# Diet Manipulation Reduces Early Maturation in Umatilla River Fall Chinook

Lance R. Clarke

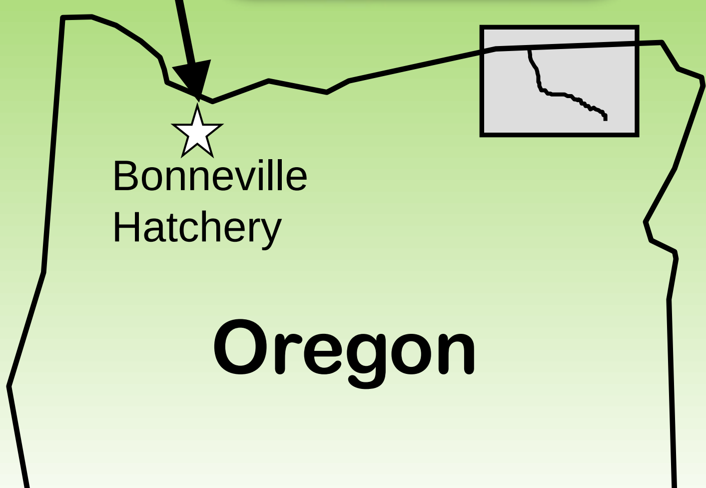
Coauthors: Don Larsen, William Cameron, Robert Hogg, Brett Requa, Brian Beckman, Deborah Harstad, Dina Spangenberg

ODFW and NOAA Fisheries

Funded by

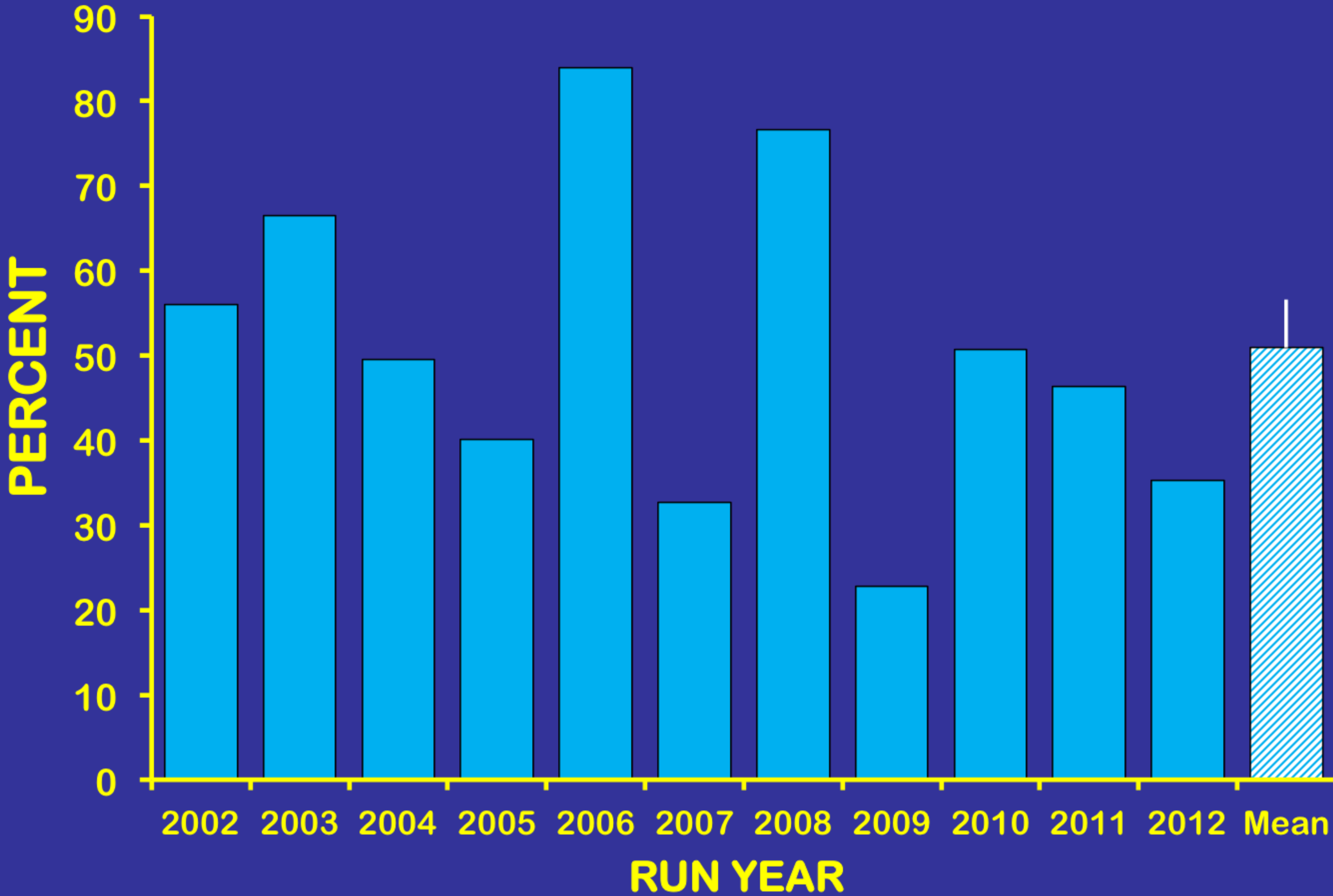
# Presentation Outline

- Background on Umatilla minijack problem
- Study design – ODFW
- Physiology of early male maturation and results – NOAA
- Post-release results – ODFW

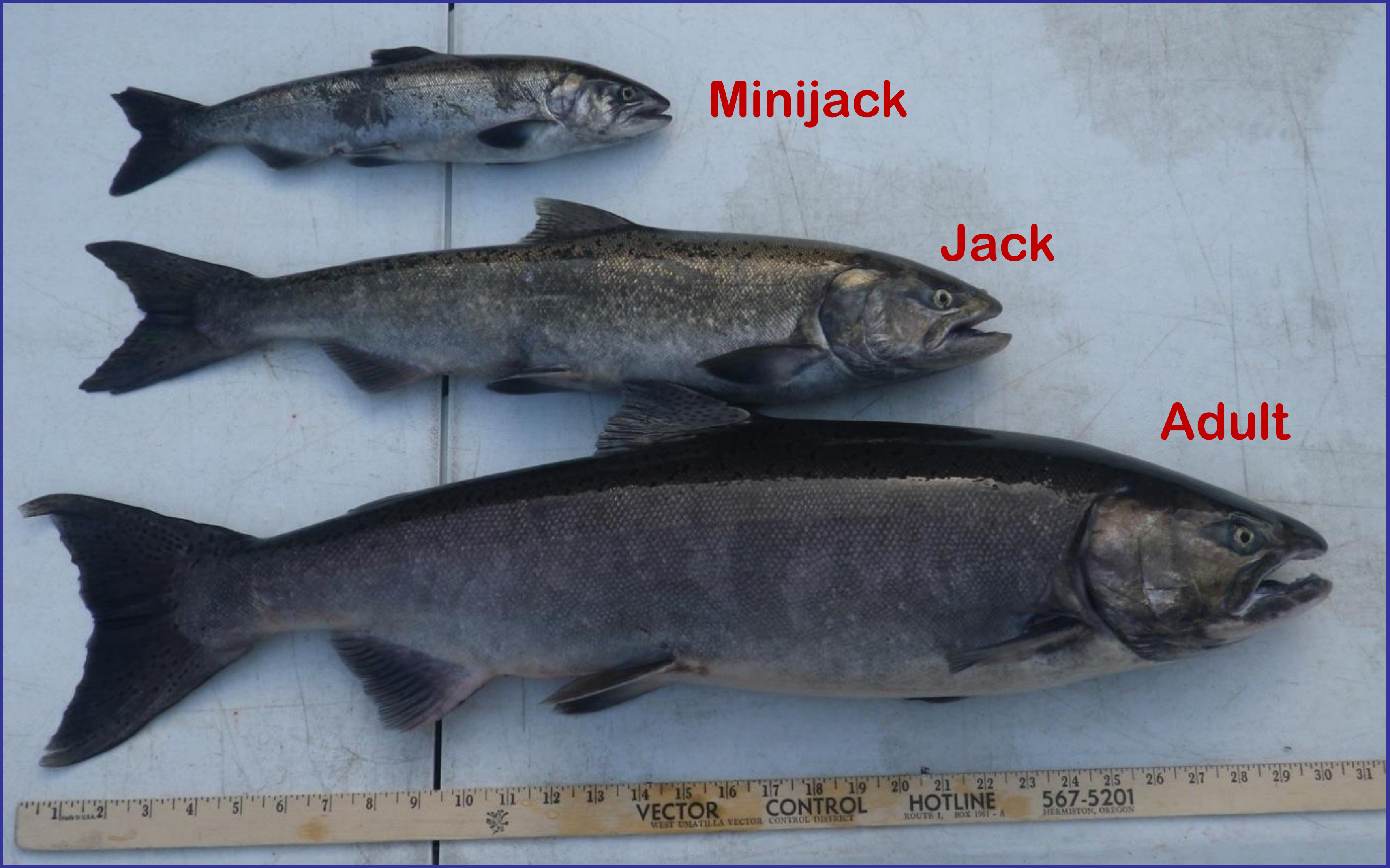




- **UBR stock**
- **Reared at Bonneville Hatchery followed by a 1 month acclimation**
- **900,000 yearling smolts released**

# Percentage of Male Returns that are Minijacks



# Umatilla Fall Chinook Returns



# Literature Review

*Transactions of the American Fisheries Society* 135:1017–1032, 2006

DOI: 10.1577/T05-200.1

[Article]

## Growth Modulation Alters the Incidence of Early Male Maturation and Physiological Development of Hatchery-Reared Spring Chinook Salmon: A Comparison with Wild Fish

