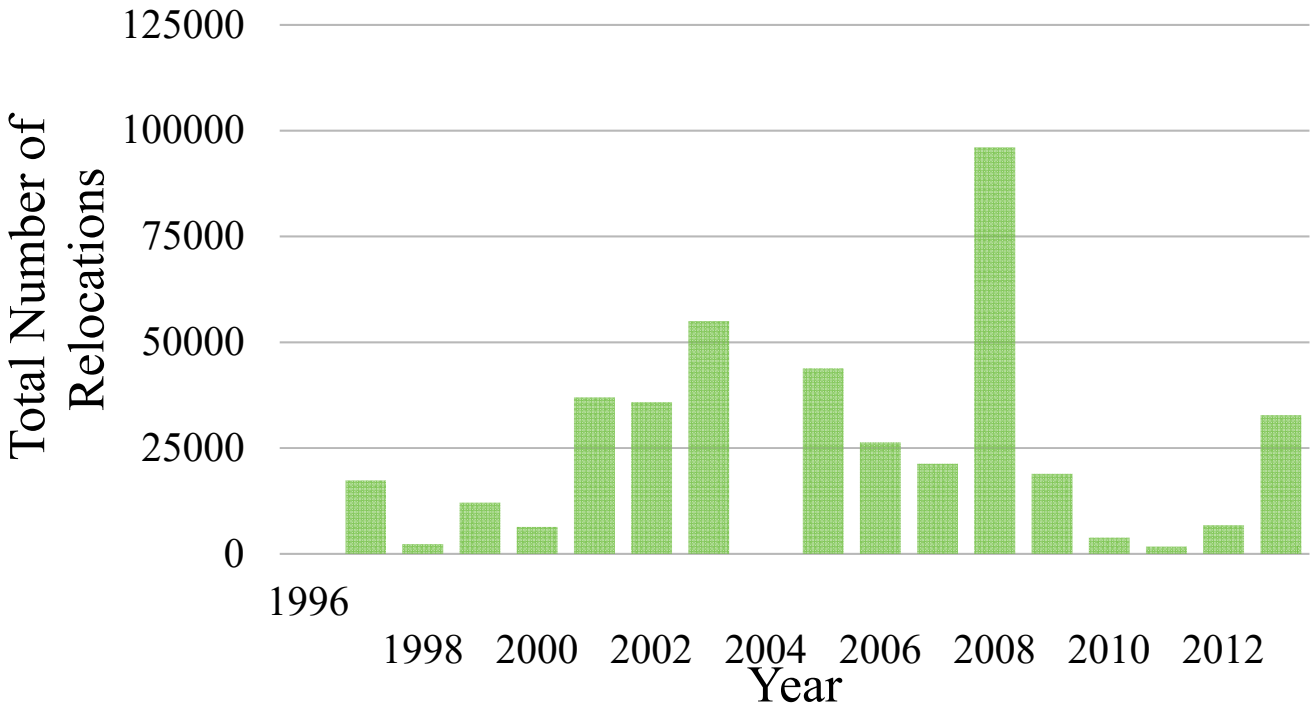
Adult Counts

- Yearly counts at the San Clemente Dam



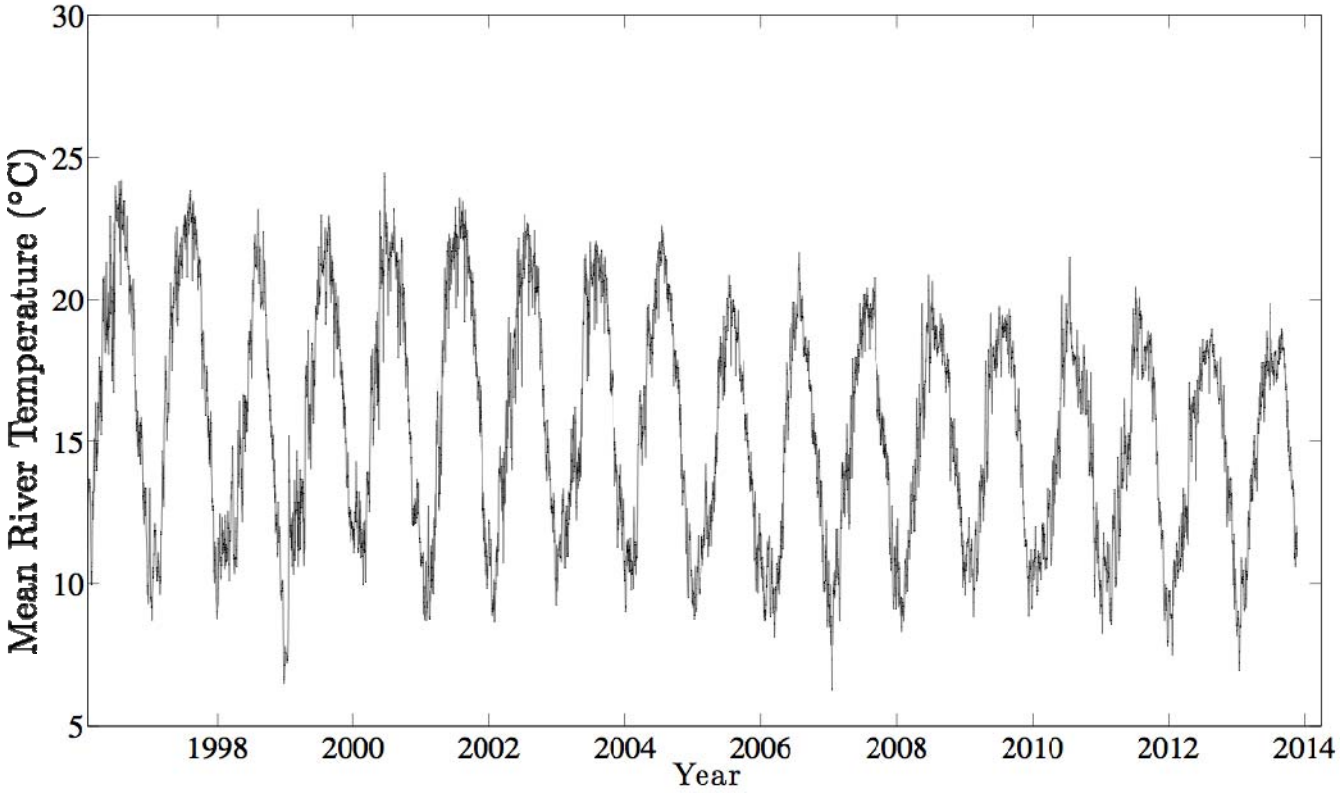
Total Relocations

- Yearly relocations by the Carmel River Steelhead Association (CRSA) and MPWMD



Temperature

- In-stream temperature measurements at 4 locations
- Interpolated to the fall survey sampling sites



