Considering Life-History Variation in Salmonid Restoration

A Concurrent Session at the 39th Annual Salmonid Restoration Conference held in Santa Cruz, California from April 19 – 22, 2022.

- **Session Coordinators:**
  - John Carlos Garza, Ph.D, *UC Santa Cruz and NOAA Fisheries*

Salmonid fishes are characterized by high levels of variation in life-history traits related to migration and reproduction. In some cases, the variation is so great that fish with alternate strategies even have different names, such as steelhead/rainbow trout, spring-run/fallrun salmon, sockeye/kokanee. In California, salmon and steelhead display a full array of variation in such life-history traits including the presence, location, age and timing of migratory behaviors, and related variation in reproductive behavior. Much of this variation has a genetic basis, so may not be very flexible and is also subject to selection. Restoration projects often alter habitat conditions in ways that change the availability or quality of resources available to fish on a temporal or spatial basis, with potentially profound consequences for fitness of associated salmon and steelhead populations. Understanding how life-history variation of salmon and steelhead is coupled with habitat use and how specific changes in the physical and biological habitat can affect salmonid populations is a key to implementing successful restoration projects. This session will bring together biologists studying the patterns and underlying bases of life-history variation in salmon and steelhead, restoration practitioners working on projects that consider this variation and policy makers that plan, prioritize and permit such projects. The session goal is to highlight the importance of explicitly considering variation in migratory and reproductive traits in salmonid restoration projects.

Presentations

Slide 4 - **Is It Just a Matter of Time? Allowing for Changing Phenology in Salmon Restoration and Management,** Michael Tillotson, Ph.D., *ICF*

Slide 32 - **A Multigenerational Pedigree Analysis Reveals the Potential for Selection on Steelhead Life-History Traits,** Anne Beulke, *UC Santa Cruz*

Slide 55 - **Counting the Parts to Understand the Whole: Rethinking Monitoring of Steelhead in California's Central Valley,** Tyler Pilger, Ph.D., *FISHBIO*

Slide 70 - **The Importance of Life-History Variation in Salmonid Restoration,** John Carlos Garza, Ph.D., *Southwest Fisheries Science Center and UC Santa Cruz*

Slide 86 - **Evaluating Estuary Residency and Restoration Potential for Chinook Salmon in Redwood Creek Via a Life Cycle Model,** Emily Chen, *UC Berkeley*

Slide 126 - **Habitat Restoration to Support Life History Diversity for Coho Salmon in Small Coastal Streams,** Darren Ward, Ph.D., *Cal Poly Humboldt*

Is It Just a Matter of Time? Allowing for Changing Phenology in Salmon Restoration and Management

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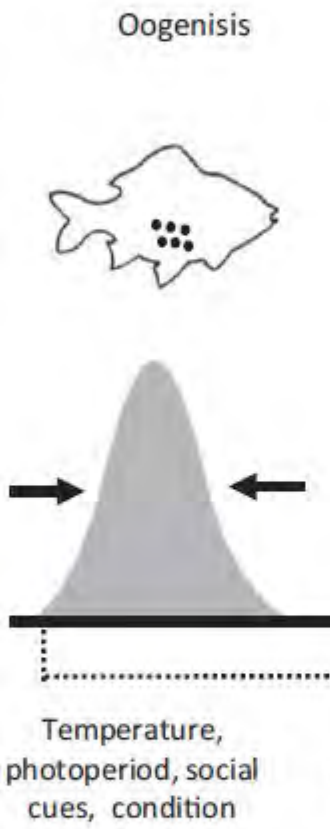
Salmon Restoration Federation Conference, Santa Cruz, CA
April 21, 2022

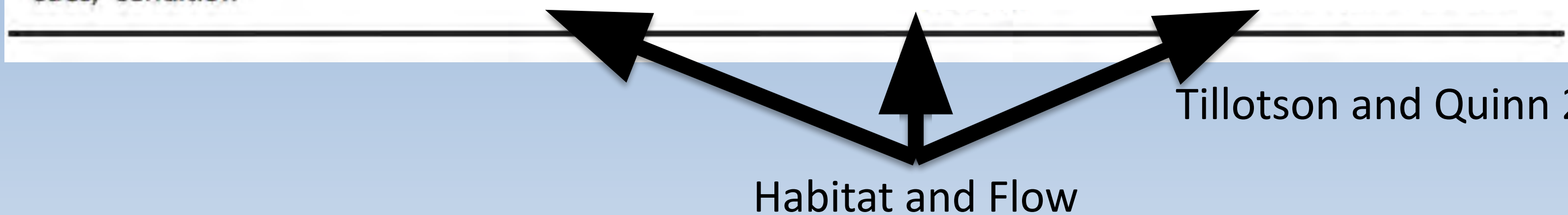
Overview

1. Reproductive phenology in fishes
2. The timing of migration and spawning in salmonids
3. Phenological shifts in response to climate change
4. Alternative drivers of phenological change
5. Case Study: Patterns and drivers of phenological change in Cedar River sockeye salmon
6. Implications for salmon management in California

Reproductive phenology in fishes

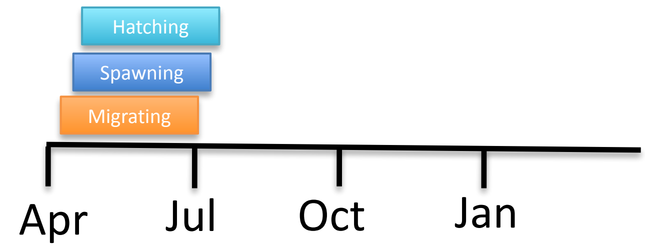


- Fish reproduction is not distributed randomly through time
- Spawning occurs at predictable times in association with seasonal, lunar or other environmental cycles
- The timing of several sequential events may be phenotypes subject to natural and artificial selection



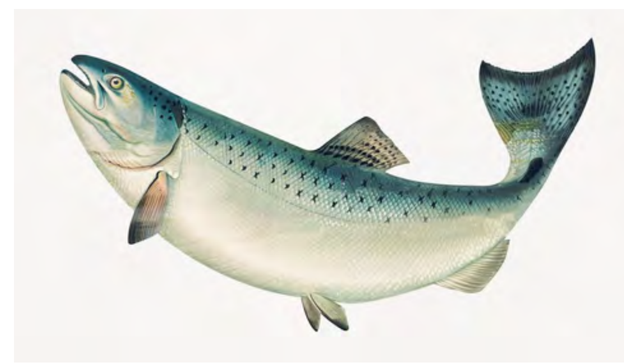
Tillotson and Quinn 2018

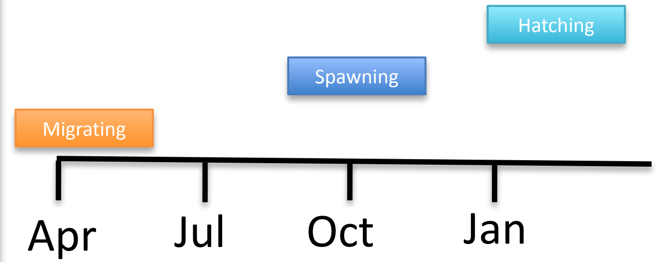
Important aspects of reproduction in salmonids



Consequences for migratory and reproductive phenology

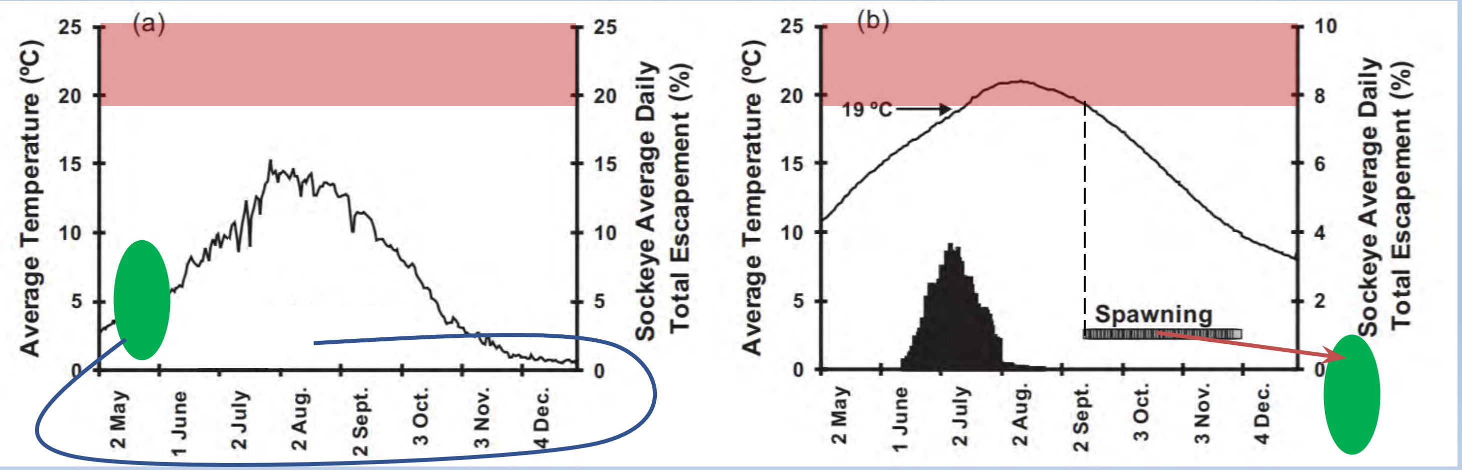
- Salmon are less reliant on proximate environmental cues
- Subject to stronger genetic control of phenology
- Greater potential for mismatch when conditions change
- Adapt to change on evolutionary time-scales





Impact of phenology on salmon fitness

- Spawning is timed so that offspring are likely to encounter favorable conditions after hatching
- The timing of migration and spawning must also balance survival of adults and their offspring

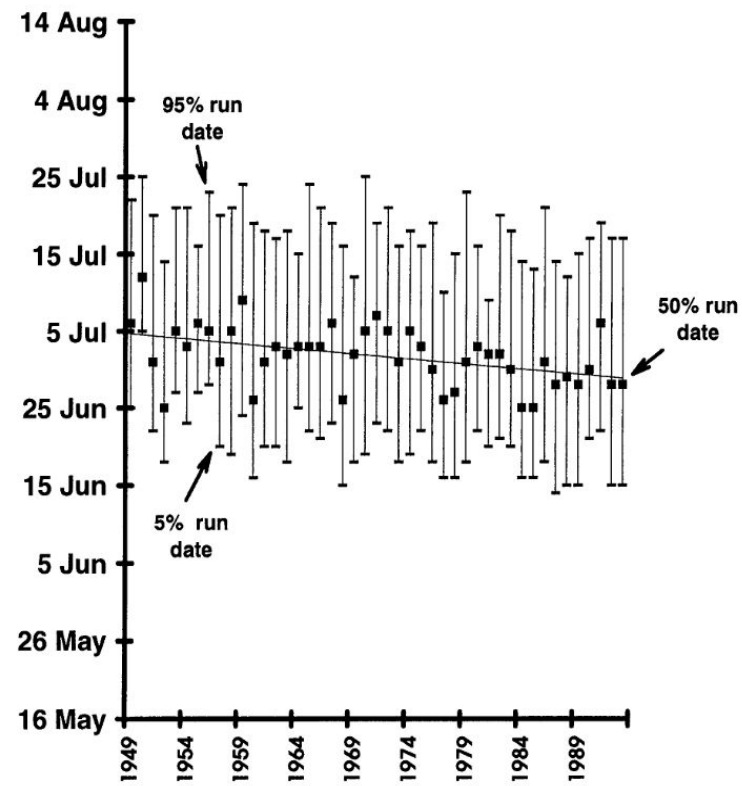


Adapted from Hodgson and Quinn 2002

Climate adaptation through shifting phenology

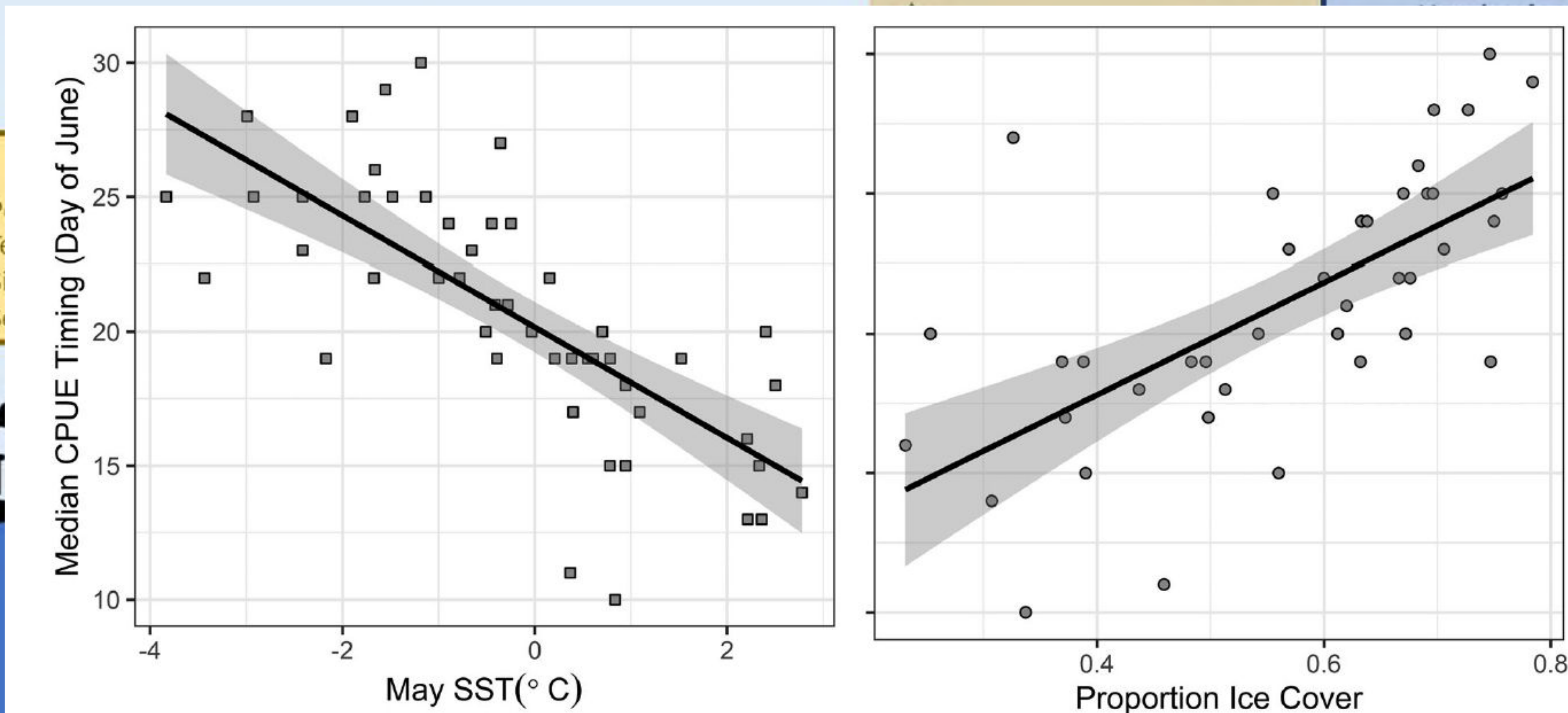
- Changes in migration and spawning timing are regularly observed
- Shifts in recent decades commonly attributed to climate change
- Phenological change likely reflects a combination of plasticity and natural selection
- Shifts are hypothesized to reflect adaptive response to stressful temperatures and/ or shorter incubation periods

Advancing run timing in Columbia River sockeye



Quinn and Adams 1996

Diverse controls of migration and spawn timing



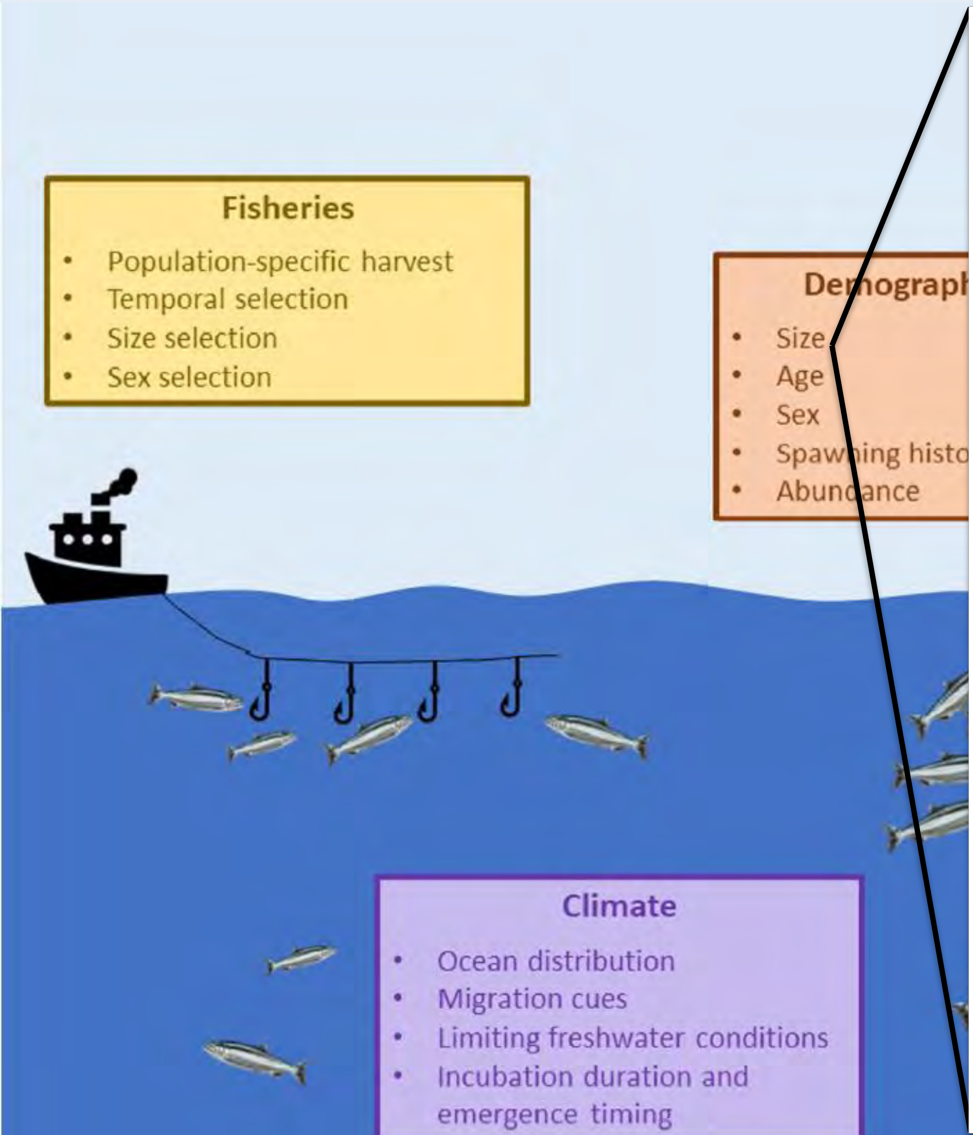
Warm winters and springs are associated with earlier river entry by Yukon River Chinook salmon.

Adapted from Mundy and Evenson (2011)

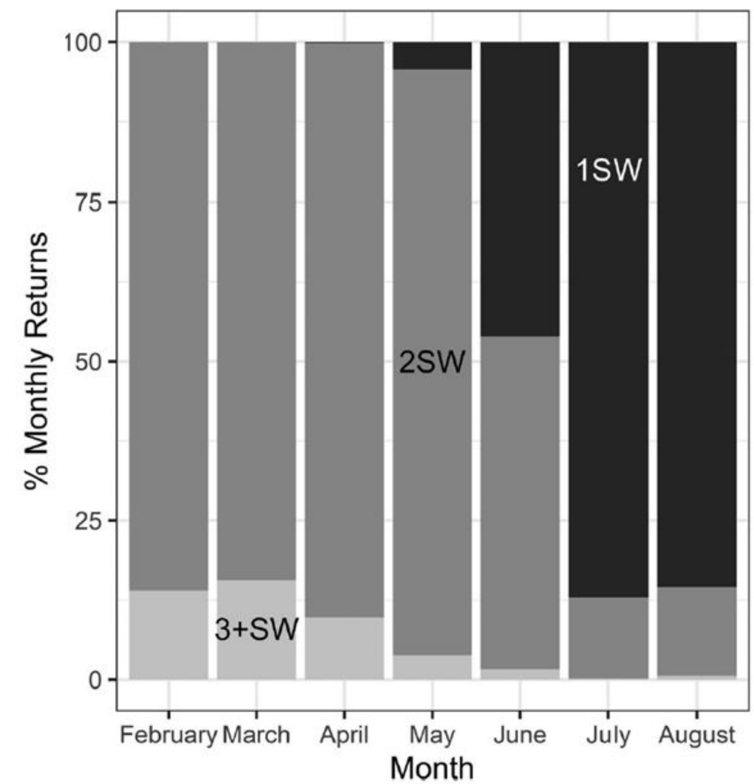
Climate
Ocean distribution
Migration cues
Limiting freshwater conditions
Incubation duration and emergence timing

Tillotson et al. (2021)

Diverse controls of migration and spawn timing



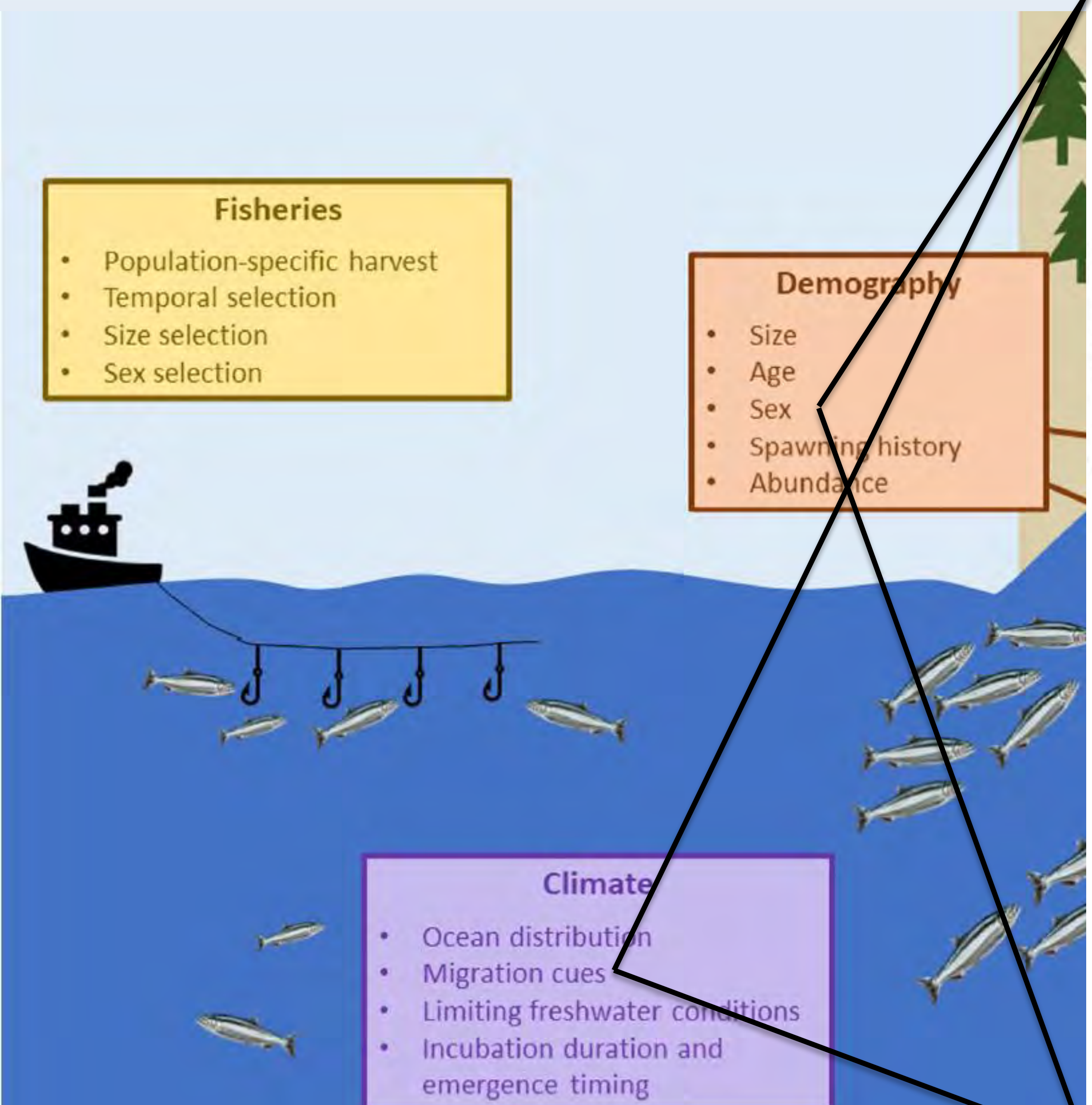
Tillotson et al. (2021)



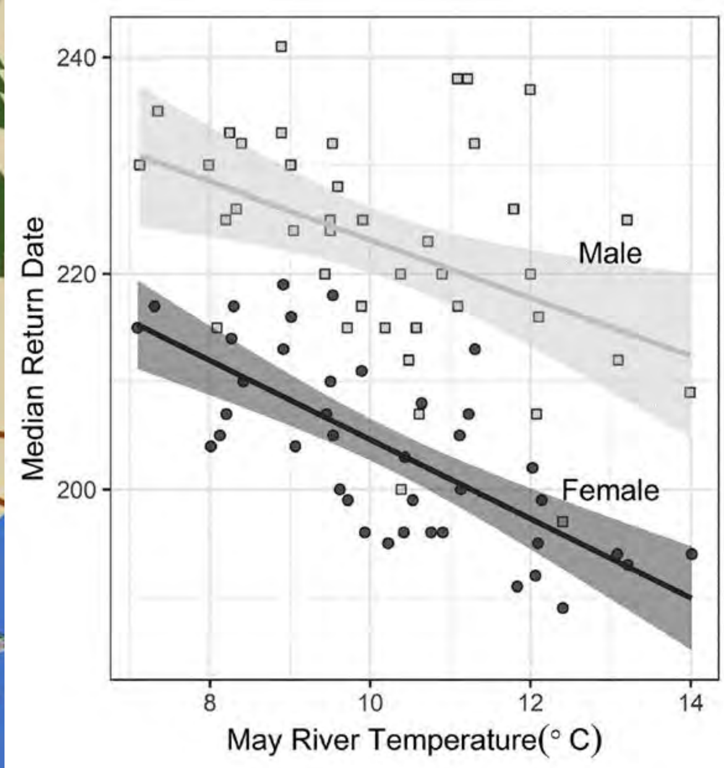
The average timing of river entry by Atlantic salmon of different ages varies by multiple months

Adapted from Shearer (1990)

Diverse controls of migration and spawn timing



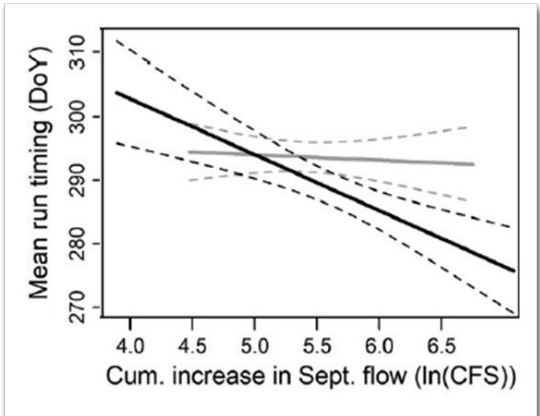
Tillotson et al. (2021)



Earlier river entry is associated with water temperatures, but also large differences between sexes in an Atlantic salmon population.

Adapted from Dahl et al. (2004)

Diverse controls of migration and spawn timing

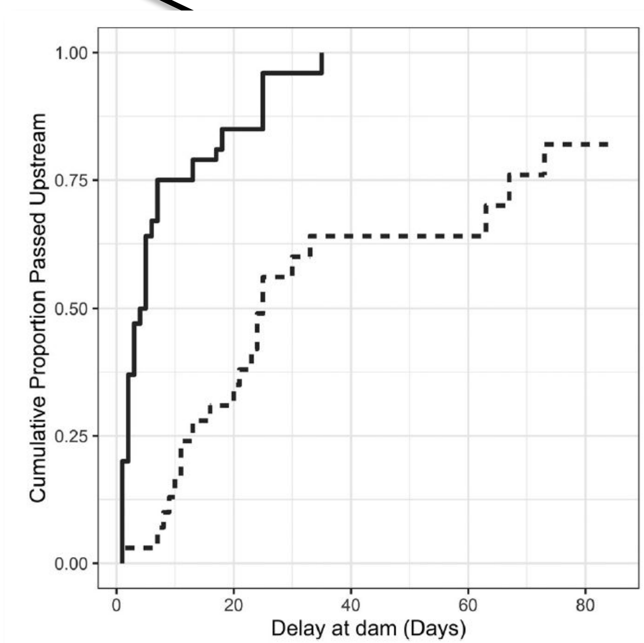


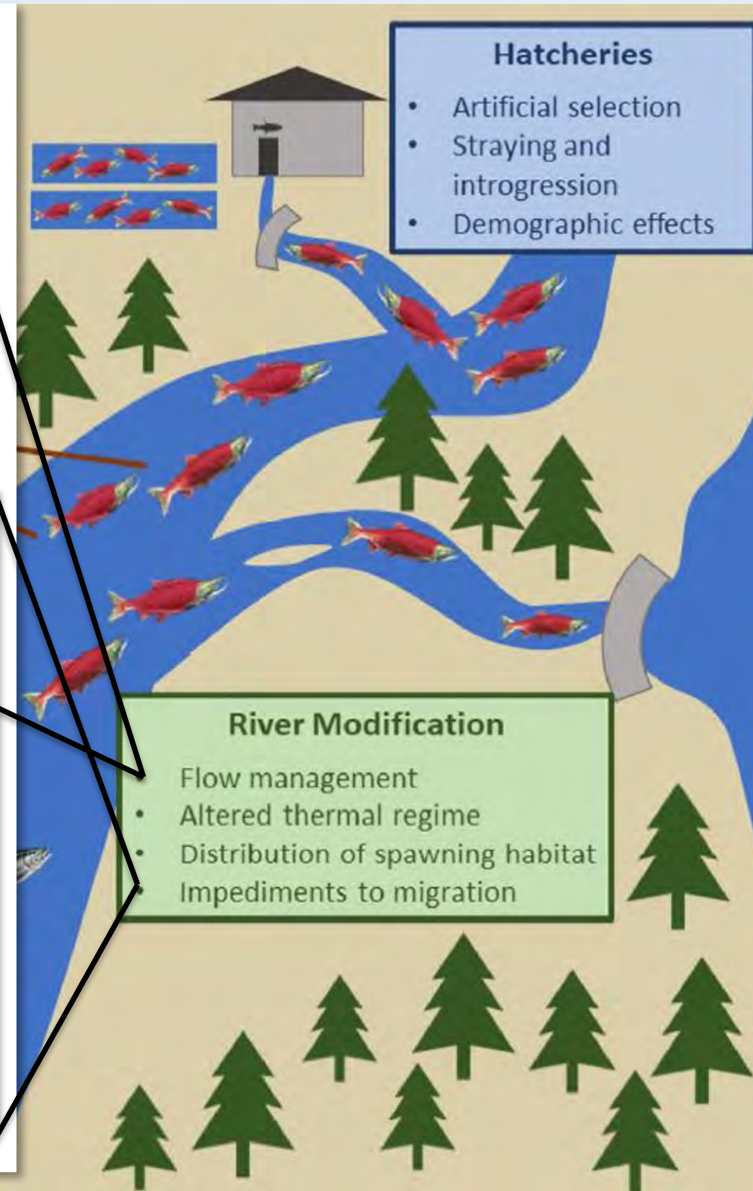
Date of river entry is earlier when high flows occur earlier in the fall for a sockeye salmon population

Adapted from Tillotson et al. (2017)

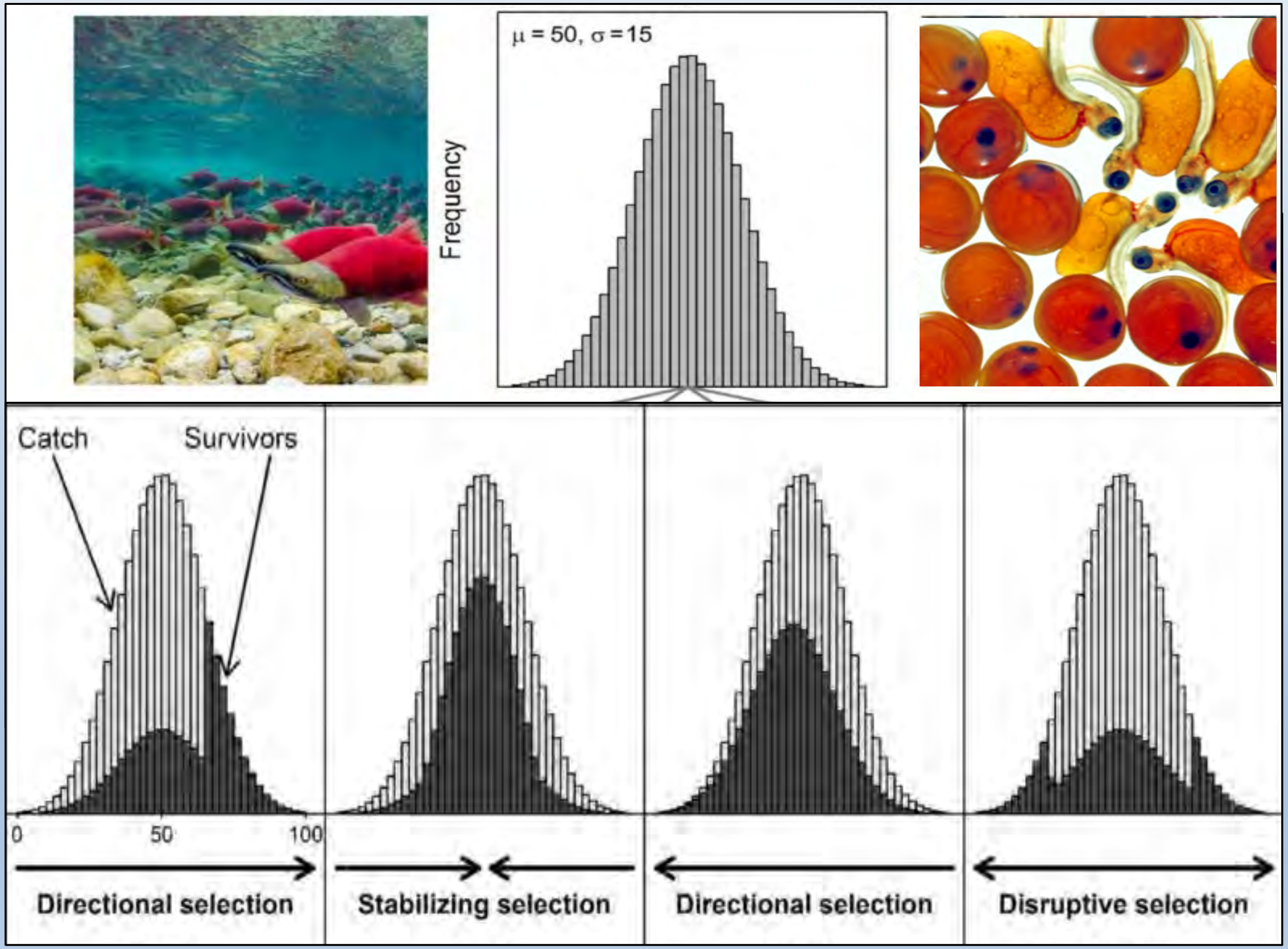
Traditional fishway at a dam delays upstream migration by weeks relative to nature-like fishway in an Atlantic salmon population

Adapt. from Nyqvist et al. (2017)



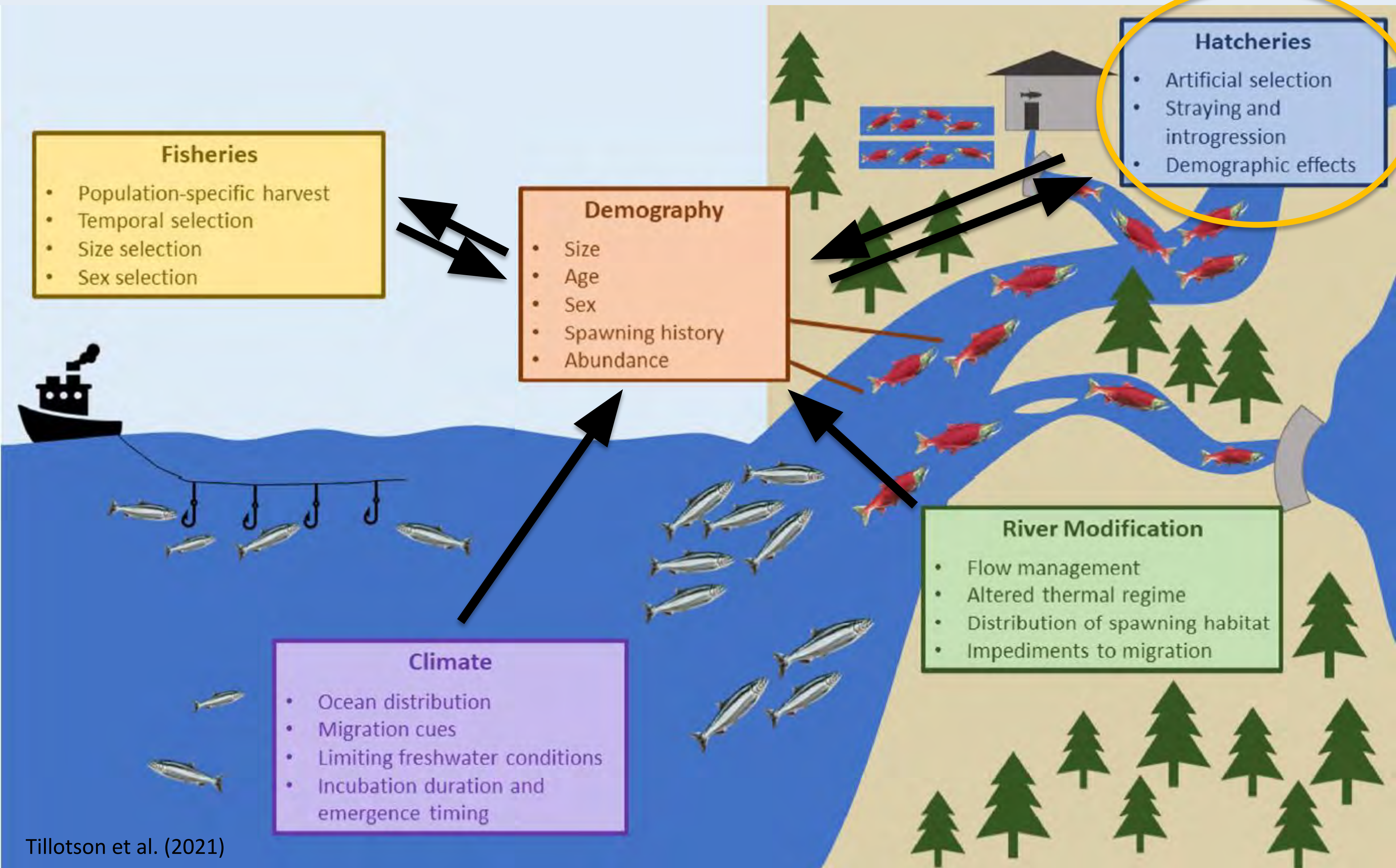


Diverse controls of migration and spawn timing



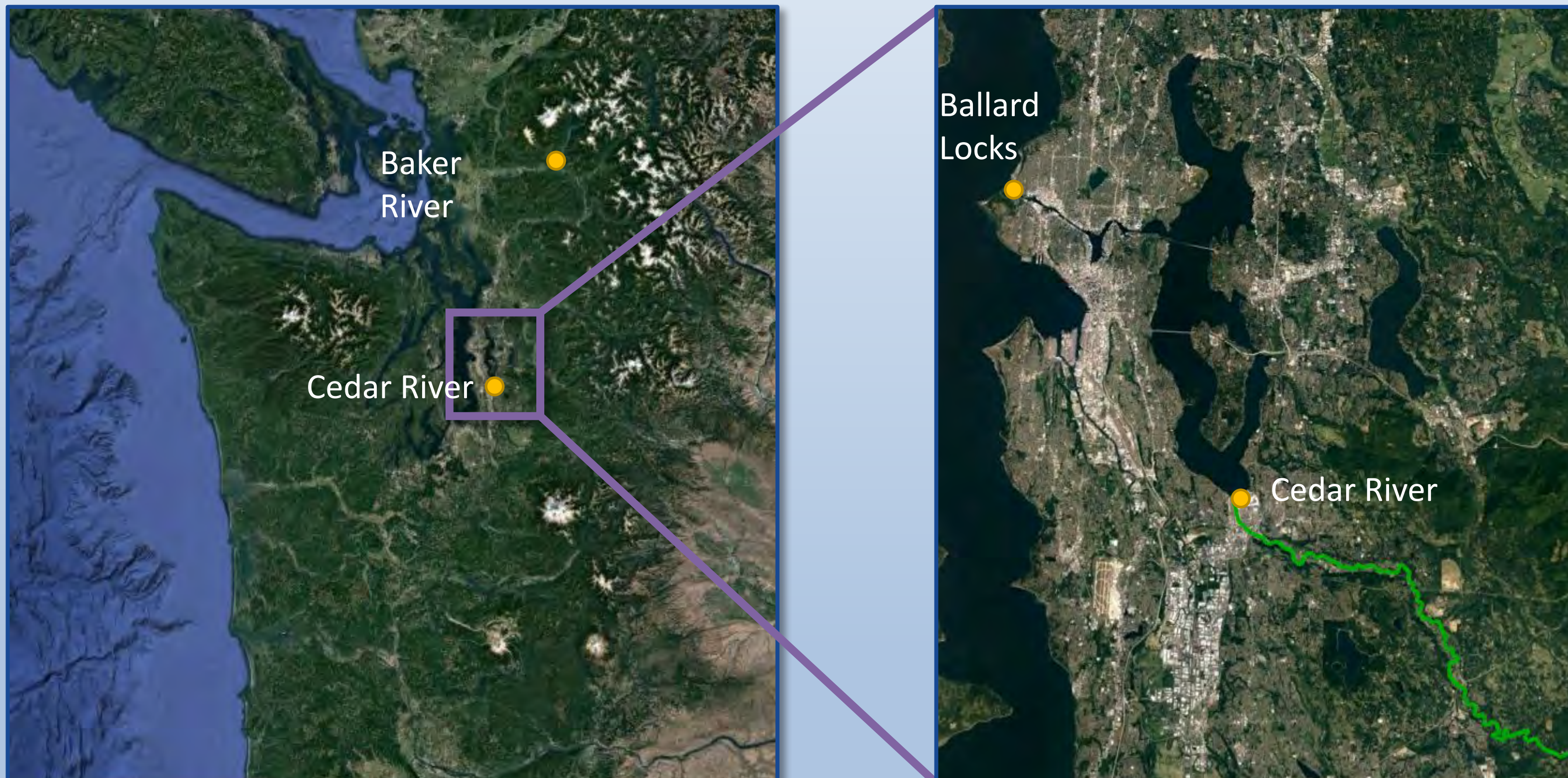
Adapted from Tillotson and Quinn 2018

Diverse controls of migration and spawn timing



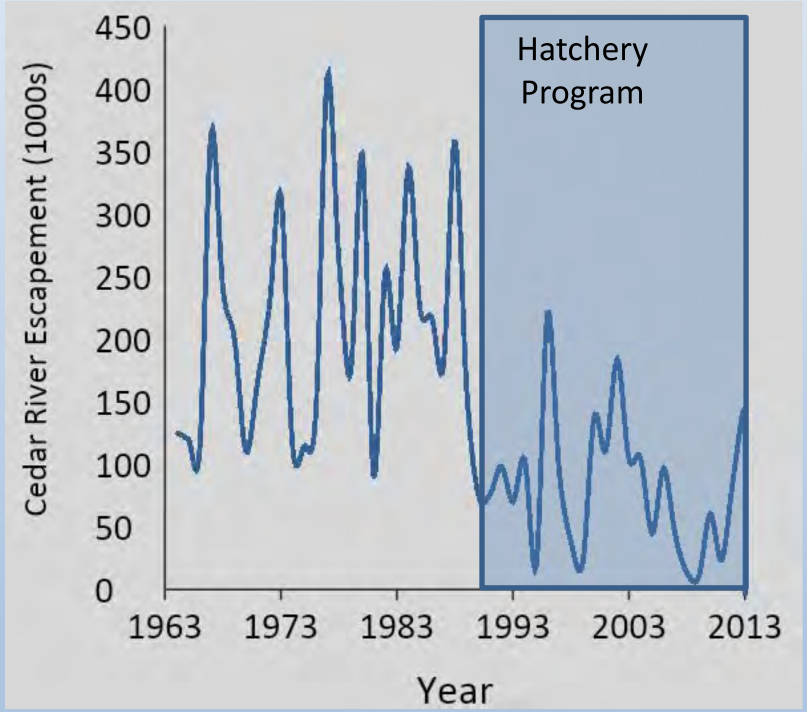
Tillotson et al. (2021)