DONALD A. LARSEN* AND BRIAN R. BECKMAN
*NOAA Fisheries, Northwest Fisheries Science Center, Integrative Fish Biology Program, 2725 Montlake Boulevard East, Seattle, Washington 98112, USA*

CHARLES R. STROM
*Yakama Nation, Cle Elum Supplementation and Research Facility, 800 Spring Chinook Way, Cle Elum, Washington 98922, USA*

PAUL J. PARKINS AND KATHLEEN A. COOPER
*School of Aquatic and Fisheries Science, University of Washington, Seattle, Washington 98195, USA*

DAVID E. FAST
*Yakama Nation, Nelson Springs Research Center, 771 Pence Road, Yakima, Washington 98902, USA*

WALTON W. DICKHOFF
*NOAA Fisheries, Northwest Fisheries Science Center, Integrative Fish Biology Program, 2725 Montlake Boulevard East, Seattle, Washington 98112, USA; and School of Aquatic and Fisheries Science, University of Washington, Seattle, Washington 98195, USA*

*Abstract.*—Previous studies conducted at the Cle Elum Spring Chinook Salmon Supplementation Hatchery in Washington State demonstrated that 37–49% of the male Chinook salmon *Oncorhynchus tshawytscha* released from this facility in its first years of operation precociously matured at age 2 rather than the more typical age 4. We examined the effects of altering seasonal growth rate on the incidence of age-2 male maturation in an experimental subset of that population and compared their physiological development (size, growth rate, condition factor, whole-body lipid, gill $Na^+,K^+$-ATPase activity, and plasma insulin-like growth factor-I [IGF-I]) with that of both hatchery (production) and wild fish. Altering summer and autumn rations resulted in four growth trajectories with the following size and precocious male maturation rates: the high summer–high autumn growth trajectory produced fish averaging 25 g and 69% precocious maturation; the high summer–low autumn trajectory yielded fish that averaged 18 g and exhibited 58% precocious maturation; the low summer–high autumn trajectory produced 18-g fish with 51% precocious maturation; and the low summer–low autumn trajectory yielded fish averaging 16 g and 42% precocious maturation. Production fish averaged 22 g and exhibited a 53% precocious maturation rate. The high summer growth treatments and production fish were largest among all groups and had higher plasma IGF-I, adiposity levels, and precocious male maturation rates than did the low summer growth treatments. Wild fish were significantly smaller and leaner and had much lower plasma IGF-I levels than all other groups. Gill $Na^+,K^+$-ATPase activity was not different between groups, suggesting that there was no differential effect on smoltification. Growth modulation reduced the precocious male maturation rate by 39% among experimental treatments and by 21% between production fish and the low–low treatment. However, the maturation rate and adiposity of hatchery fish differed markedly from those of wild fish, suggesting that more dramatic alterations of rearing regime may be required to further reduce the prevalence of this phenotype in cultured fish.

The age of maturation in male spring Chinook salmon *Oncorhynchus tshawytscha* is highly plastic, occurring 1–6 years after fertilization (Healey 1991). The incidence of precocious male maturation (age 1 or 2) in wild spring Chinook salmon is poorly characterized but reportedly constitutes less than 5% of males (Gebhards 1960; Mullan et al. 1992). In contrast, the proportion of males maturing at age 2 in some hatchery and laboratory populations of spring Chinook salmon ranges from 11% to 93% (Foote et al. 1991; Mullan et al. 1992; Clarke and Blackburn 1994; Shearer and Swanson 2000; Shearer et al. 2006). Thus, the hatchery environment may increase the incidence of this life history phenotype beyond natural levels.

* Corresponding author: don.larsen@noaa.gov

Received August 2, 2005; accepted February 15, 2006
Published online July 20, 2006



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Available online at www.sciencedirect.com
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Aquaculture 252 (2006) 545–556
Aquaculture
www.elsevier.com/locate/aqua-online

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## Effects of growth rate/body size and a low lipid diet on the incidence of early sexual maturation in juvenile male spring Chinook salmon (*Oncorhynchus tshawytscha*)

Karl Shearer [a,*], Paul Parkins [b], Brad Gadberry [a], Brian Beckman [a], Penny Swanson [a,c]

[a] *Integrative Fish Biology Program, Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, United States*
[b] *School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195, United States*
[c] *Center of Reproductive Biology, Washington State University, Pullman, WA 98164, United States*

Received 7 April 2005; received in revised form 28 June 2005; accepted 28 June 2005

**Abstract**

Two experiments were conducted sequentially to examine the roles of growth rate (size) and body fat on the incidence of early sexual maturation in male spring Chinook salmon (*Onchorynchus tshawytcha*). In both experiments two replicate groups of fish for each treatment were reared on experimental diets for 17 months after first feeding (February). Fish were sampled approximately monthly to monitor growth and determine whole body lipid level, gender and the state of sexual maturation. In the first experiment fish were pair-fed either a low (7%) lipid diet at one of six ration levels (satiation, or 88%, 76%, 64%, 52%, 40% of satiation) or a commercial feed (22% lipid) at the 64% level. The incidence of 1+ age male maturation in July ranged from 66.2% to 92.8% in fish with mean body weights ranging from 51 to 110 g during the previous December, which is within the period of initiation of maturation. Maturation rates in fish fed the low lipid experimental feed and the higher lipid commercial feed at the same ration level (64%) were similar suggesting that dietary (body) lipid level had no effect on maturation in relatively fast growing juvenile Chinook salmon. In the second experiment, fish were fed a commercial feed (22% lipid) using a regimen designed to produce fish of 10, 15, 20, 25, 30, and 110 g in December. The incidence of 1+ age male maturation the following July ranged from 12% to 51.0% for fish that had mean body weights ranging from 10 to 108 g in December. The relationship between December fish weight and maturation in both experiments was modeled with a quadratic equation. A mean threshold body size for initiation of maturation of 7.9 g was obtained for this stock of Chinook salmon by meta-analysis using data from both experiments and from a previous experiment conducted at the same facility under similar rearing conditions. The results of this study support previous conclusions that growth rate or size is the major factor influencing onset of puberty in males. Development of rearing strategies that produce healthy small nonmaturing 1+ age male Chinook salmon will require a better understanding of the relative contributions and interactions of multiple factors on the bioenergetics of this species.
Published by Elsevier B.V.

*Keywords:* Chinook salmon; *Oncorhynchus tshawytscha*; Precocious male sexual maturation; Growth; Reproduction; Puberty

* Corresponding author. Tel.: +1 206 860 3293; fax: +1 206 860 3467.
*E-mail address:* karl.d.shearer@noaa.gov (K. Shearer).

0044-8486/$ - see front matter. Published by Elsevier B.V.
doi:10.1016/j.aquaculture.2005.06.027

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*Transactions of the American Fisheries Society* 139:564–578, 2010

DOI: 10.1577/T08-209.1

[Article]

## Examining the Conflict between Smolting and Precocious Male Maturation in Spring (Stream-Type) Chinook Salmon

DONALD A. LARSEN* AND BRIAN R. BECKMAN
*National Oceanic and Atmospheric Administration–Fisheries, Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, Washington 98112, USA*

KATHLEEN A. COOPER
*School of Aquatic and Fisheries Science, University of Washington, Seattle, Washington 98195, USA*

*Abstract.*—Precocious male maturation is a natural life history strategy for spring Chinook salmon *Oncorhynchus tshawytscha*. During spawning, precocious males employ a "sneaker" strategy to fertilize eggs in competition with full-size anadromous adults. Hatchery rearing practices may increase the incidence of this phenotype beyond its natural levels. Previous research reported high rates (>40%) of precocious male maturation at age 2 (minijacks) in the Yakima River spring Chinook salmon supplementation program in Washington State. Minijack rates in wild populations are believed to be less than 5%. We compiled seasonal profiles for size, condition factor (*K*), gill $Na^+,K^+$-ATPase activity, whole-body lipid levels, plasma 11-ketotestosterone (11-KT), insulin-like growth factor-I (IGF-I), and thyroxine (T4) in minijacks and immature smolts in the hatchery and during out-migration. In the hatchery, minijacks were larger and had higher *K*, whole-body lipid, plasma 11-KT, and IGF-I levels than smolts. Plasma T4 and gill $Na^+,K^+$-ATPase activity increased in minijacks in spring, but the levels were slightly lower than those of smolts. Most minijacks are thought to remain resident in headwater streams throughout the summer in preparation for autumn spawning. A subset of these minijacks migrate hundreds of kilometers toward the ocean in the spring, only to reverse course later in the summer in an effort to return to their natal spawning grounds. These migrating minijacks had elevated plasma 11-KT, IGF-I, and T4 levels and gill $Na^+,K^+$-ATPase activity. It is generally thought that smoltification and reproductive maturation are mutually exclusive life history events in salmonid fishes. This investigation examined the physiology of a unique phenotype in which smoltification and downstream migration appear to occur in fish that have already initiated the maturation process. These results suggest that hatchery programs with high minijack rates may produce significant numbers of fish that are maladapted for either smoltification or competing on the spawning grounds, and it is likely that they die in the freshwater environment before contributing to subsequent generations.

Smoltification and reproductive maturation are two major developmental events in the life of anadromous salmonid fishes. Smolting is characterized by a suite of physiological, morphological and behavioral changes that prepare the freshwater dwelling parr for life as a seawater-adapted smolt (see Hoar 1988 for review). Physiological changes include increased activity of the thyroid, interrenal, and growth endocrine axes, and elevations in metabolism, lipolysis, and gill $Na^+,K^+$-ATPase (enzyme number 3.6.1.36; IUBMB 1992) activity. Morphological changes include decreased condition factor (*K*), increased body silvering, and darkening of the fin margins. Behavioral changes include schooling and downstream migration. By contrast, reproductive maturation involves gonad growth and maturation (see Nagahama 1983 for review), movement into freshwater, upstream migration, development of secondary sexual characteristics (nuptial coloration and changes in body morphology), courtship, and nest guarding (see Groot and Margolis 1991; Quinn 2005).

