# Restoration of Anadromy

## Recovering Lost Migratory Behavior in Coastal Fishes

2016 Pacific Coast Steelhead Management Meeting
Asilomar, CA

Corey Phillis, MWD
March 9, 2016

Photo Credit: Morgan Bond

# Collaborators

Jon Moore
Simon Fraser University

Eric Palkovacs
UC Santa Cruz

George Pess
Northwest Fisheries Science Center

Michael Beakes
Southwest Fisheries Science Center

Corinna Favaro
Simon Fraser University

Holly Nesbitt
Simon Fraser University

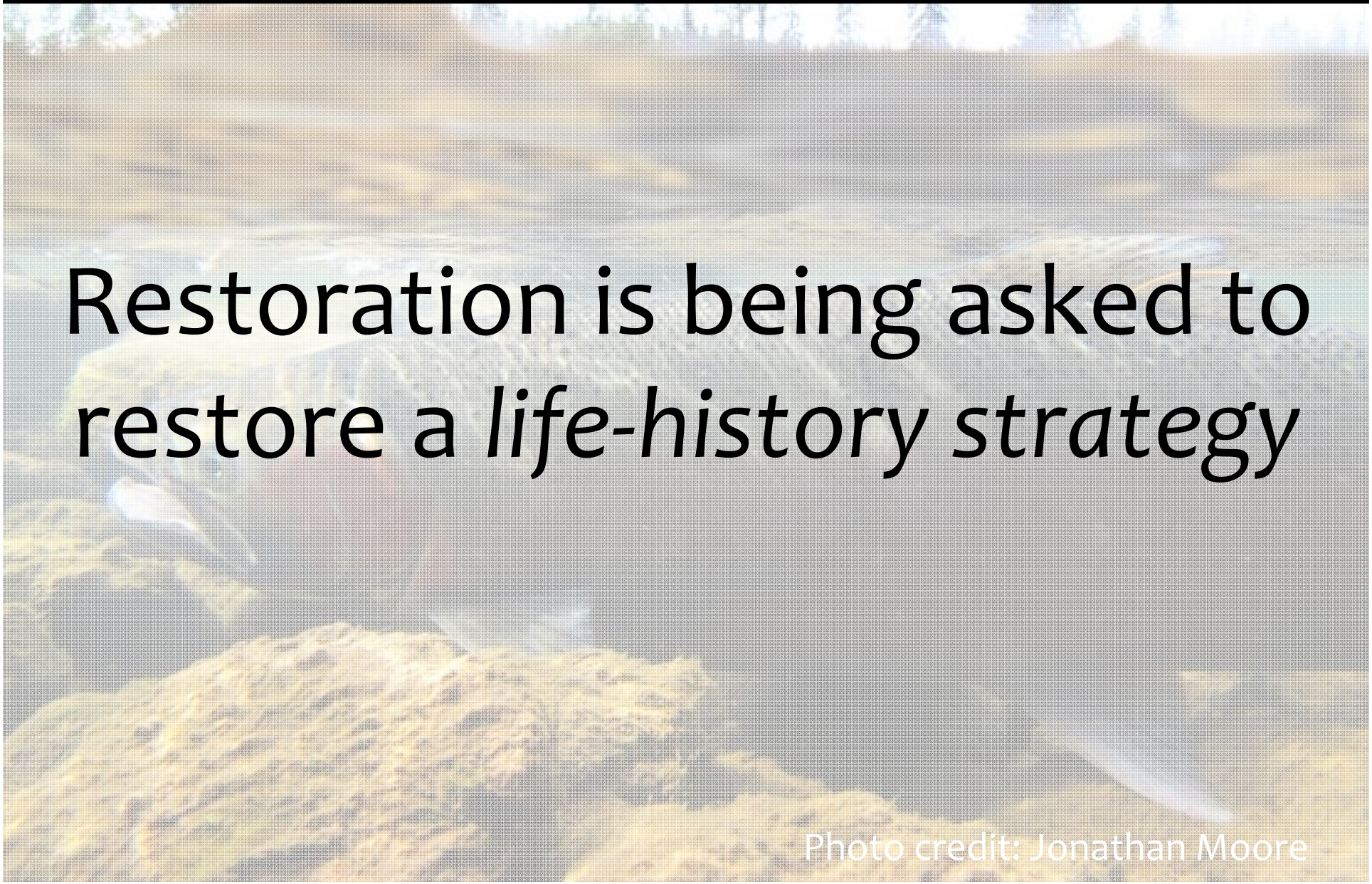
# Restoration is being asked to restore a *life-history strategy*

# Restoration of Anadromy

Losses of migratory behavior have become widespread

Photo credit: Jonathan Moore

# Restoration of Anadromy



Restoration is being asked to restore a *life-history strategy*

Photo credit: Jonathan Moore

# Restoration of Anadromy

Migratory life histories are controlled by genetic and environmental factors

Photo credit: Jonathan Moore

# 3 Pathways to Restore Anadromy

1) Re-Colonization
2) Re-Expression
3) Re-Evolution

Photo credit: Jonathan Moore

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These pathways work together but on different timescales

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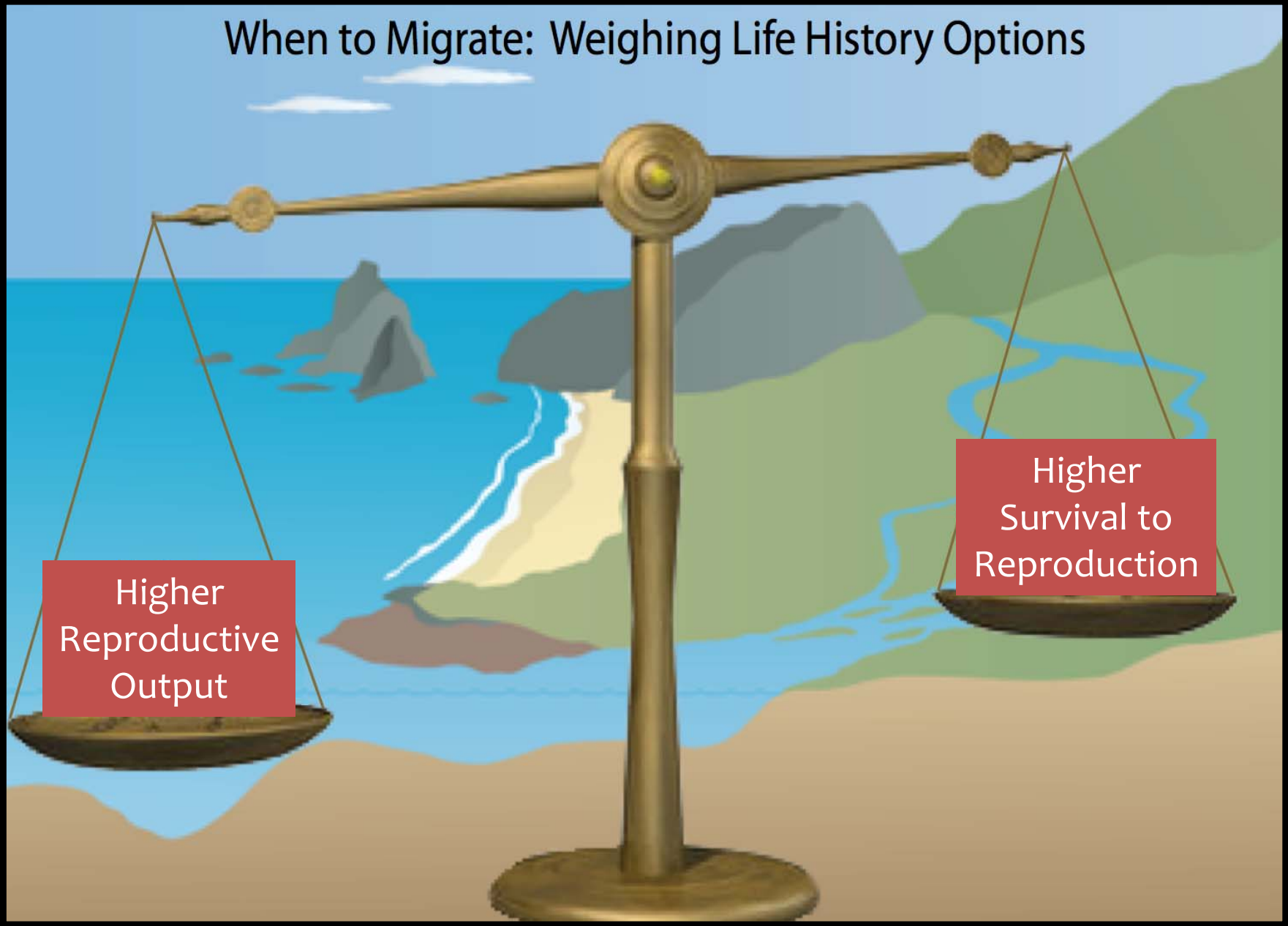
# Restoration of Anadromy


When to Migrate: Weighing Life History Options
Higher Reproductive Output
Higher Survival to Reproduction

# Controls on Anadromy

## Genetic

Genetic variation associated with differentiation above and below barriers to anadromy

- Pearse et al 2009, 2014

Heritability of migration

- Thrower et al 2004
- Phillis et al 2016

# Controls on Anadromy


## Environment

Anadromy is expressed when resources become growth-limiting

Temperature

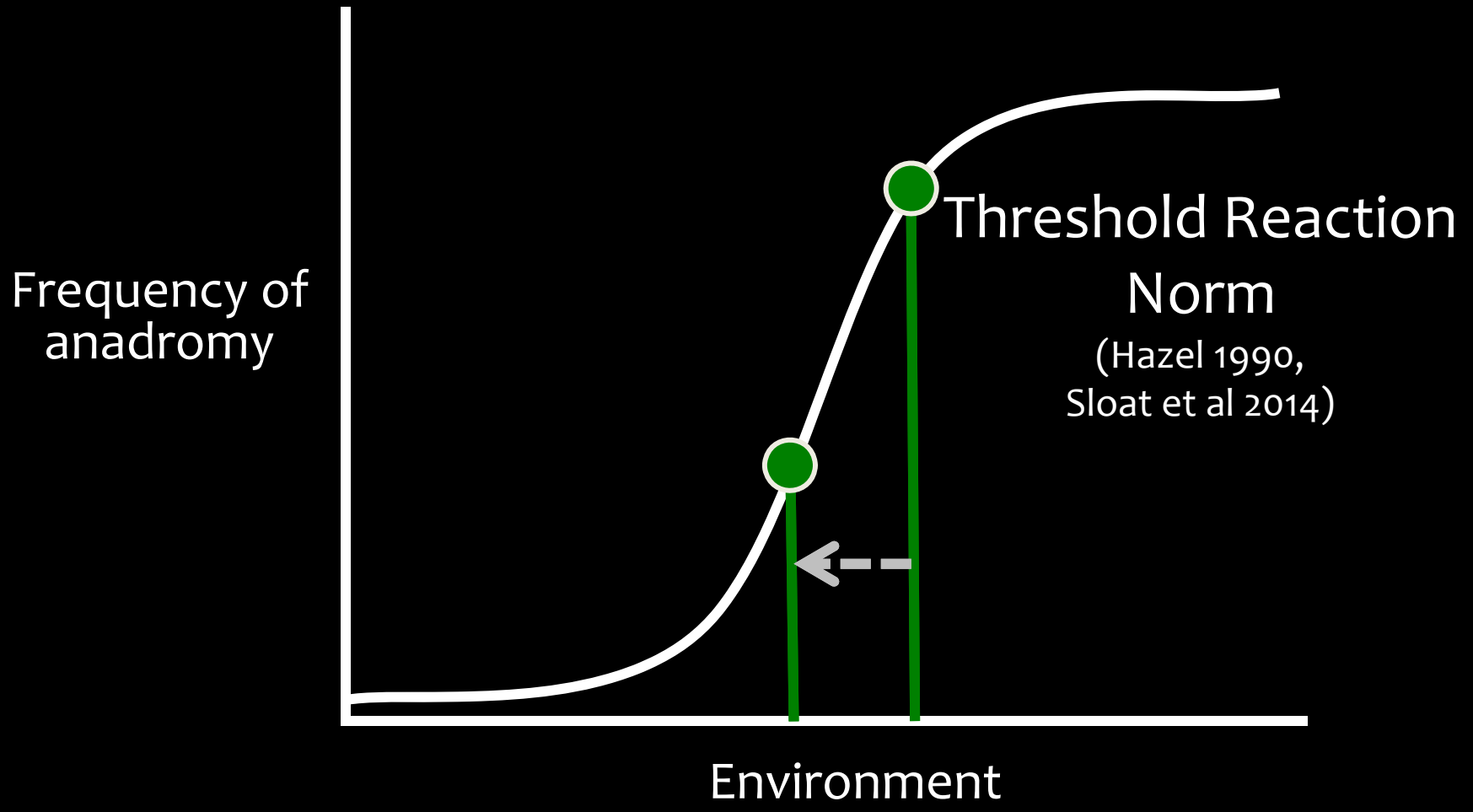
Food

Density

(Sloat et al 2014, Kendall et al 2015)

# Controls on Anadromy

**Genetic** X **Environment**



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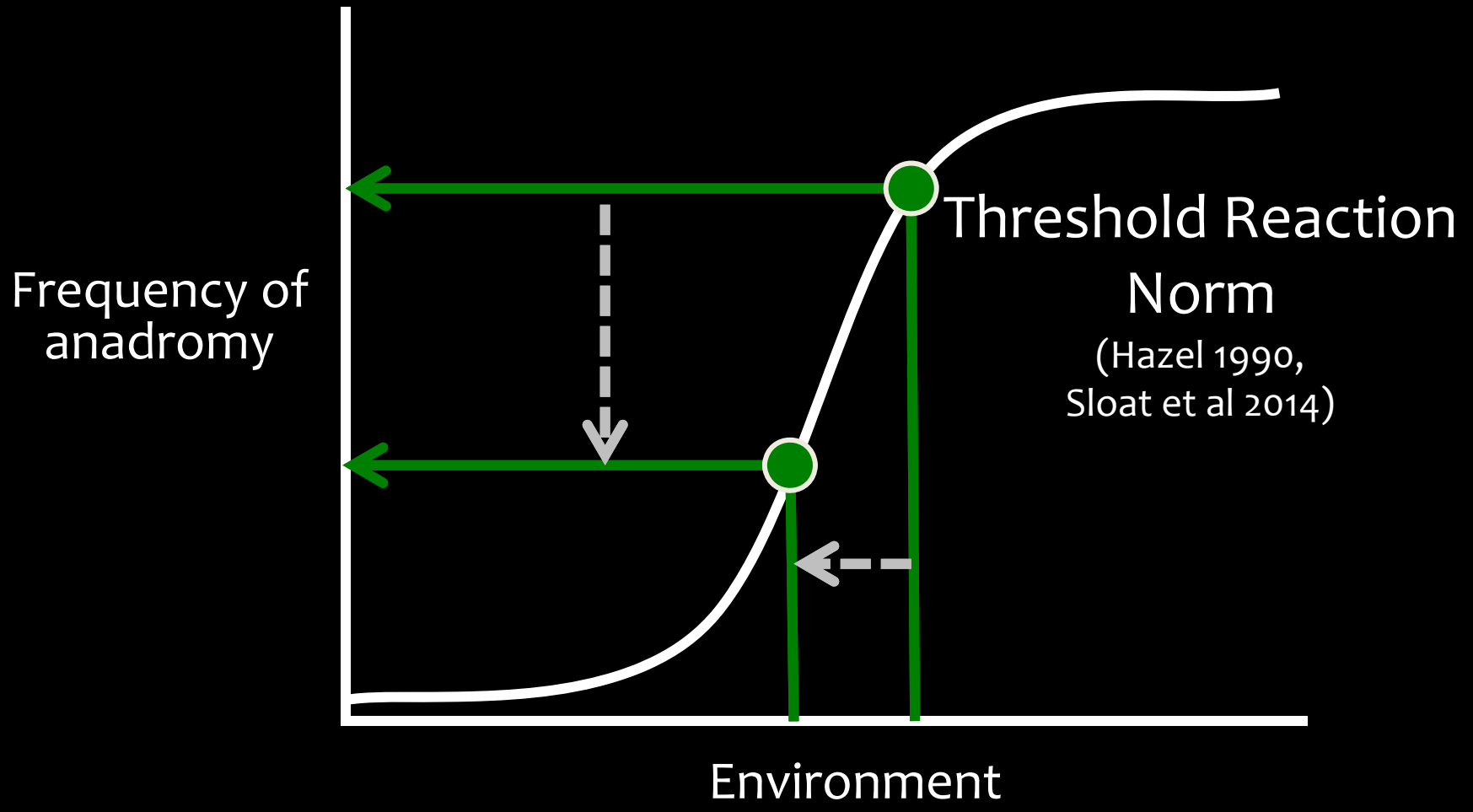
**Genetic** X **Environment**



