Recovery, rematuration, and reproductive performance in repeat spawning reconditioned female steelhead

LE Jenkins, AP Pierce, ND Graham, LR Medeiros, R Branstetter, D Hatch, JJ Nagler

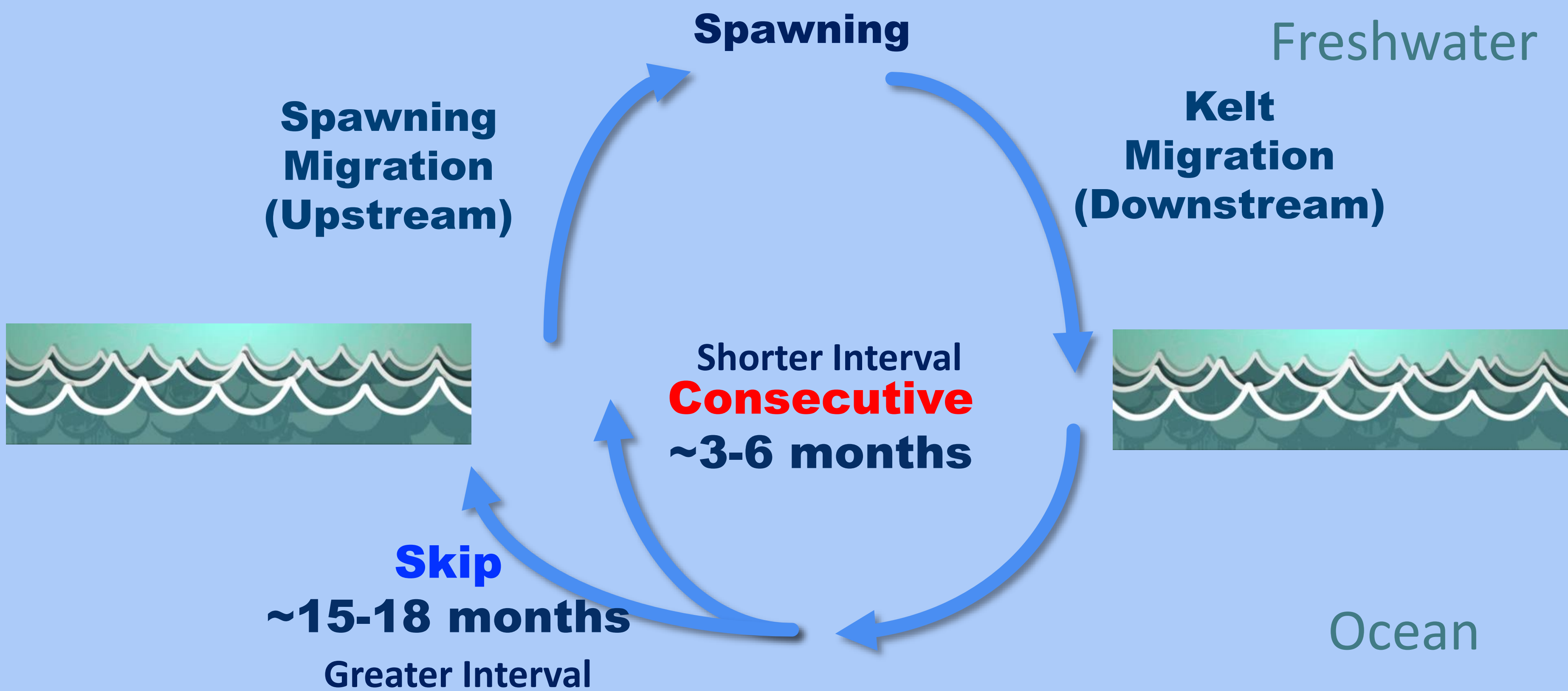
Department of Biological Sciences, University of Idaho

Nagler Lab

Model *O. mykiss* – Life History Diversity

- Freshwater residents vs. anadromous (sea run) – steelhead; interbreed
- Variation in ages & sizes
  - seaward/downstream migration
  - upstream spawning migration
  - **iteroparous, spawning interval:** consecutive or skip
- Leads to diverse pathways in individuals... 16 (32?) theorized for anadromous

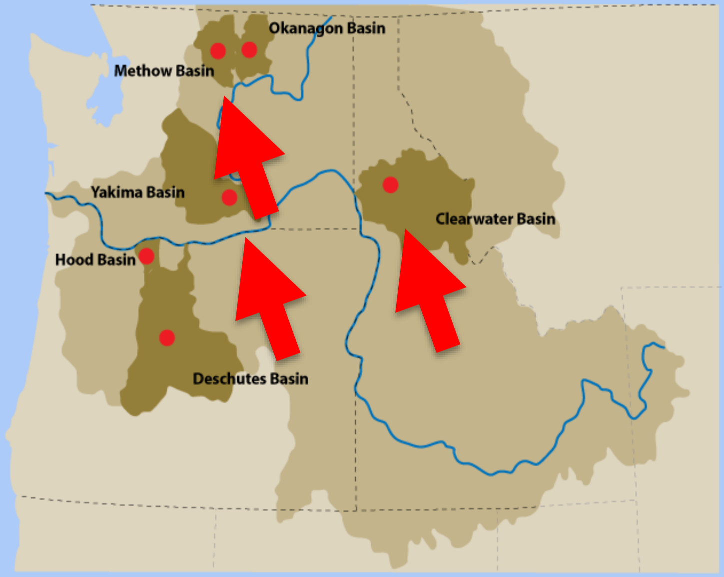
Spawning Interval Diversity



- recovery from spawning
- accumulating energy stores
- initiating rematuration of the gonad

Kelt Reconditioning: Conservation

- Active conservation recovery tool in Columbia R. Basin
- Columbia River Inter-Tribal Fish Commission and local tribes
- Yakima R. largest project
- Capitalizes on
  - Repeat spawning ability
  - Natural selection
  - Availability for collection
    - >50% attempt to migrate out
  - Low occurrence of repeat spawning in current system
    - 0.5% (Keefer 2008), 1.3% last 7 years (Copeland in prep)