In Columbia River spring (or stream-type) Chinook salmon *Oncorhynchus tshawytscha*, male maturation can occur at ages 1 (precocious parr), 2 (minijacks), 3 (jacks), 4, or 5 years postfertilization, the age being influenced by both genetic (Silverstein and Hershberger 1992; Hankin et al. 1993; Heath et al. 1994; Unwin et al. 1999) and environmental factors, including body size, growth rate, and body lipid level (Silverstein et al. 1997, 1998; Shearer and Swanson 2000; Campbell et al. 2003; Larsen et al. 2004a, 2006; Shearer et al. 2006). Several studies in spring Chinook salmon have demonstrated that the male maturation process for any given age-class is physiologically initiated approximately 1 year prior to spermiation in autumn (Silverstein et al. 1997, 1998; Shearer and Swanson 2000; Campbell et al. 2003; Larsen et al. 2004a, 2006; Shearer et al. 2006).

* Corresponding author: don.larsen@noaa.gov

Received October 29, 2008; accepted October 1, 2009
Published online January 18, 2010



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"*In conclusion, this investigation has demonstrated the efficacy of ration manipulation at specific times of the year to modulate growth and the rate of yearling precocious male maturation without adversely impacting smolt development in spring Chinook salmon.*" – Larsen et al. 2006

# What Factors Affect Age of Male Maturation?

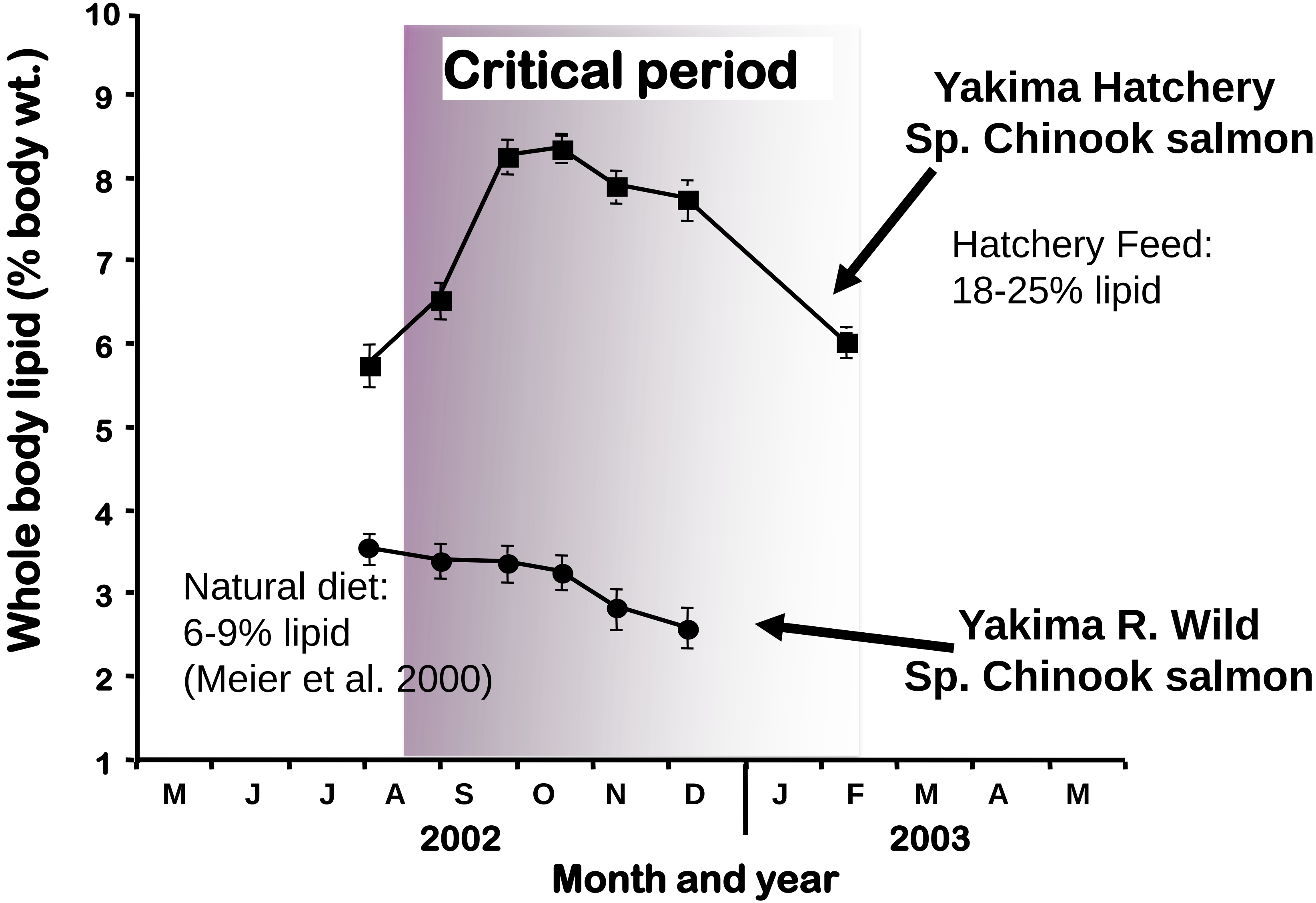
Mature male salmon

- ✓ Genetics
- ✓ Environment
  - temperature
  - food availability
  - food quality
  - emergence timing

Growth & Body energy stores

D. Larsen, NOAA Fisheries

# Fish reared in hatcheries are much fatter than "wild" naturally reared fish




Larsen et al. 2006

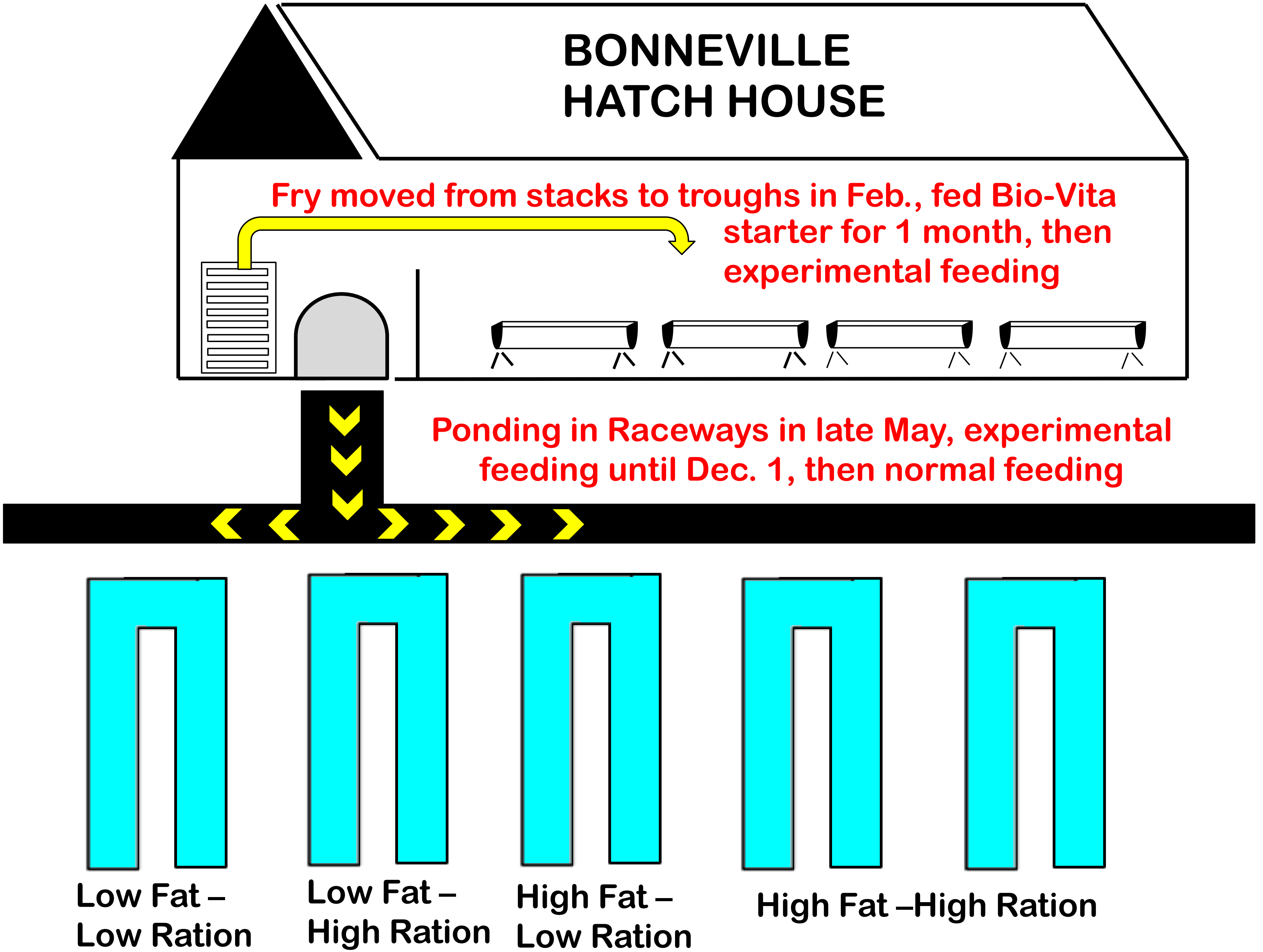
# Experimental Design

## Two x Two Factorial, 4 replicate years

### DIET TYPE

| FEEDING RATE | Bio-Clark's 18% Fat | Rangen's 12% Fat |
|---|---|---|
| 7 x week | • 96,000 fish, 100% CWT<br>• ~ 2,000 PIT tags<br>• Control Group, normal feeding | • 48,000 fish, 100% CWT<br>• ~ 1,500 PIT tags<br>• Experimental diet from April-November |
| 4 x week | • 48,000 fish , 100% CWT<br>• ~ 1,500 PIT tags<br>• Reduced ration from April-November | • 48,000 fish, 100% CWT<br>• ~1,500 PIT tags<br>• Experimental diet from April-November |

