Life-history diversity and ecology of *O. mykiss* in a coastal California watershed

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NOAA National Marine Fisheries Service, Southwest Fisheries Science Center

Motivation for this presentation:

- Introduce steelhead managers, biologists, and researchers to our work at Big Creek
- To provide a context for steelhead managers and recovery planners to consider life-history diversity and habitat/ecological processes when consideration actions and developing plans

Outline:

- Big Sur environment, Big Creek study area
- Overview of studies
- Observations and data so far
- Management considerations

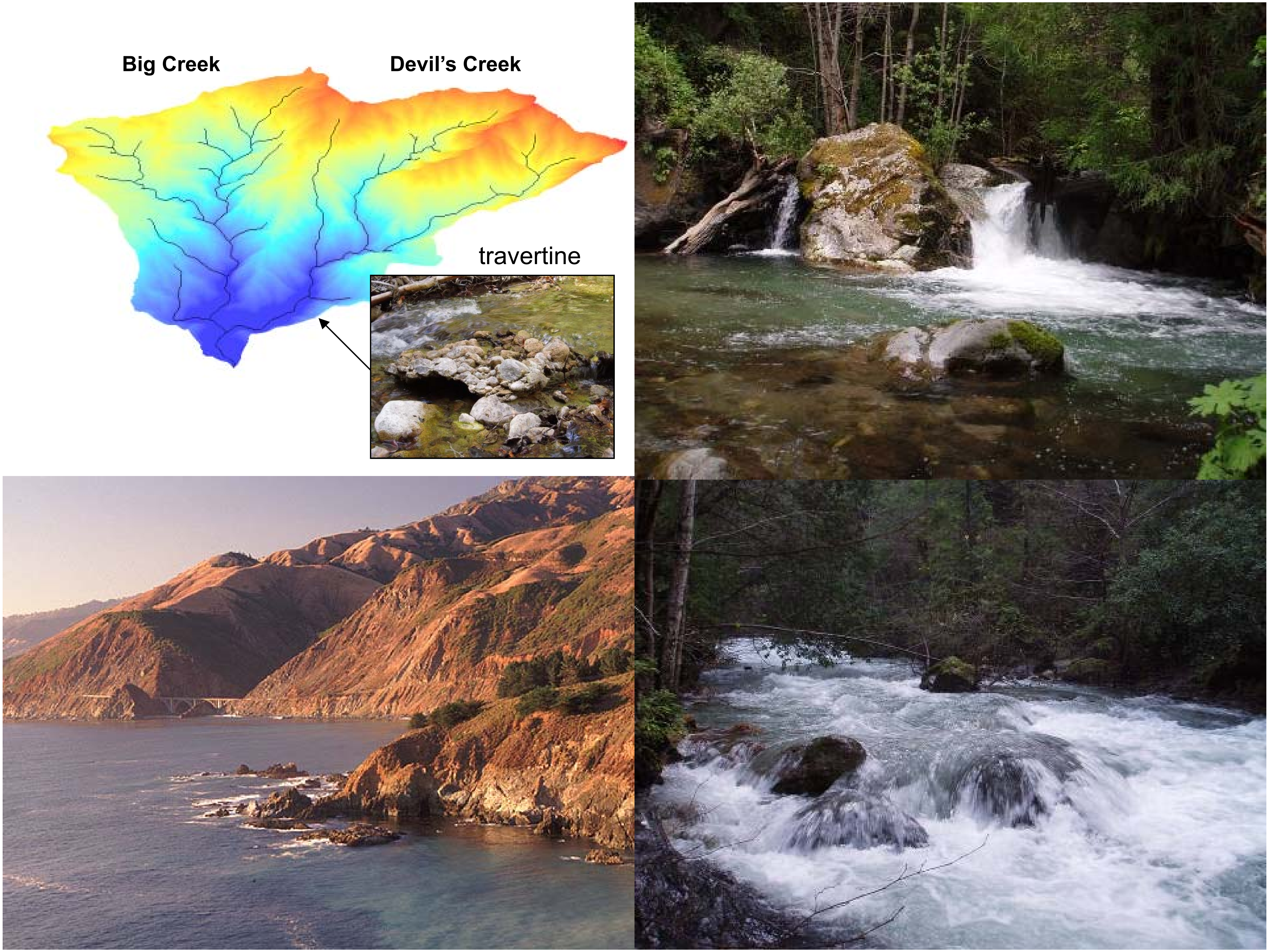
Big Creek Research Overview

O. mykiss population in Big Creek

- Estimate demographics and vital rates
- Develop a state-based life-cycle population model to assess dynamics
- Examine "population" response to disturbance events
- Gain better understanding of *O. mykiss* ecology in central California watersheds

Foundation – long-term population monitoring, state-based model approach to examine population dynamics

- **Focus to date is in Big Creek**
- **Future plans include additional Big Sur area streams**

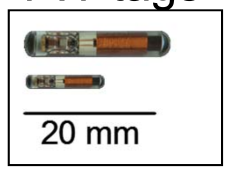

Big Creek
Devil's Creek
travertine

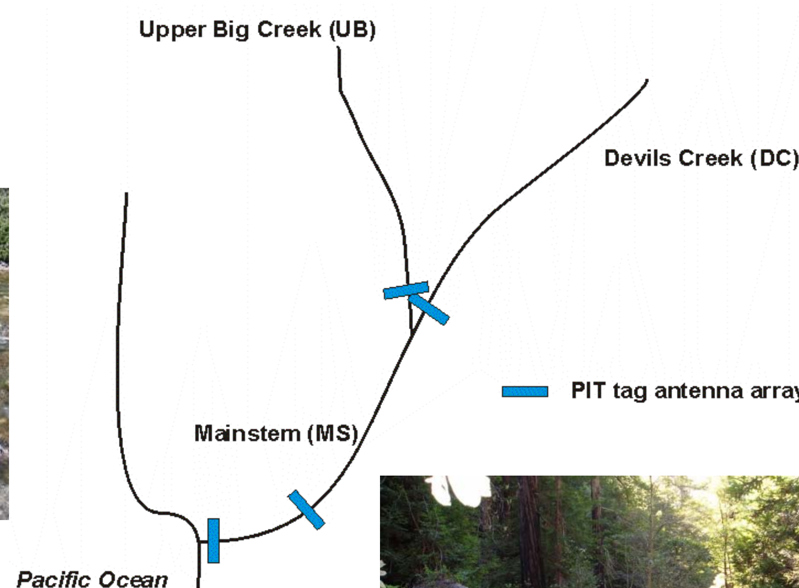
Study design - population dynamics

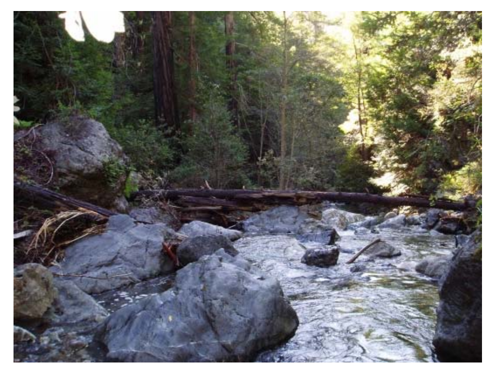
Field methods:

- Capture-recapture sampling using PIT tags
  - fall and spring since fall 2005
- Track fish with PIT tag antennas
  - within basin and to and from ocean

PIT tags







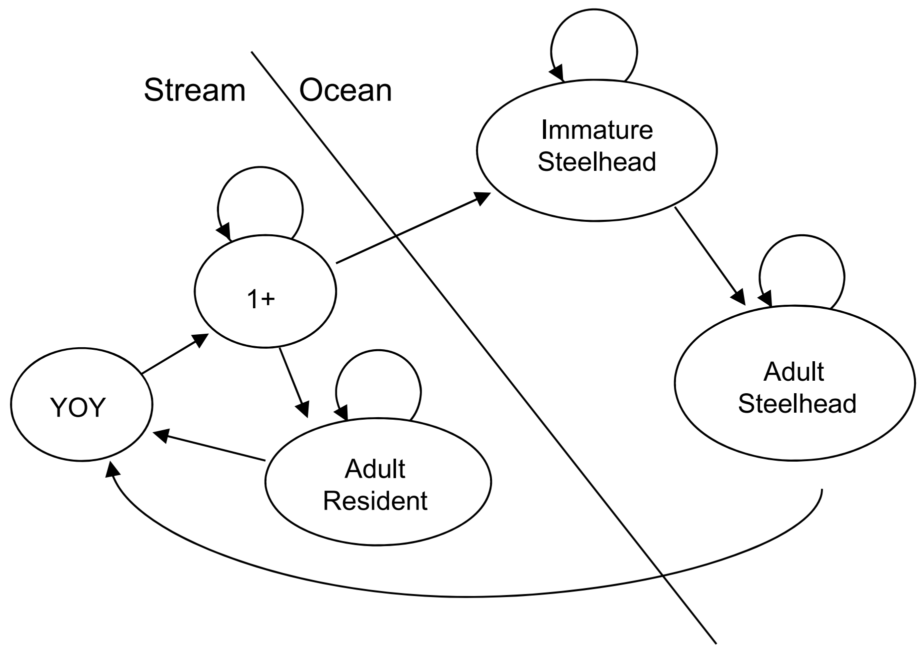
Study design - population dynamics

Population modeling:

- Analyze tagging data with capture-recapture models
  - abundance, survival, and transition rates among size/age classes
  - non-anadromous vs. anadromous pathways
  - residence times in stream/ocean

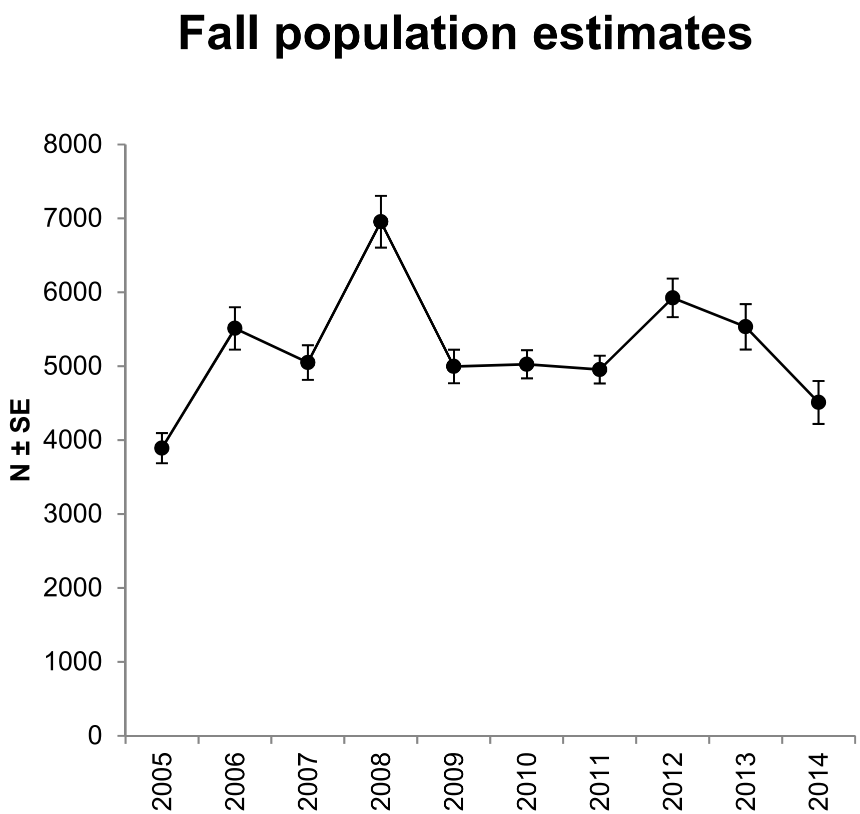
⬇

- Life-cycle based population model
  - population growth rate
  - simulate population dynamics
    - longer time frames
    - effects of changes to specific life stages, metapopulations, etc.
    - resilience and critical life stages