Case Study: Illuminating the drivers of phenological change in Cedar River sockeye



warming

Cedar River sockeye background

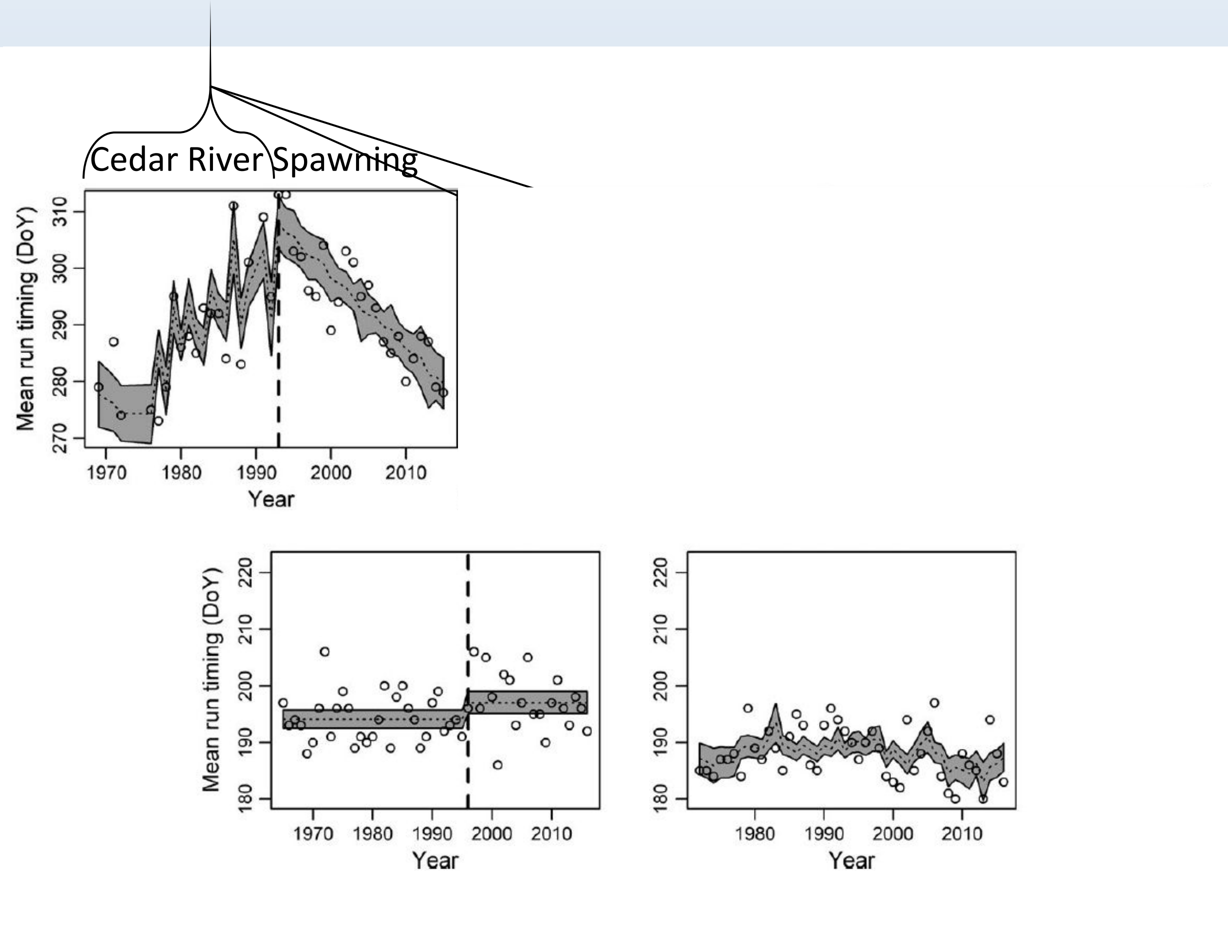


Data and methods summary

- Daily observed or interpolated adult fish counts used to calculate median run timing in Cedar River and the origin population in the Baker River
- Hatchery records used to estimate timing of artificially spawned fish
- Trend analysis with model selection to identify temporal patterns and environmental covariates of freshwater entry and spawning timing
- Simple evolutionary model and sensitivity analysis to understand the strength of artificial selection and its probable impact on spawning timing

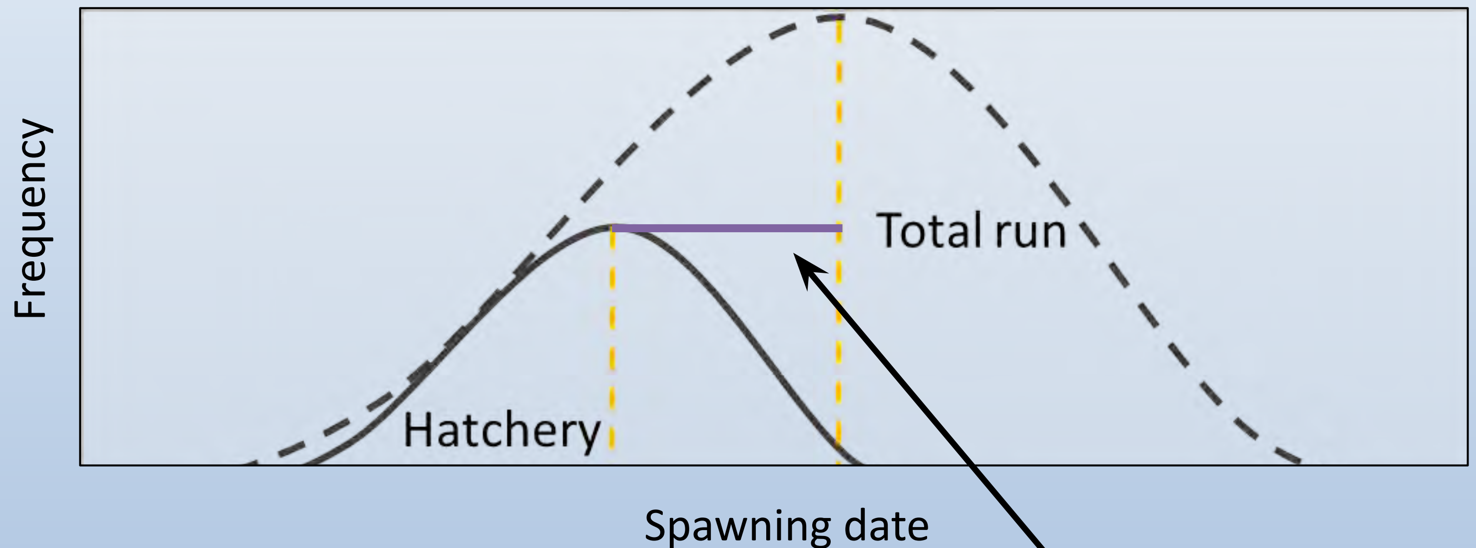
Patterns of change in Cedar River sockeye

- Little change in freshwater entry timing suggests minimal marine influence
- A trend towards later spawning in the Cedar River until reversing in mid-1990s
- Prior to mid-1990s shift to later spawning was correlated with changes in flow and temperature
- Can selection by hatchery practices explain residual trend in timing?



Tillotson et al. 2019

Estimating selection and trait change



The breeder's equation

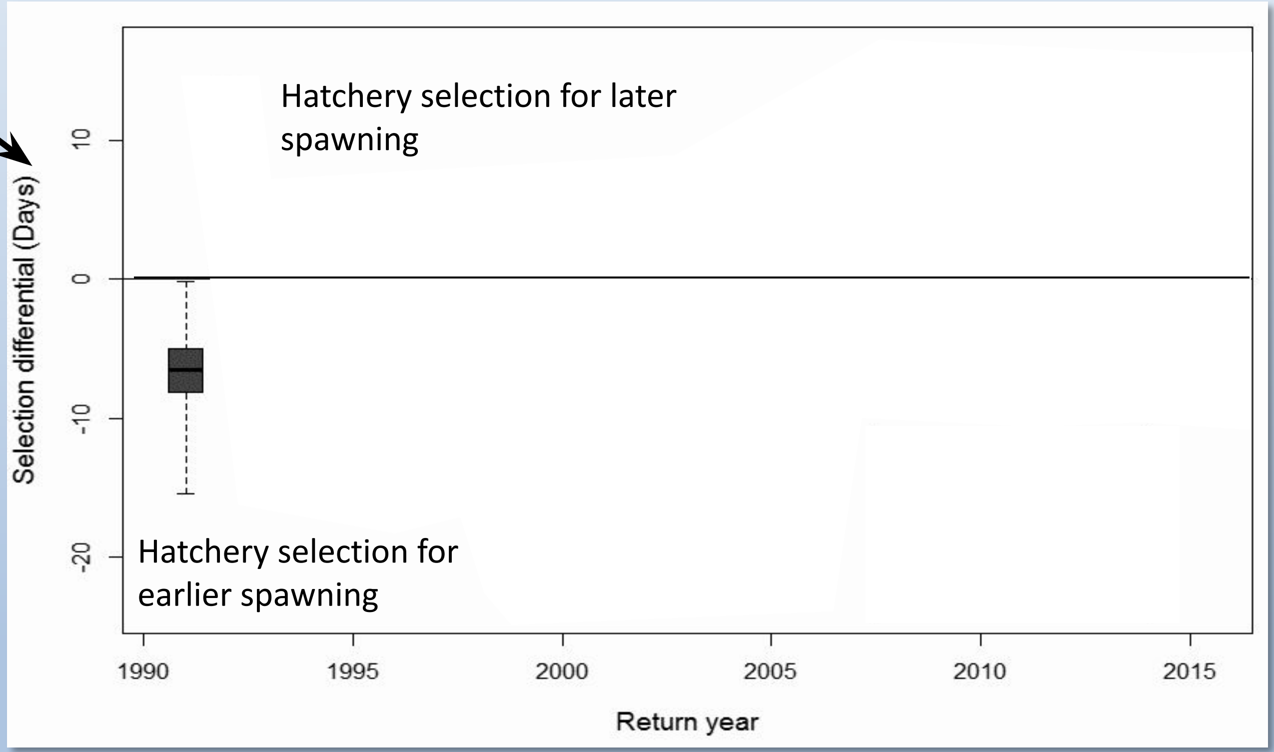
$R = h^2 S$ ← $S = \text{Spawn.date}_{run} - \text{Spawn.date}_{hatchery}$

Artificial selection for early spawning

$R = h^2S$

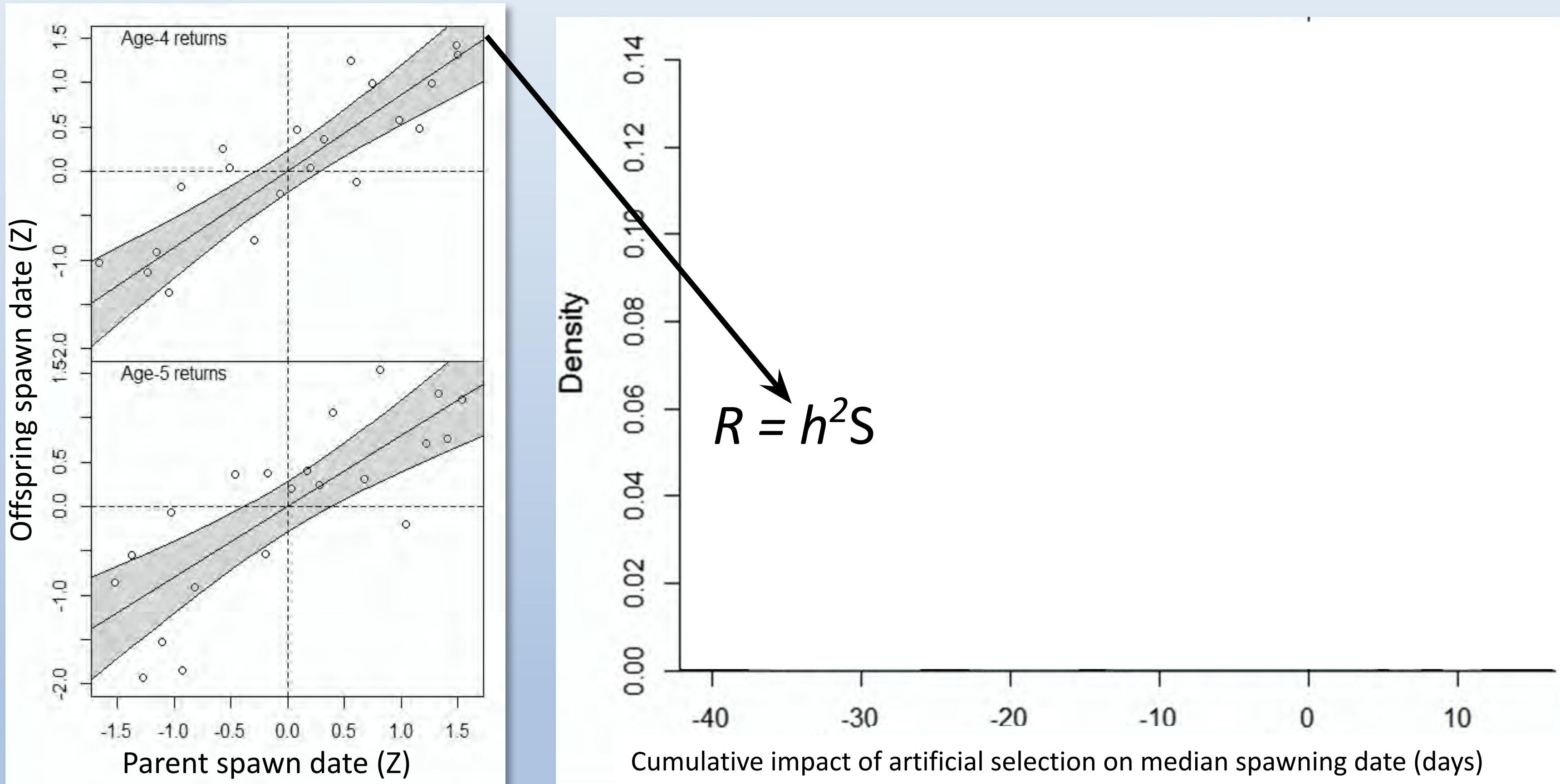
- Estimated selection using a range of assumptions about spawning behavior

- Selection for early spawning is most common, especially 1995 - 2006



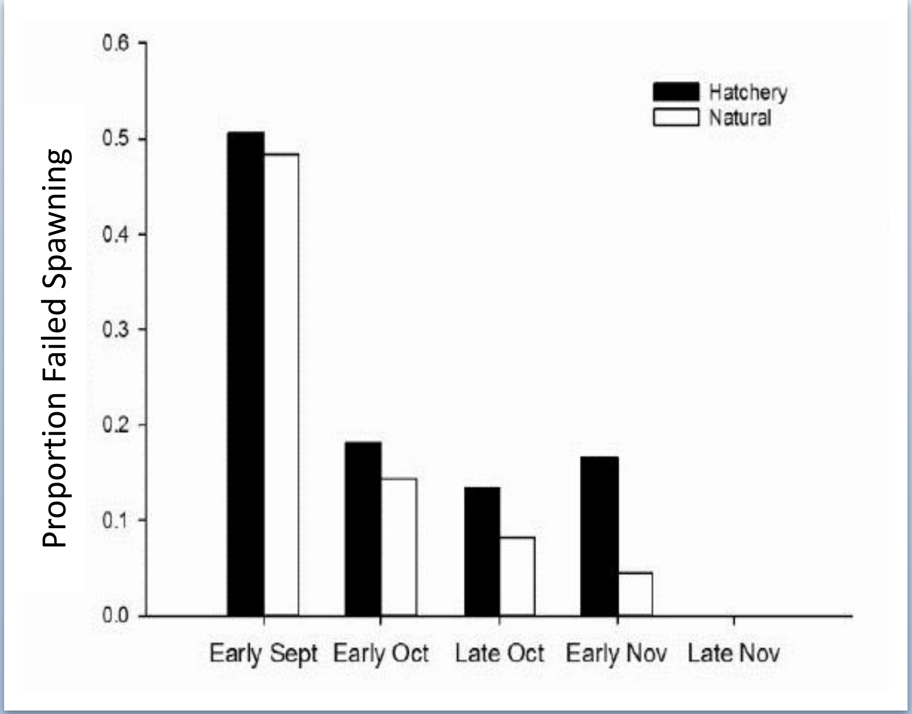
Tillotson et al. 2019

Estimated effect of selection on spawning date



Tillotson et al. 2019

Impacts of early spawning on fitness



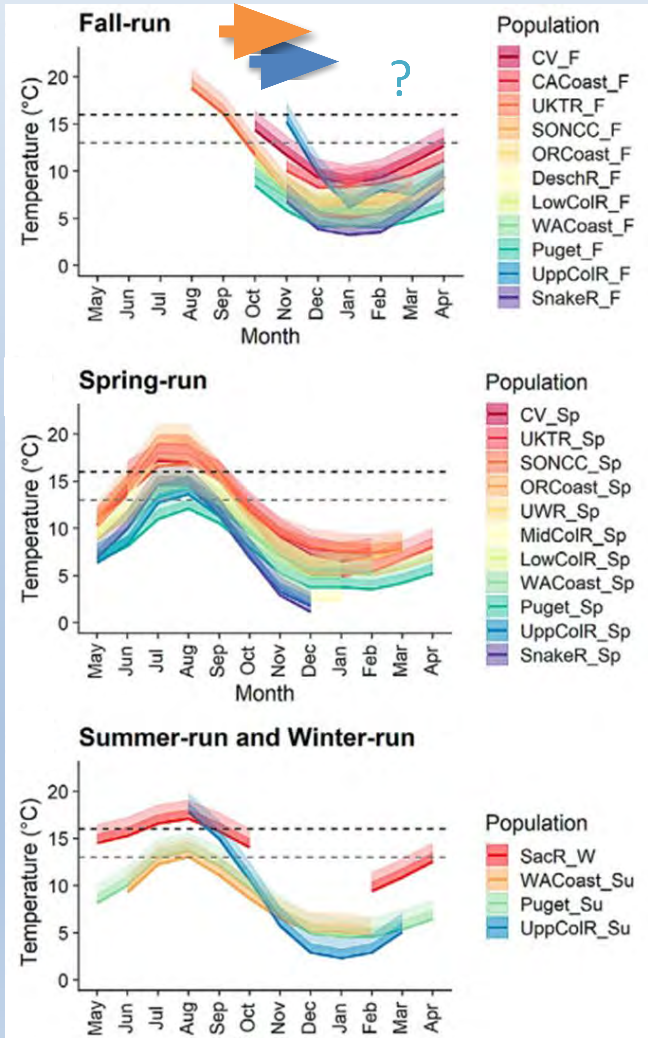
Barnett et al. 2015

- Though data are incomplete, evidence suggests that fry are emerging and entering the lake earlier, potentially prior to peak zooplankton availability
- Pre-spawning mortality (i.e. spawning failure) has been observed in the hatchery and in the Cedar River at increasing rates
- Proportion of fish dying prematurely tends to decline over the spawning season

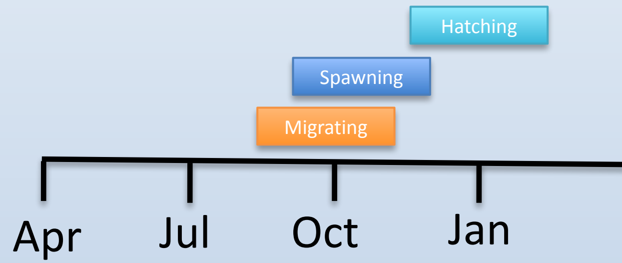
Case study summary

- Phenological change in Cedar River sockeye is driven by local processes
- Hatchery operations have on average selected for earlier spawning, likely accounting for a 1-2 week advance in spawning
- Artificially altered phenology is a potential contributor to reduced productivity in the population

Implications for California Salmon



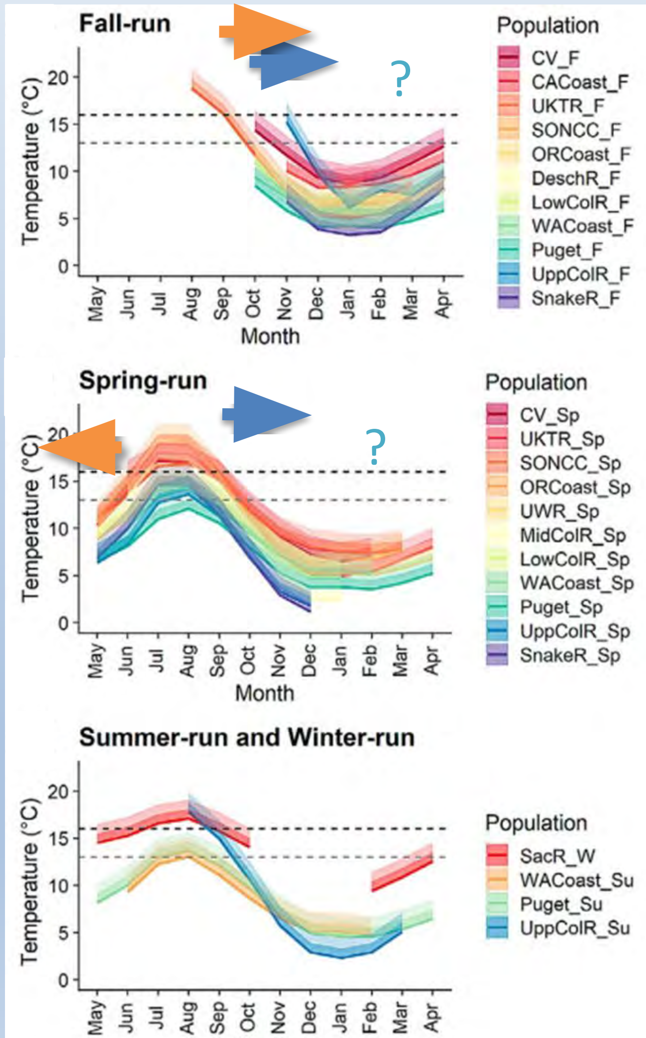
Fitzgerald et al. (2021)



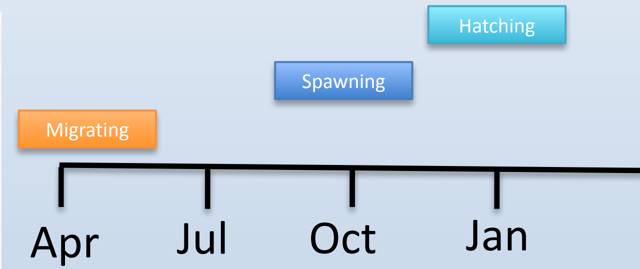
<u>Fall Run</u>

- Enter and spawn while water temperatures are falling
- Later river entry and spawning expected in response to warming
- Fry emerge as waters warm, but impact on timing will depend on relative influence of spawn timing and changes to incubation temperature
- Outmigration may advance to avoid warming river temperatures or to match changing ocean conditions
- Overall, warming may lead to shorter occupation of freshwater habitats

Implications for California Salmon



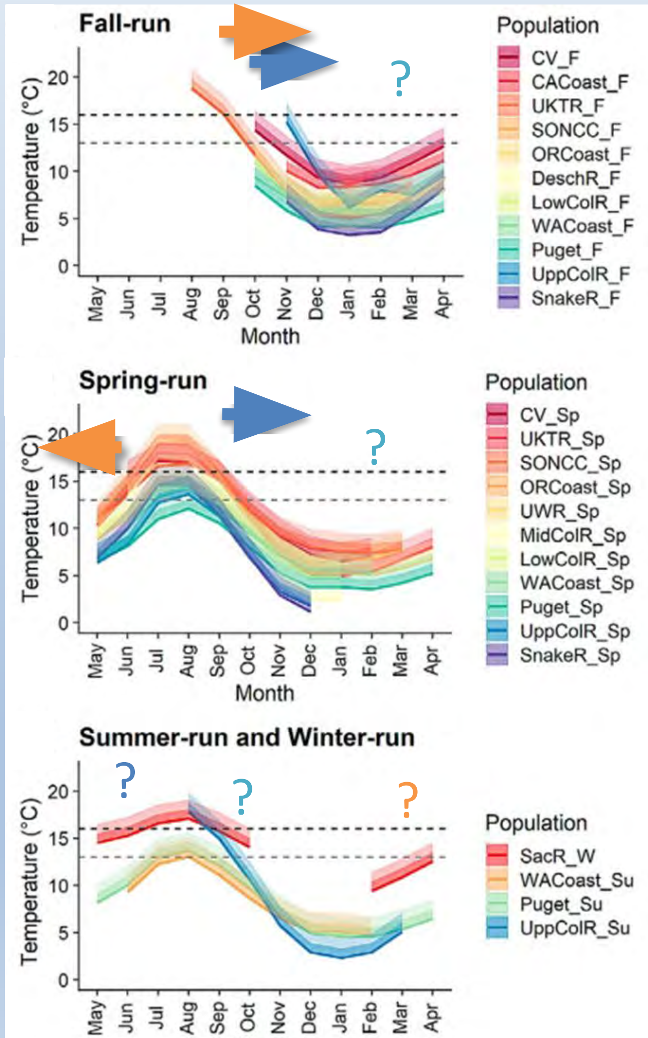
Fitzgerald et al. (2021)



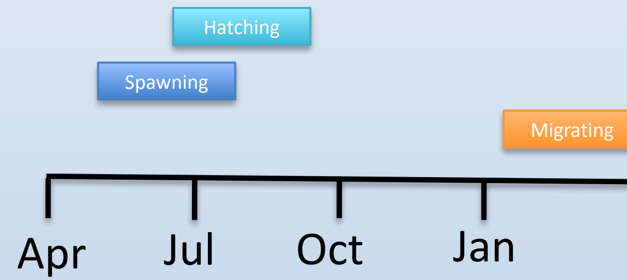
<u>Spring Run</u>

- Enter while temperatures are increasing, so expected response to warming is earlier river entry
- As with fall run, spawning occurs as temperatures decline, and so is expected to become later
- Combined, these changes may result in protracted freshwater holding by adults, though this duration is presumably subject to bioenergetic constraints
- As with fall run, impact on emergence is uncertain, but longer duration of freshwater rearing should largely decouple outmigration timing from adult phenology

Implications for Central Valley Chinook



Fitzgerald et al. (2021)



<u>Winter Run</u>

- As with spring run, enter while temperatures are increasing, though given earlier timing, seem unlikely to experience strong selection on this trait
- In contrast to other runs, spawning occurs before or during peak temperatures
- No obvious phenological adaptation in response to warming (basically need to find colder water)
- Incubation will occur more rapidly, but given proximity to temperature limits, increased mortality is the likely outcome.

Conclusions

- Reproductive phenology reflects a critical group of traits with high potential to be impacted by human activities
- Phenological shifts reflect an important adaptive strategy for populations faced with climate change, but these changes will interact with other anthropogenic influences including habitat modification, flow regulation, hatchery practices and fisheries managment
- Protecting the habitats and genetic diversity that support variability in reproductive timing is critical for long-term viability of salmon in California

Recommendations for Central Valley salmonids

1. Evaluate current availability of phenological data
2. When possible, collect and report data on fisheries catches, fish passage, hatchery egg-take and redd/spawner surveys on weekly or finer timescale
3. Evaluate relationships between flow and adult migration
4. Evaluate hatchery practices in order to identify instances of artificial selection on spawning phenology
5. Characterize patterns of pre-spawn and *en route* mortality
6. For fall run, evaluate fishing regulations and their resilience to later migration and spawning
7. For spring run, identify opportunities to provide additional cold-water holding areas
8. For winter run… more cold water or access to higher elevations

Questions?

- Tillotson, M. D., & Quinn, T. P. (2018). Selection on the timing of migration and breeding: A neglected aspect of fishing-induced evolution and trait change. *Fish and Fisheries*, *19*(1), 170-181.
- Hodgson, S., & Quinn, T. P. (2002). The timing of adult sockeye salmon migration into fresh water: adaptations by populations to prevailing thermal regimes. *Canadian Journal of Zoology*, *80*(3), 542-555.
- Quinn, T. P., & Adams, D. J. (1996). Environmental changes affecting the migratory timing of American shad and sockeye salmon. *Ecology*, *77*(4), 1151-1162.
- Tillotson et al. (2021). Challenges in the identification and interpretation of phenological shifts: anthropogenic influences on adult migration timing in salmonids. *Reviews in Fisheries Science & Aquaculture*, *29*(4), 769-790.
- Shearer, W. M. (1990). The Atlantic salmon (*Salmo salar* L.) of the North Esk with particular reference to the relationship between both river and sea age and time of return to home waters. *Fisheries Research*, *10*(1-2), 93-123.
- Tillotson et al. (2019). Artificial selection on reproductive timing in hatchery salmon drives a phenological shift and potential maladaptation to climate change. *Evolutionary applications*, *12*(7), 1344-1358.
- Mundy, P. R., & Evenson, D. F. (2011). Environmental controls of phenology of high-latitude Chinook salmon populations of the Yukon River, North America, with application to fishery management. *ICES Journal of Marine Science*, *68*(6), 1155-1164.
- Nyqvist et al. (2017). Upstream and downstream passage of migrating adult Atlantic salmon: remedial measures improve passage performance at a hydropower dam. *Ecological Engineering*, *102*, 331-343.
- Barnett et al. (2020). Increased prespawning mortality threatens an integrated natural-and hatchery-origin sockeye salmon population in the Lake Washington Basin. *Fisheries Research*, *227*, 105527.
- Dahl, J. et al. (2004). The timing of spawning migration: implications of environmental variation, life history, and sex. *Canadian Journal of Zoology*, *82*(12), 1864-1870.

Data and Funding

IGERT Program on Ocean Change

Skagit River System Cooperative

National Science Foundation — Where Discoveries Begin

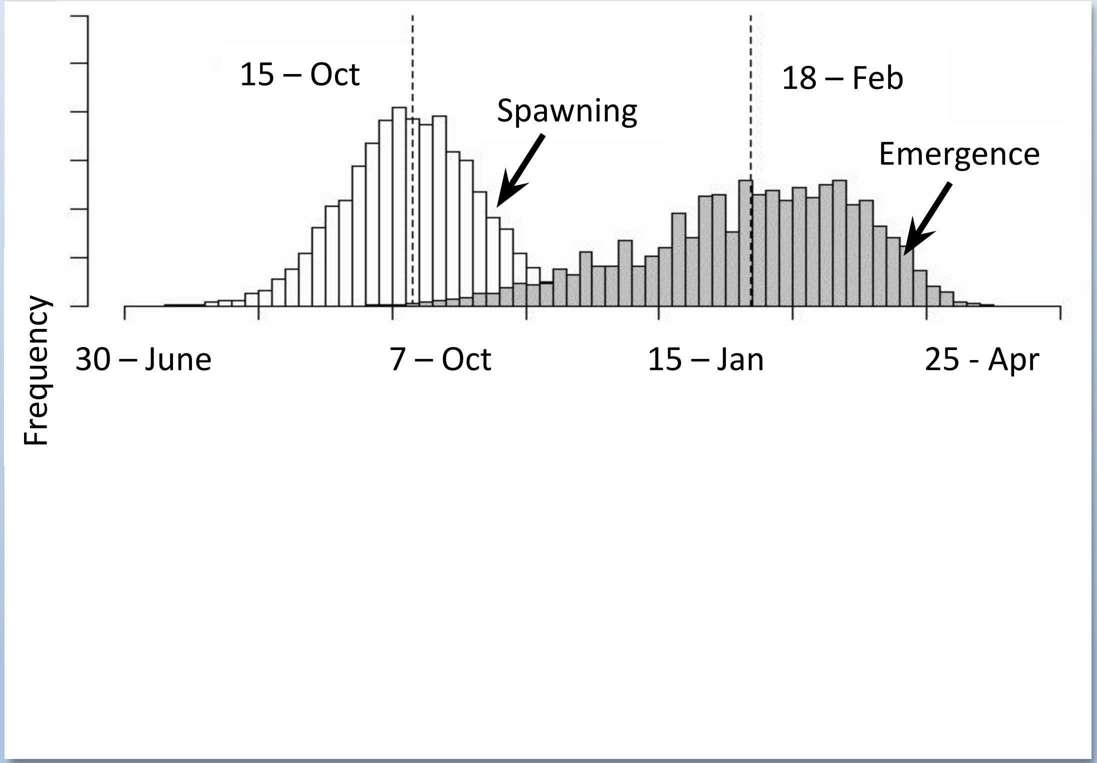
School of Aquatic & Fishery Sciences

Washington Department of Fish and Wildlife

Seattle Public Utilities

Fitness impacts: Emergence timing

- Incubation time is temperature-dependent; earlier spawning is also warmer spawning
- Spawning one week earlier leads to emergence almost two weeks earlier
- On average, later emerging fry experience higher survival upon entering Lake Washington (Hovel 2015)



A Multigenerational Pedigree Analysis Reveals the Potential for Selection on Steelhead Life-History Traits

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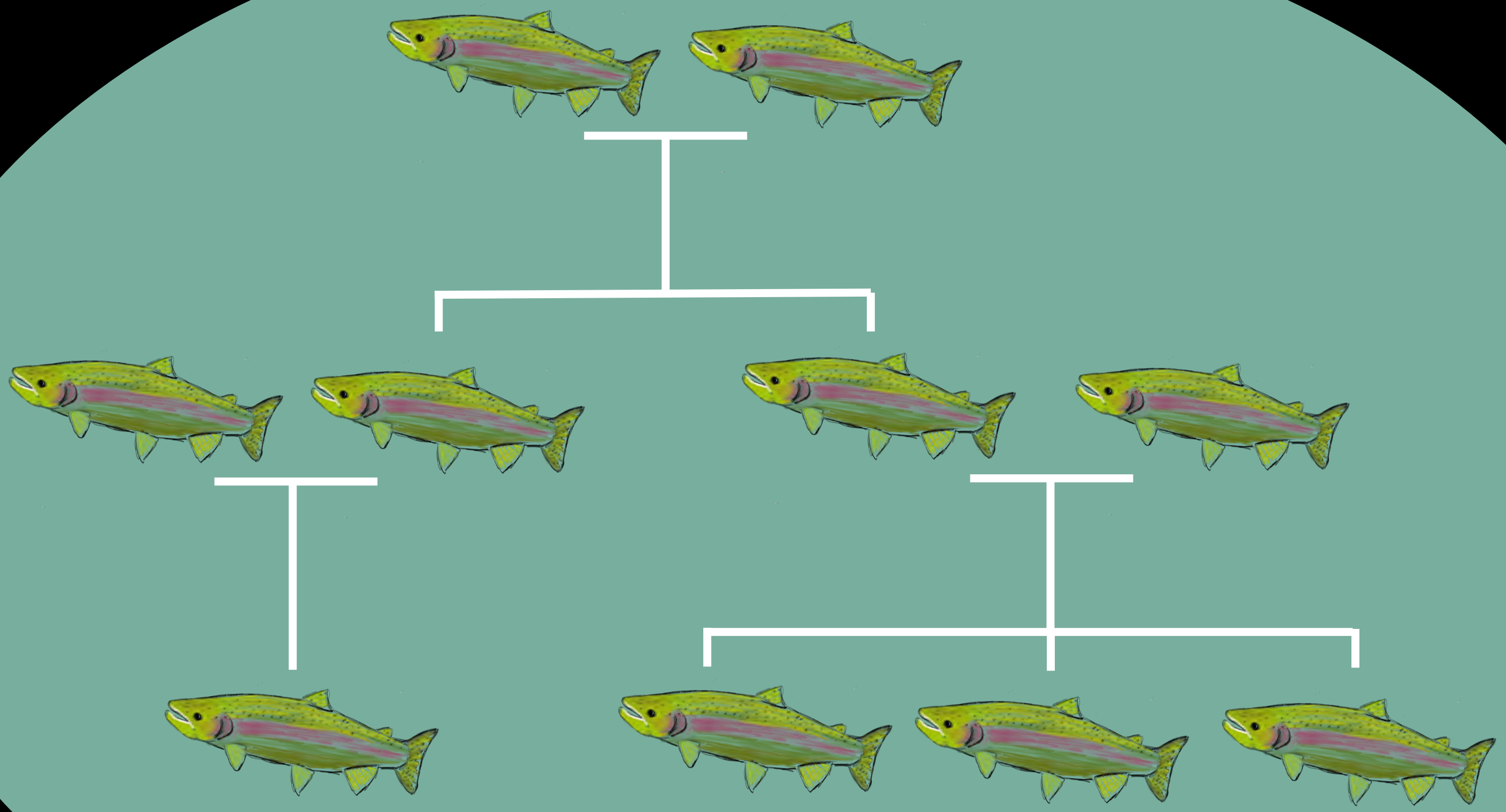
University of California, Santa Cruz
NOAA Southwest Fisheries Science Center

Multigenerational pedigrees though parentage-based tagging (PBT)

- Fin clip taken at spawning
- Genetic markers match parents to their offspring
- Long-term monitoring with PBT enables multigenerational pedigrees



Benefits of parentage-based tagging

- Non-lethal sampling
- No differential survival between tagged and untagged fish
- Pedigree-based research opportunities
    - Trait heritability
    - Reproductive success
    - Inbreeding

Heritability of life-history traits

Human activities may select for specific phenotypes in heritable traits

Human activities may select for specific phenotypes in heritable traits

- Hatchery management
- Restoration efforts
- Fishing regulations

Russian River steelhead (*O. mykiss*)

Hatchery broodstock

2007-2020

18,358 fin clip samples

Russian River steelhead (*O. mykiss*)

