



**NOAA
FISHERIES**

Northwest
Fisheries
Science Center

9.0 Evolution and Life- History Overview

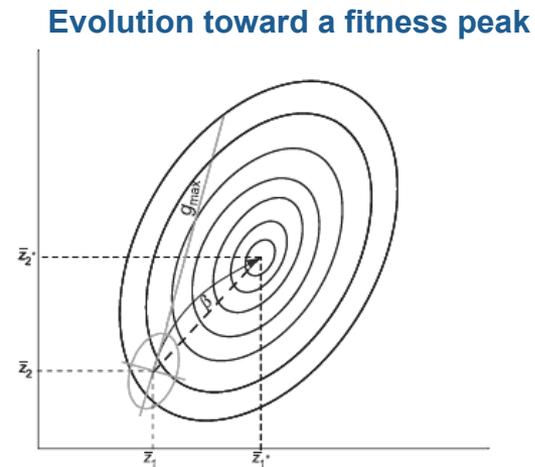
Jeff Hard and Robin Waples



May 6, 2015

What is life-history evolution?

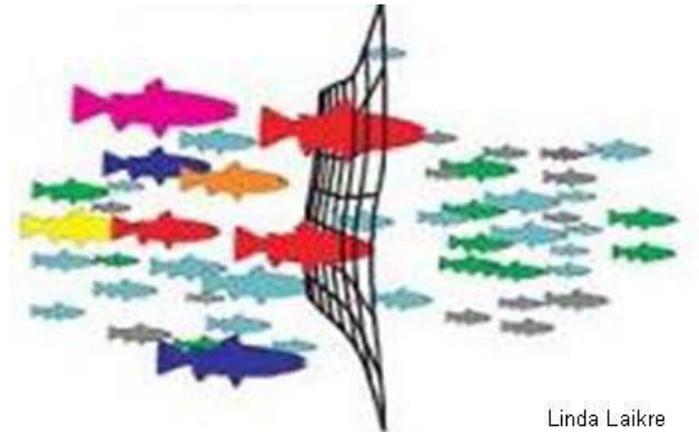
- Genetic change in age & size at maturity, offspring number & quality, lifespan & reproductive investment, and the schedule and seasonal timing of these transitions
- A key objective is to understand how genetic diversity and natural selection influence fitness and resilience
- We combine genetic tools such as GWAS and pedigree reconstruction with tools from physiology and ecology: e.g., lifecycle modeling, PVAs, and IPMs



Naish & Hard (2008)

Why is life-history evolution important?

- Abrupt, persistent life-history changes in response to selective pressures can affect productivity and viability
- Evolutionary responses to relaxation of novel selective pressures might occur more slowly (“Darwinian debt”)



Linda Laikre

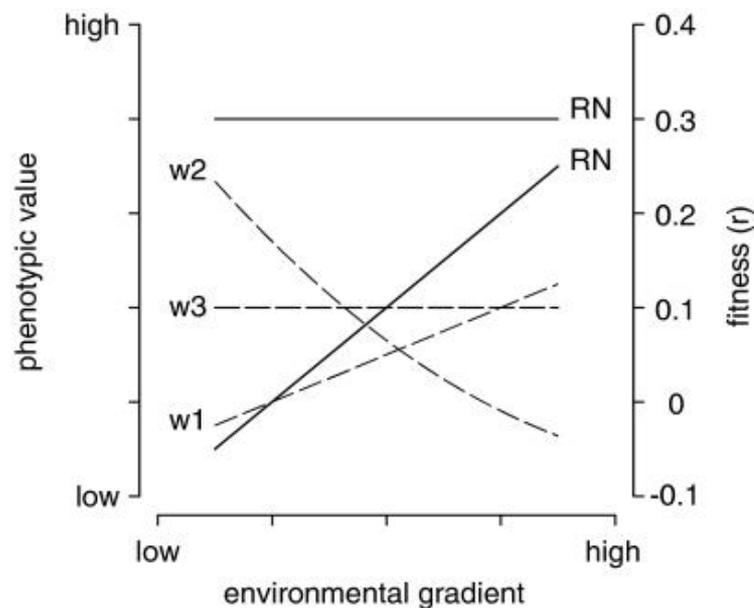


H. Soltes (Seattle Times, 2001)

- Is it acceptable to allow human-mediated evolution in a protected species?

How is it relevant to protected species?

- Anthropogenic changes to ecosystems protected species depend upon are likely to change their life histories
- These changes reflect adaptations away from historical patterns forged by natural selection
- Changes may involve plasticity (reaction norms)
- Genetic changes can also occur on ecological time frames relevant to conservation and management

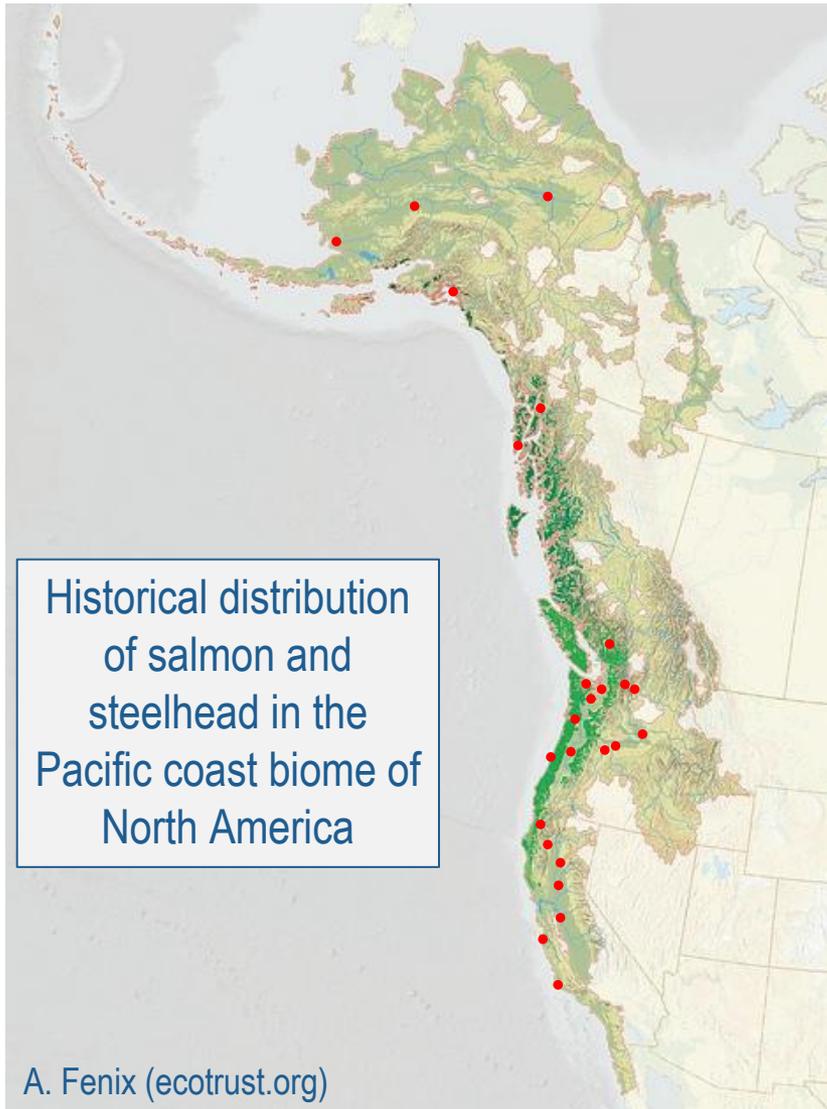


Hutchings (2011)

NOAA's life-history work on protected species

- Research at both Centers focuses on characterizing factors that influence life-history expression
- You'll hear about a variety of studies aimed at understanding key facets of salmonid life history
- Additional work at both Centers is examining other relevant topics in salmonid life history:
 - Genomics and epigenomics of life history strategies
 - Selection on size and migration, reproductive success
 - Partial anadromy (*Oncorhynchus mykiss*)
 - Plasticity in maturation, smoltification and migration
 - Variation in habitat use and migratory behavior