**ALL FISH ARE ON STANDARD HIGH-HIGH FEEDING STARTING DEC. 1


BONNEVILLE
HATCH HOUSE
Fry moved from stacks to troughs in Feb., fed Bio-Vita starter for 1 month, then experimental feeding
Ponding in Raceways in late May, experimental feeding until Dec. 1, then normal feeding
Low Fat – Low Ration
Low Fat – High Ration
High Fat – Low Ration
High Fat –High Ration

# Experiment Objectives

1. Determine portion of male fall Chinook undergoing early maturation.

2. Assess physiological status during rearing to determine how growth rates and lipid levels affect minijack rates.

3. Assess effect of diet and ration level on post-release performance.

# Metrics Evaluated

## Juveniles

1. Growth
2. % Solids (lipids)
3. Food conversion efficiency
4. Mortality rates
5. Cost efficiency
6. Smolting profiles
7. Size at release
8. Outmigration timing
9. Outmigration survival

## Adults

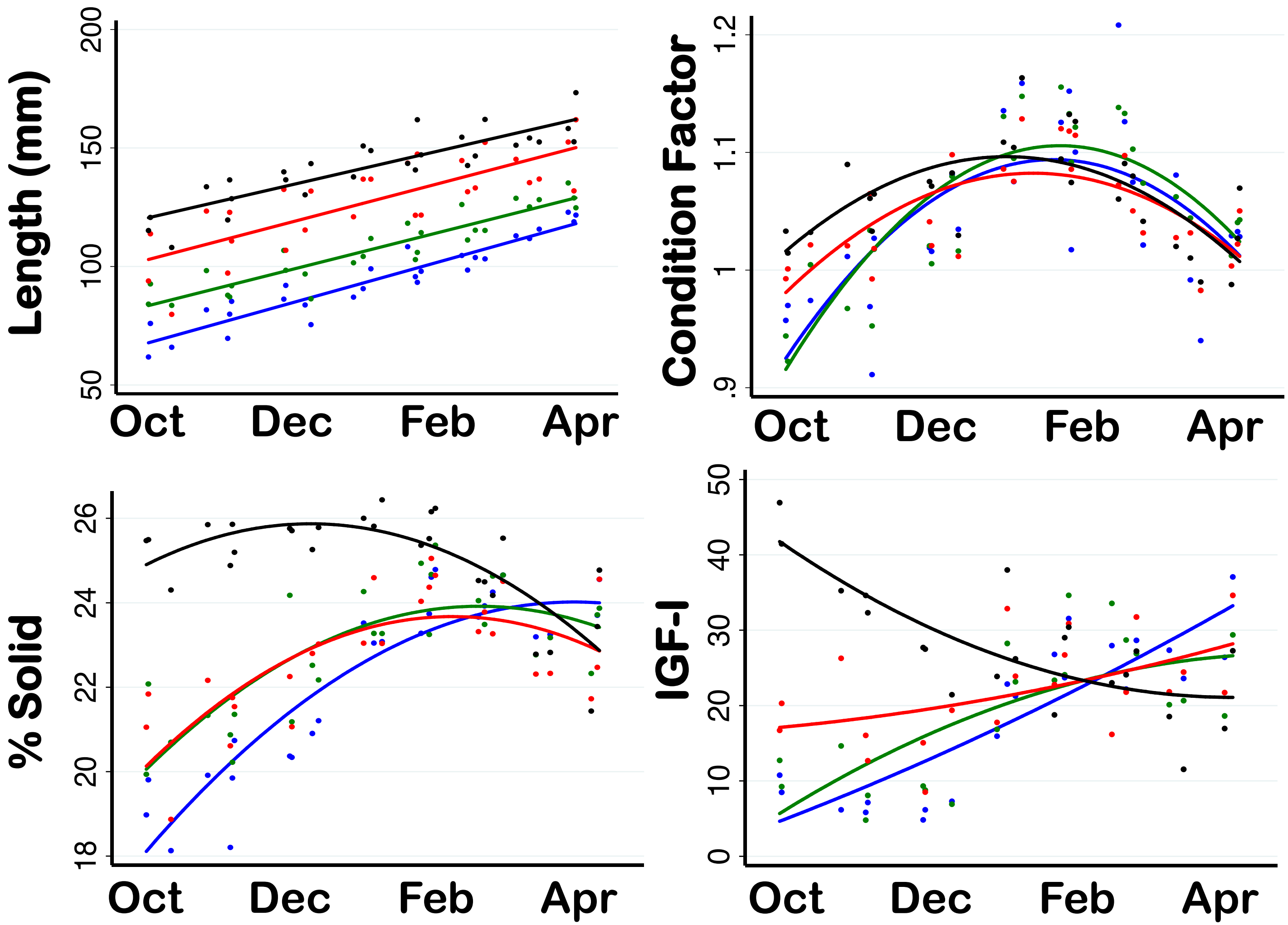
1. Timing of adult returns
2. Number of adult returns
3. Age at Return
4. Size at age
5. Straying
6. Harvest

# Don Larsen, NOAA Fisheries

## Smolt Physiology and Development

# Results

# Growth/Energy Status




High Fat, High Ration | Low Fat, High Ration | High Fat, Low Ration | Low Fat, Low Ration

1. Size difference established prior to October

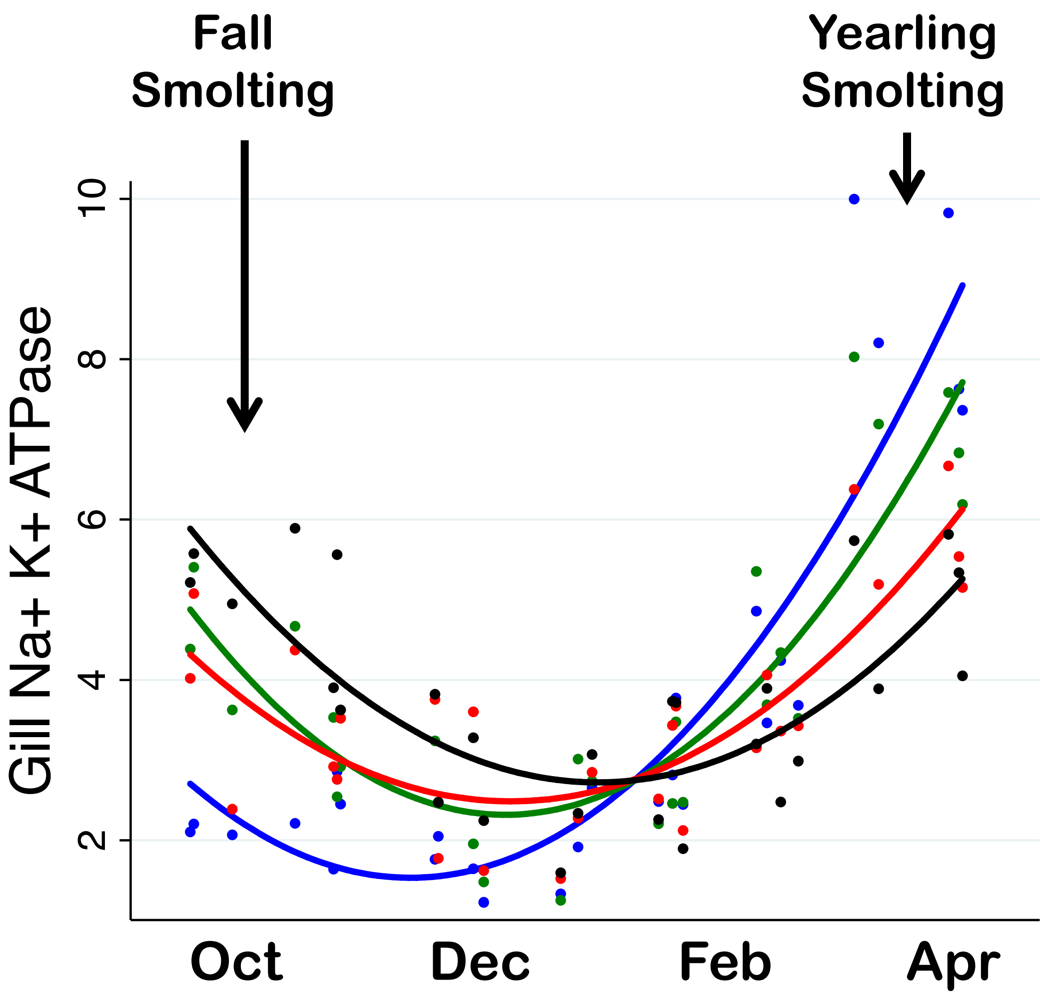
2. **High Ration** have highest Condition Factors in Fall

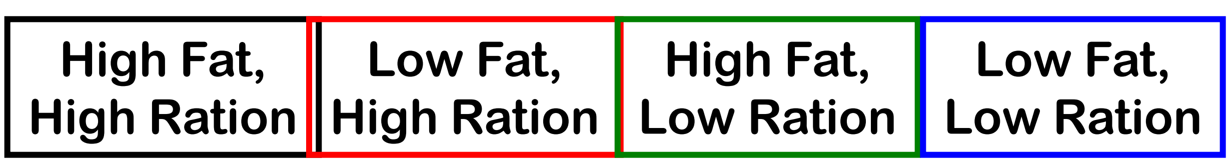
3. **High-High** fish have much greater energy stores (%Solid) in Fall