Combining the Model with Data

Including Life History
Focusing on YOY

The Approach

Birth

Growth

Time of Emigration

Smolting Probability

Resident

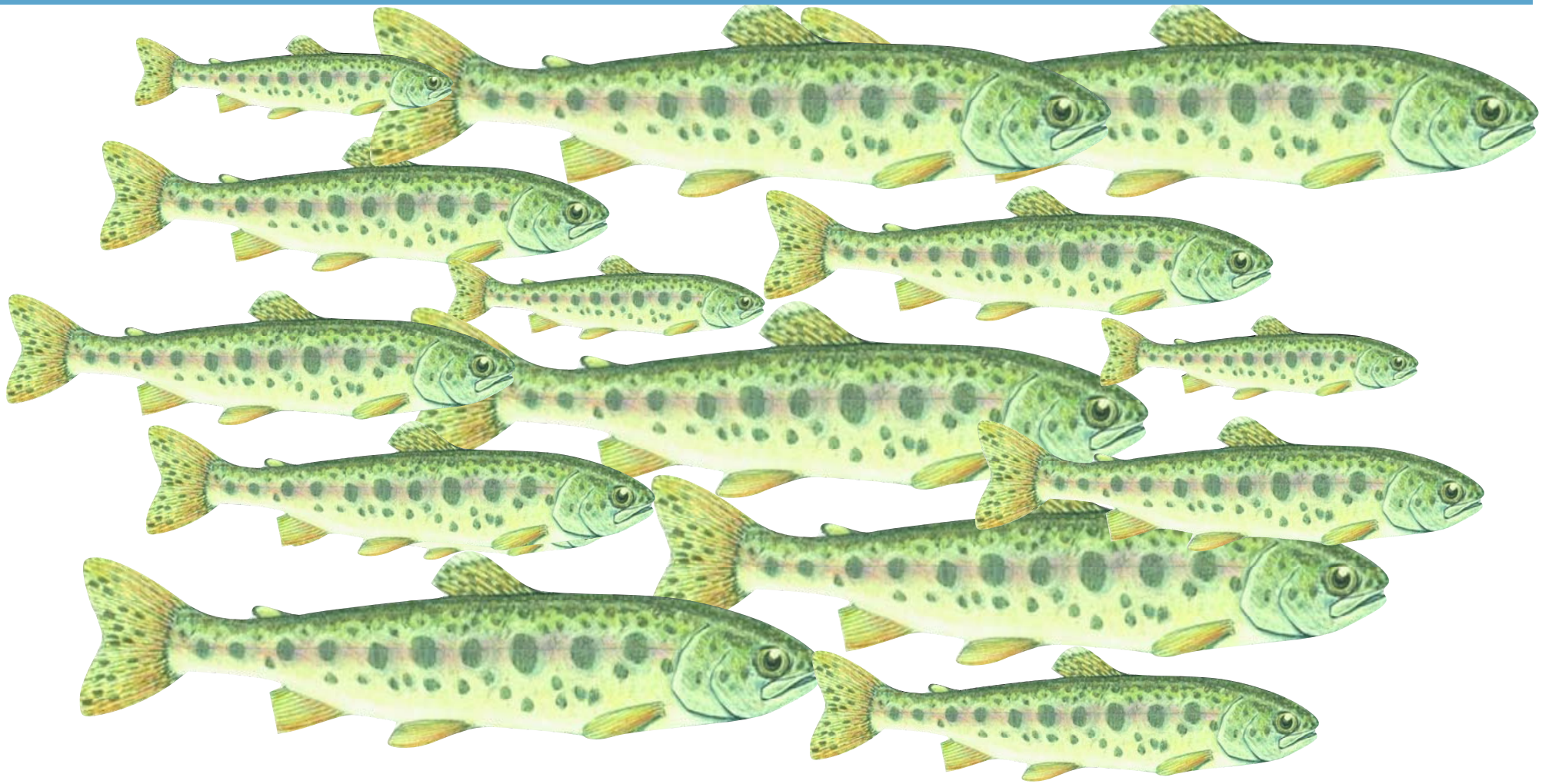
Ocean Survival

53% return 1 year later
47% return 2 years later

Steelhead

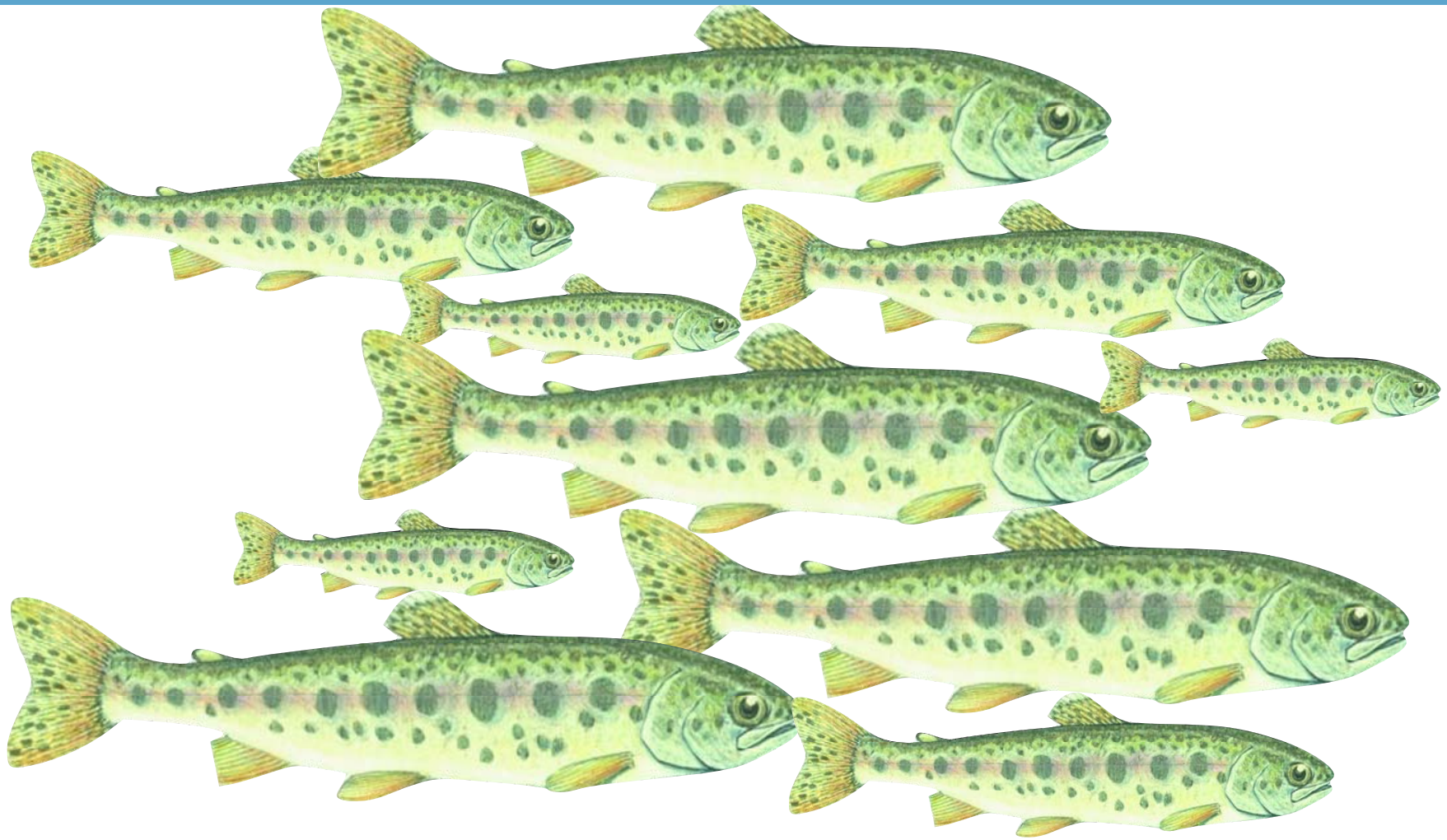
→ Focus of this project

Total Abundance at Site



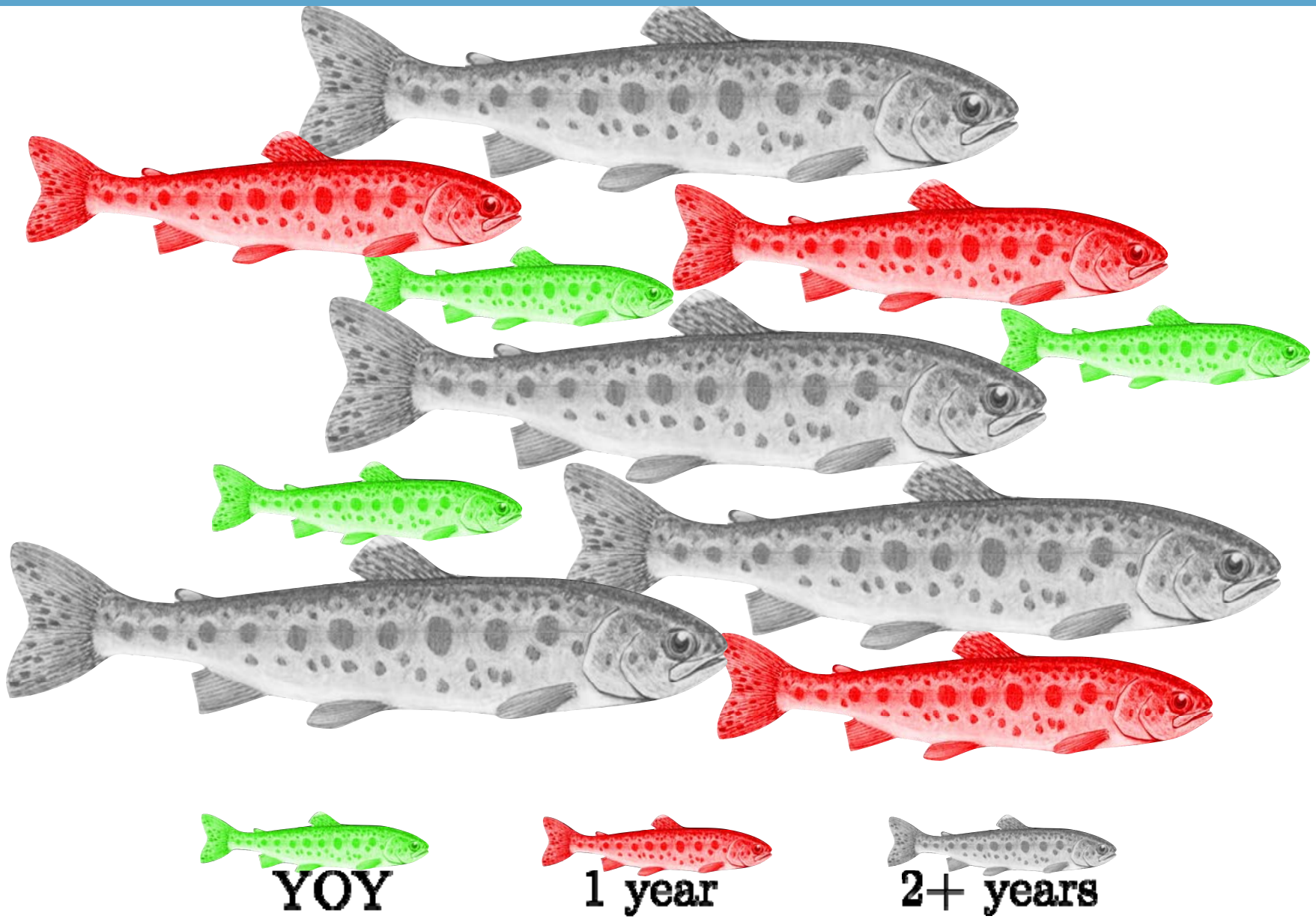
N_0 total individuals

Sampled Abundance at Site



N individuals captured in the fall survey