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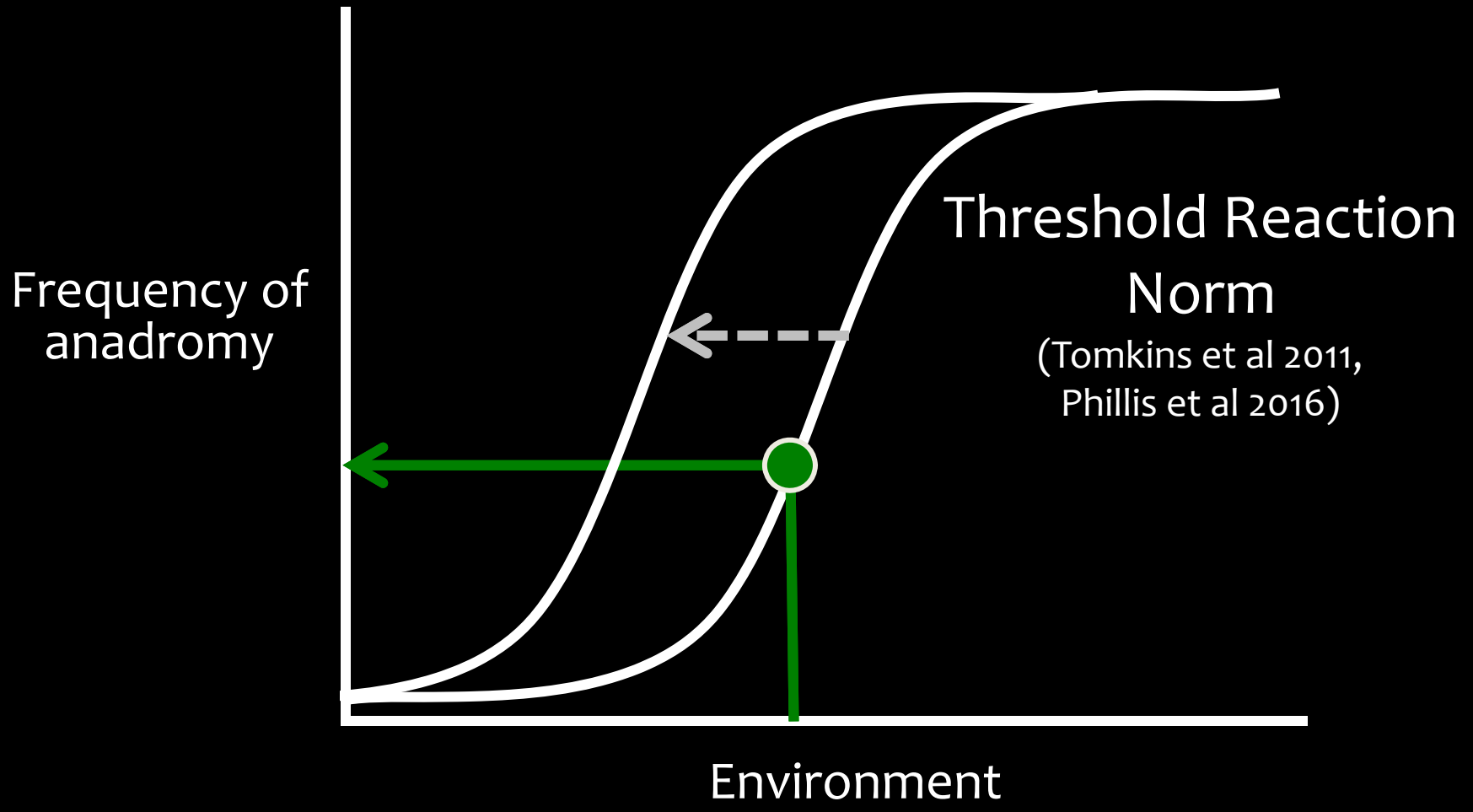

# Controls on Anadromy

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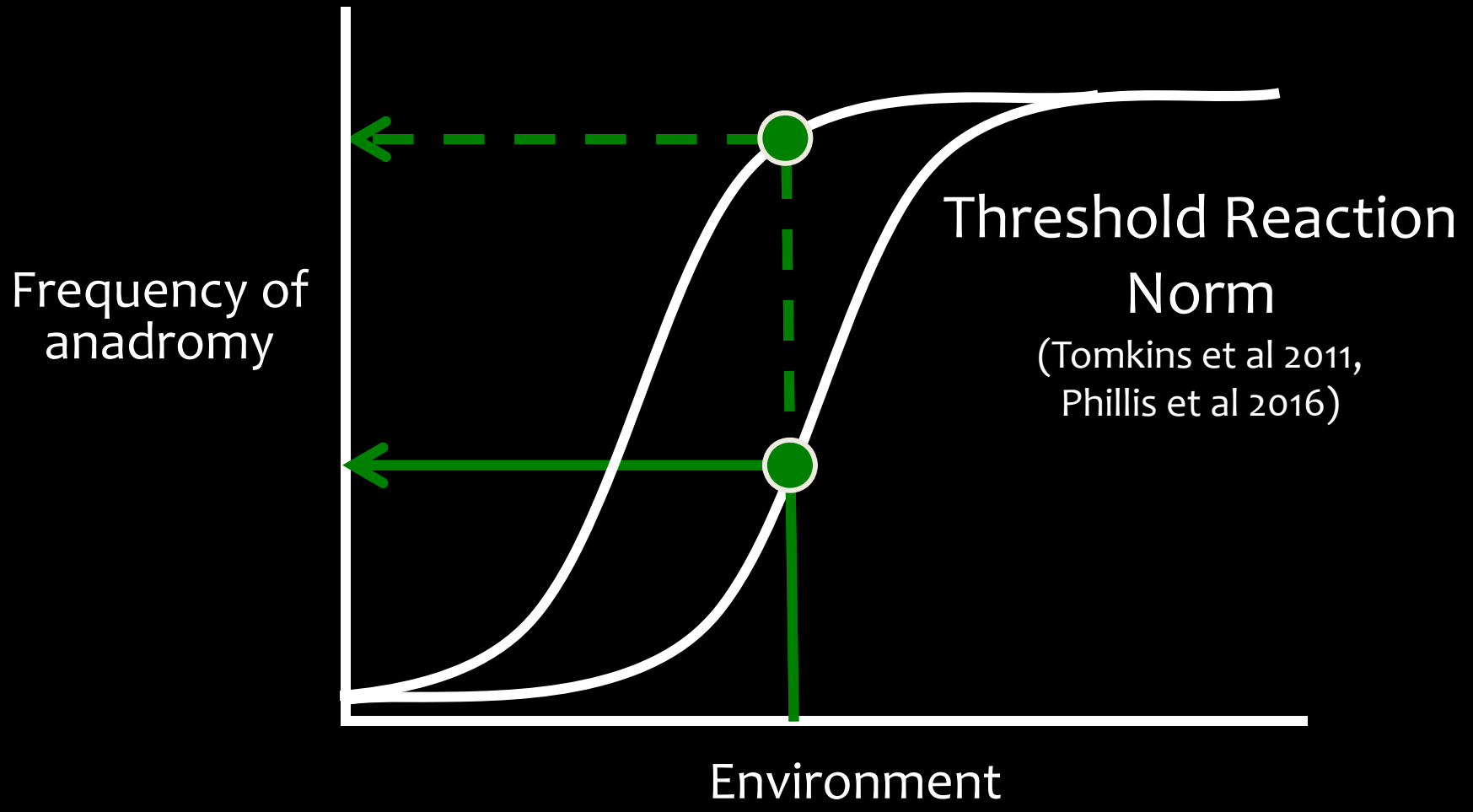

# 3 Pathways to Restore Anadromy

1) Re-Colonization

2) Re-Expression

3) Re-Evolution

Photo credit: Jonathan Moore

# Re-Colonization

Early colonists experience little density dependence, potentially extremely high fitness

May also lack key traits such as the timing of life-history events that match well with the new environment

Re-colonization will go in concert with re-evolution of associated locally adapted traits

# Re-Colonization

1. In-basin colonists via straying
    1. Timescale on the order of years to decade
    2. Probability of strays reaching a given habitat area is a function of distance to a source population as well as the size of the source population
2. Stocking from out-of-basin
    1. Timescale can be quick (subject to mgmt. decisions)
    2. Lack local adaptations
    3. Largely unsuccessful to date
3. Bet-hedging mothers
    1. Timescale on the order of a single generation
    2. "Resident populations by themselves should not be relied upon to maintain long-term viability of an ESU."

-- (Salmon Recovery Science Review Panel, 2004)

# 3 Pathways to Restore Anadromy

1) Re-Colonization

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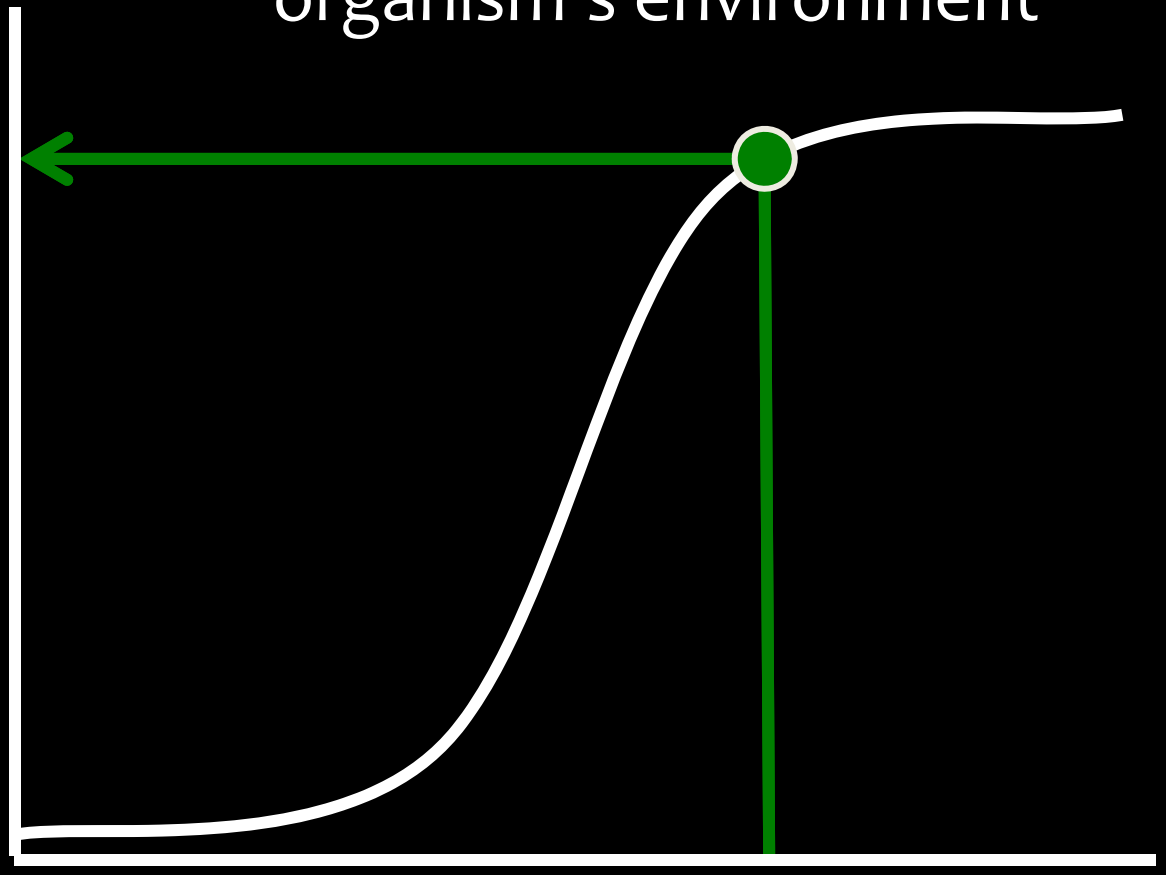
Photo credit: Jonathan Moore

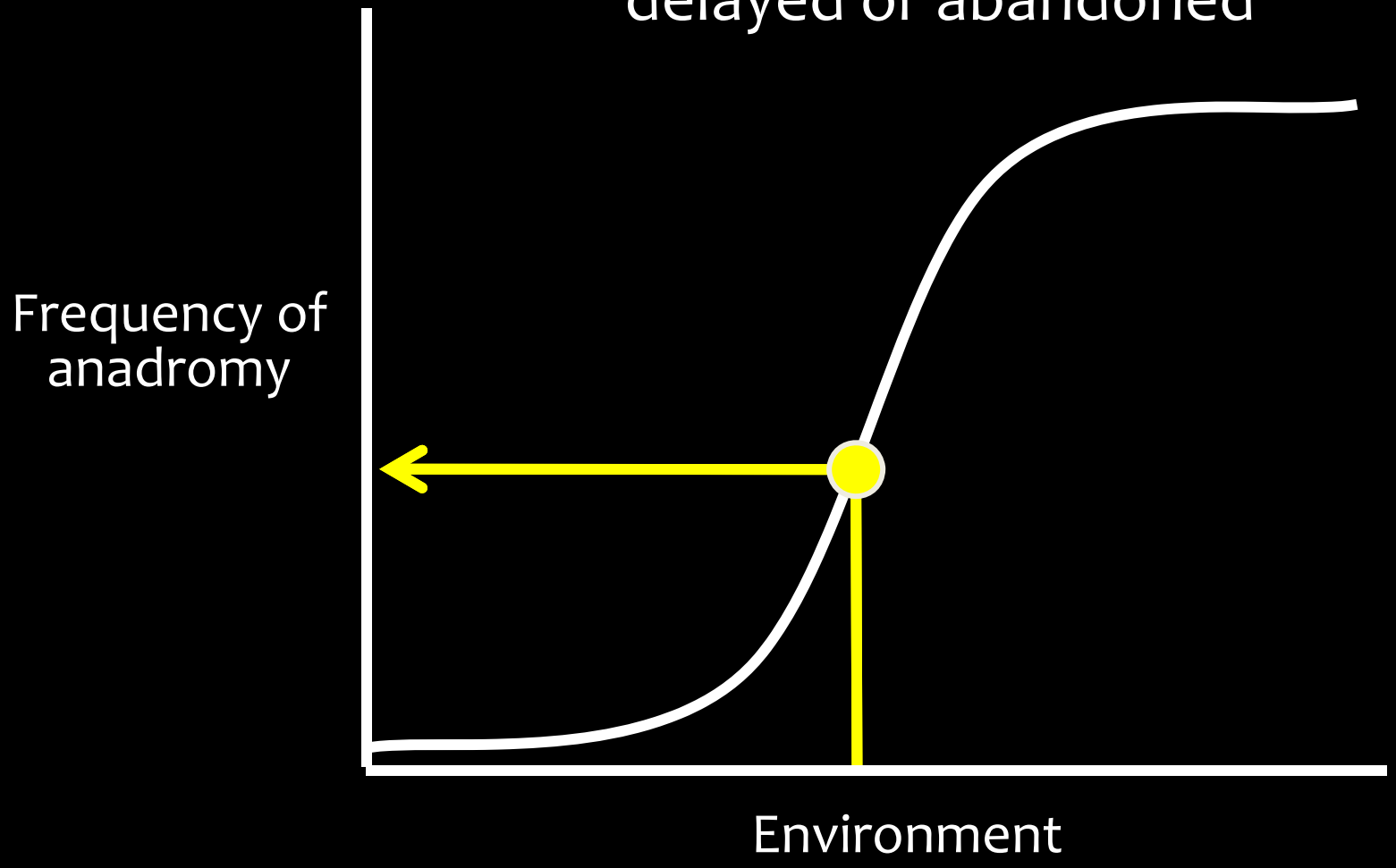
# Re-Expression

Onset of migration is cued by an organism's environment



# Re-Expression

If cues change, migration may be delayed or abandoned



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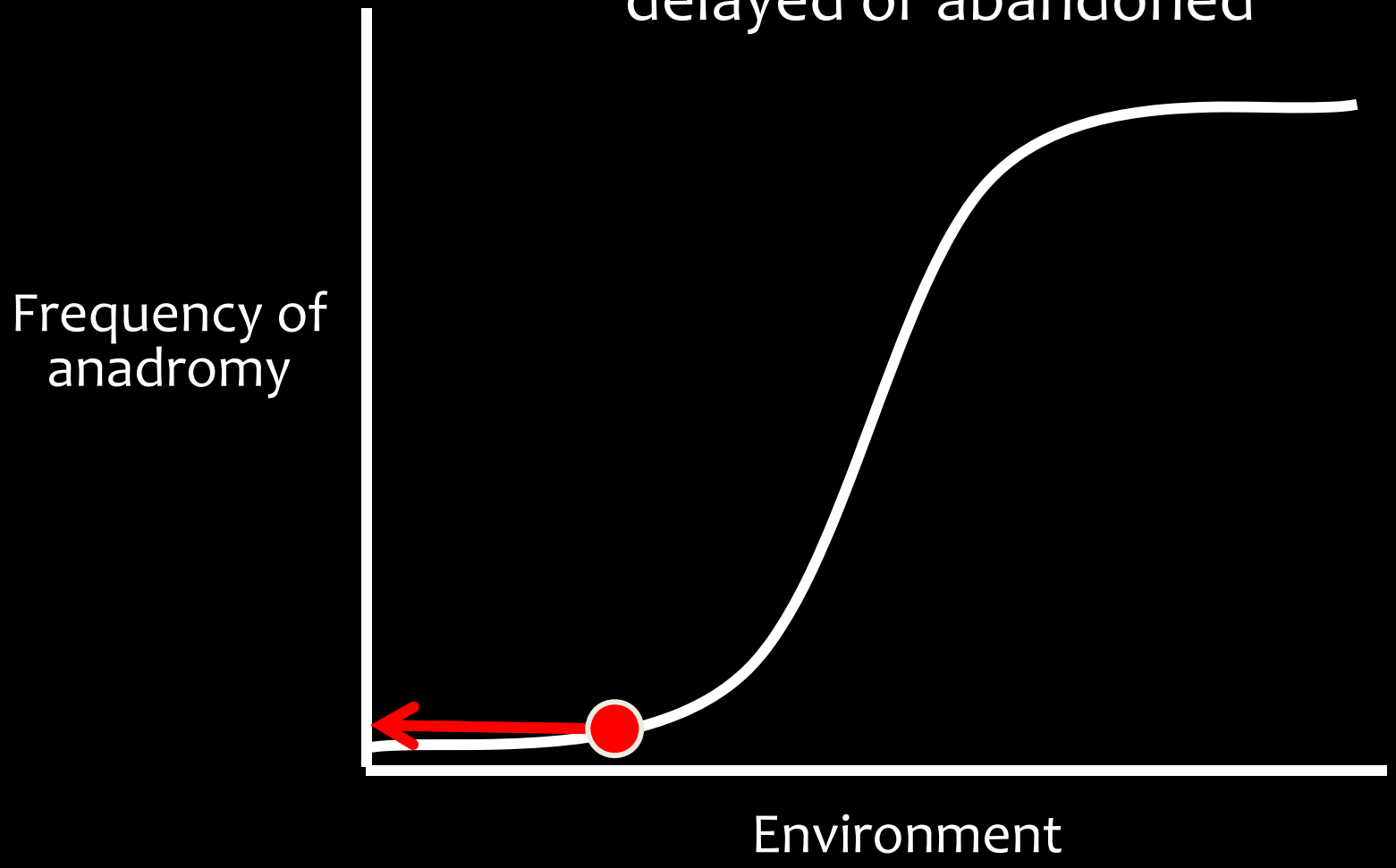
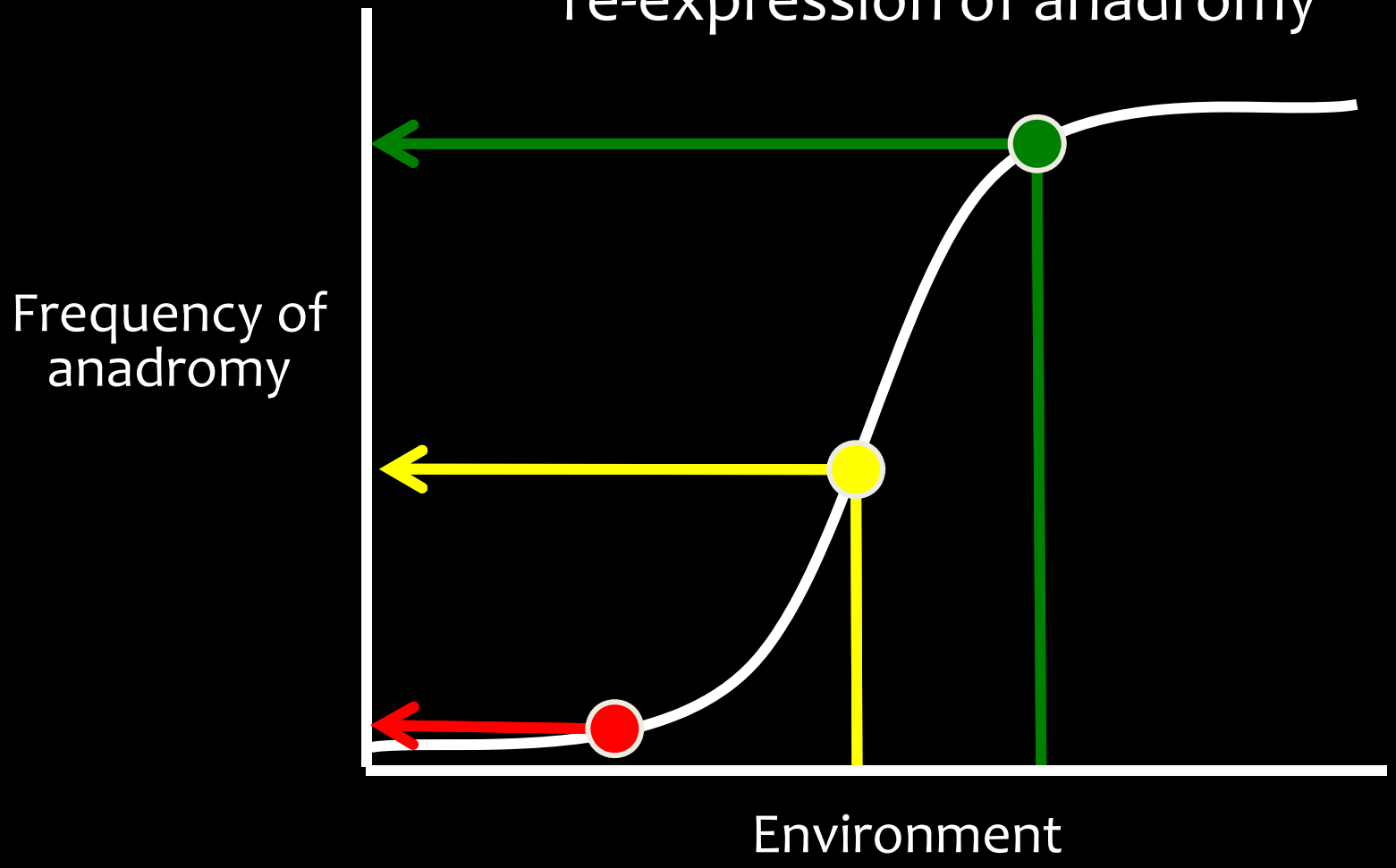