4. And **High-High** much higher Growth Factor levels.

REMINDER: ALL FISH ARE ON STANDARD HIGH-HIGH FEEDING STARTING DEC. 1

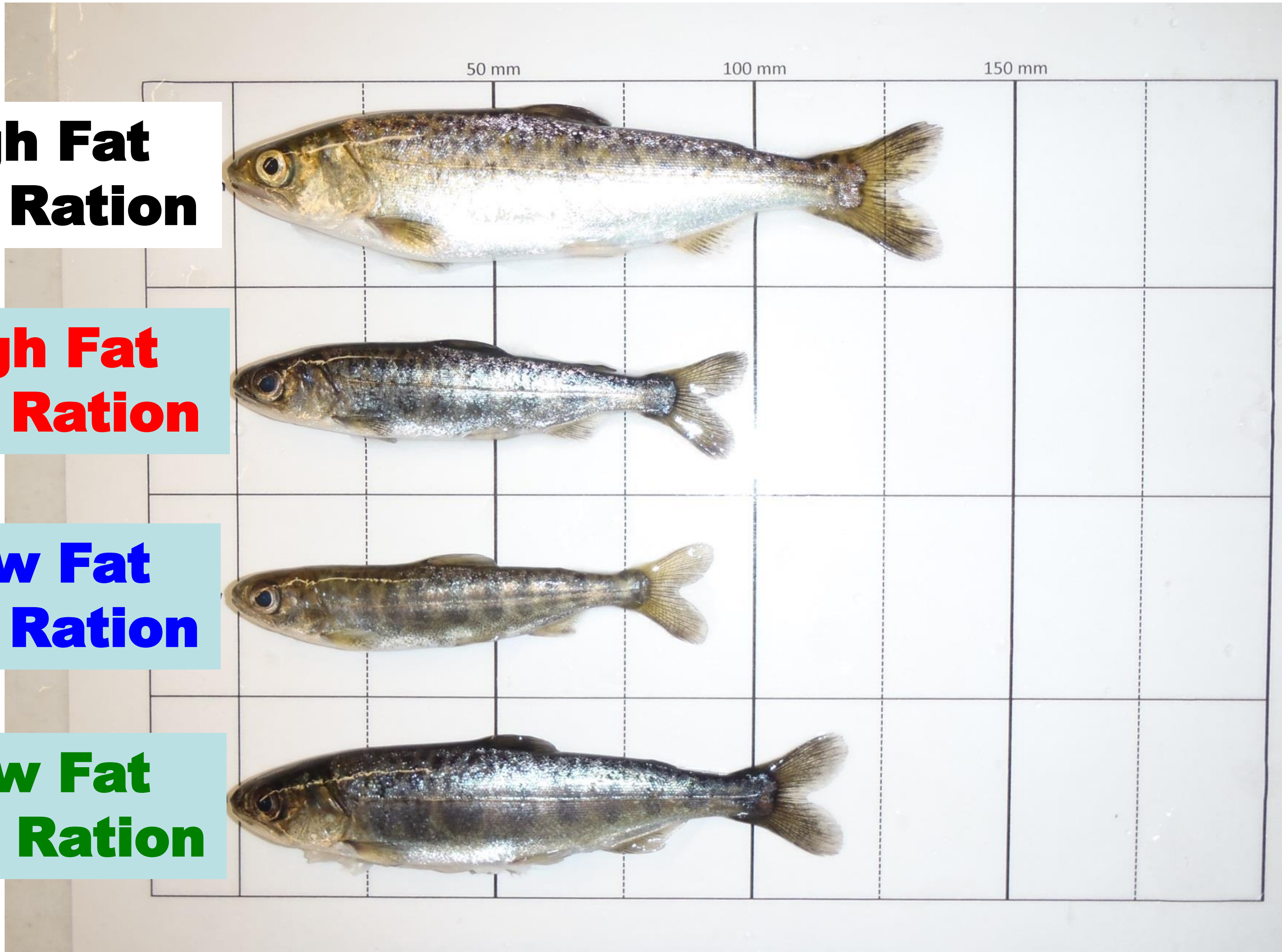
# Smolting




- **Elevated gill ATPase levels were present in both the fall and spring**
- **The smallest fish (Low-Low) had the lowest degree of fall smolting but had the highest ATPase levels as yearling smolts!**

# Smolt Size At End of Experimental Feeding (November 28)




High Fat High Ration

High Fat Low Ration

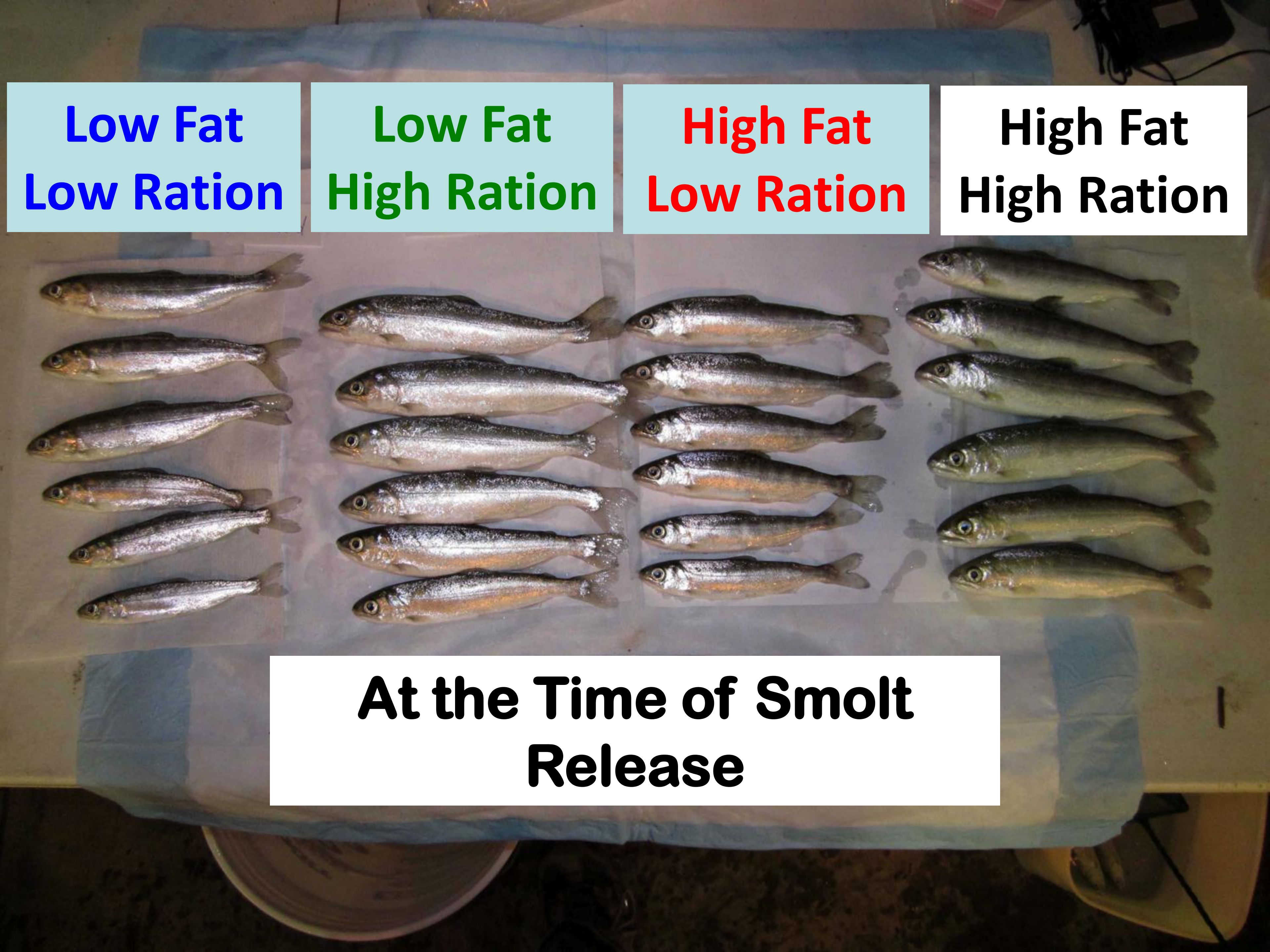
Low Fat Low Ration

Low Fat High Ration

# Loss Rates From Coded Wire Tagging to Liberation

| Brood Year | Low Fat Low Ration | Low Fat High Ration | High Fat Low Ration | High Fat High Ration |
|---|---|---|---|---|
| 2010 | 5.8% | 7.5% | 2.0% | 5.7% |
| 2011 | 14.6% | 1.3% | 1.6% | 2.8% |
| 2012 | 17.4% | 2.2% | 0.1% | 2.8% |
| 2013 | 34.3% | 31.0% | 1.8% | 3.5% |

Fish Health Issues: Hexamita, Enteric Redmouth, External Fungus (at acclimation), Cannibalism