Samples Have Different Ages

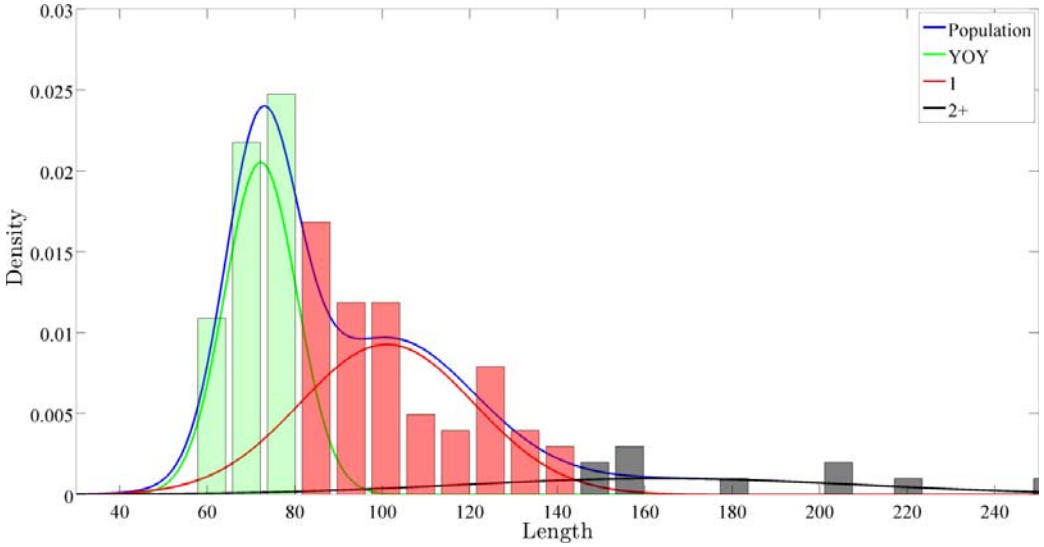


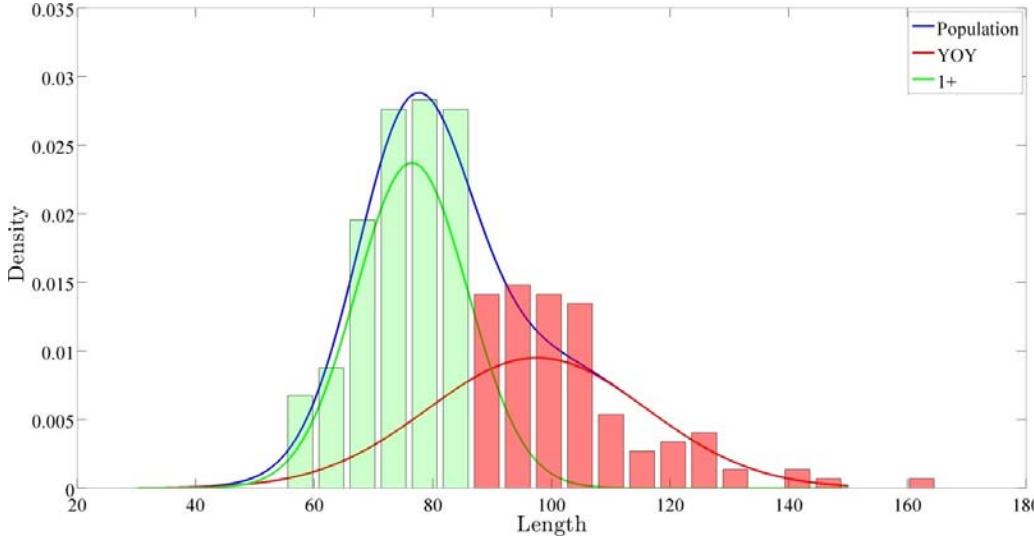
Selecting only YOY from Population

$$l_i \sim \sum_{a=1}^{a=A} \alpha_a N(\mu_a, \sigma_a)$$

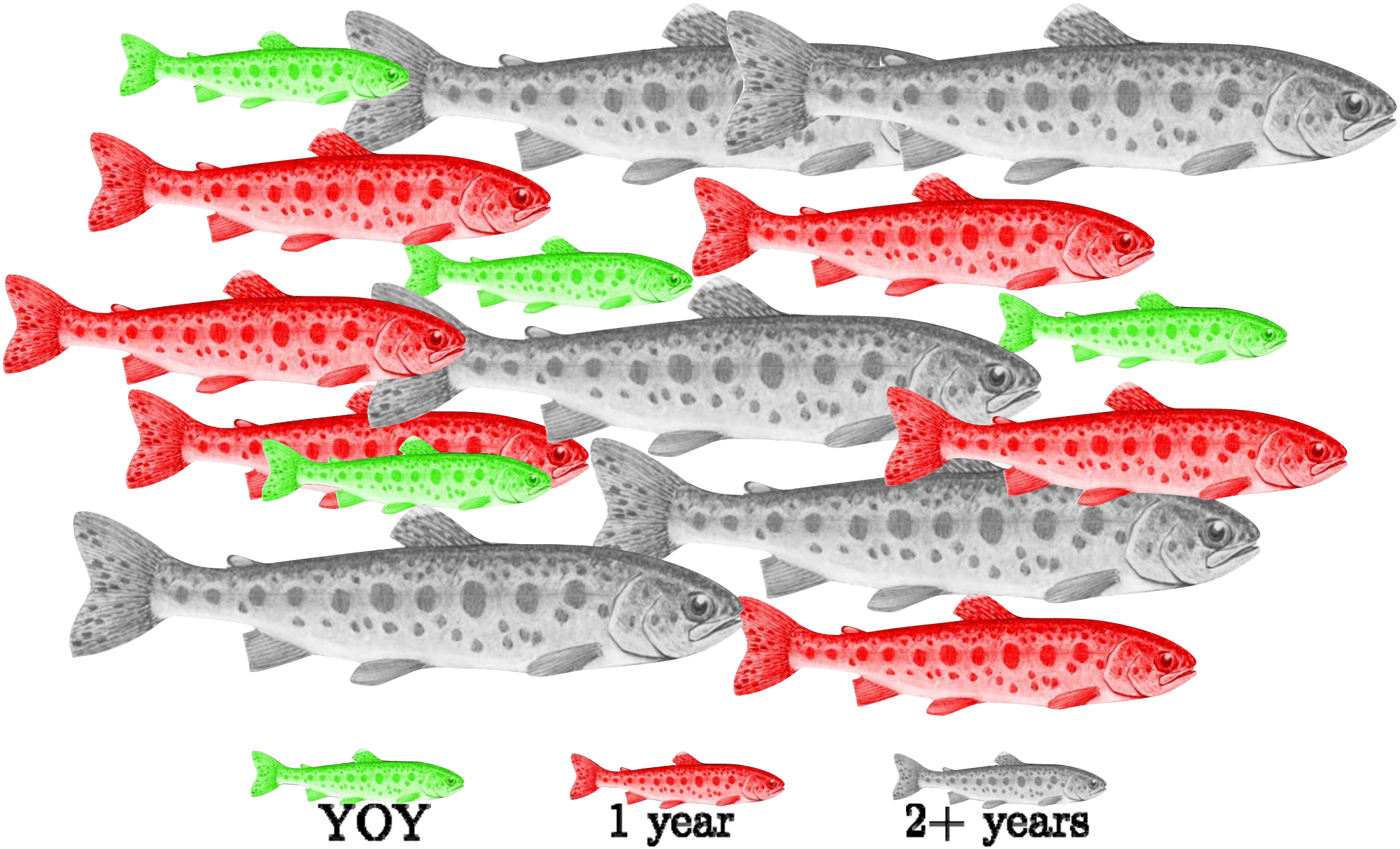
A : Number of age classes present
μ_a : Mean length of age class a
σ_a : Deivation in length of age class a
α_a : Mixing proportion of age class a

Find best fit using BIC





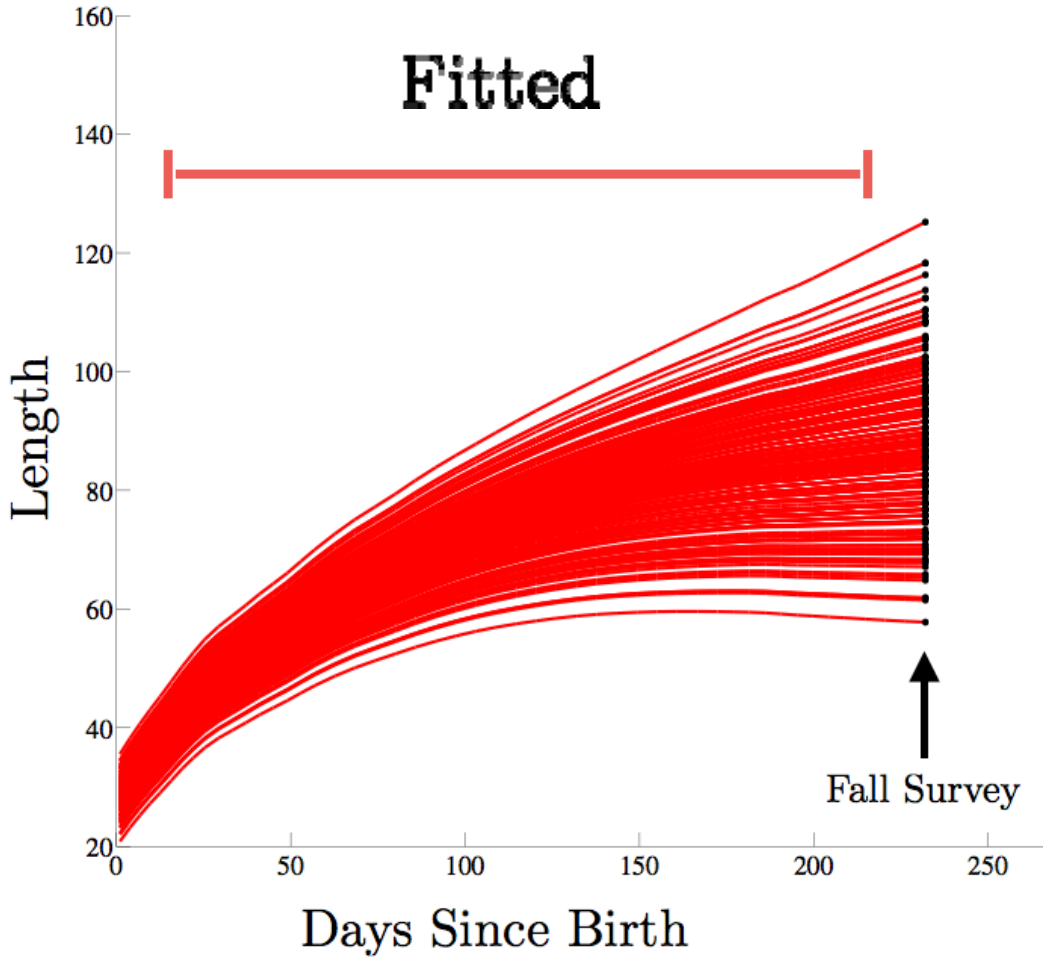
Imputing Age Classes For Individuals Not Caught