# Re-Expression

Restoring the environment will lead to re-expression of anadromy



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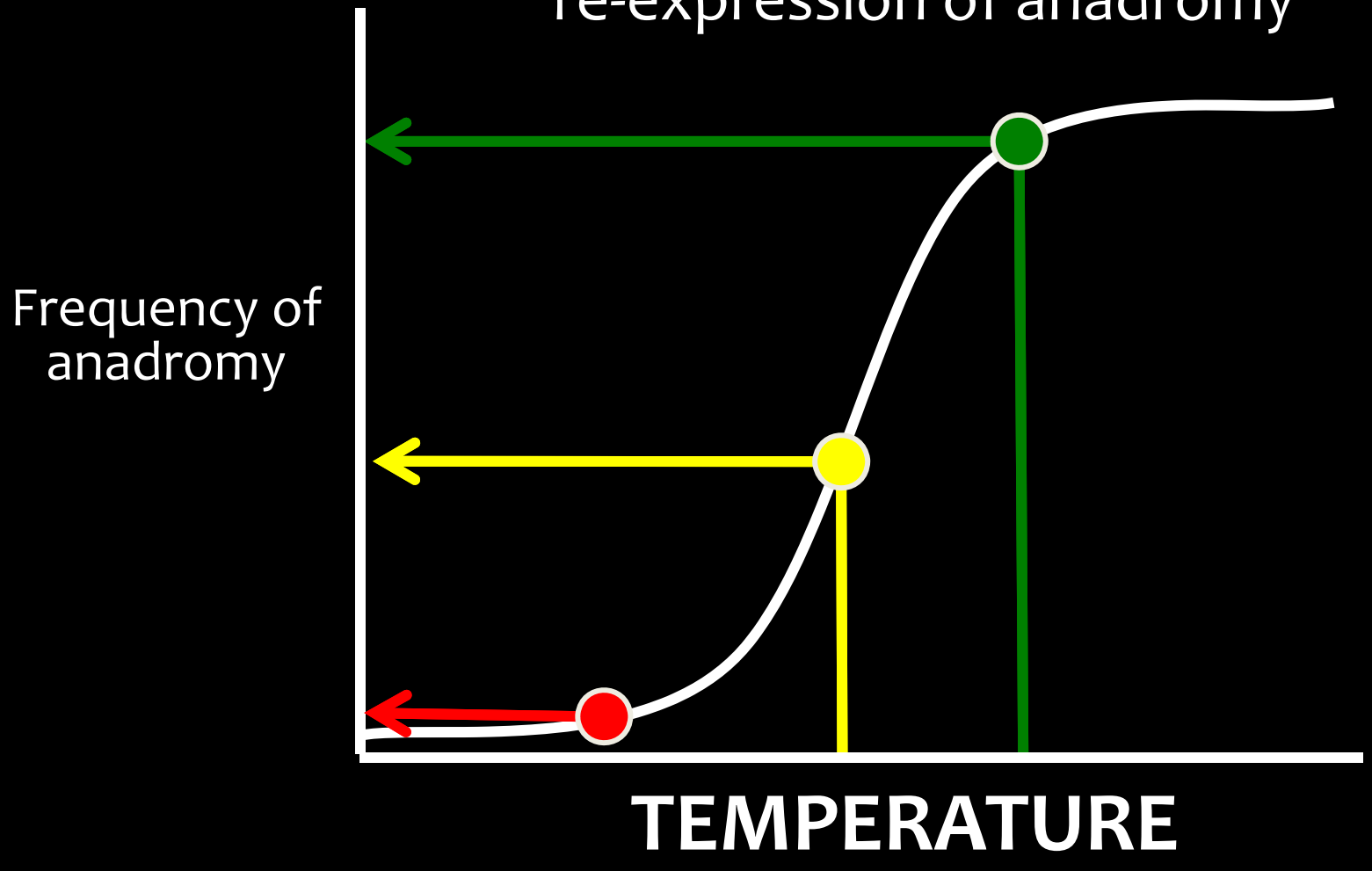

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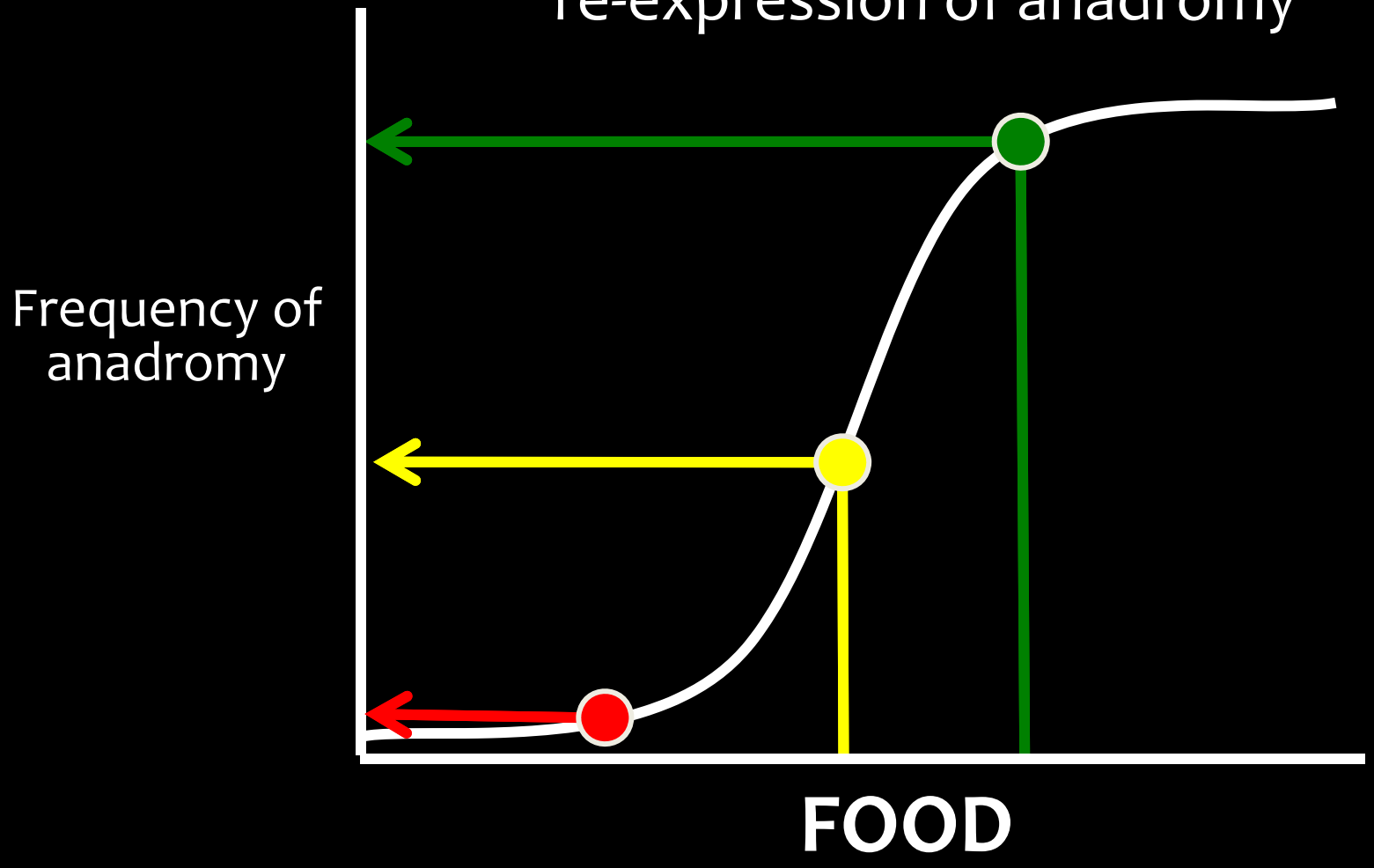

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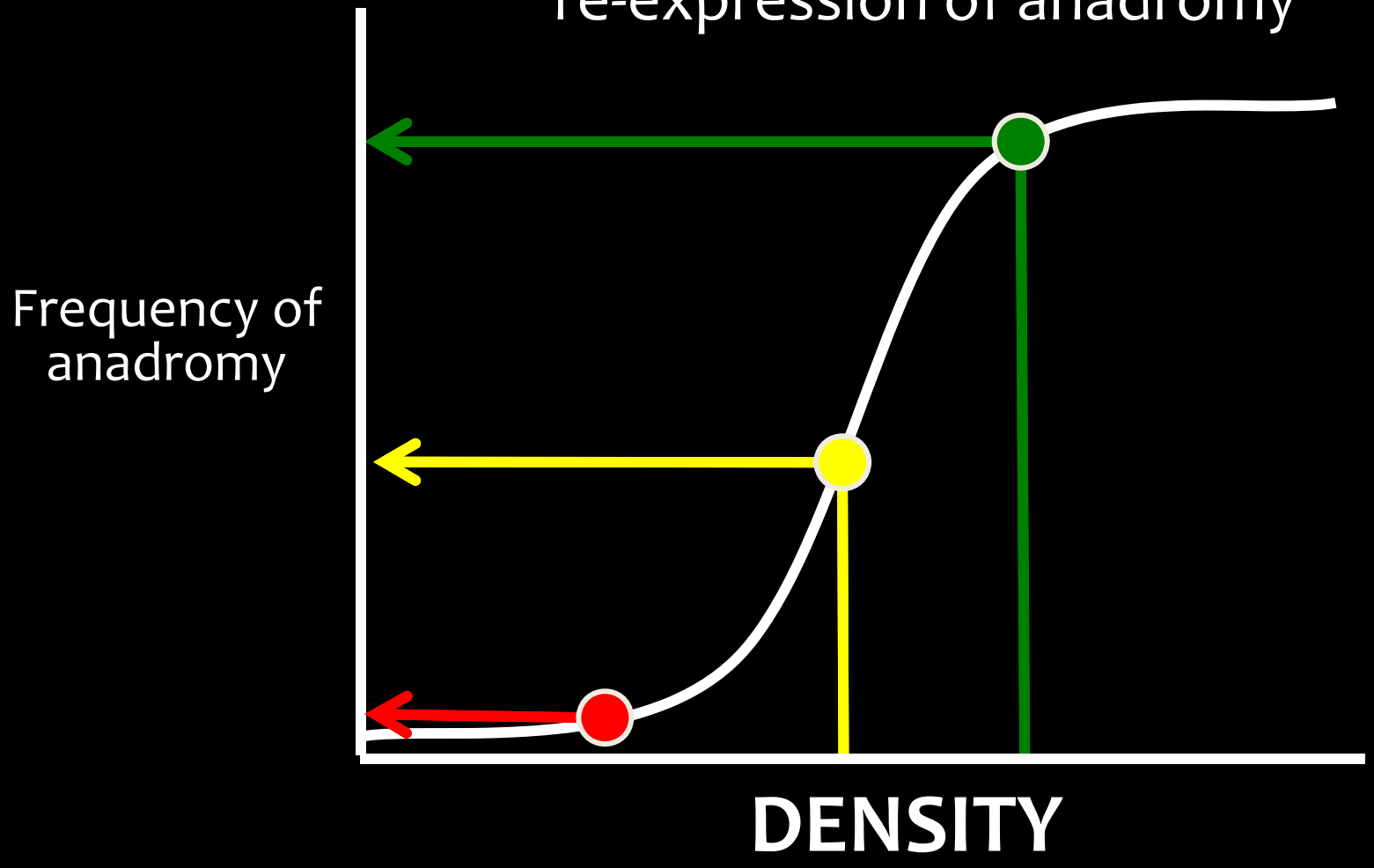
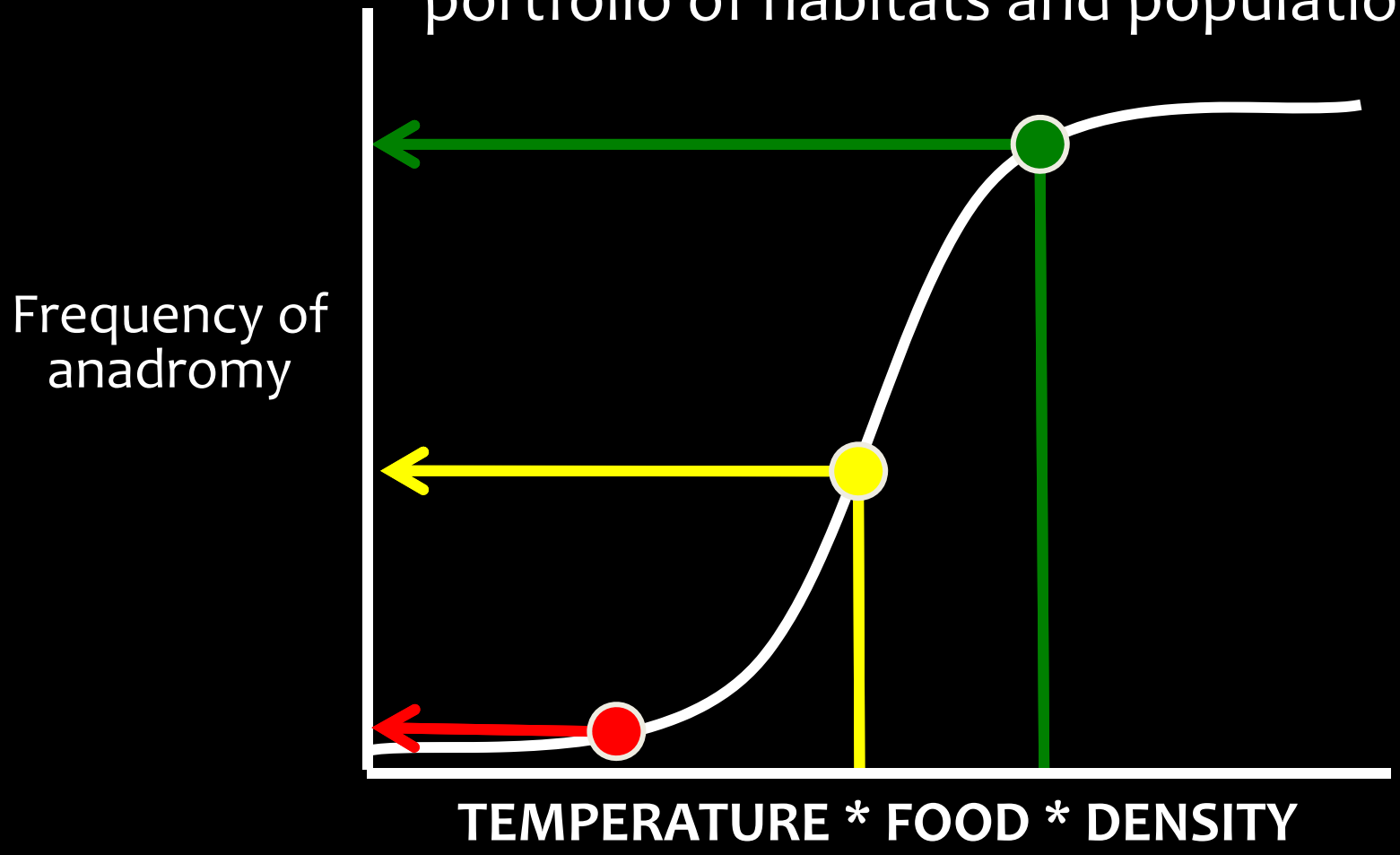


# Re-Expression

Re-expression requires a diverse portfolio of habitats and populations



# 3 Pathways to Restore Anadromy

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Photo credit: Jonathan Moore