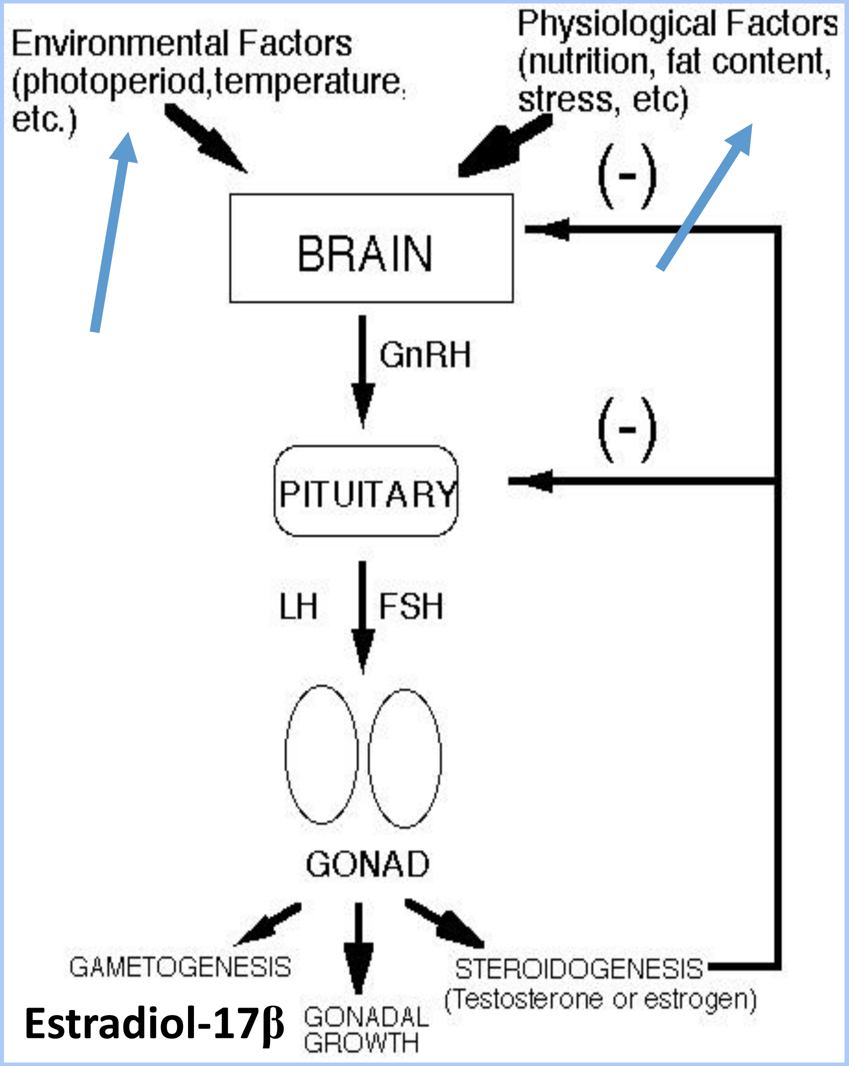
Kelt Reconditioning: Conservation

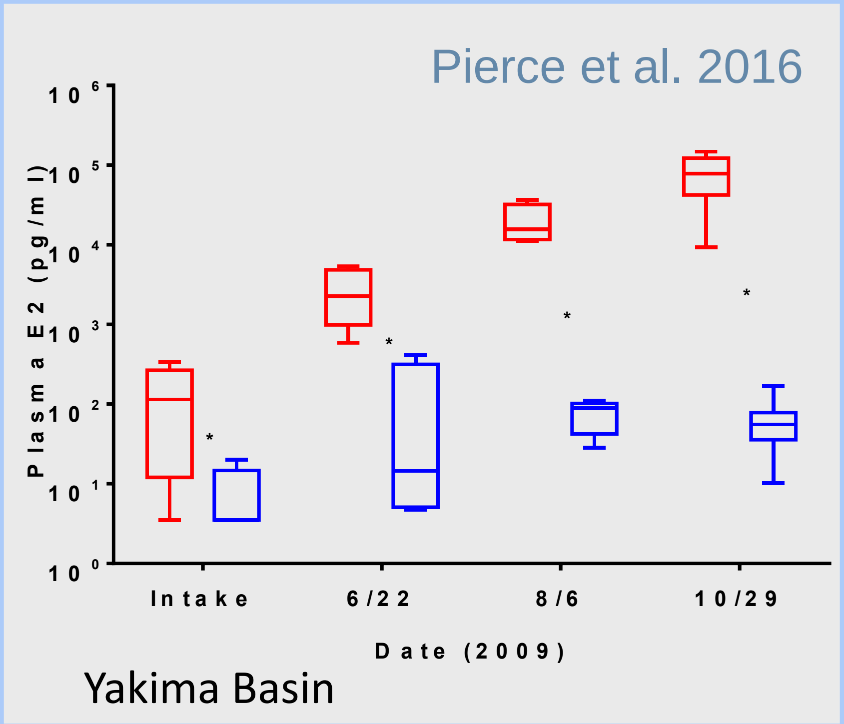
- Collected during downstream migration
- Transport

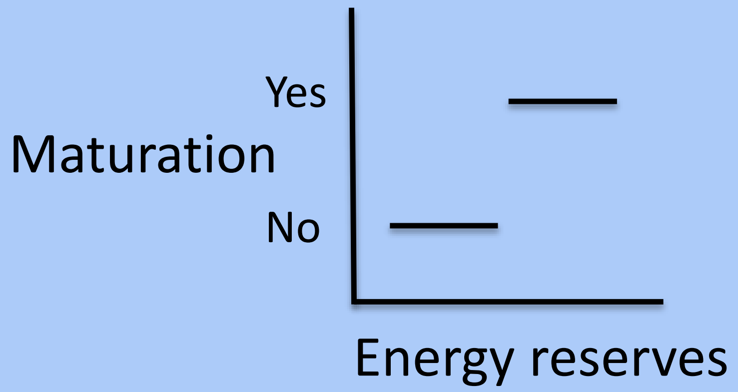
- Tanks with river water
- Natural photoperiod
- Fed pellets, krill - satiation feeding

- Release mature fish to migrate upstream
- Hold over non-mature fish

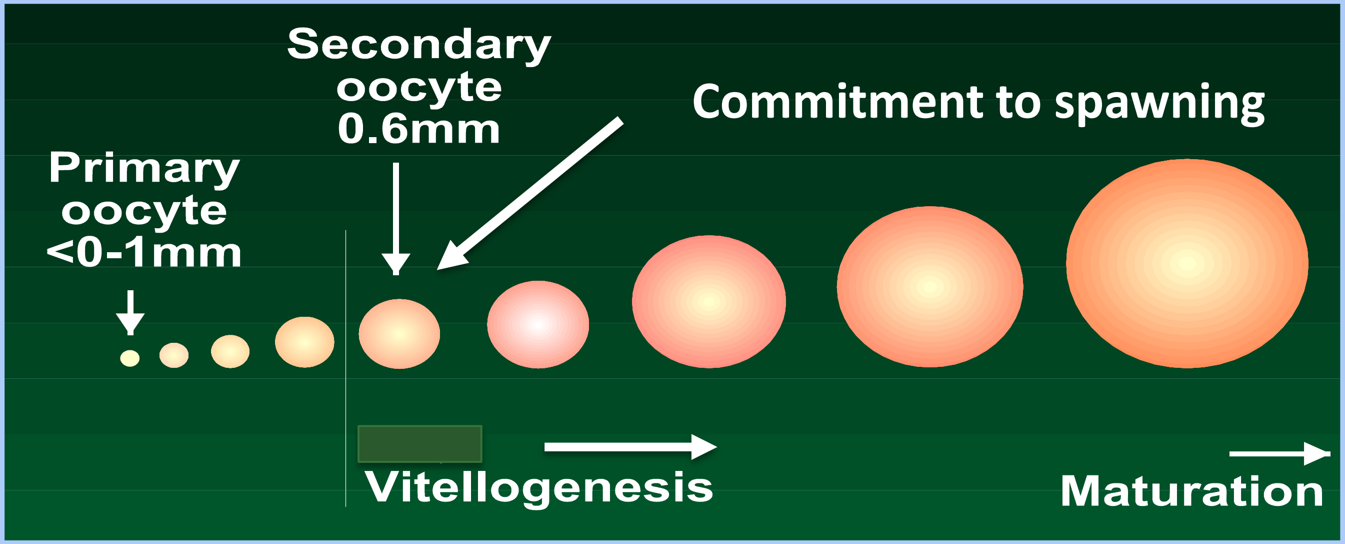
Current Models for (Re)Maturation



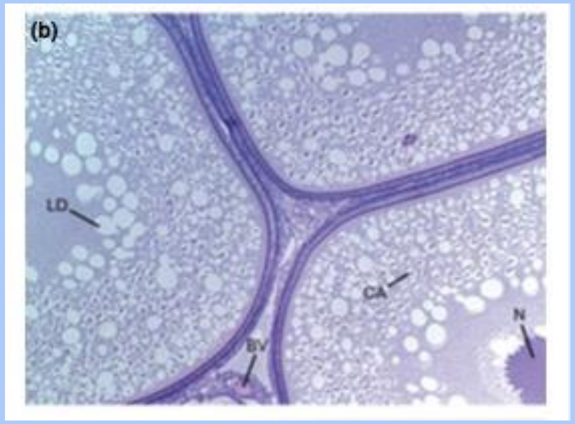




Commitment to spawning, egg size and egg number in *O. mykiss*



- Coincide with energy transfer to oocytes
- Signaled ~1 year prior to spawning
- Fecundity (egg #) set prior to vitellogenesis
- Energy partitioned between egg size & #

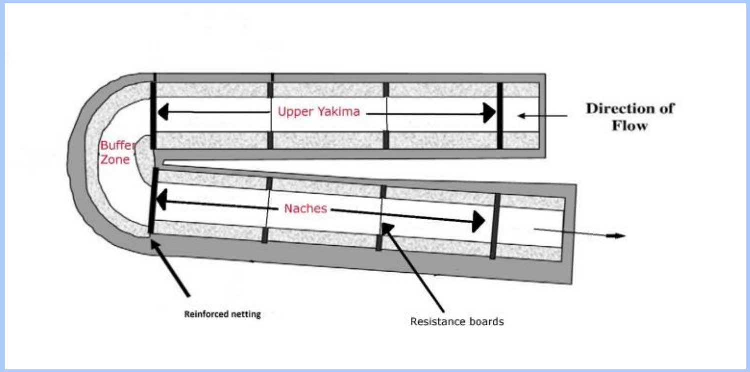


Objectives

1. Determine spawning interval trajectory using Estradiol-17β
2. Assess **changes in growth and energy reserves** during:
   a. Recovery from maiden spawning
   b. Rematuration for repeat spawning
3. Quantify the potential **benefits** of kelt reconditioning
4. Quantify **reproductive performance** differences between maiden, consecutive, and skip spawning steelhead

Kelt Reconditioning: Reproductive Performance Assessment

- Artificial spawning channels – Ryan Branstetter
- Genetic parentage analysis – Jeff Stevenson
- Reproductive performance in hatchery fish



Hatchery Fish as a Research Model

- Migration/fasting/depletion similar to wild population
- Artificially spawned
- Know origin and prior life history, uniform
- Reproductive performance quantified
- Sample regularly – increase resolution on patterns
- Repeat spawn in captivity

Methods

~150 females/year collected at Dworshak National Fish Hatchery

Air-spawned – non-lethal method →

Collected eggs – number, size

Collected blood – Estradiol, triglycerides

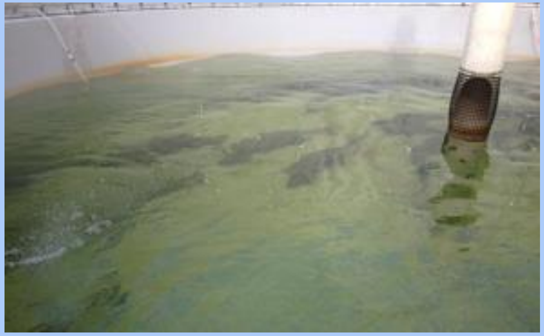
Measured length, mass, fat

Reconditioned in tanks at Dworshak – fed, etc.

