RRS Project Review

Project ID: 2003-054-00[1]

Title: Evaluate the Relative Reproductive Success of Hatchery-Origin and Wild-Origin Steelhead Spawning Naturally in the Hood River

Short Description: This project has been using genetic samples, collected from adult steelhead at Powerdale Dam between 1991-2010, to estimate relative reproductive success (RRS) over multiple brood years for two populations (summer and winter run) of hatchery and wild steelhead in the Hood River. To date, the results from this project show that hatchery steelhead have reduced fitness in the wild resulting from "extremely fast genetic adaptation to hatchery conditions." While this project continues to work towards completing the full 19 year pedigree (4 generations) estimates of RRS of steelhead in the Hood River, the research focus has expanded to include identifying environmental conditions driving rapid adaptation to captivity and genetic traits under selections in the hatchery culture of steelhead.

Sponsor: Oregon State University

BiOp association:

RPA 64.1 Estimate relative reproductive success (RSS) of hatchery,
RPA 64.2 Determine if artificial production contributes to recovery

Is this an Accord project? No

Budget (2008 to present):

BPA	Total	$3,103,893
	FY16	$ 331,526
Cost share	No cost share	

Proposal from last Categorical Review:

https://www.cbfish.org/Proposal.mvc/Summary/RMECAT-2003-054-00

Most recent Council recommendation:

https://www.cbfish.org/Assessment.mvc/CouncilRecommendationAssessmentSummary/Assessment/2003-054-00-NPCC-20110124

** Sponsor has addressed Council recommendations.

[1] This is one of the six exclusively RRS projects in the program.

Date of most recent annual report available on Pisces/cbfish? FY15 Annual Report: *Reproductive Success-Steelhead in the Hood River*. Submitted April 2016. https://pisces.bpa.gov/release/documents/DocumentViewer.aspx?doc=P148409

Short summary of project reporting compliance: Contract management and project performance has been excellent. Sponsor was on time with all annual reports. To date, 9 peer-reviewed scientific papers have been published from this project.

Summary of the scope of the project as it was reviewed by Council: The work to date on this project has "provided evidence that multi-generation hatchery stocks of steelhead are less productive when spawning naturally than non-captive fish, that a single generation in the hatchery results in depressed performance in the wild, and that hatchery effects on natural production persist in wild-born individuals with hatchery-born parents." As such, the sponsor proposed to Council that future directions of work include the following objectives: 1) complete the full 19- year pedigree for summer and winter-run steelhead in the Hood River; specifically, test where the summer run F1 hatchery fish show fitness declines similar to that of the winter run F1 hatchery fish, 2) identify the selective mechanisms in the Hood River steelhead hatchery that make hatchery fish different from wild fish, and 3) identify the genes whose expression levels are under selection in the hatchery, which could point to the traits under selection. Specific mechanisms to be tested are rearing density, feeding methods, and flow regimes.

Summary of the scope of the project now: The research focus of this project has expanded to include examining the effects of environmental conditions (rearing density, flow regimes, structure) on fitness and performance, and identifying which genes are differentially expressed (DE) between wild and hatchery steelhead, which may point to specific traits that are under selection in the hatchery.

Has the scope of this project changed significantly since it was reviewed? The scope of this project has changed, but not significantly, since it was reviewed by Council. The sponsor has been successful at meeting the objective of estimating RRS of steelhead in the Hood River, and the focus of the project has expanded to understanding the causes of domestication selection in hatcheries.

Link to ISRP/AB Critical Uncertainties Appendix D review:

http://www.nwcouncil.org/media/7149871/isabisrp2016-1appendixd.pdf#page=124

Comments: This project is specifically listed in the 2008 FCRPS BiOp (RPA 64.1), and the May 2010 document on Recommendations for Implementing RM&E for the 2008 NOAA fisheries FCRPS BiOp (RPA 64.2). The sponsor addressed all Council and BPA project manager recommendations since the review, has been timely with all required deliverables and contracting deadlines, and the quality of their work is exemplary.