Geographic scope of NOAA's life-history work



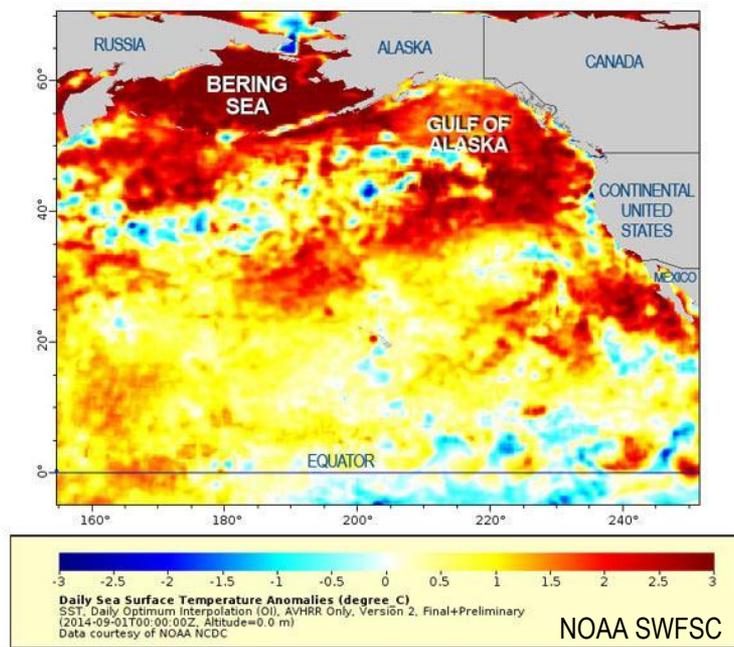
- Research on salmon and steelhead life history at the Northwest and Southwest Fisheries Science Centers covers much of the range of these species' historical distributions
- Focus is on anadromous populations in California, Idaho, Oregon, and Washington
- Some studies in Alaska

Three examples for protected species

1. Evolutionary demography of steelhead
 - All listed steelhead DPSs have resident fish
 - Conclusions about viability of steelhead DPSs depend on how one considers resident fish
2. Effects of the Columbia River hydropower system on salmon life history
 - Changes in selective regimes from pristine rivers to a series of reservoirs connected with bypass facilities
 - Millions spent on minimizing the lethality of dams to salmon, but little spent on evaluating *which* fish survive

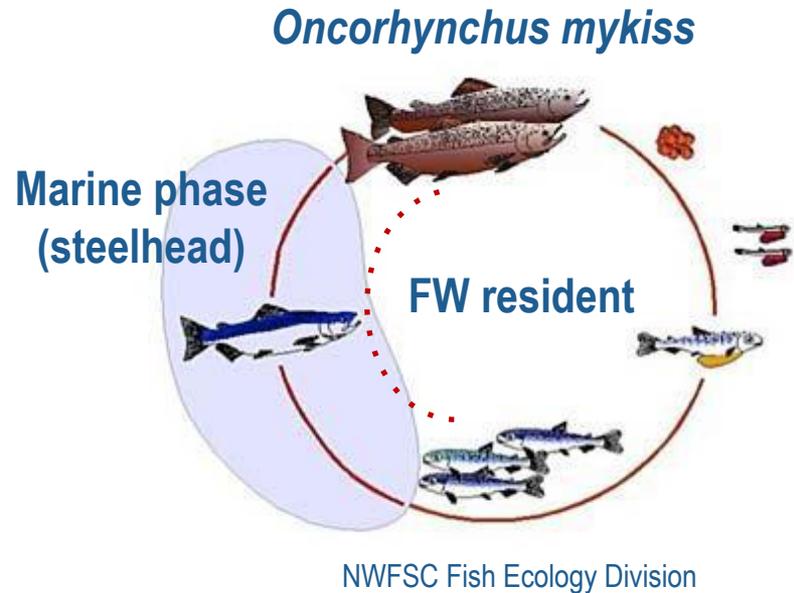
Three examples for protected species

3. Consequences of climate change for salmon
 - Likely to alter seasonal timing of reproduction and migration away from optima
 - Could increase extinction risk or yield range shifts
 - Capacity to respond depends on genetic diversity in life history and the nature of climate change selection



The hybrid migratory strategy of *O. mykiss*

- Growth, size at age and morphology influence migratory trajectories
- These traits are heritable and map to genomic sites known to influence migration propensity
- Resident and migratory paths may be canalized
- How do residents contribute to viability of anadromous populations? Can resident fish help to conserve steelhead?



Steelhead life history in two coastal streams

- Different solutions to a problem
- Residents produce seaward migrants; steelhead can produce residents
- Disparate age structures
- Low rates of iteroparity



Snow Creek Sashin Creek

Age structure

Age 3	3.5%	0.0%
Age 4	87.4%	35.8%
Age 5	9.1%	52.8%
Age 6	0.0%	11.3%

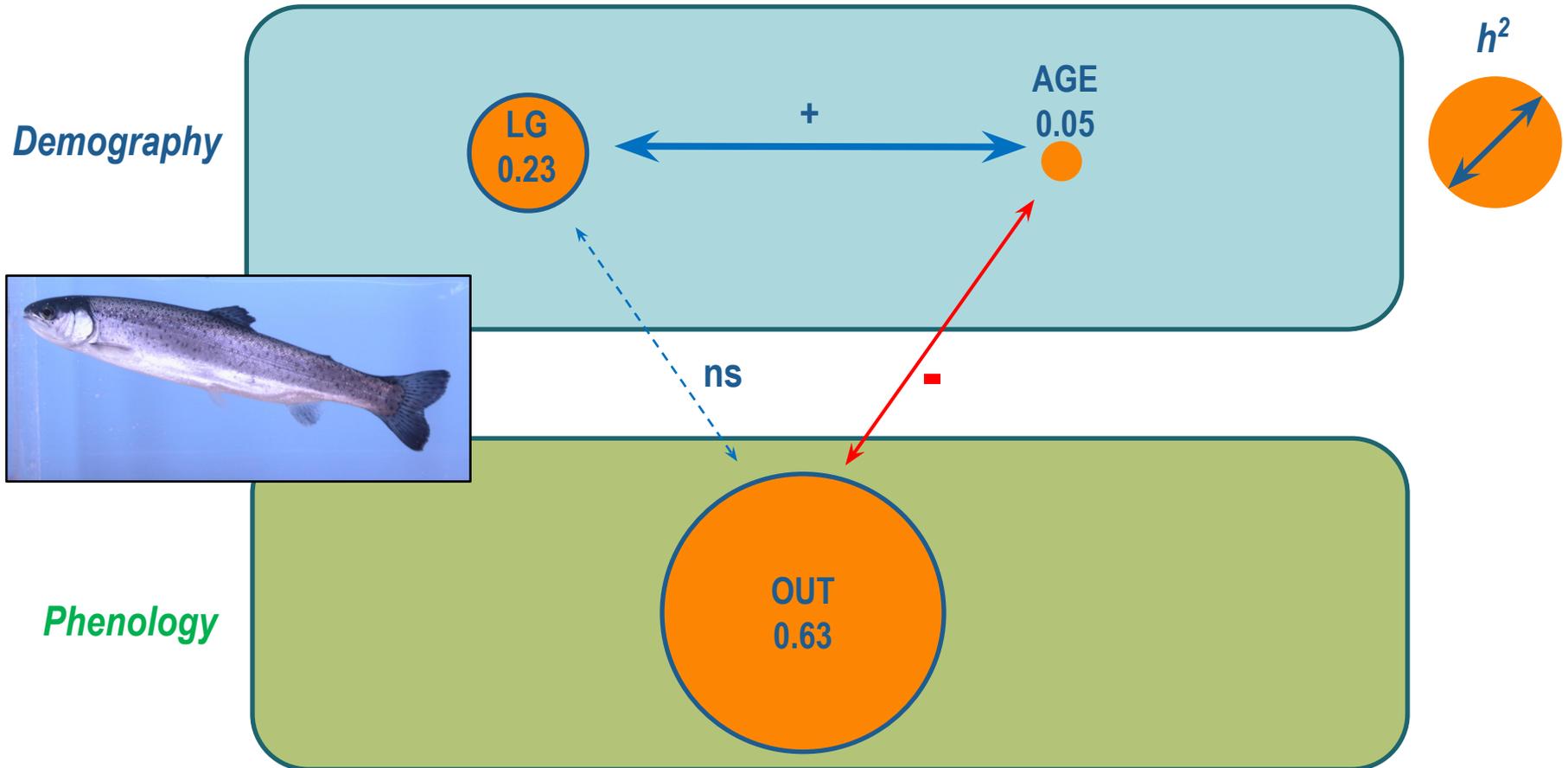
Demography

Smolts/spawner	30.1	13.2
Marine survival	4.8%	10.8%
Recruits/spawner	1.0	1.1
Iteroparity	< 2%	4.5%