Sampled every 10 weeks

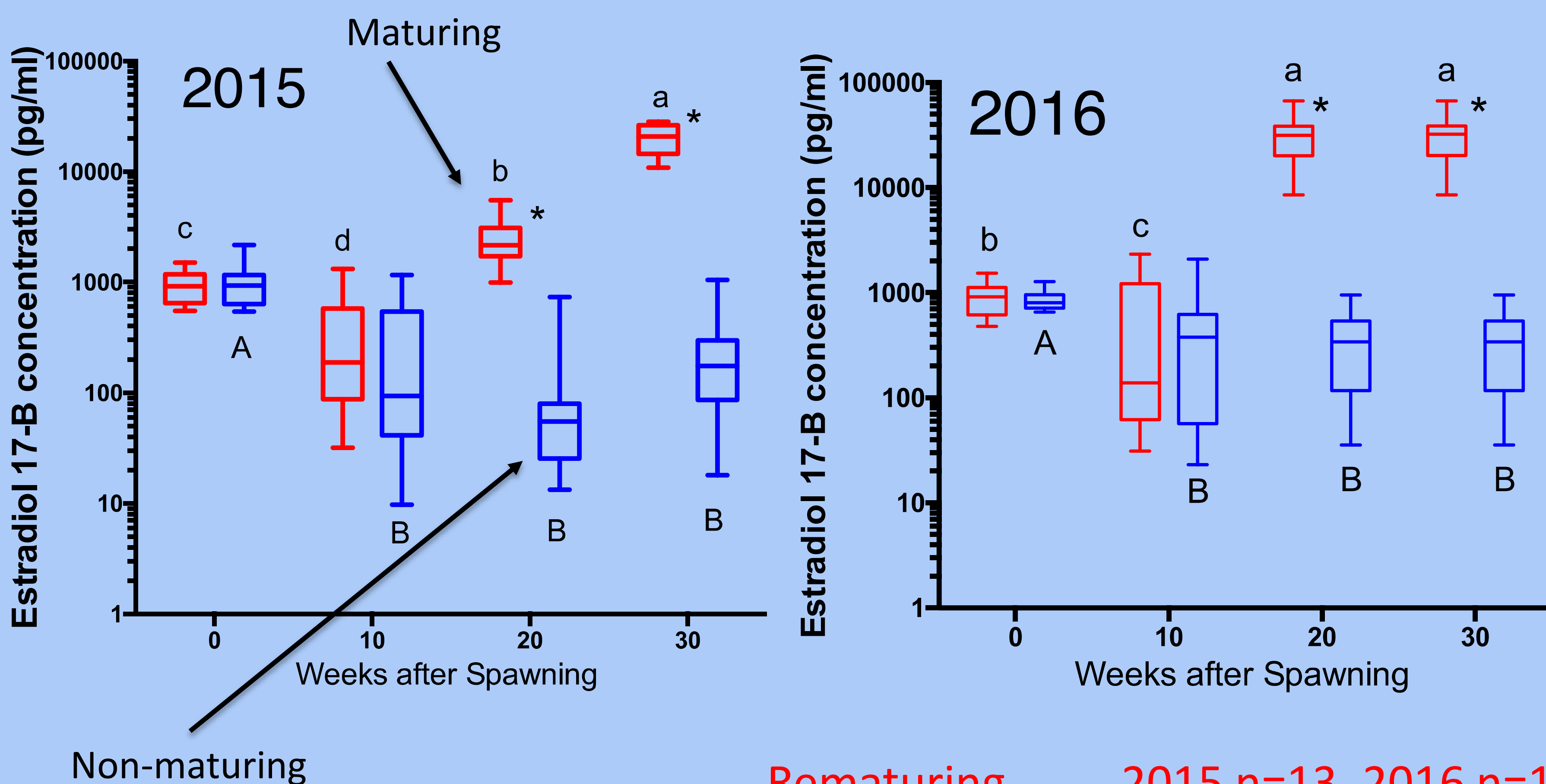
Assigned maturation status at 30 weeks

Spawned repeat spawners 1-2 years later



Results

Trajectory: E2 greater in rematuring fish at 20 weeks after maiden spawning



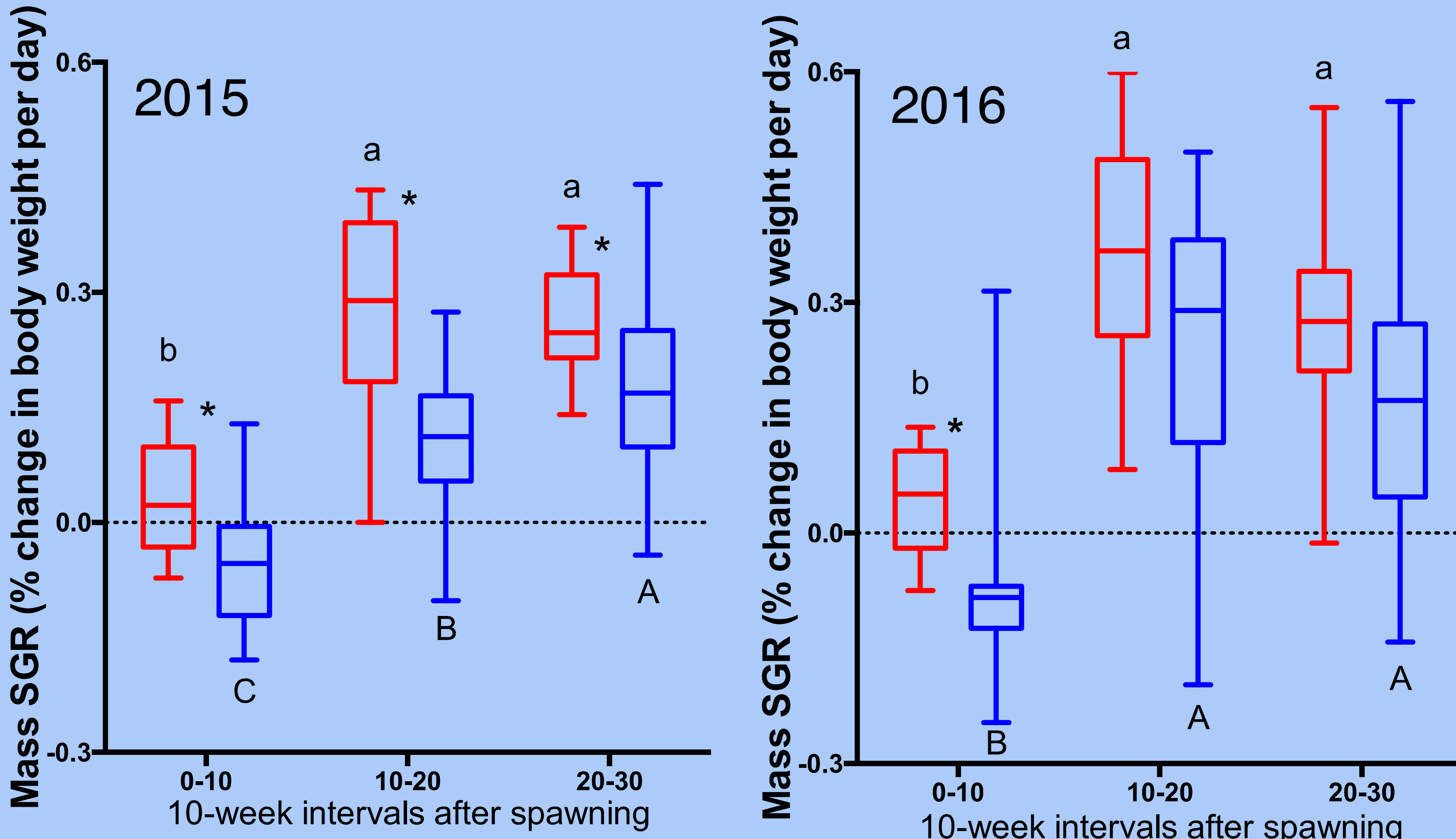
Rematuring 2015 n=13, 2016 n=12

Non-rematuring 2015 n=12, 2016 n=18

Asterisks - differences between rematuring and non-rematuring fish; letters - differences over time.