Questions to all project sponsors with RRS studies:

- How does this project inform (1) the Council's Research Plan and (2) the Council's Fish and Wildlife Program objectives?

- Can any results from this study be extrapolated to other geographic locations or other populations?
- How does the Idaho Supplementation Study inform this project?
- Does this project have any of the following elements:
    - (a) A scientific question
    - (b) A hypothesis
    - (c) A specific time frame within which to answer the question posed
- How was it determined which species or geographic area to study?
- How does this effort work or collaborate with other RRS projects on aspects of the study (methodology, data and conclusions)?
- How does density dependence factor in to this study moving forward?

<u>Questions relative to this project:</u>

- Results to date show that hatchery steelhead have reduced fitness in the wild. What more information is expected from this study?

Evaluate RRS of Hatchery-Origin and Wild-Origin steelhead in the Hood River

Michael Blouin

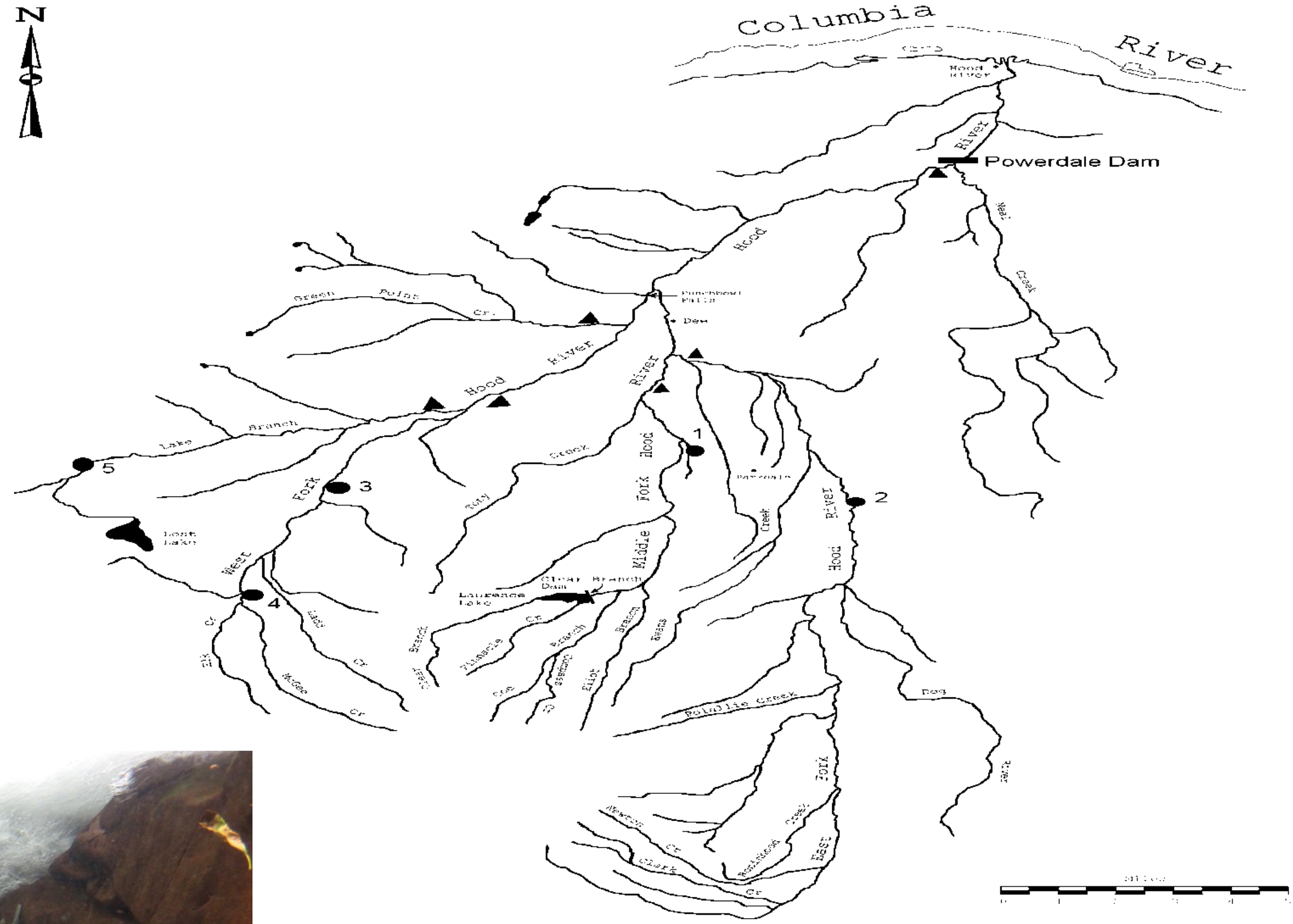
Oregon State University
Dept. Integrative Biology