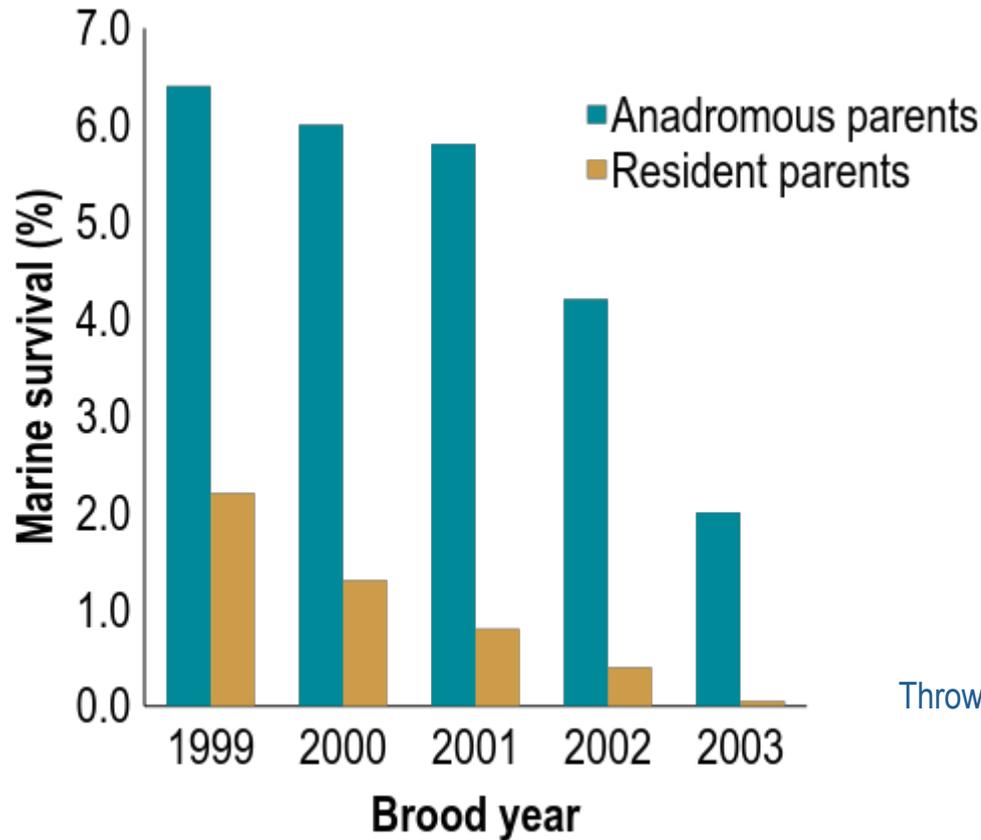
adfg.alaska.gov

Size and migration timing of steelhead smolts



- Smolt length (LG) and migration timing (OUT) are heritable but uncorrelated
- Older smolts are larger and leave earlier

Residents produce migrants – but at what cost?



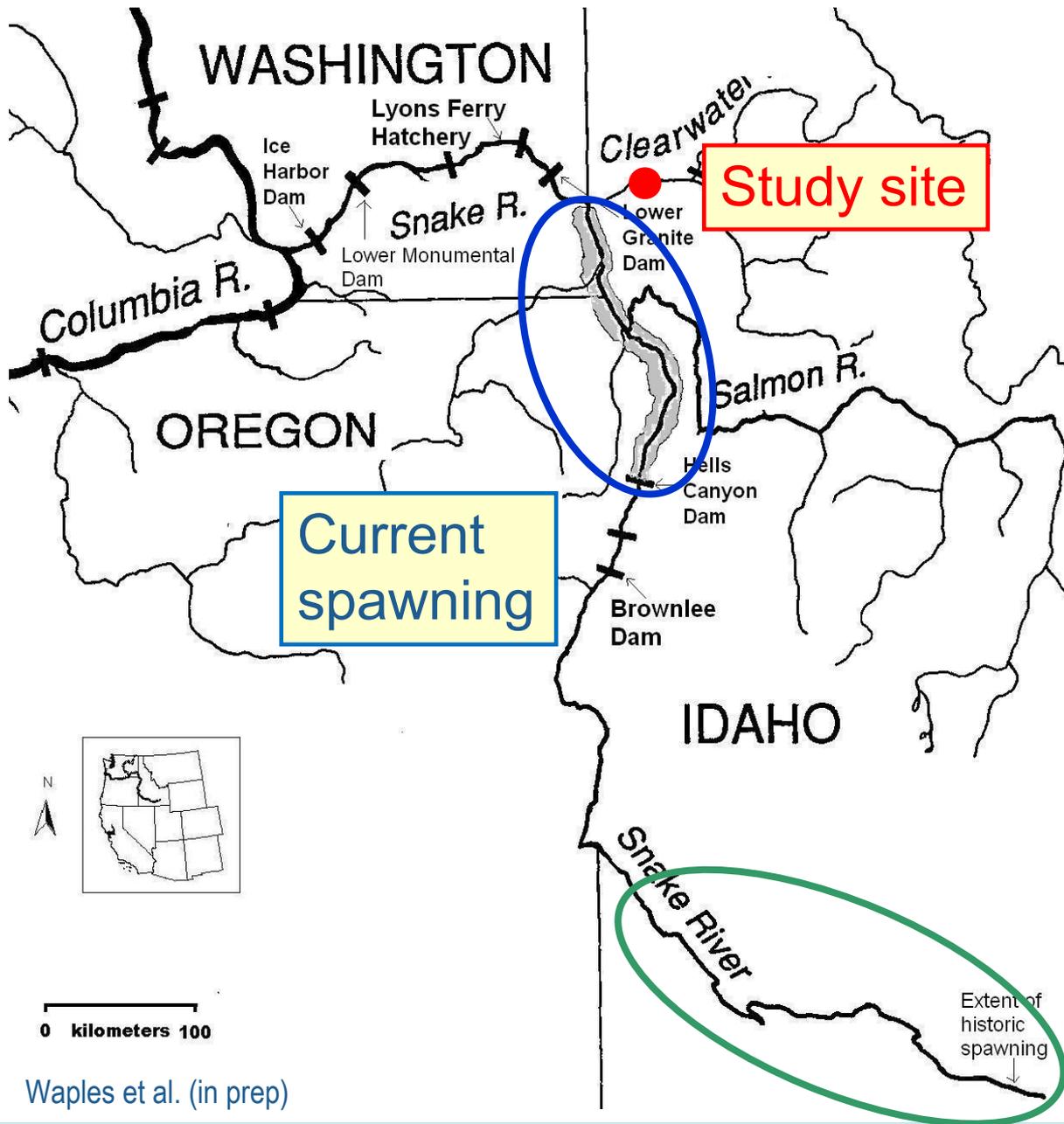
Thrower & Hard (2009)

- Residents can retain the ability to produce smolts in the face of selection
- But they have much higher marine mortality
- How do migrating offspring of residents affect anadromous productivity?

Snake River fall Chinook salmon (*O. tshawytscha*)



ESA listed 1992



Current spawning

Study site

Historical spawning

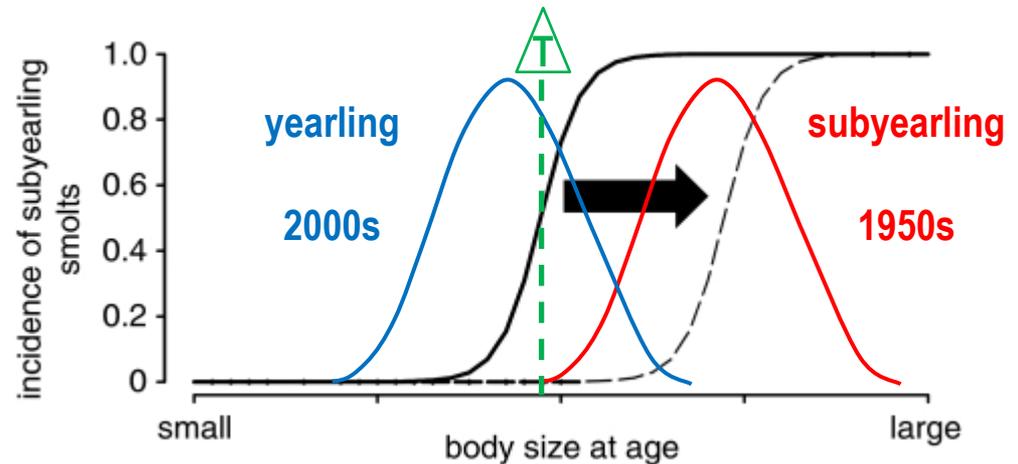
Waples et al. (in prep)

Life history changes in Snake River fall Chinook salmon

- Historically, nearly 100% subyearling migrants
 - Recently, evidence for selection favoring yearling migrants (Williams et al. 2008)
 - What happens if dams are removed?
 - If LH Δ reflects plasticity, perhaps not a problem
 - If LH Δ reflects evolution, population could be maladapted to its restored ecosystem
-  • Important to maintain genetic diversity in age of seaward migrants

Changes in migrant age: plasticity or evolution?