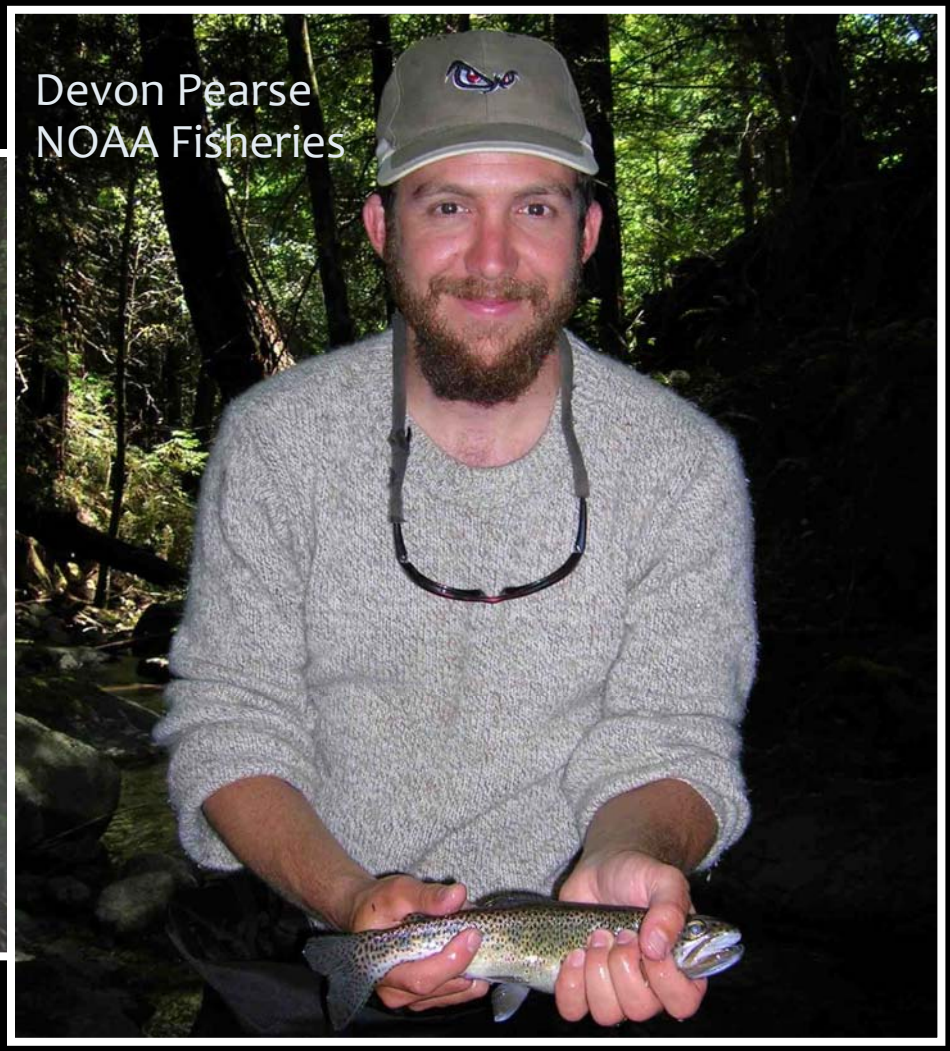
# Re-Evolution

1. Evolutionary loss of anadromy can occur on timescales that are relevant to managers

2. Re-evolution of anadromy from the resident form is possible, but the window of opportunity may be closing

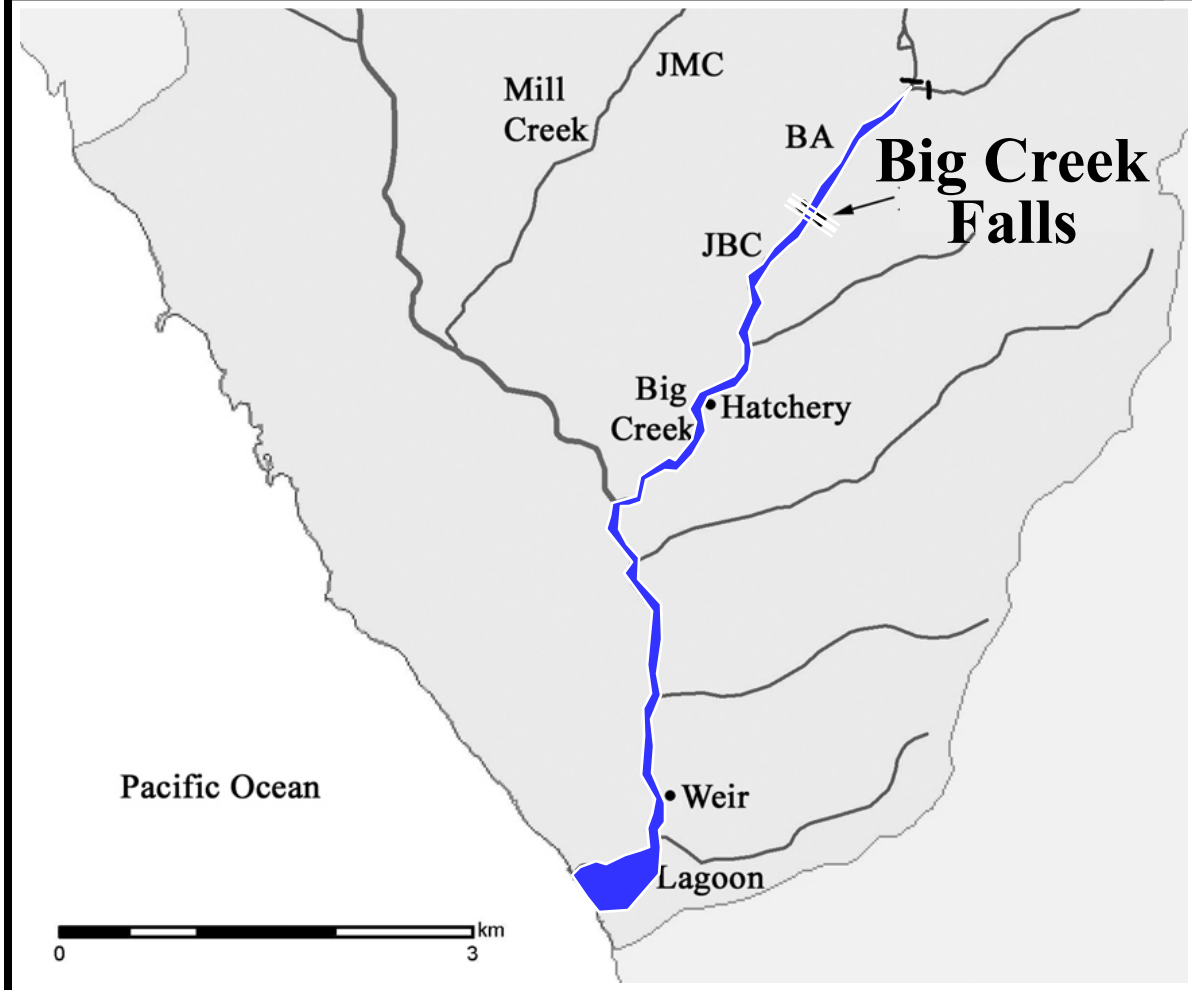
# Scott Creek Watershed, California

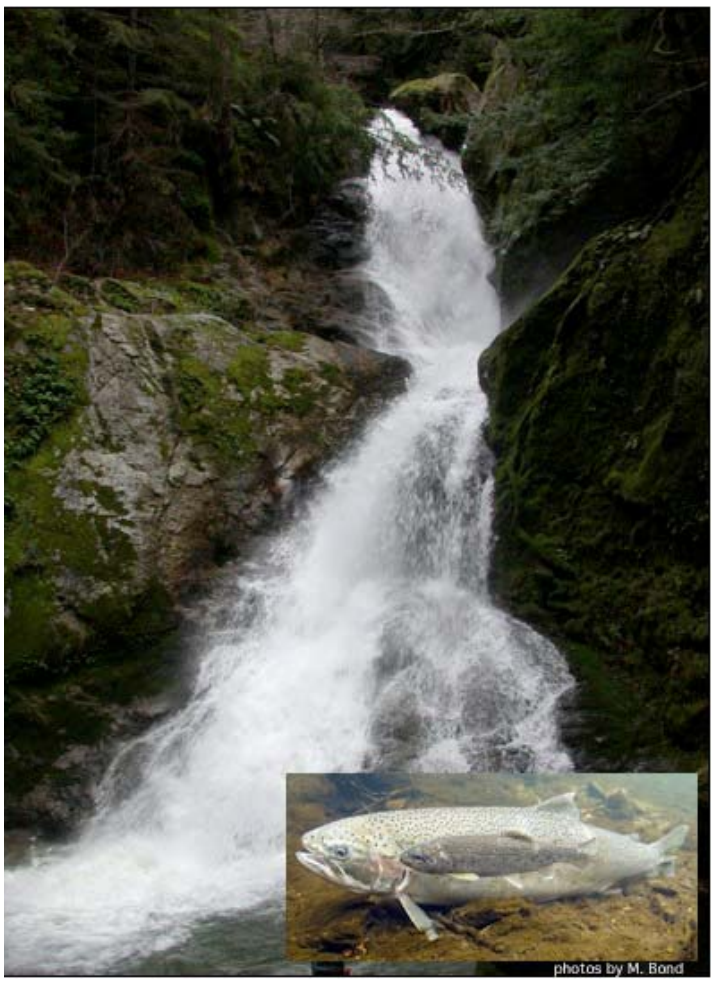

**Steelhead**




**Rainbow Trout**

# Study System: A natural experiment

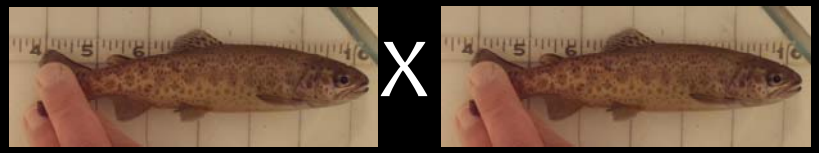



**In early 1900's *O. mykiss* below falls were introduced above a barrier waterfall**

# Controlled Breeding Experiment

Above Fall♀ X Above Fall♂

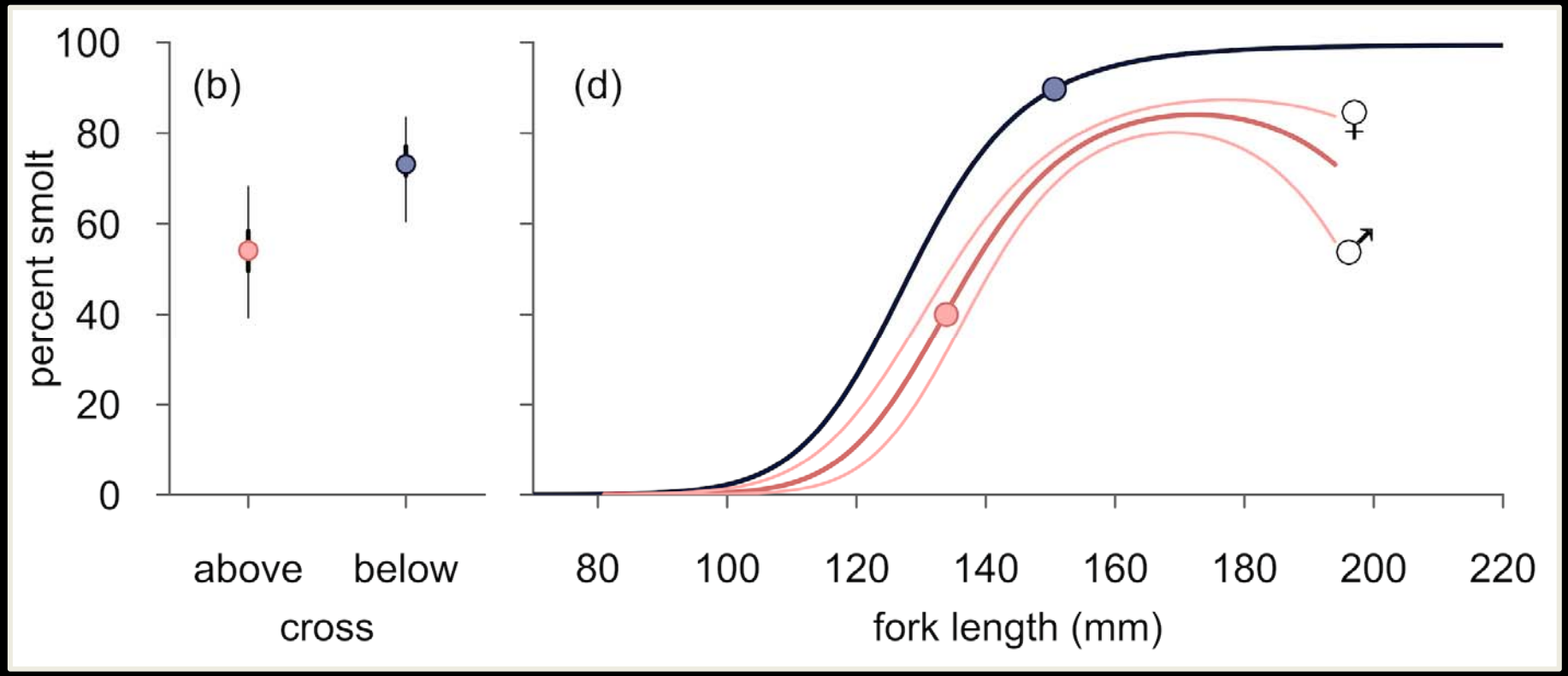


Below Fall♀ X Below Fall♂

# 1 year of Common Garden Rearing

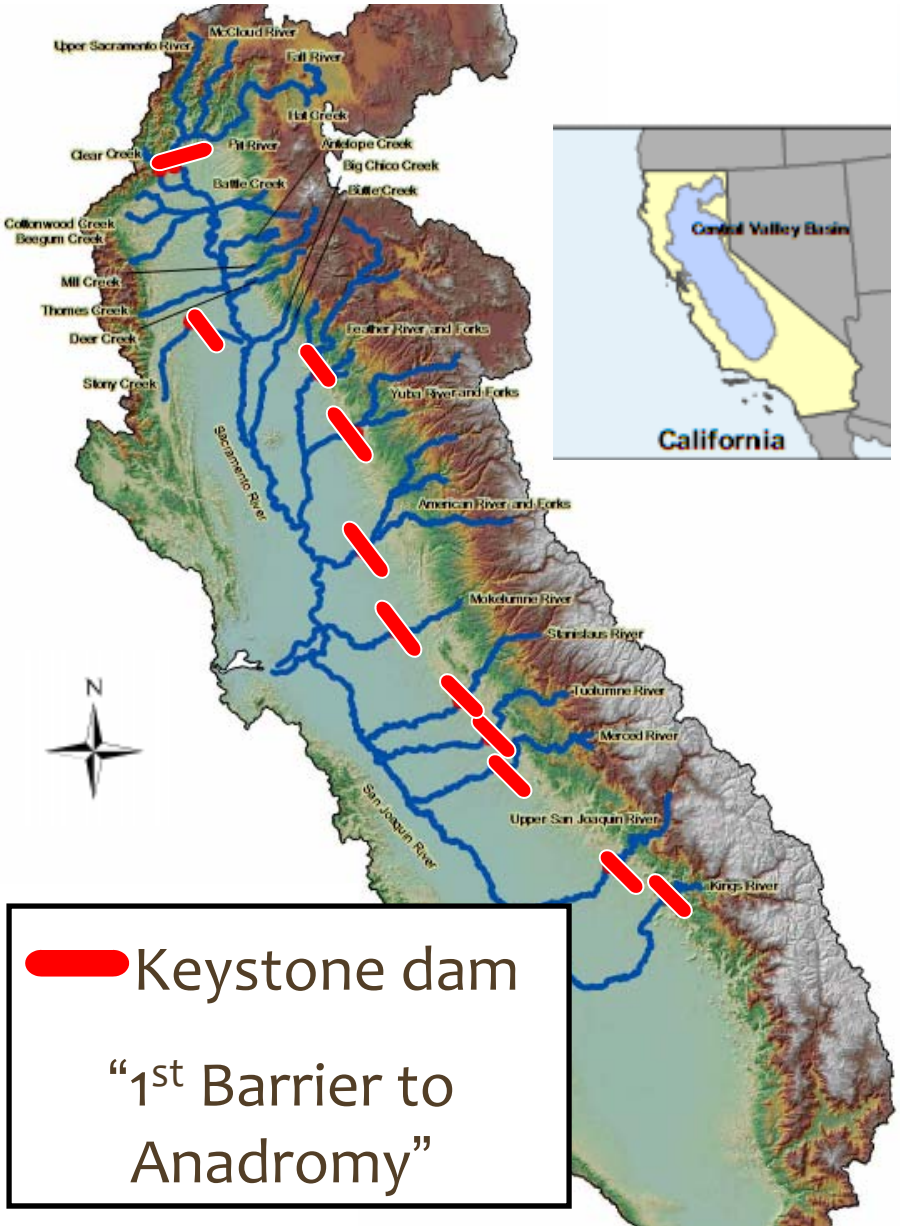
*Analyses presented are 'Animal Models' implemented in the R package MCMCglmm*