1.Do hatchery fish have lower fitness than wild fish in the wild?

2: Is the difference genetic?

3. So what is going on and what can be done about it?

Steelhead (*Oncorhynchus mykiss*) in the Hood River, Oregon



Comparisons in Hood River:

Old Stocks vs. wild (Araki et al. 2007 *Conservation Biology*)

Winter Run

1991 **RRS ~ 0.10**

Summer Run

1994-1997 (4 years) **RRS ~ 0.30**

New ("F1") stock vs. wild

Winter Run

1995-2000 (6 years) **RRS ~ 0.85**

(Araki et al. 2007 *Science*)

Review of six case studies on RRS of early-generation H fish

(Christie et al. 2014. Evolutionary Applications)

- local origin broodstock
- relatively "wild" population

Case	Species	river	# run yrs examined
1	Chinook	Wenatchee, WA	3
6	Chinook	Johnson Ck, ID	4
2	Coho	Calapooya Ck, OR	3
3	Steelhead	Hood River, OR	6
5	Steelhead	Little Sheep Ck. OR	6
4	Atlantic salmon	Malbaie, Quebec	3

48 point estimates from 6 studies

Weighted geometric mean **RRS = 0.48** across all studies (0.45 if exclude steelhead).

3: Is the difference genetic?

2: Is the difference genetic?

Evidence for rapid adaptation to captivity

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H_{WxH} ~50% RRS of H_{WxW}

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2. Fitness of *Wild-born* adults depends on parents (H vs W)
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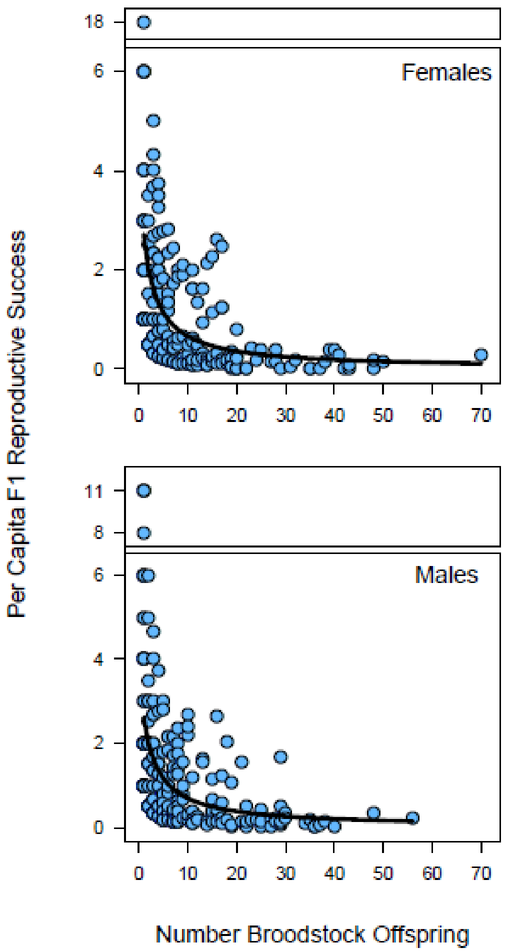
3. F1 fish make better broodstock than wild fish in hatchery
(Christie et al., 2012 *Proc. Nat. Academy*)