Jenkins et al., in preparation.

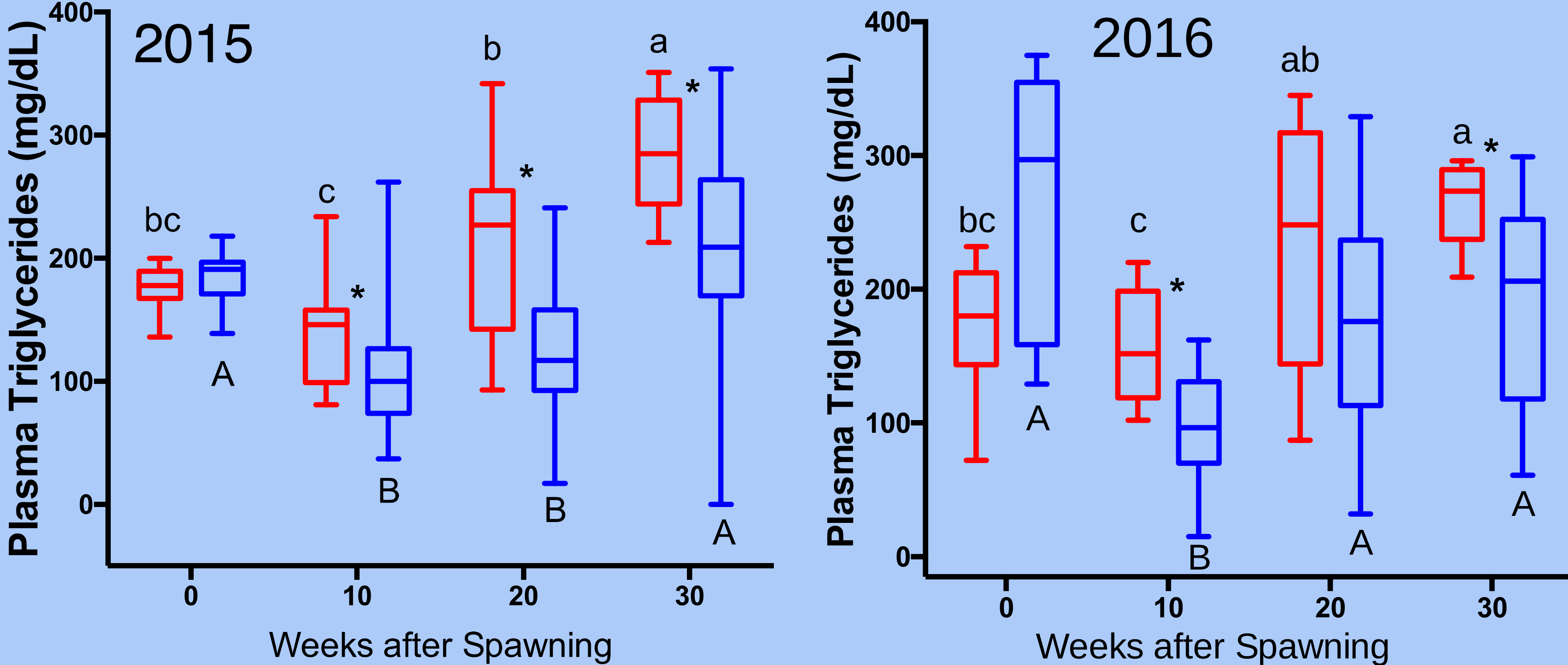
Recovery: Rematuring fish grew more (mass) over first 10 weeks after spawning



Rematuring Non-rematuring

Jenkins et al., in preparation.

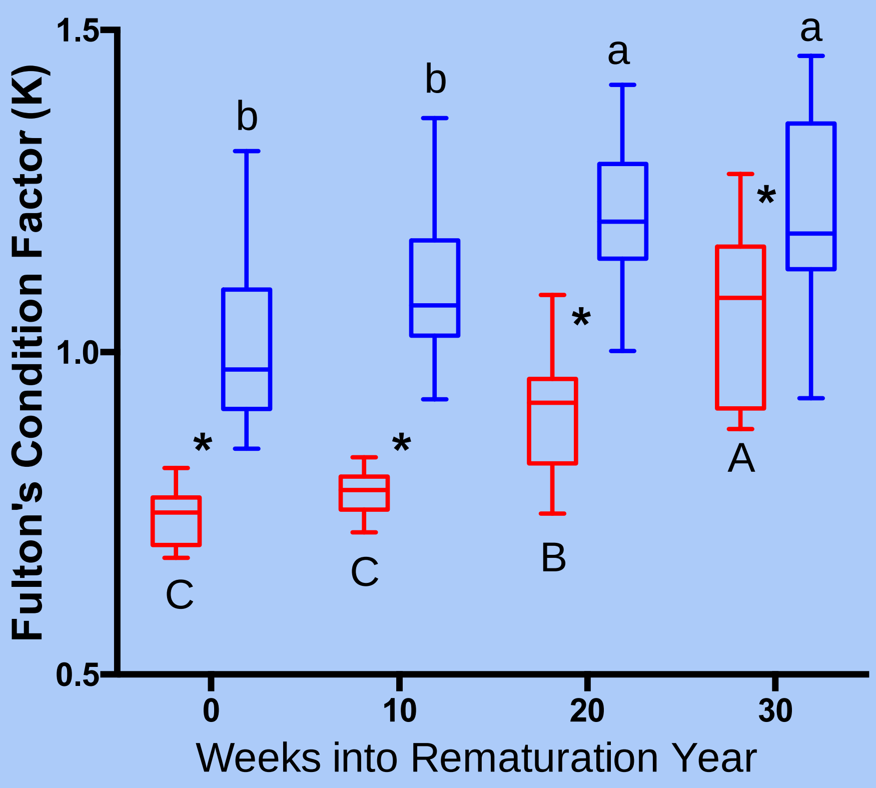
Recovery: Rematuring fish had greater circulating triglycerides at 10 weeks

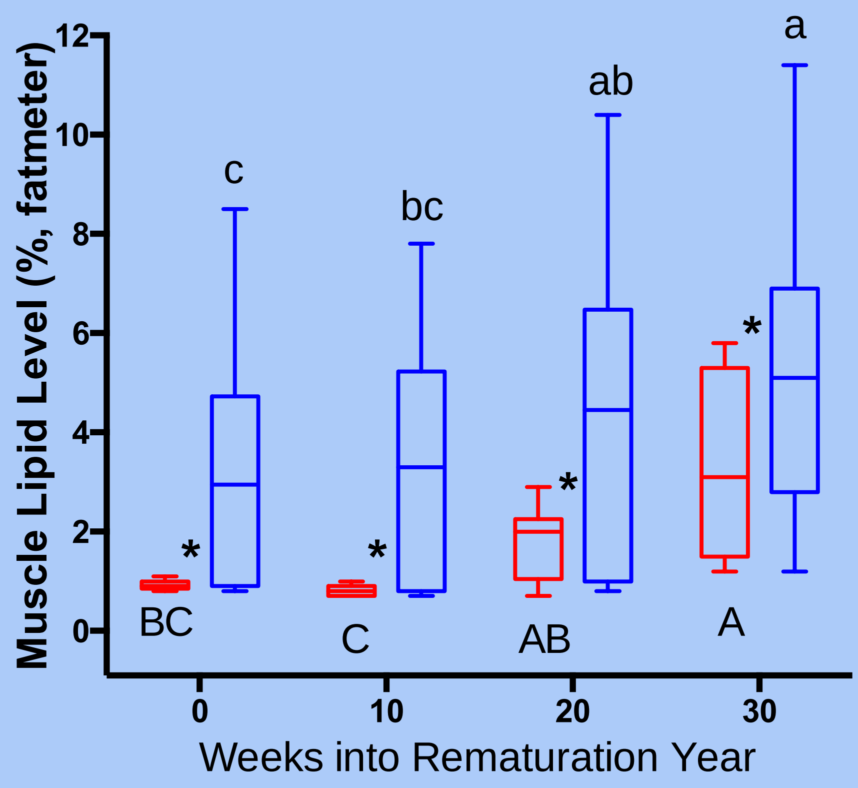


Rematuring Non-rematuring

Jenkins et al., in preparation.