Tagging summary

- 25,431 fish tagged since 2005
- 64% of “fish” with HDX tags detected on antennas

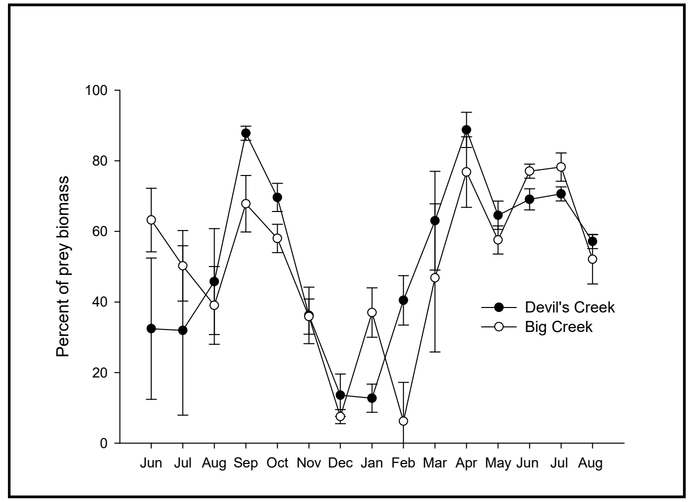


Studies

- Population dynamics
  (Williams, Rundio, Lindley)
  - Case study of one basin (Big Creek)
  - Additional basins??
  - Mark-recapture sampling
  - Population modeling
- Otolith microchemistry
  (C. Donohoe)
  - Maternal origin of juveniles
  - Maternal-offspring correspondence
  - Migration history
- Genetic analysis
  (D. Pearse, C. Garza)
  - Gender identification
  - Family structure, heritability of life-history tactics

Terrestrial subsidies to *O. mykiss*: seasonal patterns and non-native prey

Dave Rundio and Steve Lindley



Summary of Rundio and Lindley (2008)

- Among systems studied to date, terrestrial inputs to Big Creek were protracted with relatively low seasonal fluctuations.
- Seasonal patterns of aquatic invertebrates and terrestrial inputs were closer in phase than other systems.
- Terrestrial invertebrates were 50-60% of prey biomass consumed by steelhead.
- Non-native terrestrial isopod *Armadillidium* was 30-40% of prey biomass.

Transactions of the American Fisheries Society 137:467–480, 2008
American Fisheries Society 2008
DOI: 10.1577/T07-076.1

[Article]

Seasonal Patterns of Terrestrial and Aquatic Prey Abundance and Use by *Oncorhynchus mykiss* in a California Coastal Basin with a Mediterranean Climate

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Abstract.—Terrestrial invertebrates are a major source of prey for salmonids in many streams. Their importance as prey appears to be related to (1) the seasonal timing of terrestrial inputs relative to the abundance of aquatic prey and (2) water temperature, which affects food demand by fish. Most studies of seasonal patterns of terrestrial inputs have come from temperate systems, and patterns in most other systems are unknown. We measured monthly biomass of aquatic invertebrates, input of terrestrial invertebrates, and diets of *Oncorhynchus mykiss* (non-anadromous and juvenile anadromous life history forms) for 15 months in two streams in a basin with a Mediterranean-type climate on the Big Sur coast of California. Biomass of aquatic invertebrates and terrestrial inputs followed a similar seasonal pattern; highest levels occurred in summer and early autumn and were highly correlated with water temperature. Total annual input of terrestrial invertebrates was 8.7 $g \cdot m^{-2} \cdot year^{-1}$, and terrestrial inputs provided about half of the prey biomass and energy consumed by *O. mykiss* during the study. Nonnative terrestrial isopods, primarily *Armadillidium vulgare*, contributed 30–40% of the biomass and 20–30% of the energy consumed—the highest proportions among all taxa. The annual input, seasonal pattern, and contribution of terrestrial invertebrates to salmonids in this coastal Mediterranean-type basin were similar to published values from temperate forested streams. However, the magnitude of seasonal fluctuations of inputs was less pronounced than that in most temperate streams and appears to reflect the lower intra-annual temperature variation and longer leaf-out period in this system. Unlike many temperate streams, where terrestrial inputs provide an alternate prey source when aquatic invertebrate abundance is low, terrestrial inputs to these two coastal streams apparently provide a year-round additional source of prey that (like aquatic prey) peaks when water temperature is warmest and hence when fish growth potential is high.

Terrestrial invertebrates are an important source of prey for fish in many streams and can influence population and food web dynamics (Hunt 1975; Baxter et al. 2005). Annual inputs of terrestrial prey potentially equal the production of aquatic invertebrates in small forested streams (Mason and MacDonald 1982; Cloe and Garman 1996), and fish, particularly salmonids, often feed selectively on terrestrial prey (Hunt 1975; Nakano et al. 1999a). Terrestrial invertebrates constitute 50–85% of the prey biomass consumed by salmonids during certain times of year in many forested streams (Hunt 1975; Baxter et al. 2005) and support 50% of the annual energy budgets for several species in a Japanese stream (Kawaguchi and Nakano 2001; Nakano and Murakami 2001) and for brook trout *Salvelinus fontinalis* in West Virginia streams (Utz and Hartman 2007; Sweka and Hartman 2008). Experiments have shown that terrestrial inputs affect the distribution, movement, and local abundance of trout within streams (Kawaguchi et al. 2003) and mediate trophic interactions by altering top-down effects of trout predation on stream communities and interactions between salmonid species (Nakano et al. 1999b; Baxter et al. 2004).

Use of terrestrial prey by fish is affected by spatial and temporal variation in inputs related primarily to riparian vegetation and climate (Baxter et al. 2005). Terrestrial inputs generally are highest to streams in deciduous forests, followed by coniferous forests and then grasslands (Edwards and Huryn 1996; Wipfli 1997; Bridcut 2000; Kawaguchi and Nakano 2001; Allan et al. 2003; Romero et al. 2005), although inputs vary considerably among systems within each vegetation type (Baxter et al. 2005). Terrestrial inputs also fluctuate on daily and annual bases but follow a regular seasonal pattern in temperate zones, with inputs highest in summer and lowest in winter (Cloe and Garman 1996; Bridcut 2000; Nakano and Murakami 2001; Baxter et al. 2005). Within this general seasonal pattern in temperate systems, the magnitude of fluctuations between seasons appears to reflect the level of temperature variation and the length of the leafing period of riparian vegetation. For example, variation in the amount of terrestrial inputs between seasons was

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Male-biased sex ratio of nonanadromous *O. mykiss*

Dave Rundio, T. Williams, D. Pearse, S. Lindley

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ECOLOGY OF
FRESHWATER FISH

Male-biased sex ratio of nonanadromous *Oncorhynchus mykiss* in a partially migratory population in California

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Abstract – Differential rates of anadromy between males and females are common in partially migratory salmonid populations, but this pattern is not fully clear for *Oncorhynchus mykiss* (rainbow trout/steelhead) from the limited but mixed data available. In particular, there are very few data on sex ratios of juvenile and nonanadromous (resident) fish to help assess sex composition of various life stages and life-history types. We used a recently developed Y-chromosome genetic marker to assess sex ratio of stream-dwelling (i.e., juvenile and nonanadromous) *O. mykiss* in a small coastal basin in central California, USA. We analysed 384 samples collected from three contiguous study reaches over 3 years. Sex ratio was 1:1 among juvenile-sized *O. mykiss* (<150 mm) but highly male-skewed (83%) among nonanadromous-sized individuals (≥150 mm), and this sex ratio × size pattern did not differ among years or study reaches. Our results suggest that the rate of anadromy differs between males and females in this basin. Our study also demonstrates the application of new genetic markers to determine sex composition of immature and nonanadromous salmonids, which will help assess sex-specific life-history behaviour in partially migratory populations of *O. mykiss* and other species.

Key words: Salmonidae; sex ratio; partial migration; anadromy; life history; genetic sex marker

Introduction

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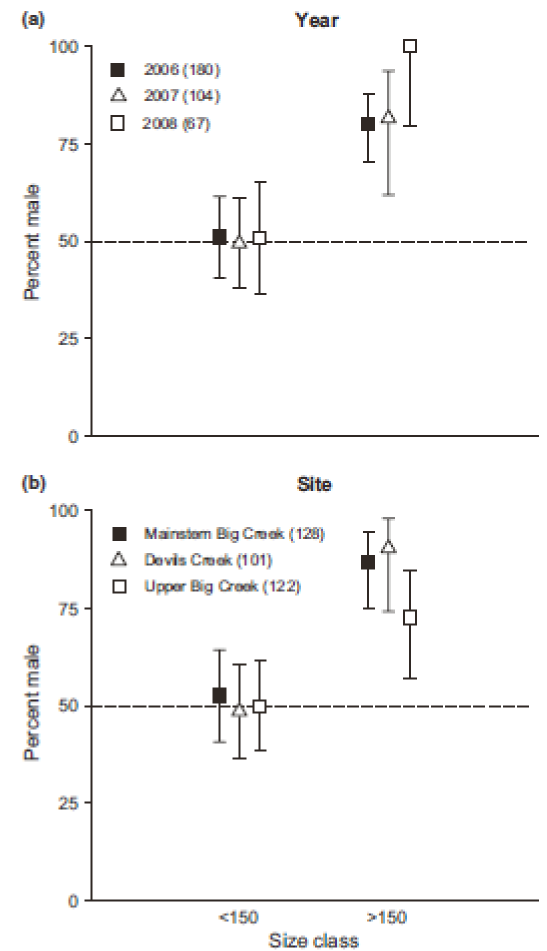


Fig. 3. Percentage of males in small (<150 mm) and large (≥150 mm) size classes of *Oncorhynchus mykiss* in the Big Creek basin by (a) year and (b) site. Error bars indicate 95% binomial confidence intervals, and dashed line indicates 1:1 sex ratio. Sample sizes are given in parentheses in legends.