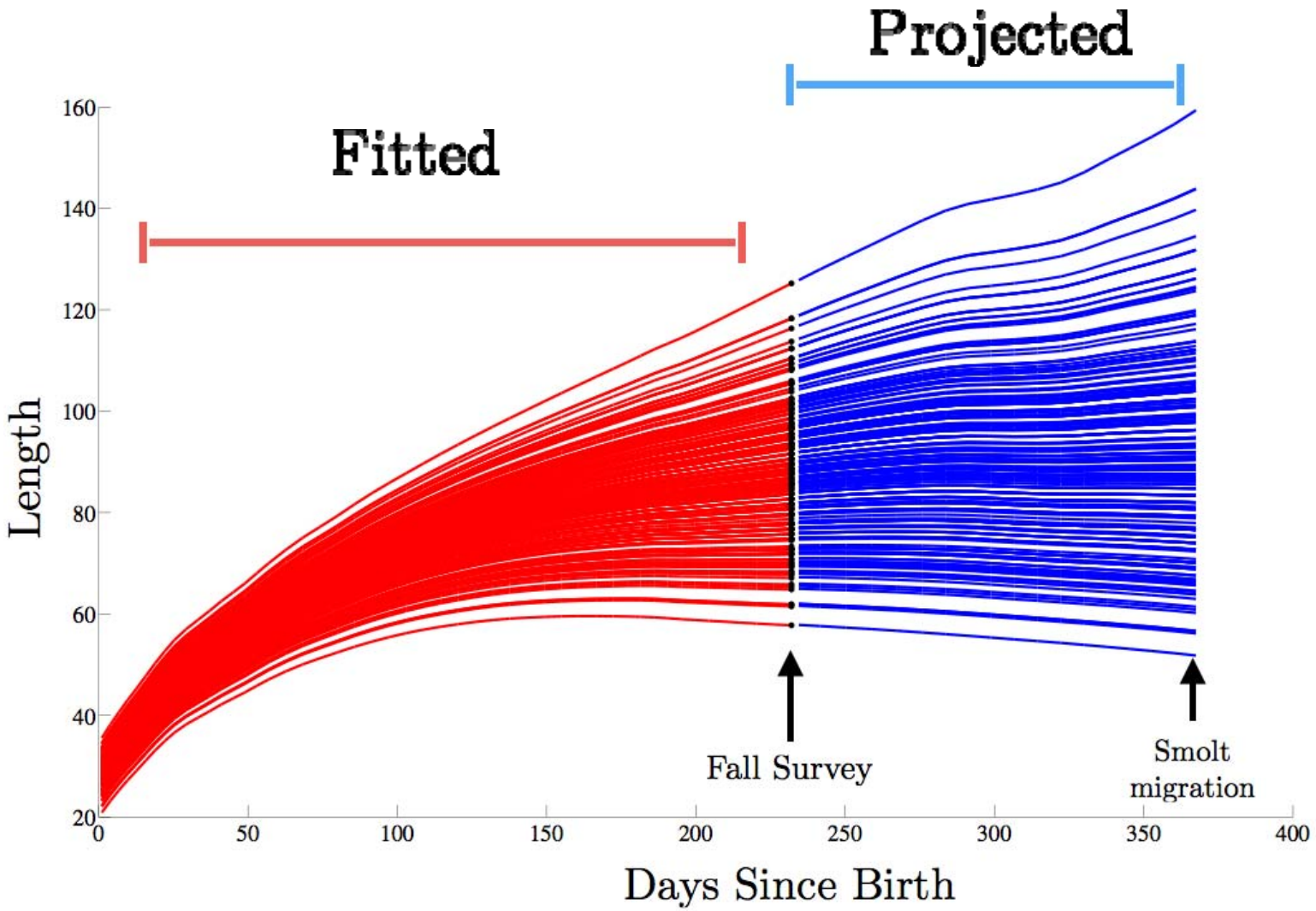
Focusing on YOY individuals

YOY

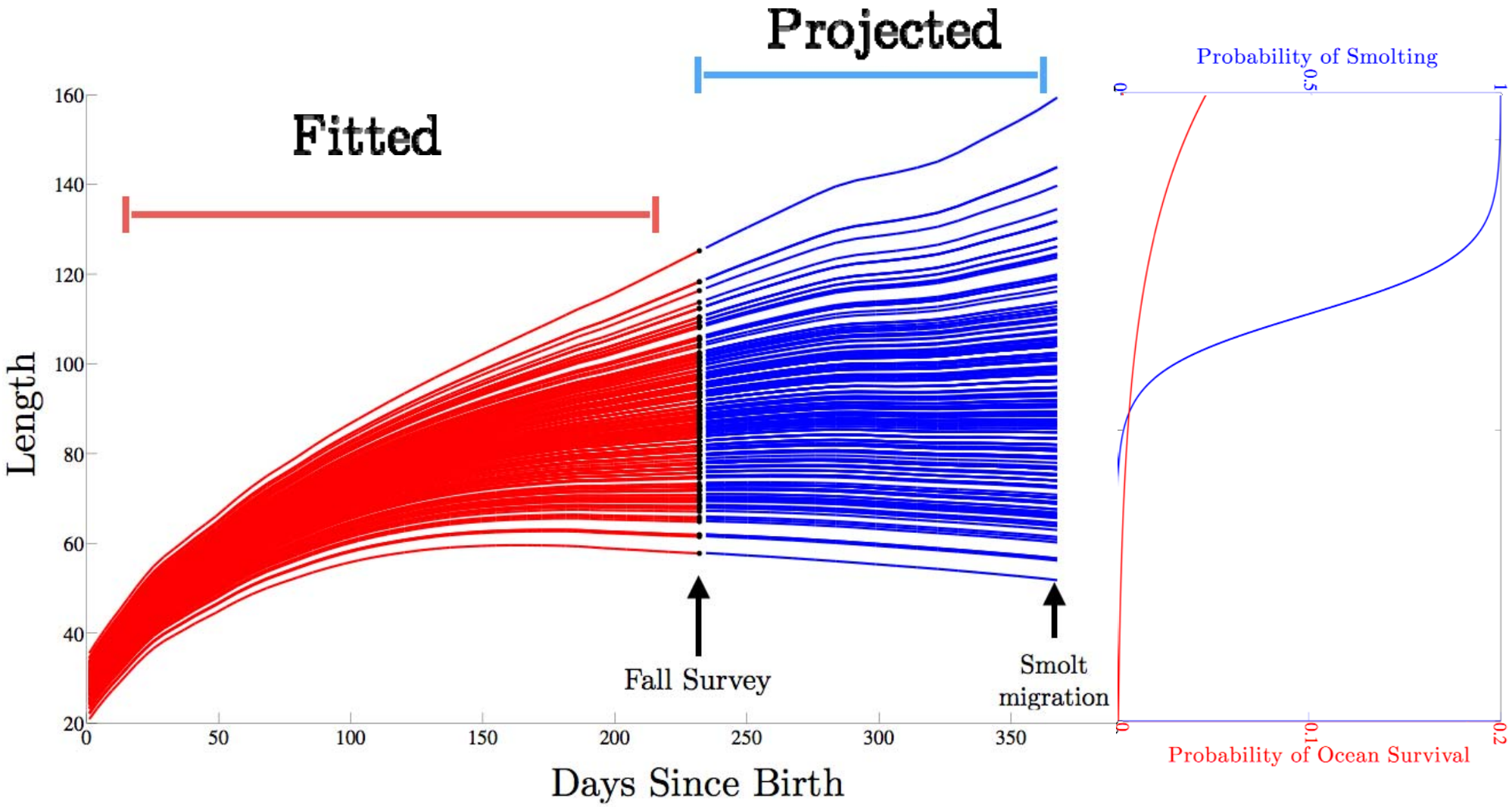
Back Calculated Growth



Forward Projected Growth



Smolting and Survival



Introduction and Motivation

Modeling Approach

Application To The Carmel River

Results

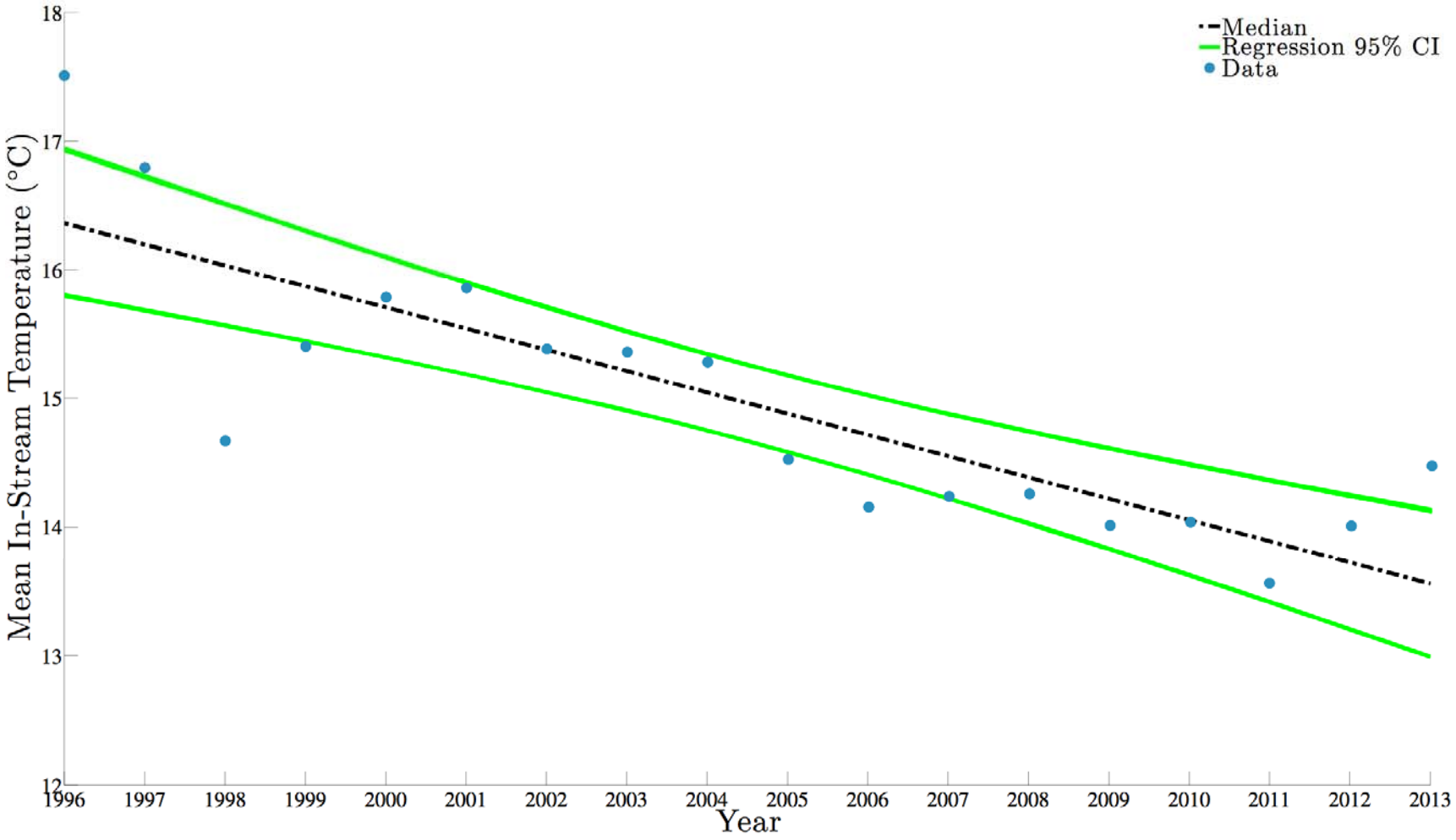