Hatchery broodstock

2007-2020

18,358 fin clip samples

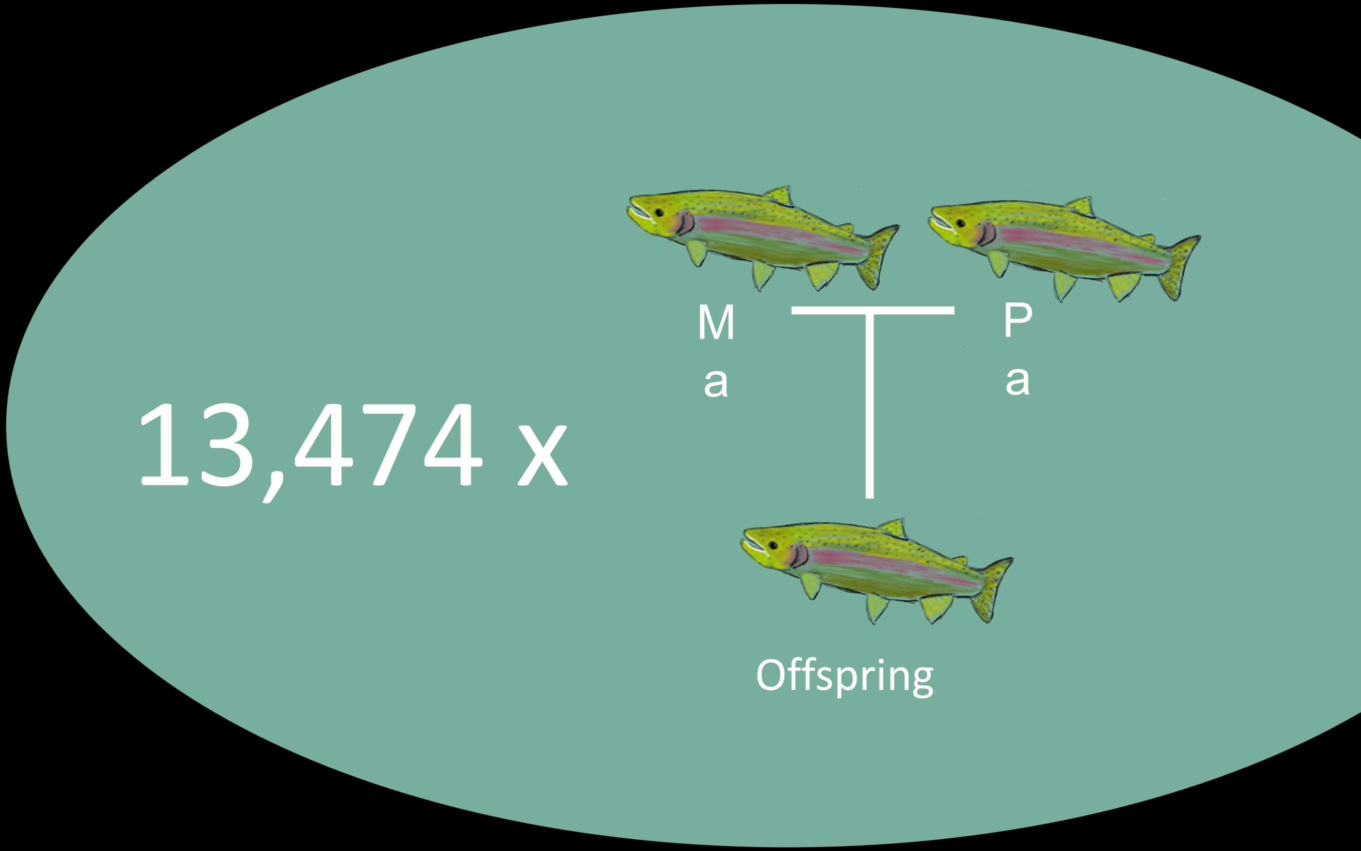
Warm Springs Hatchery

Coyote Valley Fish Facility

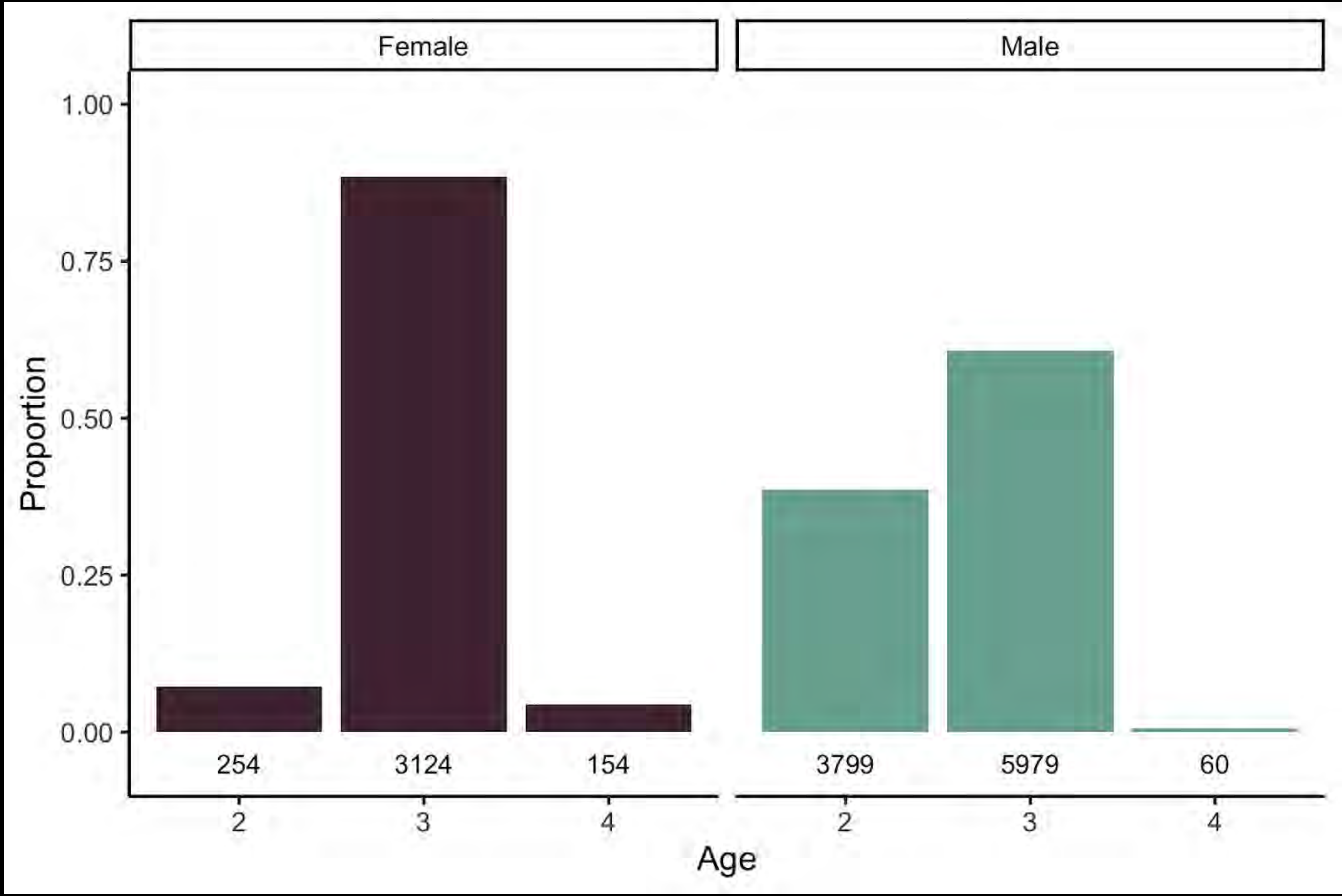
Russian River steelhead pedigrees

Parent pairs were identified for **13,474** offspring

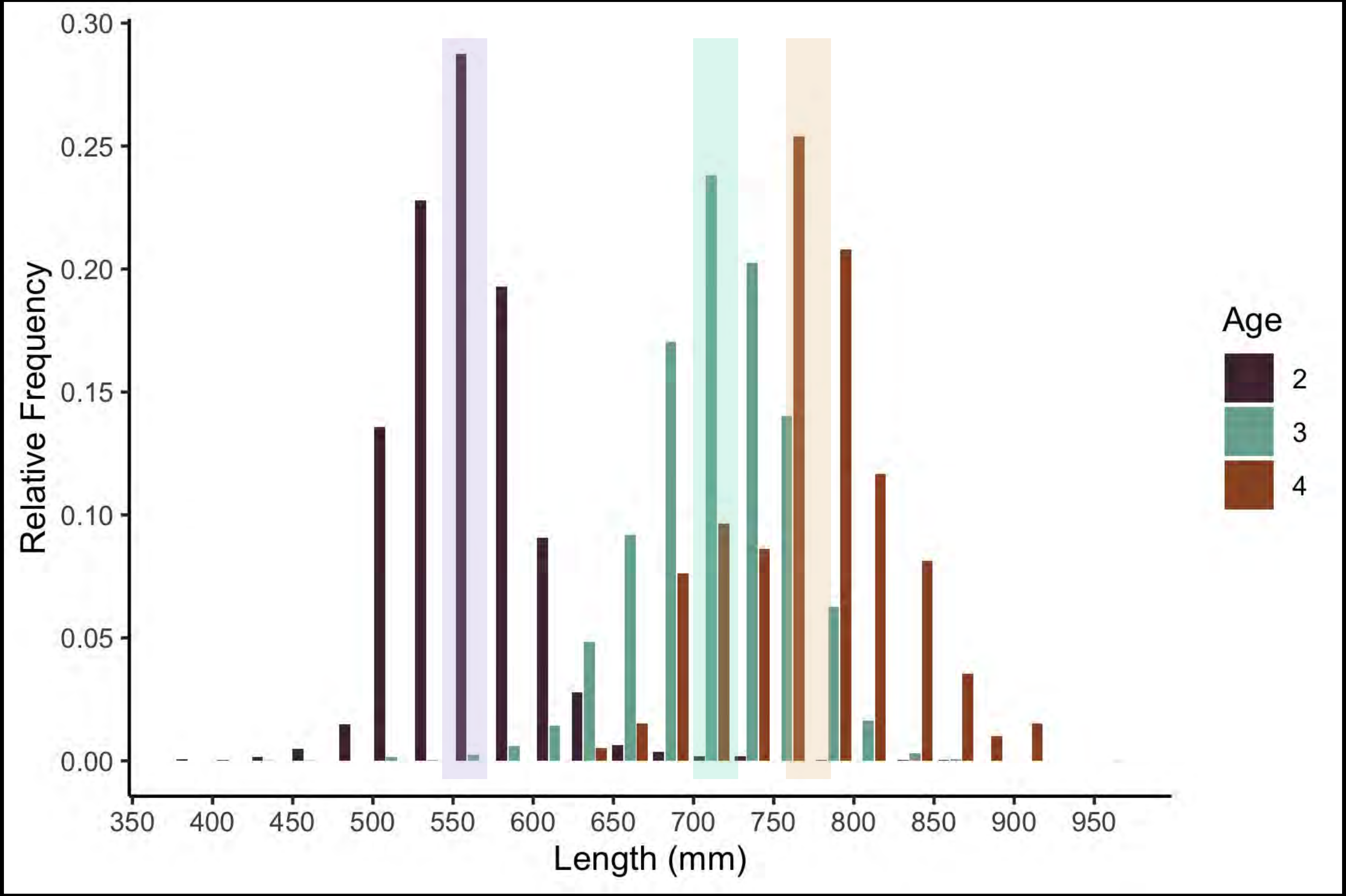
Total of **15,991** steelhead



Age at maturity

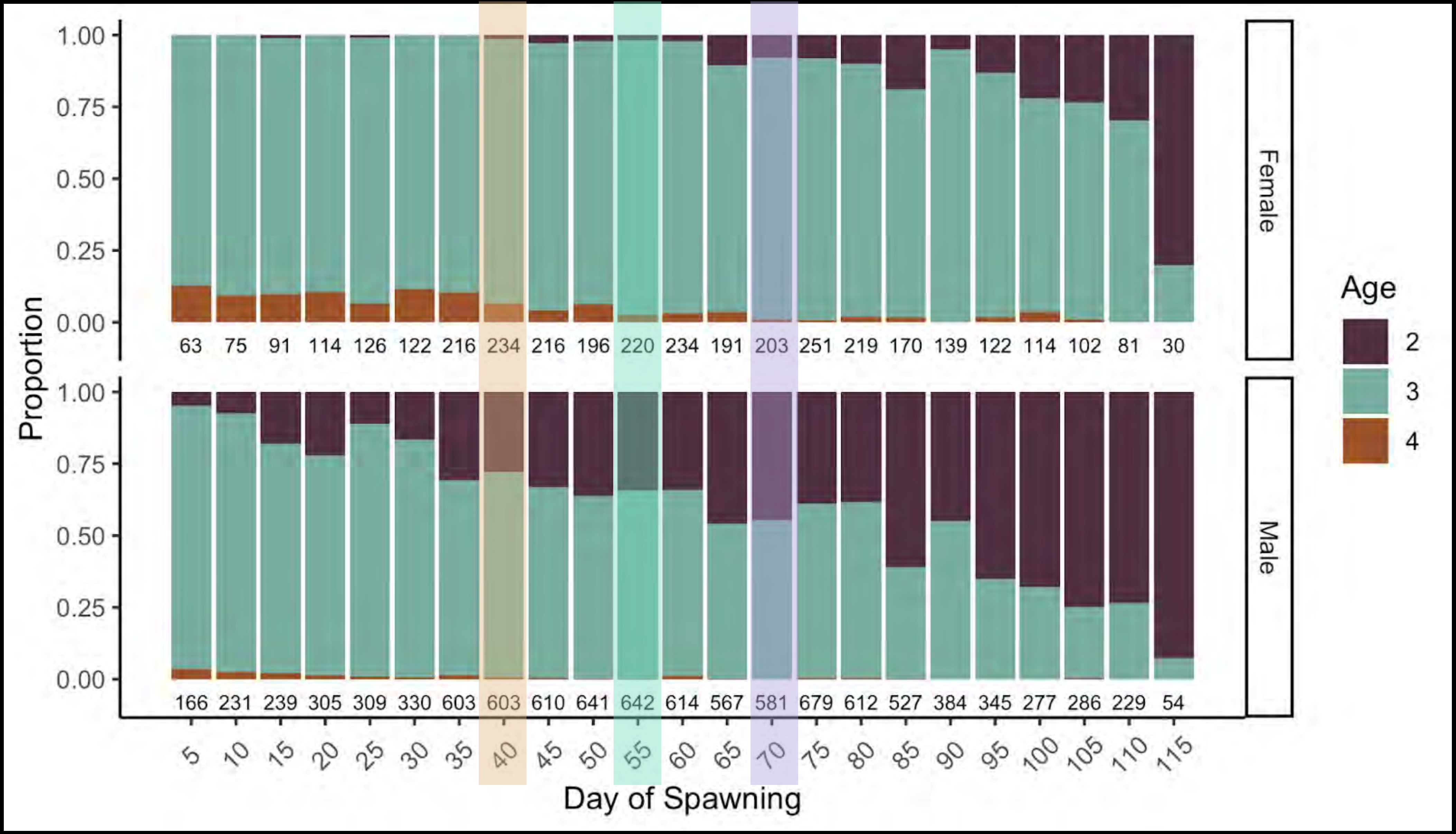


Age & length



Relative Frequency
0.30
0.25
0.20
0.15
0.10
0.05
0.00
350
400
450
500
550
600
650
700
750
800
850
900
950
Length (mm)
Age
2
3
4

Spawn date & age



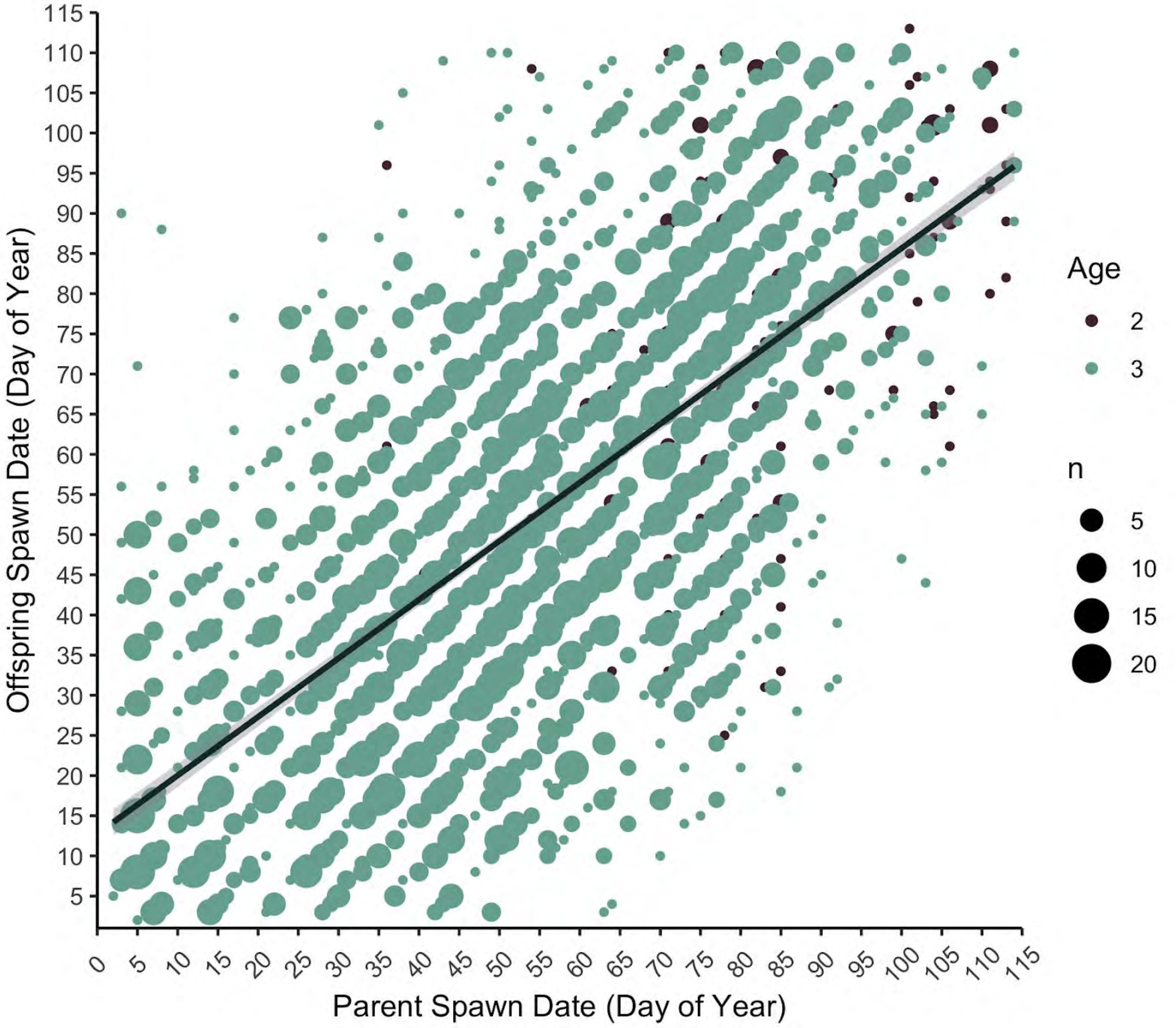
Pedigrees allow heritability estimates

Comparison of traits in related individuals

- Spawn date
- Age at maturity

Spawn date: parent-offspring regression

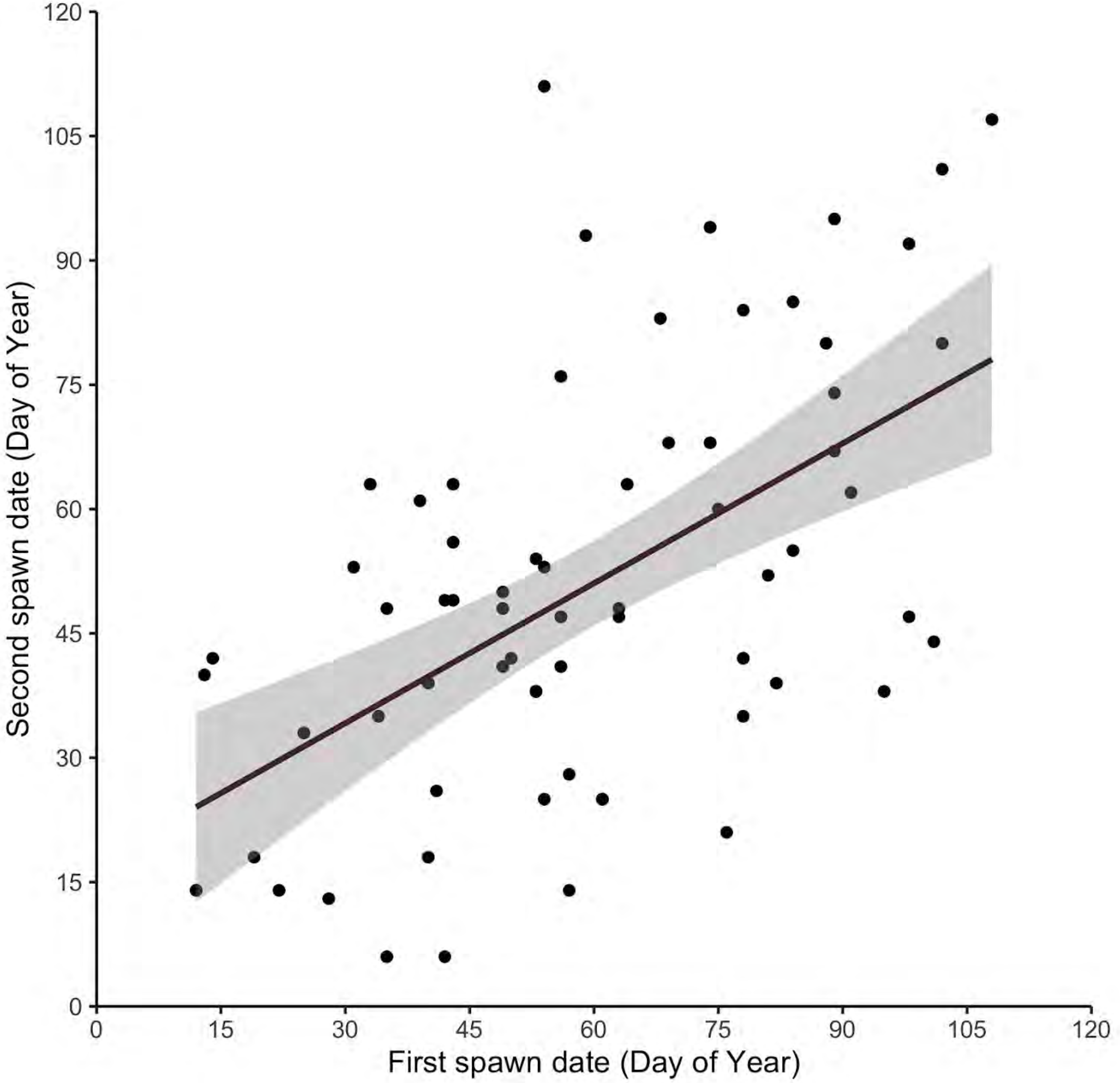
Slope: 0.73
R^2: 0.43



Iteroparous individuals

Spawn date of first & second spawn year

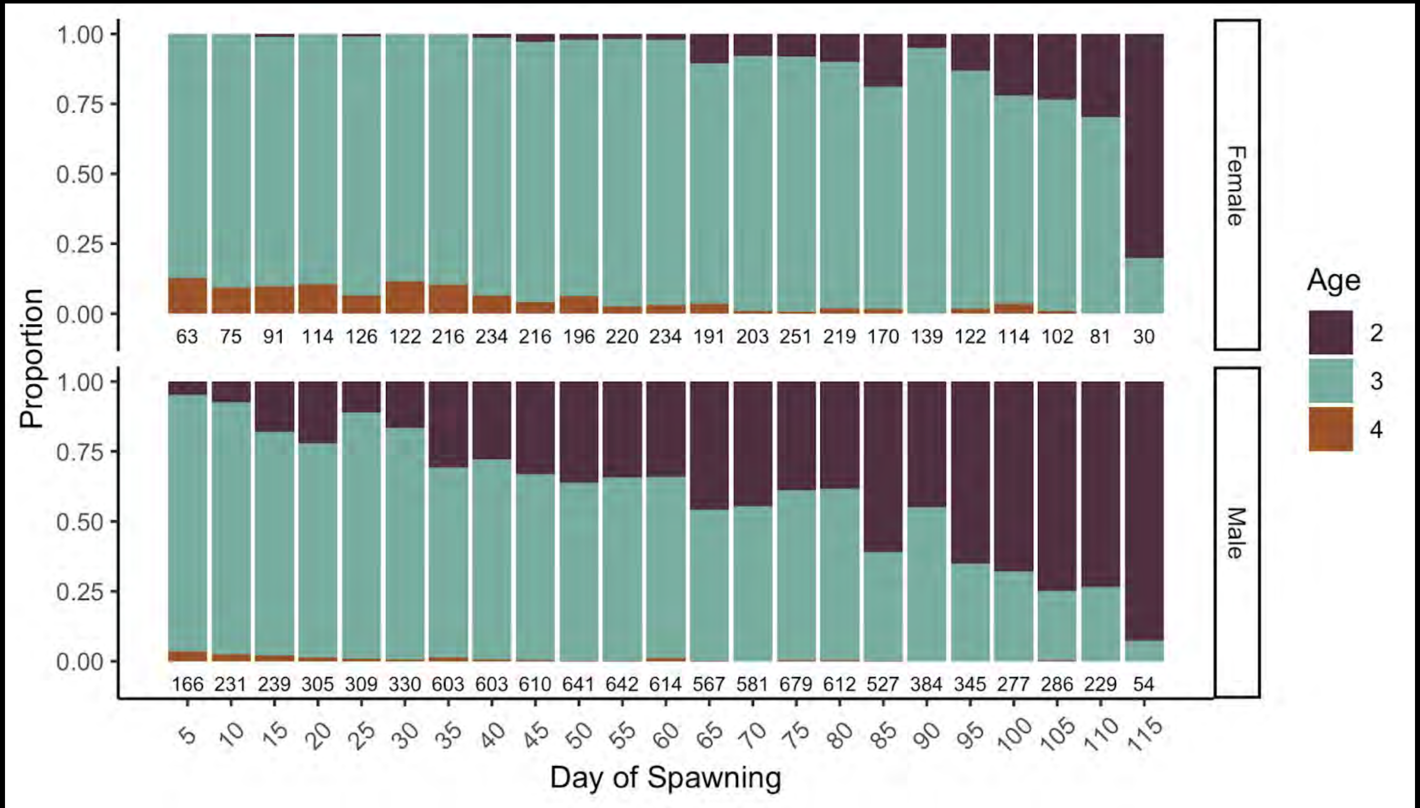
Slope: 0.56
R^2: 0.29



Heritability of spawn date and its connection to restoration

- Flow regimes during the spawning season could lead to selection for specific spawning date
    - Water releases during spawning seasons

- Spawn date and age are associated



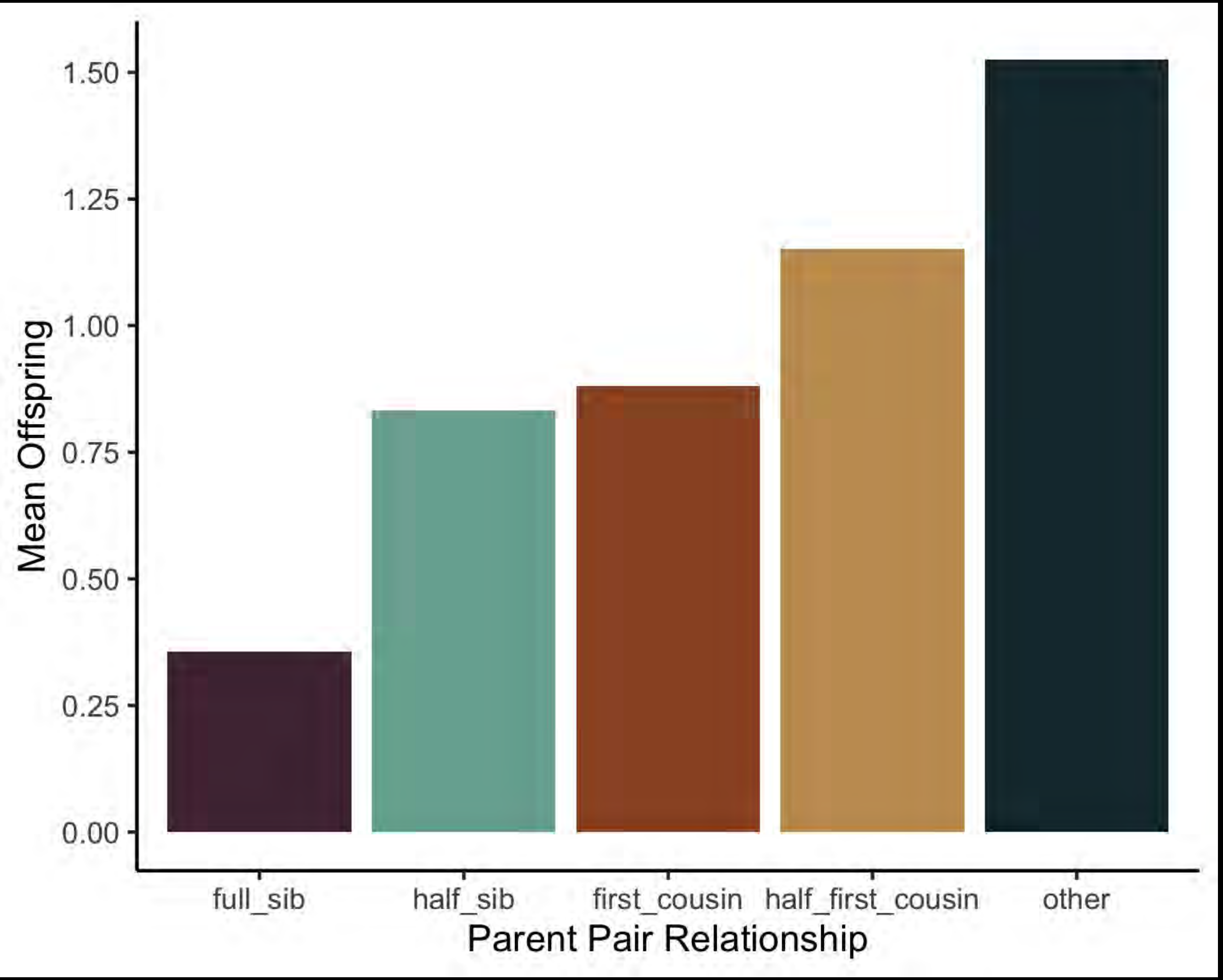
Inbreeding impact

Unrelated parent pairs:

- 70.7% had offspring that returned to hatchery

Full-sibling parent pairs:

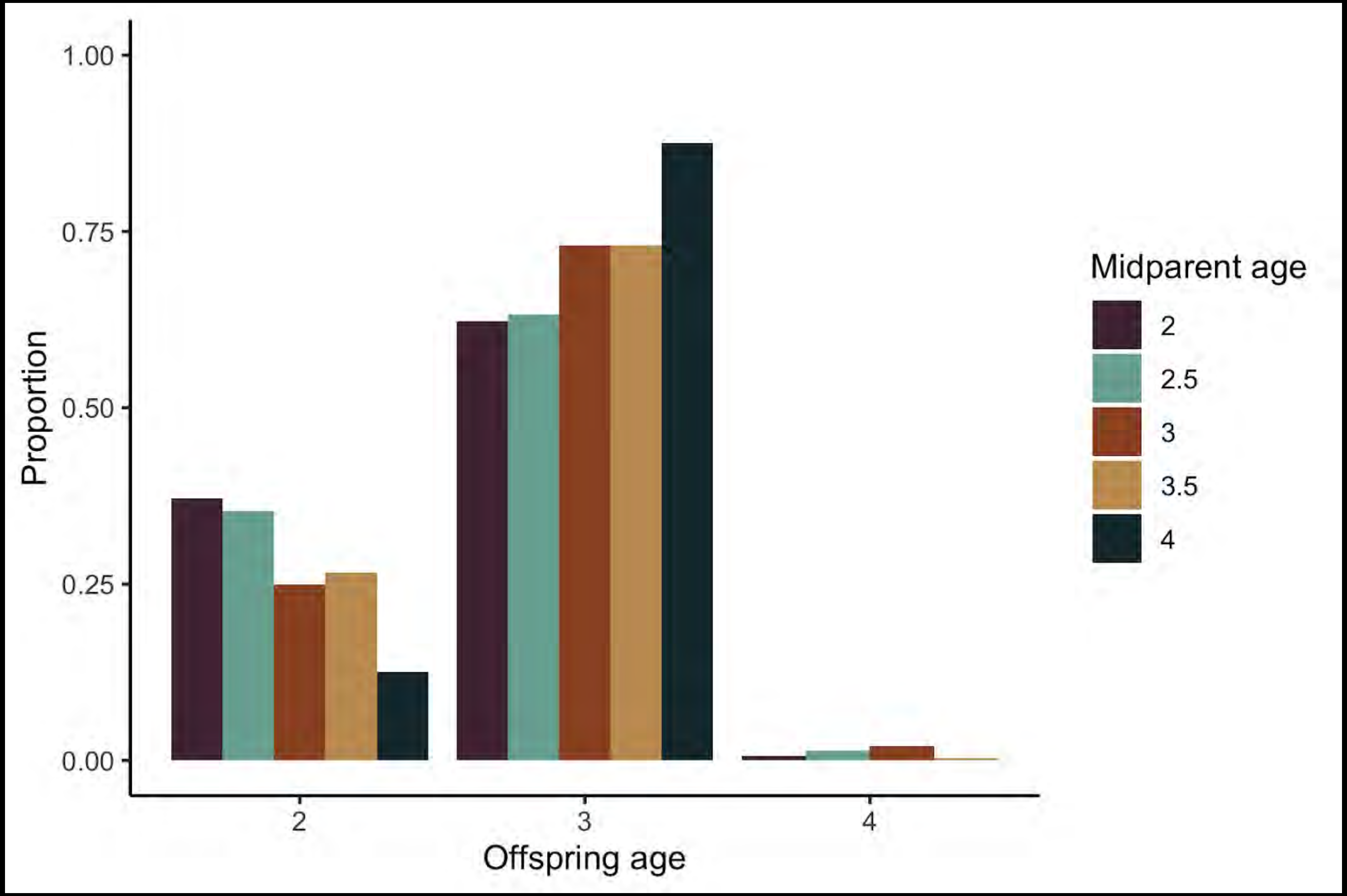
- 14.3% had offspring that returned to hatchery



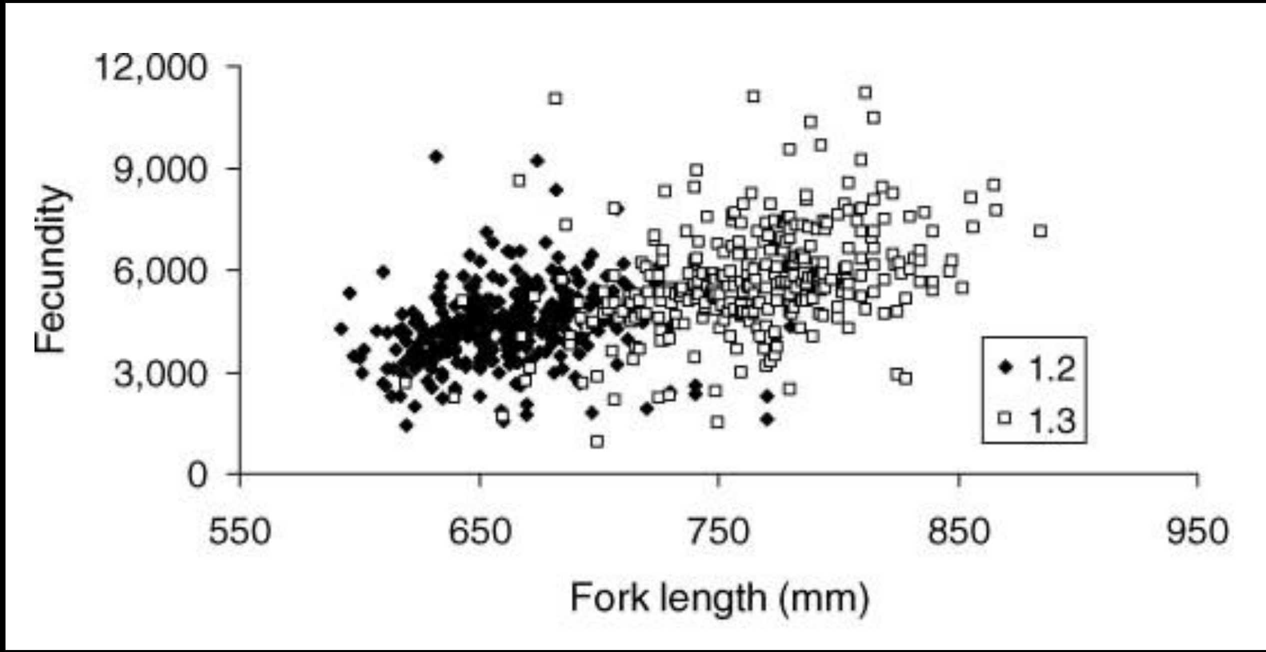
Age at maturity

Heritability estimates

- Threshold equation
  - $h^2 = 0.41$
    - Males only, 0.37
    - Females only, 0.53
- Animal Model
  - $h^2 = 0.21$
    - Males only, 0.26
    - Females only, 0.48



Selection pressures differ on male and female age at maturity

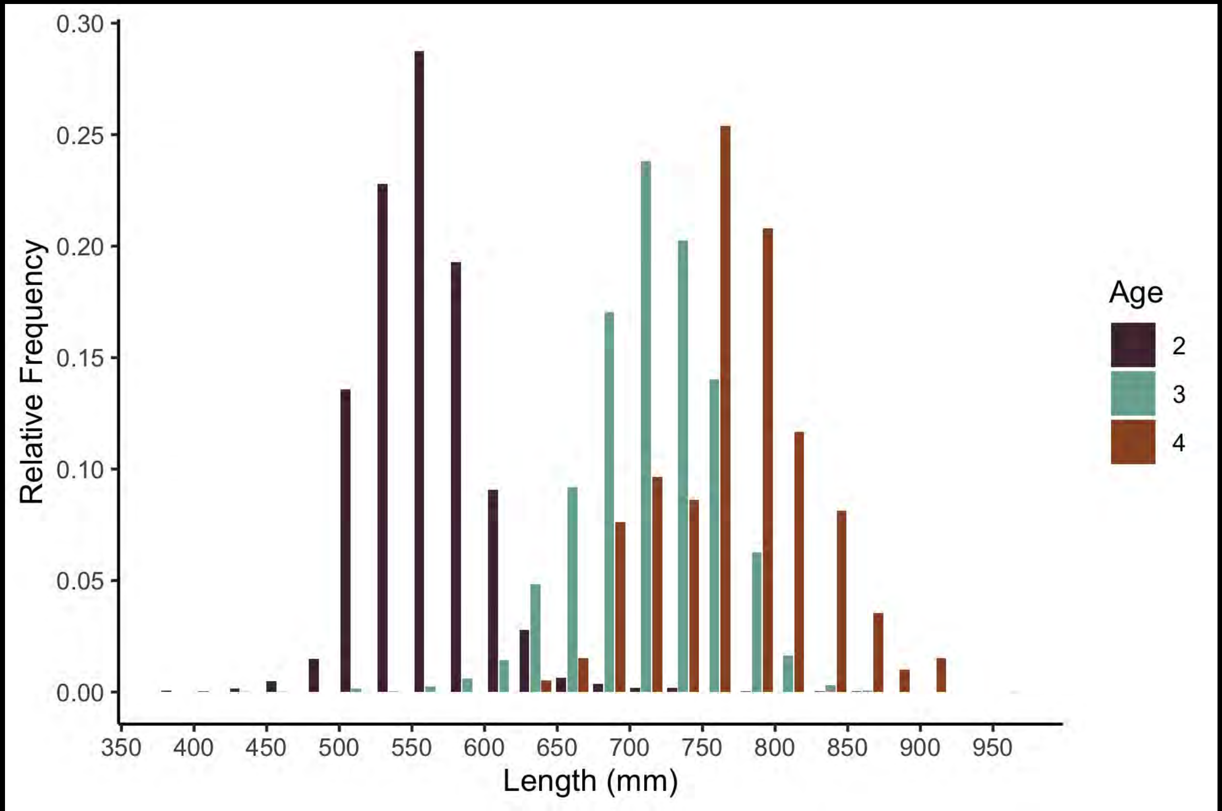


Quinn et al., 2011

- Female fecundity is correlated with body size
- Male fecundity is not
- More time in the ocean prolongs predation risk

Heritability of age at maturity and its impact on restoration

- Age is associated with body length
  - Female fecundity
- Body length impacts jump height
  - Fish passage restoration projects
- Body length impacts ideal spawning substrate size
  - Spawning ground restoration projects



Selection on life-history traits

- Could lead to a loss of phenotypic and genetic diversity in steelhead
  - Loss of fecundity in females
  - Increased inbreeding potential

- Diversity in ages and spawn timing aids in population resiliency to environmental changes and extreme events

Conclusions

- Parentage-based tagging is a powerful tool in hatchery management and restoration efforts.
- Heritable life-history traits have potential for selection through hatchery management and restoration efforts.
- Selection on life-history traits could reduce phenotypic and genetic diversity – this could reduce resiliency in steelhead.
- The selection potential of heritable life-history traits should be considered when designing restoration projects and deciding hatchery management plans.

Acknowledgments

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Laney Correa
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Keith Hernandez

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Jennifer Hoey
Thomas Ng

Warm Springs and Coyote Valley Hatchery Staff

Questions?