# Above Barrier Smolt Less & Are Larger When They Smolt




Phillis et al 2016 Journal of Heredity

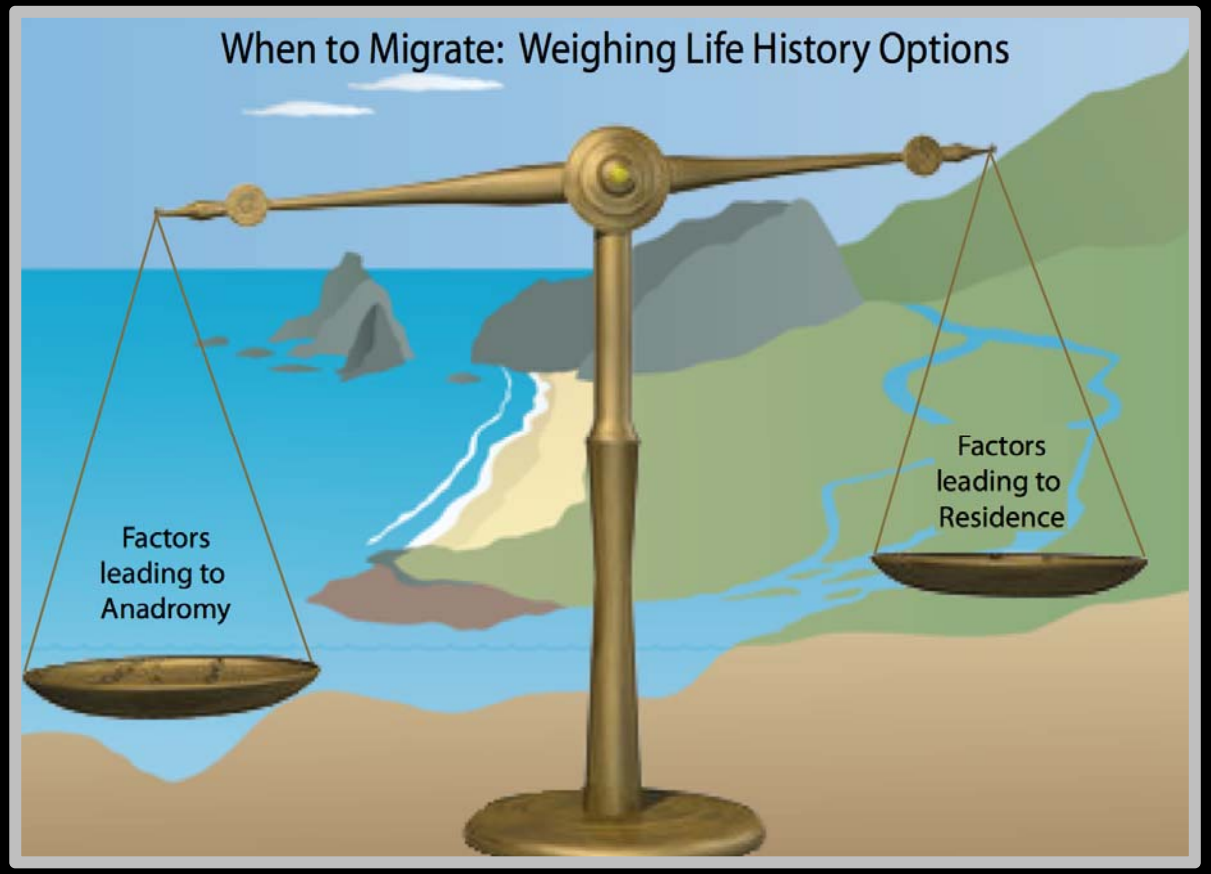
# Dams Create Landlocked Populations







# Novel Selection Against Anadromy




# The Fate Of Anadromy

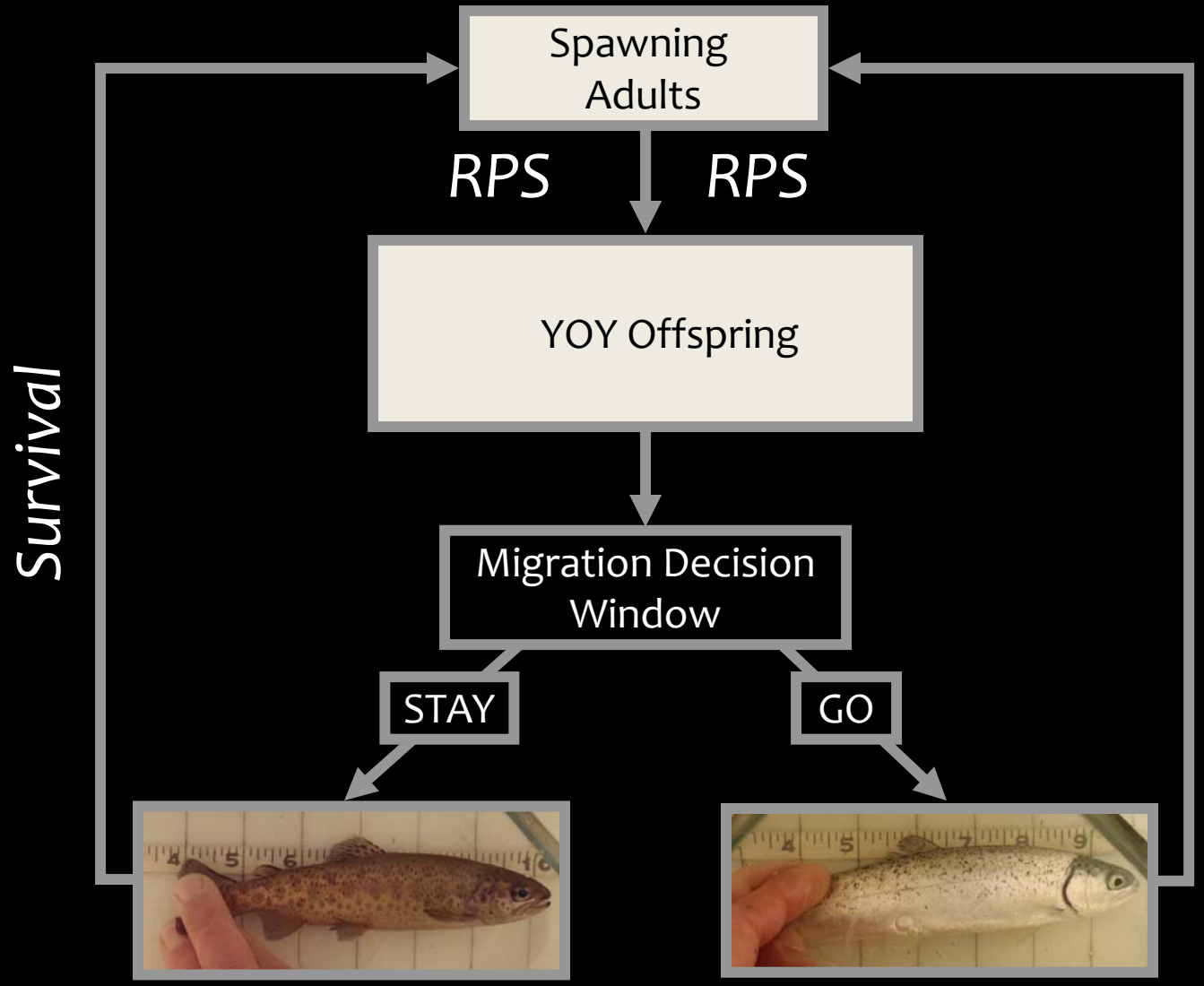
Can evolution rescue populations from extinction?

What is the fate of anadromy?

How long does it take for anadromy to re-evolve?

Photo credit: Jonathan Moore

# Evolution of Anadromy: An Individual Based Model Approach



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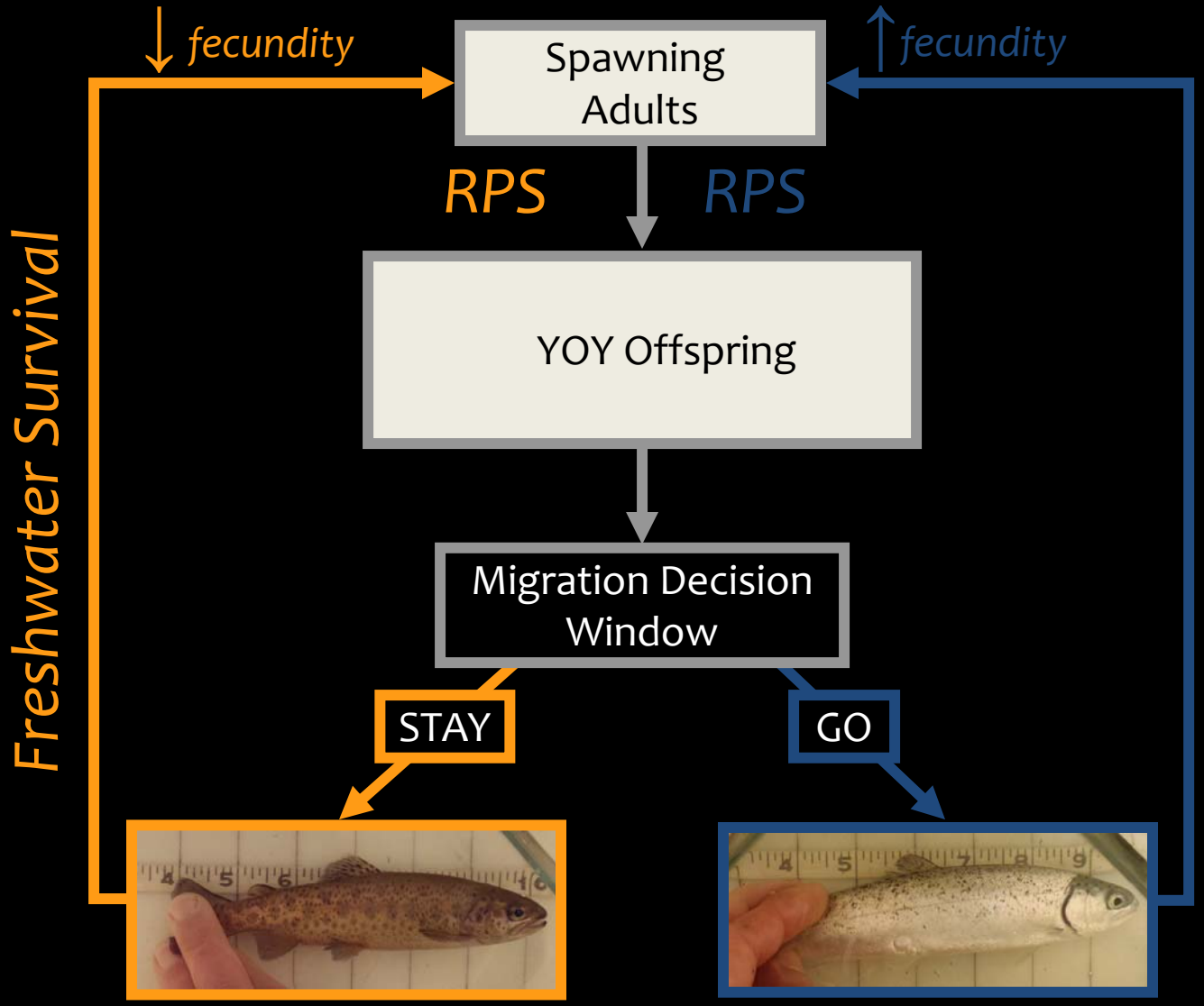
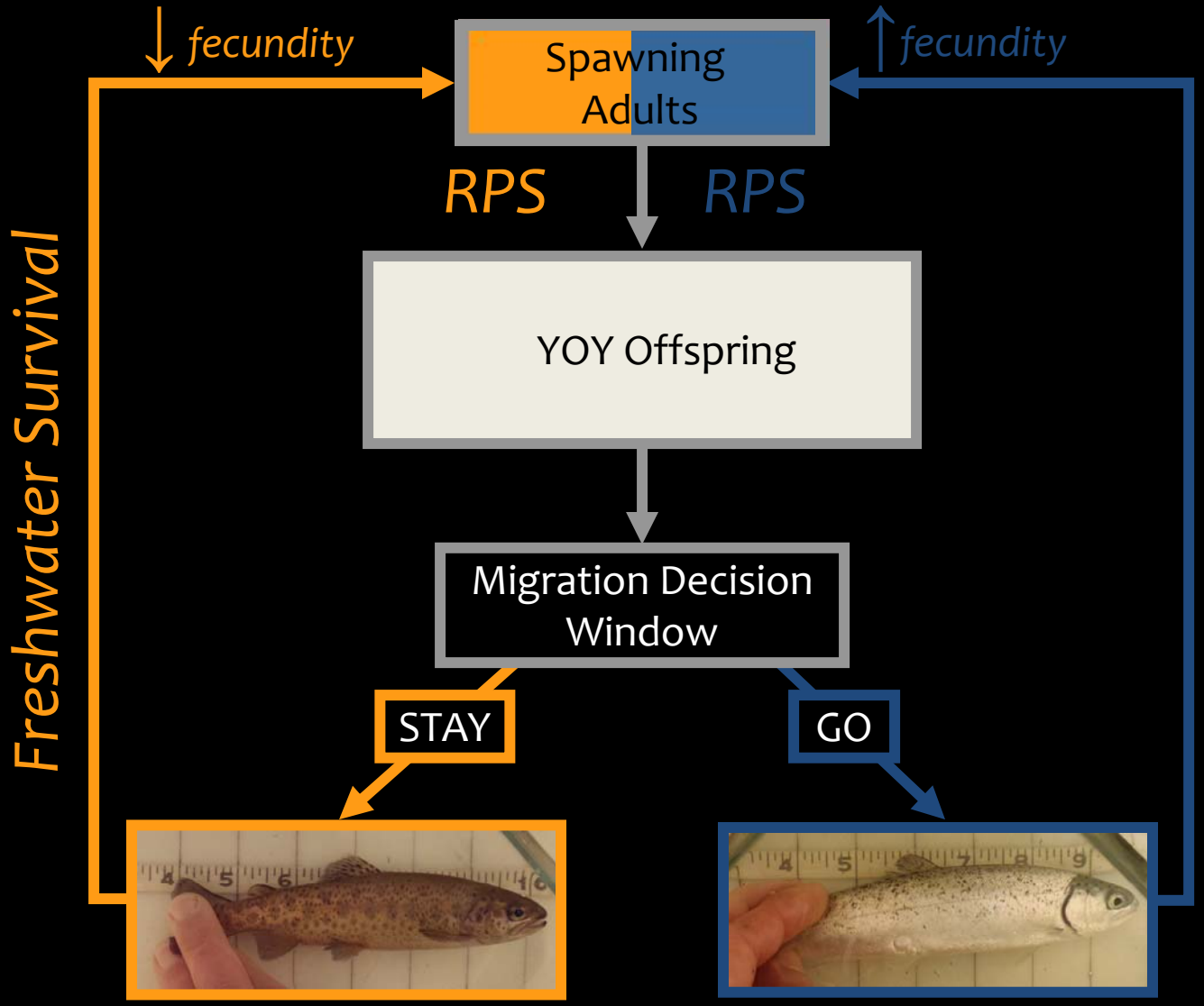
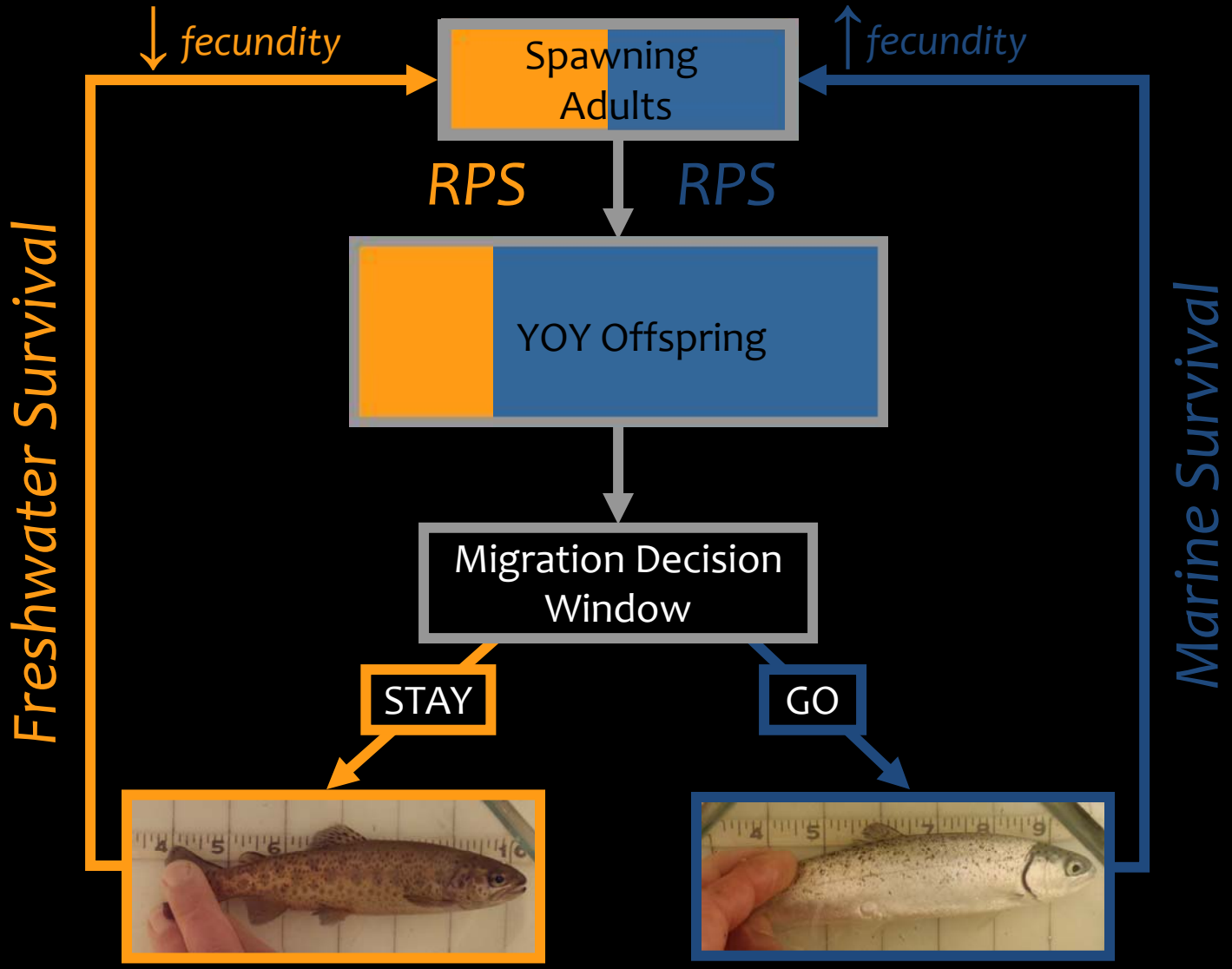