- The influence of dams on migrant survival has increased the frequency of yearling migrants
- This shift may reflect an increase in the size threshold required for fish to migrate as subyearlings
- It could also reflect an evolutionary response to selection on smolt age or growth

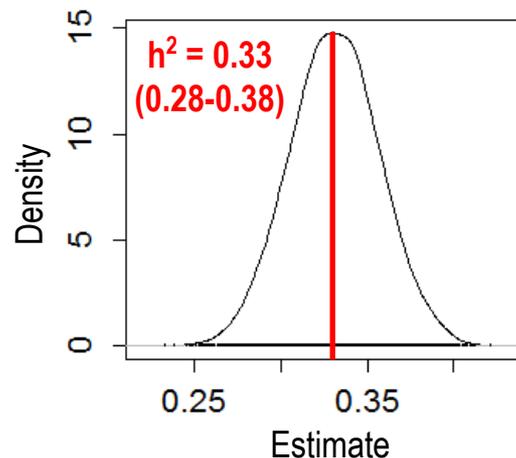


Modified after Hutchings (2011)

Heritability of smolt LH in fall Chinook salmon

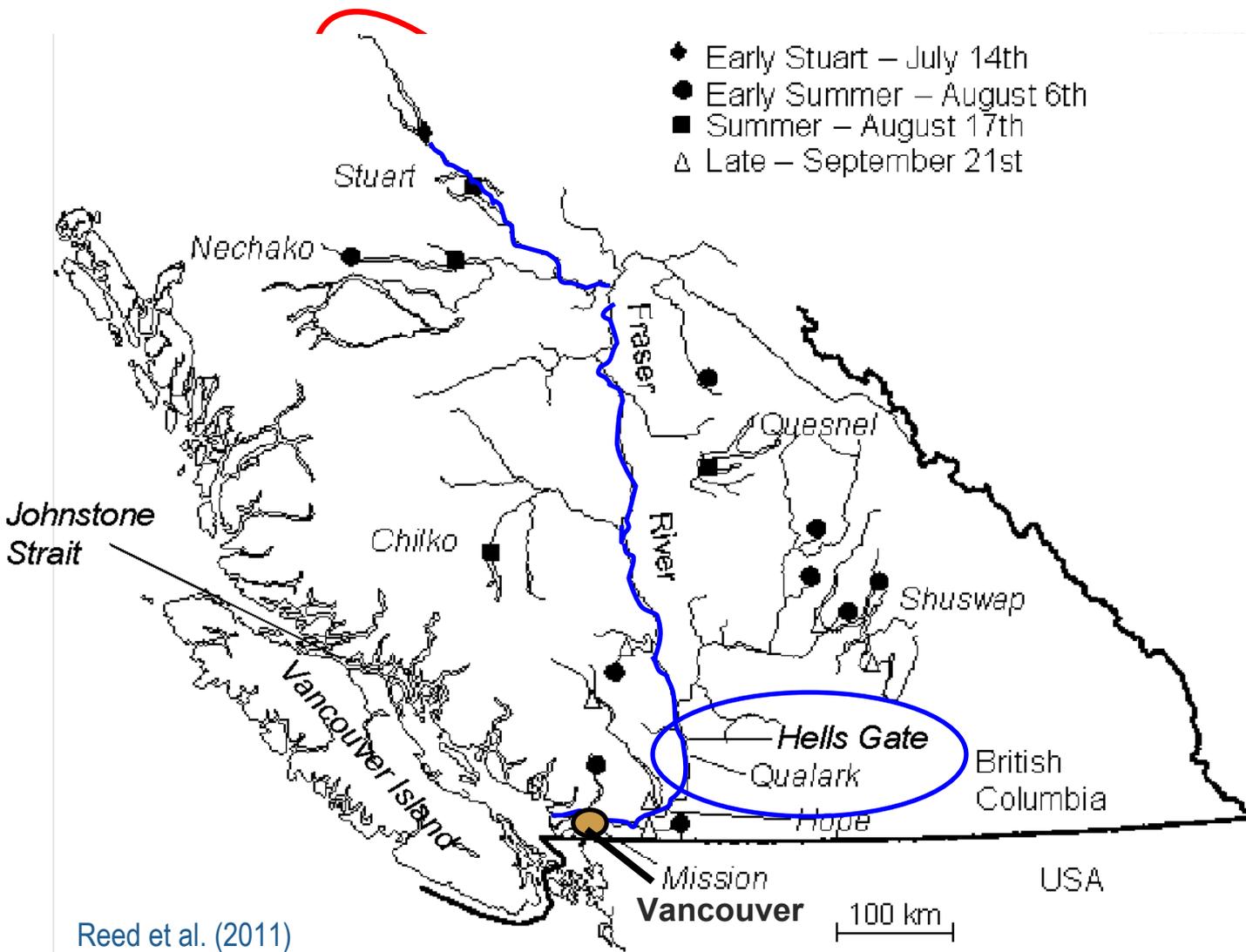
- 3 year spawning matrix of known crosses (NPTH, Idaho)
- Parentage analysis to correlate parent with offspring LH
- Subyearling parents generally produced faster growing offspring than yearling parents
- Parents reared as yearlings in H produced fastest-growing offspring