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Rethinking Monitoring of Steelhead in California’s Central Valley

Jack Eschenroeder, Matt Peterson, Michael Hellmair, **Tyler Pilger**, Doug Demko, and Andrea Fuller

39th Salmonid Restoration Conference 21 April 2022

Acknowledgements

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STOCKTON EAST WATER DISTRICT

U.S. FISH & WILDLIFE SERVICE
DEPARTMENT OF THE INTERIOR

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Sponsored by the Delta Science Program and the UC Davis Muir Institute

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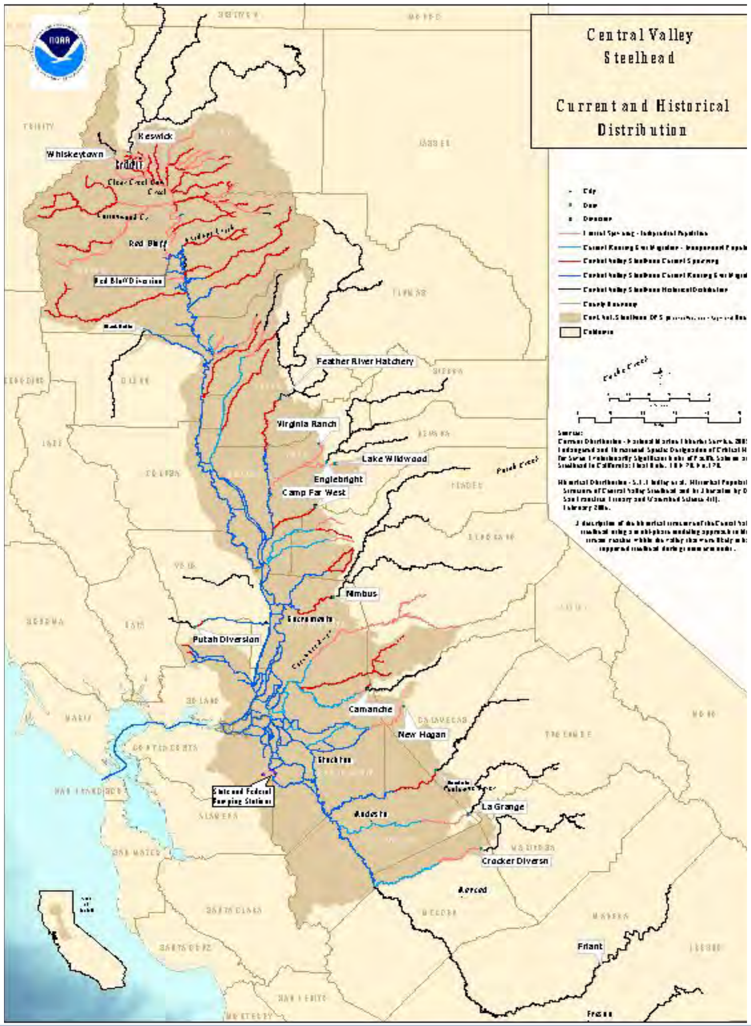
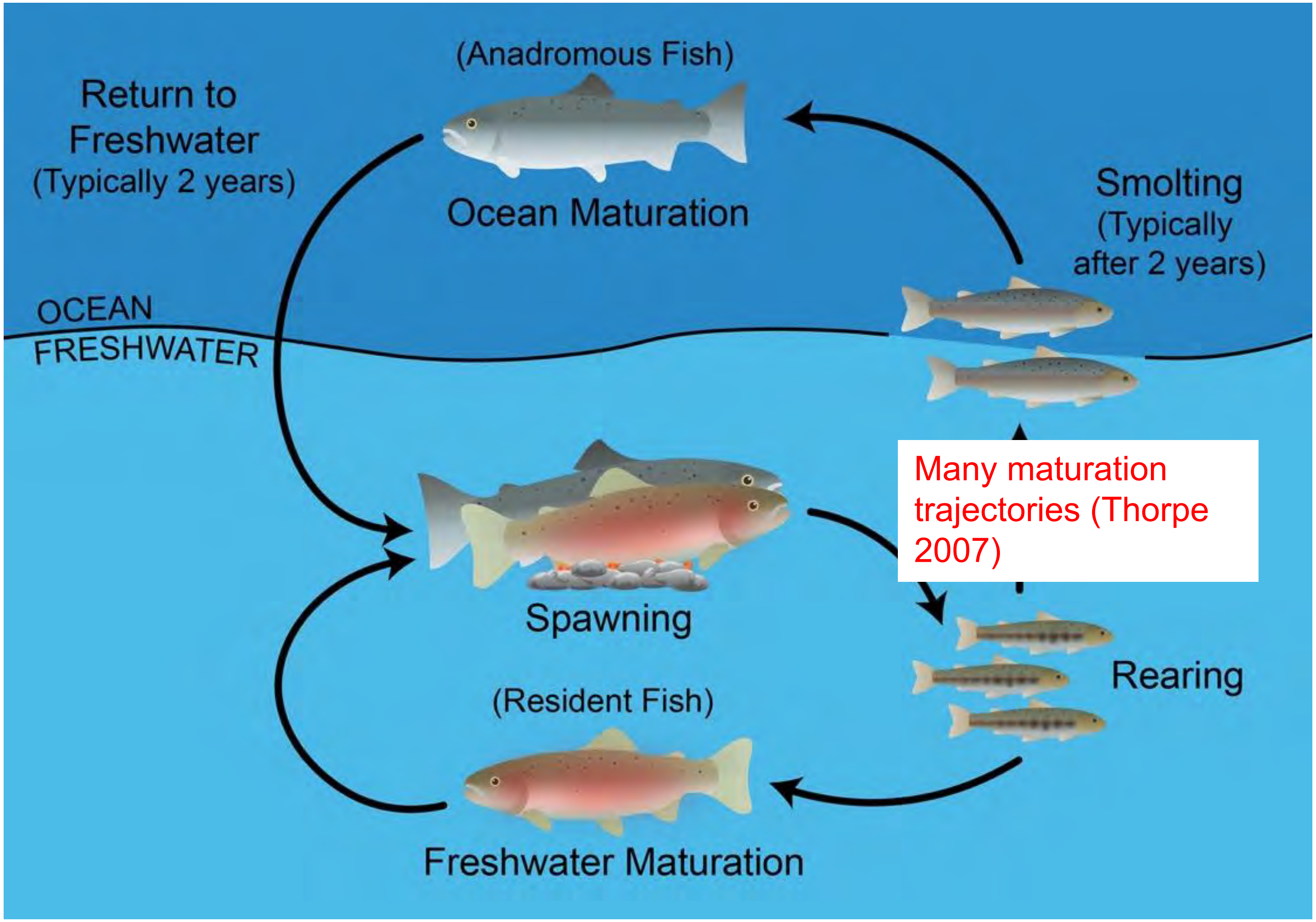
Central Valley Steelhead

- Designated Population Segment
  - Listed as threatened in 1998, reaffirmed in 2006
  - 6 diversity groups
- > 200 recovery actions solely for steelhead
  - Region and river specific
  - Comprehensive CV steelhead **monitoring**
  - Understanding of role of **resident fish** in species maintenance and persistence
- Primary metric to assess recovery: **abundance**



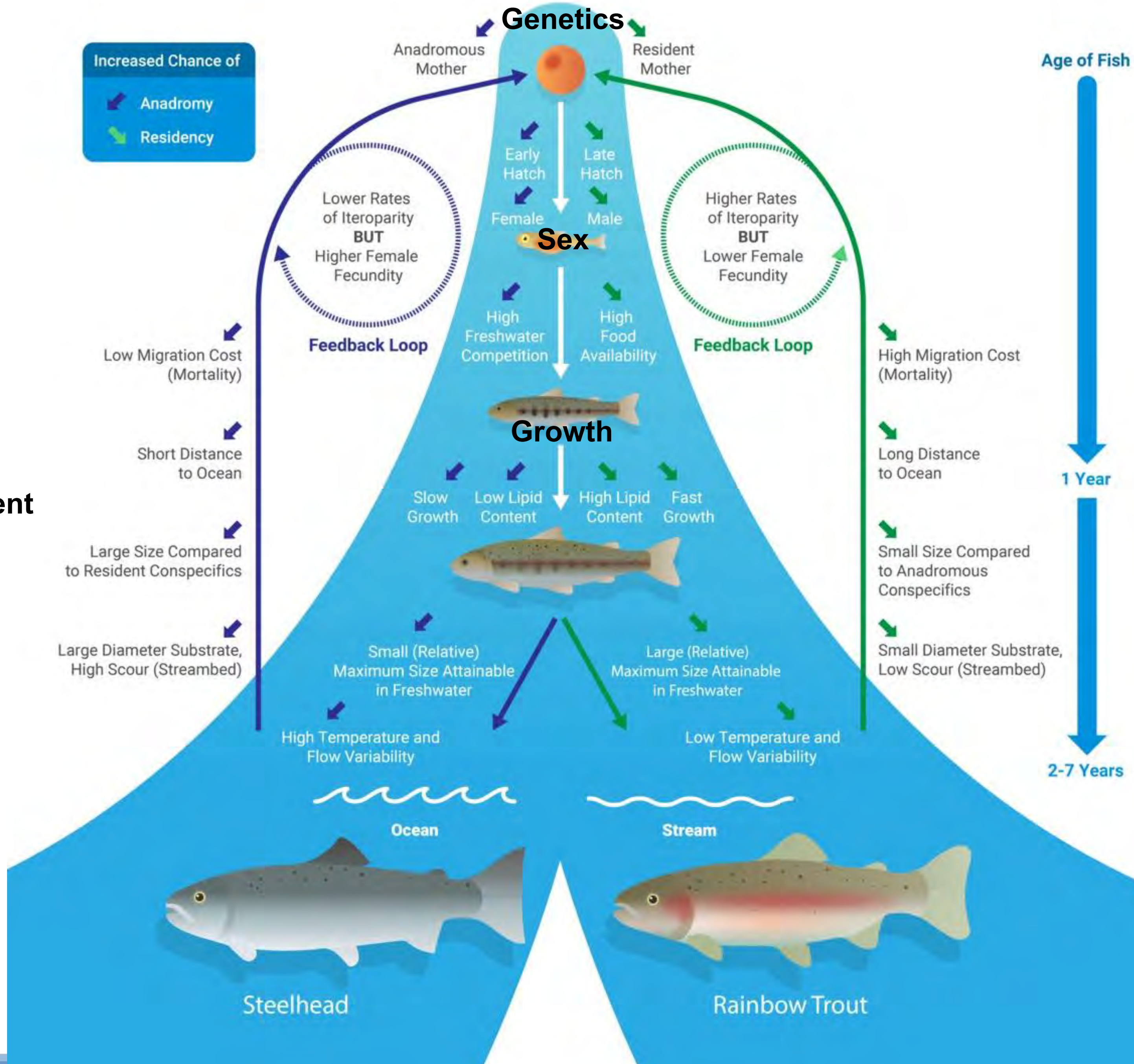
Facultative Anadromy



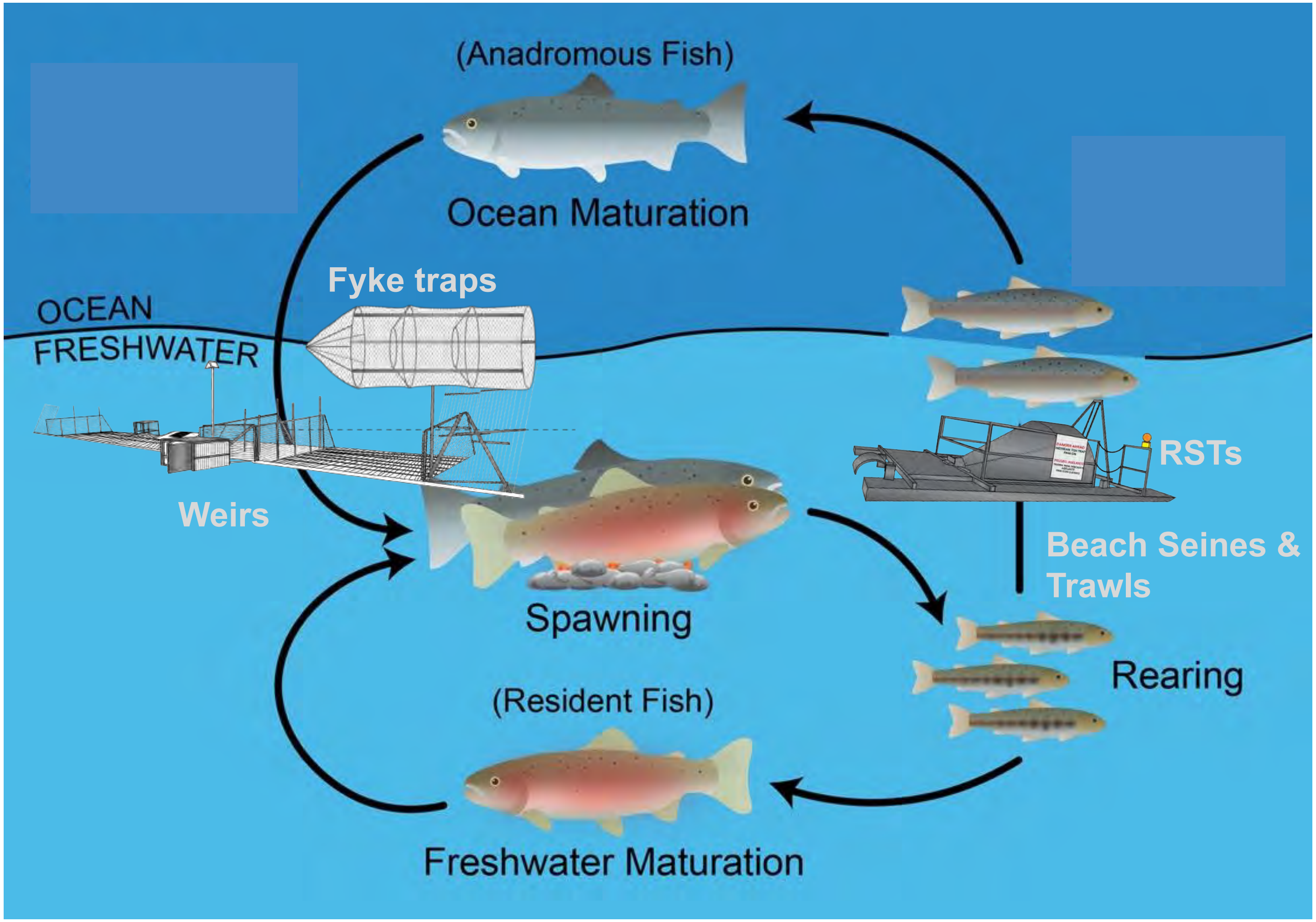
Many maturation trajectories (Thorpe 2007)

Survival

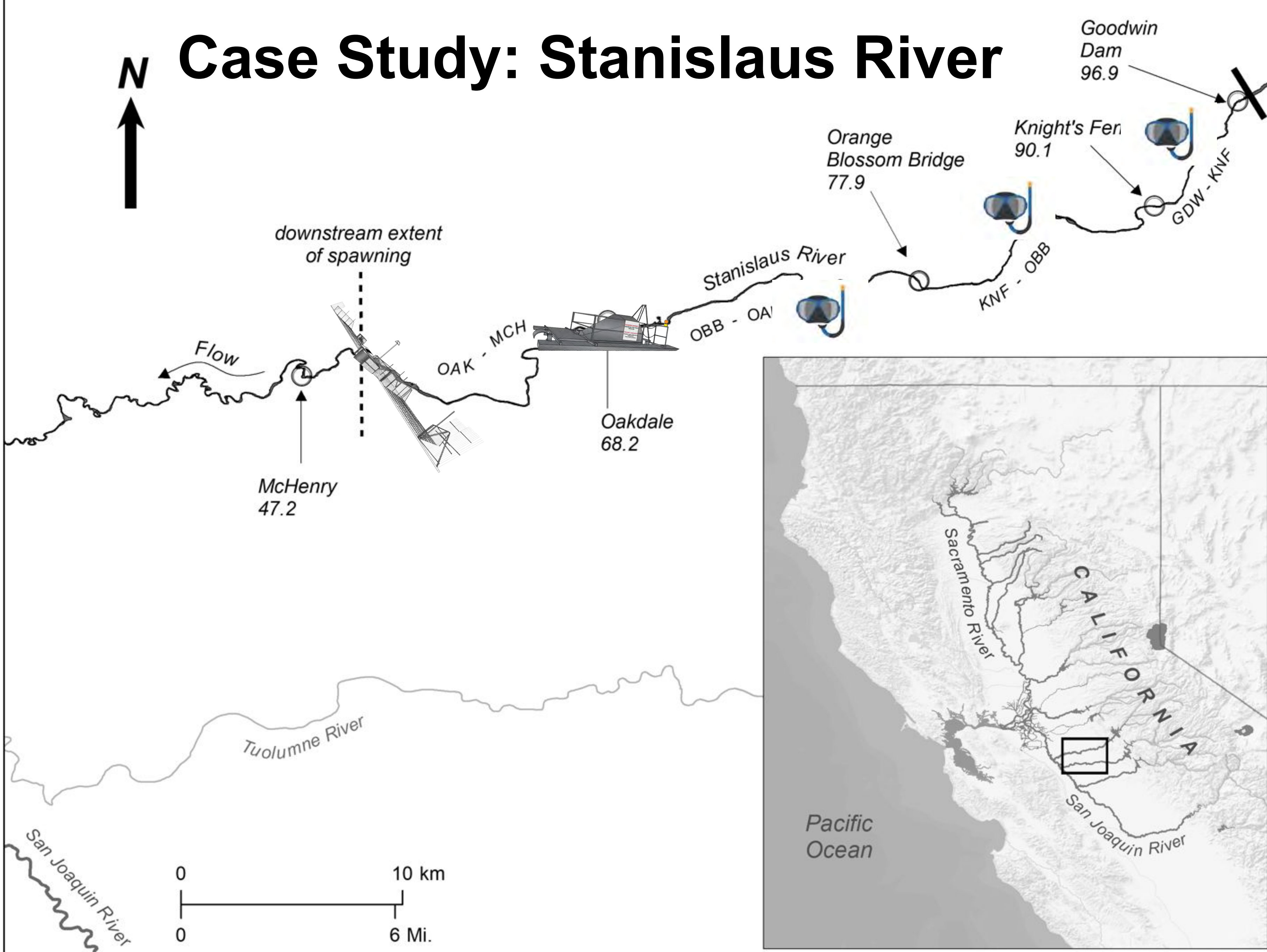
Environment



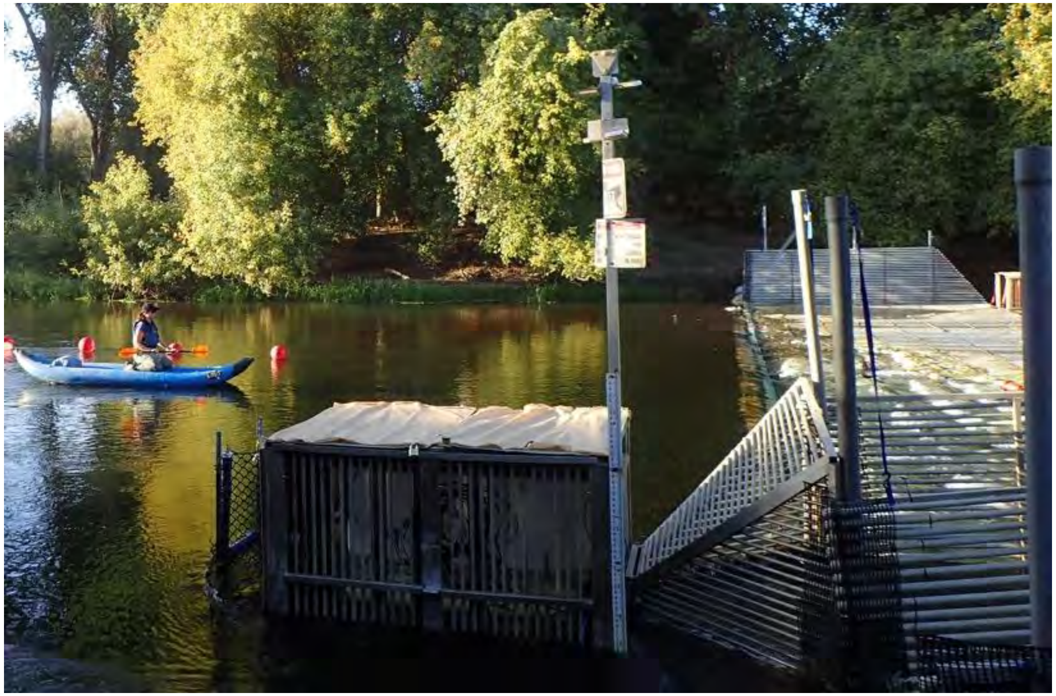
Standard Steelhead Monitoring

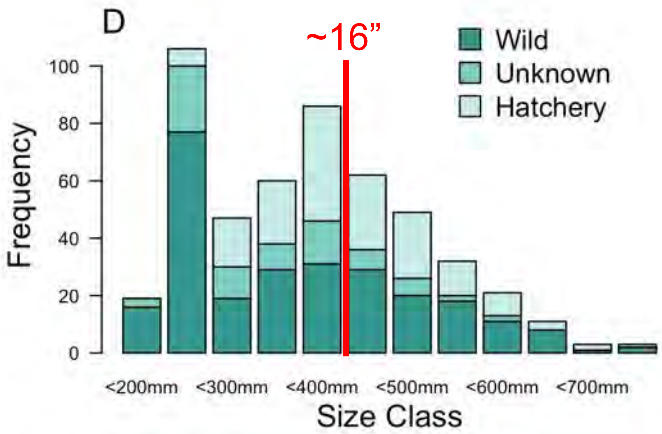


Case Study: Stanislaus River



Adult Escapement Monitoring

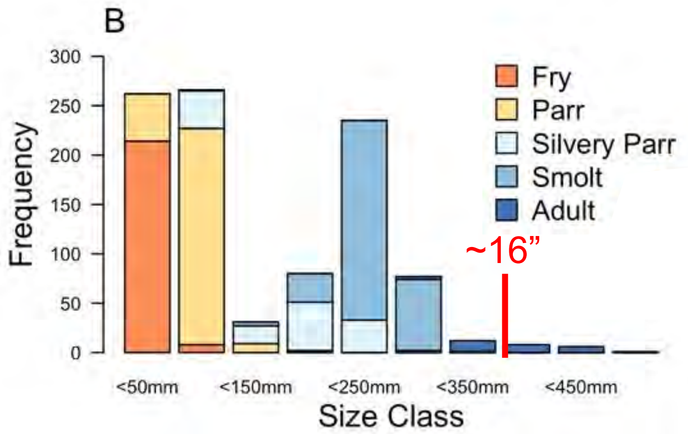




Years: 17 (2003 – 2019)
Months: September – December
Median observations: 13 (1-170)

Juvenile Migration Monitoring

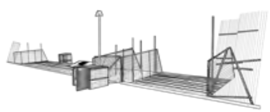
Years: 23 (1996 – 2019)
Months: January – June
Median catch: 36 (10-143)
Smolt ages: 1+ (4%) 2+ (81%), 3+ (15%)



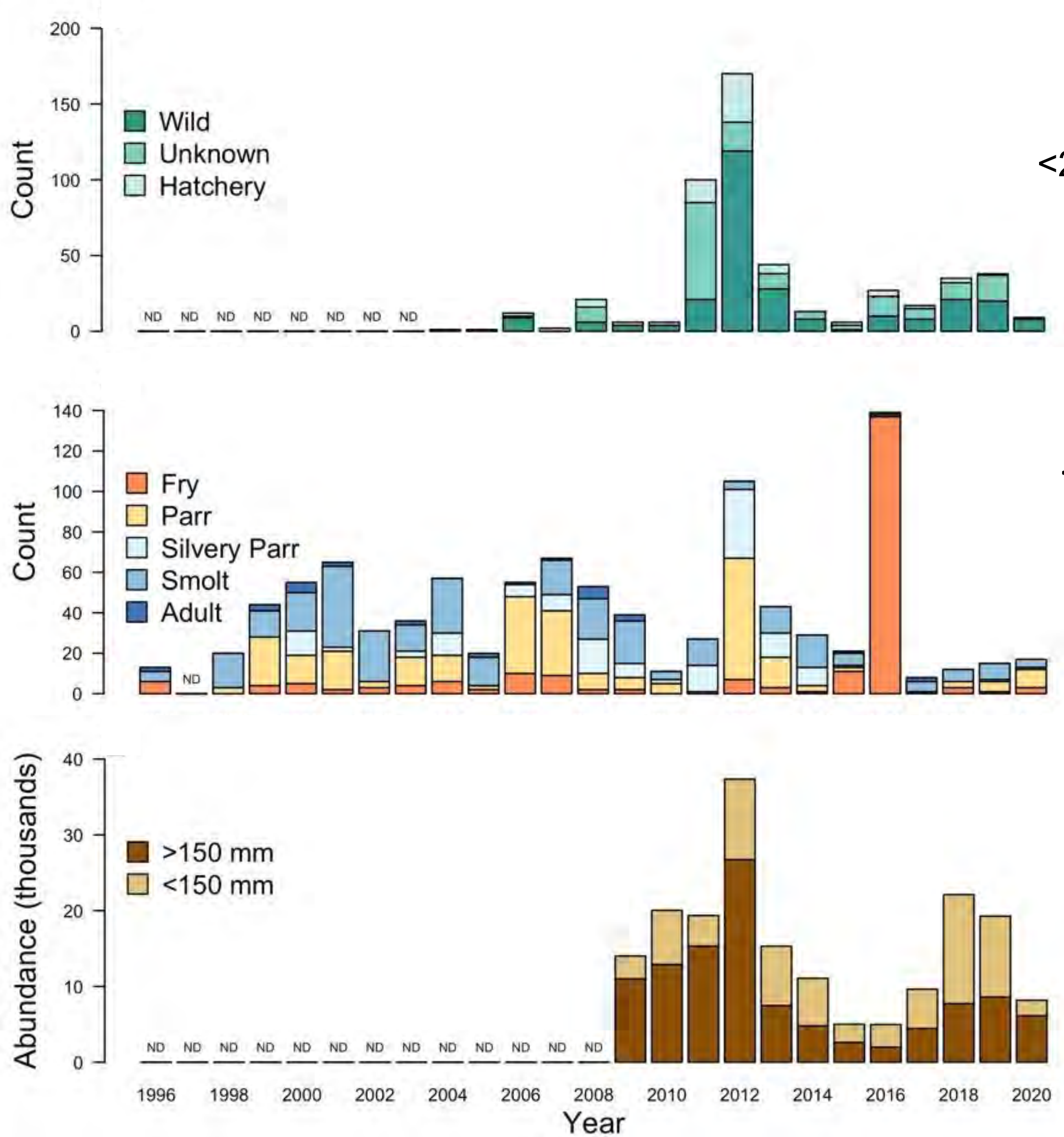
Over-summer Resident Monitoring

Years: 12 (2009 – 2020)
Months: July – August
Median abundance: 14,663 (4,968 – 37,355)

Two size classes <150 mm, ≥150 mm
Method of bounded counts
Reach specific abundance estimates



Sept – Dec



<200 mm – >700 mm

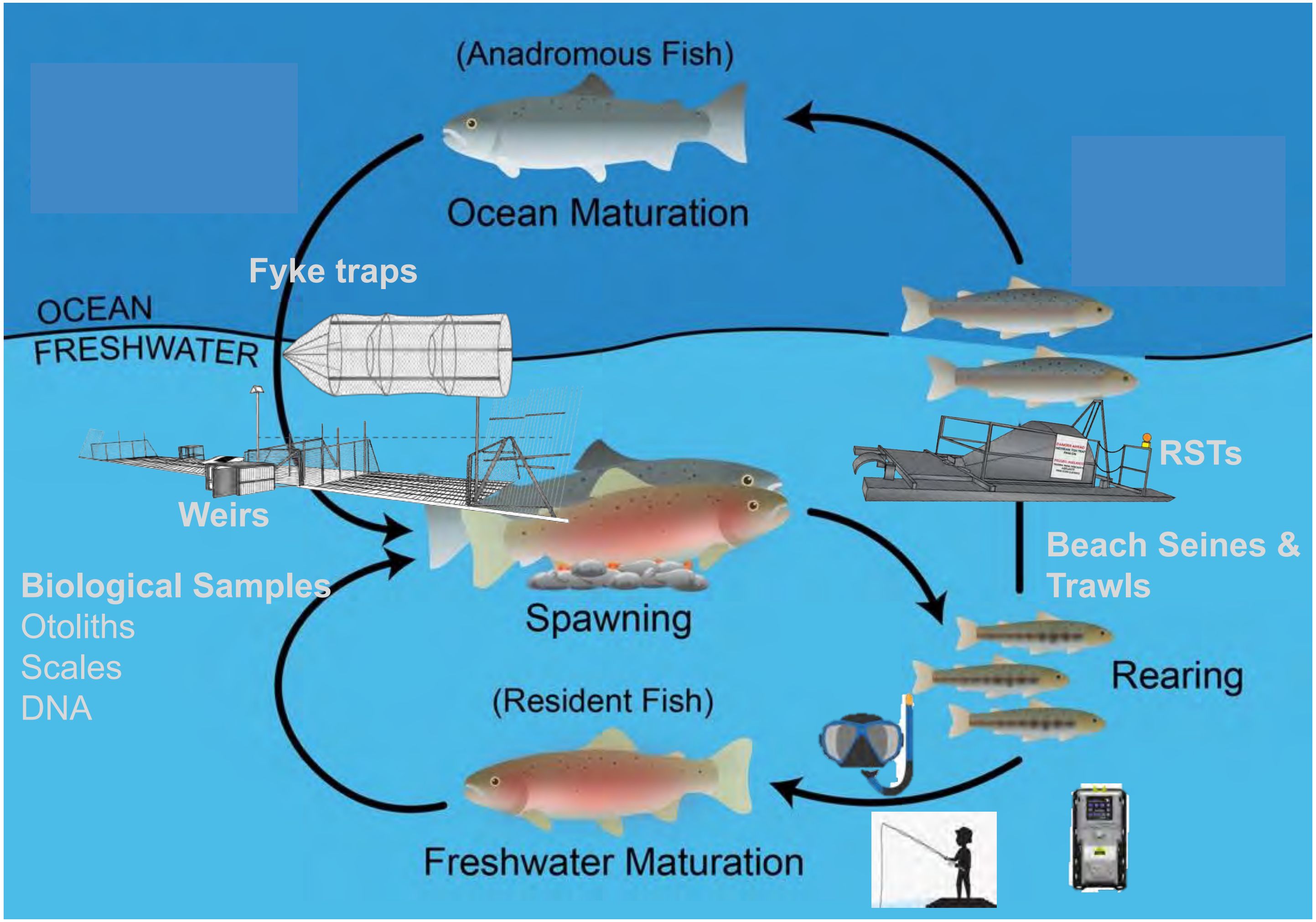
Jan – Jun

<50 mm – >500 mm

Jul – Aug

Anadromy in an Altered Landscape

Enhanced Monitoring & Studies



Summary

- Abundance is difficult to estimate when steelhead are rare
- Conditions in Central Valley may favor resident life history
- Enhanced monitoring of both resident and anadromous individuals
- More studies on Central Valley DPS

Questions?

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Santa Cruz, California

FISHBIO Laos
Vientiane Capital, Lao PDR

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Costa Rica

The Importance of Life-History Variation in Salmonid Restoration

John Carlos Garza
Southwest Fisheries Science Center
and
University of California, Santa Cruz

The Origins of Conservation Biology

M. Busse-2007
UCSD BioSphere
Alumni Magazine

Building on a Legacy of Excellence

Conservation Science — Its Roots & Future at UC San Diego

Most people, when hearing of biology at UC San Diego, think of the outstanding basic biology and biomedical research programs. But scientists in the Ecology, Behavior, and Evolution Section of the Division of Biological Sciences have long stood at the forefront of research in their respective fields. In fact, conservation biology as we know it today first came into existence at UCSD in the late 1970's.

The practice of nature conservation was not new, thanks to prominent figures such as Theodore Roosevelt and John Muir, but prior to the 1970's, conservation was focused solely on real-world applications such as hunting and fishing limits and the placement of duck nesting boxes. Wildlife conservation was not science; there was very little quantification, theory, or hypothesis testing.

That all changed dramatically when Michael Soulé, then an associate professor of biology at UCSD, and his graduate student, Brian Wilcox, organized the First International Conference on Conservation Biology in the fall of 1978. The meeting marked the first use of the term "conservation biology" and the birth of a new interdisciplinary research field.

Soulé's inspiration for bringing science to conservation came to him while on sabbatical at the

Once Soulé returned to UCSD, he began to think seriously about combining conservation with several sciences he thought could better inform conservation activists. Says Soulé, "We were concerned that the scientific findings coming out of ecology, biogeography, and population genetics were not percolating into the mainstream conservation organizations."

Backed by an NSF grant to fund their new idea, Soulé and Wilcox assembled a group of prominent scientists from diverse fields such as population genetics, ecology, evolution, and reproductive biology. The participants included Edward Wilson, Paul Ehrlich, Thomas Lovejoy, and Jared Diamond, all of whom were giants in their respective fields and went on to play pivotal roles in conservation.

According to David Woodruff, a professor of biology at UCSD who joined the faculty shortly after the conference, "The motivating factor was a realization that wildlife was entering a period that probably would constitute a mass extinction." A scientific approach was necessary to make wildlife conservation more effective.

The conference brought together two ideas that would go on to shape much of modern conservation biology: the theory of island biogeography and the concept of the minimal

Gibbons are threatened by deforestation throughout southeast Asia. Former master's student, Carlos Garza, is shown collecting hair (a DNA source) from a brother–sister pair of orphaned gibbons in northern Thailand. Such non-invasive genetic studies have contributed to the management of the surviving populations of these important dispersers of forest tree seeds. Photo courtesy of David Woodruff and Carlos Garza. Garza is a magna cum laude biology graduate, who went on to win UC President's and NSF Postgraduate Fellowships and is now the research geneticist at the federal Southwest Fisheries Science Lab at UC Santa Cruz.

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The study of intraspecific variation is a foundational pursuit in Conservation Biology

Intraspecific Variation

Several main types (often not independent):

Phenotypic: Coloration, size, morphometric, etc.

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Life history: Timing of reproduction, age at reproduction, patterns of migration, mating strategies, sex ratio, etc.

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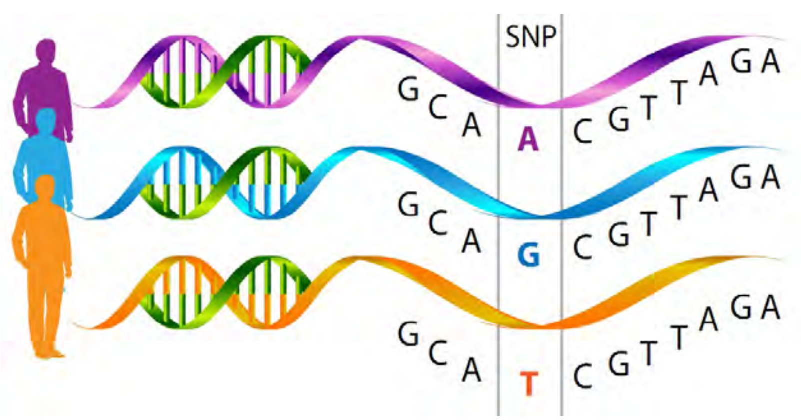
Several main types (often not independent):

Phenotypic: Coloration, size, morphometric, etc.

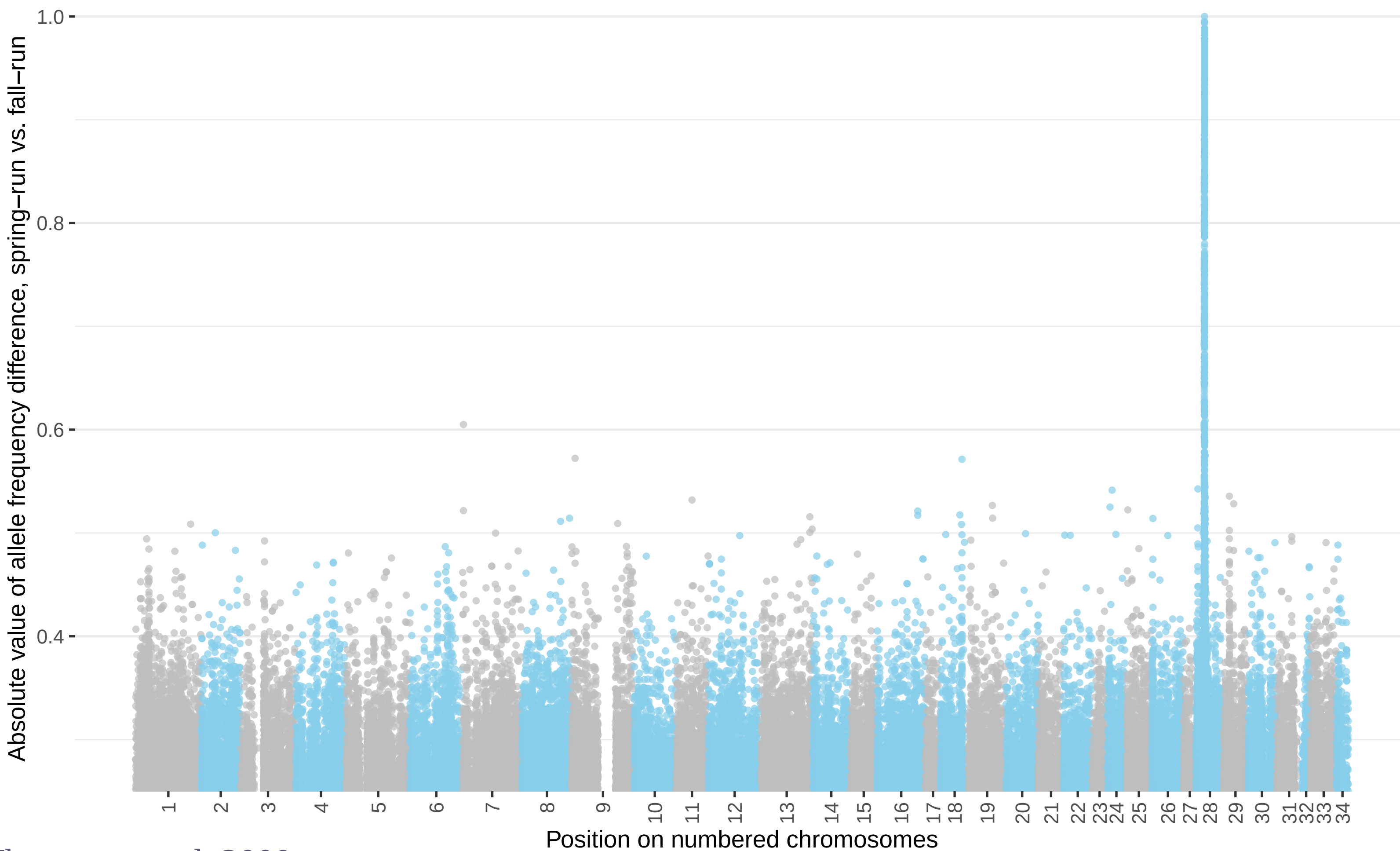
Life history: Timing of reproduction, age at reproduction, patterns of migration, mating strategies, sex ratio, etc.

Variation in these traits usually has a genetic basis, which means an opportunity for selection



Genes of Large Effect

Early vs. late migration in California Chinook salmon

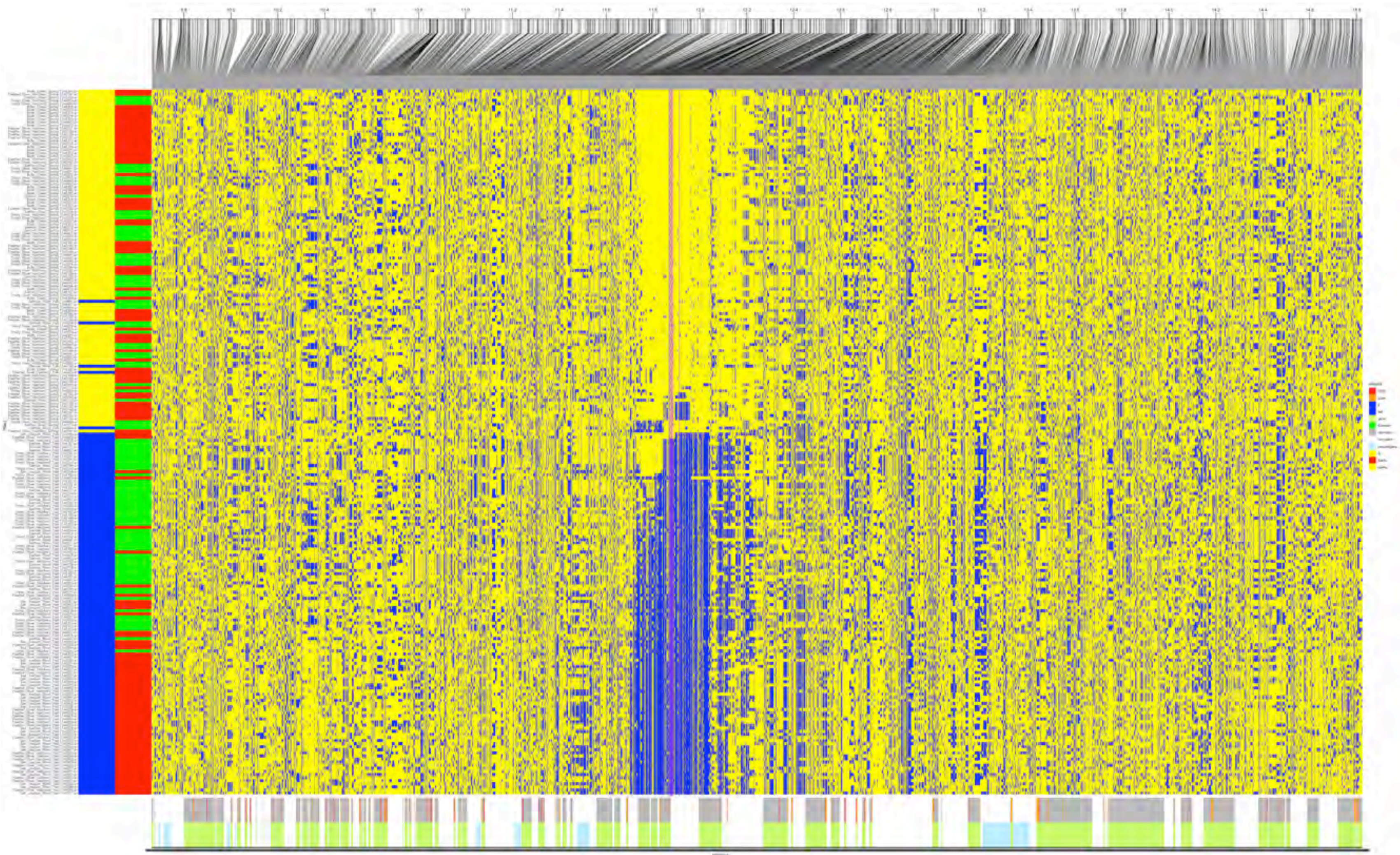


Thompson et al. 2000

A single associated region genome-wide!