Conclusions

Results

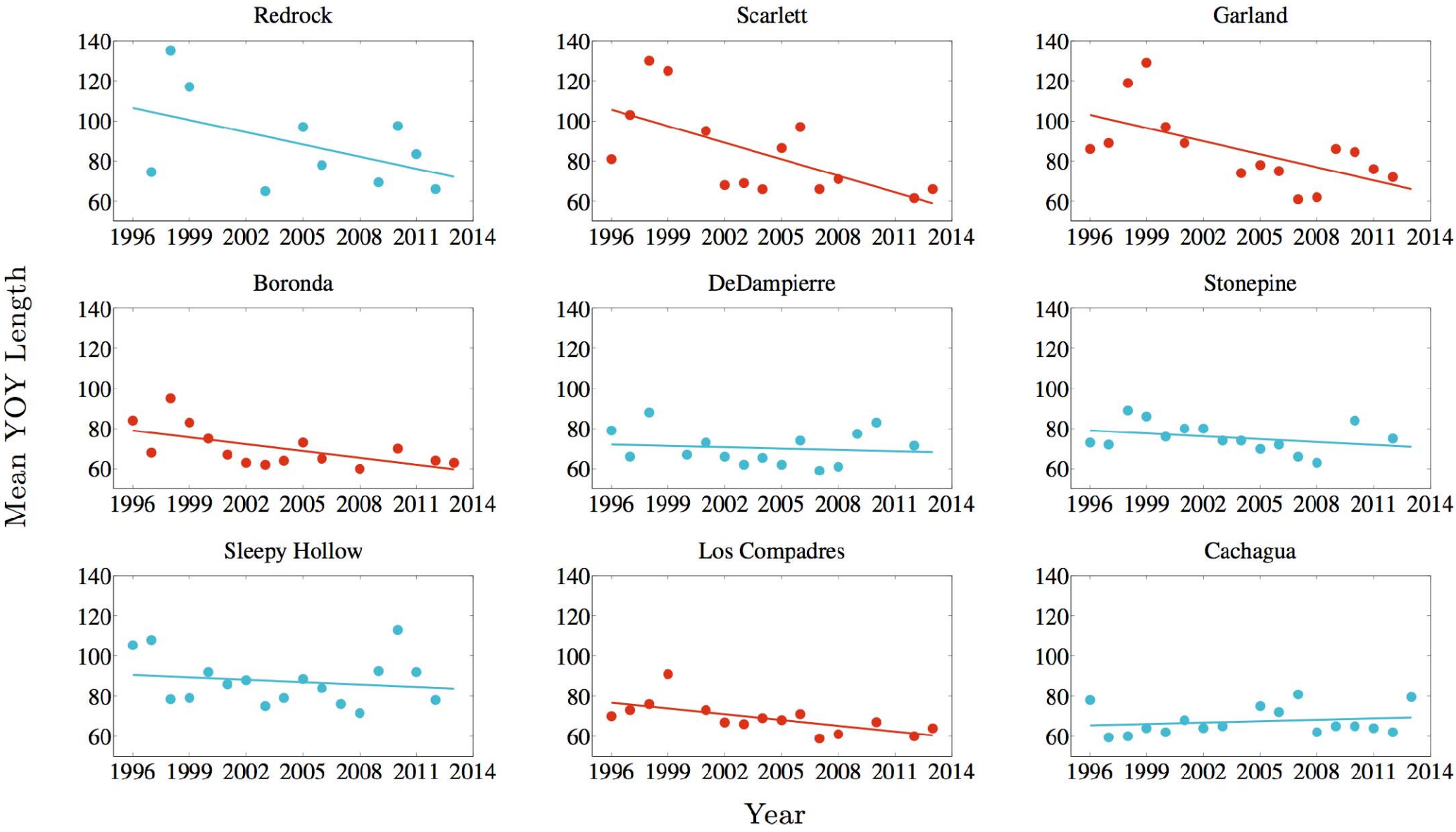
General Patterns

Predictions of Adult Returns

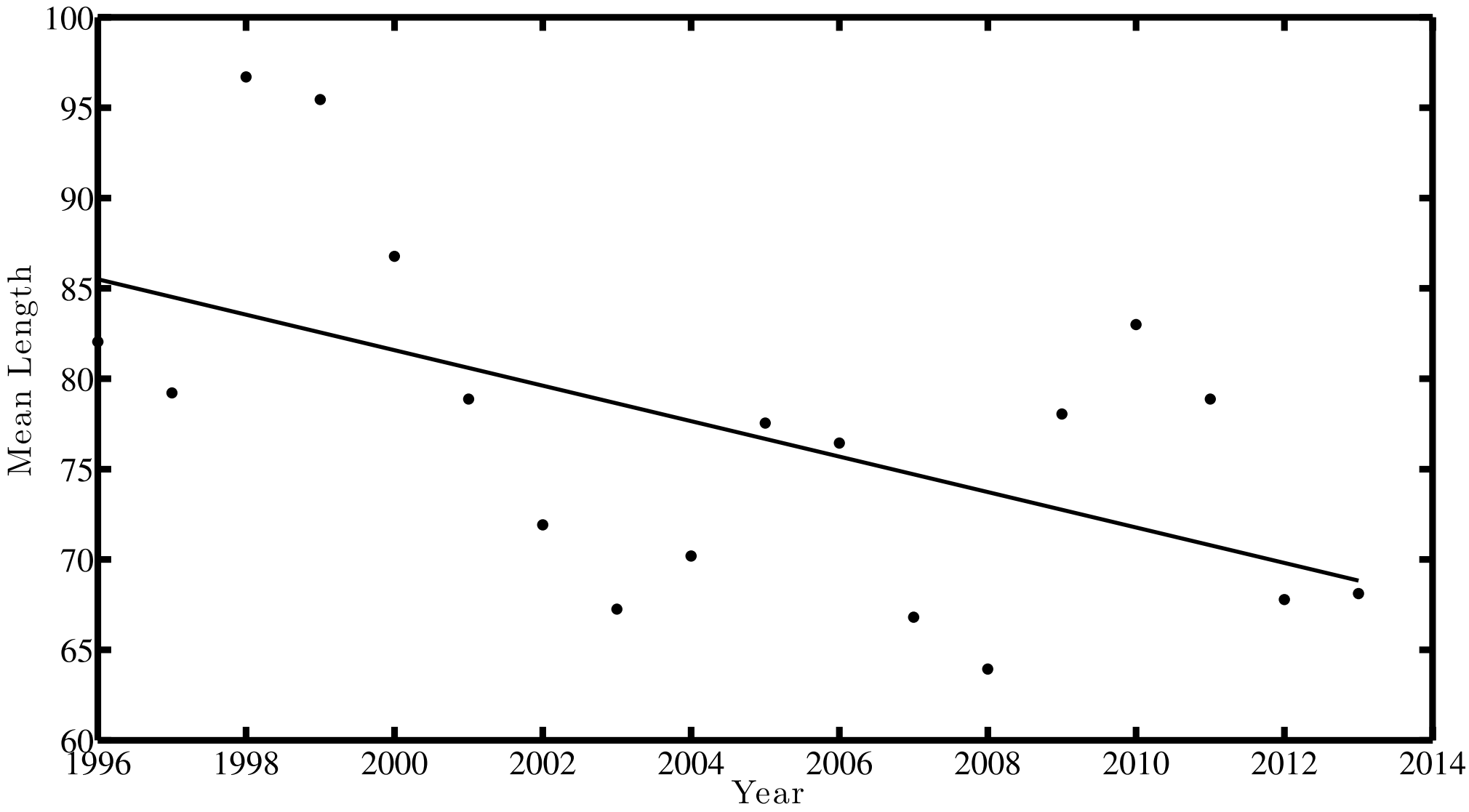
In-Stream Temperature



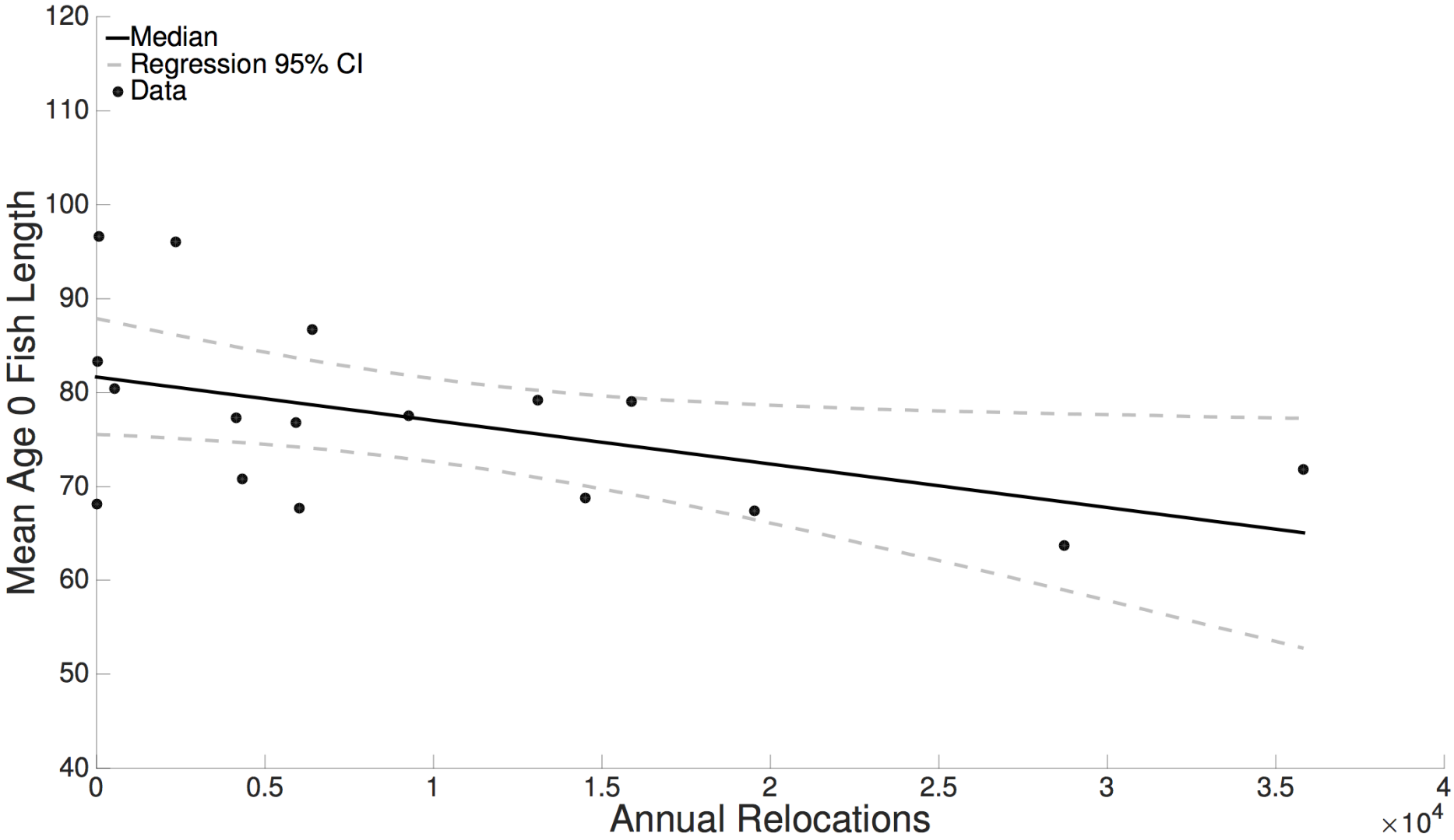
Length At Sites



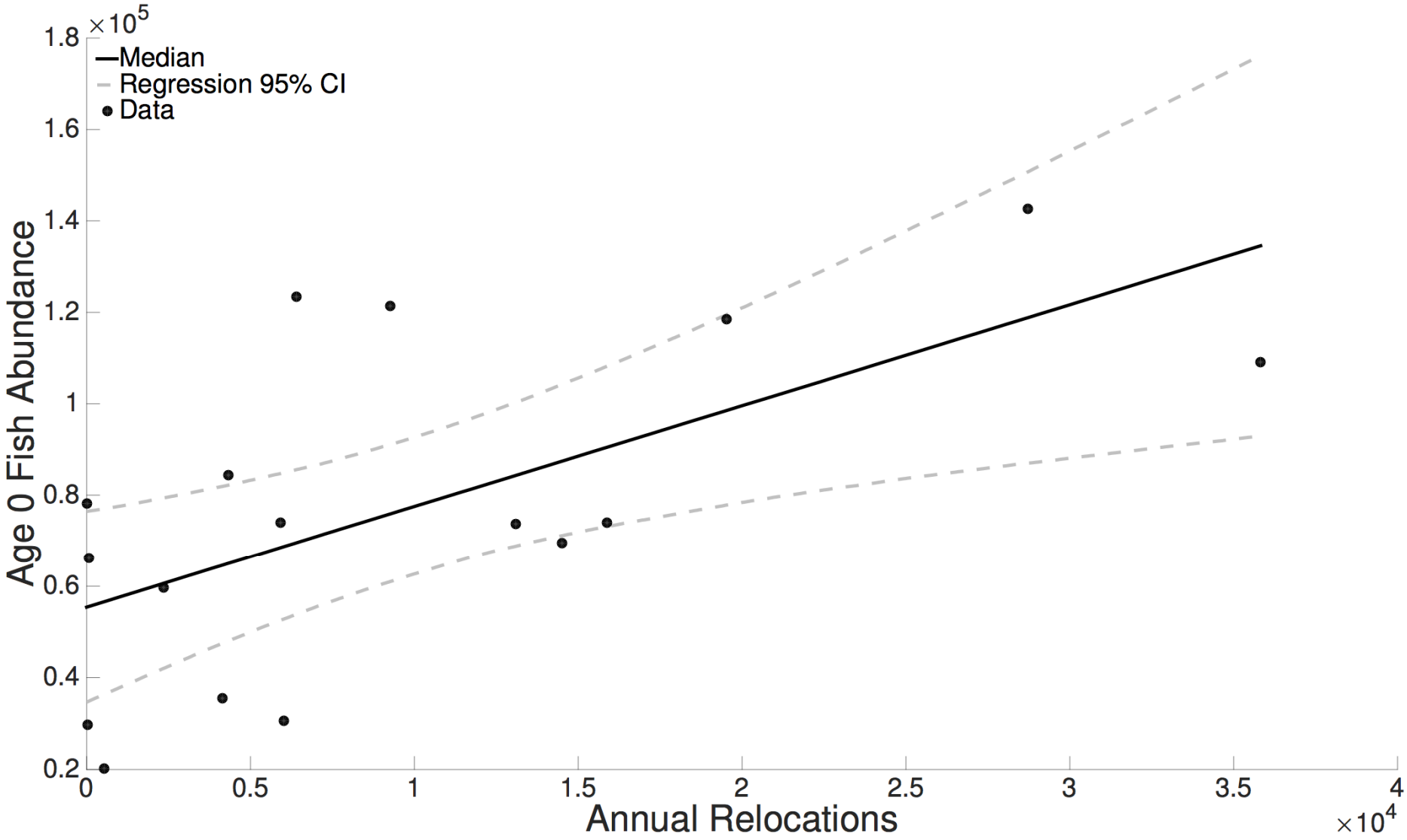
Stream-Wide Lengths