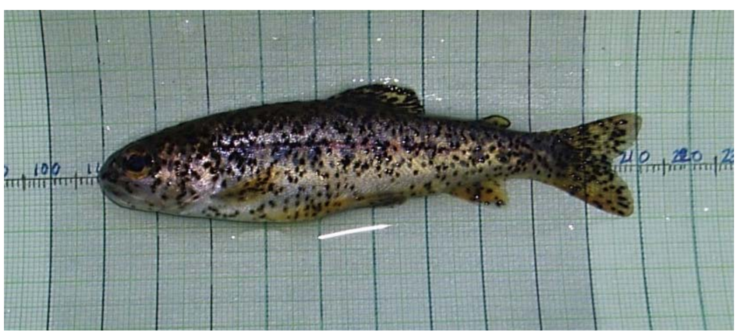
Summary of Rundio et al. (2012)

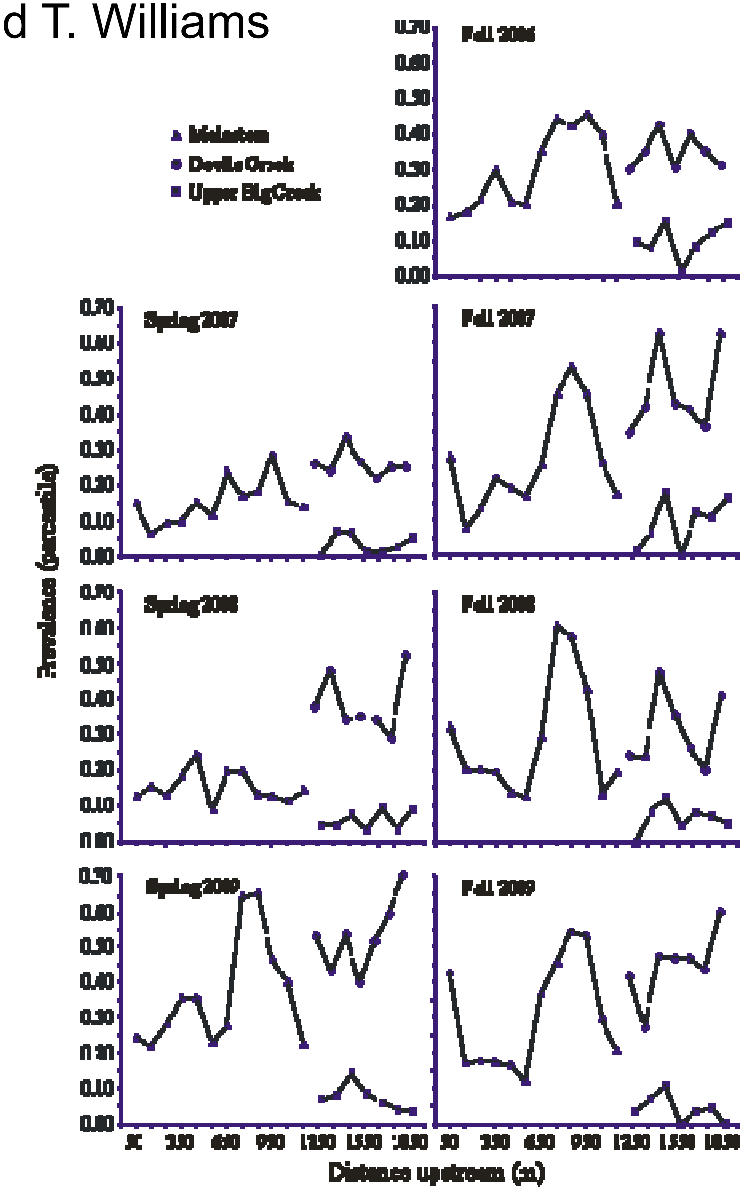
- Y-chromosome genetic marker used to assess sex ratio of stream-dwelling *O. mykiss*
- Sex ratio was 1: 1 among juveniles (< 150 mm)
- Sex ratio highly male-skewed, 83%, among nonanadromous-sized individuals (> 150 mm)
- Sex ratio X size pattern did not differ among years or study reaches
- Rate of anadromy differs between males and females within Big Creek

Prevalence of black spot

Pascale Goertler, S. Lindley, D. Rundio, and T. Williams

- Trematode (*Apophallus* sp.)
- Variable temporally and spatially



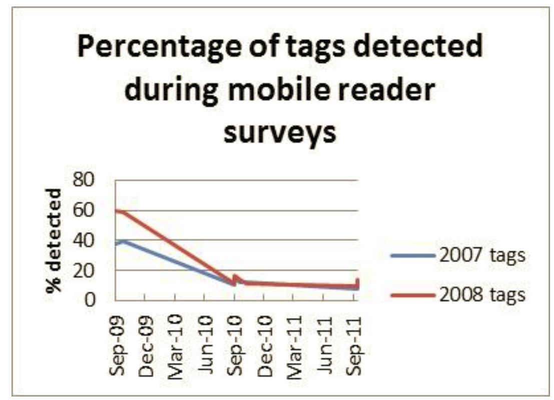


PIT tags in the stream: fish movement or rouge tags?

Kerrie Pipal and Steve Lindley

Problem: shed PIT tags can affect analysis when tag detection cannot be definitely linked to a live fish OR if shed tags are transported by flows (mimics fish moving downstream)

Approach: Mark/Recapture experiment with intentionally “released” tags



Summary

- Time was the most significant indicator of tag survival and detection probability
- The longer tags were in the system the less likely they were to be detected
- Tags either moved out of the system, settled into substrate and not detectable, or damaged so as not to function

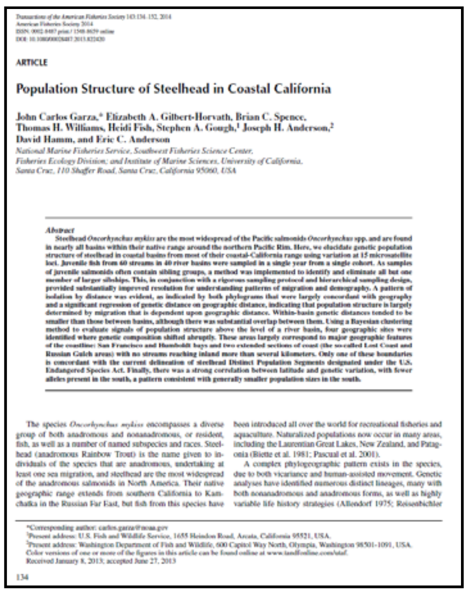
Other projects with Big Creek connections:

California coast-wide genetic survey (2003)

Garza et al. 2014 TAFS

Summary

- 60 streams in 40 watersheds
- Single cohort – YOY summer 2003
- Evident pattern of isolation by distance
- Strong correlation between latitude and genetic variation, fewer alleles present in southern populations
- *Sites resampled in summer 2014 (analyses underway)*



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ARTICLE

Population Structure of Steelhead in Coastal California

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Abstract
Steelhead *Oncorhynchus mykiss* are the most widespread of the Pacific salmonids *Oncorhynchus* spp. and are found in nearly all basins within their native range around the northern Pacific Rim. Here, we elucidate genetic population structure of steelhead in coastal basins from most of their coastal-California range using variation at 15 microsatellite loci. Juvenile fish from 60 streams in 40 river basins were sampled in a single year from a single cohort. As samples of juvenile salmonids often contain sibling groups, a method was implemented to identify and eliminate all but one member of larger sibships. This, in conjunction with a rigorous sampling protocol and hierarchical sampling design, provided substantially improved resolution for understanding patterns of migration and demography. A pattern of isolation by distance was evident, as indicated by both phylograms that were largely concordant with geography and a significant regression of genetic distance on geographic distance, indicating that population structure is largely determined by migration that is dependent upon geographic distance. Within-basin genetic distances tended to be smaller than those between basins, although there was substantial overlap between them. Using a Bayesian clustering method to evaluate signals of population structure above the level of a river basin, four geographic sites were identified where genetic composition shifted abruptly. These areas largely correspond to major geographic features of the coastline: San Francisco and Humboldt bays and two extended sections of coast (the so-called Lost Coast and Russian Gulch areas) with no streams reaching inland more than several kilometers. Only one of these boundaries is concordant with the current delineation of steelhead Distinct Population Segments designated under the U.S. Endangered Species Act. Finally, there was a strong correlation between latitude and genetic variation, with fewer alleles present in the south, a pattern consistent with generally smaller population sizes in the south.

The species *Oncorhynchus mykiss* encompasses a diverse group of both anadromous and nonanadromous, or resident, fish, as well as a number of named subspecies and races. Steelhead (anadromous Rainbow Trout) is the name given to individuals of the species that are anadromous, undertaking at least one sea migration, and steelhead are the most widespread of the anadromous salmonids in North America. Their native geographic range extends from southern California to Kamchatka in the Russian Far East, but fish from this species have been introduced all over the world for recreational fisheries and aquaculture. Naturalized populations now occur in many areas, including the Laurentian Great Lakes, New Zealand, and Patagonia (Biette et al. 1981; Pascual et al. 2001).

A complex phylogeographic pattern exists in the species, due to both vicariance and human-assisted movement. Genetic analyses have identified numerous distinct lineages, many with both nonanadromous and anadromous forms, as well as highly variable life history strategies (Allendorf 1975; Reisenbichler

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Color versions of one or more of the figures in this article can be found online at www.tandfonline.com/utaf.
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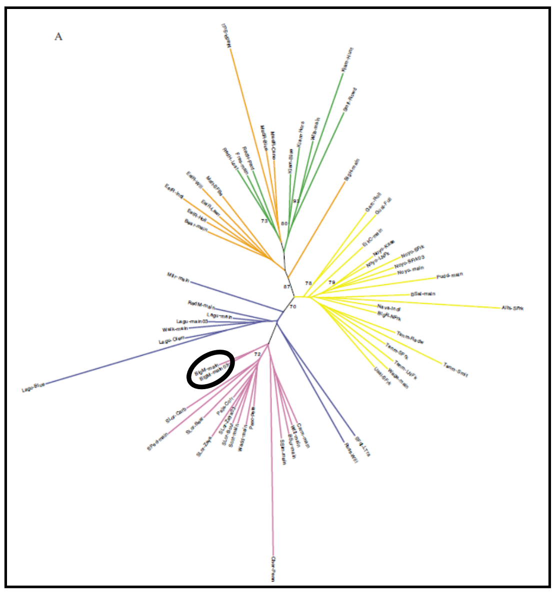
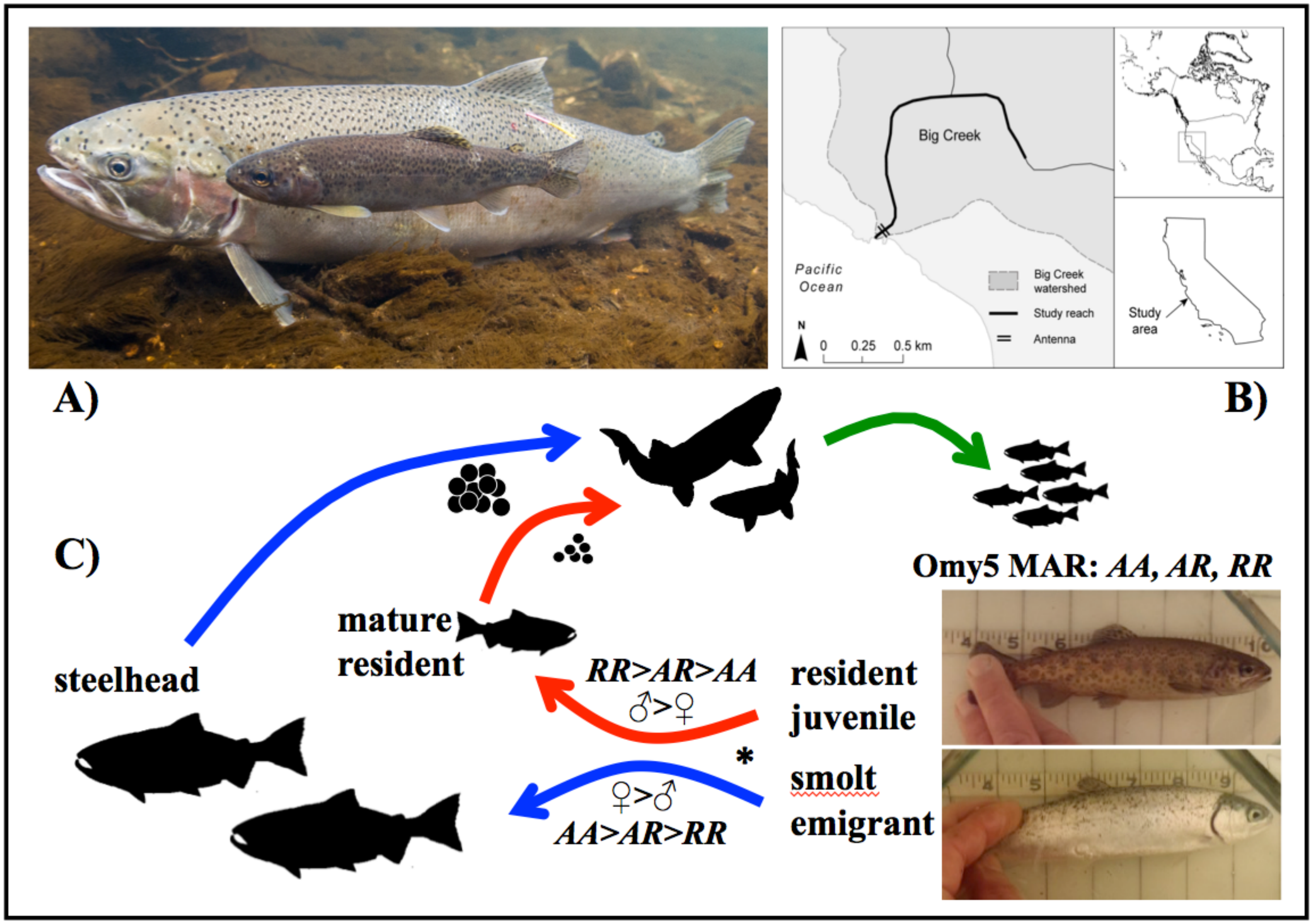