Genes of Large Effect

Detailed view of 5MB associated region



Thompson et al. 2000

Klamath

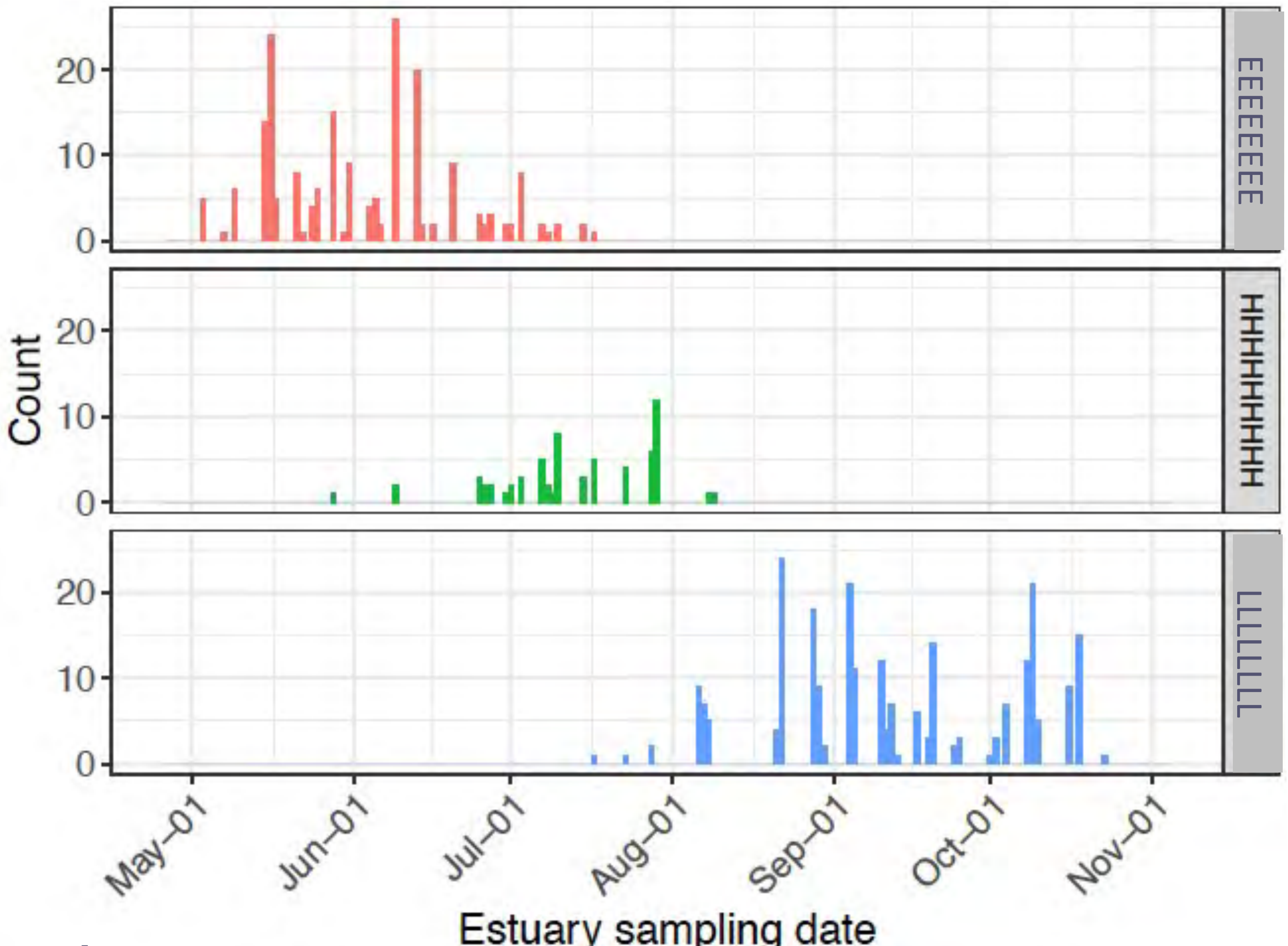
Sacto

fall

spring

Genes of Large Effect

Klamath River Estuary

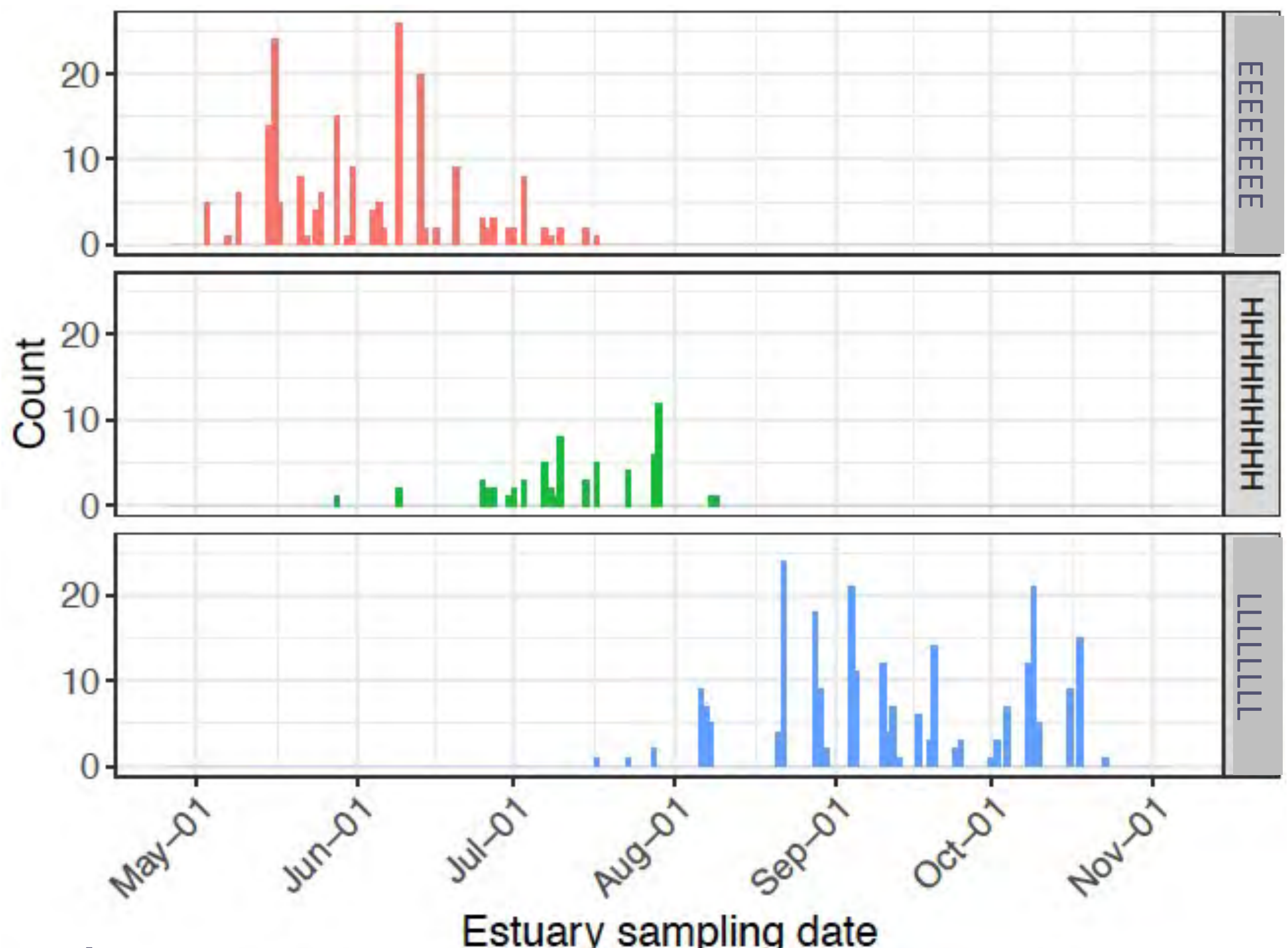


Thompson et al. 2000

Genotypes predict entry timing, with no overlap between EE and LL homozygotes

Genes of Large Effect

Klamath River Estuary



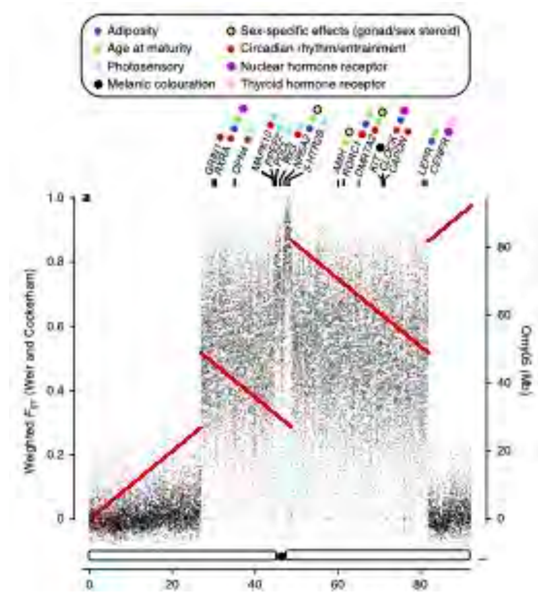
Thompson et al. 2000

Genotypes predict entry timing, with no overlap between EE and LL homozygotes

Genes of Large Effect

Anadromous vs. Resident

Two adjacent inversions on Chromosome Omy05 (containing ~1K genes) strongly influence migratory life-history strategy. Not deterministic, and the inversions influence phenotypic variation as well, so major driver of intraspecific variation.



Pearse et al. 2019

But, but, but…..

These genes of large effect are unusual in the biological world and most intraspecific variation is multifactorial (i.e., lots of genes involved).

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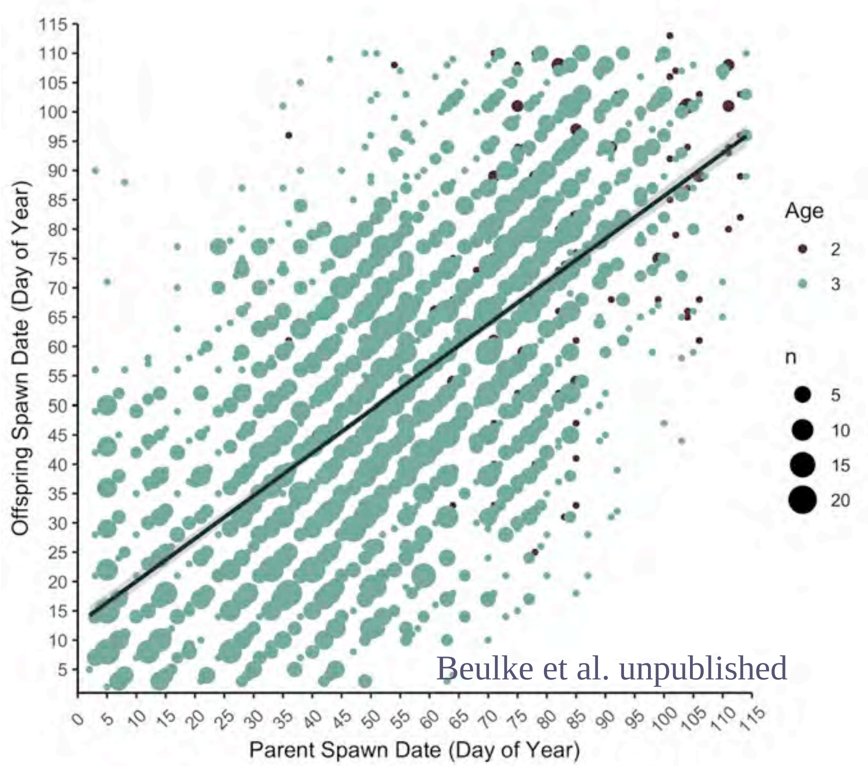
These genes of large effect are unusual in the biological world and most intraspecific variation is multifactorial (i.e., lots of genes involved).

And also results in continuously distributed trait values

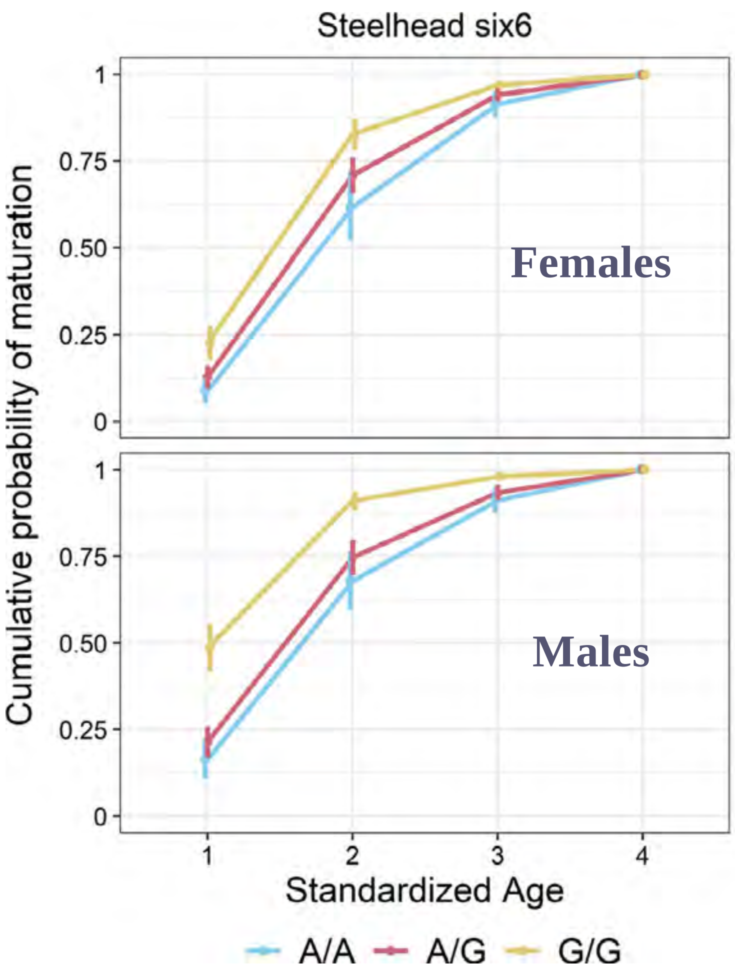


Beulke et al. unpublished

Spawn date of steelhead in the Russian River (2007-20) is highly heritable.
Parent's spawn date predicts about half the variation in offspring spawn date. Four-month period similar to that of seasonal migration ecotypes.

But, but, but…..

These genes of large effect are unusual in the biological world and most intraspecific variation is multifactorial (i.e., lots of genes involved).



Waters et al. 2021

The SIX6 gene is associated with age at maturation in steelhead (including in the Russian River, but more so in males than females. However, most variation in age at maturation is due to other factors.

Life-history variation must be considered in conservation and restoration actions

If we design projects for the mean trait value (e.g. age-3 spawners in coastal steelhead) we will induce selection and get that mean value, but not much else.
When environmental conditions shift, and that mean value is no longer optimal, fitness will decrease.

- Flow schedules
- Jump pool depths
- Hatchery practices
- Large wood placement

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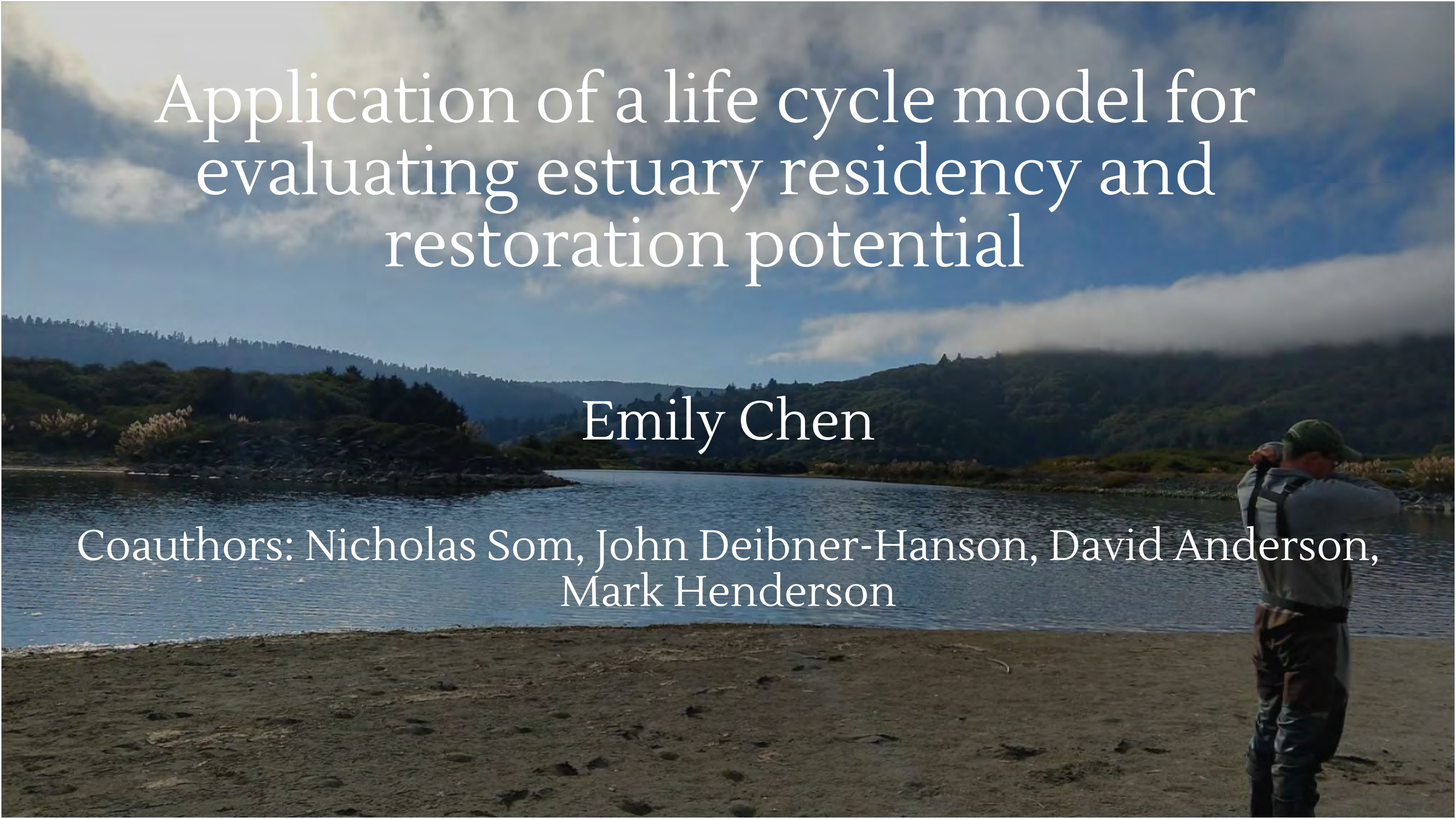
Typological thinking in conservation and restoration is not our friend.



Application of a life cycle model for evaluating estuary residency and restoration potential

Emily Chen

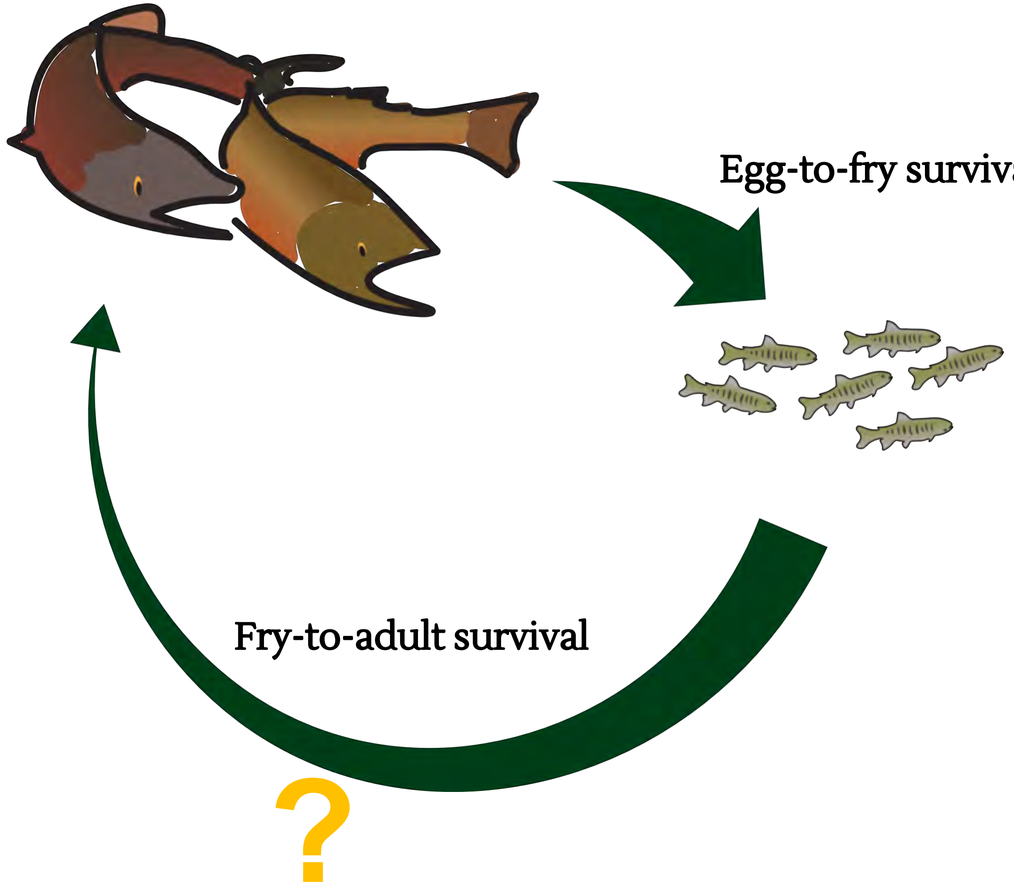
Coauthors: Nicholas Som, John Deibner-Hanson, David Anderson, Mark Henderson

Life Cycle Model

Integrates data from 2+ life stages

Stage-specific parameters and transitioning

Abundance, growth, movement, maturation



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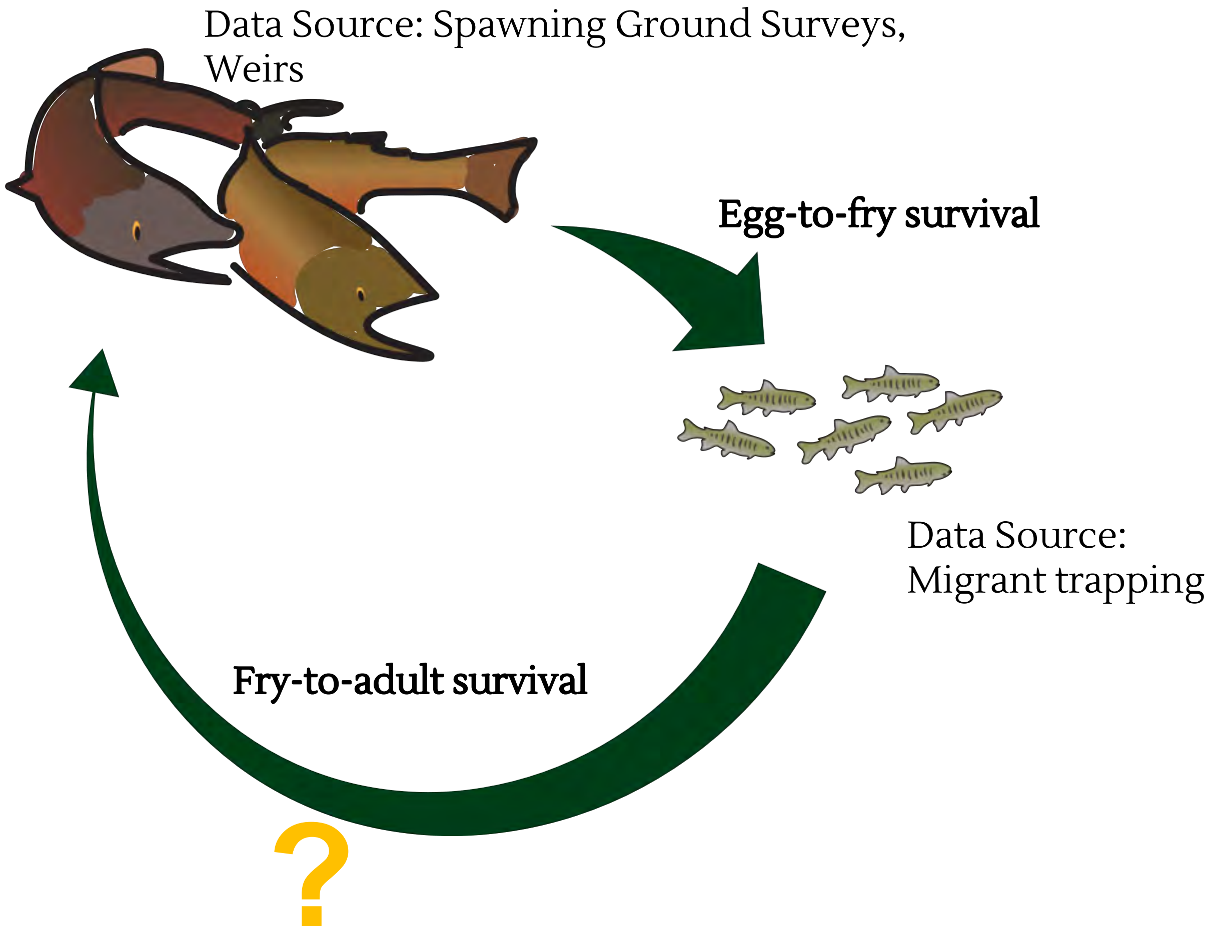


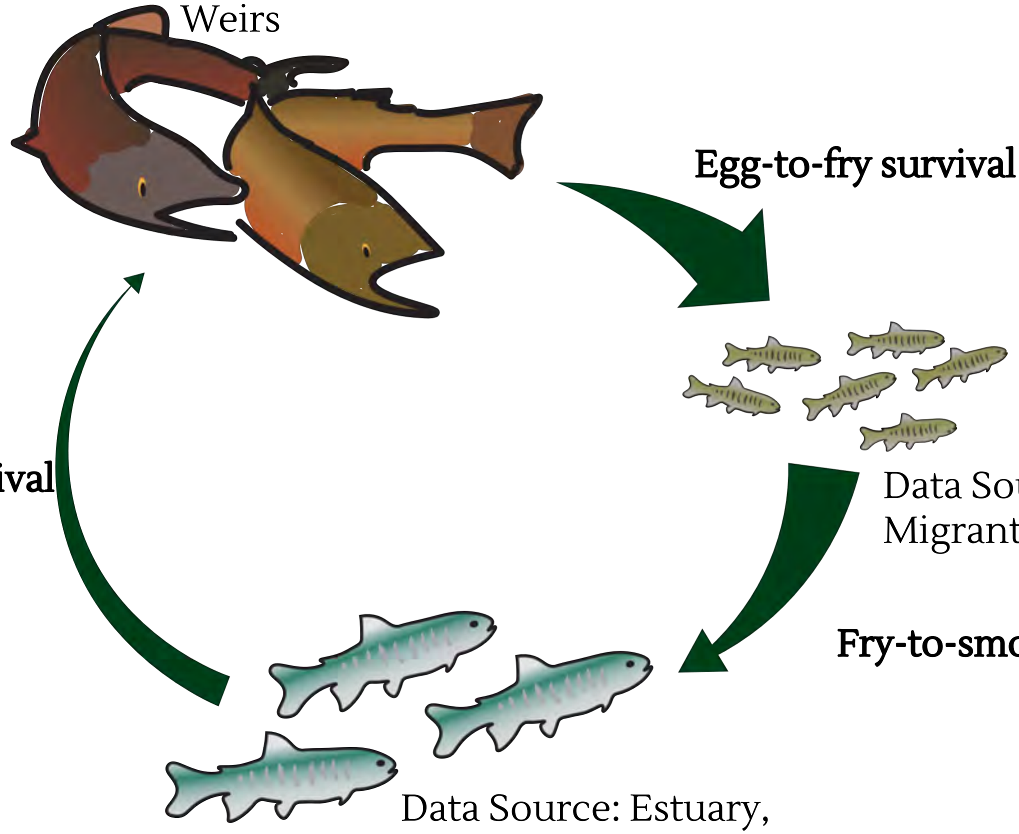
Life Cycle Model

Integrates data from 2+ life stages

Stage-specific parameters and transitioning

Abundance, growth, movement, maturation

More data, greater resolution



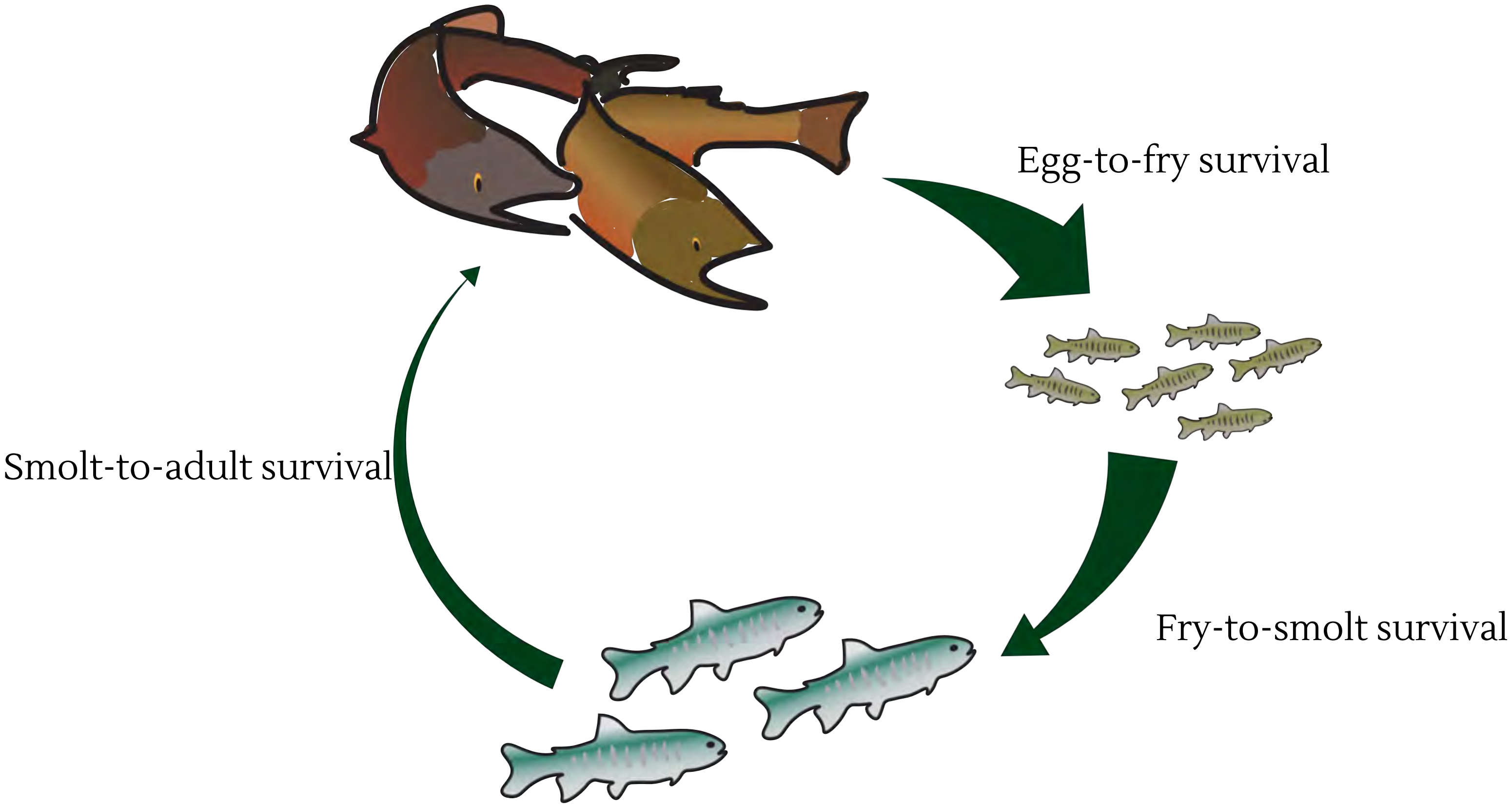
Life Cycle Model

<u>Benefits</u>

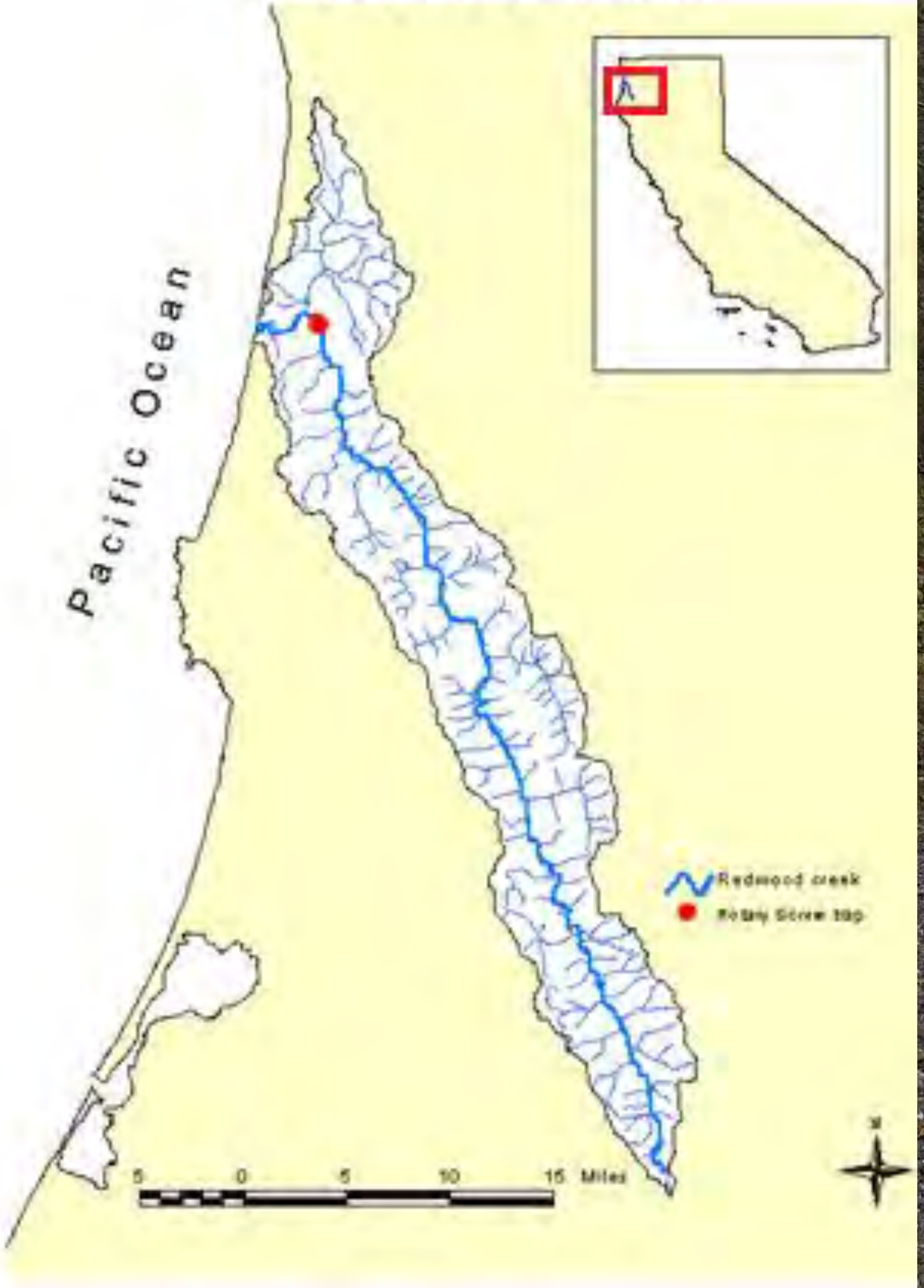
Identify limiting life stages and life histories

Scale: population or basin

Compare actions affecting different life stages



Redwood Creek



Upstream Logging

NPS

Figure 1. Location map of the Redwood Creek basin showing the distribution of roads in (A) 1978 and (B) 1992. Since 1978, about 300 km of road have been removed from the downstream third of the basin, which is managed by federal and state parks. The upstream two-thirds of the basin is privately owned and timber harvest is the primary land use

Madej 2001

Restoration

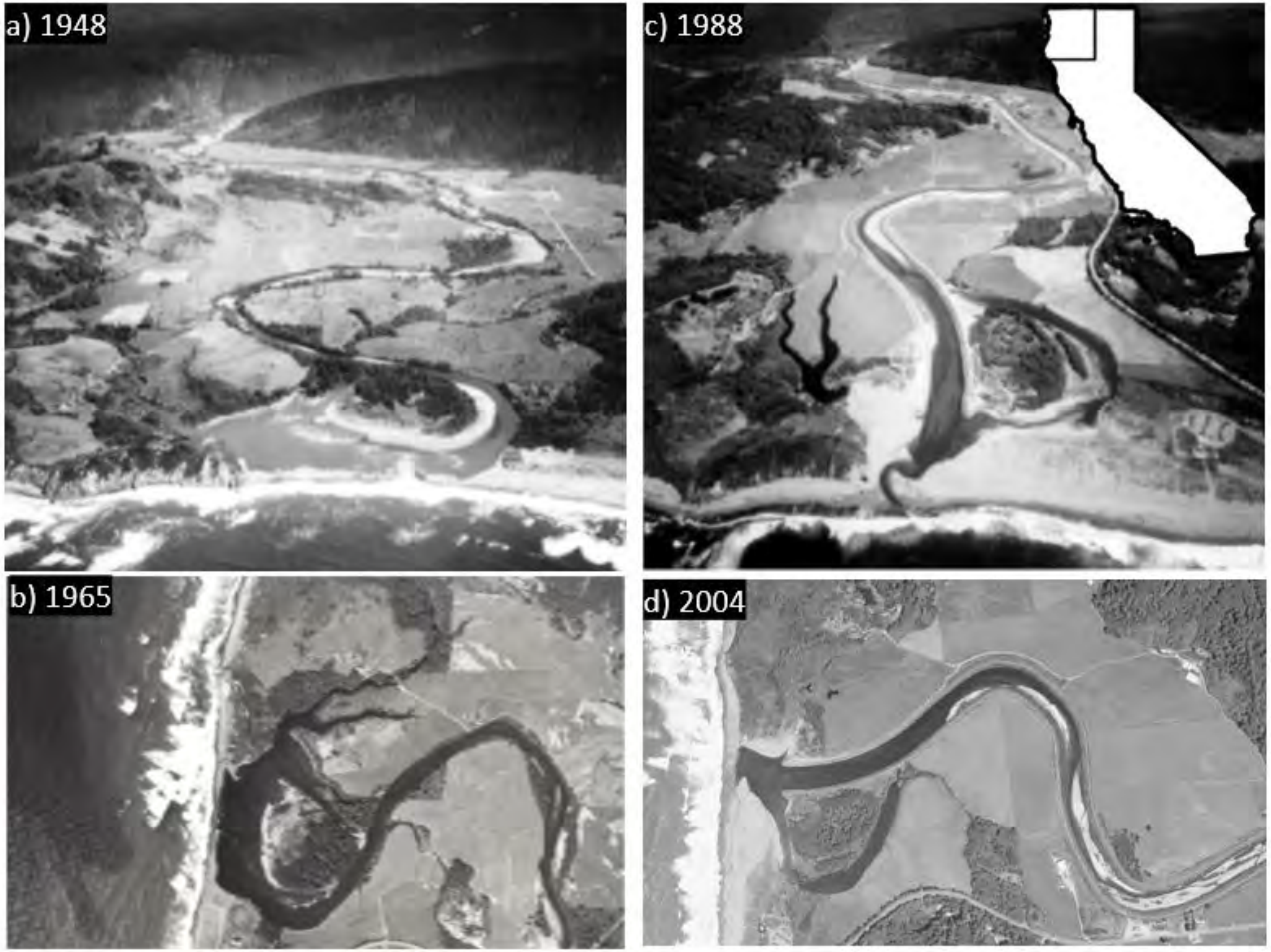
NPS

NPS

Redwood Creek Estuary

"a major limiting factor to the production of anadromous salmonids"

"highest restoration potential in the watershed"



a) and c) Redwood National and State Parks; b) USDA Natural Resources Conservation Service d) Google Earth, USDA Farm Service Agency.

Redwood Creek estuary: a bar-built estuary

Open (June

Closed

Redwood Creek estuary: a bar-built estuary

Life History 1: Ocean Migrants

Open (June

Closed

Life History 2: Estuary Residents

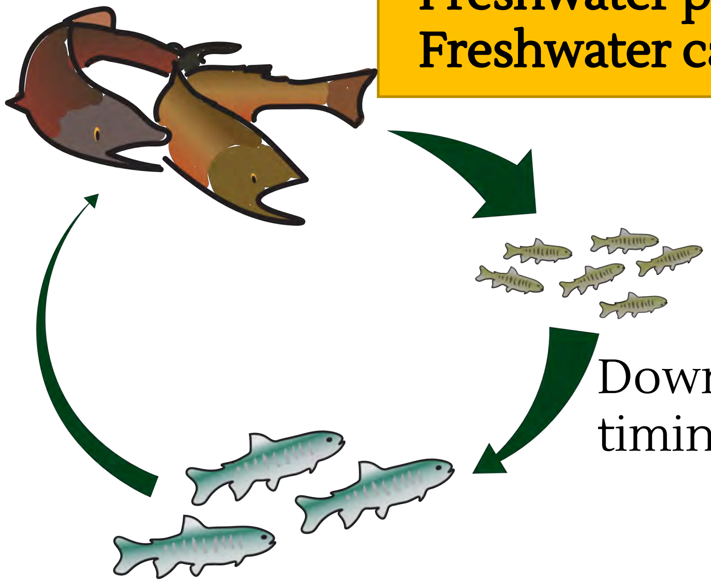
Questions

How many fish do we expect to use the estuary based on annual environmental conditions?

How would freshwater vs estuary restoration influence recruitment?