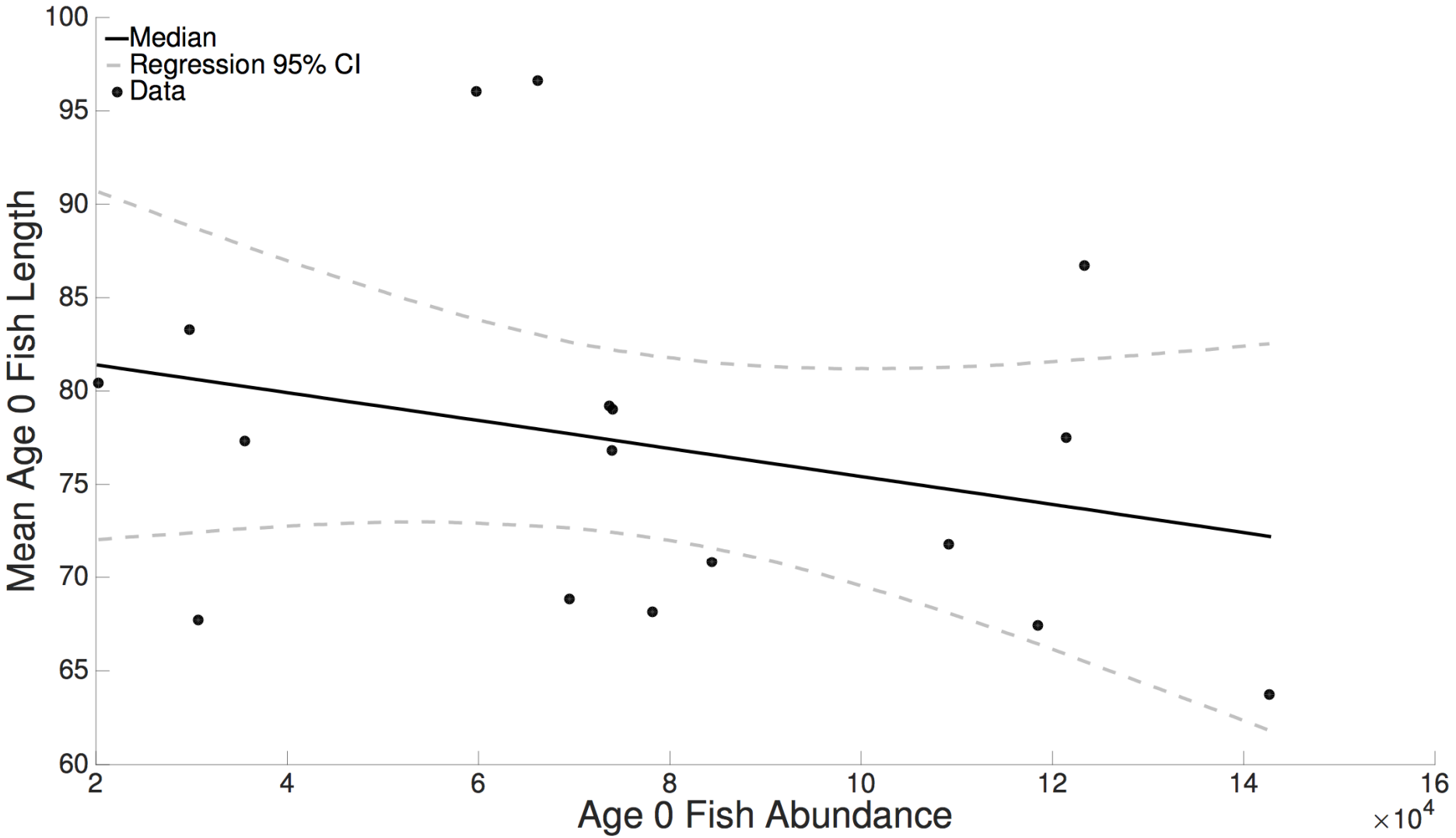
Relocations and Length



Relocations and Density



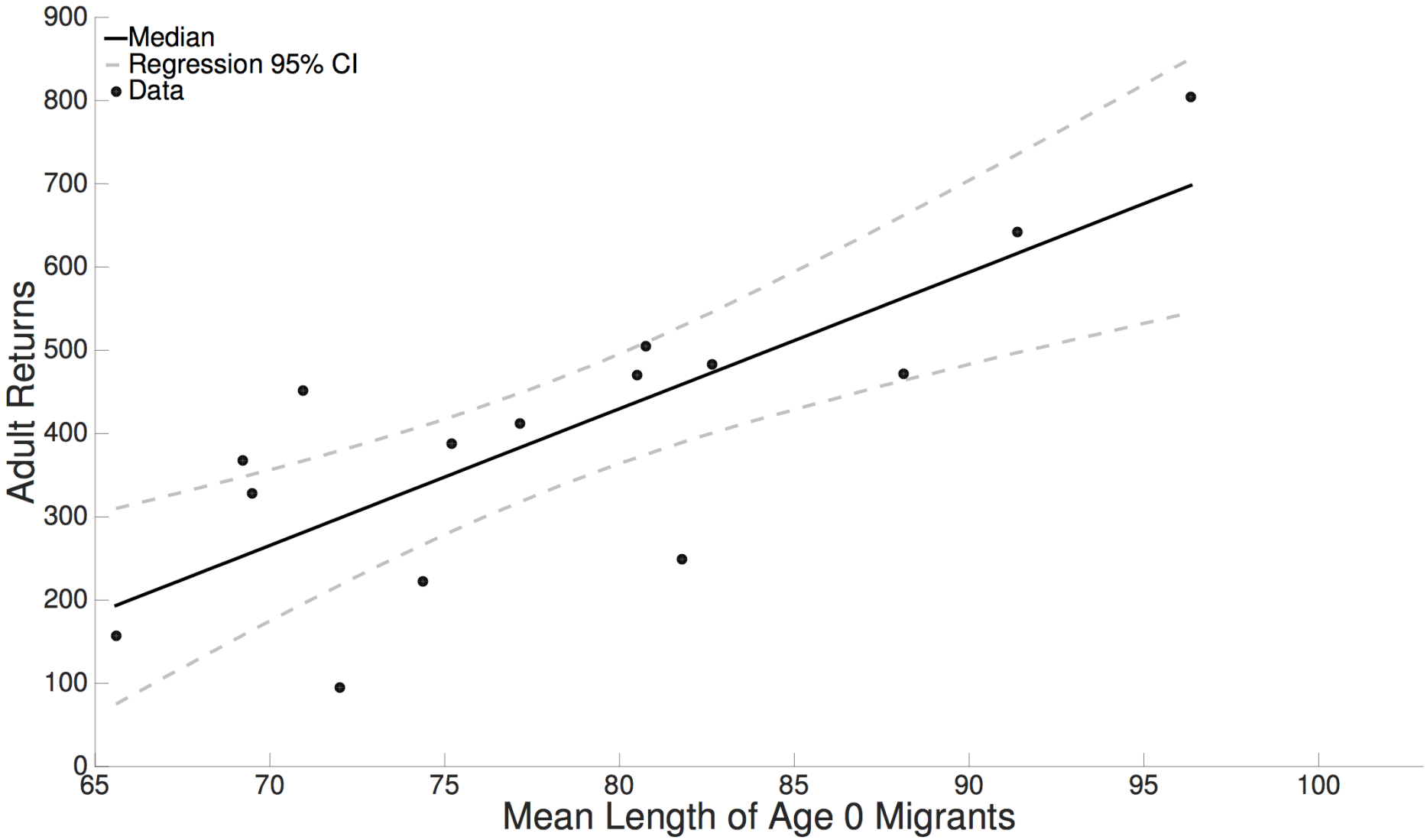
Abundance and Length



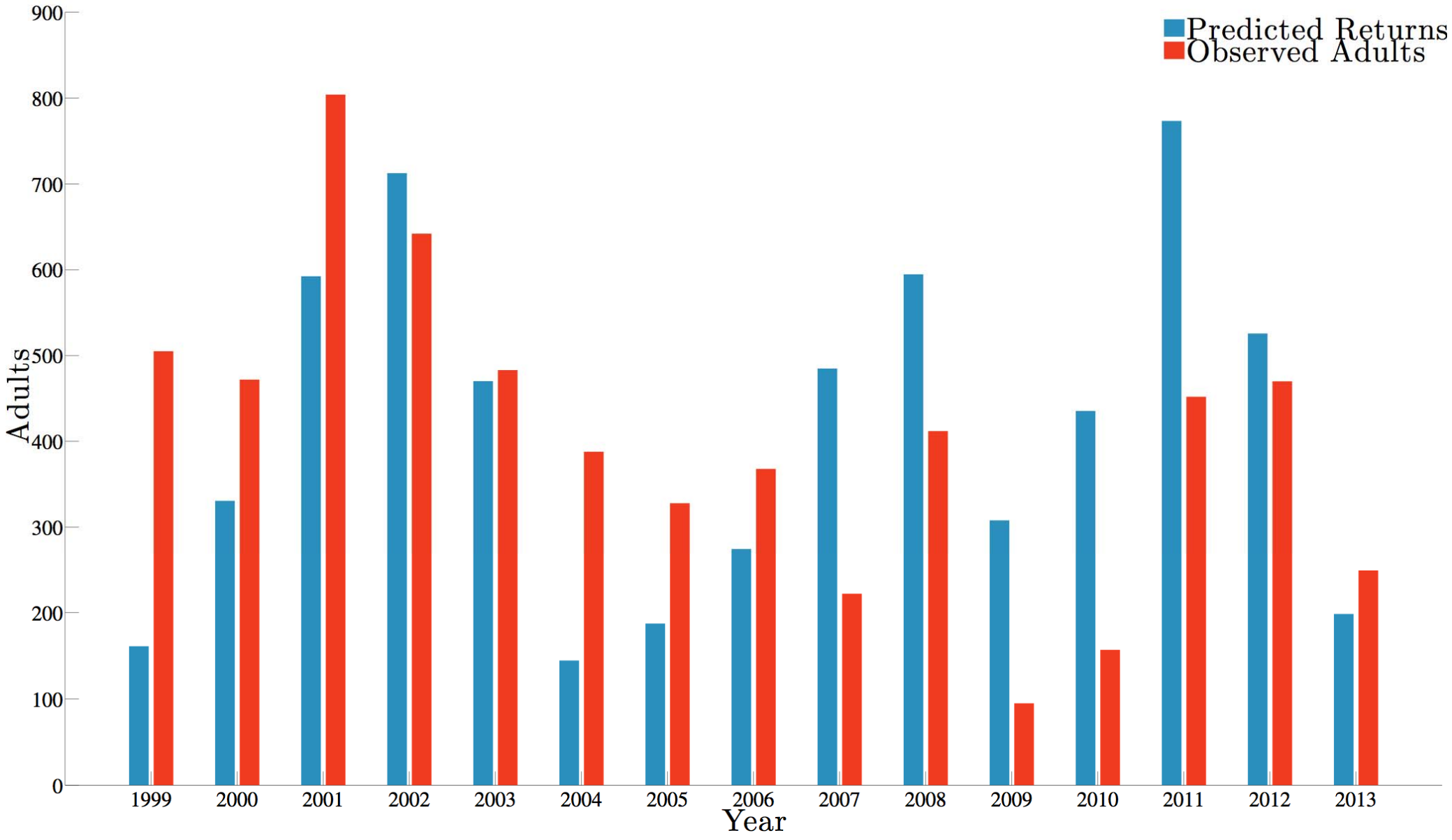
Results

Adult Returns

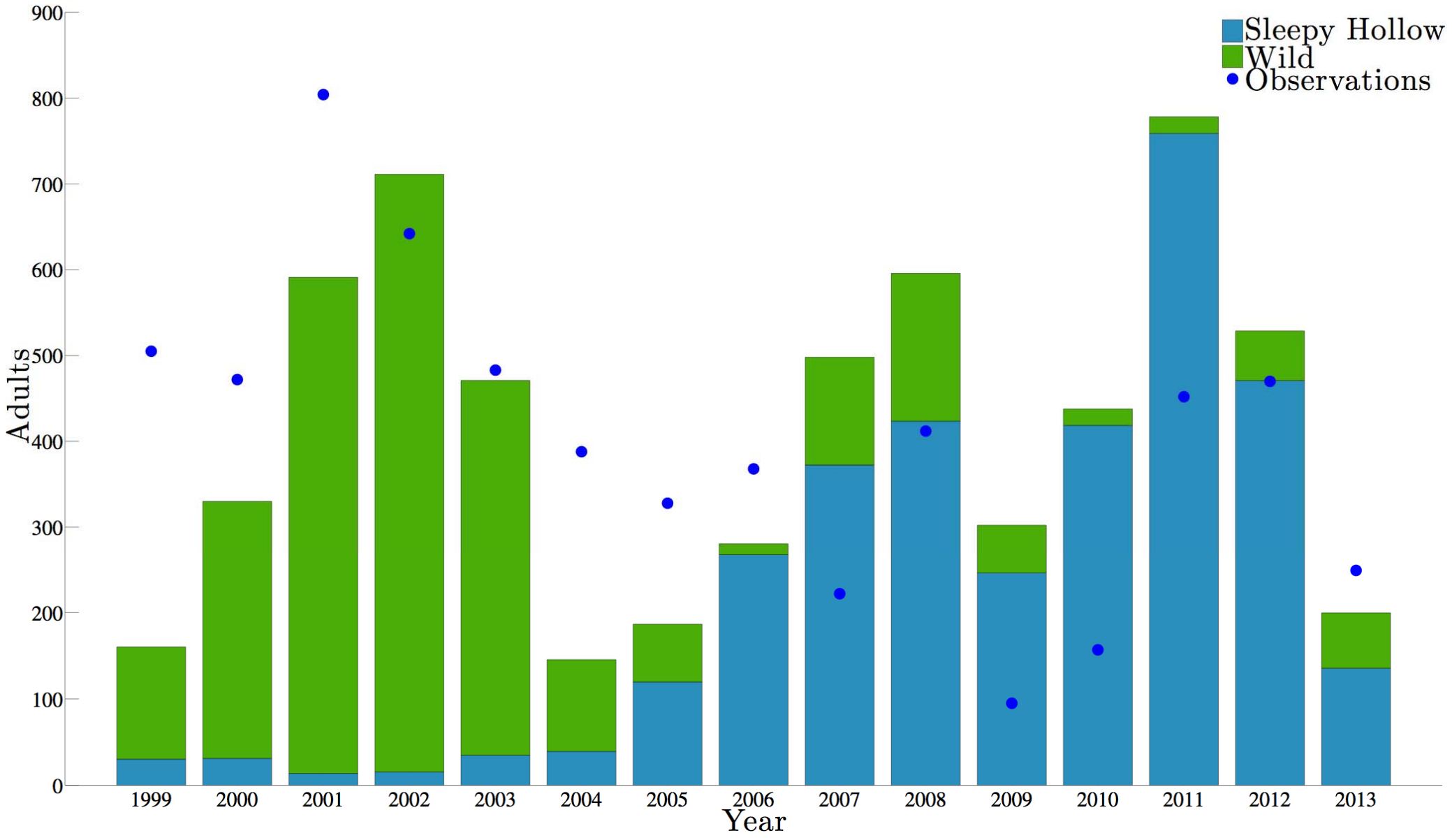
Length and Adult Returns



Predictions Based on Life History