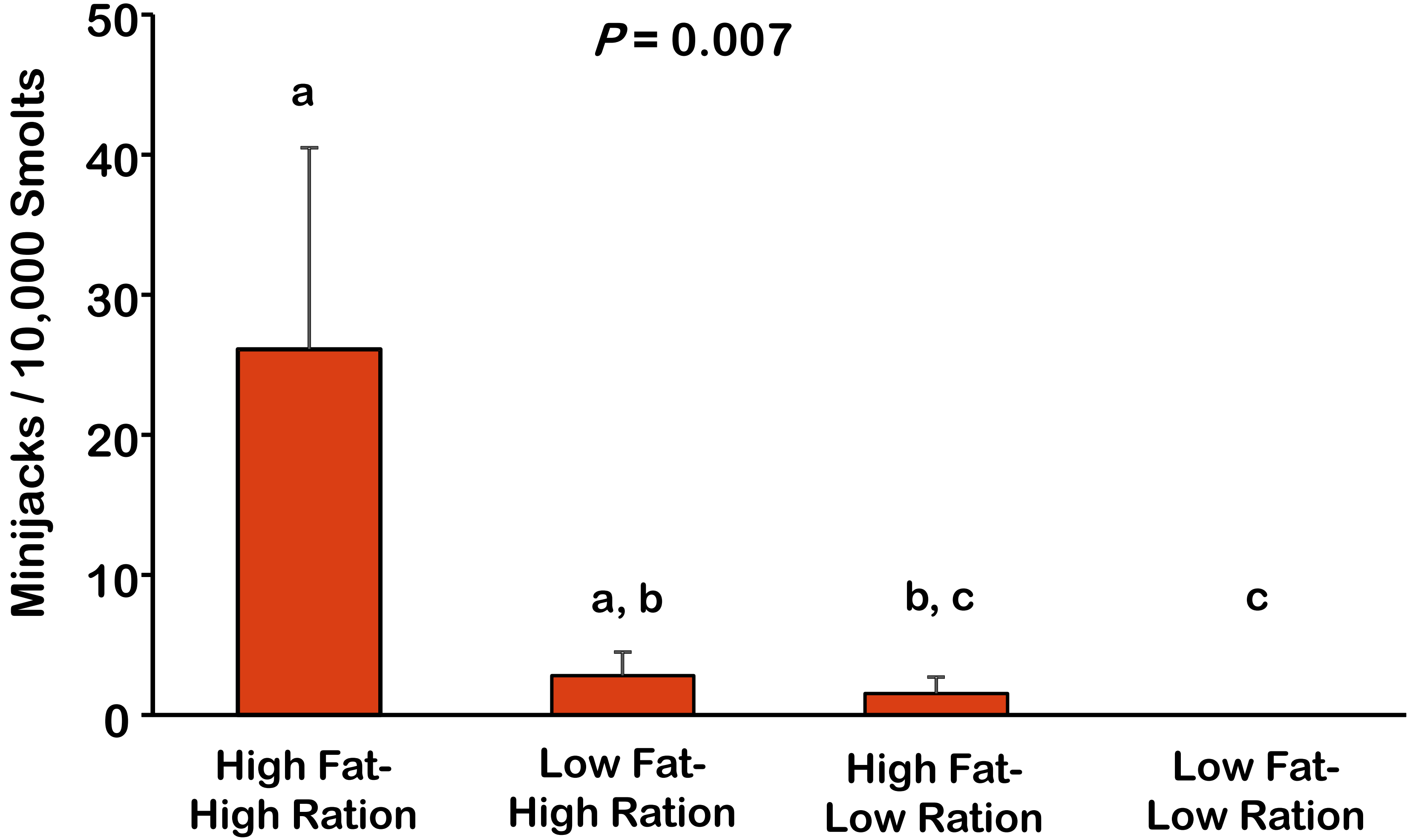

Low Fat
Low Ration
Low Fat
High Ration
High Fat
Low Ration
High Fat
High Ration
At the Time of Smolt
Release

# Results from Minijack and Adult Returns

**Smolts from the fourth and final year of the study were released in 2015, so most post-release datasets are incomplete!**

# Minijack Returns by Experimental Group

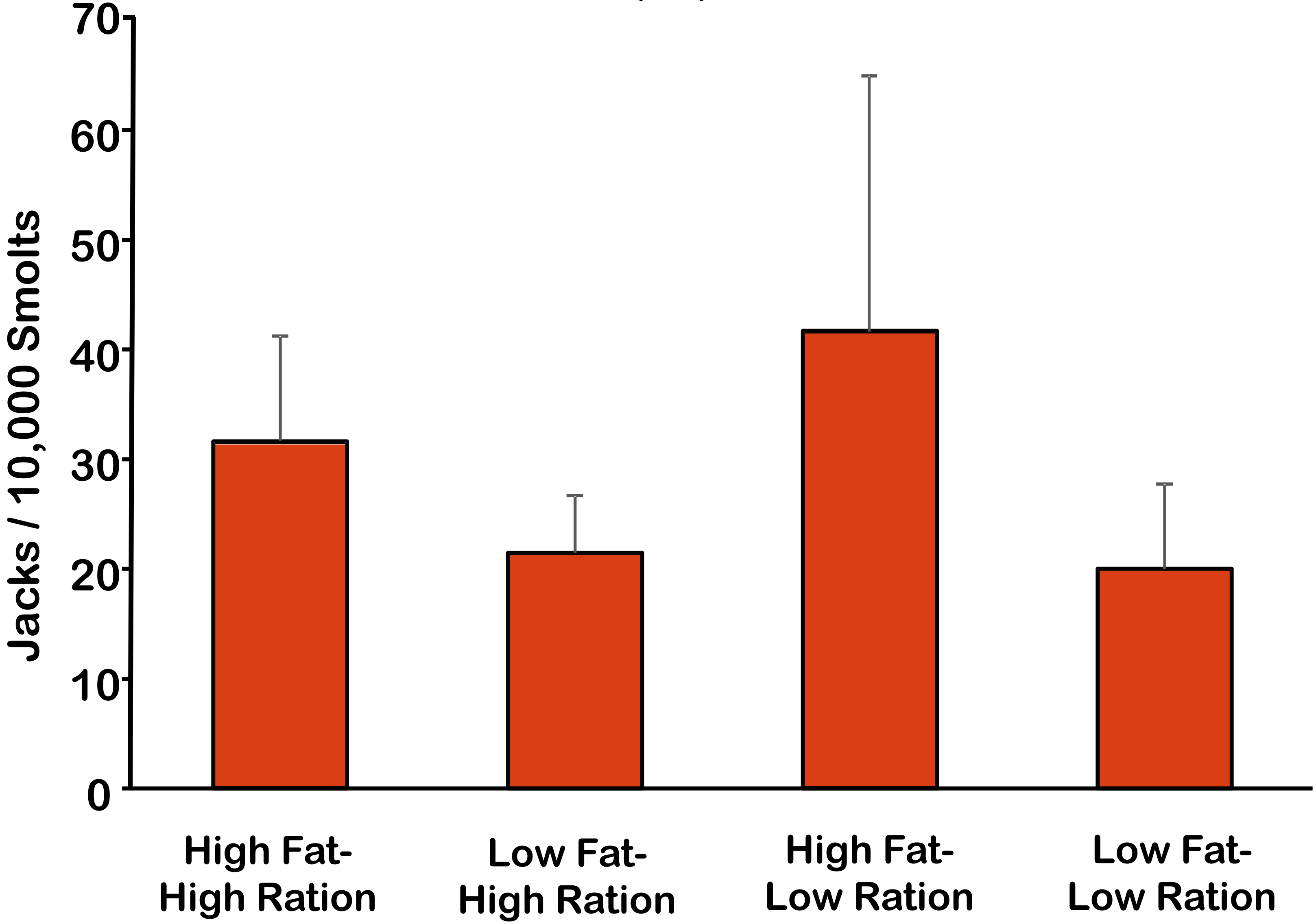
## (BYs 2010-13; 1,208 CWT Recoveries)