Redwood Creek Life Cycle Model

Freshwater productivity
Freshwater capacity



ocean survival

Downstream migration timing and size

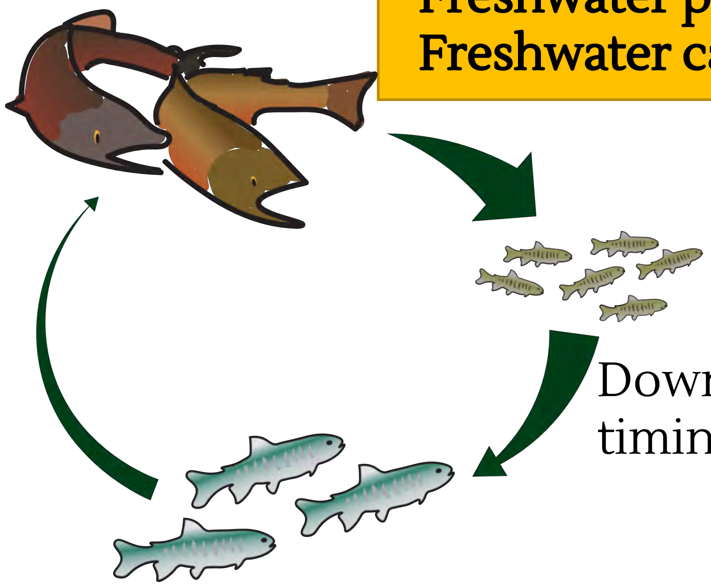
Estuary residency, survival, growth

Spawning Ground Surveys

CALIFORNIA DEPARTMENT OF FISH & WILDLIFE

CALIFORNIA FISH & WILDLIFE RESEARCH UNIT

Redwood Creek Life Cycle Model



Freshwater productivity
Freshwater capacity

Downstream migration timing and size

Estuary residency, survival, growth

ocean survival

Migrant trapping

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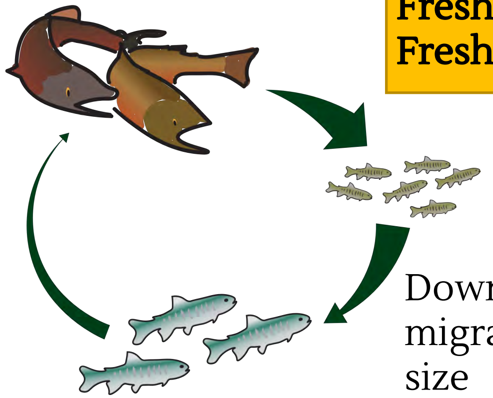
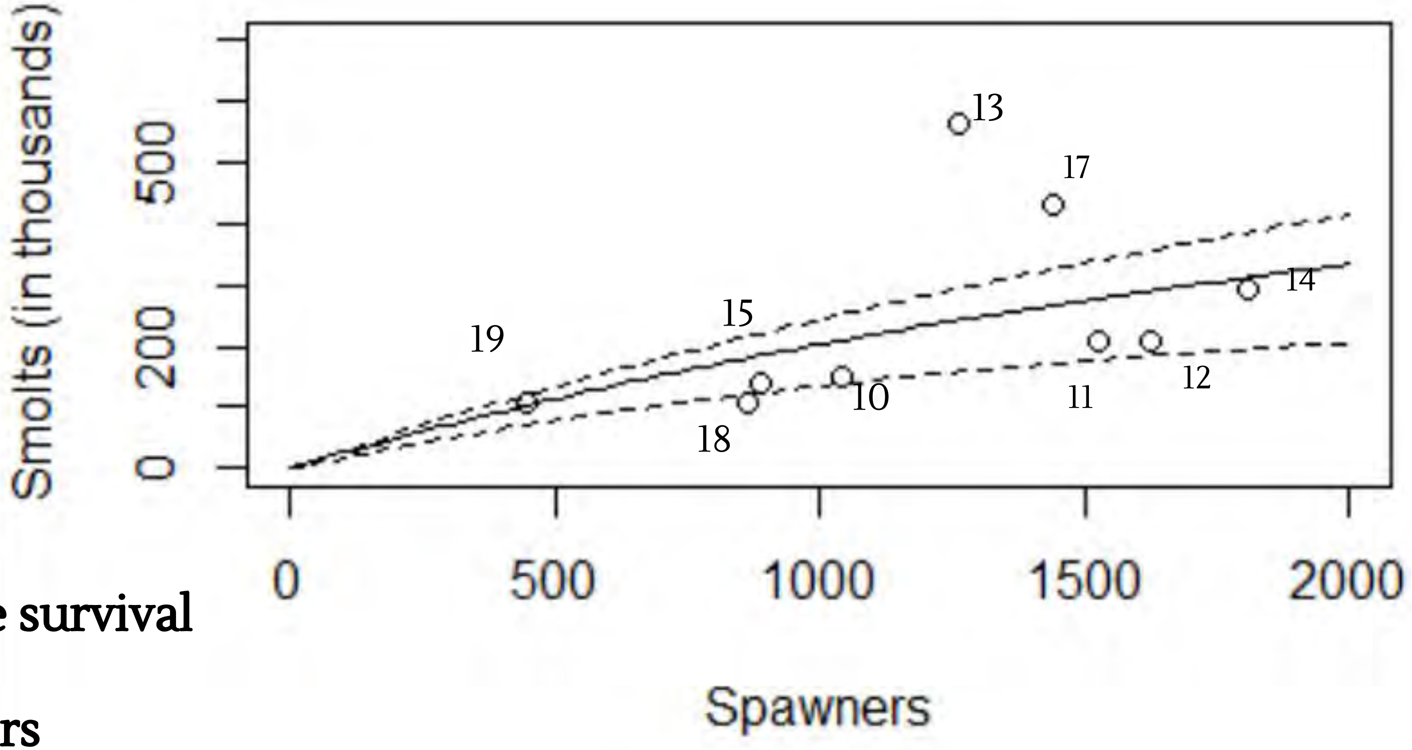
Spawner-to-Juvenile stage

Freshwater productivity
Freshwater capacity



Beverton-Holt Juvenile Production Curve



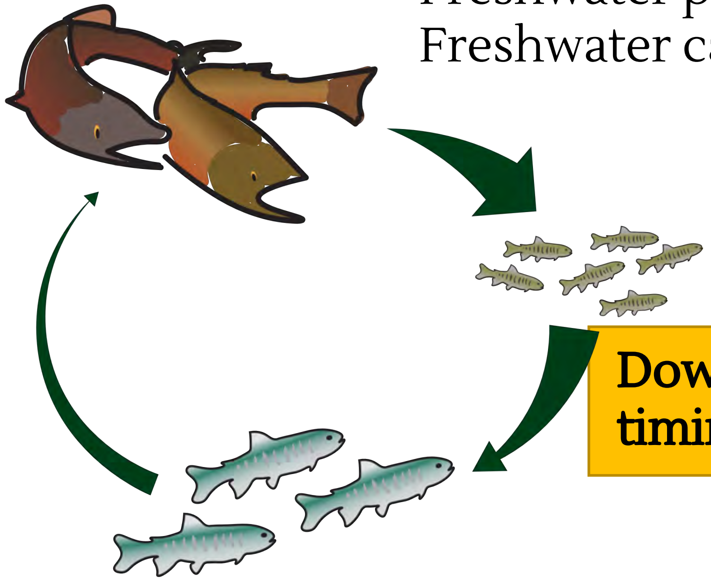
Freshwater productivity = egg-to-juvenile survival

Freshwater capacity = capacity of spawners

Chen et al. *in review*

Redwood Creek Life Cycle Model

Freshwater productivity
Freshwater capacity



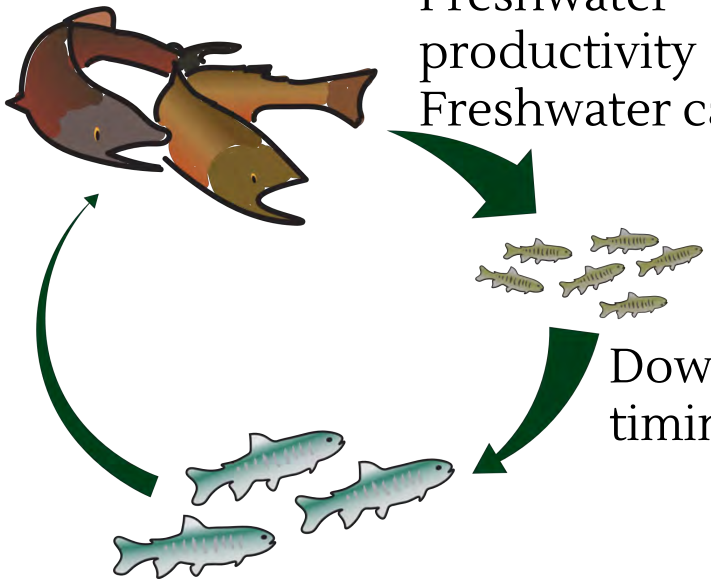
ocean
survival

Downstream migration timing and size

Estuary residency,
survival, growth

Migrant trapping

Redwood Creek Life Cycle Model



Freshwater productivity
Freshwater capacity

Downstream migration timing and size

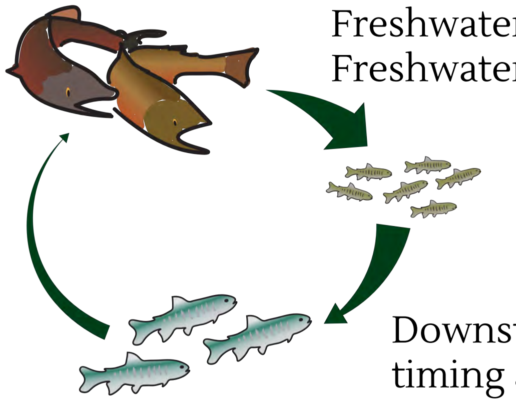
ocean survival

Estuary residency, survival, growth

Estuary seining and recapturing tagged fish

NATIONAL PARK SERVICE

Redwood Creek Life Cycle Model



Freshwater productivity
Freshwater capacity

Downstream migration
timing and size

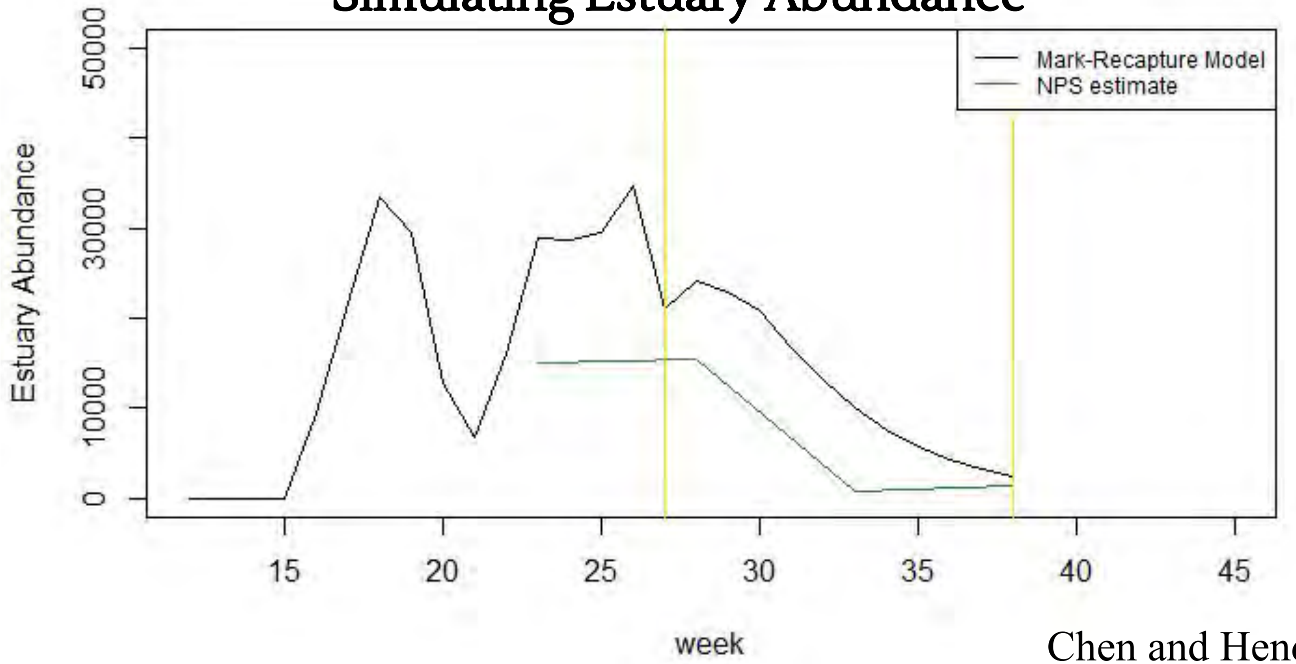
ocean
survival

Estuary residency, survival, growth

Cormack Jolly Seber model

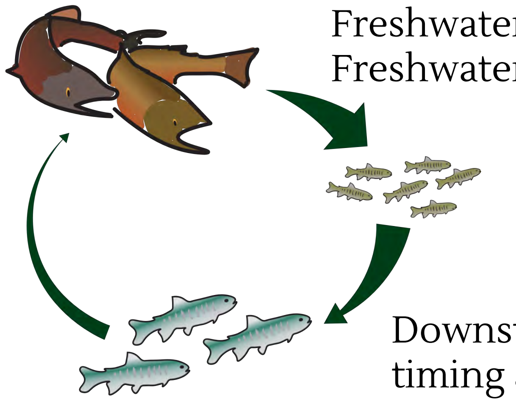
$\boldsymbol{\Phi_{open}}$ **= apparent survival = 1 – (emigration + mortality)**
$\boldsymbol{\Phi_{closed}}$**= apparent survival = 1 – mortality**

Simulating Estuary Abundance



Chen and Henderson 2021

Redwood Creek Life Cycle Model



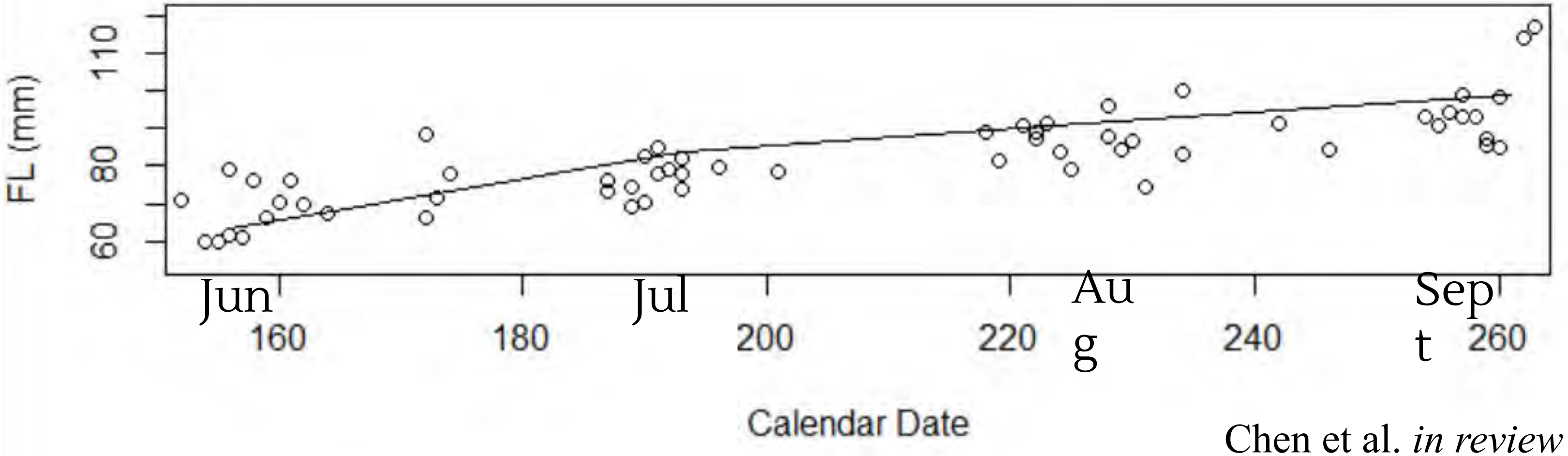
Freshwater productivity
Freshwater capacity

Downstream migration
timing and size

ocean
survival

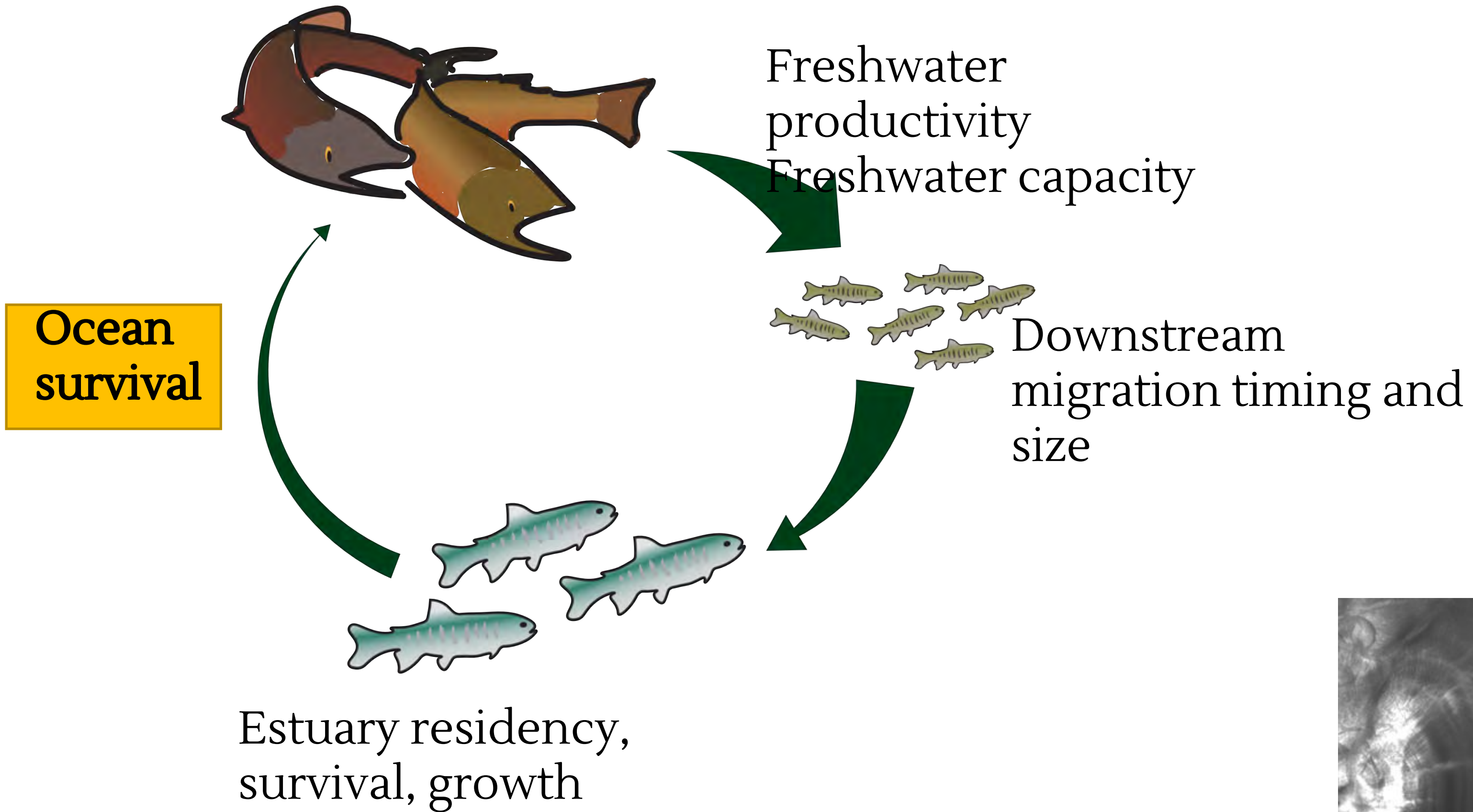
Estuary residency, survival, growth

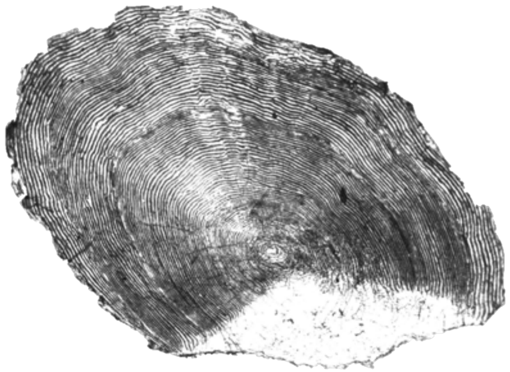
Growth Model



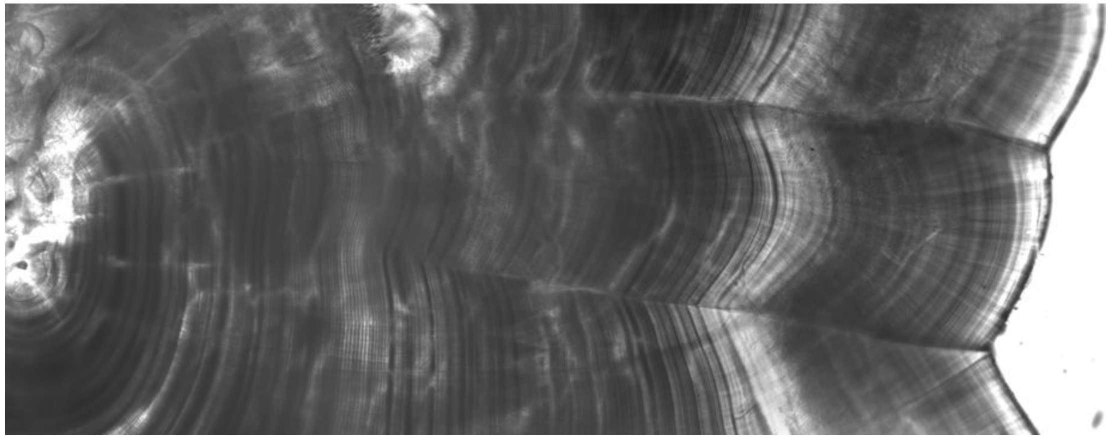
Chen et al. *in review*

Redwood Creek Life Cycle Model

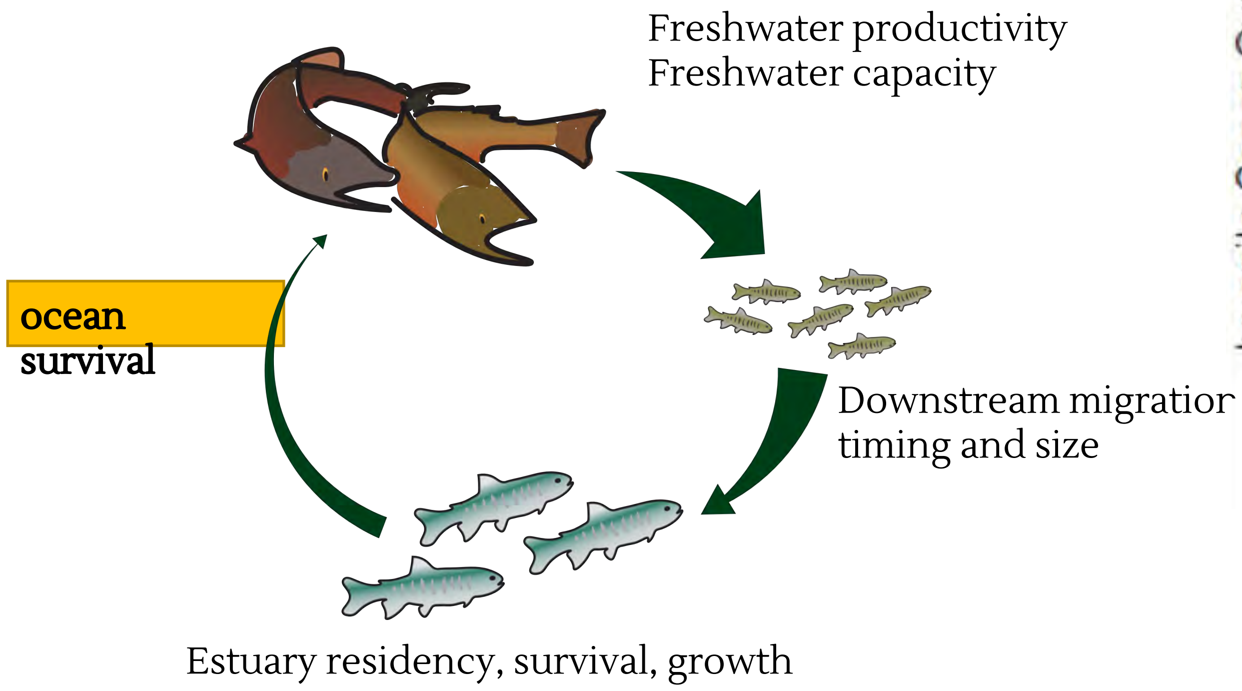


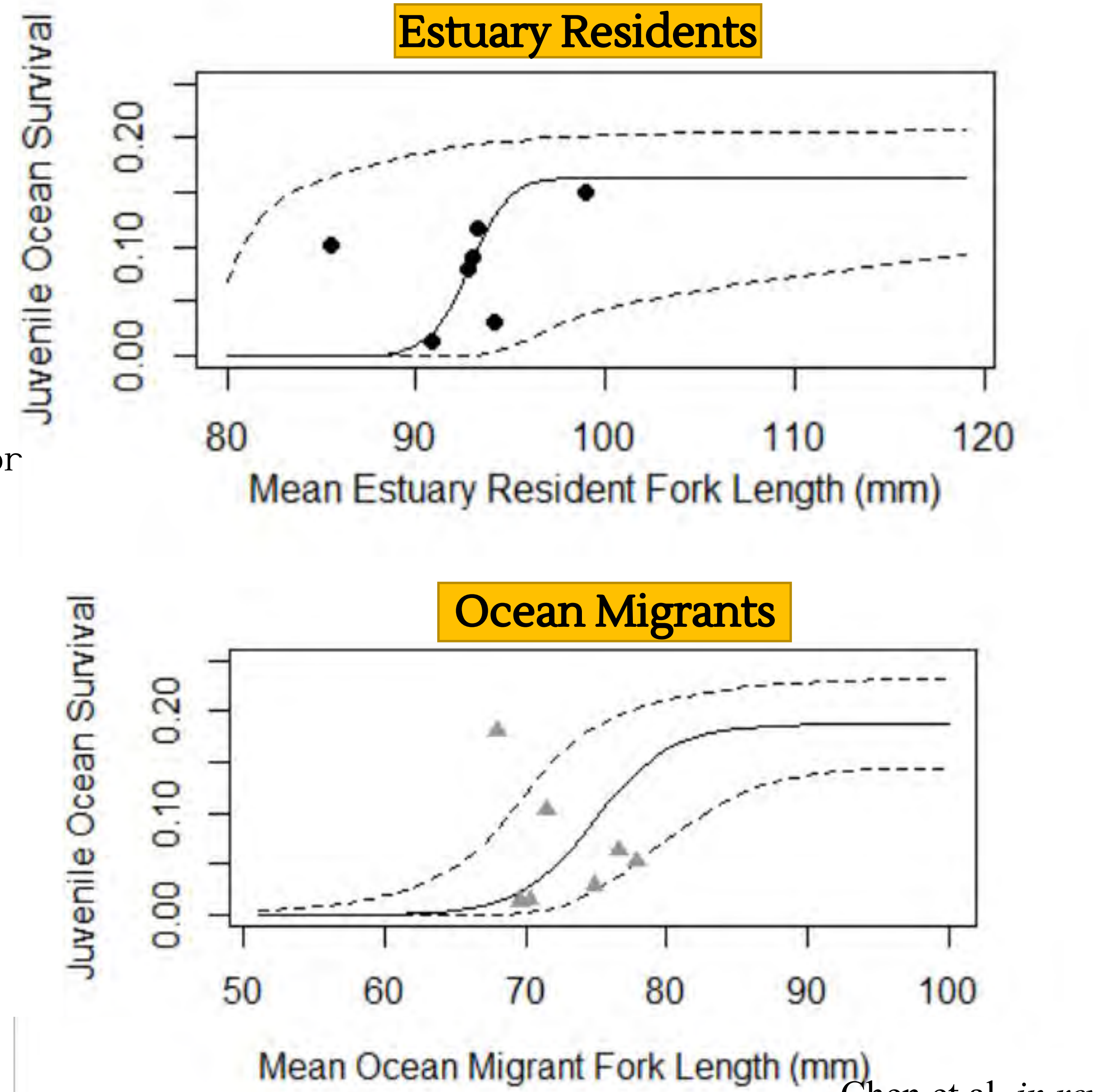


Scale and otolith analysis



Size-dependent Ocean Survival





Chen et al. *in review*

Questions

How many fish do we expect to use the estuary based on annual environmental conditions?

How would freshwater vs estuary restoration influence recruitment?

Questions

How many fish do we expect to use the estuary based on annual environmental conditions?

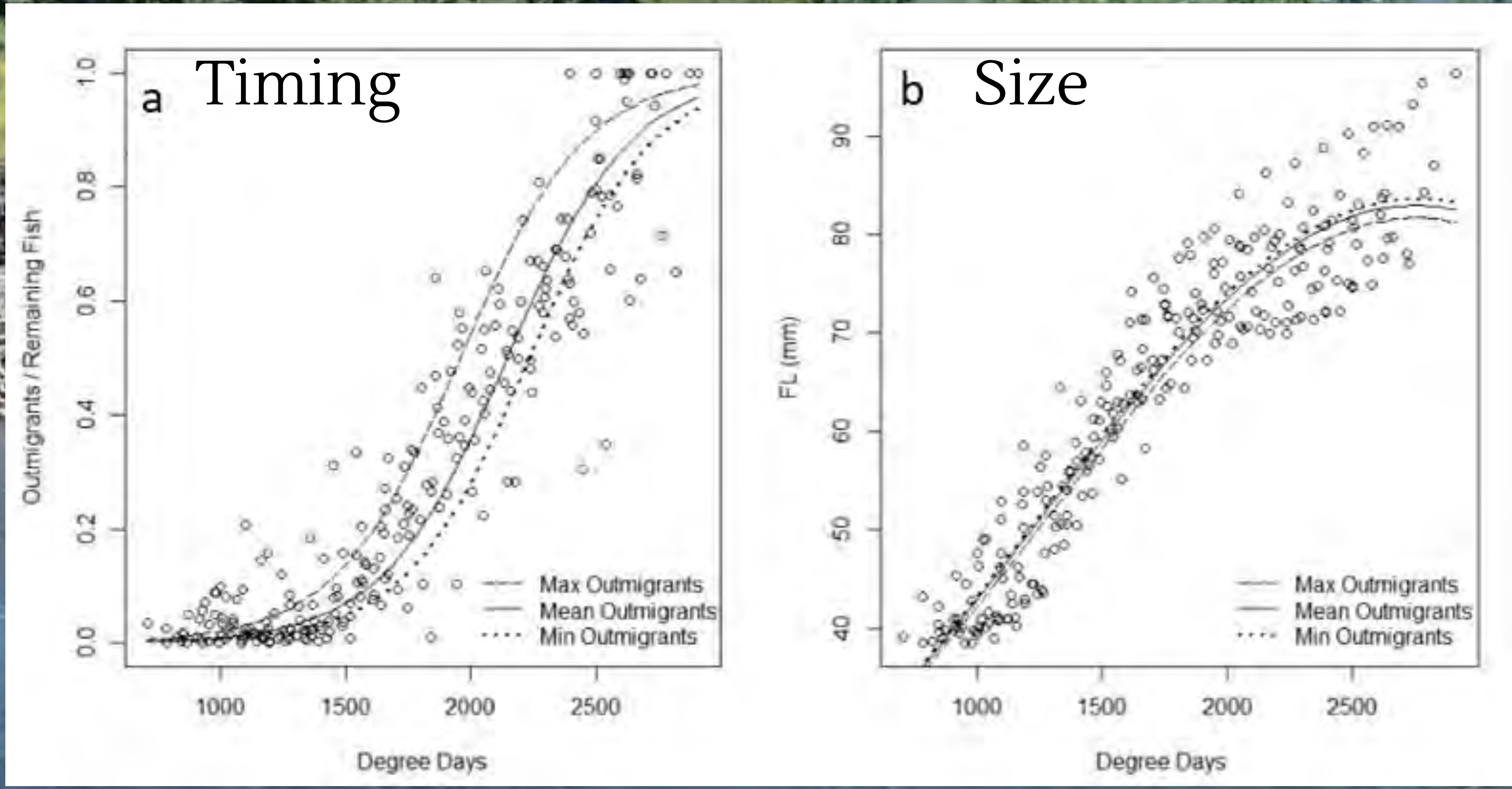
- Freshwater temperatures
- Flow
- Density dependence
- Estuary closure

Downstream migration

Temperature (Degree Day)

~~Flow (Cumulative River Discharge)~~

Density Dependence (Smolt Abundance)



Chen et al. *in review*

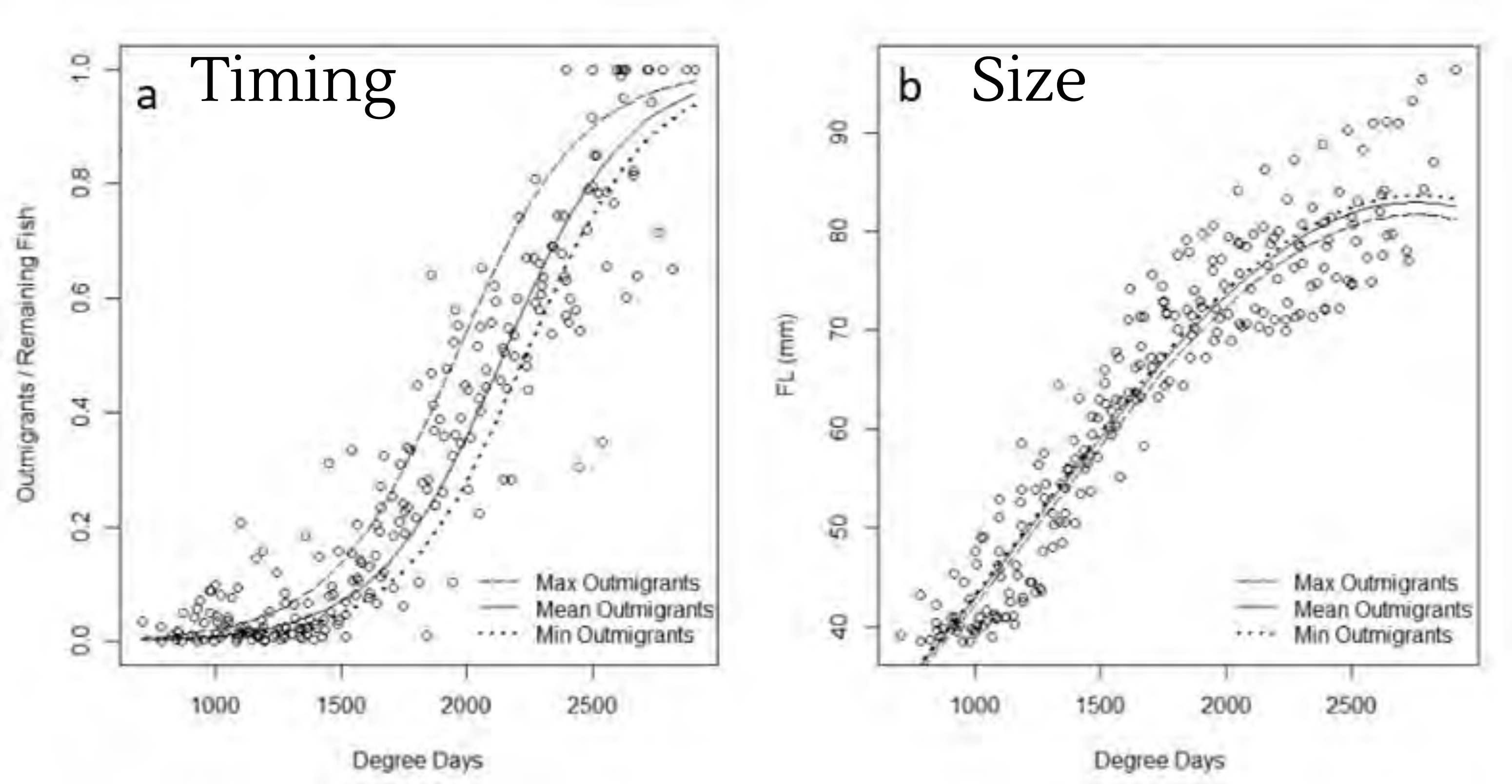
Downstream migration

Temperature (Degree Day)

- positive effect on timing and size

Density Dependence (Smolt Abundance)

- positive effect on timing
- negative effect on size

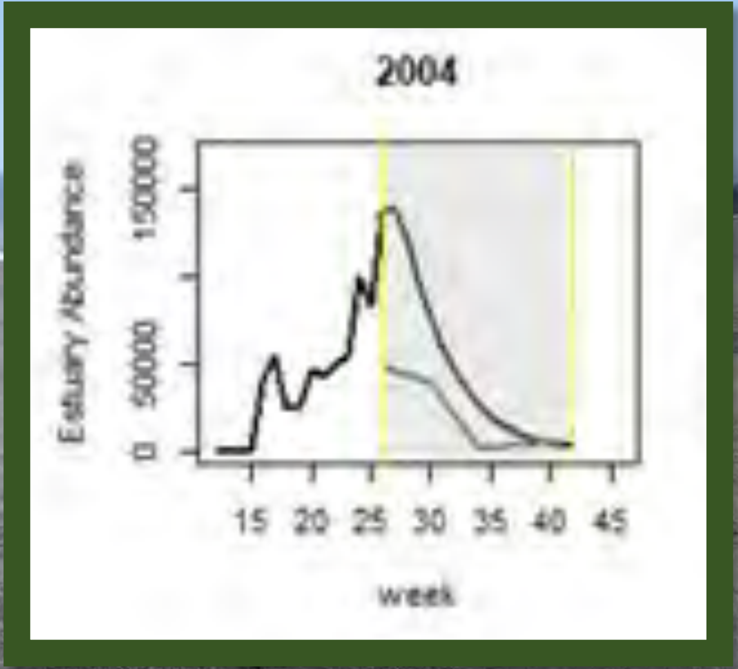


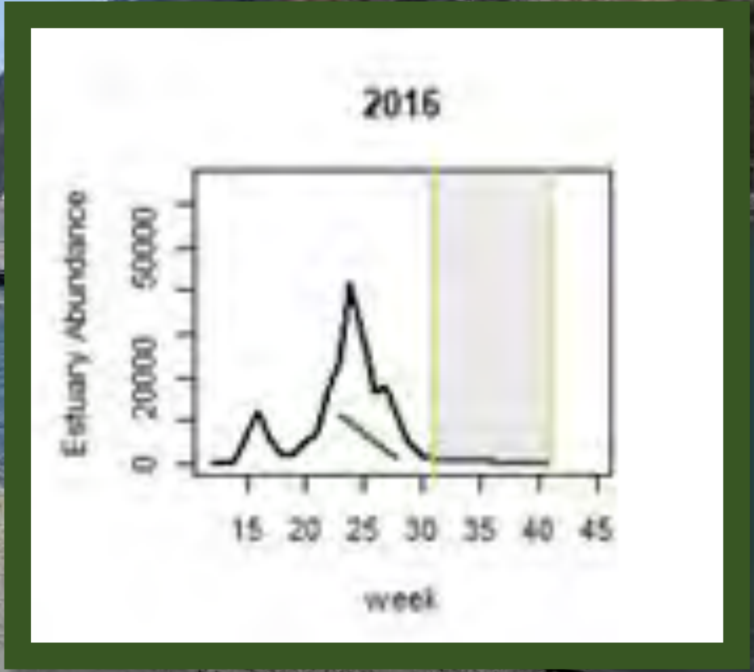
Chen et al. *in review*

Bar Closure

When closed, emigration is not possible.

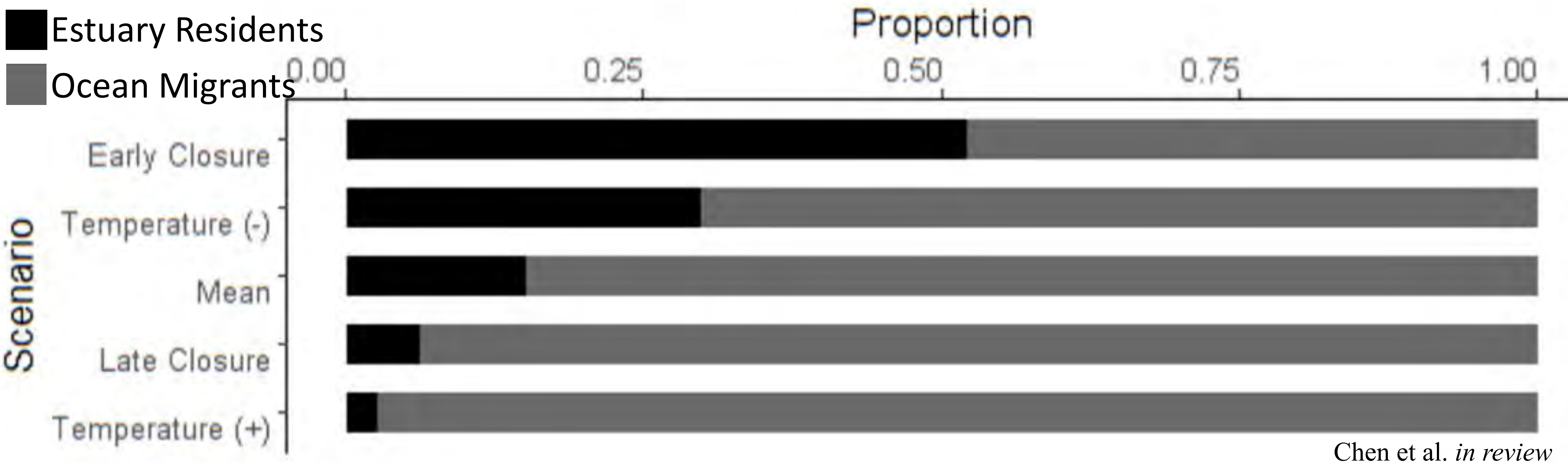
Earlier seasonal closer = more fish in the estuary





Chen and Henderson 2021

Estuary Life History



Chen et al. *in review*

How many fish are in the estuary every year?

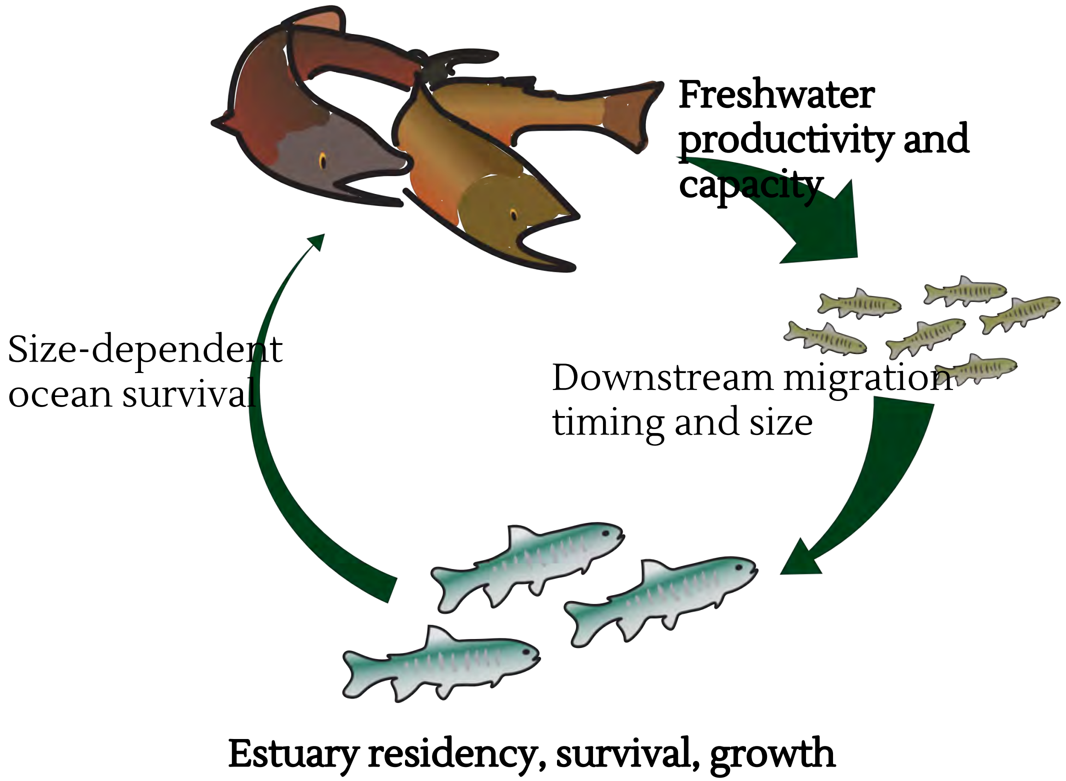
- Warmer temperatures = less estuary fish
  - Climate change
- Higher densities = fish moving to estuary earlier
- Bar closure date, especially early bar closure

Questions

How many fish do we expect to use the estuary based on annual environmental conditions?

How would freshwater vs estuary restoration influence recruitment?