h^2 of offspring growth rate



- Evolution might be involved in the observed life-history response

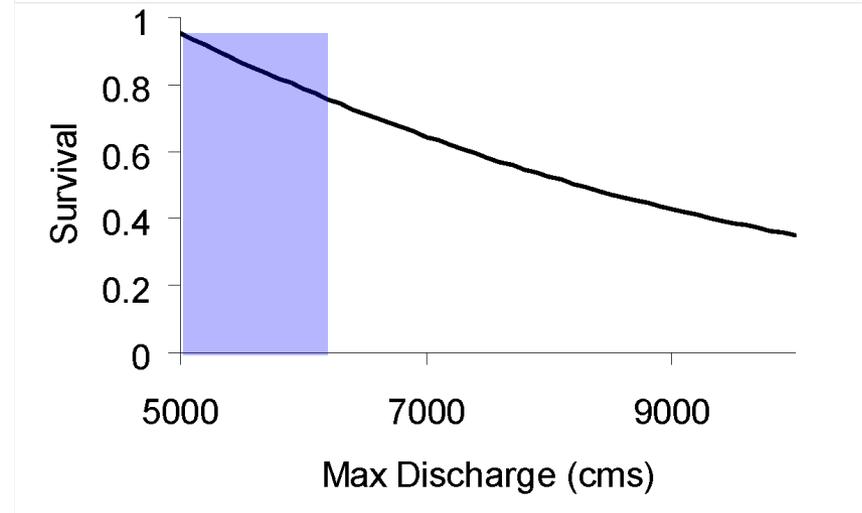
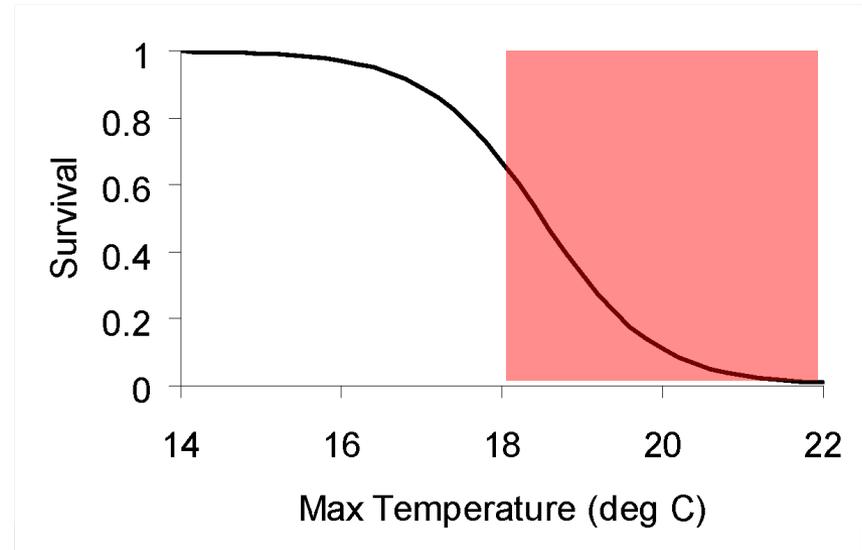
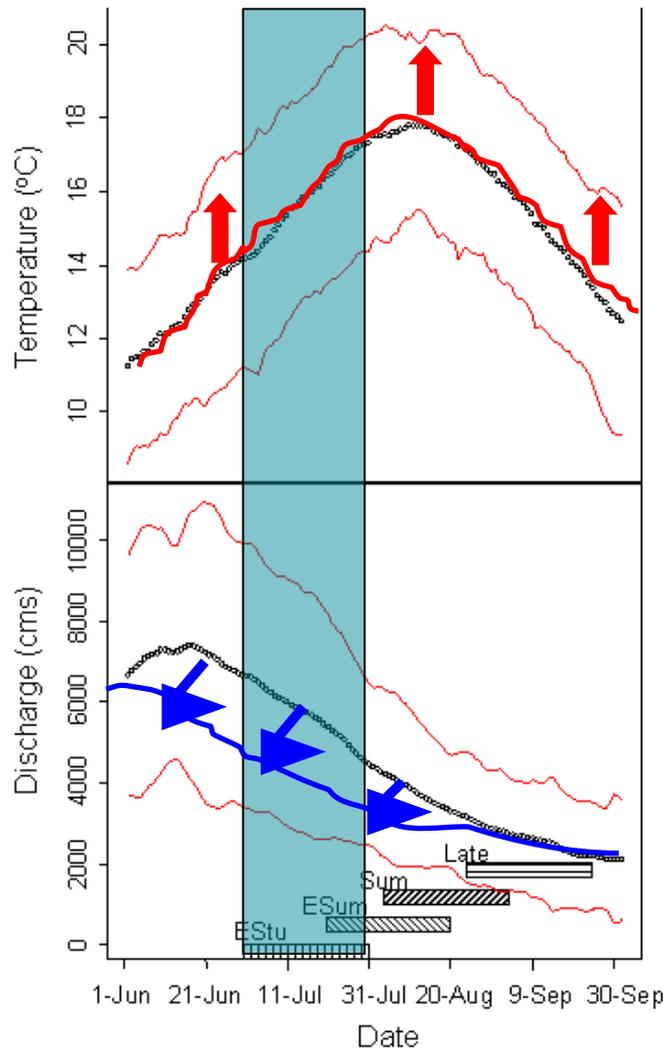
Fraser River, B.C. sockeye salmon (*O. nerka*)



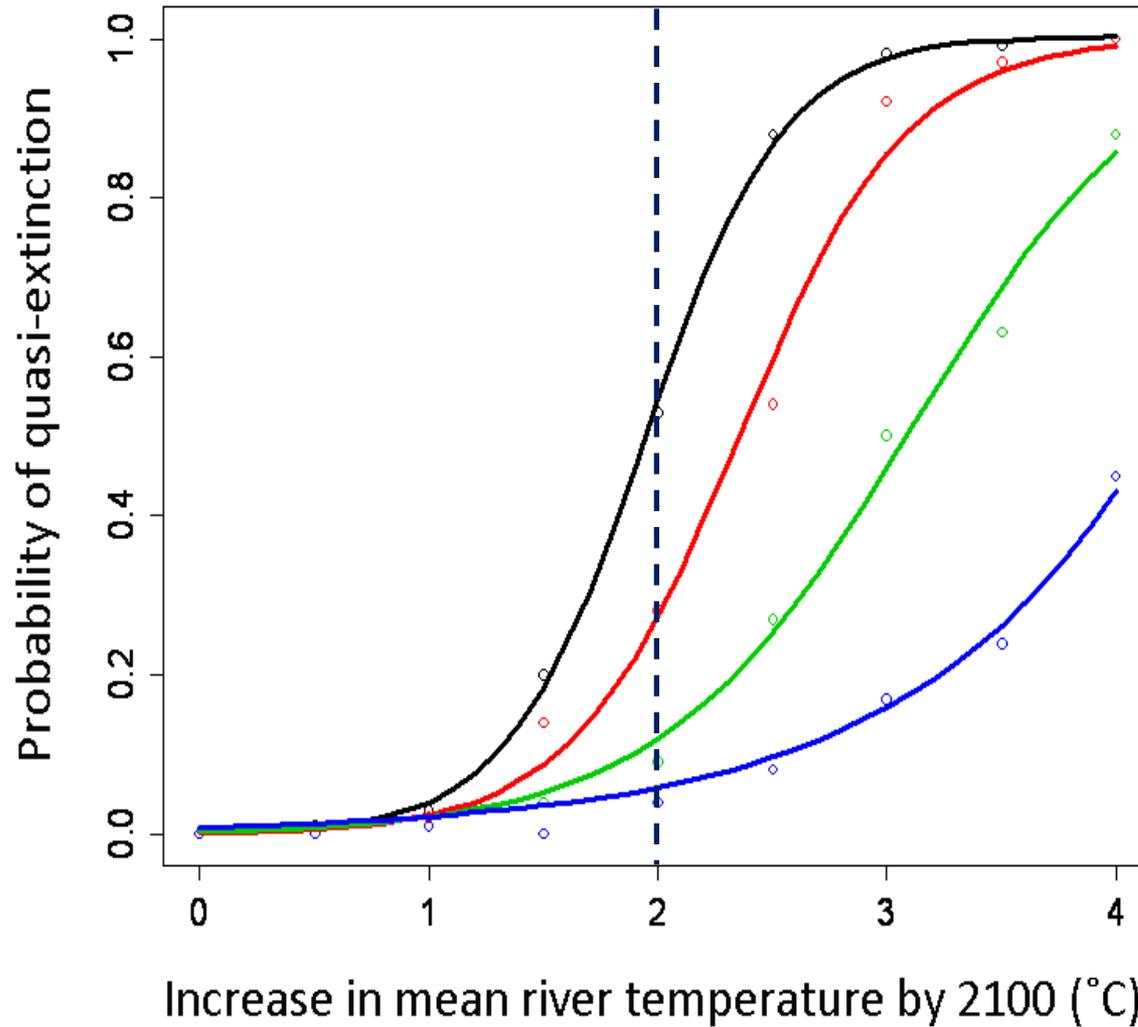
Temperature and flow patterns in upper Fraser R.

Est. survival functions

MacDonald et al. (2010)



Genetic rescue is feasible if h^2 is high enough



Reed et al. (2011)

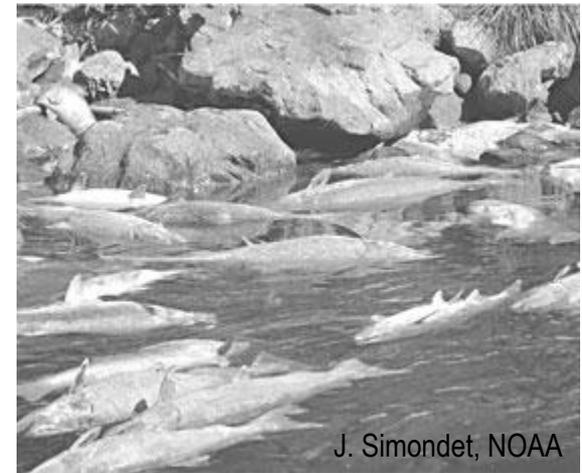
— heritability = 0 — heritability = 0.25 — heritability = 0.5 — heritability = 0.75

Some key findings

1. Evolutionary demography of steelhead
 - Life history traits are heritable and under selection
 - Success of anadromous migrants depends on sufficient genetic variability but also on nature of past selection
 - Population modeling indicates evolution of life history transitions can influence population dynamics
2. Effects of the Columbia River hydropower system on salmon life history
 - Altered selective regimes have resulted in life-history changes that are heritable
 - These changes could be maladaptive in historical habitat

Some key findings

3. Consequences of climate change for salmon
 - Effects depend on ability of fish to cope with increasing temperature and altered hydrographs
 - Climate change will probably narrow optimal windows for migration and reproduction
 - It will likely shift the seasonal timing of these optima as well
 - Ability of salmonids to adapt ultimately depends on the capacity to respond to selection



Future questions to explore

- To what extent can resident *O. mykiss* contribute to abundance, productivity, and diversity of anadromous steelhead?
- Will hatchery supplementation alter the degree of anadromy in *O. mykiss* populations?
- What is the rate and form of adaptation to restored habitat conditions after removal of barriers to migration?
- Under what conditions can phenotypic plasticity ameliorate genetic change in response to strong directional selection (e.g., from climate change or fisheries selectivity)?