DIDSON feasibility study

Summary:

- DIDSON deployed 3 Jan – 8 May 2007; 2636 hours of operation
- Raised issues of “milling”, contributed to development of “Decision Support Tool”
- 990 fish observations, with DST estimate of 22 – 33 steelhead adults

O. mykiss below barriers in Big Creek
Population dynamics and life-history variation



Study design—genetic analysis

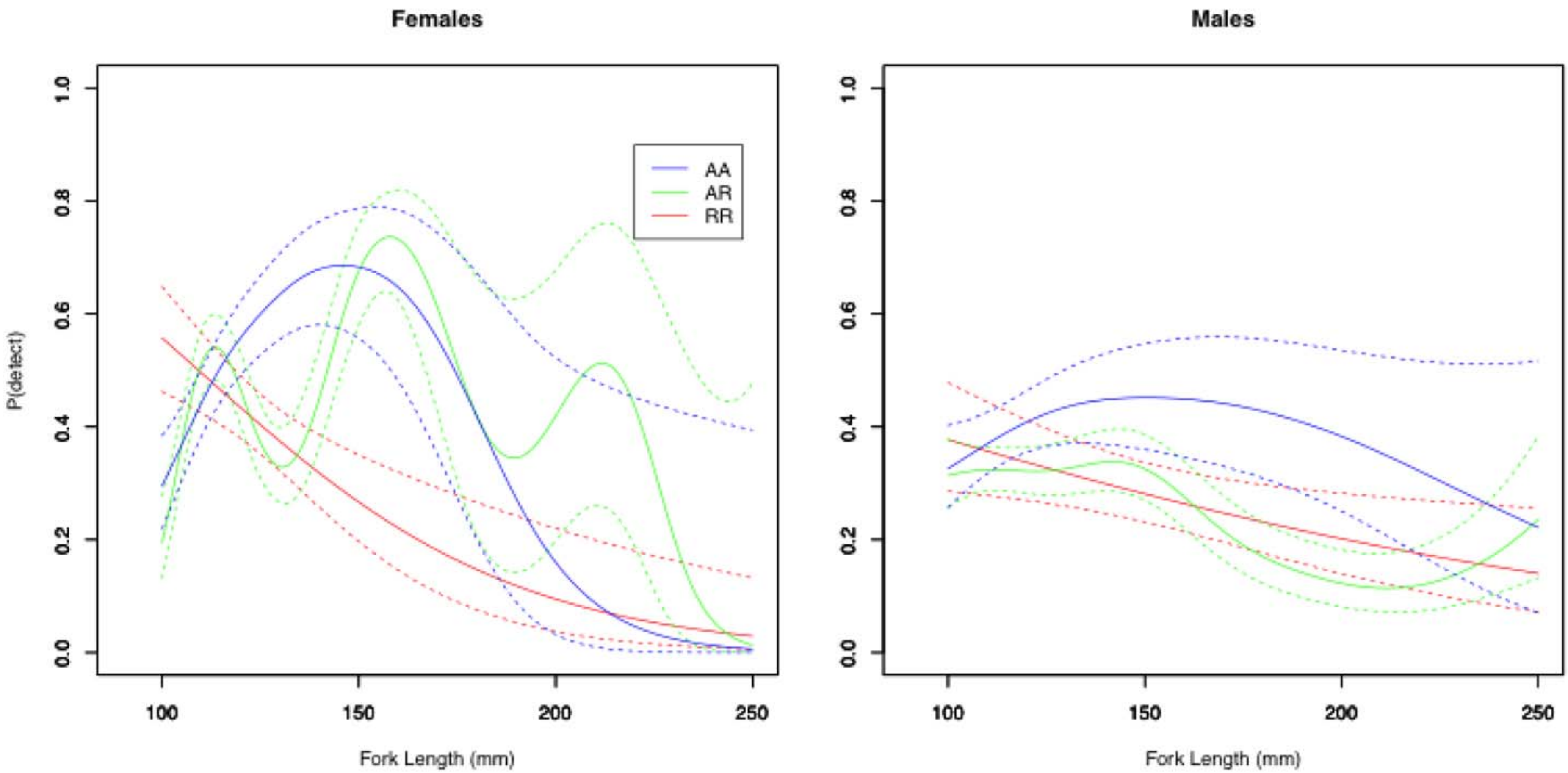
3,700 samples with length, weight, and re-capture histories.

Genotype 96 SNP loci:

- 92 neutral SNPs for population genetics and sibship analysis
- Genetic assay for gender

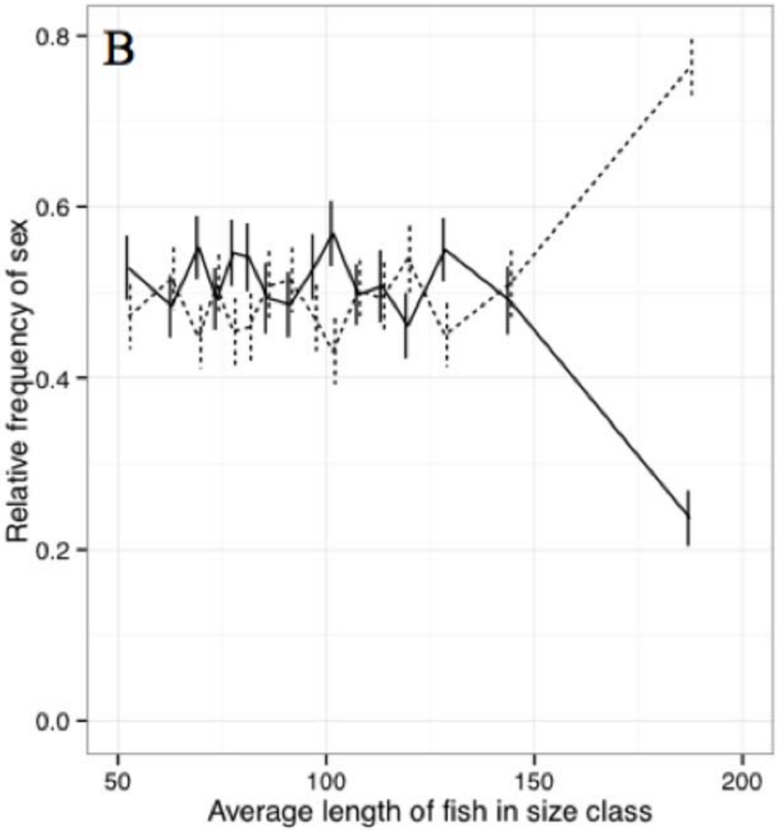
Two loci located within the *Omy5* linkage block

>Highly significant individual effect of *Omy5* genotype.

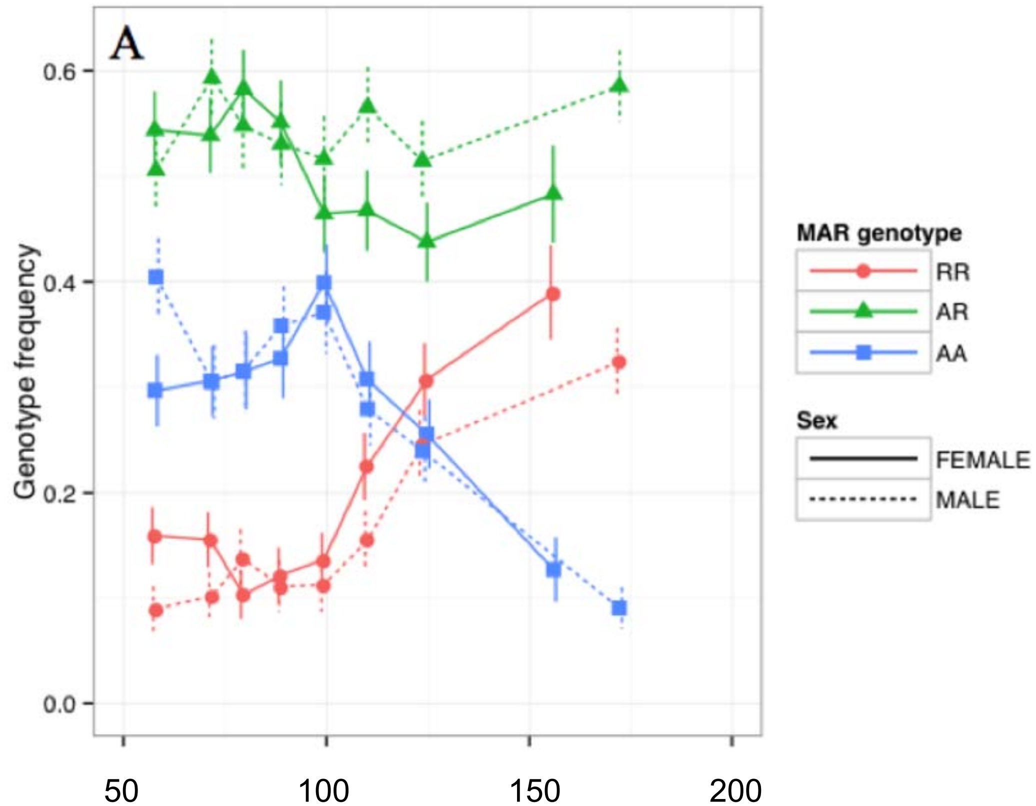


Pearse, Anderson, Garza, Rundio, Williams, Lindley, *Unpub.*

Highly skewed sex and *Omy5* ratios in post-smolt population:



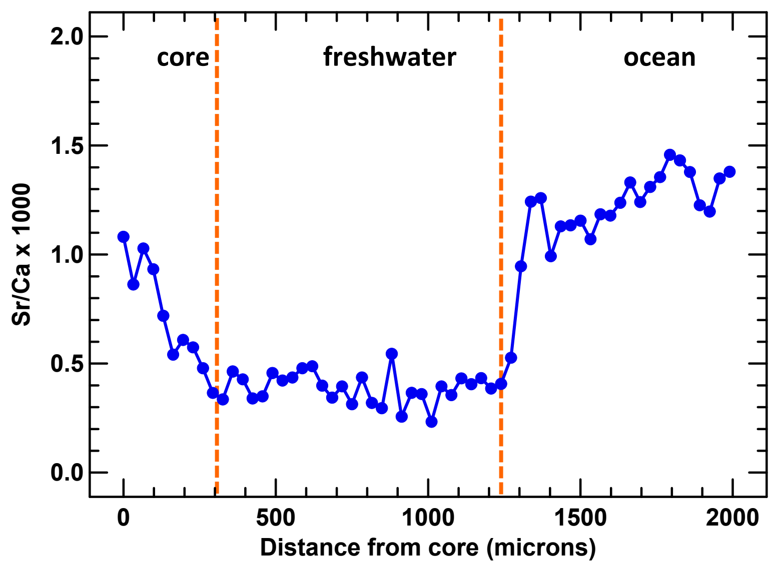
Rundio et al. 2012 Ecol. Freshwater Fish



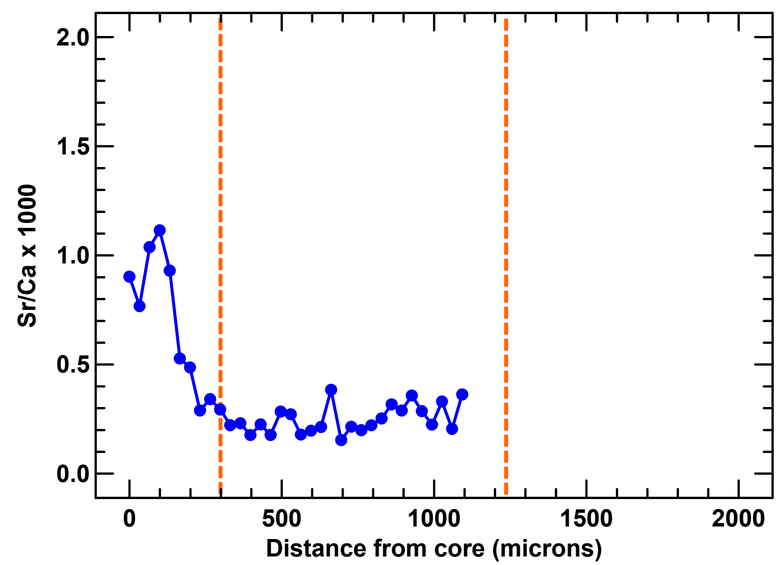
Pearse, Anderson, Garza, Rundio, Williams, Lindley, *Unpub*.

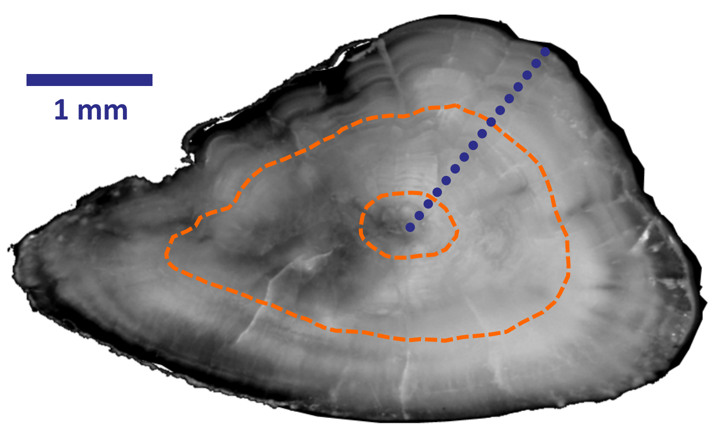
Maternal origin and migratory life histories using otolith Sr/Ca and $^{87}Sr/^{86}Sr$ ratios

Adult FL = 740 mm



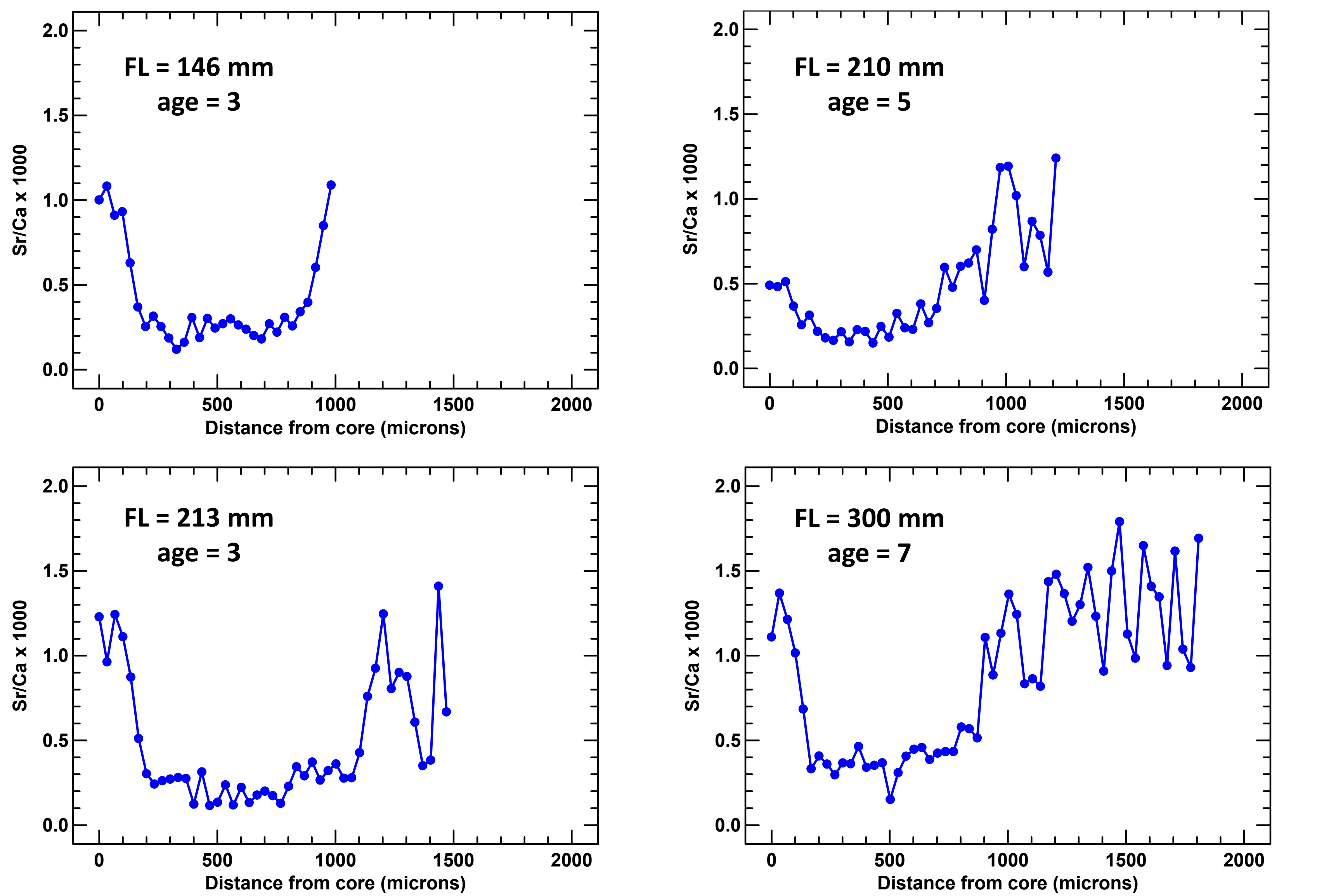
juvenile FL = 165 mm



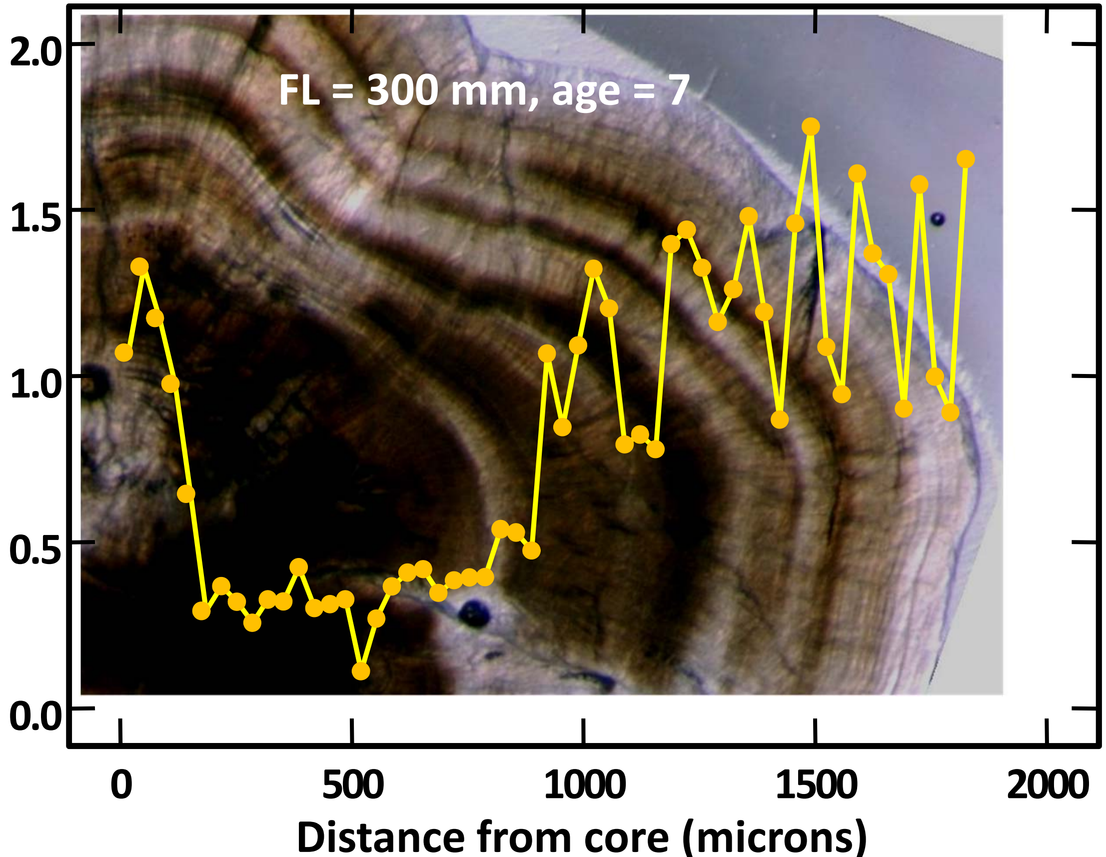


Chris Donohoe
UC Santa Cruz

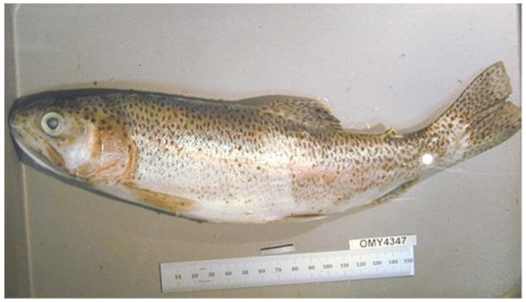
Sr/Ca profiles - “residents” migrate to sea