~2X more returning hatchery offspring

4. Family level trade-offs in performance in hatchery *vs*. in wild

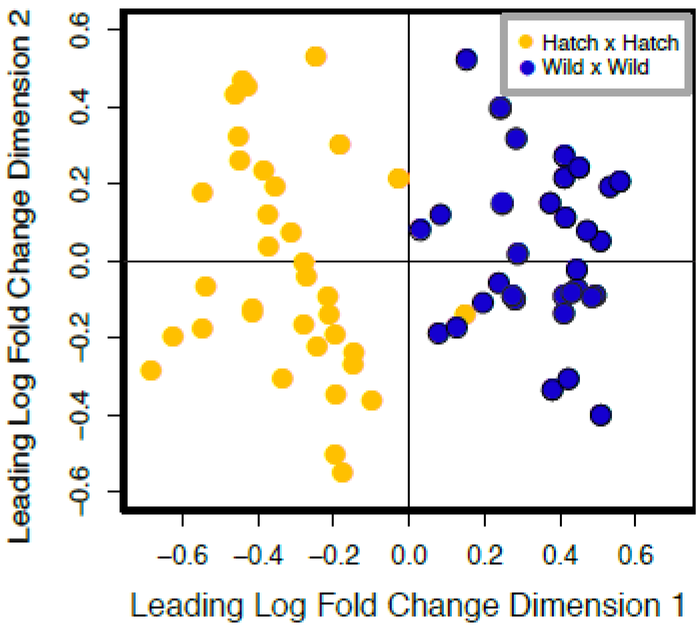
(Christie et al., 2012 *Proc. Nat. Academy*)



5. *Offspring* of HxH and WxW differ in whole-genome patterns of gene expression (RNAseq)

Common garden experiment

Christie et al. 2016 *Nature Communications*



Not a maternal effect

4. So what is going on and what can be done about it?

Current Research

Two big questions:

1. **What traits are under selection?**

2. **What aspects of hatchery culture exacerbate that selection?**

Current Research

Two big questions:

1. **What traits are under selection?**

2. **What aspects of hatchery culture exacerbate that selection?**

Goal: Can we create hatchery fish that are more like wild?

1. What traits are under selection?

Approach 1: What types of genes are differentially expressed between H and W?

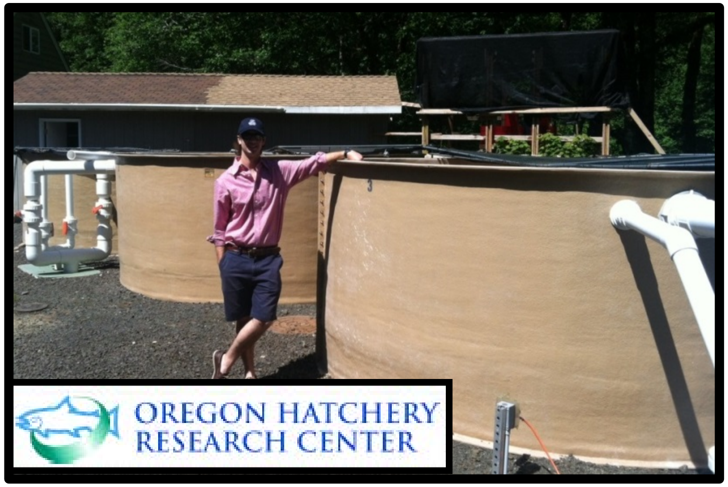
Christie et al. 2016 *Nature Communications*

Approach 2: What traits distinguish fast and slow-growing families in hatchery?