Related life-history studies at NWFSC & SWFSC

- Evolution of smolt age in hatcheries (Berejikian, Tue PM)
- Evolution of age at spawning in hatcheries (Ford, Tue PM)
- Climate change effects on adult migration timing (Crozier, Mon PM)
- Residency and anadromy in *O. mykiss* (Pearse, Satterthwaite)
- Epigenetics/genomics and LH expression (Swanson & Nichols)
- Phenotypic plasticity and cue reliability (Reed et al.)
- Fisheries- and predator-induced evolution (Hard et al.)
- Evolutionary response to climate change (Audzijonyte & Waples)



Other genetic research on protected species

- Current and historical population structure
- Mixed-stock fishery analysis
- Genetic effects of captive breeding and rearing
- Wild pedigree reconstruction and parentage assignment
- Effective population size and rates of genetic change
- Genetic identification of killer whale prey



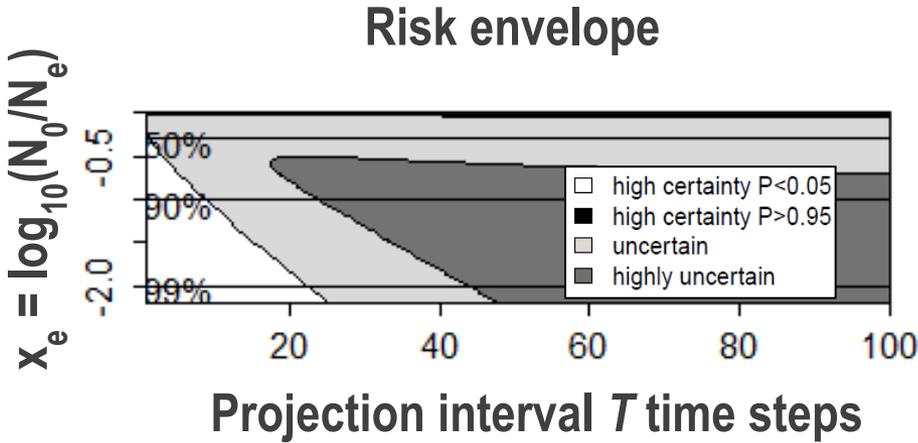
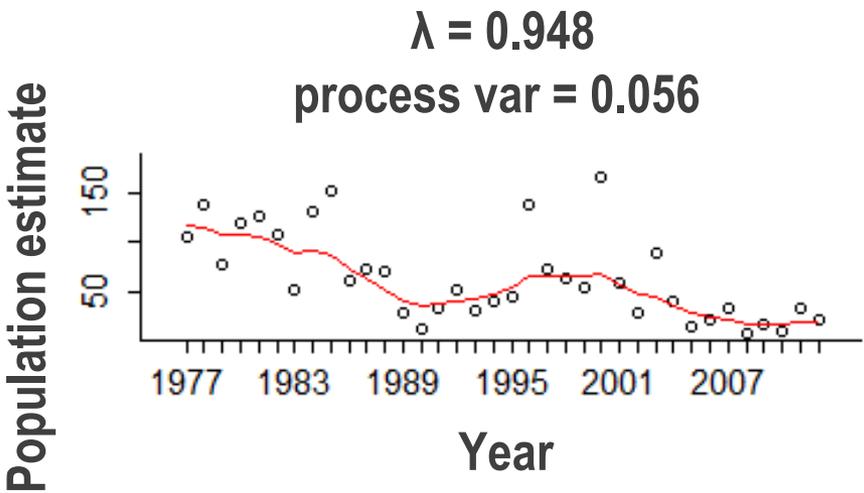
Acknowledgments

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- Nez Perce Tribal Hatchery & USFWS
- Many other collaborators from NOAA, UW, OSU, CDFO, WDFW, ODFW, CRIFTC, and tribal agencies

FIN

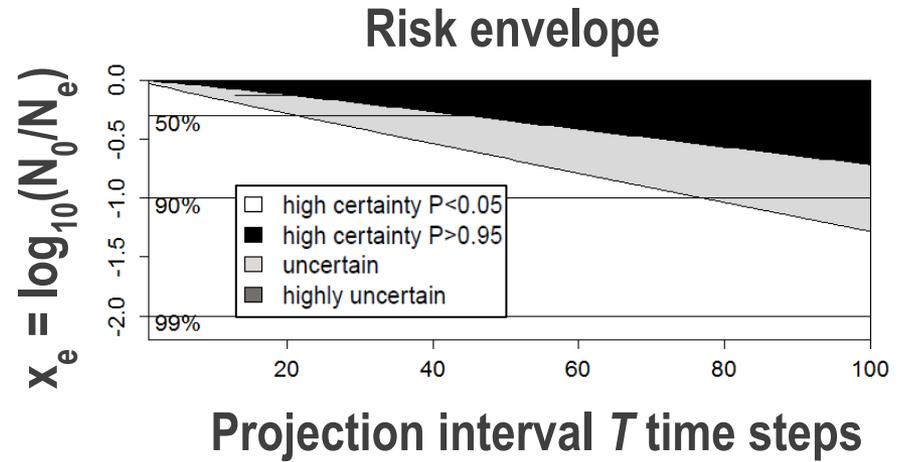
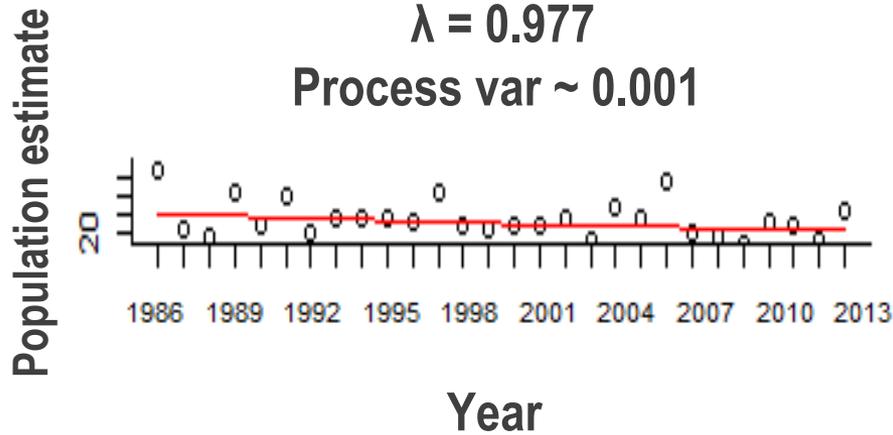
- Extra slides (for questions/discussion) here

Abundance and extinction risk of Snow Creek steelhead



- No definitive evidence for declining productivity, but abundance has fallen
- Future abundance is unpredictable

Abundance and extinction risk of Sashin Creek steelhead



- No evidence for declining productivity; abundance is low and stable
- Resident fish are abundant, but it isn't known how many smolts they produce