Year prior to repeat spawning: Skip spawners had greater energy reserves



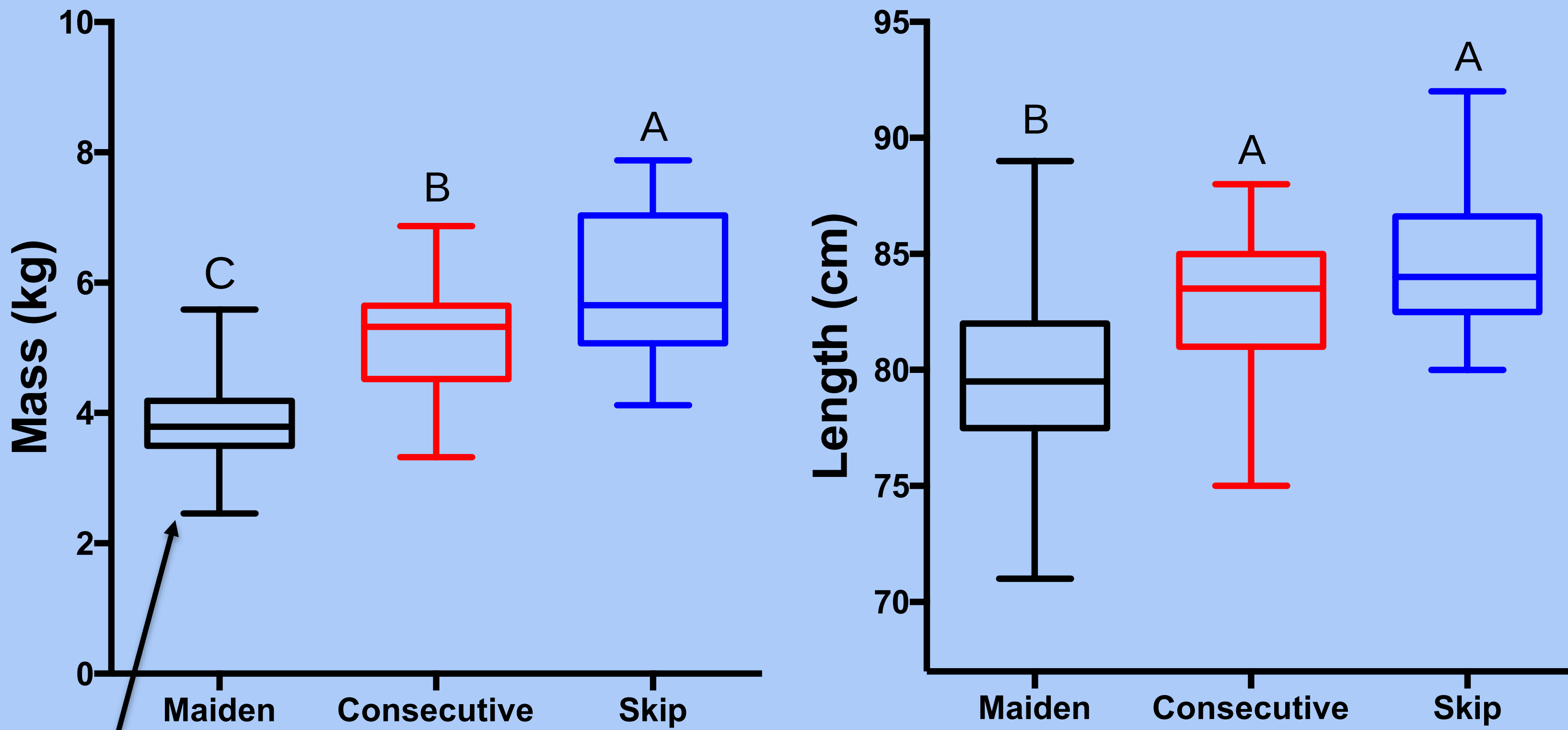


Consecutive 2015 n=13

Skip 2015 n=18

Jenkins et al., in preparation.