* Bars not sharing a letter are significantly different

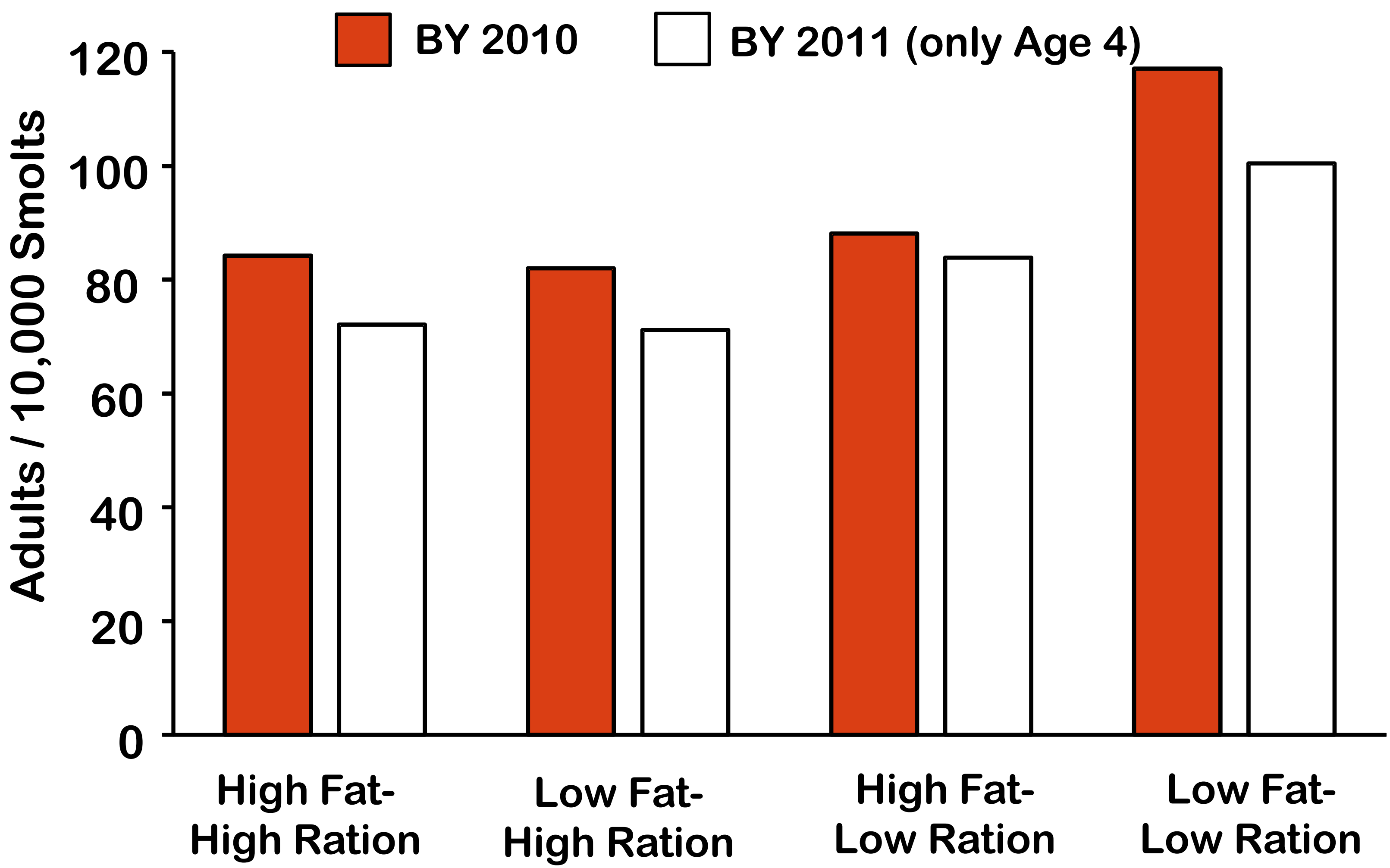
# Jack Returns by Experimental Group

## BYs 2010-12; 2,159 CWT Recoveries

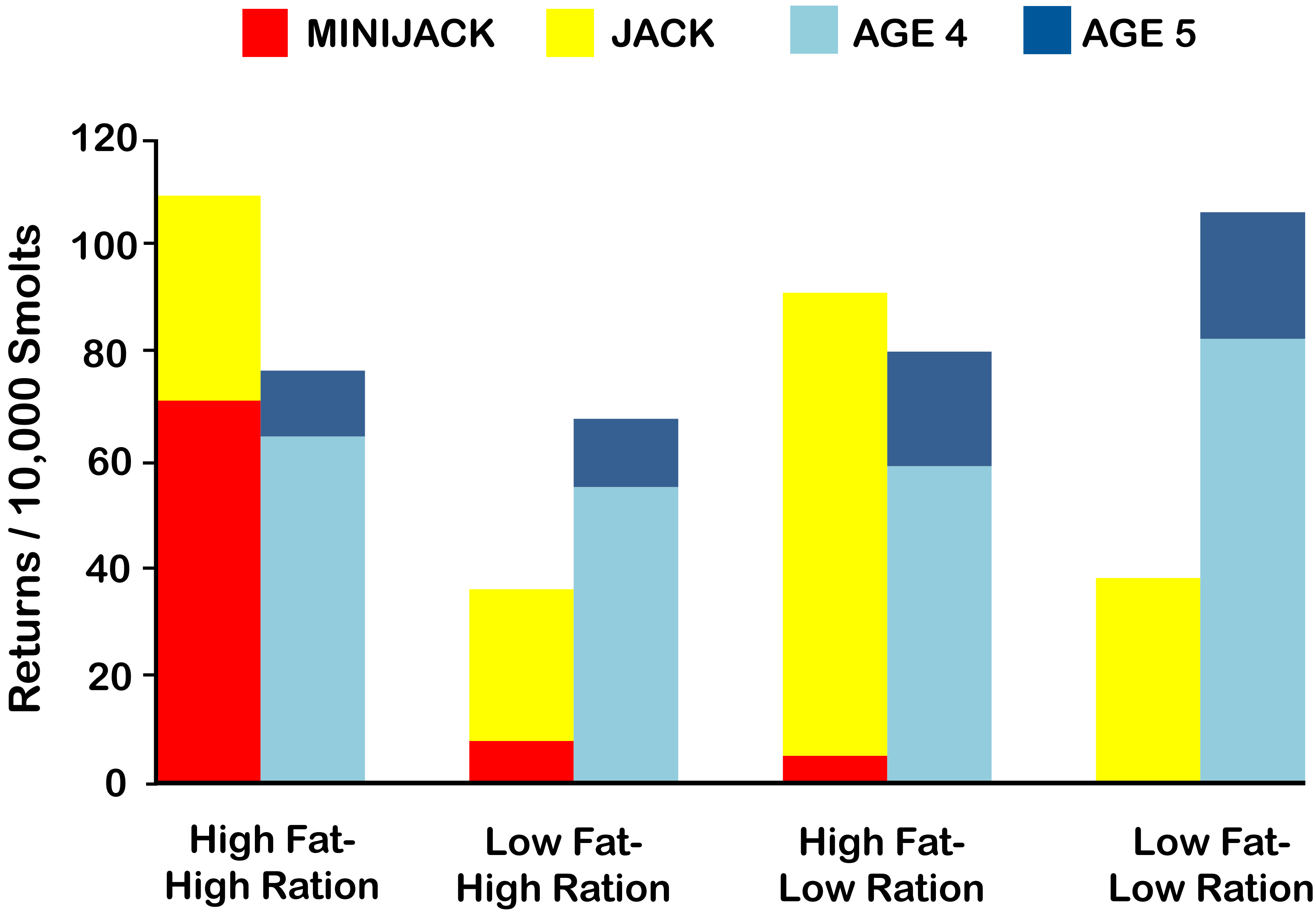


# Total Adults by Experimental Group

## (3,857 CWT Recoveries)

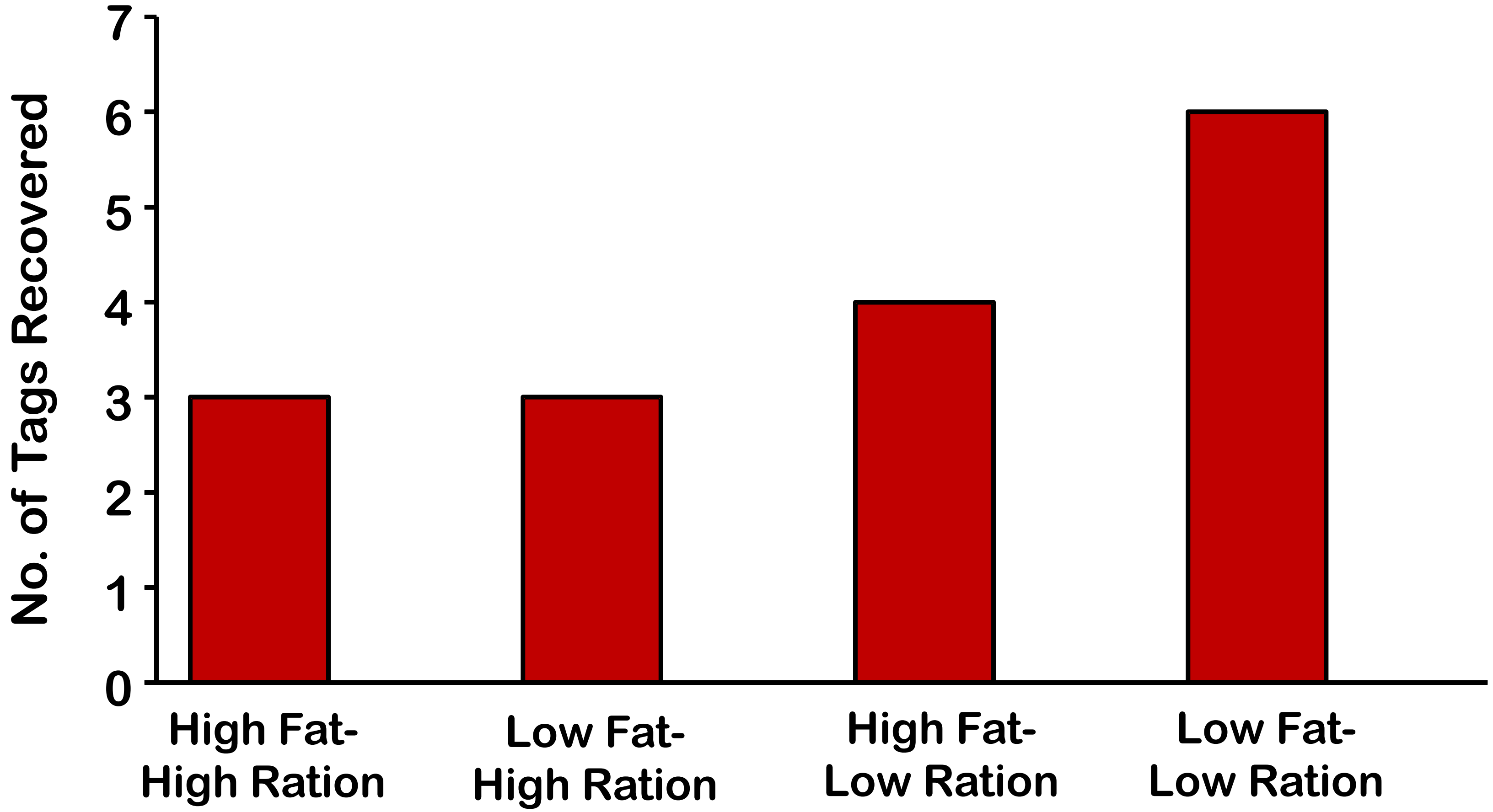


# Brood Year 2010 Age At Return

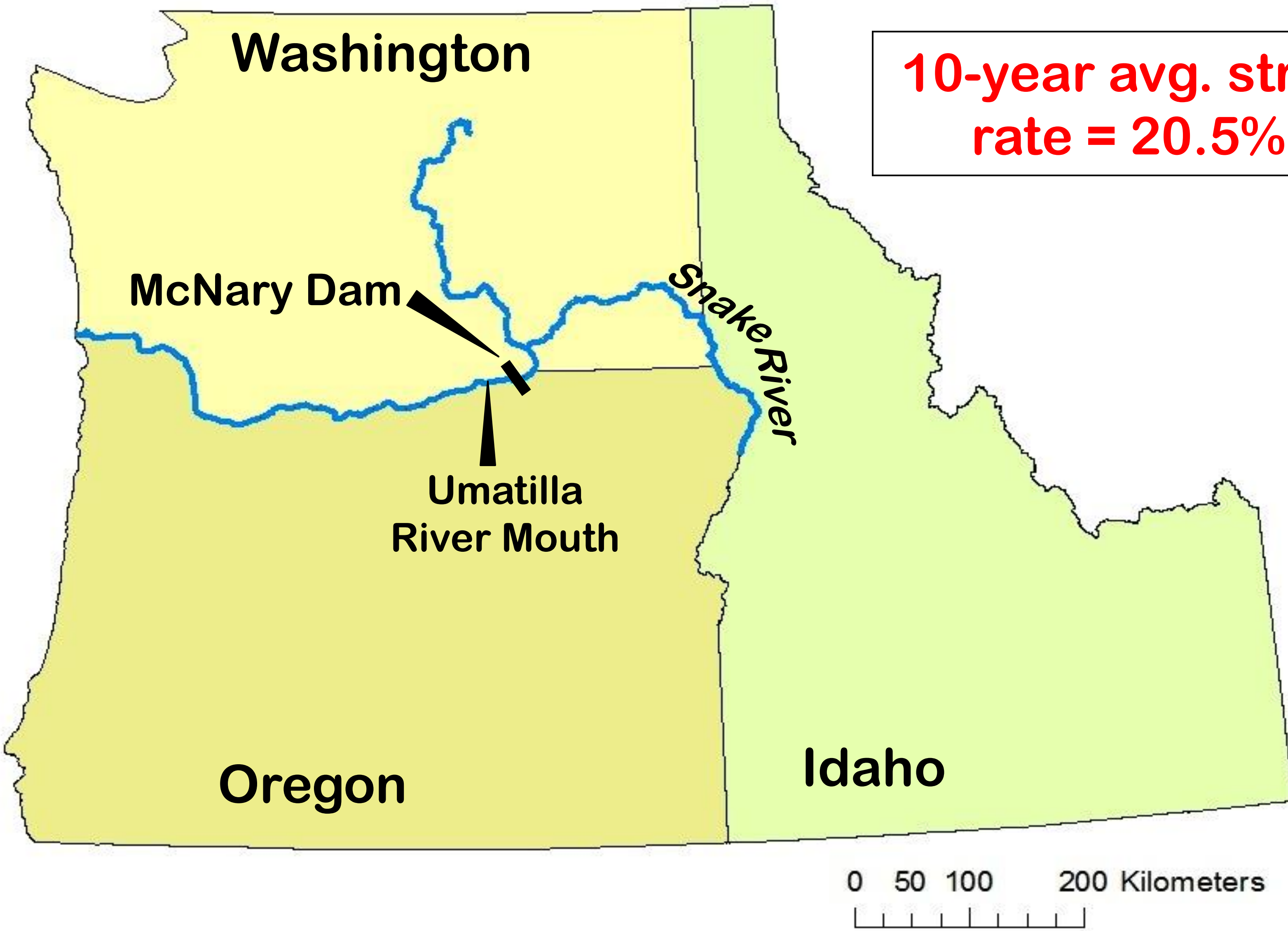