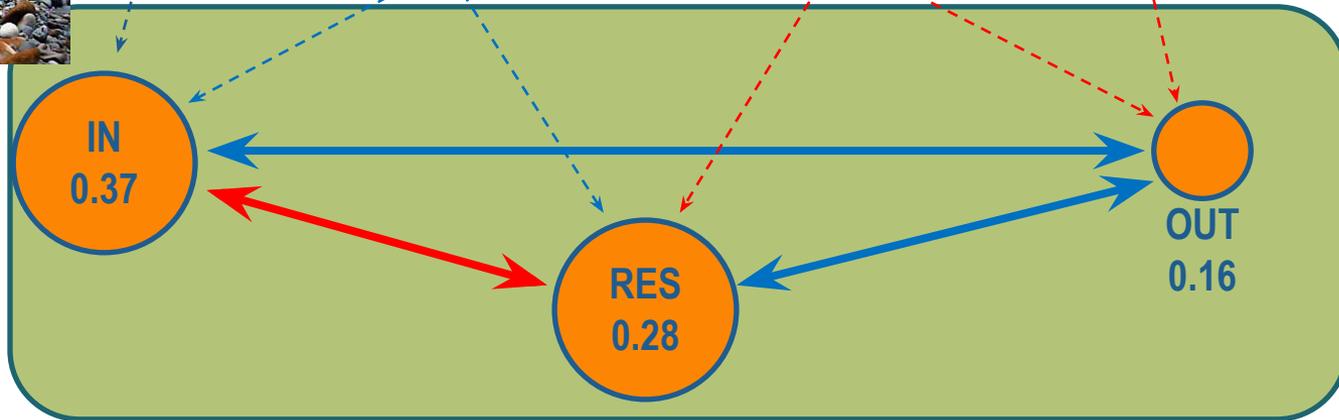
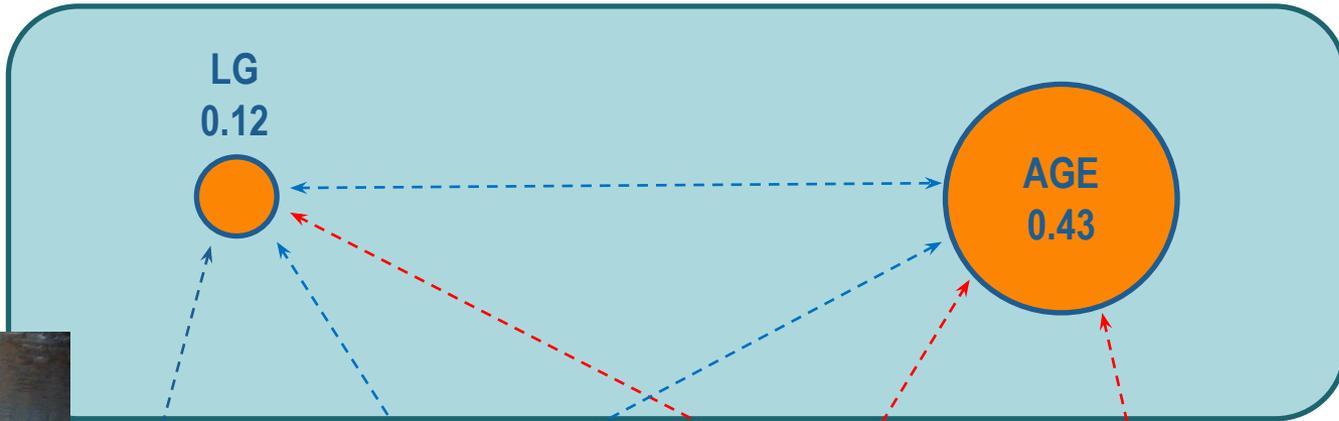
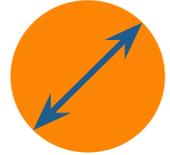
Evolution of life history in wild steelhead

Demography

LG
0.12

AGE
0.43

h^2



Phenology

IN
0.37

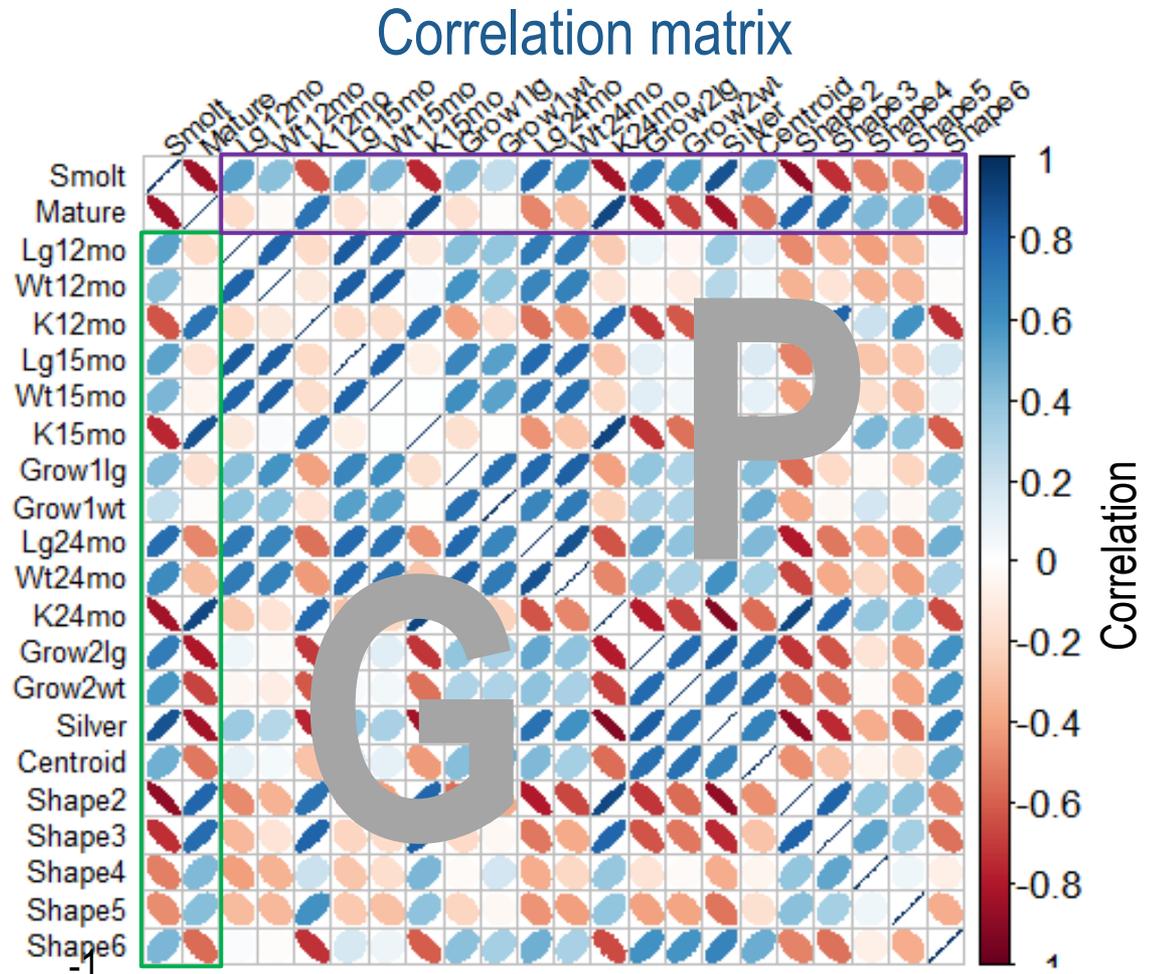
RES
0.28

OUT
0.16

- Size and run timing can and do respond to selection
- Adult phenology and stream residence covary and influence RS

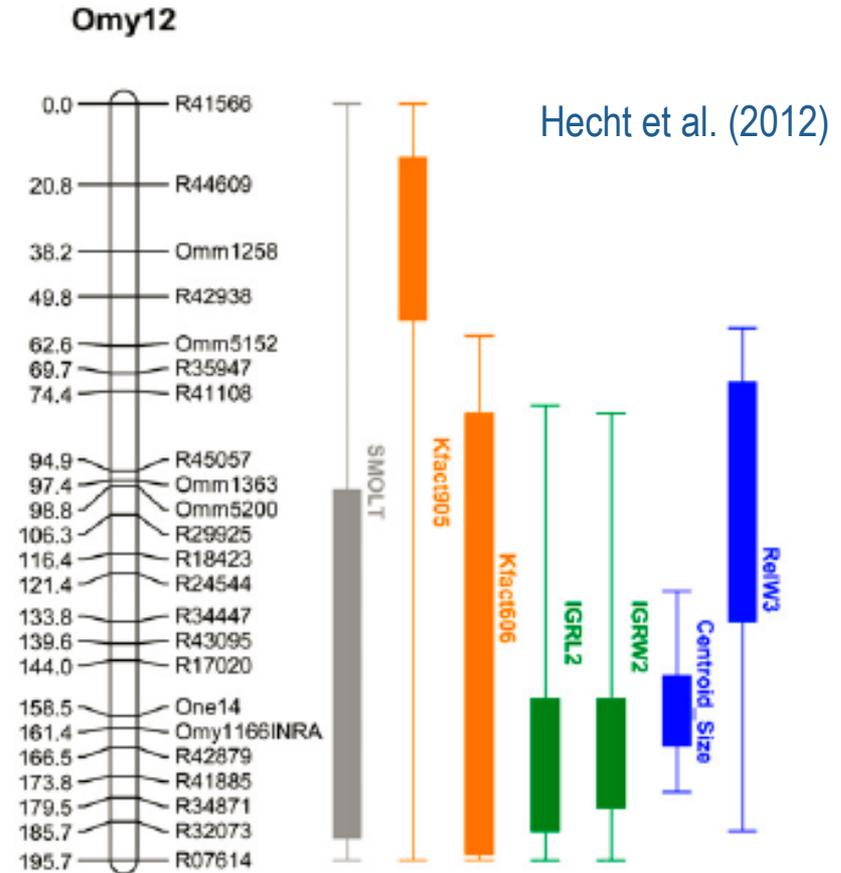
Architecture of juvenile *O. mykiss* life history