Performance: Repeat spawners were larger than maiden spawners



1st time spawners

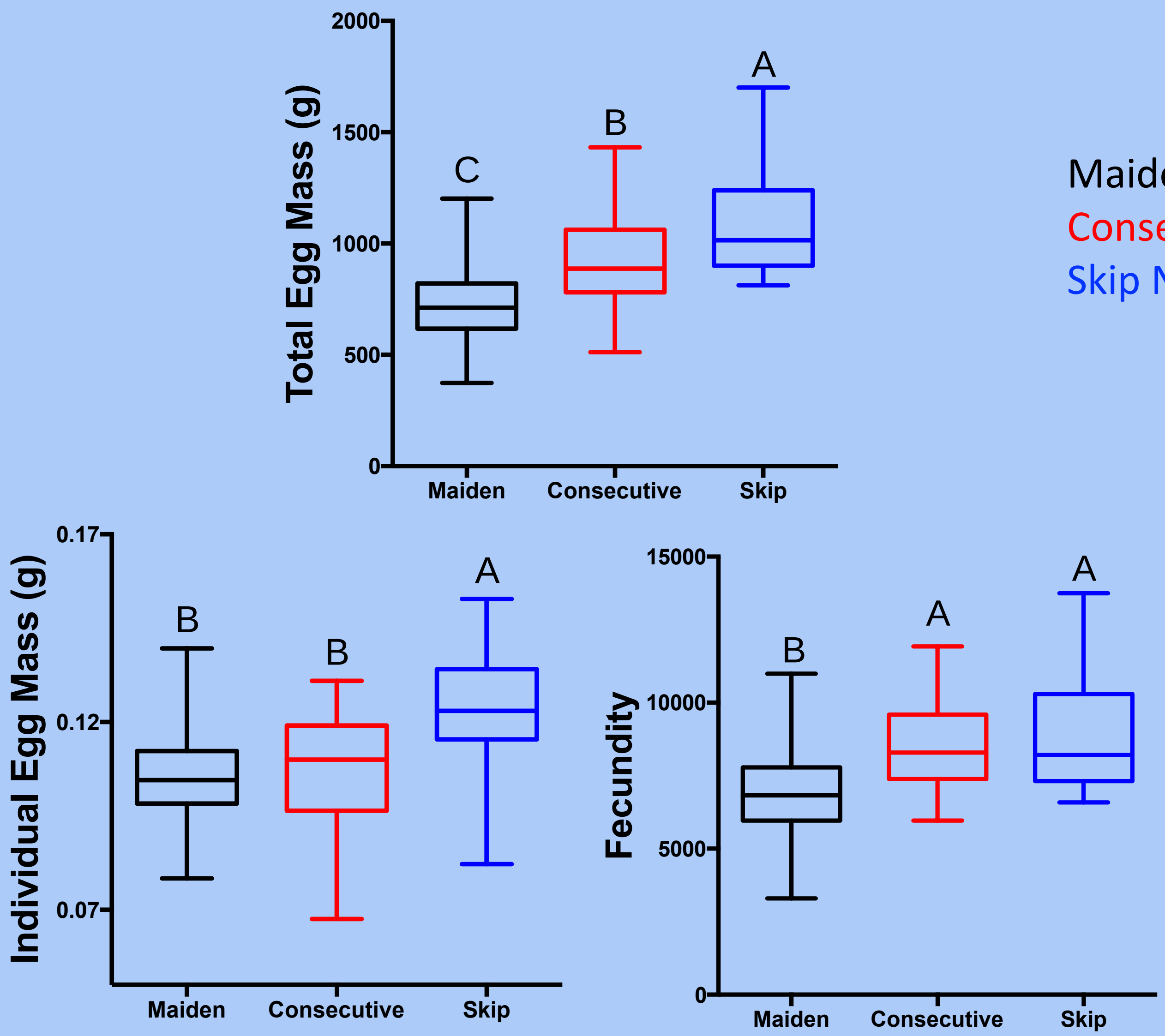
Maiden 2014-2016 N=459

Consecutive 2014-2015 N = 25

Skip 2015-2016 N = 22

Jenkins et al. 2018 TAFS in press

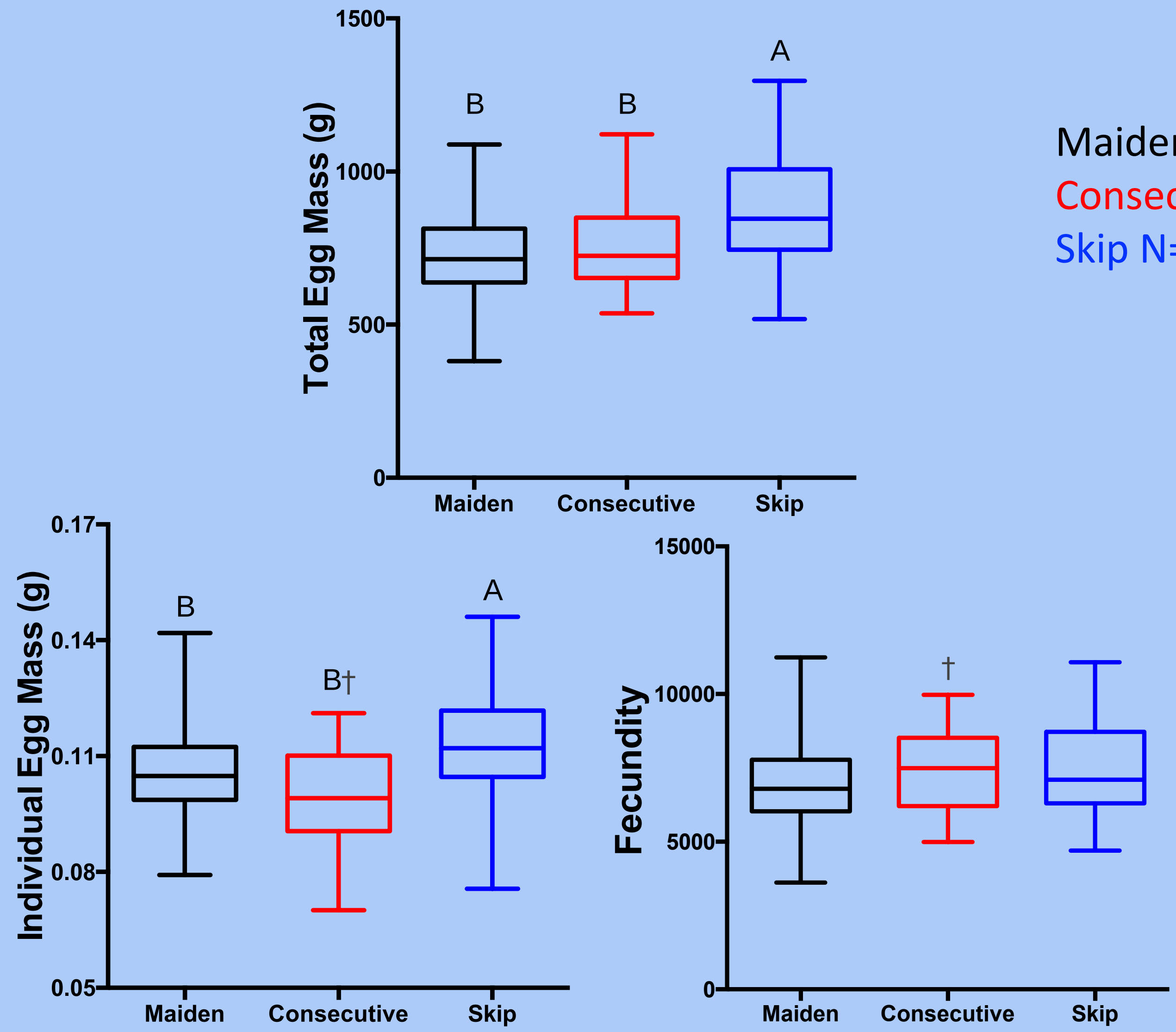
Skip spawners had greatest reproductive performance



Maiden N=459
Consecutive N=22
Skip N=16

Jenkins et al. 2018 TAFS in press

Skip spawners had greatest mass-standardized reproductive performance



Maiden N=459
Consecutive N=22
Skip N=16

Jenkins et al. 2018 TAFS in press

Conclusions

- **1. Trajectories** confirmed at 20 weeks (E2)
- **2a. Recovery:** Consecutives - Greater growth & lipids
  - – Food consumption ↔ Maturation?
- **2b. Rematuration:** Skips – Much greater energy reserves
- **3. Absolute performance:**
  - – Skips: Larger eggs
  - – Repeats: 1.28- and 1.52- fold increase in investment
  - ➢ Reconditioned females released to spawn should be + productive than maidens
- **4. Size standardized performance:**
  - – [Repeats: Larger in size]
  - – Consecutives: More but smaller eggs (vs. maidens)
  - – Skips: Same number, larger eggs, largest investment
  - ➢ Egg number-size tradeoff in energy restricted consecutives
  - ➢ Energy investment into soma in satiation fed kelts

Aesop's Fables

Acknowledgements

Columbia River Inter-Tribal Fish Commission

Andrew Pierce
Neil Graham
Ryan Branstetter
Doug Hatch
Jeremiah Newell
Jayson FiveCrows

University of Idaho

James Nagler
Tim Cavileer
Lea Medeiros
Thomas Tall Bull
Brian Hoffman
Joy Goodwin

Nez Perce Tribe

Scott Everett
Joe Samuels
Noah Jackson

Northwest Fisheries Science Center

Kelly Creek Flycasters Club

Dworshak Fish Hatchery, US Fish & Wildlife Service

Bonneville Power Administration

Thank you! Questions?

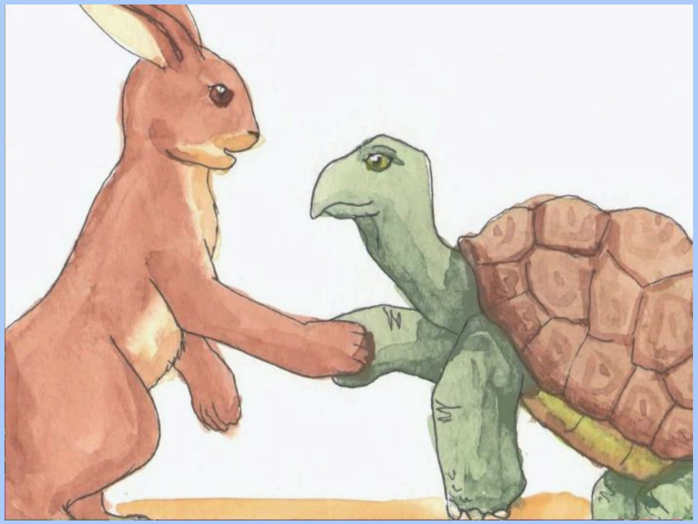
Laura Jenkins
University of Idaho
Biological Science Dept.
ljenkins@uidaho.edu

Implications & Future Work

Skips appear to be the winners, but...

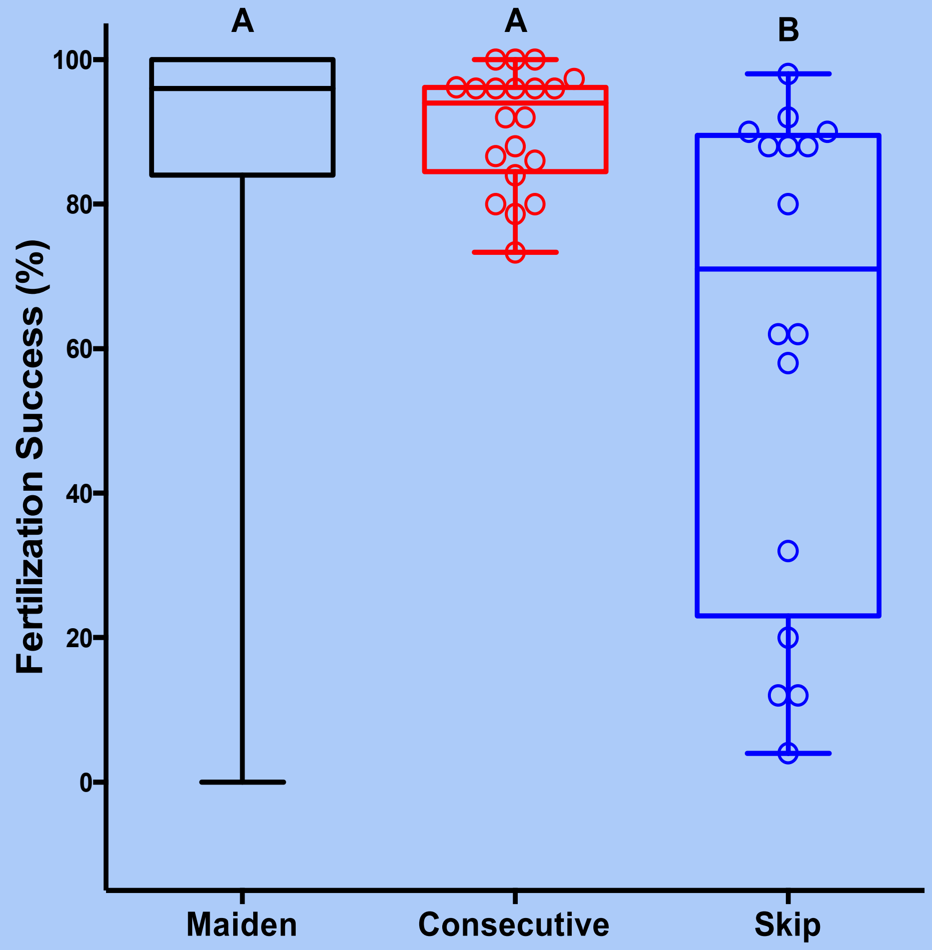
- Definitely costs and benefits to each life history
- In general, life history diversity is beneficial to populations

- Can we predict spawning interval by measuring energy reserves prior to/at maiden spawning?
- Can we influence spawning interval by manipulating energy reserves during recovery?