Population Projections



Freshwater Restoration	Estuary Restoration
Freshwater productivity	Estuary survival
Freshwater capacity	Estuary growth

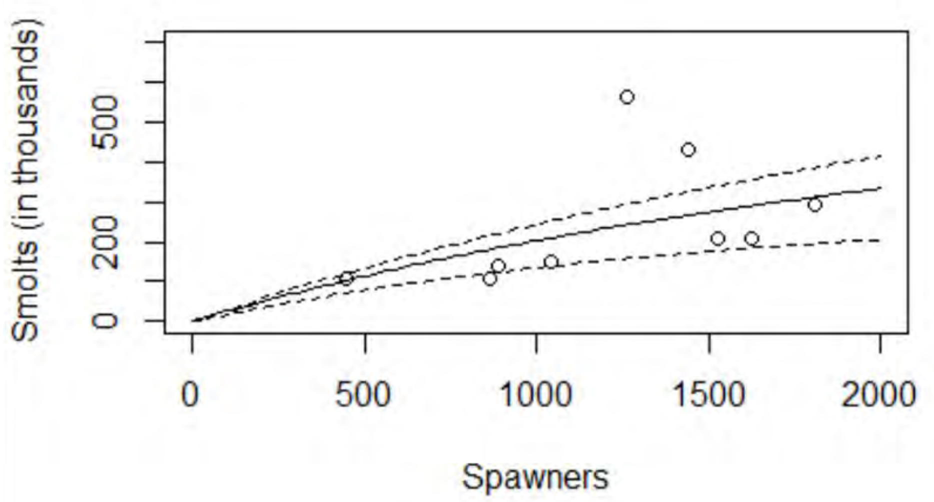
- Increased each parameter by 10 percent

Freshwater Restoration

Road removal = reduce sediment delivery

Freshwater productivity (egg-to-fry survival)

Freshwater capacity (spawner habitat)



Estuary Restoration

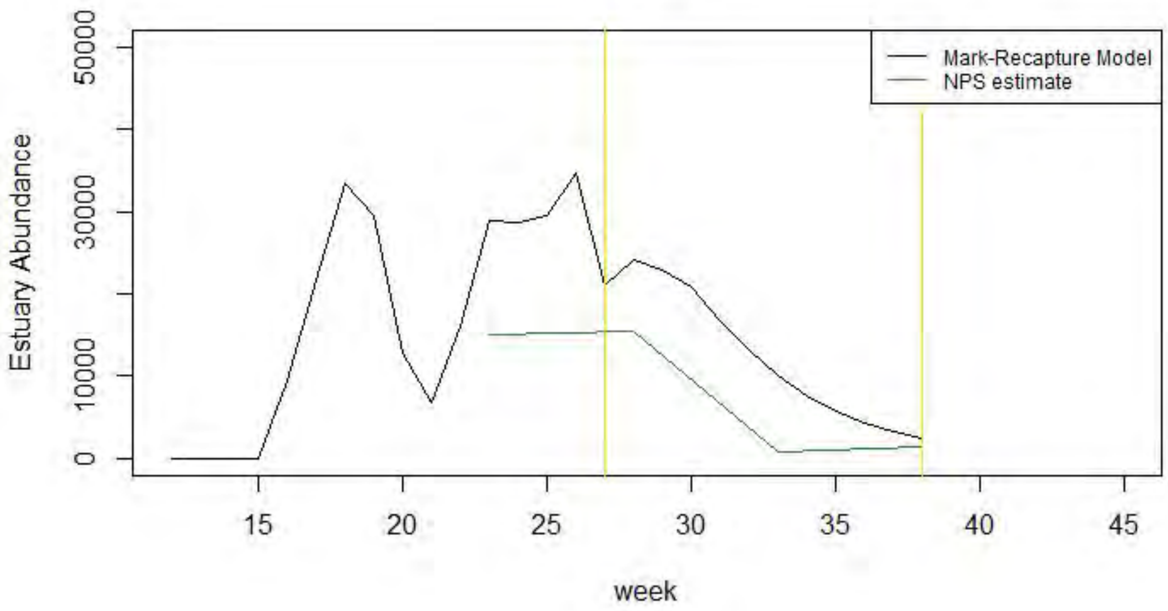
Levee setbacks, reconnect to floodplains

Expand habitat and productivity

Estuary growth and survival

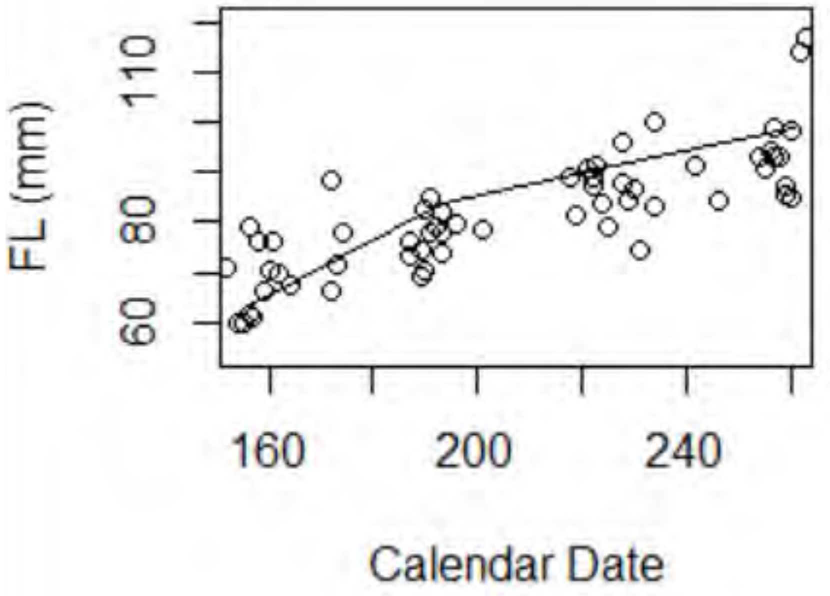
Estuary Restoration

Estuary Survival

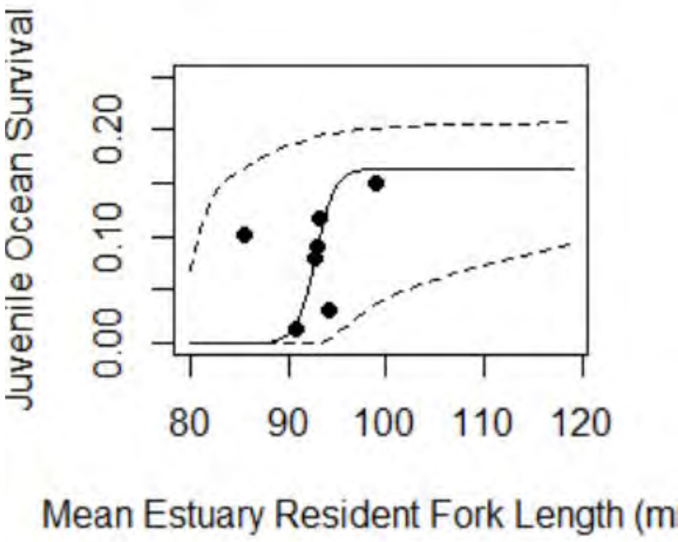


Estuary Restoration

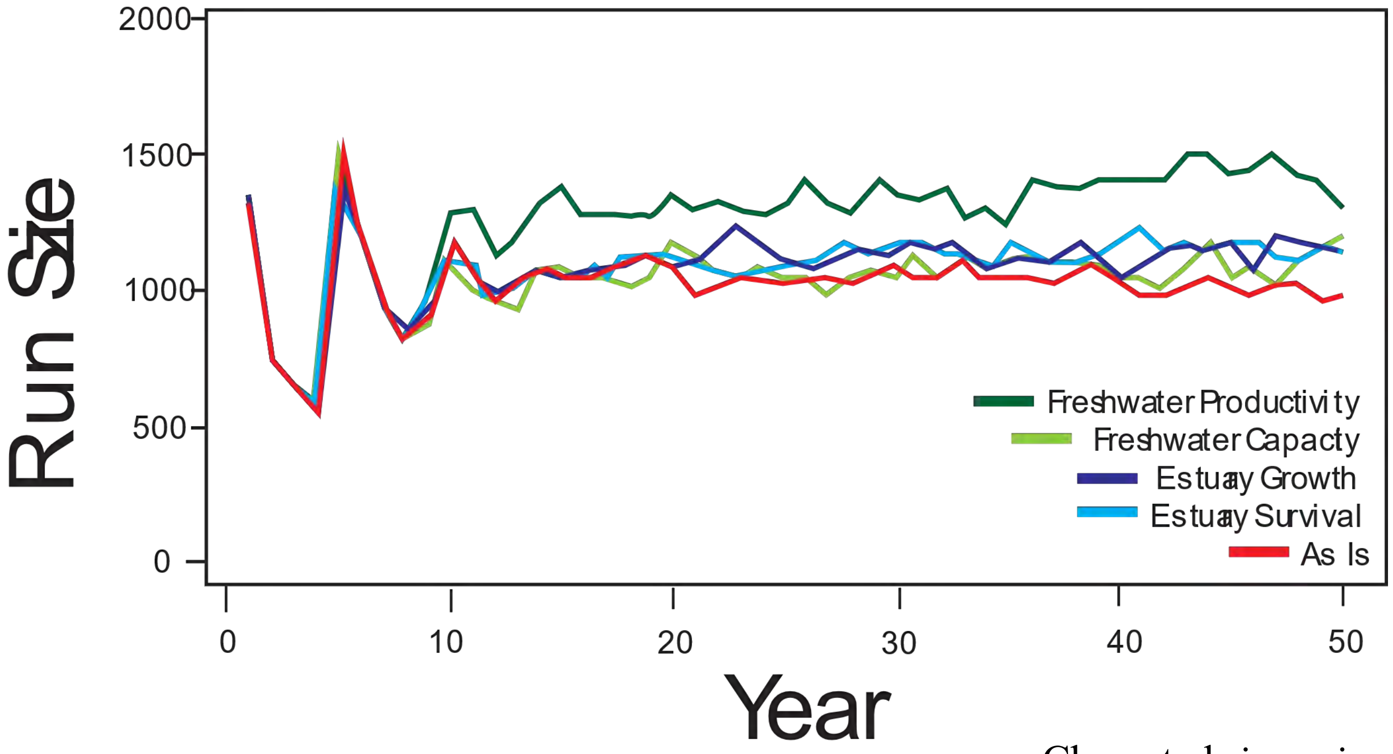
Estuary Growth



Ocean Survival



Population projections



Chen et al. *in review*

Scenario	Recruitment
Freshwater productivity	+31%
Freshwater capacity	+19%
Estuary growth	+15%
Estuary survival	+13%

Estuary life history only
20% of population

How would freshwater vs estuary restoration influence recruitment?

<u>In Redwood Creek</u>

- Freshwater productivity > Freshwater capacity
- Smaller effect of restoring estuary
    - Less common life history

Life Cycle Models

- Can evaluate population level effects of restoration
- Requires lots of data
- Longer datasets: better understand of factors that contribute to variability
- Monitoring at more life stages: Greater resolution
- Data especially should focus on areas of low survivorship and variation in survivorship.

More on Redwood Creek restoration

- *Redwood Creek Estuary Stakeholders Group; Using Strong Collaborative Process to Build Relationships and Trust*

Mary Burke, Cal Trout, and Leslie Wolff, NOAA Fisheries

Tomorrow morning session:

Opportunities for Collaboration: Tools and Initiatives for Increasing Our Collective Impact

Many thanks to:

CDFW fisheries biologists
Michael Sparkman
Seth Ricker

Redwood Creek monitoring field crew
Chris Diviney
Nicholas Easterbrook
Reed Hamilton
Nate Harris
Steve Holt
Dave Kissling
Tony Scheiff
Katelyn Southall
Nick Van Vleet
Victoria Varela-Yates

National Park Service field technicians
Kyle Max
Heather Brown
Fish and Wildlife field technicians

Committee
Darren Ward

Undergraduate technicians
Ryan Carey
Leah Lehr
Alexandra Baker

Coop Unit Administrator
Leslie Farrar

Funders
California Department of Fish and Wildlife
International Women's Fishing Association
Danielle Plum Zumbrun Scholarship
Barbara Bania Award

- Coho salmon juveniles express diverse life histories distinguished by their use of different habitats at different ages. Data from our long-term coho salmon population monitoring program in Humboldt Bay tributaries suggest that small-scale variation in habitat conditions experienced early in life is associated with larger-scale, long-term divergence in habitat use and life history later in life. For example, juveniles that spend their first summer in a small tributary are likely to remain in the stream for the winter, while juveniles that spend their first summer a short distance downstream in the main stem are likely to disperse long distances to winter rearing habitat in the estuary or an adjacent watershed. These differences in winter habitat use lead to differences in growth rate and body size, with potential implications for the age and timing of smolt migration and eventually adult life history. Habitat-dependent life history expression means that habitat alteration and habitat restoration activities can directly promote or erode life history diversity in the population over short time scales, with consequences for population stability.

Habitat restoration to support life history diversity for coho salmon in small coastal streams

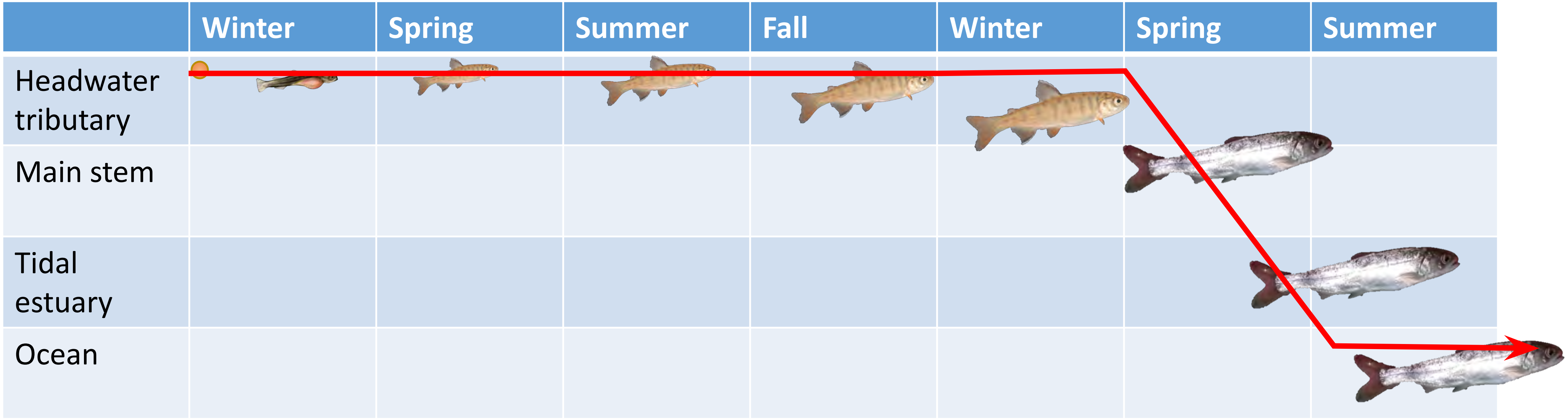
Darren Ward
Colin Anderson
Seth Ricker
Joshua Cahill
Katherine Stonecypher
Madison Halloran
Grace Ghrist

CAL POLY HUMBOLDT
CALIFORNIA DEPARTMENT OF FISH & WILDLIFE

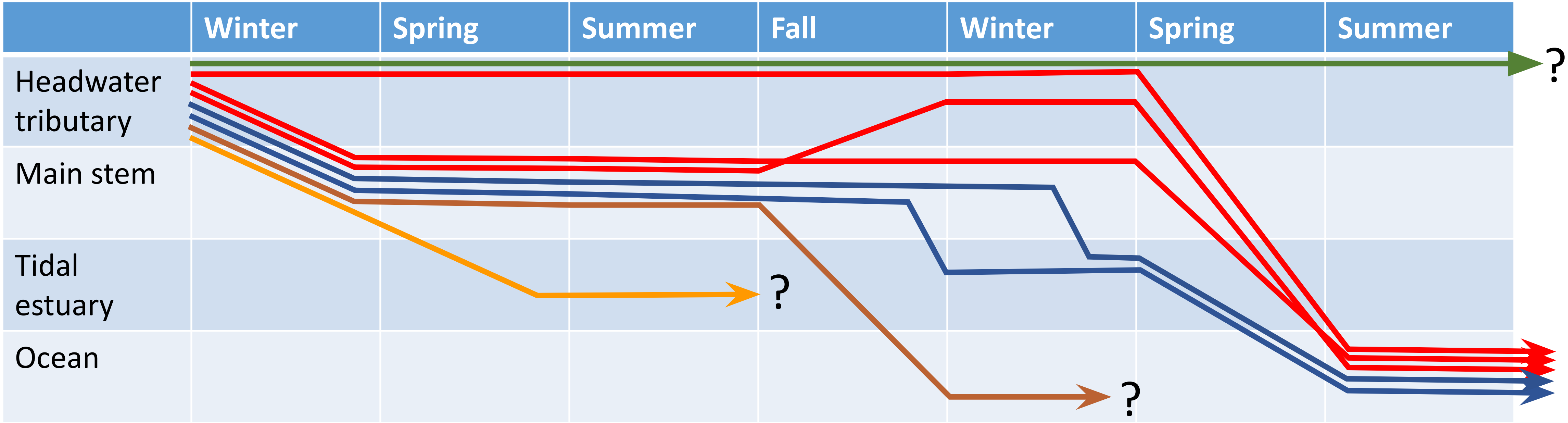
Juvenile coho life history variants

	Winter	Spring	Summer	Fall	Winter	Spring	Summer
Headwater tributary							
Main stem							
Tidal estuary							
Ocean							

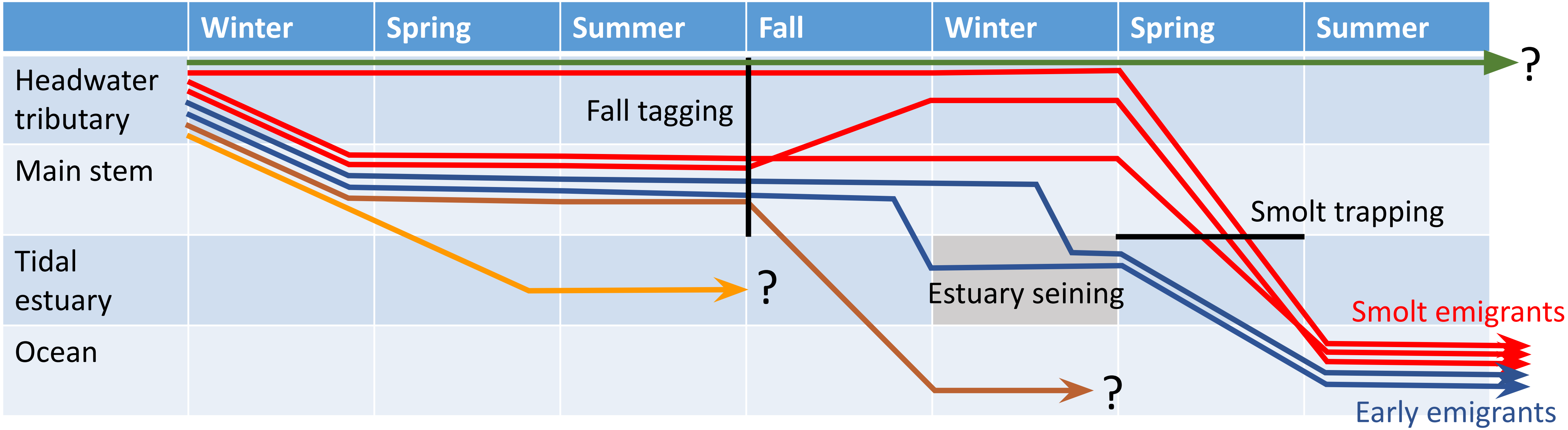
Juvenile coho life history variants



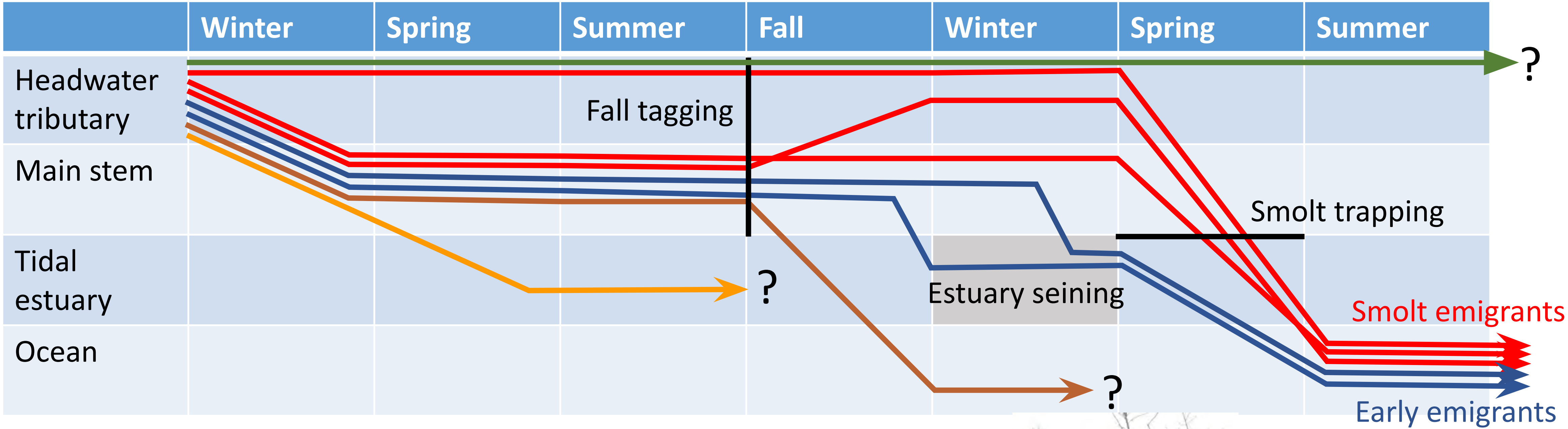
Juvenile coho life history variants



Juvenile coho life history variants



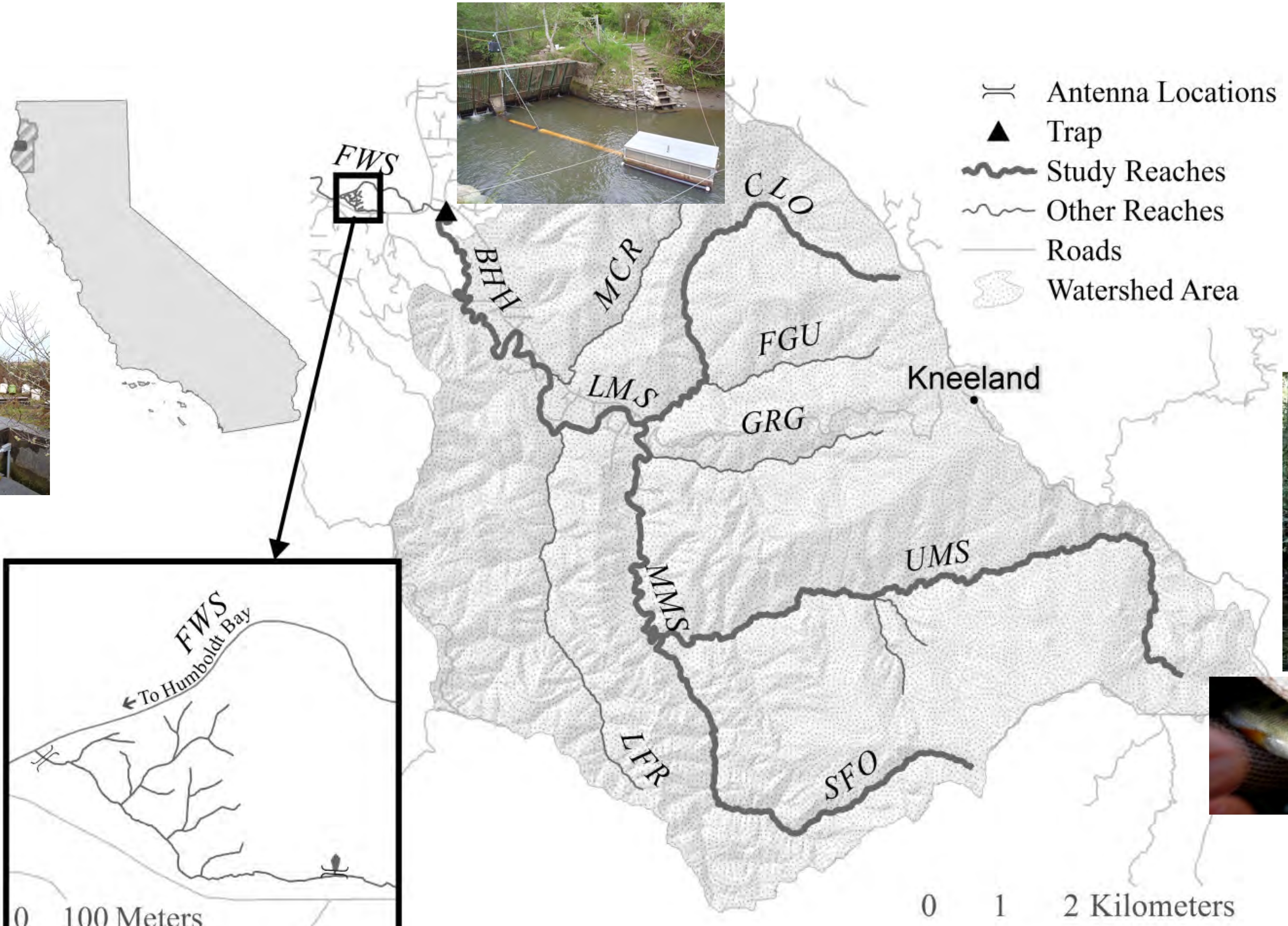
Juvenile coho life history variants



Early emigrants

Early emigrants

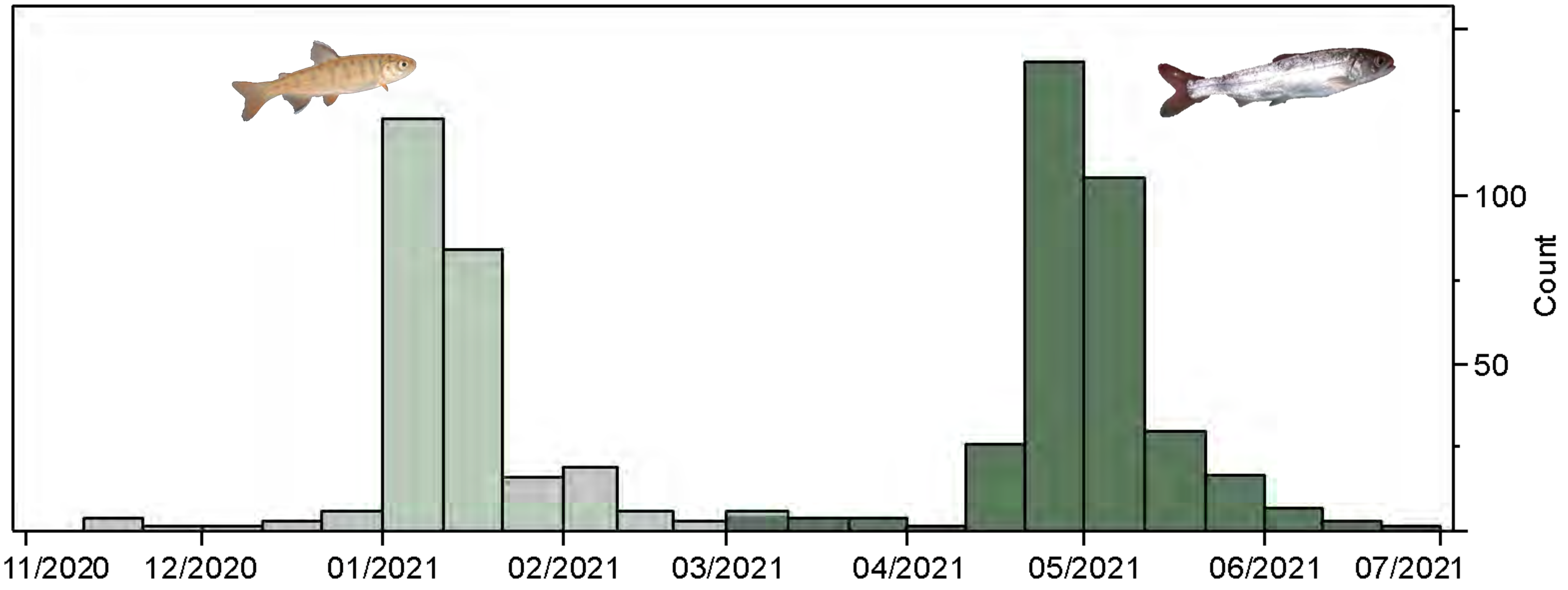
Freshwater Creek Life Cycle Station



Key questions

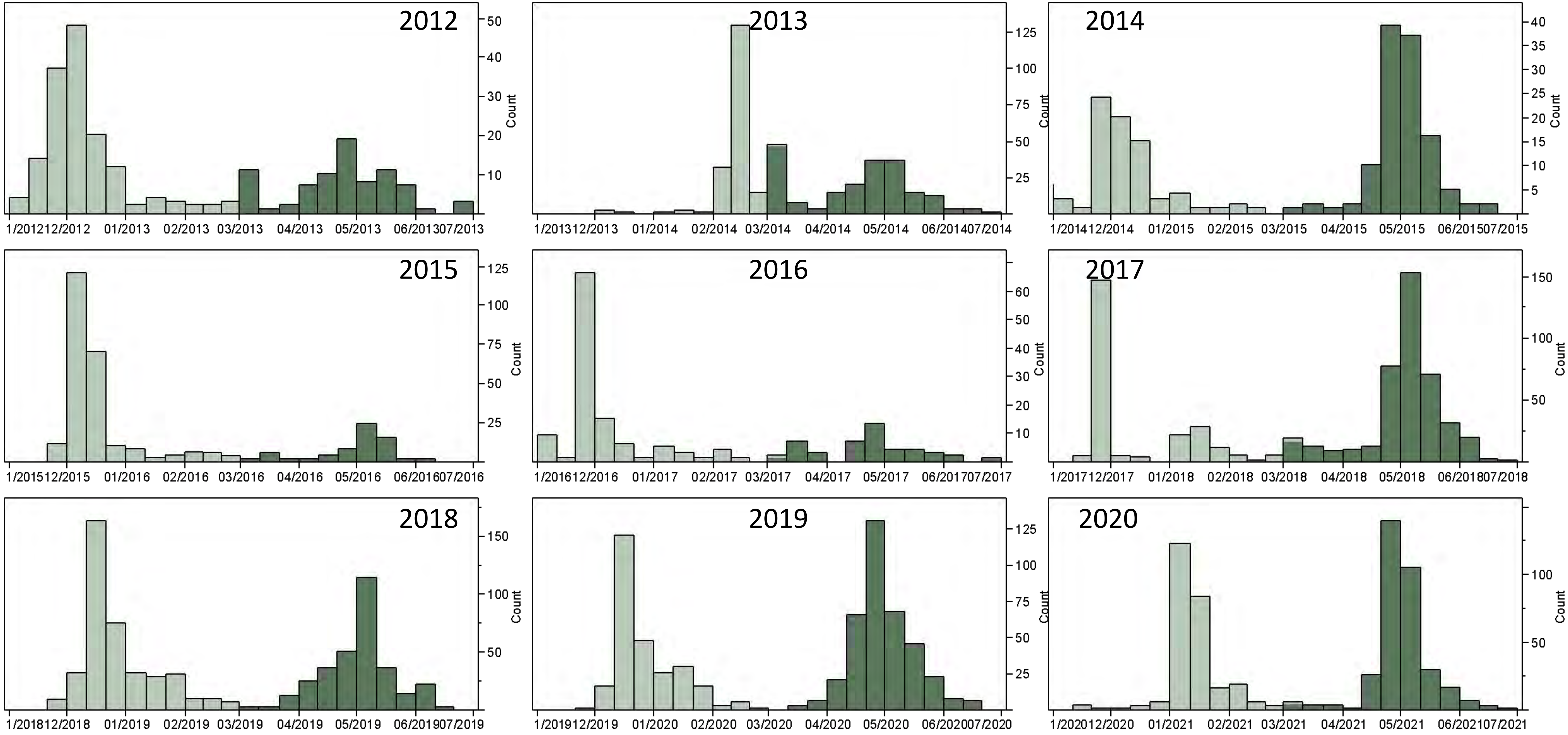
- Are early emigrants a substantial proportion of the population?

First detections in tidal habitat



Early emigrants

Smolt emigrants


2012
2013
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Count
1/2012 12/2012 01/2013 02/2013 03/2013 04/2013 05/2013 06/2013 07/2013
1/2013 12/2013 01/2014 02/2014 03/2014 04/2014 05/2014 06/2014 07/2014
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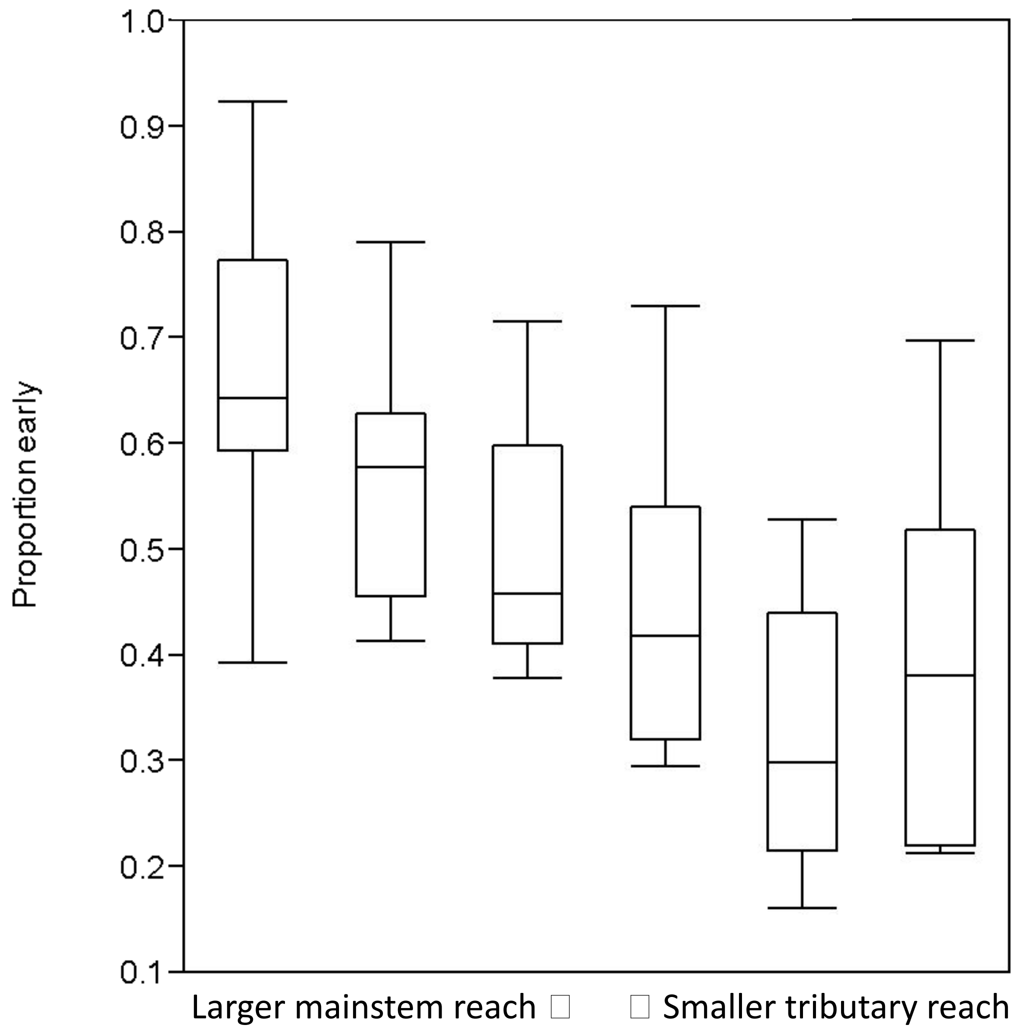
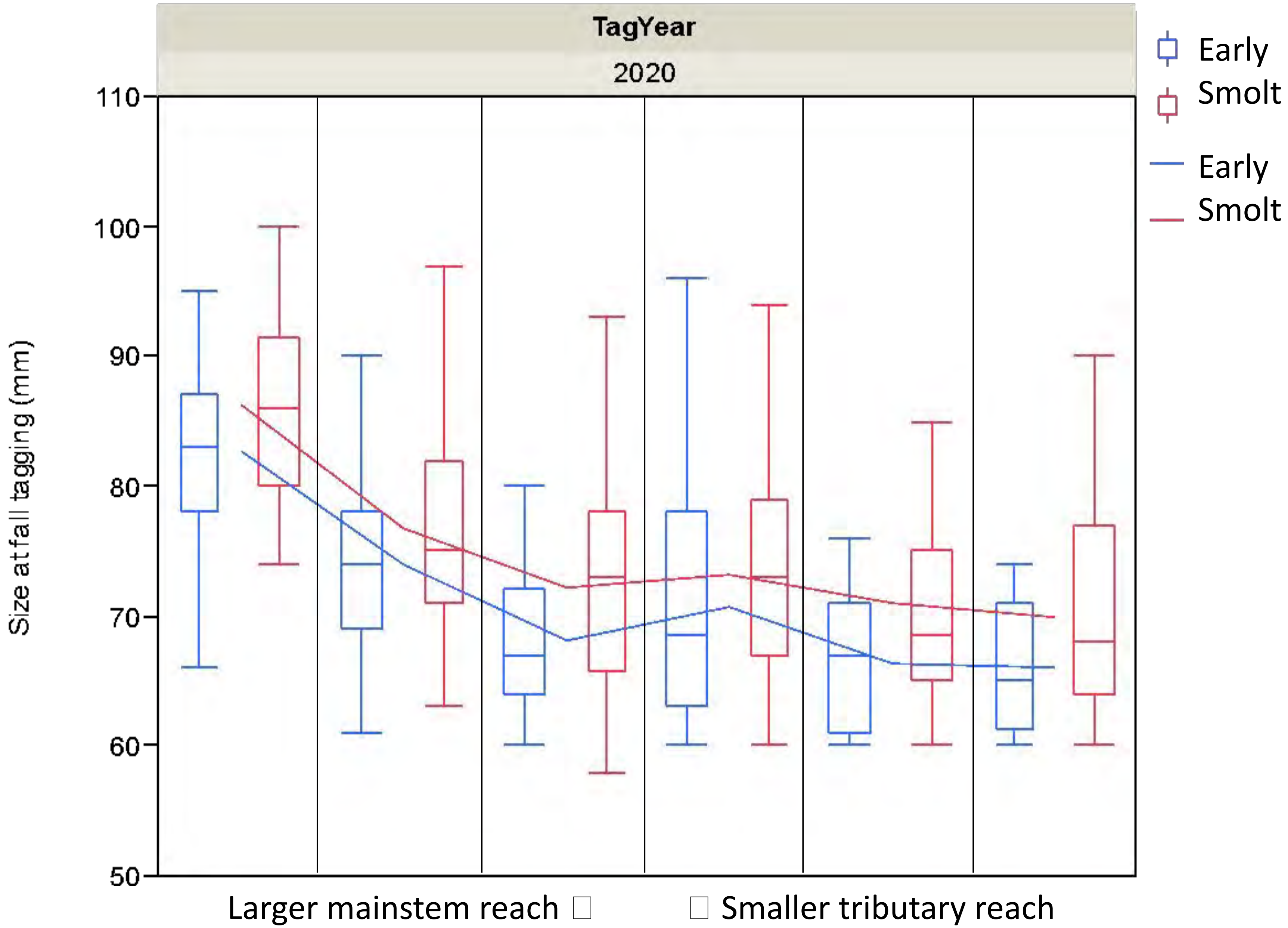
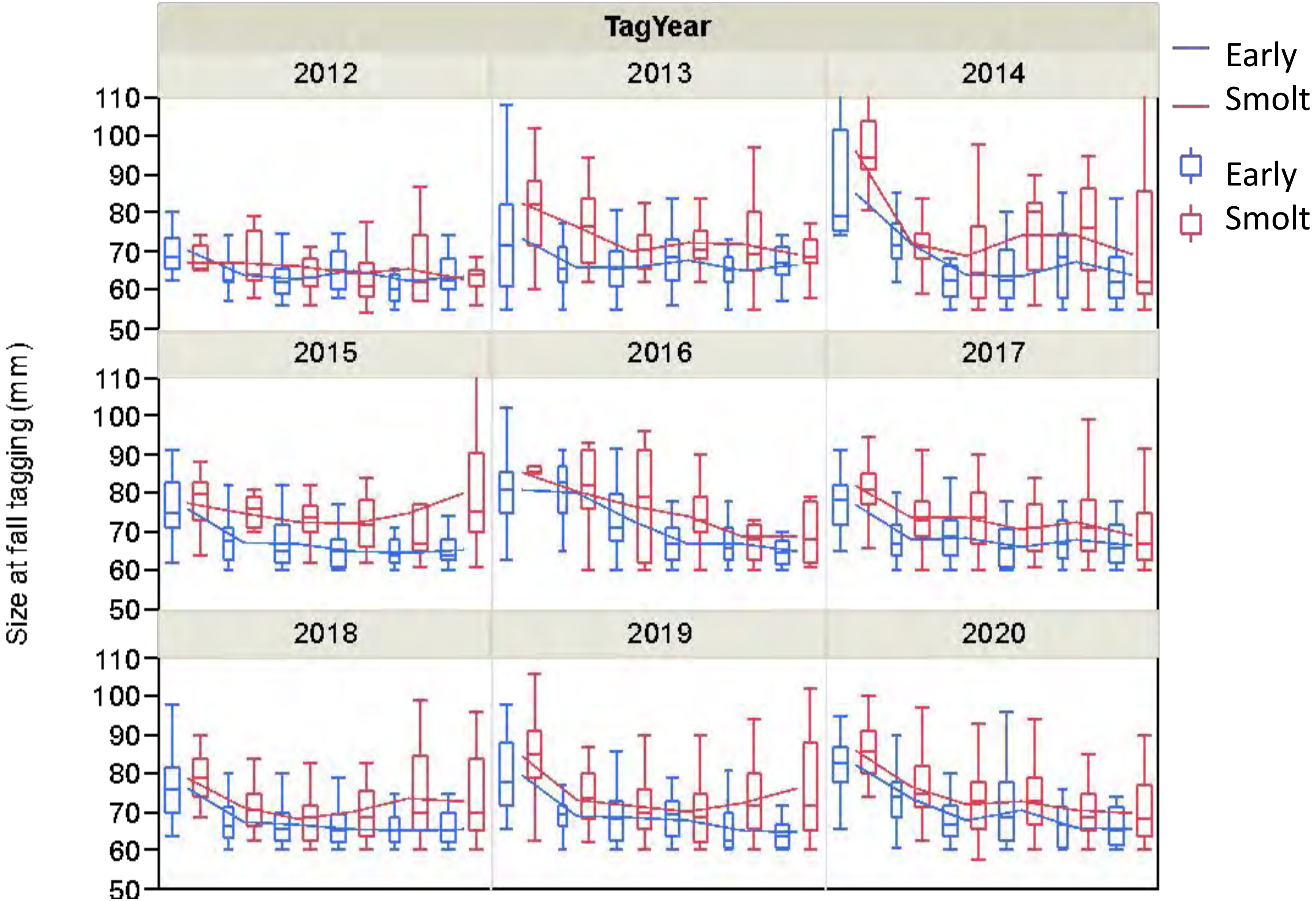
1/2020 12/2020 01/2021 02/2021 03/2021 04/2021 05/2021 06/2021 07/2021

Key questions

- Are early emigrants a substantial proportion of the population?
- What determines migration life history?