- Growth, size and shape are heritable and highly correlated
- QTL for these traits map to genomic sites known to influence migration propensity
- Resident and migratory trajectories appear to be highly canalized



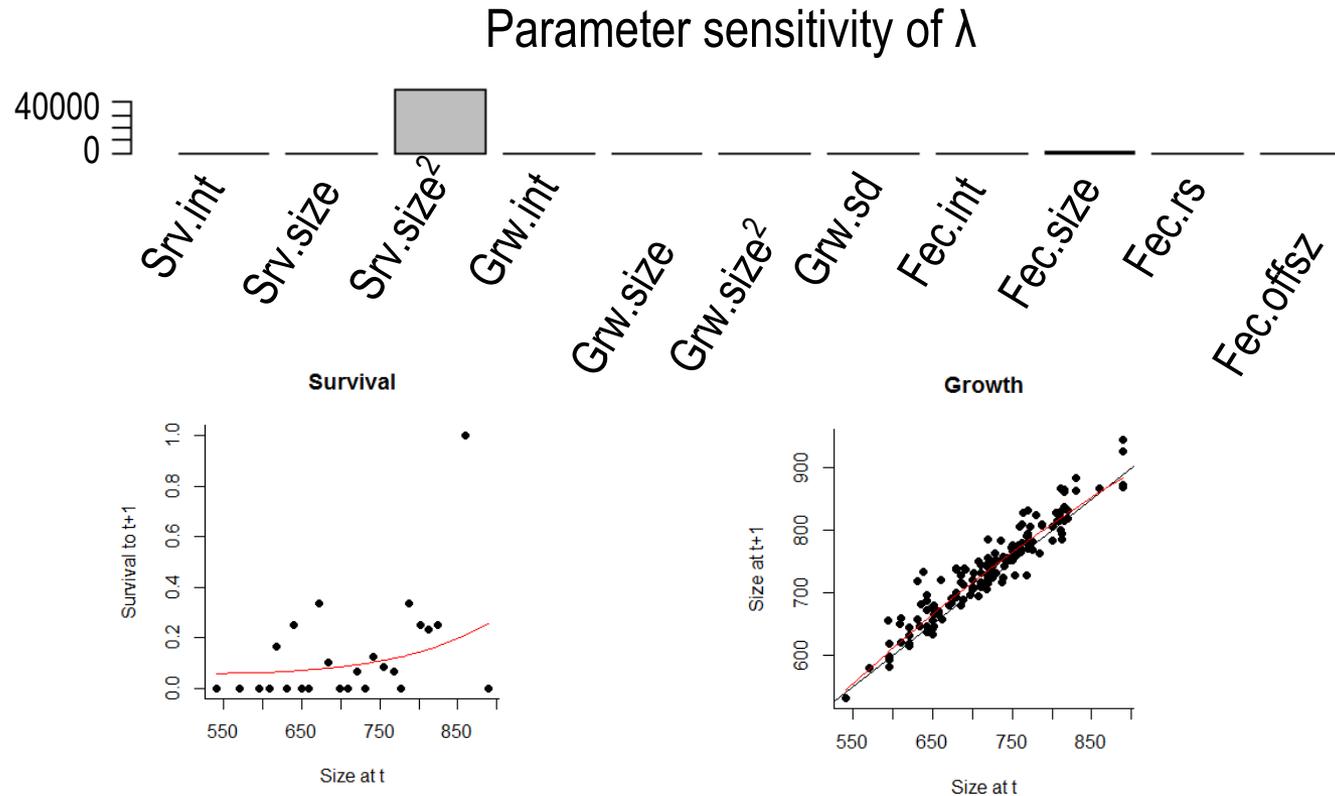
Hecht et al. (2015)

Steelhead smolt Quantitative Trait Loci



- QTL for traits associated with smolt metamorphosis map to specific linkage groups

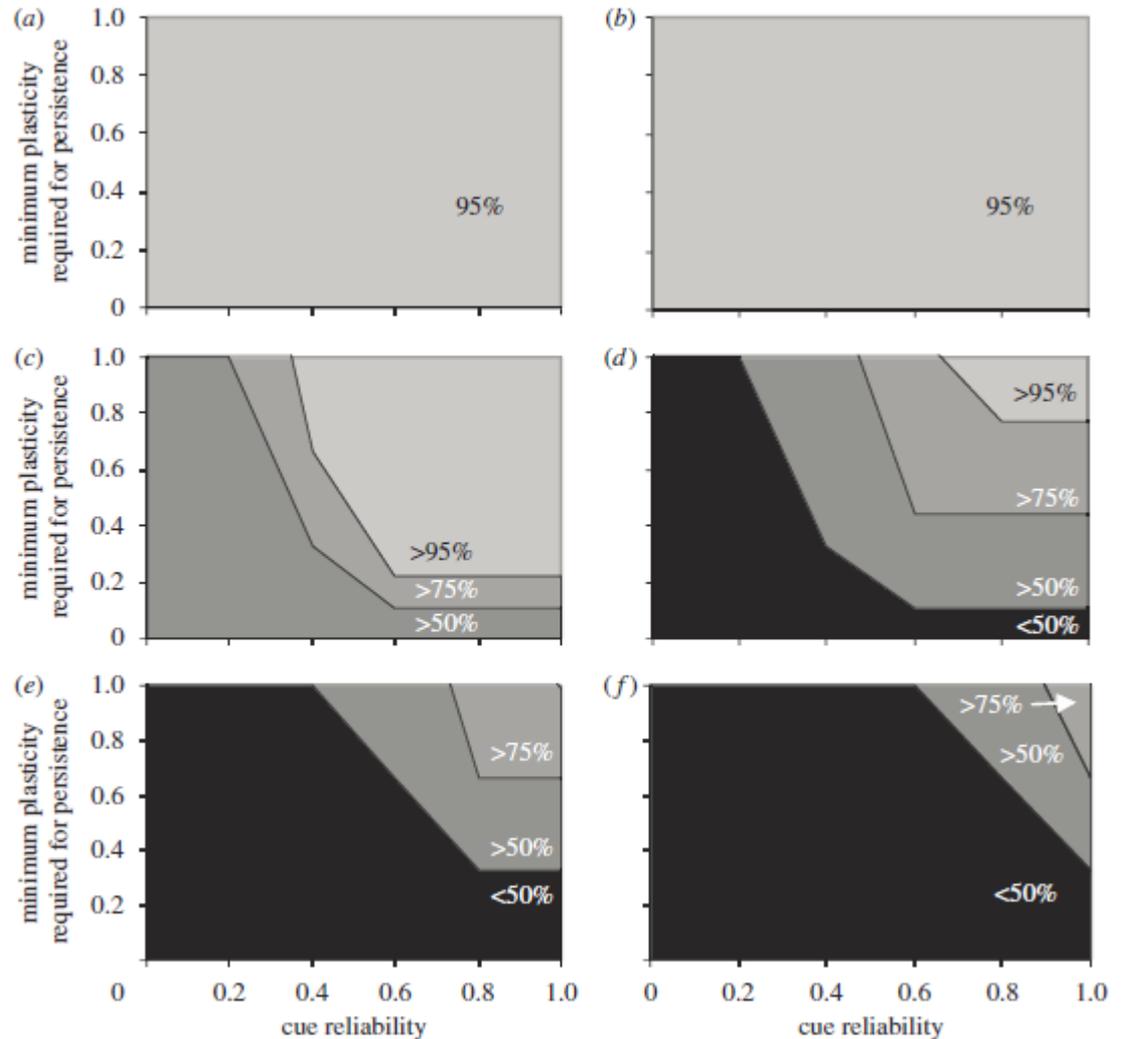
Size transitions can drive population dynamics



- Population growth is sensitive to the way that size influences annual marine survival, fertility and reproductive success

Plasticity and persistence

- Plasticity allows greater likelihood of persistence, particularly in highly unpredictable environments
- However, the environmental cue must be sufficiently reliable



Reed et al. (2010)