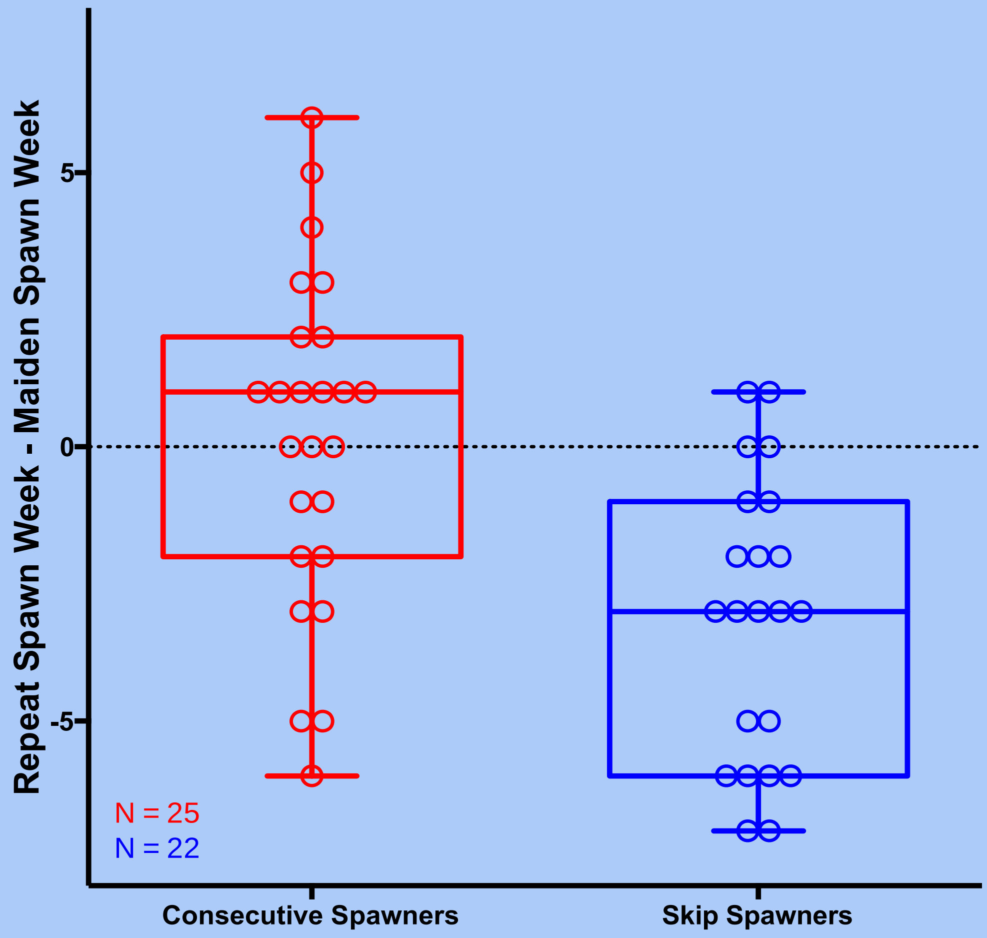


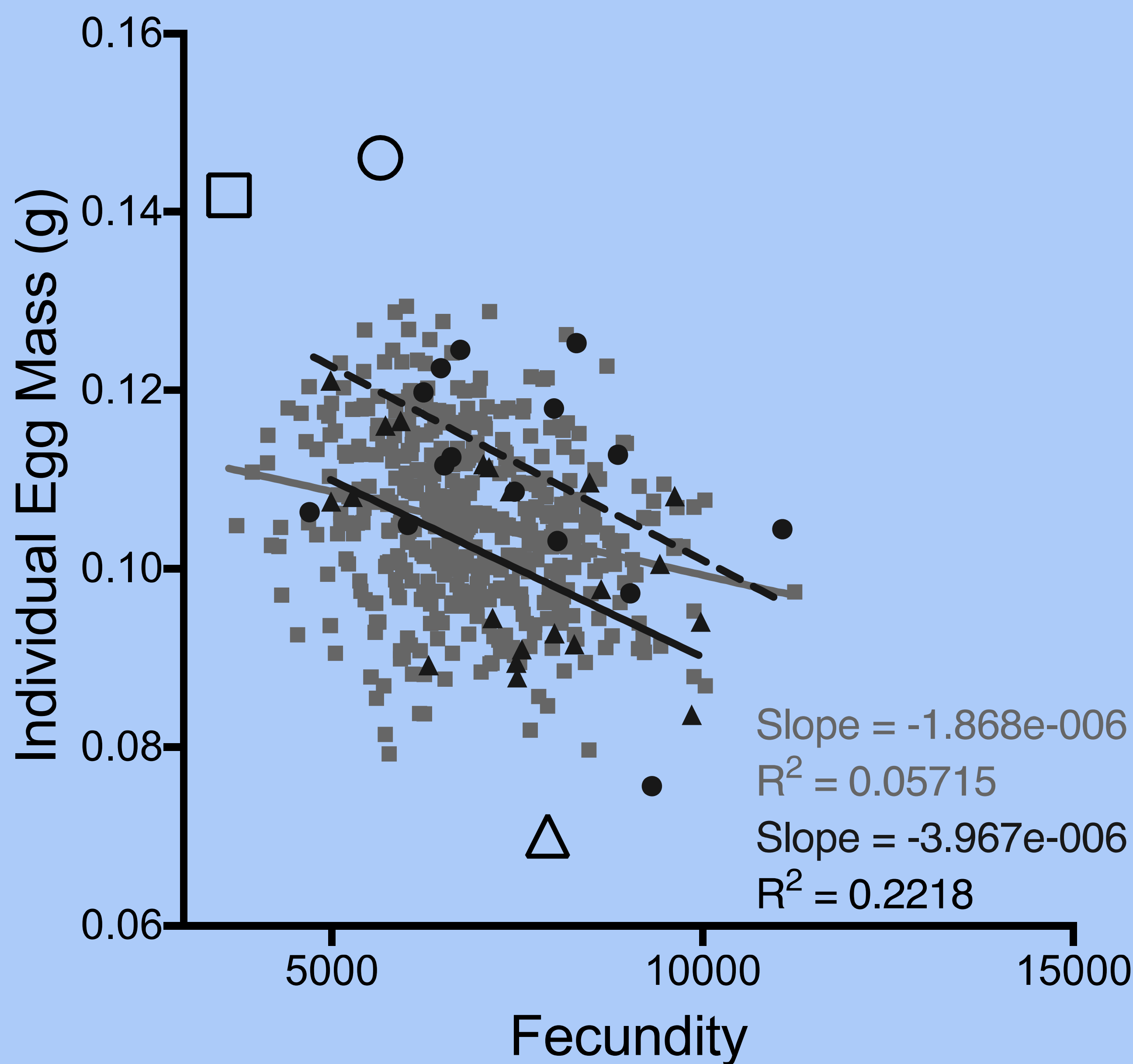
Aesop's Fables

Fertilization success decreased in skip spawners



Skip spawners spawned earlier





0.16
0.14
0.12
0.10
0.08
0.06
5000
10000
15000
Individual Egg Mass (g)
Fecundity
Slope = -1.868e-006
R2 = 0.05715
Slope = -3.967e-006
R2 = 0.2218

Consecutives had less energy during early oogenesis than skips – small but more eggs Stepwise increase in fish size with reproductive iteration and interval Consecutives fed to satiation during rematuration, we see decrease in egg size

- Energy reserves (ER) assessed early appear to impact egg size, not egg number
  - Consecutives assumed to be most energy restricted in early oogenesis
- ER gained later appear to contribute to somatic size, but not egg size
  - Maidens have least/no access to energy during late oogenesis/vitellogenesis

Aesop's Fables

Reproductive Physiology – Life History

How did natural selection give rise to variation in patterns of survival and reproduction?

- Age and size at maturity
- Age- and size- specific reproductive investment
- Growth patterns, reproductive life span
- Tradeoffs, such as between
  - Somatic vs. reproductive effort
  - Number vs. size of offspring
- **Spawning intervals** – what factors drive variation?
- Genetically fixed strategies with multiple tactics
- Adaptations for flexible responses to environment
- Fitness needs of parent vs. offspring

Conclusions

Energy reserves during pre-vitellogenic oogenesis...

- Highly available to maidens (at sea)
- Greater in skips than in maidens during rematuration
- Appear to impact (restrict):
  - Egg size (reduced in consecutives)
  - Not egg number (increased in consecutives, maintained in skips)

Energy reserves during vitellogenic period of oogenesis...