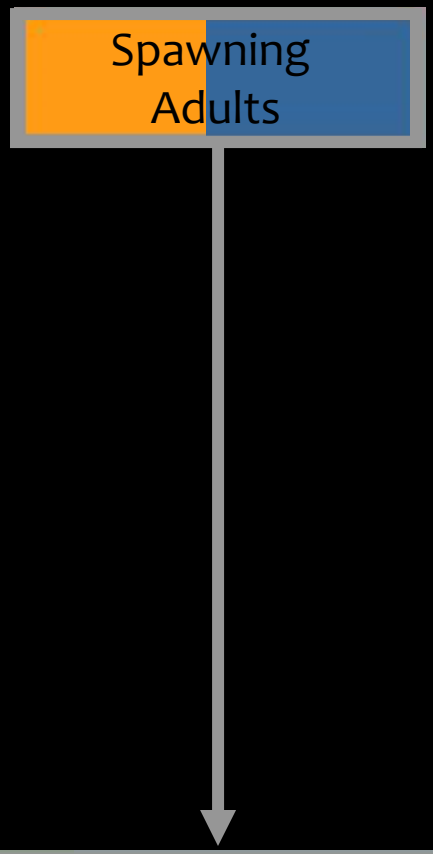
# Simulating Anadromy in *O. mykiss*

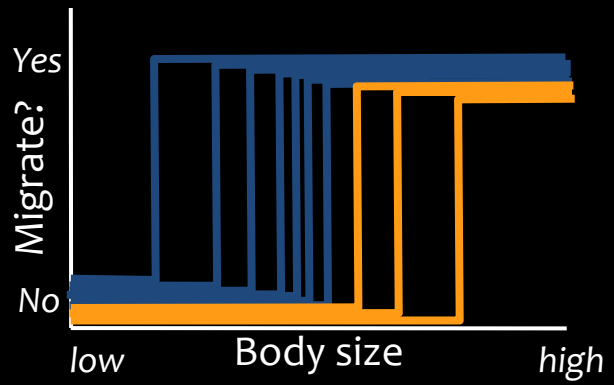


# Simulating the *O. mykiss* Life-Cycle



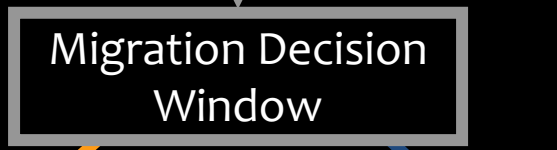
# Assigning Heritable Threshold Traits



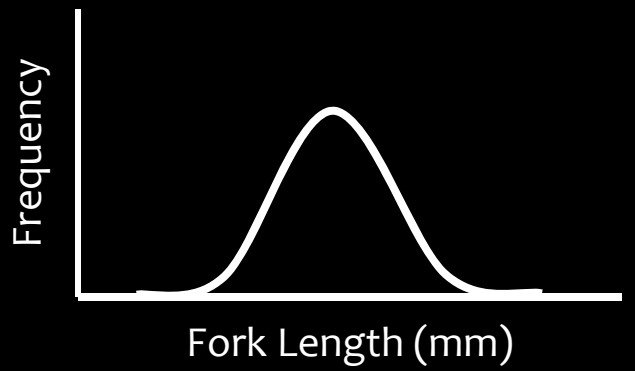

$h^2 = \sim 0.75$

# Simulating The Growth-Dependent Migration Decision

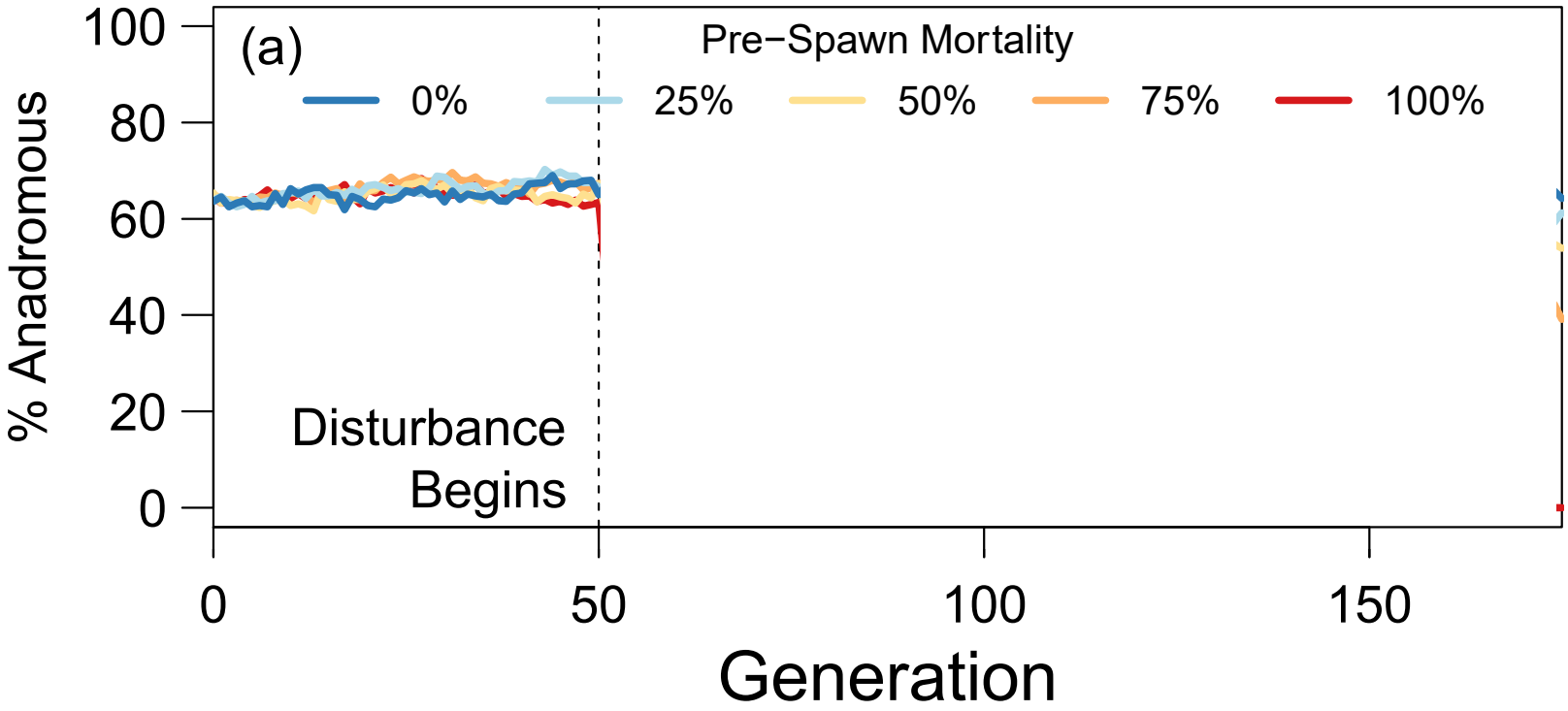



$fl_i \sim rnorm(\mu, \sigma^2)$

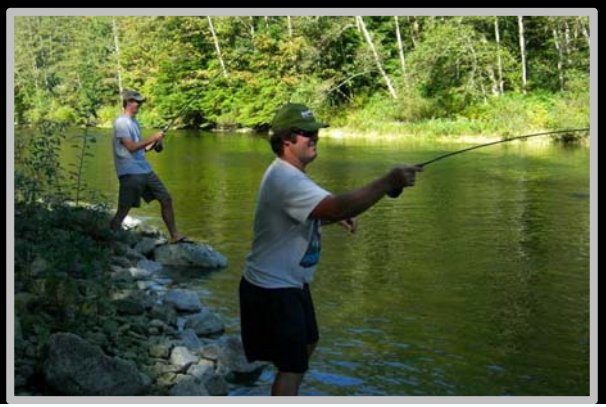


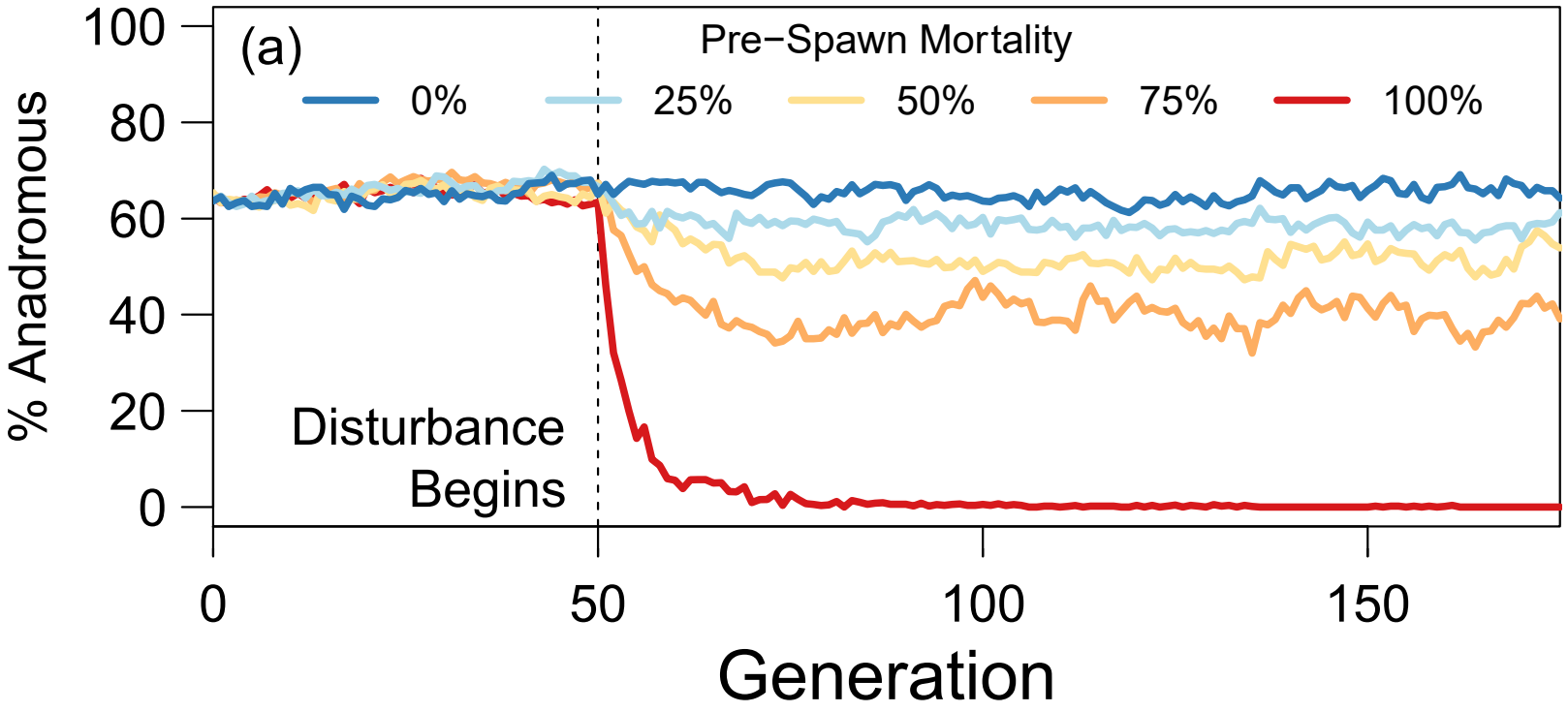

$fl_i > z_i \rightarrow$ GO

$fl_i < z_i \rightarrow$ STAY

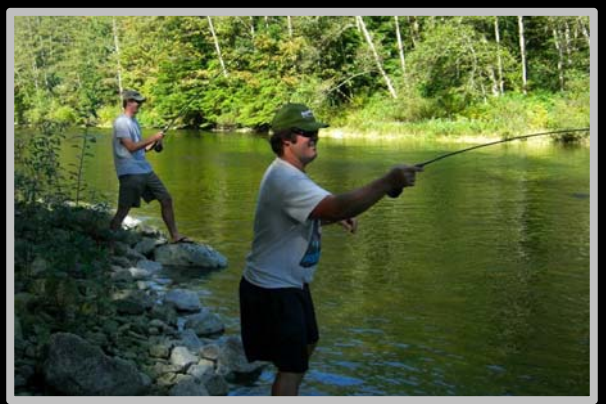


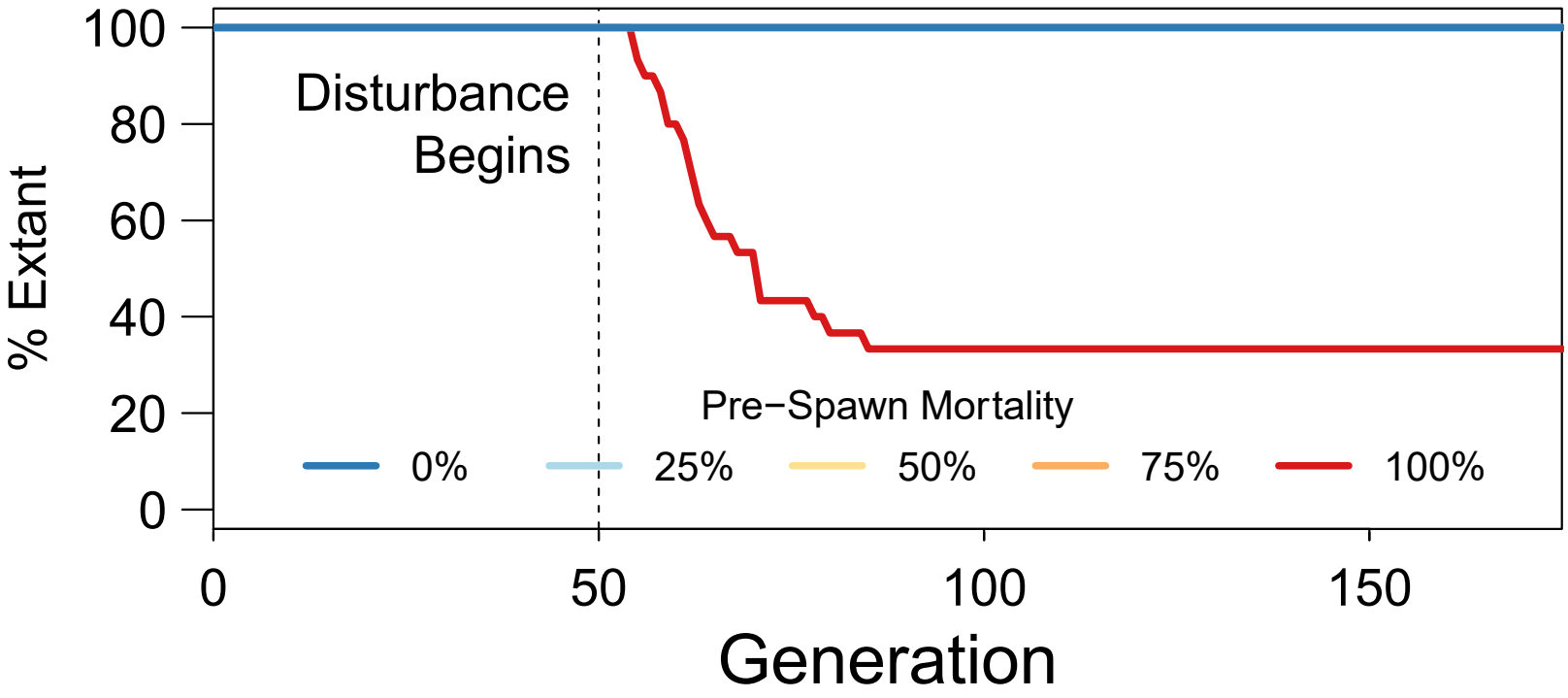

**Scenario:** Increasing novel mortality due to human pressures



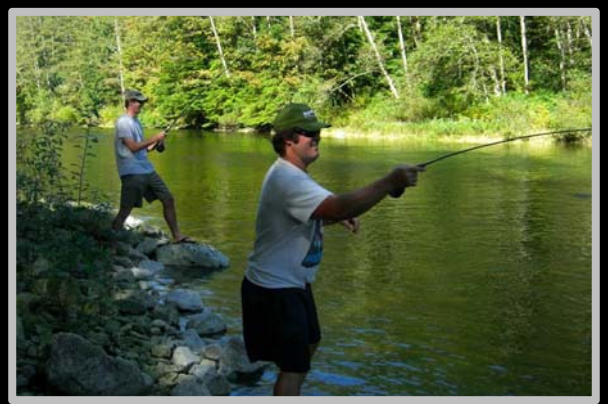



# Rapid Evolutionary Loss of Anadromy

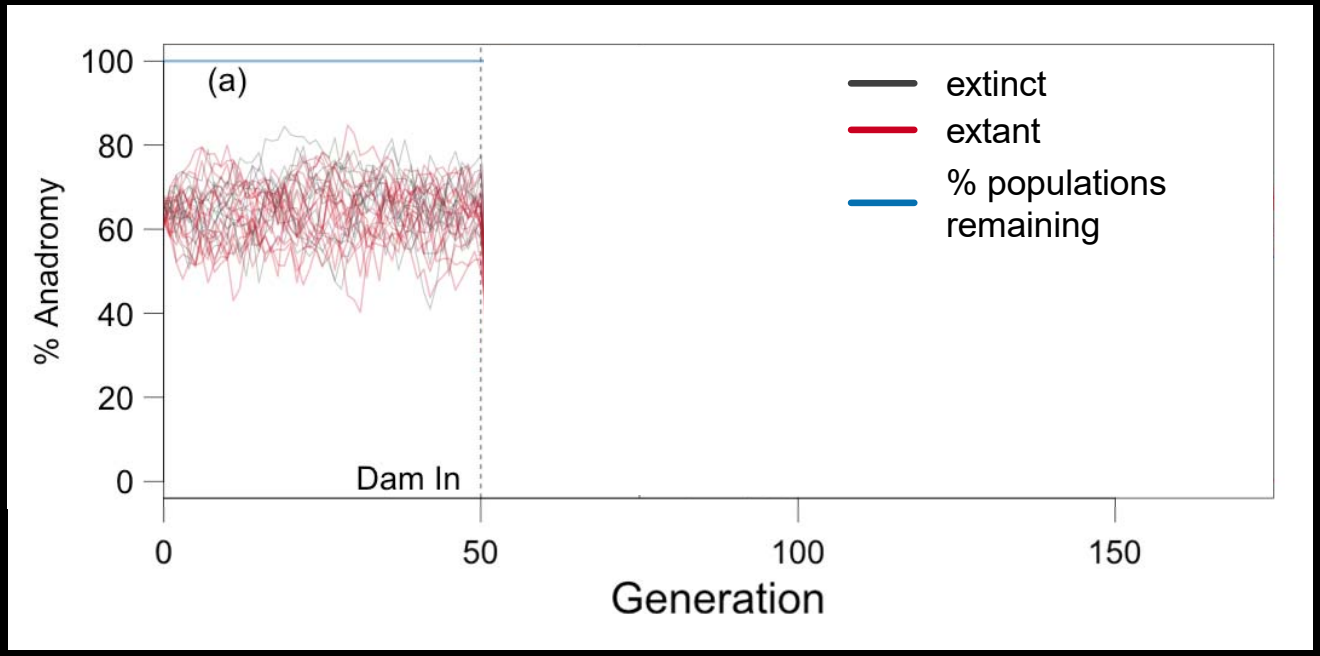





# Evolution Rescues Populations From Extinction



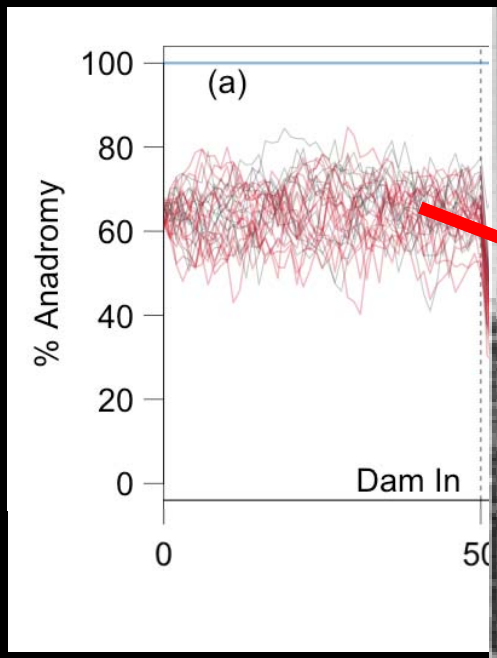
# Can Evolution Rescue A Population?