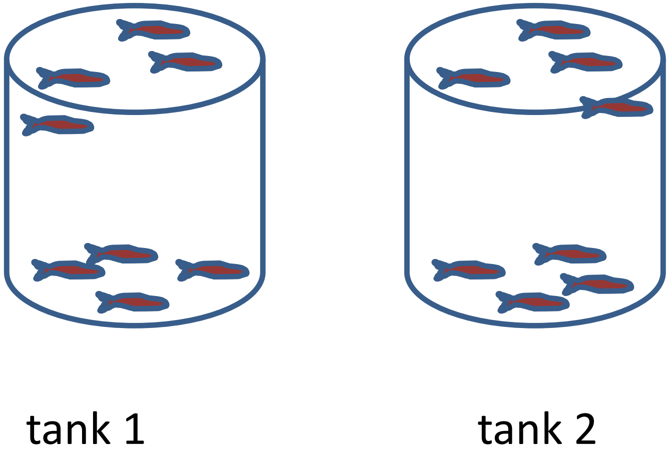
- Raise multiple families together, measure their growth
- Measure various traits on their siblings

Example traits being measured on families

- Physiological
  - e.g. Metabolic rate, stress response
- Patterns of gene expression (RNAseq)
- Behavioral
  - e.g. Position in water column
    - Dominance, aggressiveness Thompson & Blouin, in press, *Trans. Am. Fish. Soc.*



e.g. position in water column



- Strong family component
- Test do “top” families grow fastest?

2. What aspects of hatchery culture increase selection?

Question: Can we even out the performance differences among families?

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Question: Can we even out the performance differences among families?

Approach:

Vary environmental conditions

Test : *among-family* component of variance in body size

Example conditions to vary:

- Rearing density Thompson & Blouin, 2015 *CJFAS*
- Feeding method - underway
- Flow regime - underway
- Habitat complexity - coming up

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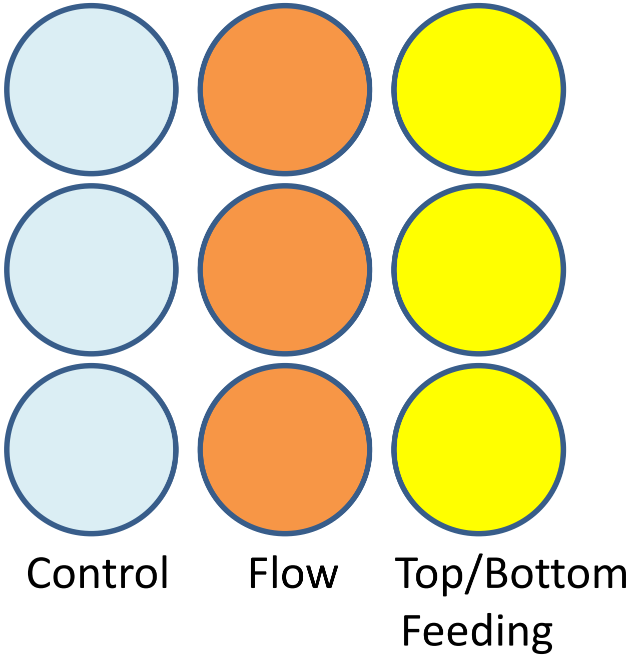

Summary

- H fish have lower fitness in the wild
- It is genetic and owing to adaptation to captivity
- Current research program:

    What traits are under selection?

    How can we reduce those selection pressures?

<u>20 publications resulting from BPA funding for Hood River studies</u>

RRS

Christie, M., M. Ford and M.S. Blouin. 2014. On the reproductive success of early-generation hatchery fish in the wild. *Evolutionary Applications,* 7:883-896. (Review. Also discusses power and precision in RRS studies)

Christie MR, ML Marine, RA French, RS Waples, MS. Blouin. 2012. Genetic adaptation to captivity can occur in a single generation. *Proceedings of the National Academy of Sciences USA* 109:238-242

Araki, H., B. Cooper and M.S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. *Biology Letters* 5: 621-624

Araki, H., B. Berejikian, M. Ford, and M.S. Blouin. 2008 Fitness of hatchery-reared salmonids in the wild. *Evolutionary Applications* 1:342-355. (Review)

Araki, H., B. Cooper and M.S. Blouin. 2007. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. *Science,* 318: 100-103.