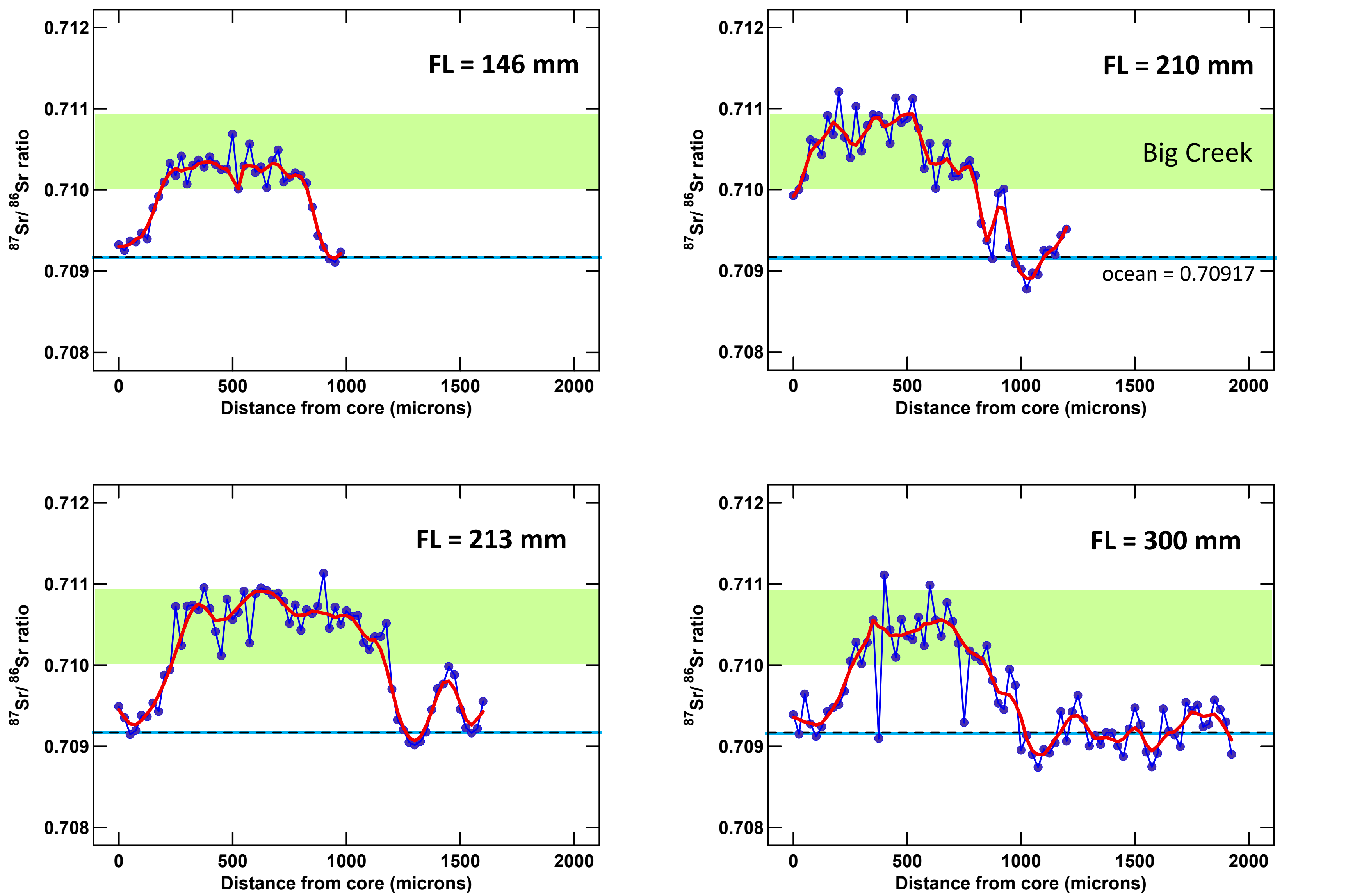
Marine migrations – coincide with otolith annuli



- 7 annuli, 7 marine migrations
- high Sr/Ca (ocean) in summer



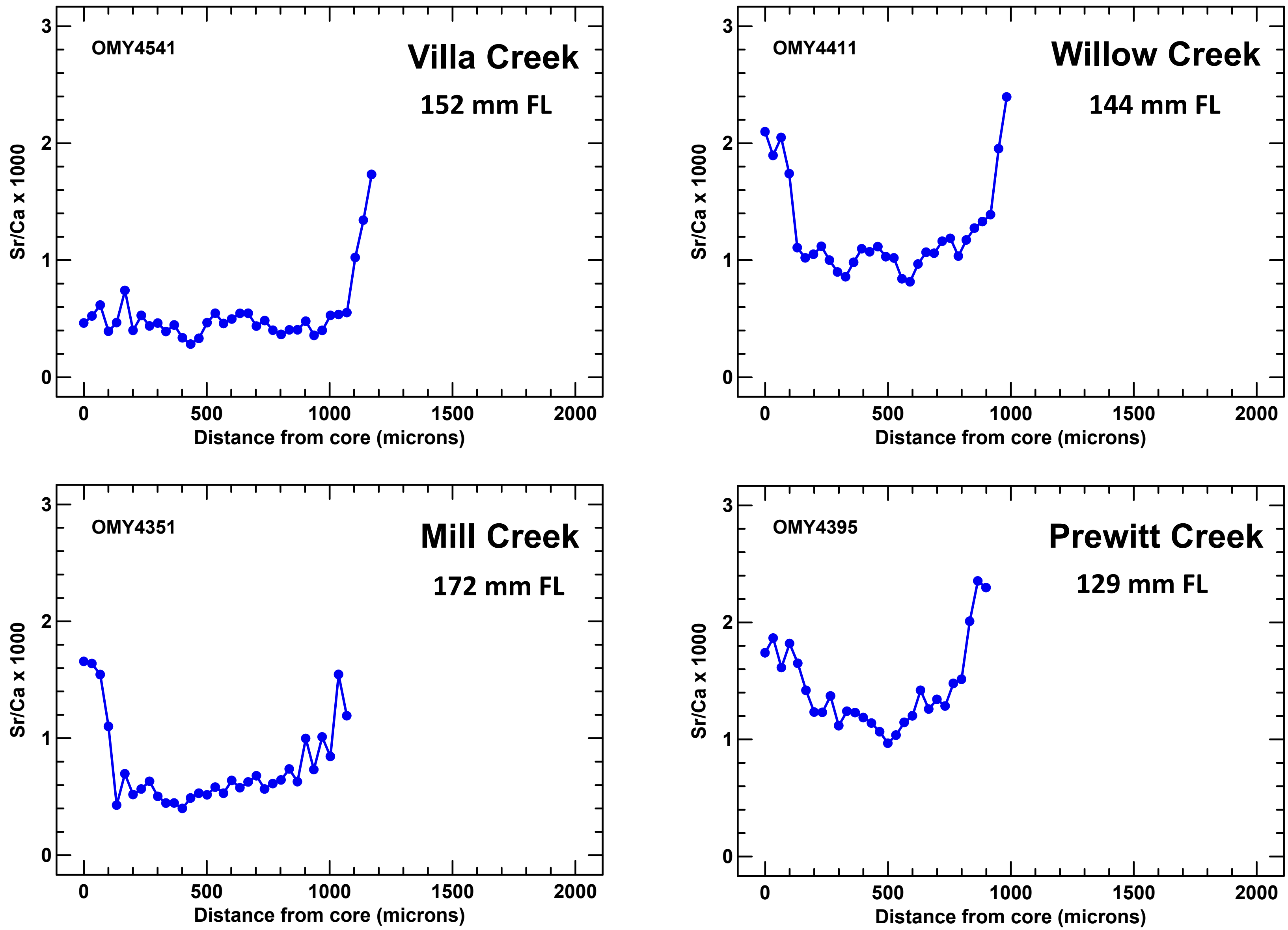
$^{87}Sr/^{86}Sr$ profiles - confirm marine migrations



Marine migrations – common in Big Crk >140 mm FL

Length class	N	% migrants
40 - 60	5	0 %
60 - 80	3	0 %
80 - 100	18	0 %
100 - 120	14	0 %
120 - 140	8	13 %
140 - 180	5	80 %
180 - 300	8	100 %
Totals	61	21 %

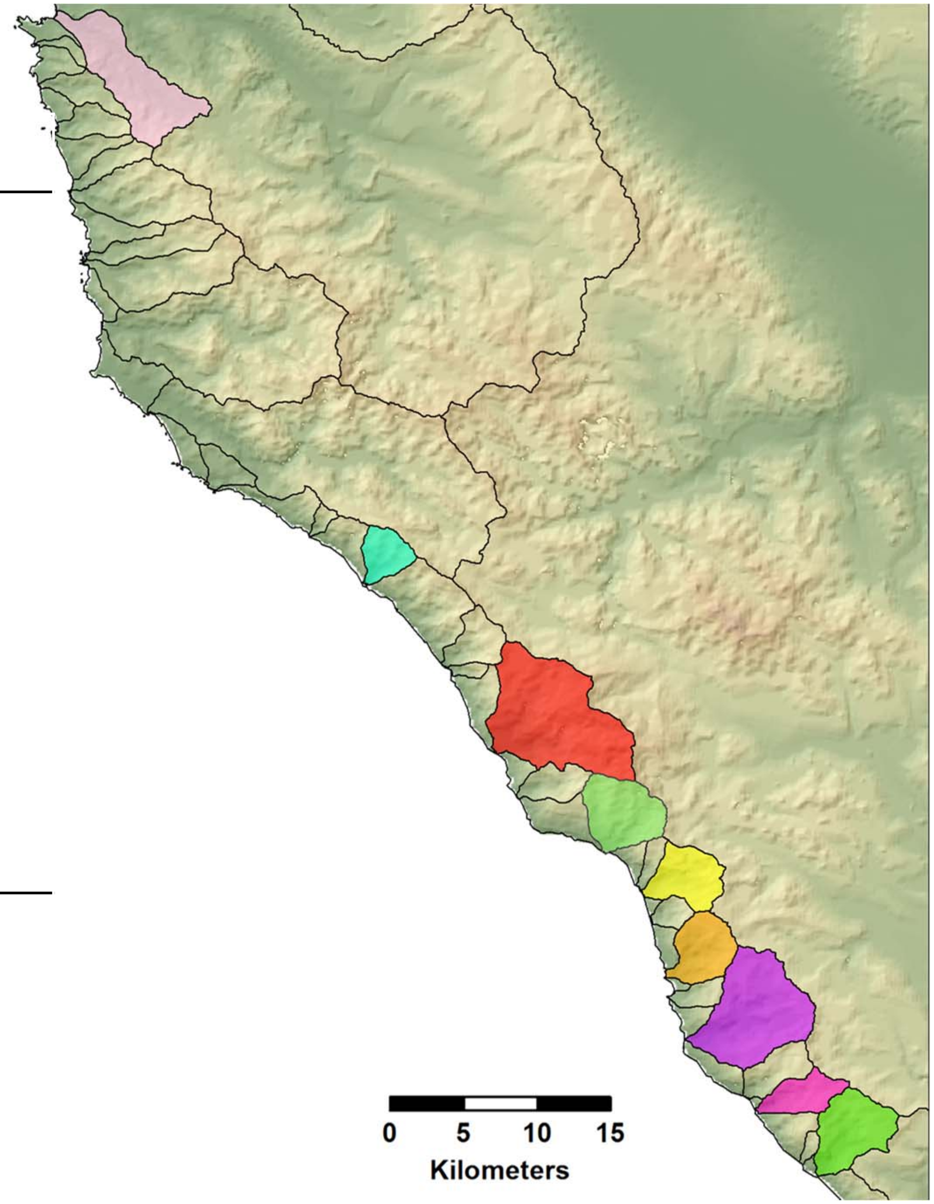
Marine migrations in other Big Sur streams