- Restricted in maidens (fasting in river)
- Readily available to repeats (fed to satiation)
- Appear to contribute to:
  - Somatic size (increased in repeats)
  - Not egg size (increased in skips, decreased in consecutives)

Analysis

Time series:

Week 30 mat. status used to assign categories

Transformations: E2 - Log10, Fat - ASIN-SQRT

Calculations: $SGR=100*LN(Mass_2/Mass_1)/days$

$K = W/L^3$

2-way ANOVA - time, treatment, interaction effects

1-way ANOVA with Tukey's HSD

Differences over time within groups

Between groups at each time point

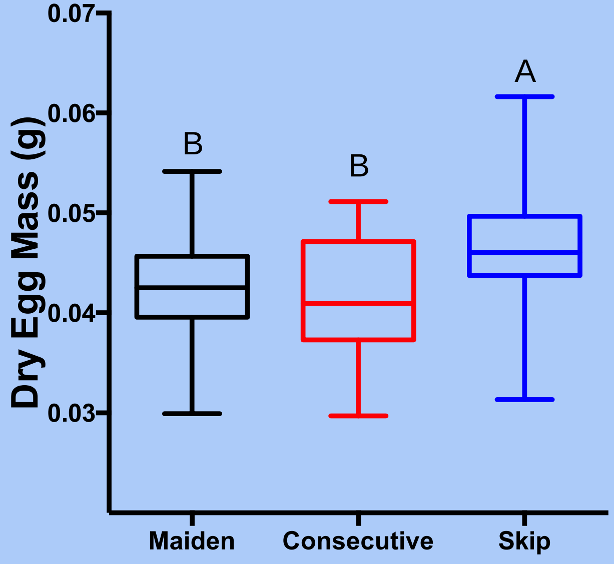
Performance:

GLMs (Bonferroni-adjusted)

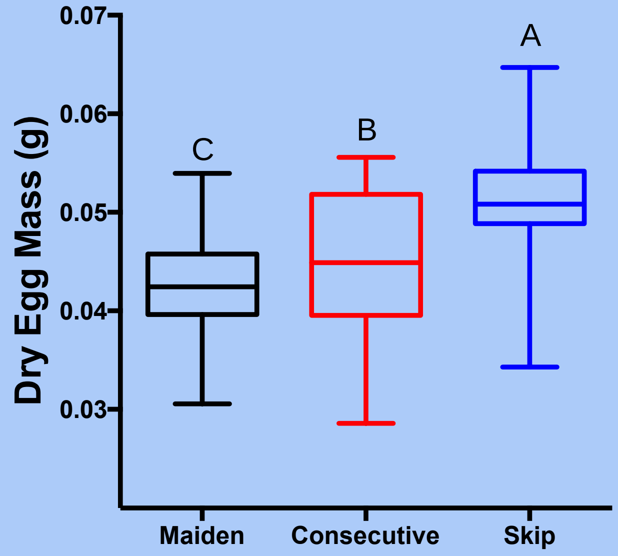
Size-standardization (mass):

standardized value = original value of individual – [(somatic mass of individual – 3.847kg) * slope]

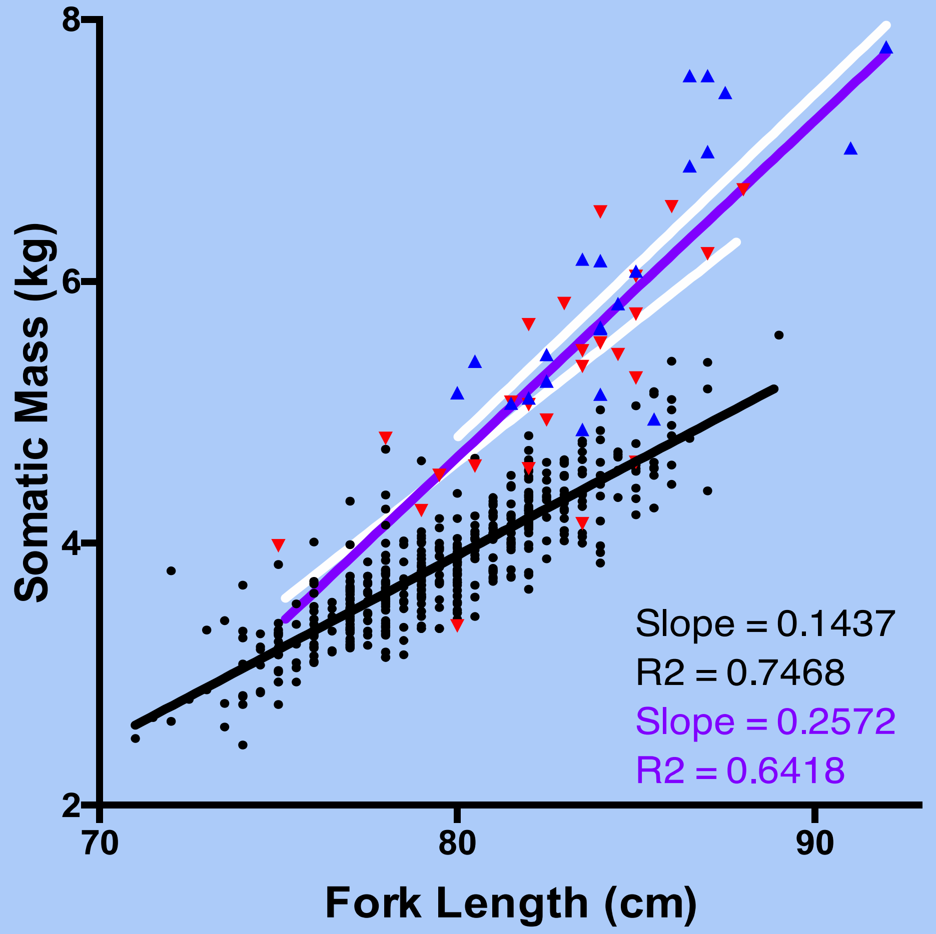
Size-Standardized Dry Egg Mass



Absolute Dry Egg Mass



Repeat spawners had greater mass per length than maiden spawners

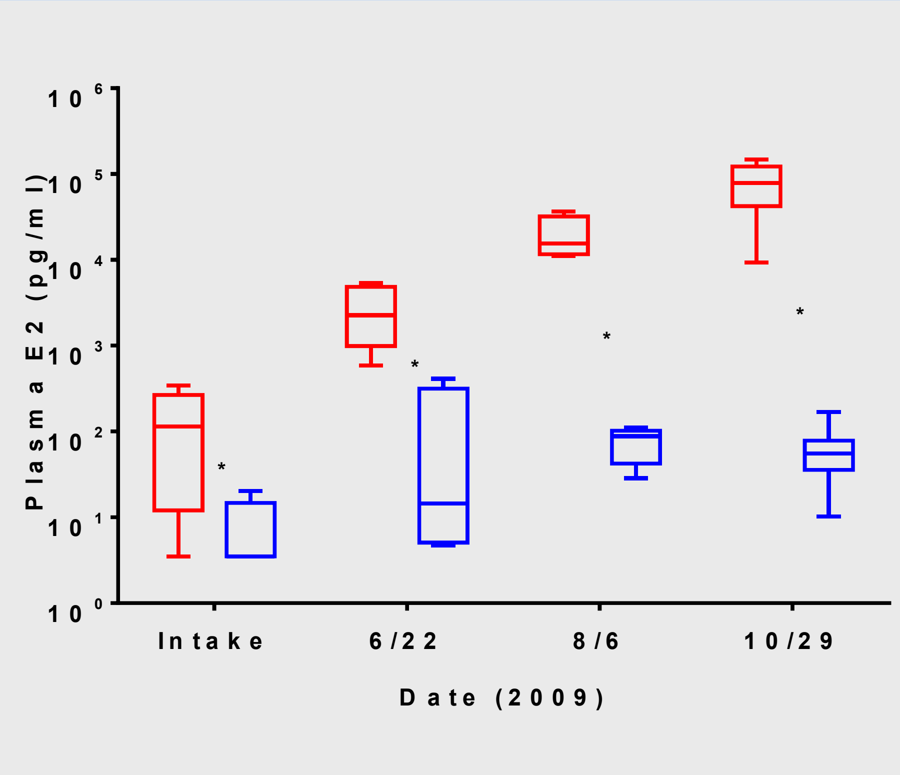


Iconic Idaho Steelhead

- Summer steelhead - enter river late summer, fast ~7-9 months
- ~800km inland, - subject to:
  - recreational fisheries & commercial bi-catch
  - Changing river conditions – dams, water temperatures
- Of conservation concern – ESA-listed population, B-run assignment
- North fork population spawning habitat cut off by Dworshak Dam in 1969, Dworshak Hatchery mitigates for that loss

Estradiol-17B as rematuration indicator

Plasma E2
(log scale)



- Reconditioned wild kelts from Yakima R. have consecutive rematuring & skip (non-rematuring) repeat spawners
- Can be determined using **plasma E2** ~9 months prior to spawn