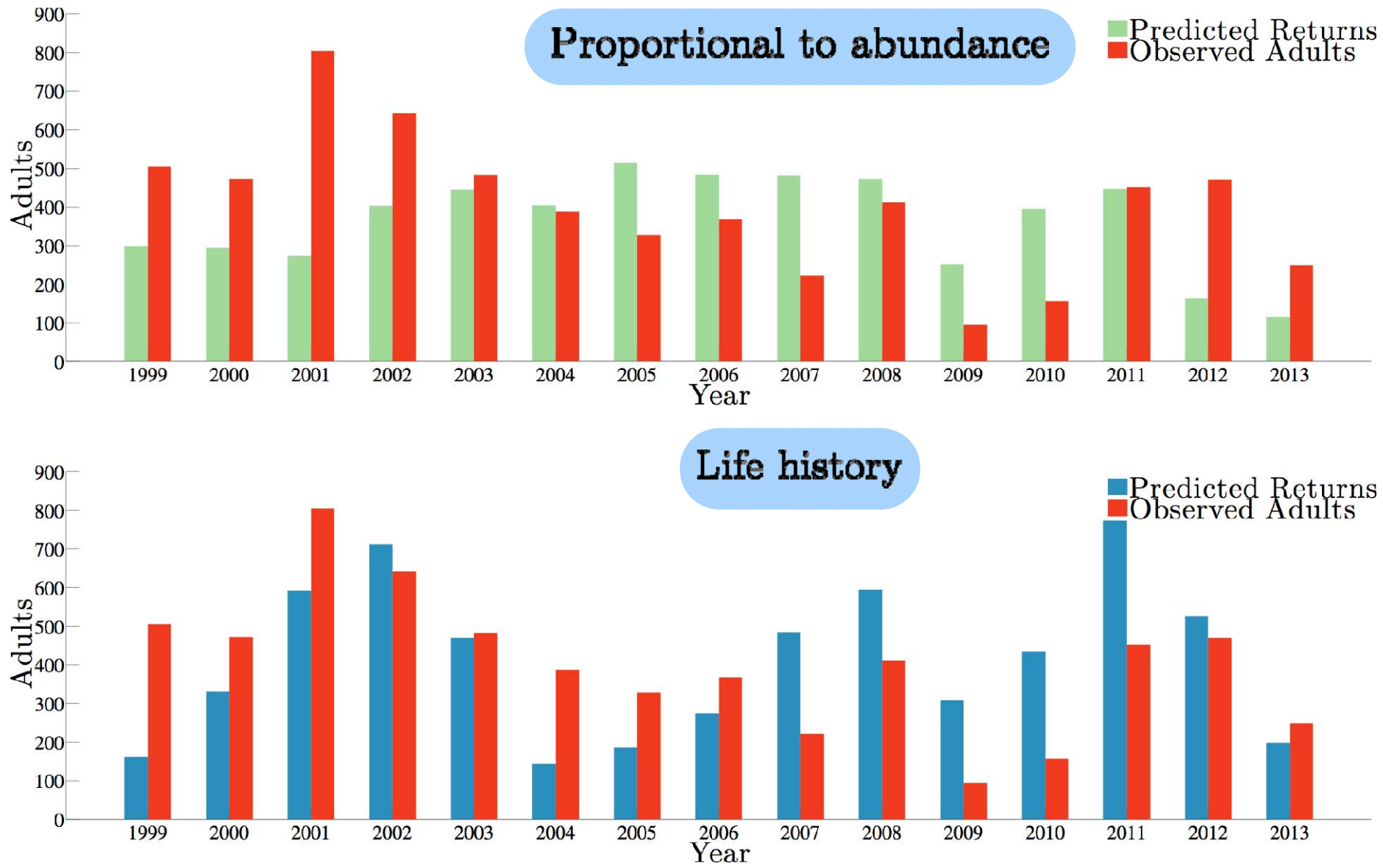


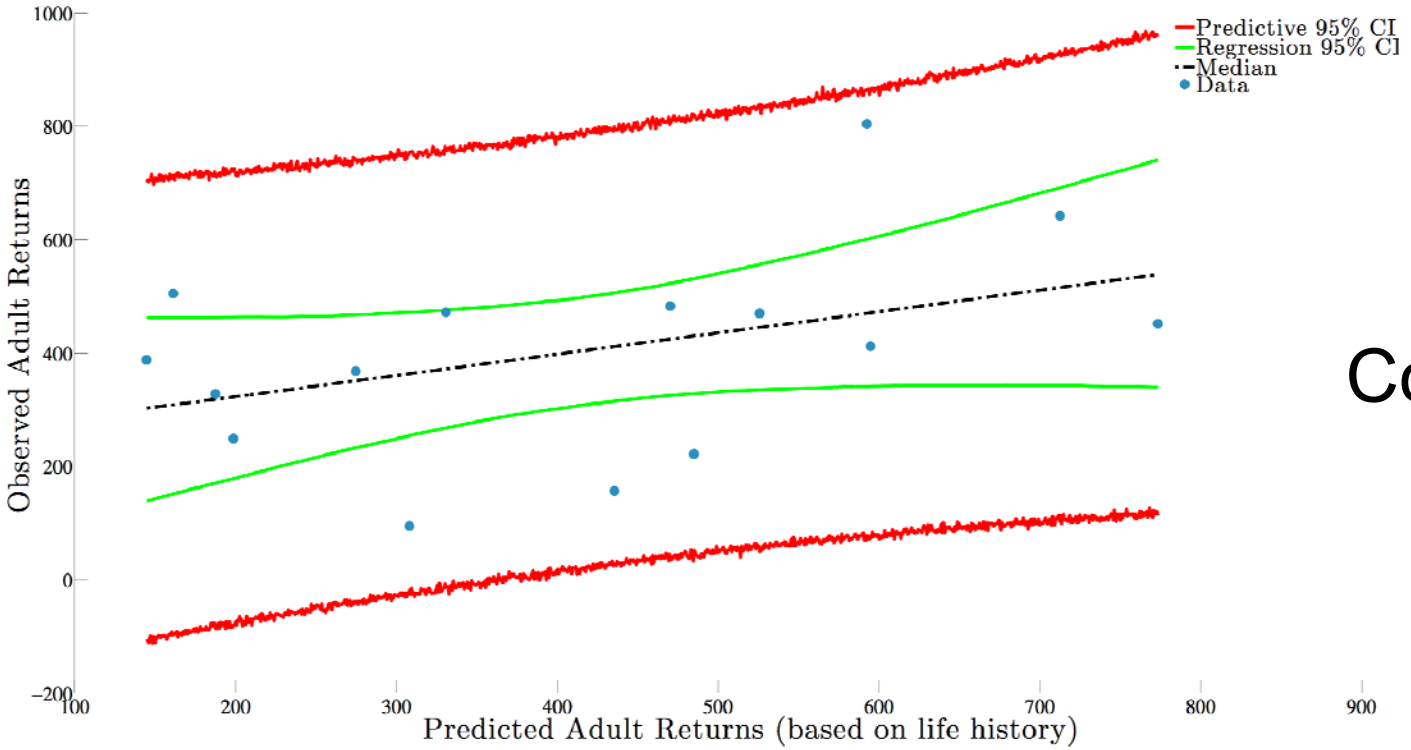
Predicted Composition of Adult Returns



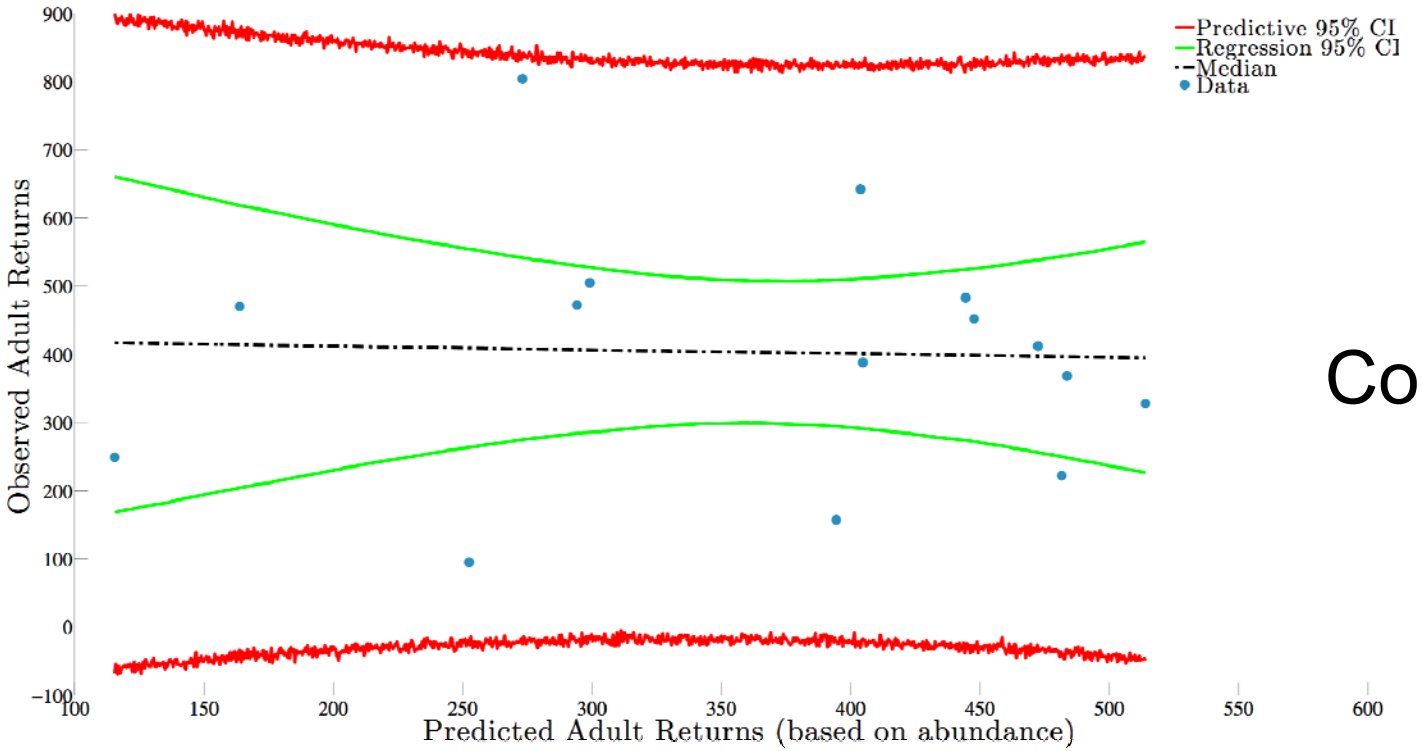
Have we gained anything by including individual life history?

Total Relocations





Correlation=0.42



Correlation=0.025

Conclusions

- The Carmel River may be experiencing a change in environmental regimes
- There has been a shift in composition of returning adults from wild to reared individuals
- The inclusion of life history attributes allows us to make better predictions of the dynamics
- Our methodology is relatively robust to our assumptions