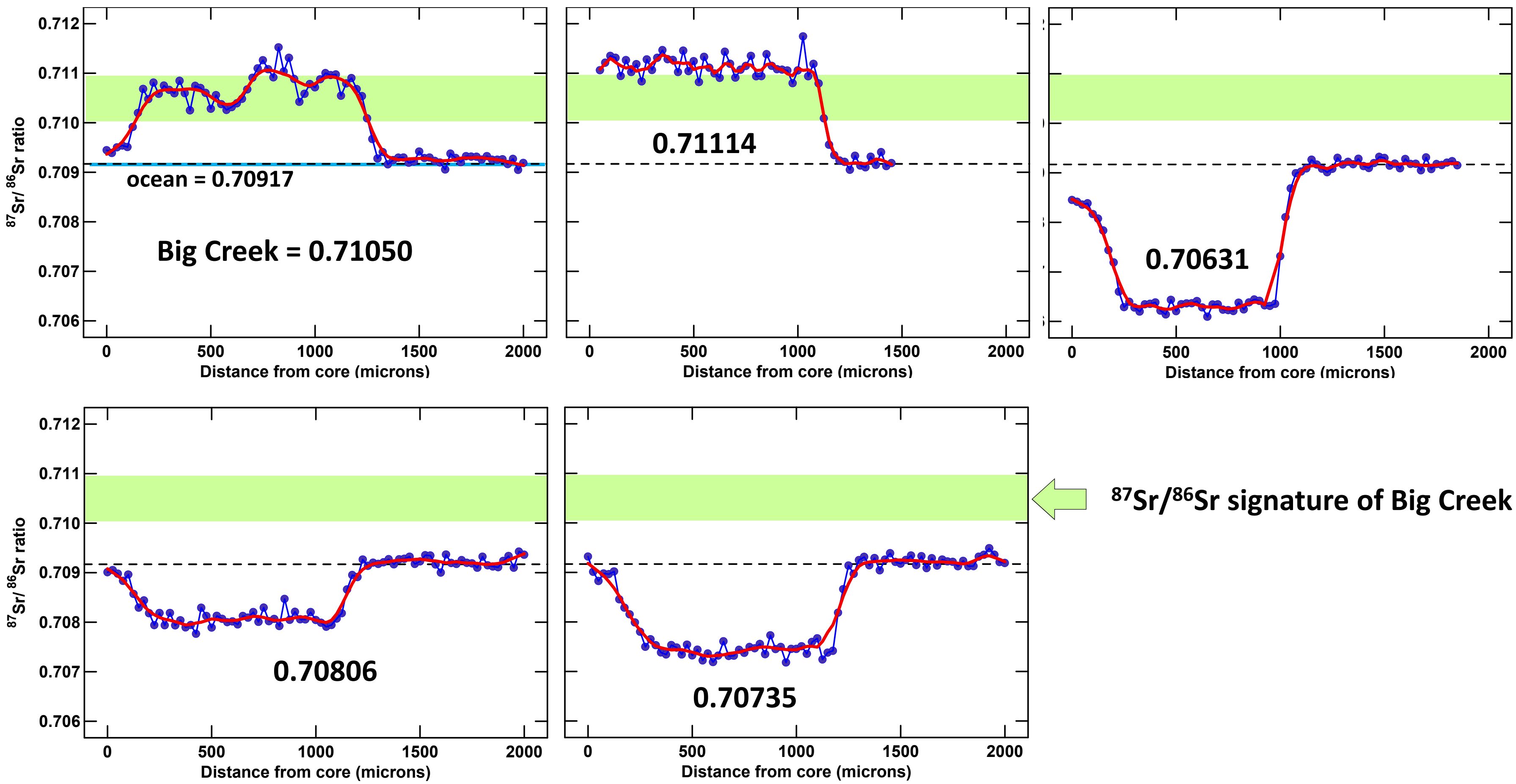
Marine migrations – several Big Sur streams

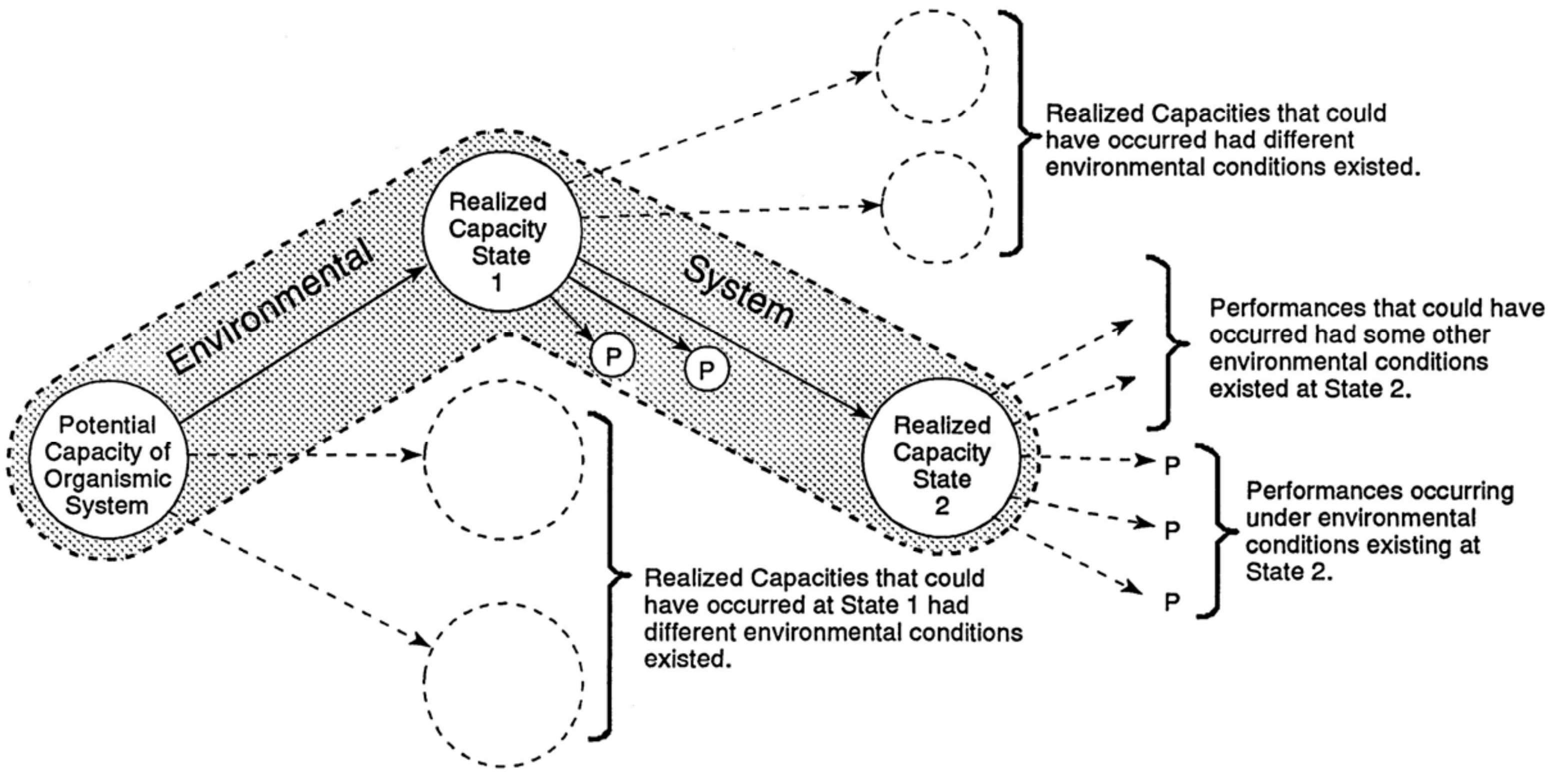
Stream	N	% migrants
San Jose	5	0 %
Partington	5	0 %
Big	22	**50 %**
Limekiln	5	0 %
Prewitt	6	**50 %**
Mill	4	**75 %**
Willow	7	**29 %**
Villa	18	**6 %**
Salmon	6	0 %
	78	26 %

for fish >120 mm FL



$^{87}Sr/^{86}Sr$ profiles of adults – most are strays





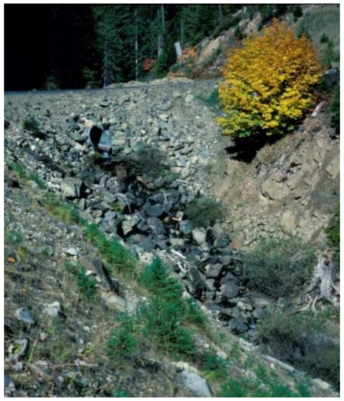
From Ebersole et al. 1997. Envir. Mgt. 21:1-14.

Natural disturbance events that influence salmonid populations throughout their range include:

- **fires**
- **landslides**
- **glaciers**
- **earthquakes**
- **volcanic eruptions**
- **floods**

Anthropogenic constraints that can influence the ability of salmonid populations to track changes in environmental conditions include:

- **urbanization**
- **land management activities (e.g., timber)**
- **fire (magnitude, frequency)**
- **flooding (magnitude, frequency)**