Araki, H., W.R. Ardren, E. Olsen, B. Cooper and M.S. Blouin. 2007. Reproductive success of captive-bred steelhead trout in the wild: evaluation of three hatchery programs in the Hood River. *Conservation Biology*, 21:181-190.

Research into the causes of domestication in hatcheries and low fitness in the wild

Thompson NF, Blouin MS. <u>In Press.</u> Family dominance level measured during the fry stage weakly influences family length at smolting in hatchery reared steelhead (Oncorhynchus mykiss). *Transactions of the American Fisheries Society*

Thompson, NF, MR Christie, ML Marine, LD Curtis and MS Blouin. 2016. Spawn date explains variation in growth rate among families of hatchery reared Hood River steelhead (*Oncorhynchus mykiss*). Environmental Biology of Fishes DOI 10.1007/s10641-016-0500-2

Christie, MR, ML Marine, SE Fox, RA French and MS Blouin. 2015. A single generation of domestication heritably alters expression at hundreds of genes. *Nature Communications* doi:10.1038/ncomms10676

Thompson, NF and MS Blouin 2015. The effects of high rearing density on the potential for domestication selection in hatchery culture of steelhead (Oncorhynchus mykiss). *Canadian Journal of Fisheries and Aquatic Sciences.* 72:1-6

Thompson, NF, KS Cole, LA McMahon, ML Marine, LD Curtis and MS Blouin. 2014. Sex reversal, selection against hatchery females or wild males does not explain differences in sex ratio between first generation hatchery and wild steelhead, *Oncorhynchus mykiss*. *Environ. Biol. Fishes* 10.1007/s10641-014-0240-0

Christie MR, RA French, ML Marine and MS. Blouin. 2013. Does inbreeding cause the reduced fitness of captive-born individuals in the wild? *J. Heredity,* doi: 10.1093/jhered/est076

Blouin, M.S. V. Thuillier, B. Cooper, V. Amarasinghe, L. Cluzel, H. Araki and C. Grunau. 2010. No evidence for large differences in genomic methylation between wild and hatchery steelhead trout (*Oncorhynchus mykiss*). *Canadian Journal of Fisheries and Aquatic Sciences.* 67: 217-224.

Hatchery fish and effective population size

Christie MR, RA French, ML Marine and MS. Blouin. 2012 Effective size of a wild salmonid population is greatly reduced by hatchery supplementation. *Heredity*, 109, 254–260

Araki, H., R.S. Waples, W.R. Ardren, B. Cooper and M.S. Blouin. 2007. Effective population size of steelhead trout: influence of variance in reproductive success, hatchery programs, and genetic compensation between life-history forms. *Molecular Ecology* 16:953-966

Araki, H., R.S. Waples and M.S. Blouin. 2007. A potential bias in the temporal method for estimating N_e in admixed populations under natural selection. *Molecular Ecology* 16: 2261–2271

New statistical methodology relative to RRS studies

Christie MR, Tennessen JA, Blouin MS. 2013. Bayesian parentage analysis with systematic accountability of genotyping error, missing data, and false matching. *Bioinformatics* 29:725-732

Christie, M.R., M.L. Marine and M.S. Blouin. 2011. Who are the missing parents? Grandparentage analysis identifies multiple sources of gene flow into a wild population. *Molecular Ecology,* 20:1263-1276.

Araki, H. and M.S. Blouin. 2005. Unbiased estimation of relative reproductive success of different groups: evaluation and correction of bias caused by parentage assignment errors. *Molecular Ecology*, 13:4907-4110.

Misc

Fox SE, MR Christie, ML Marine, HD Priest, TC Mockler and MS Blouin. 2014. Sequencing and characterization of the anadromous steelhead (*Oncorhynchus mykiss*) transcriptome. *Marine Genomics* 2014 Jun;15:13-5. doi: 10.1016/j.margen.2013.12.001. Epub 2014 Jan 17

Thanks!

BONNEVILLE POWER ADMINISTRATION

OREGON Fish & Wildlife

OREGON HATCHERY RESEARCH CENTER

Photo: John McMillan