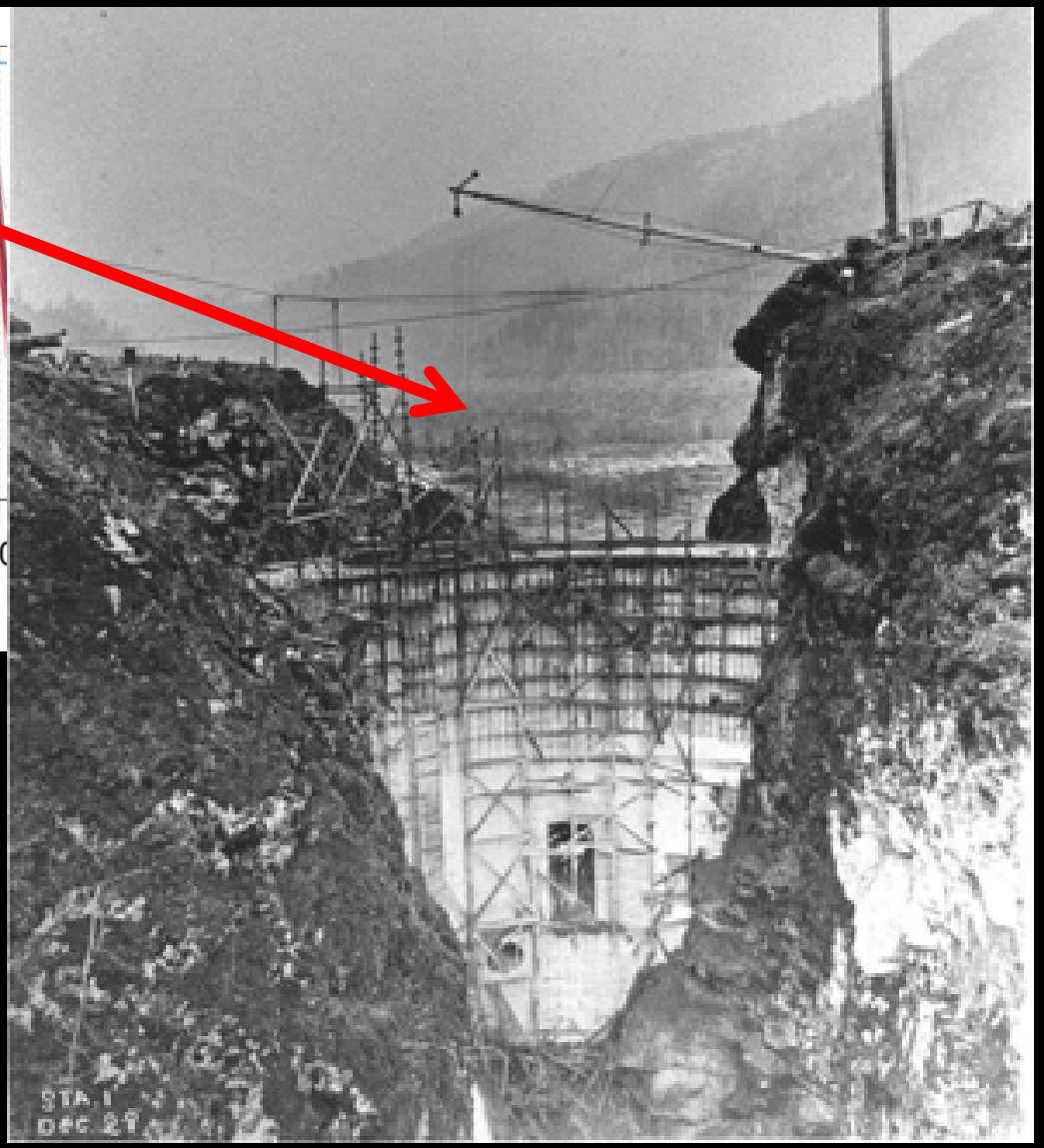



**Scenario:** Construction & removal of an impassable dam

**Phase:** Pre-dam construction

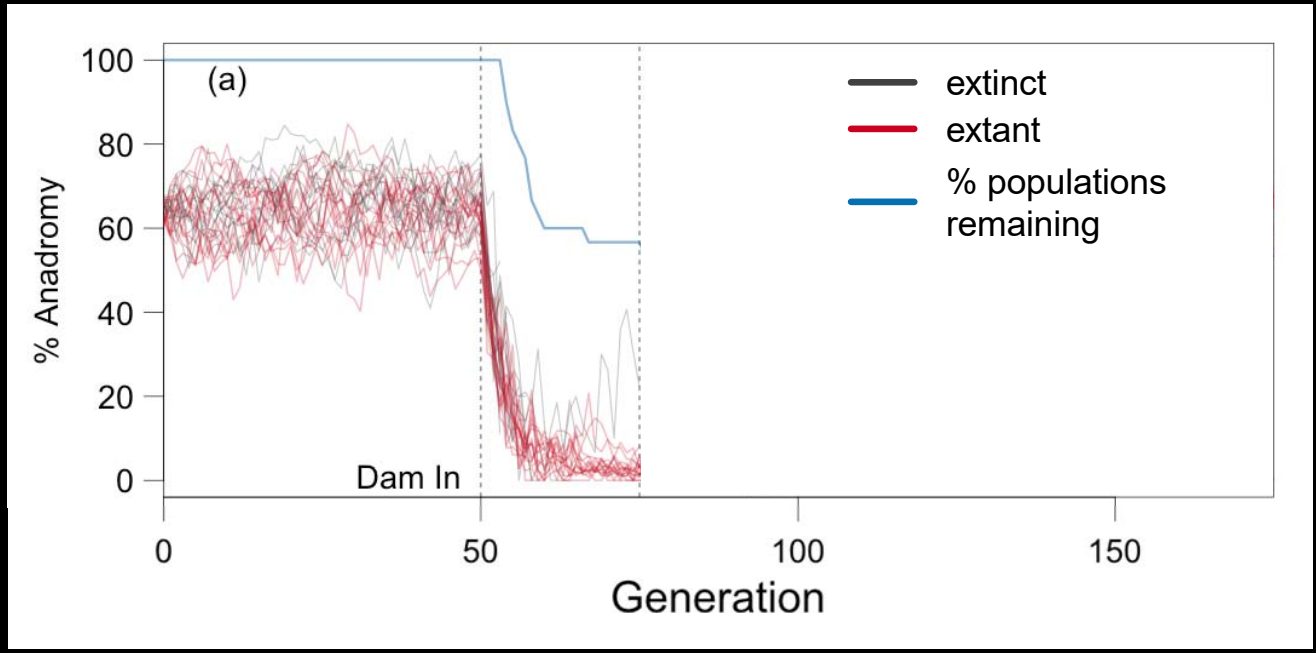
# Can Evolution Rescue A Population?



Glines Canyon Dam Construction, 1927

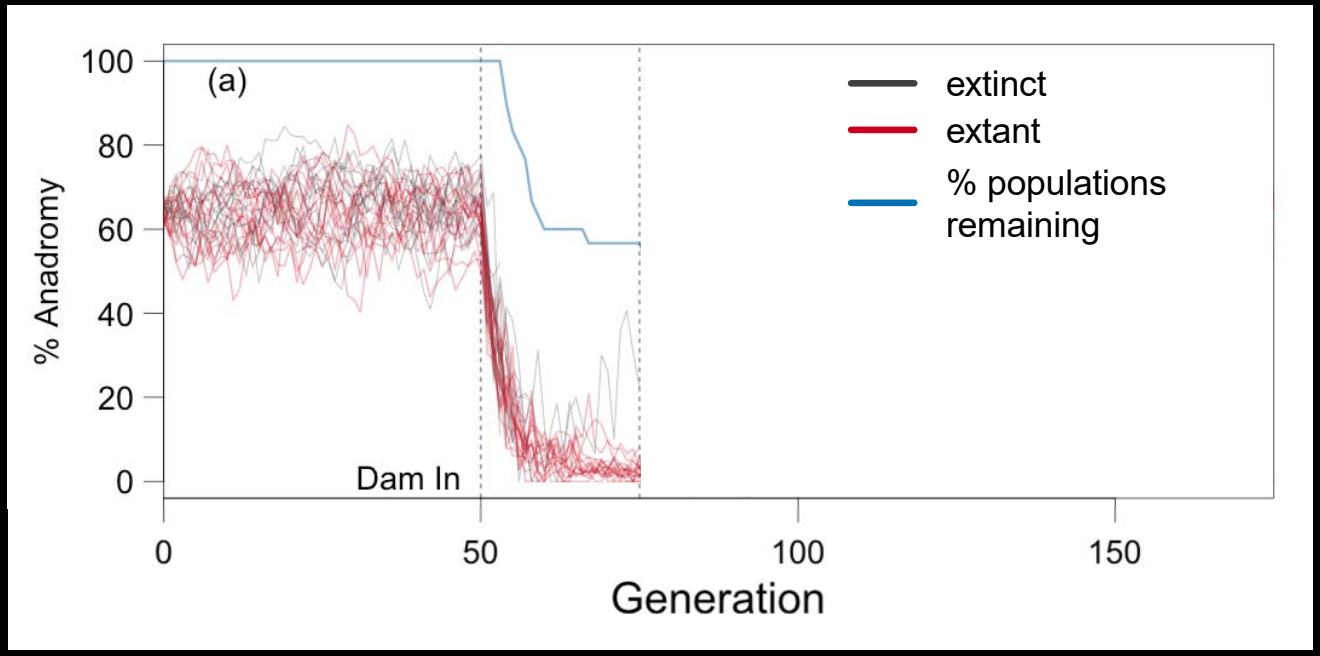
# Can Evolution Rescue A Population?