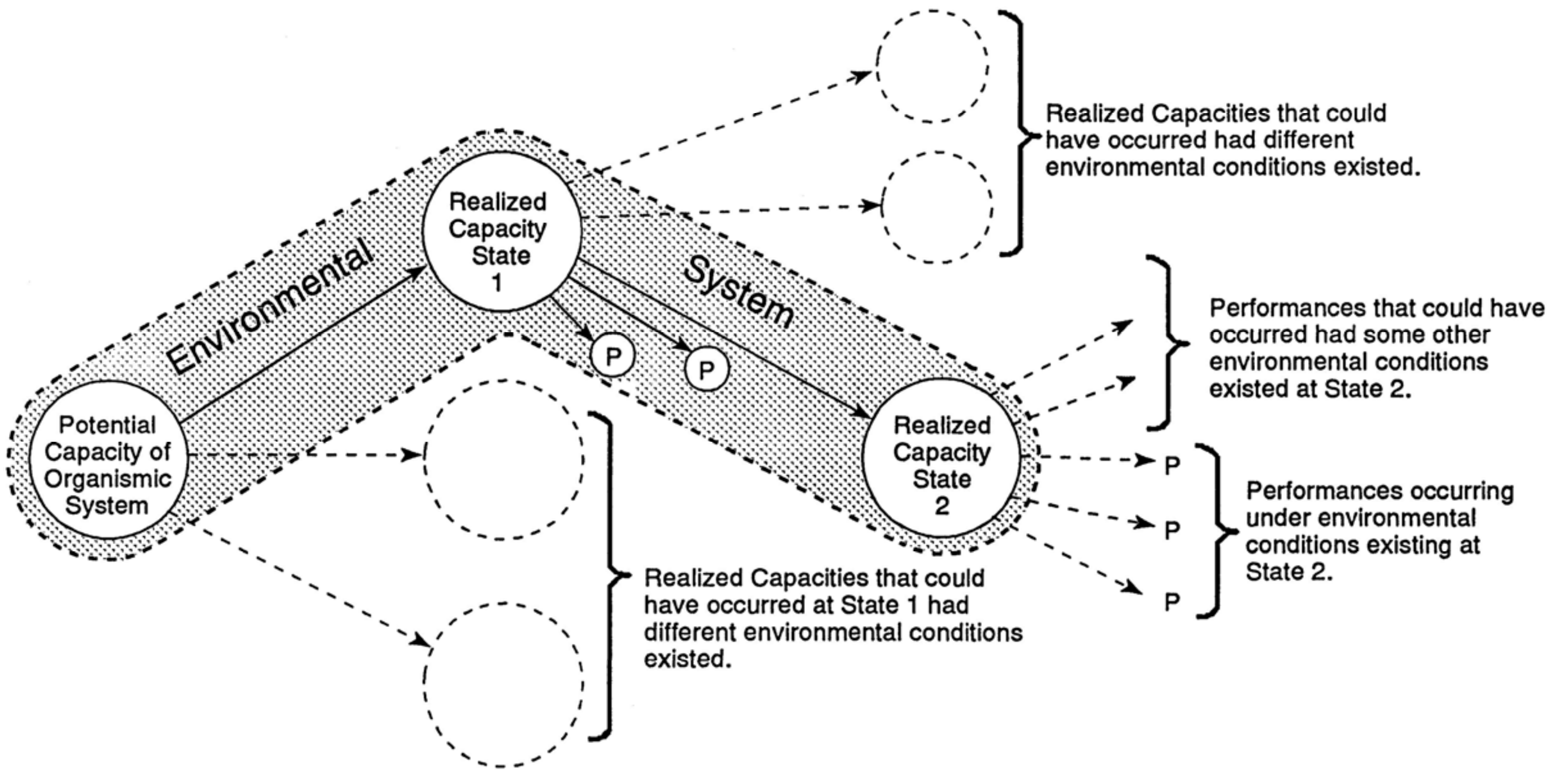
To be viable (i.e., persist) – fish need to be able to track changes in environment

- Individuals (within and between life stages, life histories, etc.)
- Populations
- Strata
- ESUs
- Species

Photo: M. Capelli

Salmonid Populations and ESUs Persist by Tracking Changes in Environmental Conditions

- **Straying by adults**
- **Relatively high fecundity**
- **Juvenile dispersal**
- **Distribution of run-timing**
- **Distribution of age at ocean entry**
- **Overlapping generations** ***(Chinook and O. mykiss, coho to some degree)***
- **For *O. mykiss* and coastal cutthroat trout, non-anadromous and anadromous life-history types**



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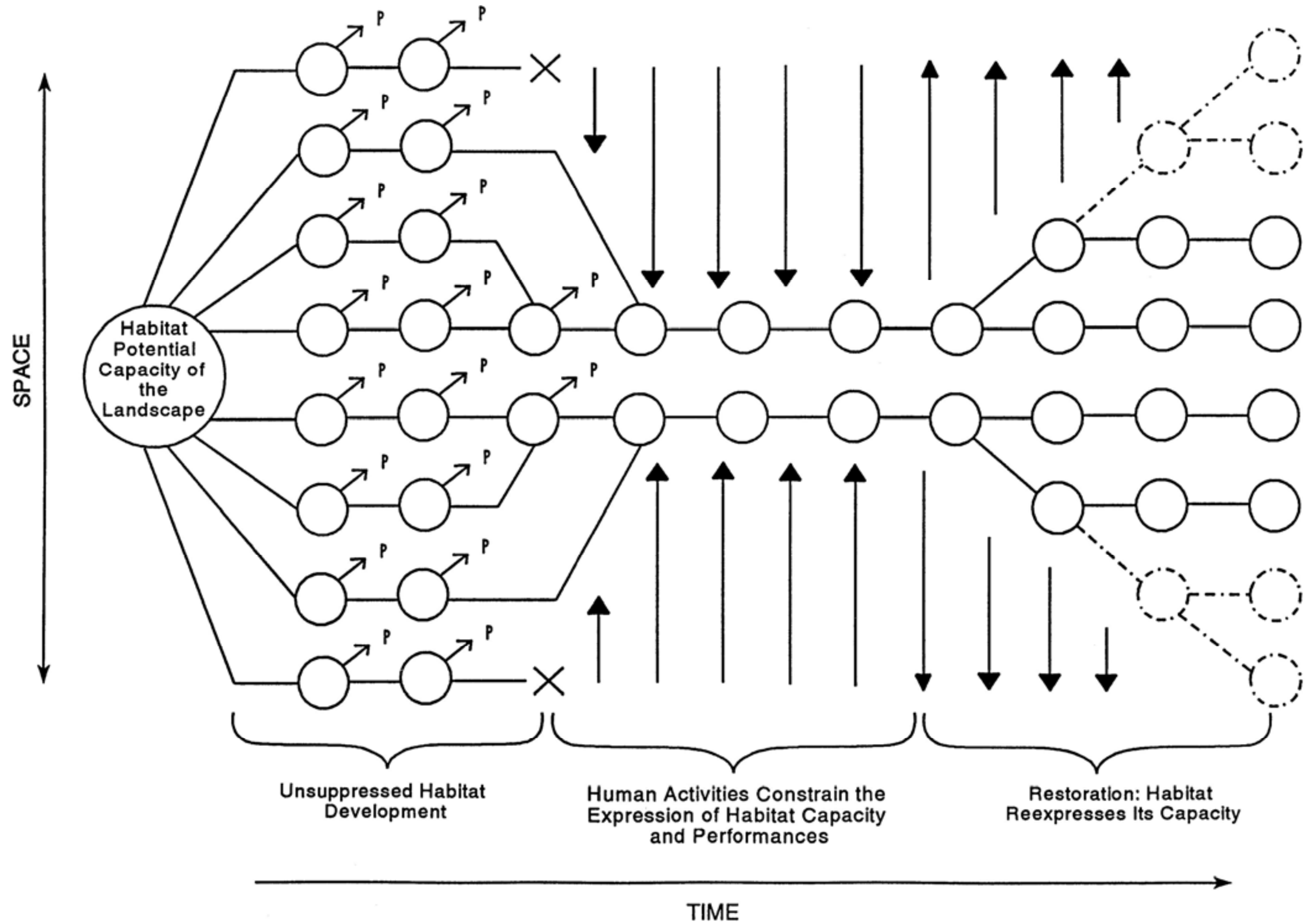


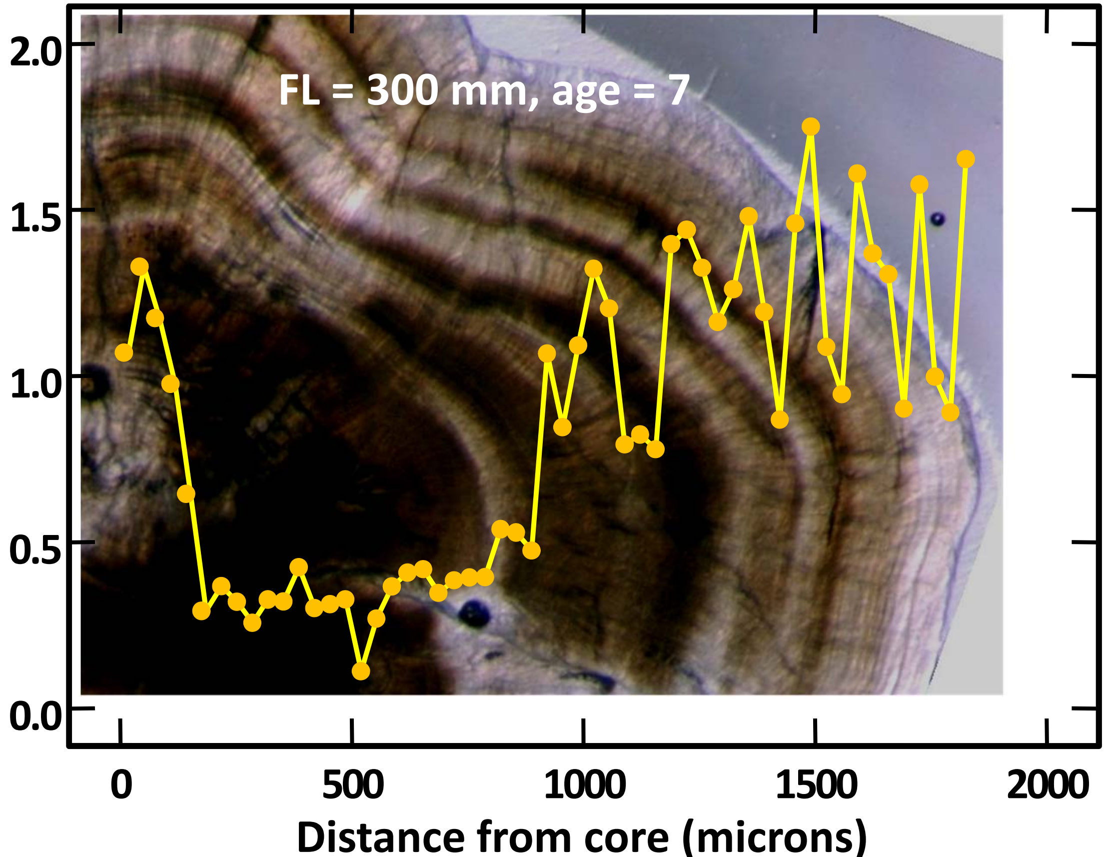
SPACE
Habitat Potential Capacity of the Landscape
P
Unsuppressed Habitat Development
Human Activities Constrain the Expression of Habitat Capacity and Performances
Restoration: Habitat Reexpresses Its Capacity
TIME

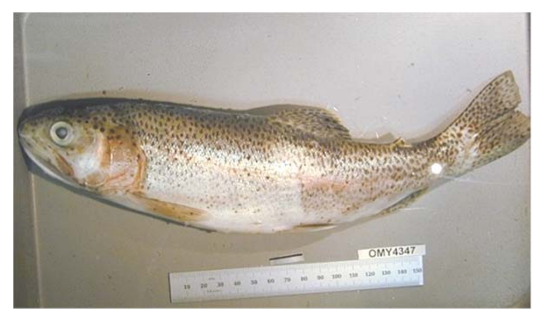
Diversity allows for fish to track changes in the environment

Diversity

- **Within and among communities**
- **Among individuals within a population**
- **Among populations within an ESU/DPS**
- **Temporal and spatial**
- **Abiotic and Biotic**
- ***Ecological processes***

Marine migrations – coincide with otolith annuli





- 7 annuli, 7 marine migrations
- high Sr/Ca (ocean) in summer

What's next?

- Continue current sampling for at least several more years
- Analyses in progress:
  - patterns in abundance, survival, and growth
- Near-term: population modeling and simulations
- In future:
  - expand to other basins:
    - what is level of movement (movement) among basins?
    - do populations in different basins have similar demographics and synchronous dynamics?
  - waiting for a major disturbance
  - assess potential of approach for monitoring population trends as alternative to other methods (e.g., smolt counts, adult counts)