# PIT Tag Returns to Bonneville Dam
# Run Year 2016

## (16 tag Recoveries)

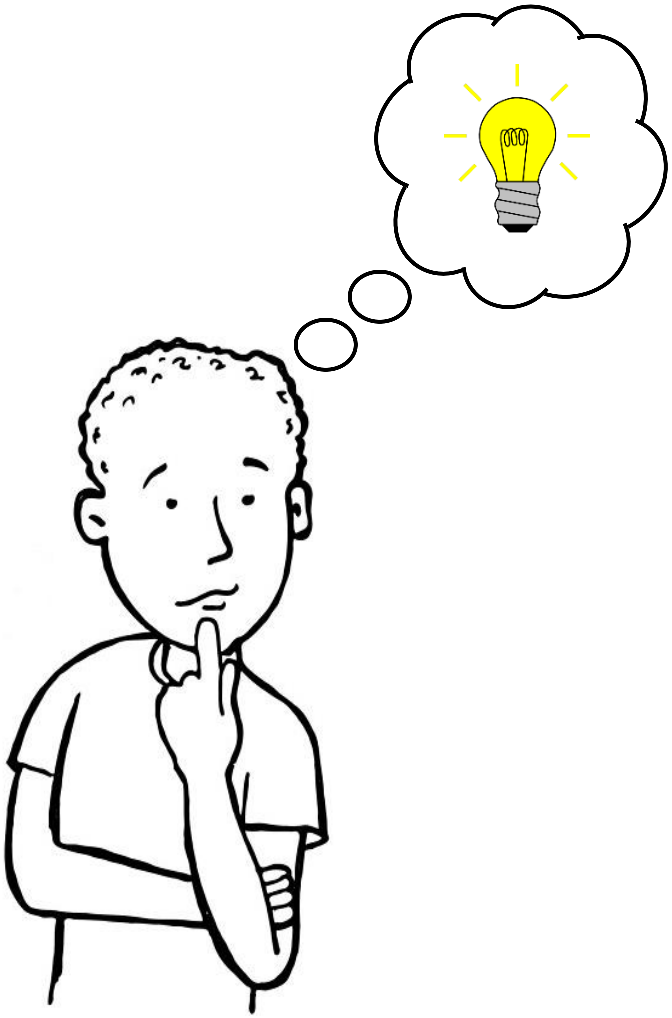


# Straying Above McNary Dam



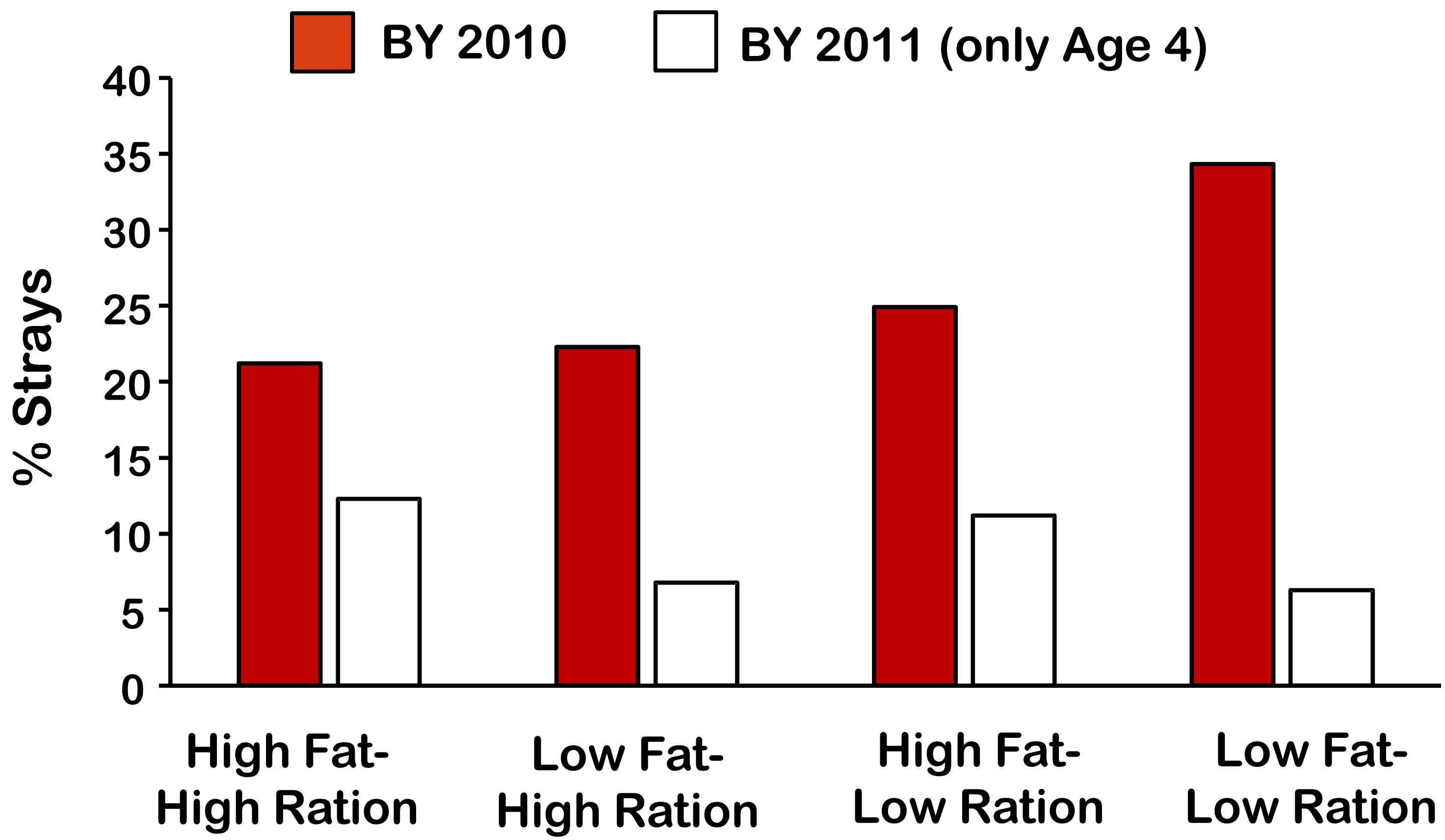

10-year avg. stray rate = 20.5%

**Hypothesis:** Release groups that exhibit better smolt profiles will have lower stray rates.



# Adult Straying

## (903 CWT Recoveries)




## Acknowledgements

- Ann Gannam, USFWS
- Scott Patterson, ODFW
- Greg Davis, ODFW
- Brian Zimmerman, CTUIR
- David Brock, Rangen, Inc