**Scenario:** Construction & removal of an impassable dam

**Phase:** Post-dam construction

# Most Populations Survived, But Anadromy Did Not

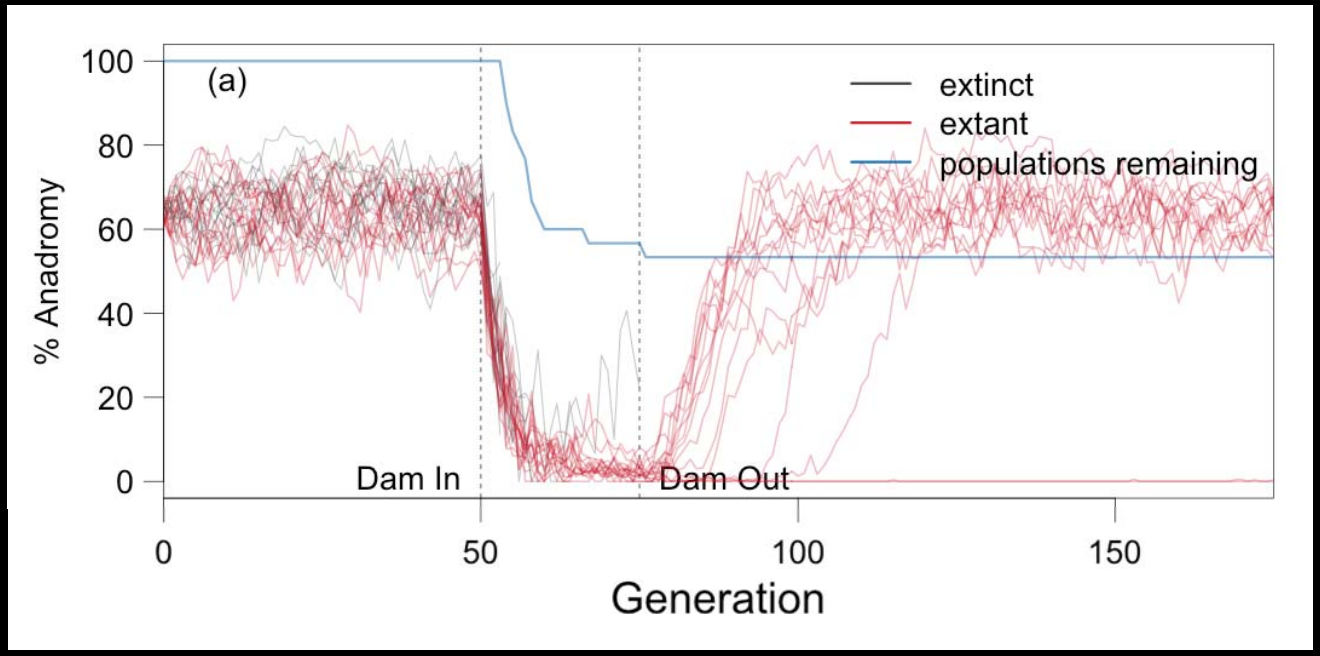



**Scenario:** Construction & removal of an impassable dam

**Phase:** Post-dam construction

# What About Evolution in the Other Direction?

# Anadromy Re-evolves, Unpredictably

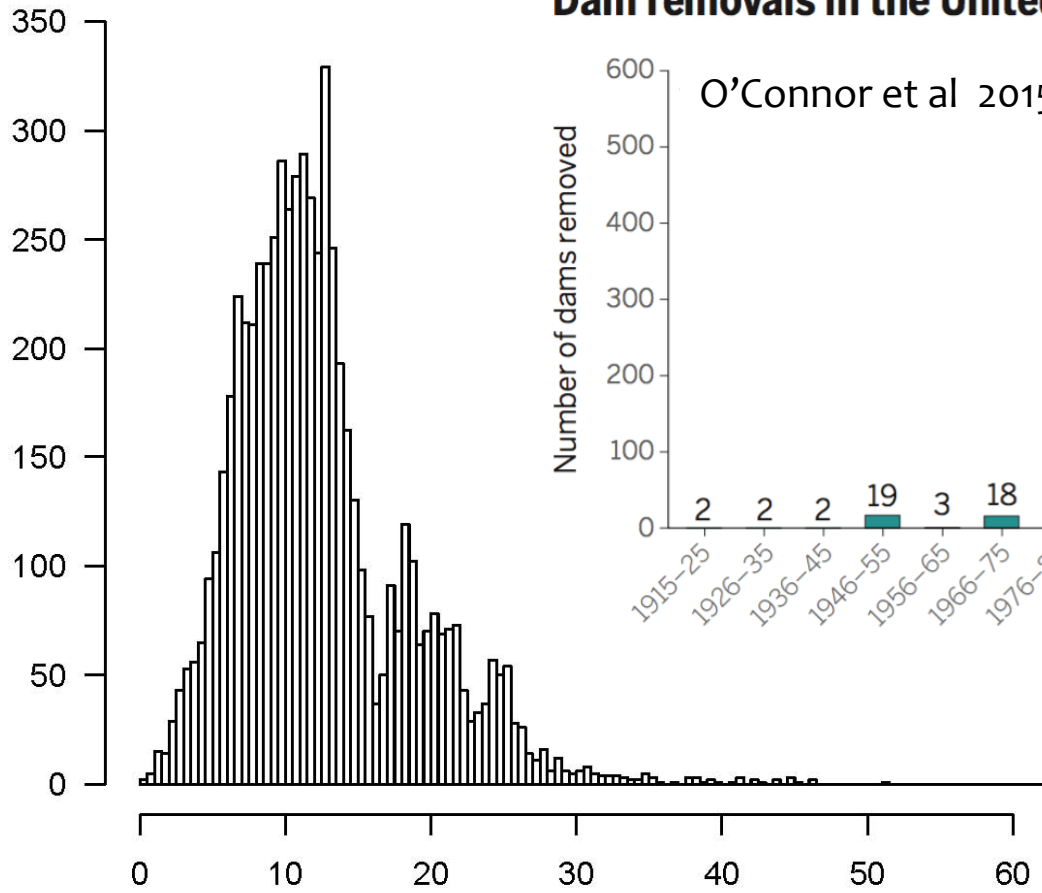



**Scenario:** Construction & removal of an impassable dam

**Phase:** Post-dam removal

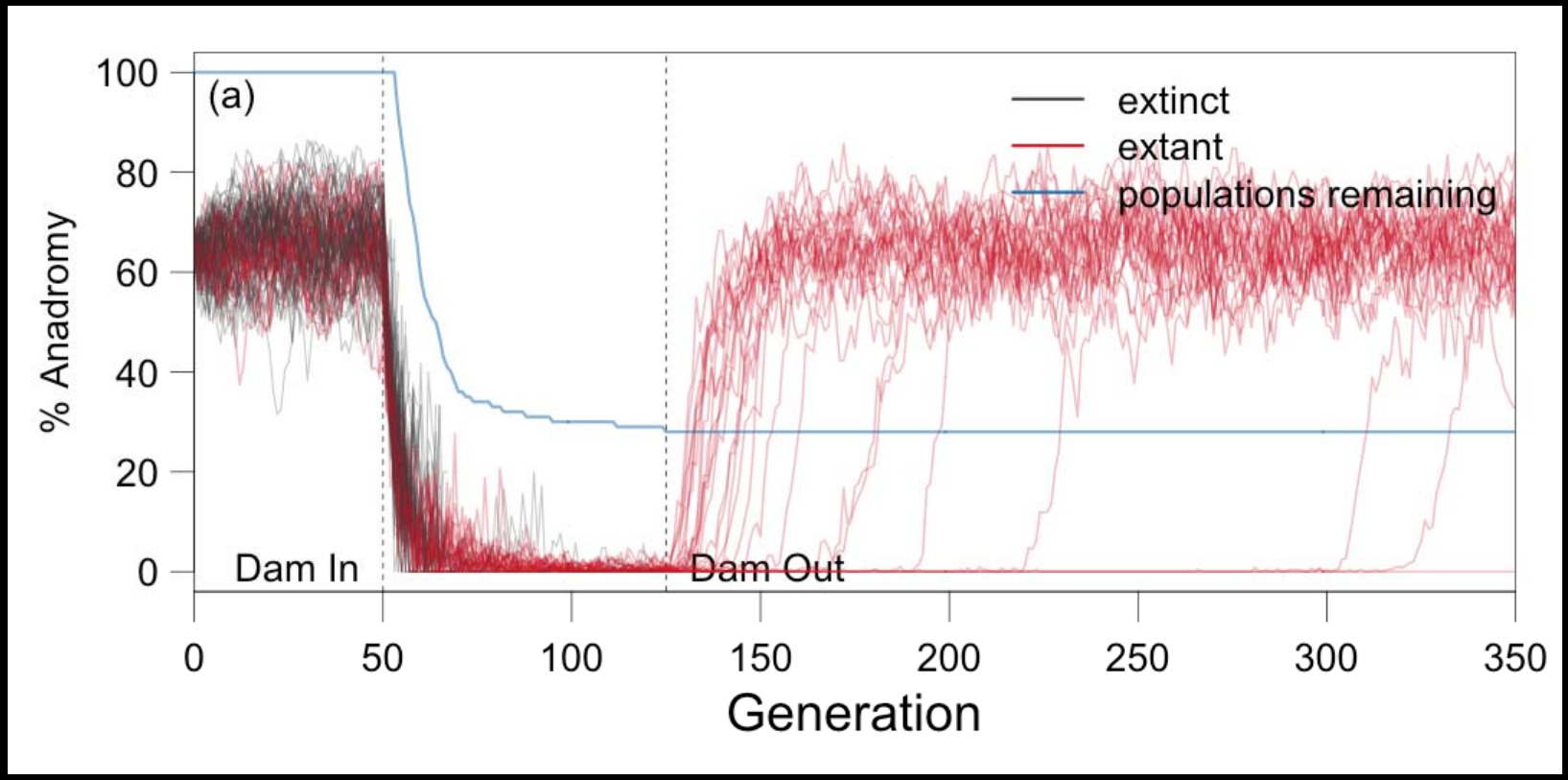
# Age Of Dams in United States

No. of Dams

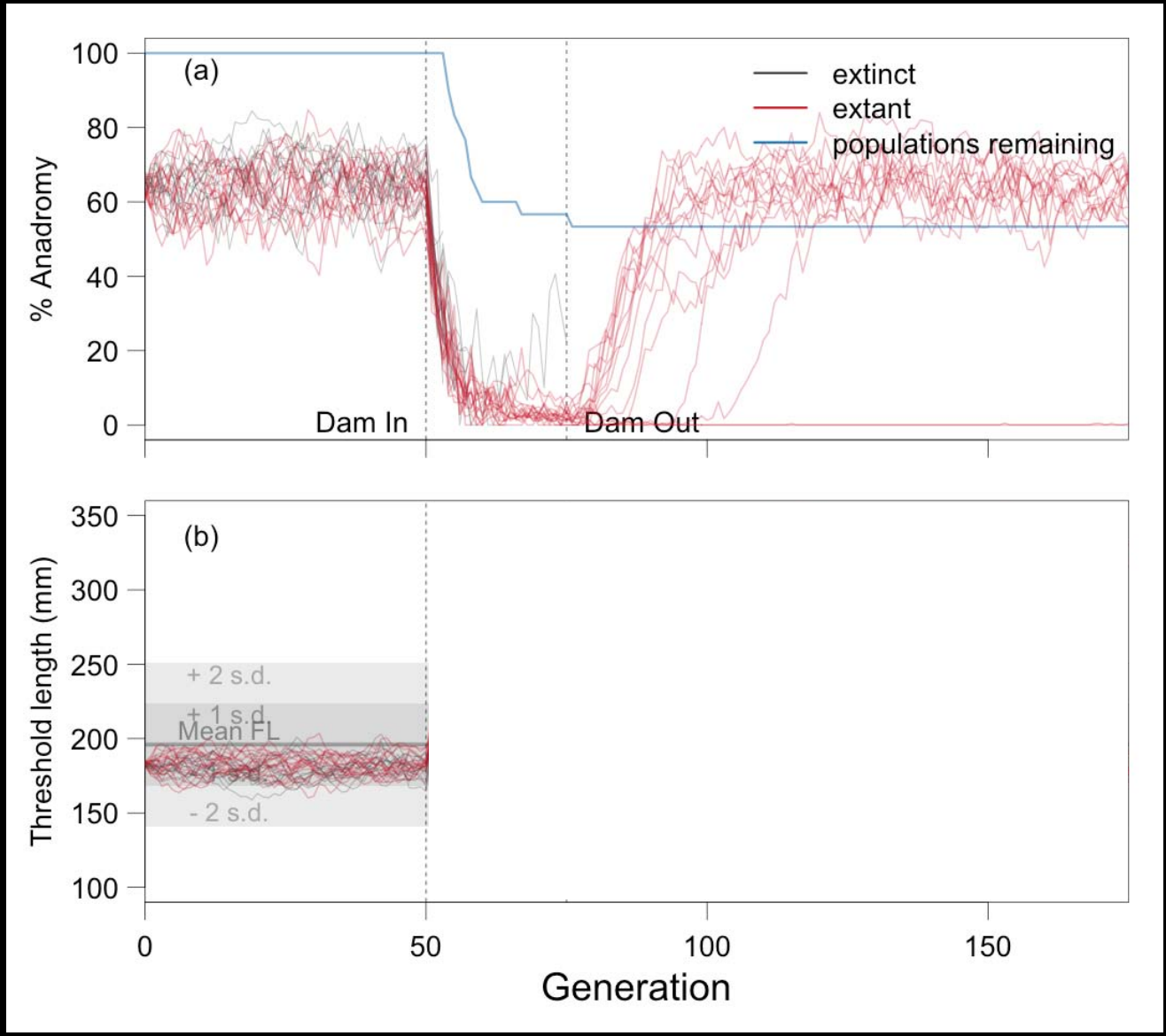



Salmon Generations (4yr/gen)

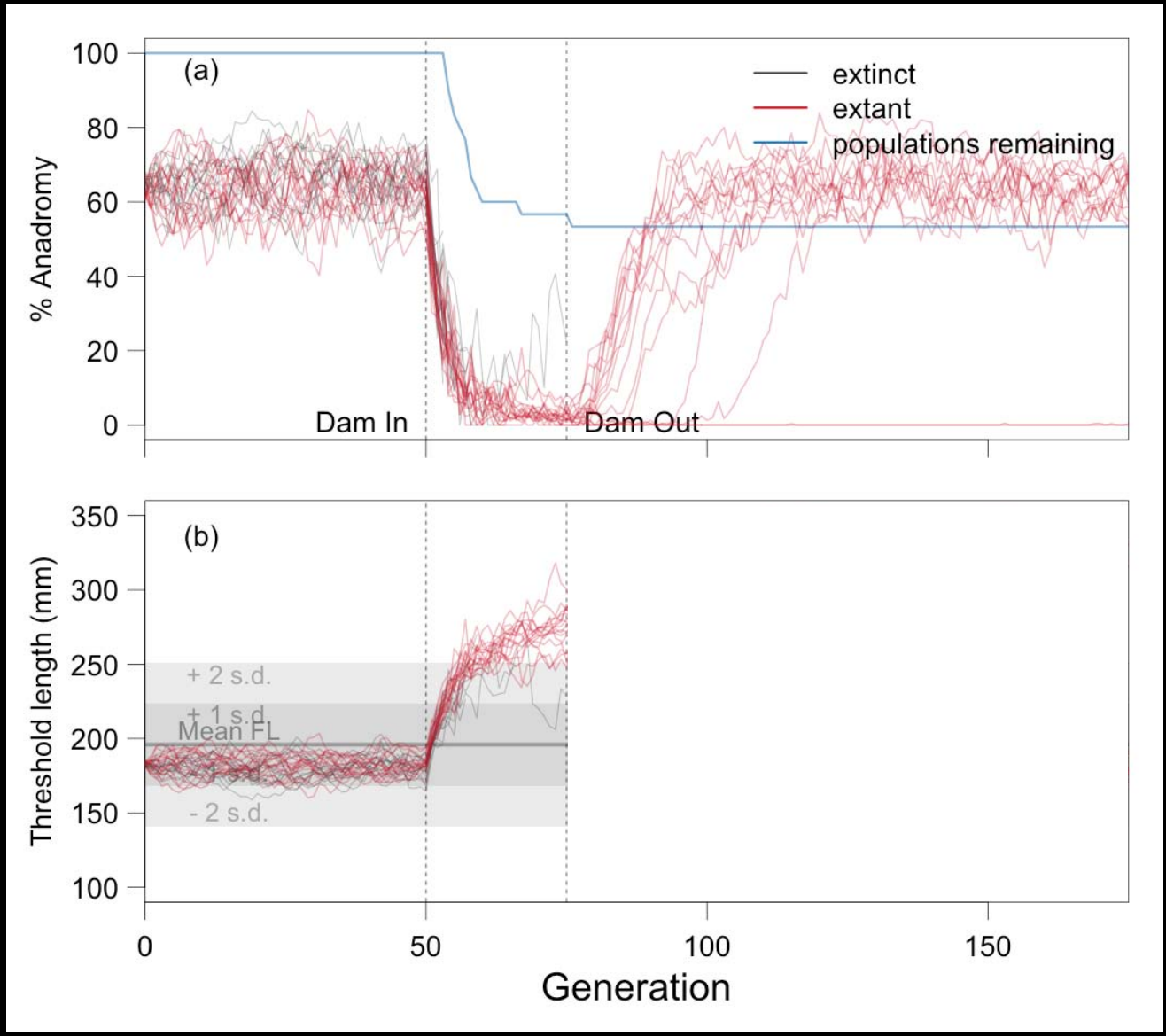
# Re-evolution is Less Predictable the Longer the Dam is in



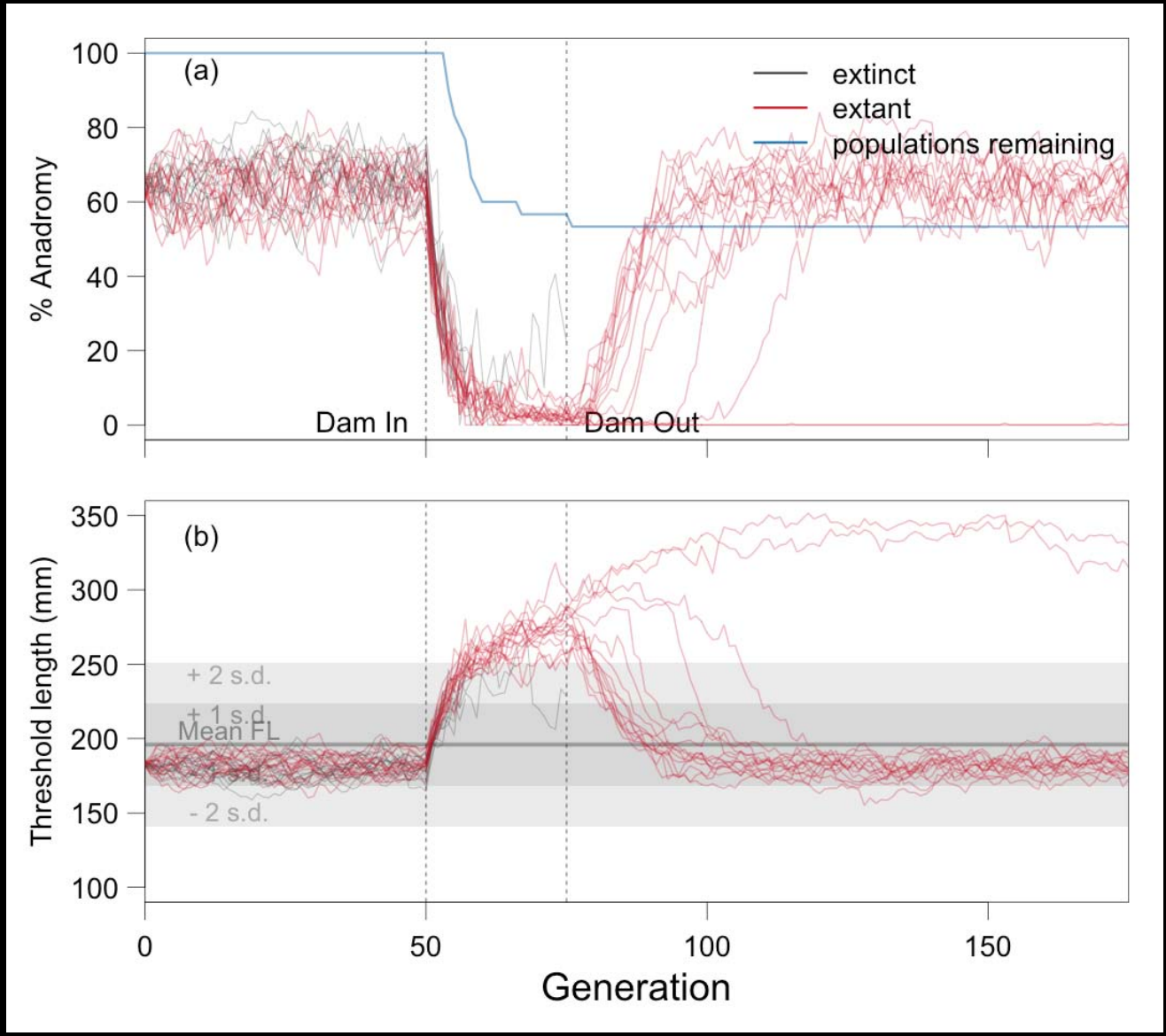
# Average Threshold Smaller Than Average Body Size



# Rapid Evolution of Larger Threshold Sizes



# Large Thresholds Prevent Expression of Anadromy



# Re-Evolution

Evolutionary shift from steelhead to residents can prevent population extinction

Loss and recovery of anadromy may proceed at different rates

Re-evolution of anadromy becomes less predictable the longer the dam is in

Photo credit: Jonathan Moore

# 3 Pathways to Restore Anadromy

1) Re-Colonization
2) Re-Expression
3) Re-Evolution

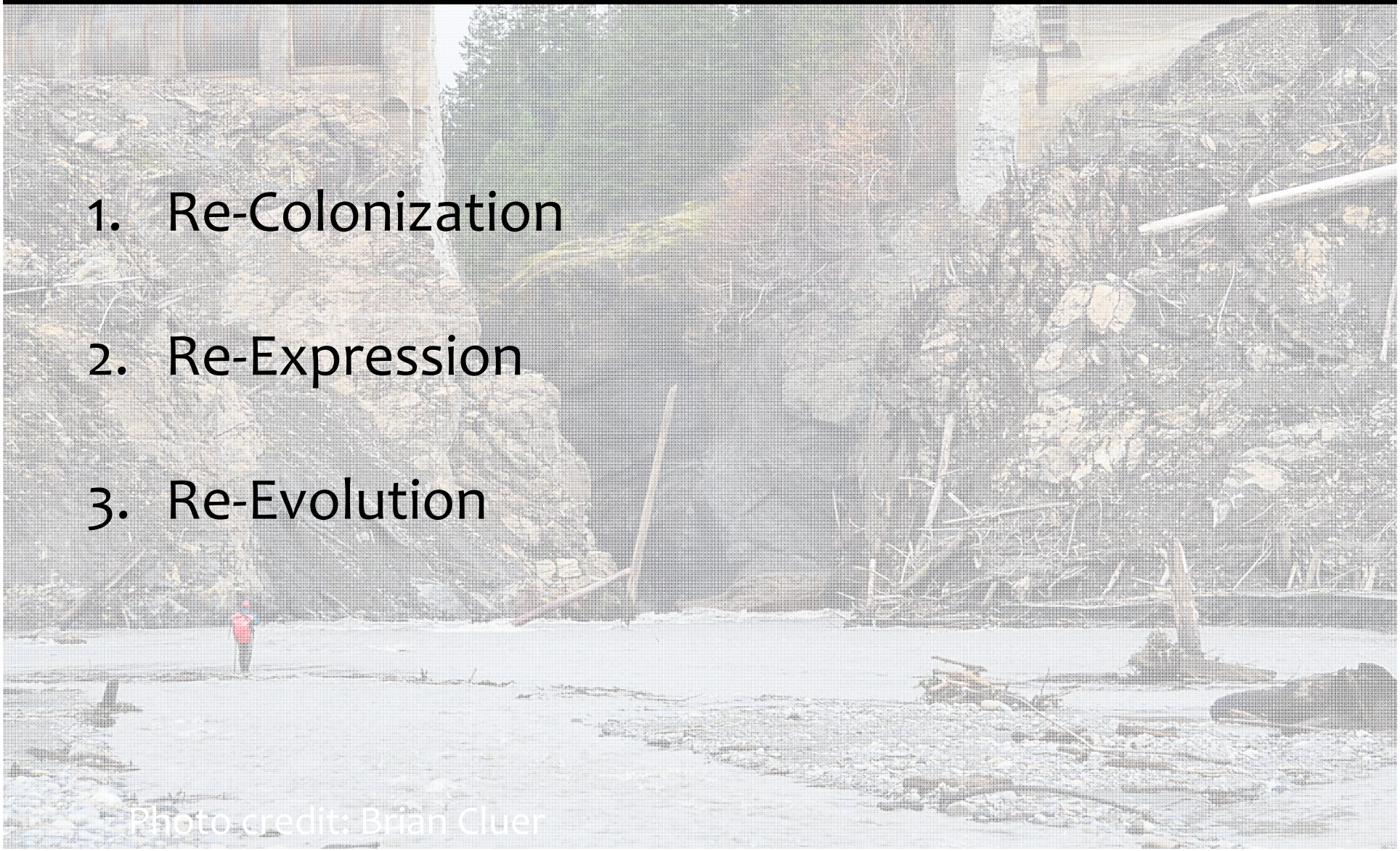
These pathways work together but on different timescales

Photo credit: Jonathan Moore

# Restoration as Large-Scale Experiments

Photo credit: Brian Cluer

# Restoration as Large-Scale Experiments



1. Re-Colonization
2. Re-Expression
3. Re-Evolution

Photo credit: Brian Cluer

# Restoration as Large-Scale Experiments

1. Re-Colonization
2. Re-Expression
3. Re-Evolution

Set recovery timelines that reflect the pathway(s) occurring

Determine relative importance of the different pathways?

Determine role of resident individuals?

Photo credit: Brian Cluer

# Migratory Behavior of Pacific Salmon & Trout

(*Oncorhynchus* spp.)

Fixed Migration

Pink (*Oncorhynchus gorbucha*)

Chum (*Oncorhynchus keta*)

Partial Migration

Chinook (*Oncorhynchus tshawytscha*)

Coho (*Oncorhynchus kisutch*)

Sockeye & kokanee (*Oncorhynchus nerka*)

Steelhead & rainbow trout (*Oncorhynchus mykiss*)

Fixed Residency

Cutthroat trout (*Oncorhynchus clarki* subsp.)

Rainbow trout (*Oncorhynchus mykiss* subsp.)