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Proportion early
Larger mainstem reach
Smaller tributary reach


TagYear
2020
110
100
90
80
70
60
50
Size at fall tagging (mm)
Early
Smolt
Early
Smolt
Larger mainstem reach
Smaller tributary reach

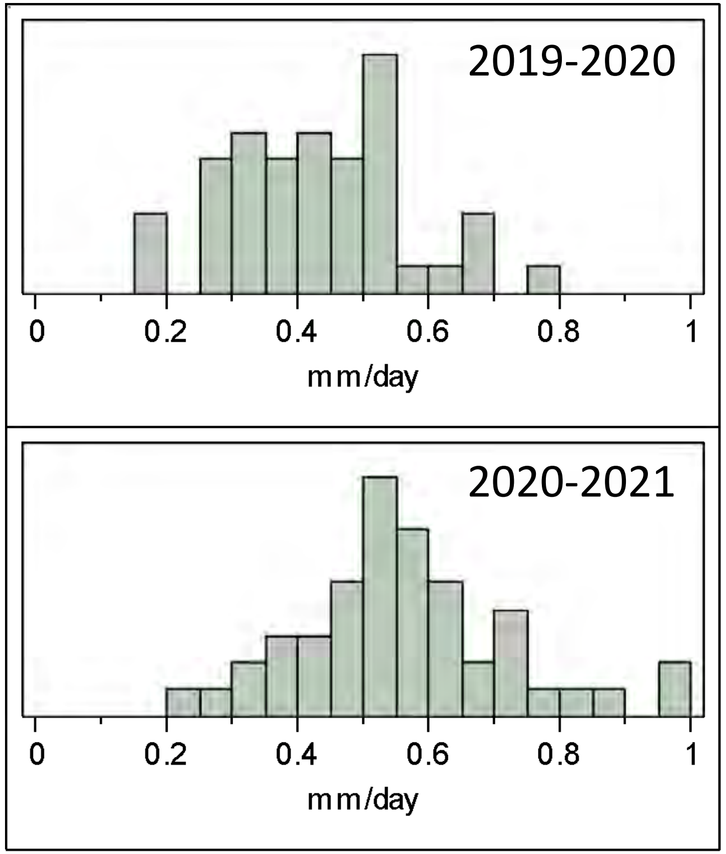


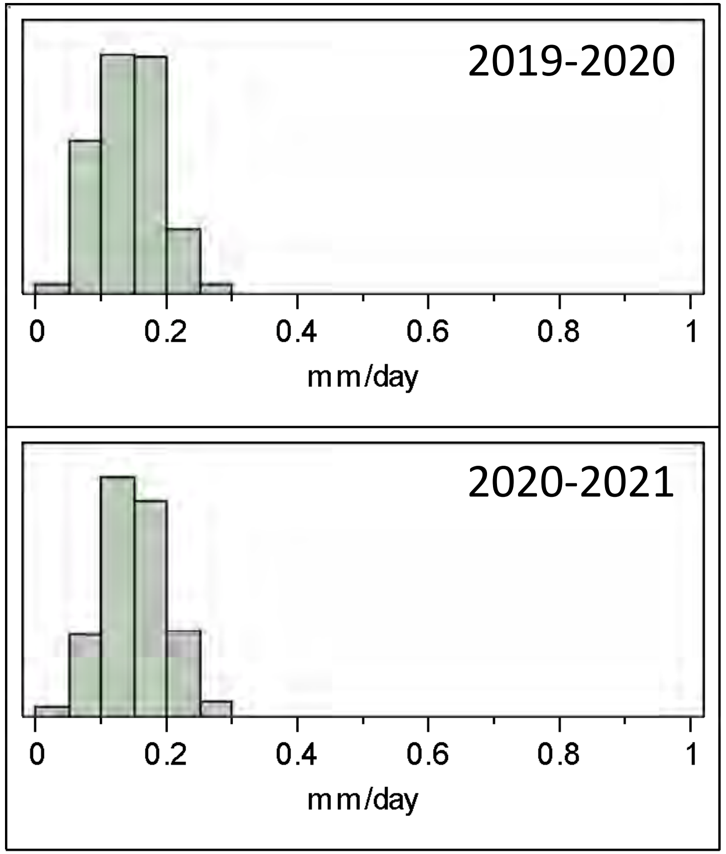
Larger mainstem reach Smaller tributary reach

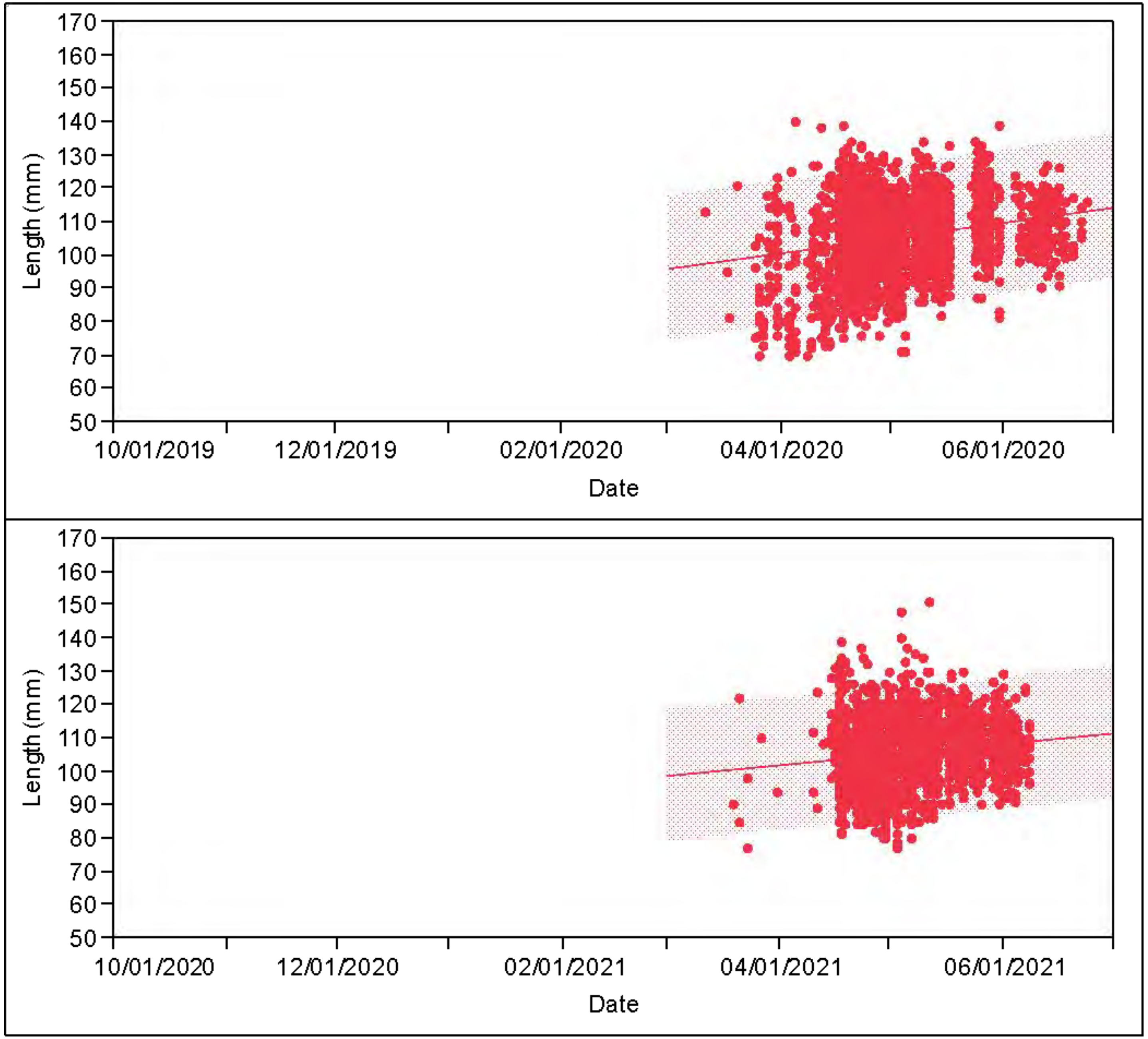
Key questions

- Are early emigrants a substantial proportion of the population?
- What determines migration life history?
- What is the fate of early emigrants?

Early emigrants


2019-2020
0 0.2 0.4 0.6 0.8 1
mm/day
2020-2021
0 0.2 0.4 0.6 0.8 1
mm/day


2019-2020
0 0.2 0.4 0.6 0.8 1
mm/day
2020-2021
0 0.2 0.4 0.6 0.8 1
mm/day



Length (mm)
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06/01/2020
Date
Length (mm)
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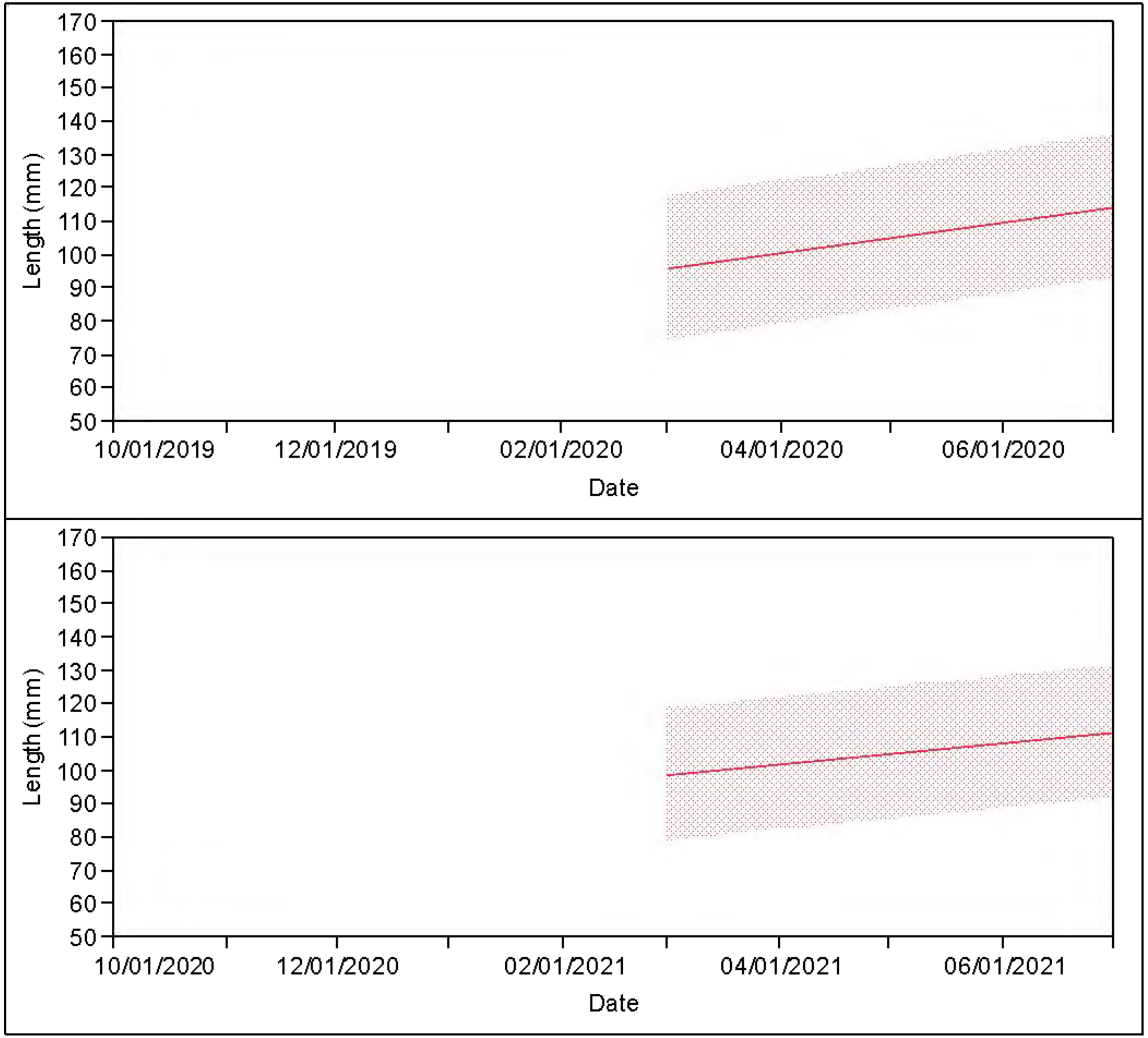
06/01/2021
Date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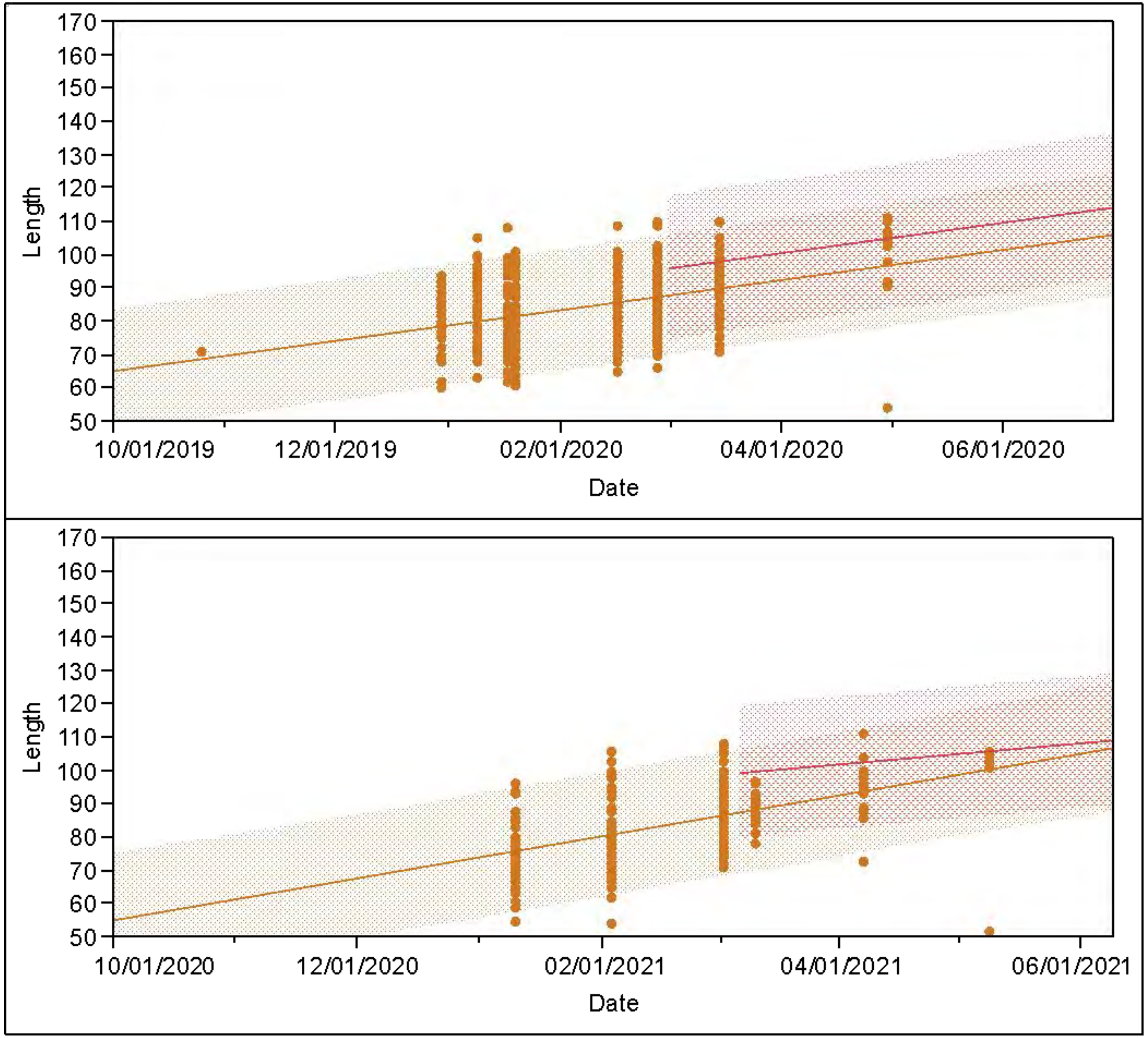
Date



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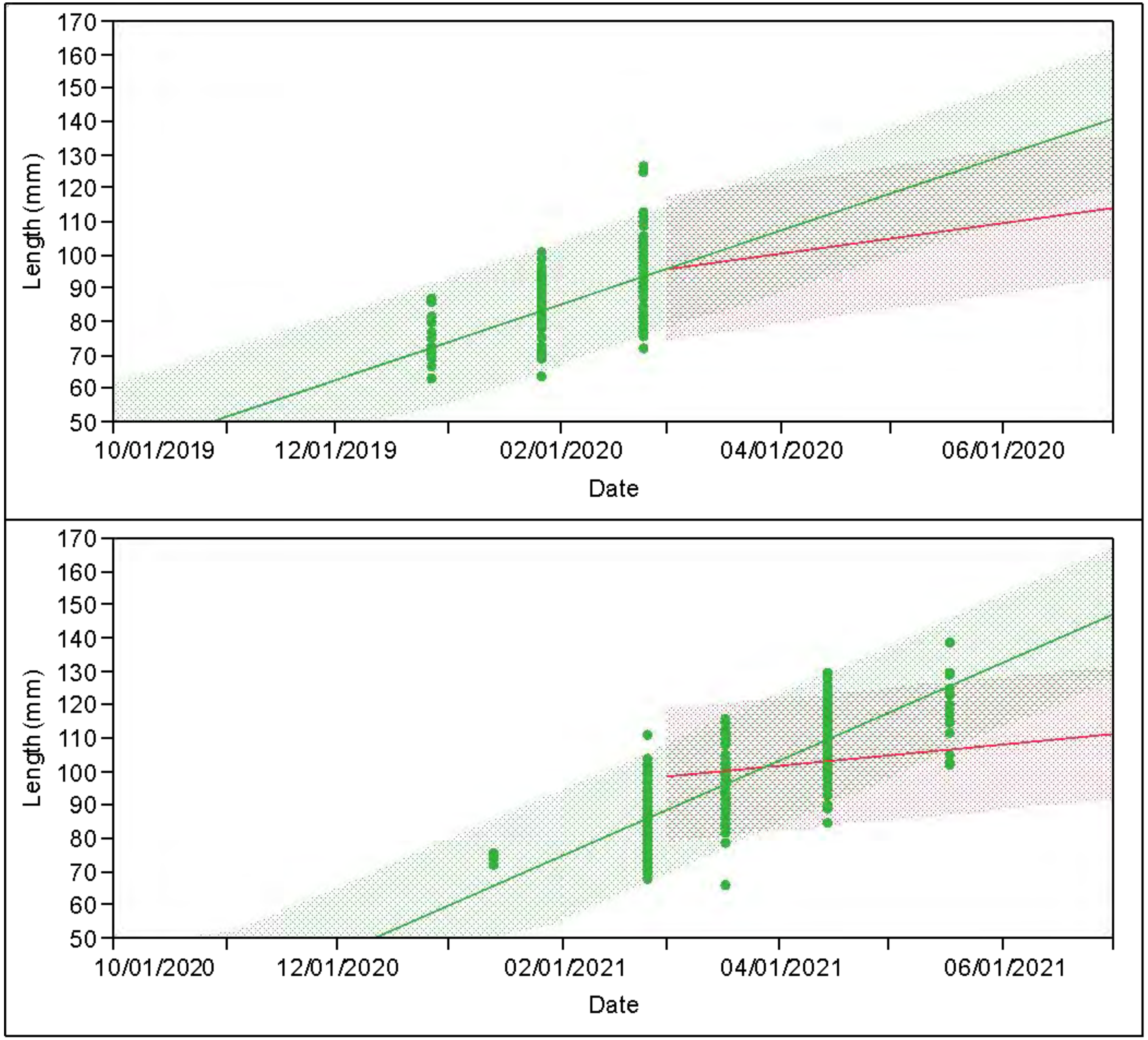
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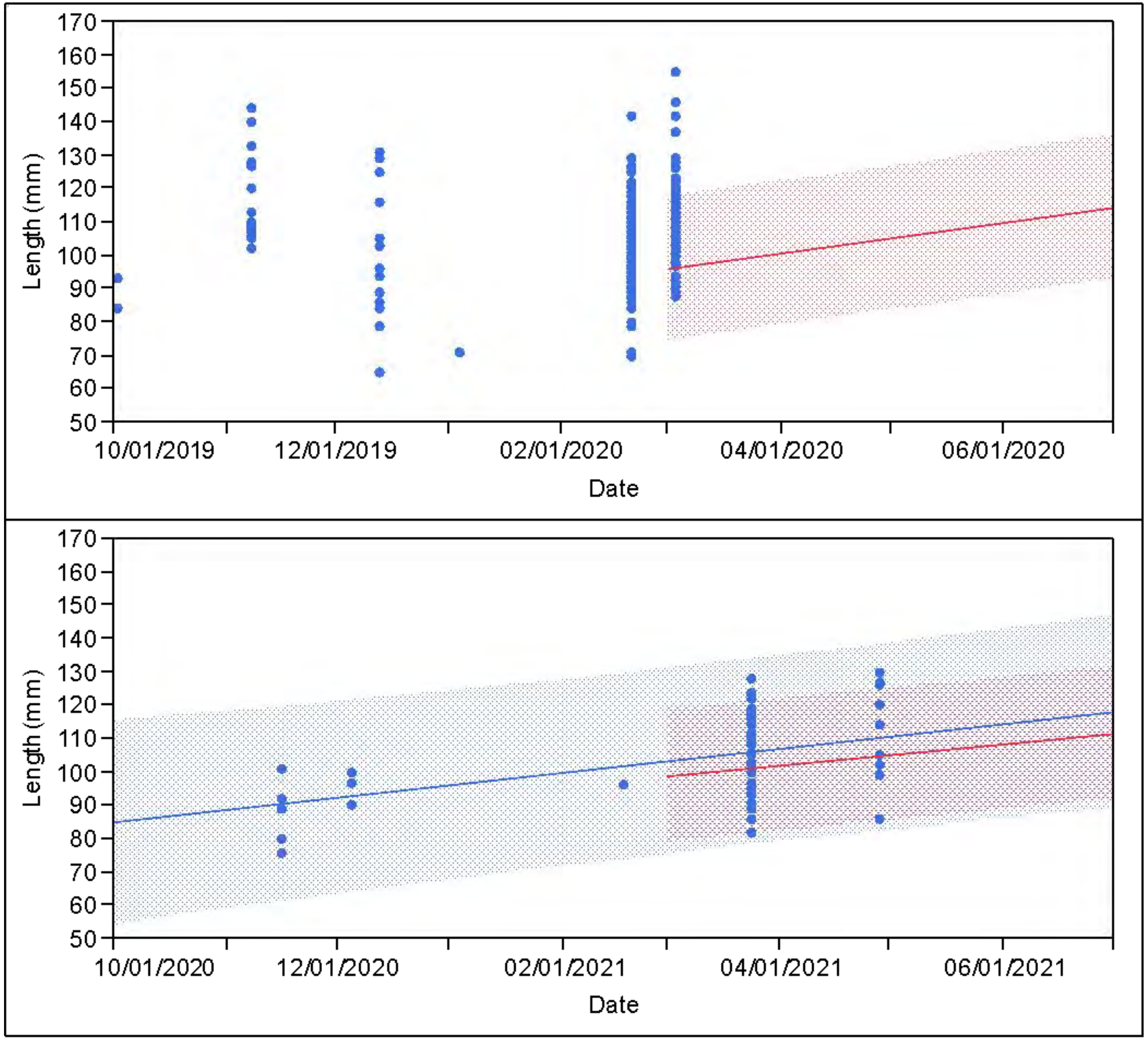
Date



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90
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70
60
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Length (mm)
10/01/2020
12/01/2020
02/01/2021
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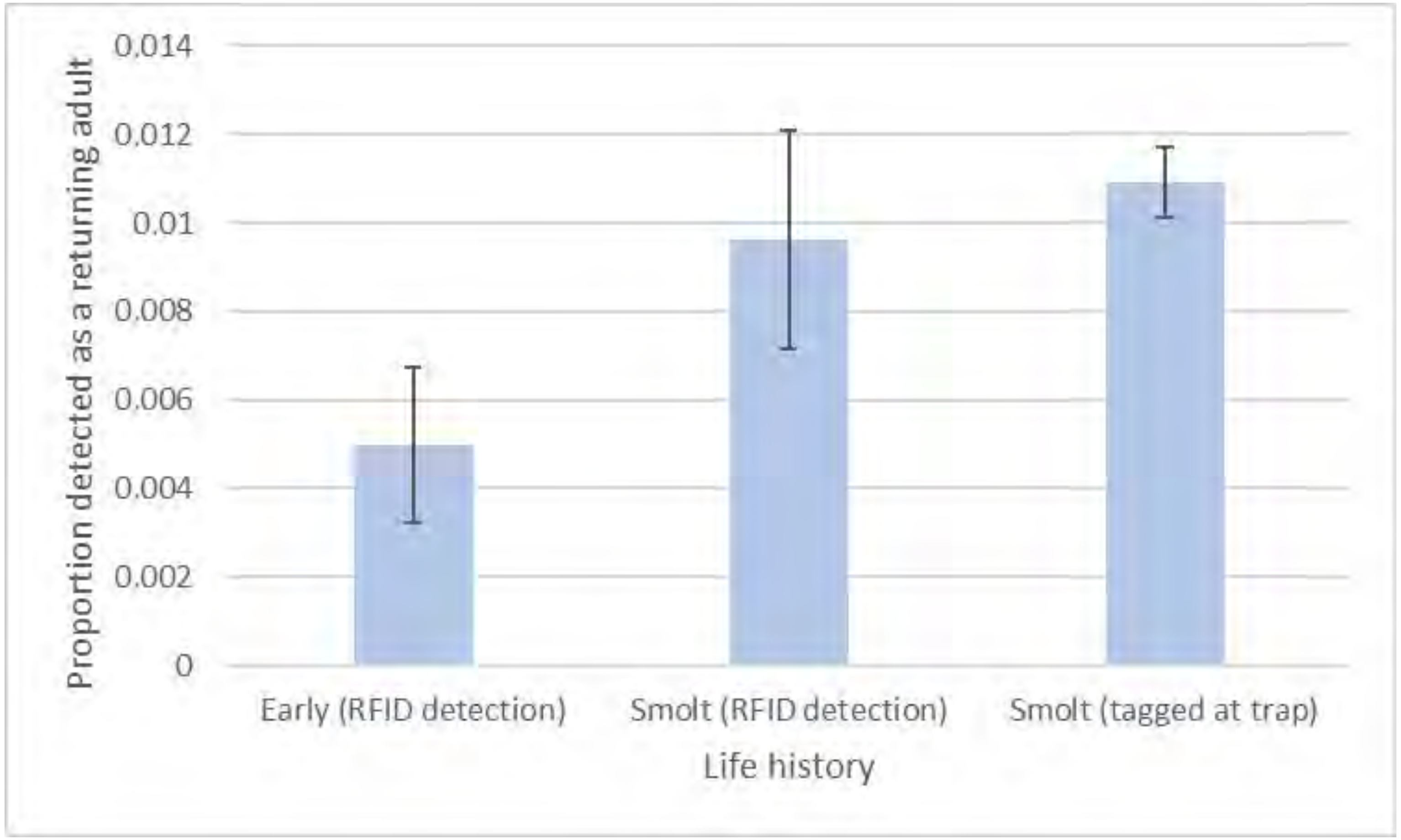
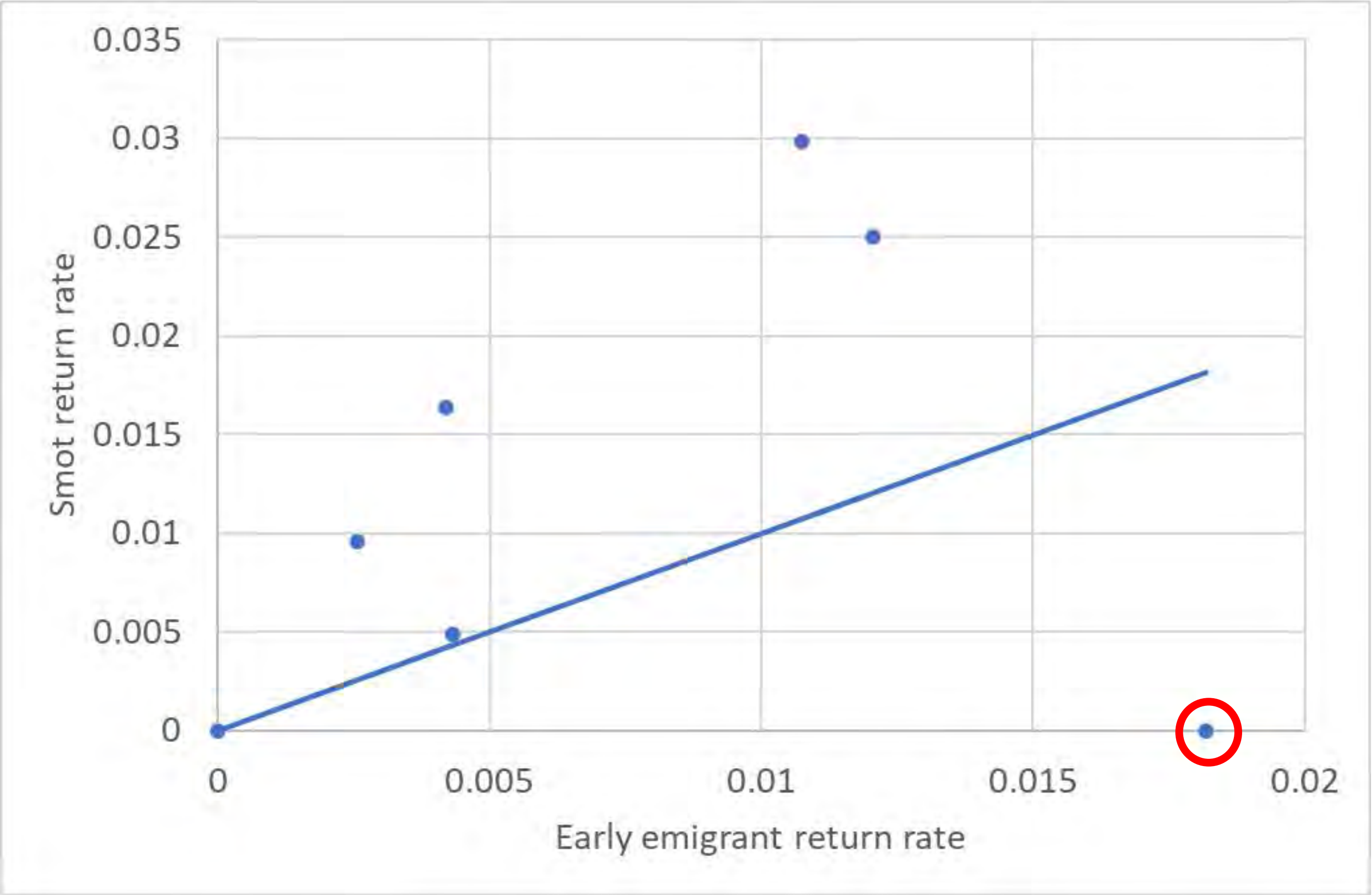
06/01/2021
Date

Key questions

- Are early emigrants a substantial proportion of the population?
- What determines migration life history?
- What is the fate of early emigrants?


0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Proportion detected as a returning adult
Early (RFID detection)
Smolt (RFID detection)
Smolt (tagged at trap)
Life history

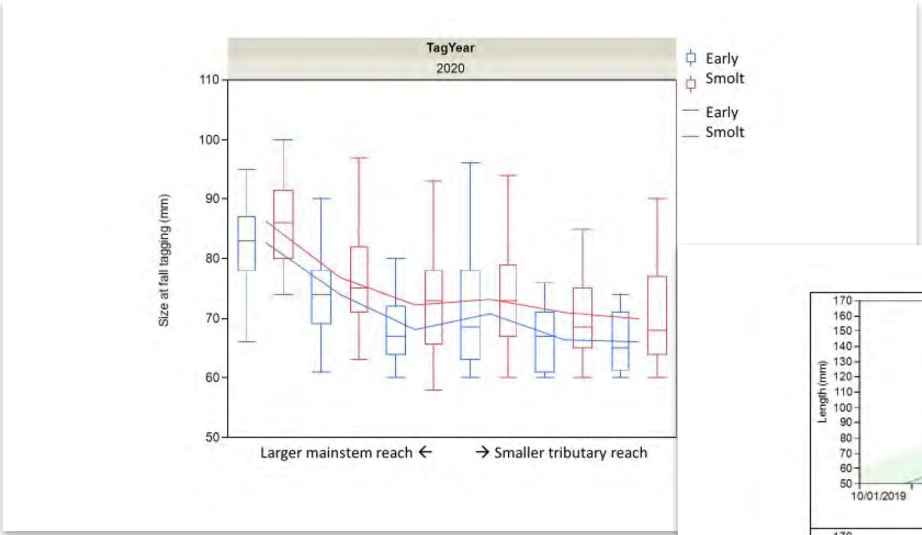

0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Smot return rate
0
0.005
0.01
0.015
0.02
Early emigrant return rate

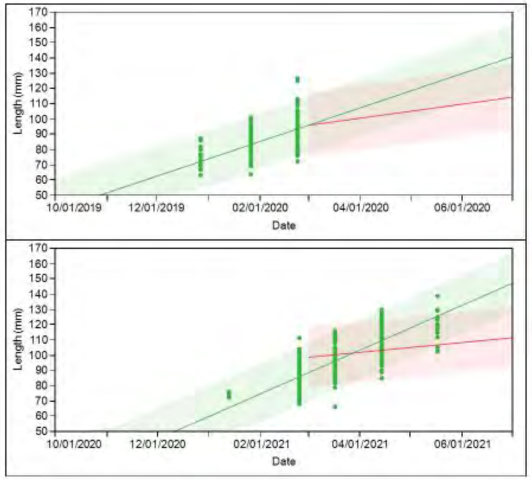
Conclusions

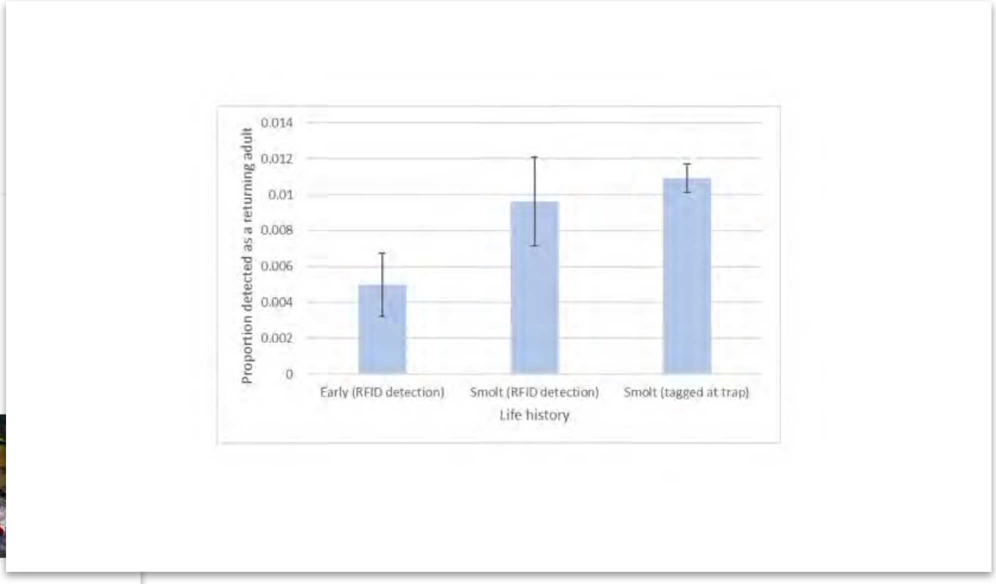
- Restoration of tidal habitats supports life history diversity for coho salmon

Conclusions

- Data on fish use of restoration sites are more useful in the context of a long-term, population-scale monitoring effort

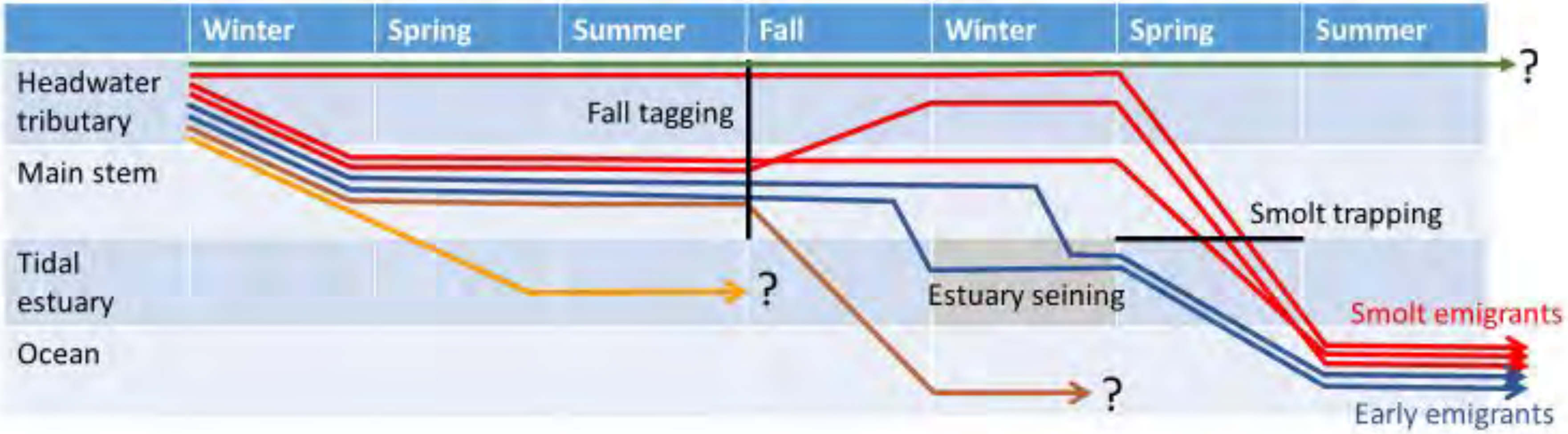


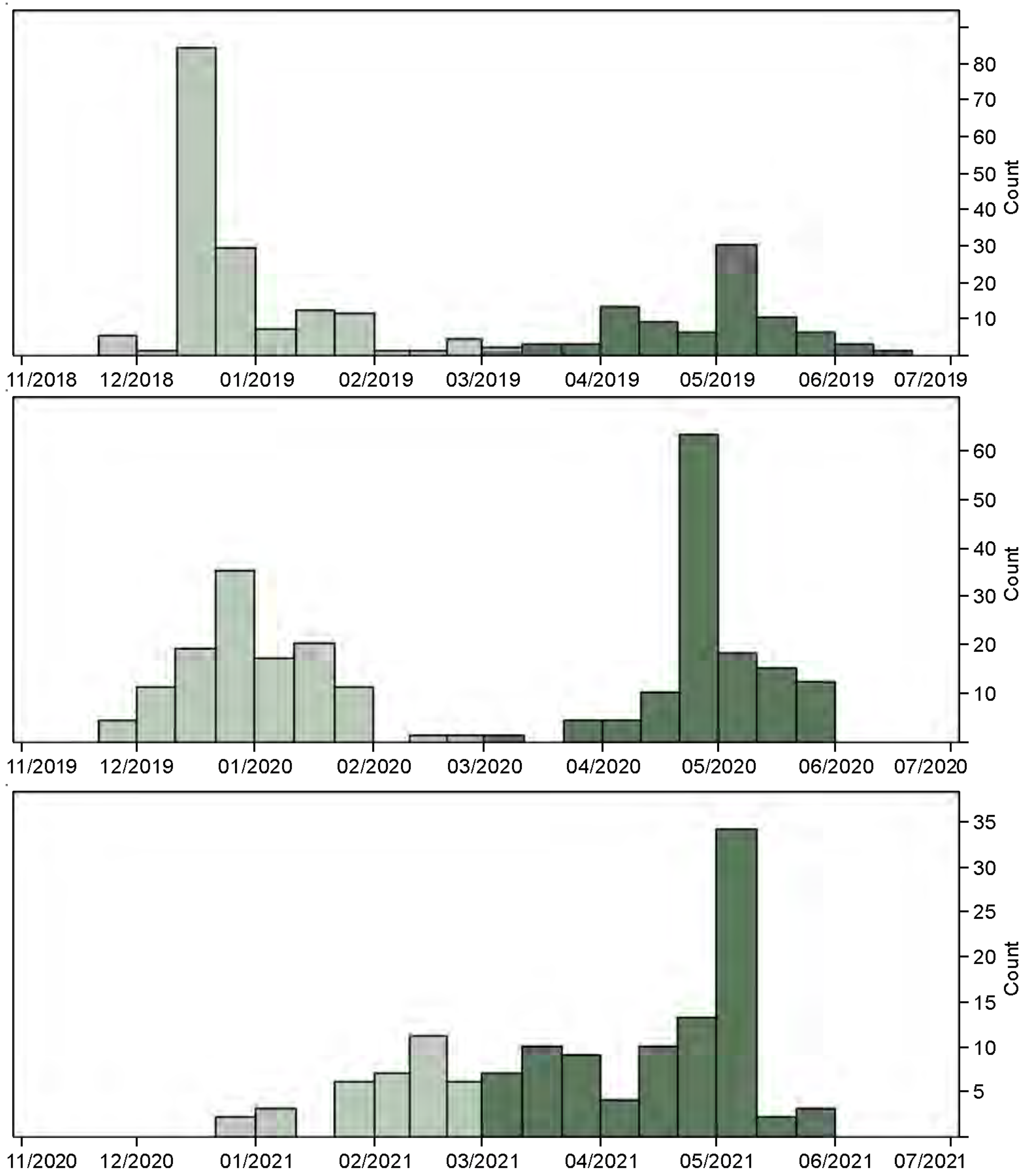




Conclusions

- There is still more diversity to explore…




Count
11/2018
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02/2020
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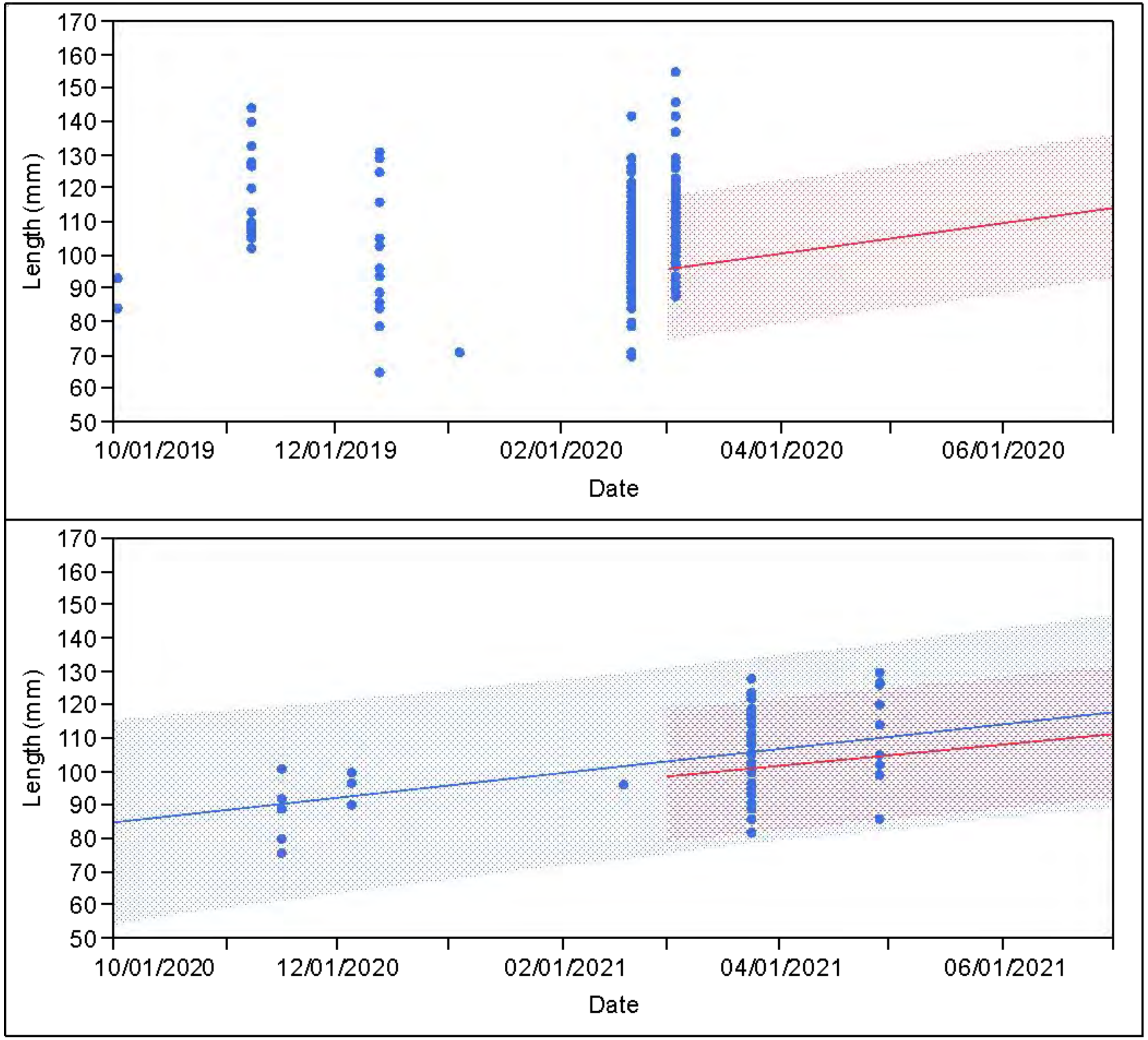
07/2021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Length (mm)
10/01/2019
12/01/2019
02/01/2020
04/01/2020
06/01/2020
Date
10/01/2020
12/01/2020
02/01/2021
04/01/2021
06/01/2021
Date

Early emigrants

Early emigrants