NOAA National Marine Fisheries Service

Diversity of coastal cutthroat trout across their distributional range

Illustration: J. Tomelleri

Thomas Williams

Research Biologist
Southwest Fisheries Science Center
Fisheries Ecology Division – Santa Cruz, California

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Co-authors/collaborators

Kitty Griswold

Ernest Keeley

Ken Currens

Gordie Reeves

- greatest latitudinal range of all cutthroat trout (2,300 km)
- subarctic to mid-latitudes to temperate Mediterranean climate
- northern portion covered by ice during the last glacial advance of the Cordilleran ice sheet
- first-order streams, ponds, lakes, and large rivers
- long narrow band of coastal mountain ranges is one of the most seismically active region in North America

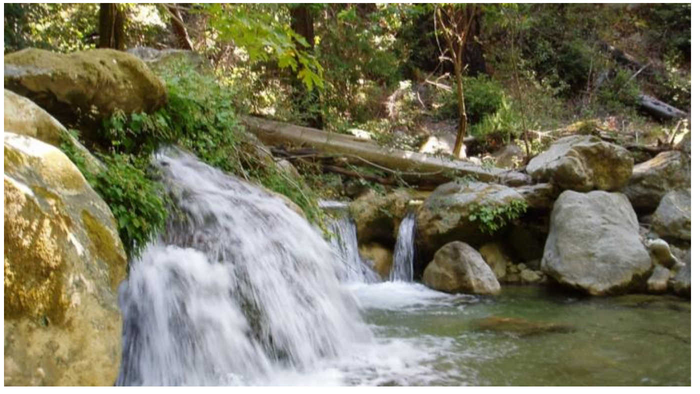


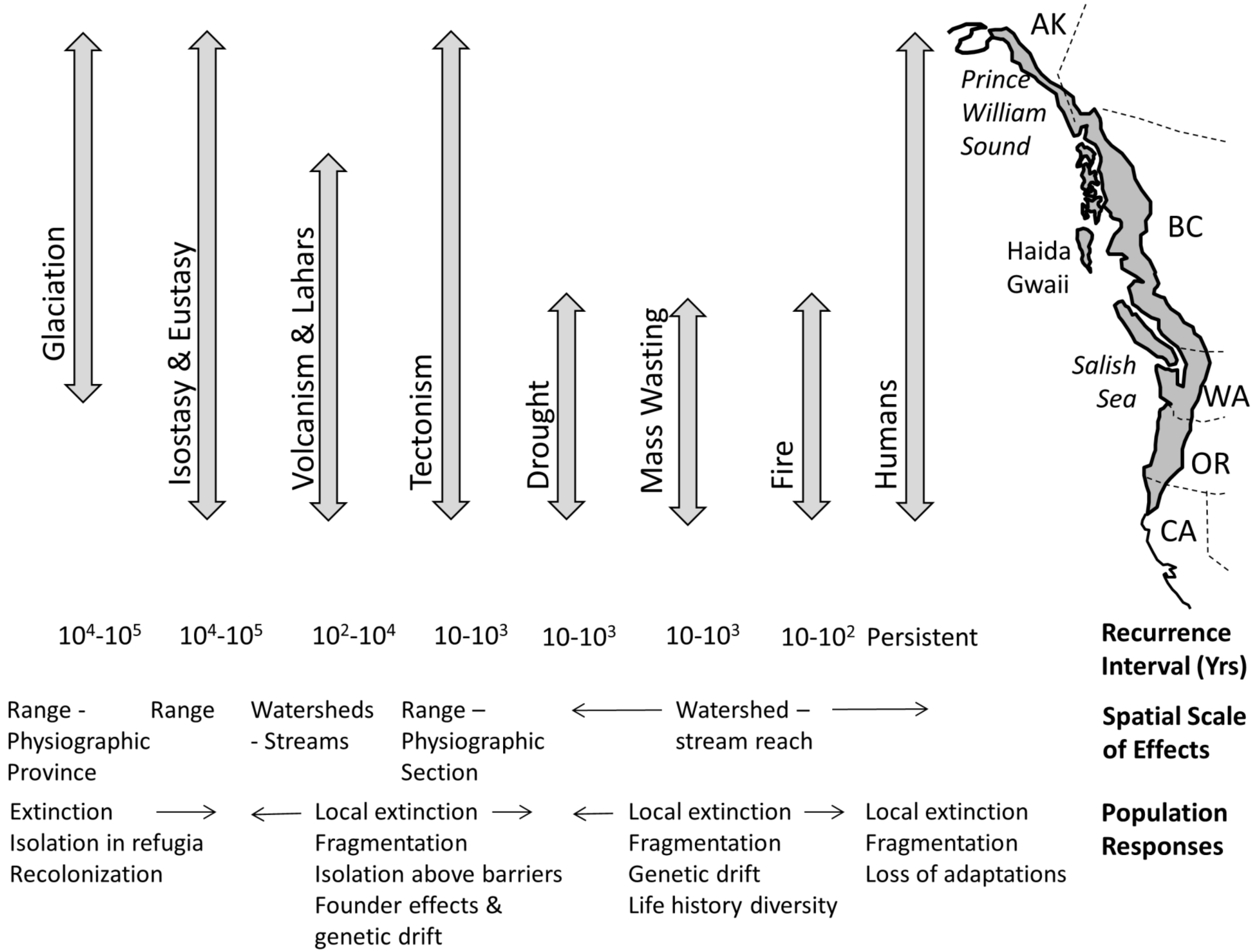


Life-History Diversity and Persistence in Dynamic Landscape

This suggests hypotheses about patterns of genetic diversity:

- *balance between contemporary processes and historical events in shaping diversity is likely different across the range*
- *Genetic diversity in areas between Alaska and the Salish Sea should show historical effects of glaciation and recolonization*
- *in the southern portion of the range that remained free of Cordilleran ice advances, genetic drift may be the dominant force shaping the current patterns of genetic diversity*




Glaciation
Isostasy & Eustasy
Volcanism & Lahars
Tectonism
Drought
Mass Wasting
Fire
Humans
AK
Prince William Sound
BC
Haida Gwaii
Salish Sea
WA
OR
CA
10⁴-10⁵
10⁴-10⁵
10²-10⁴
10-10³
10-10³
10-10³
10-10²
Persistent
Recurrence Interval (Yrs)
Range - Physiographic Province
Range
Watersheds - Streams
Range – Physiographic Section
Watershed – stream reach
Spatial Scale of Effects
Extinction
Isolation in refugia
Recolonization
Local extinction
Fragmentation
Isolation above barriers
Founder effects & genetic drift
Local extinction
Fragmentation
Genetic drift
Life history diversity
Local extinction
Fragmentation
Loss of adaptations
Population Responses



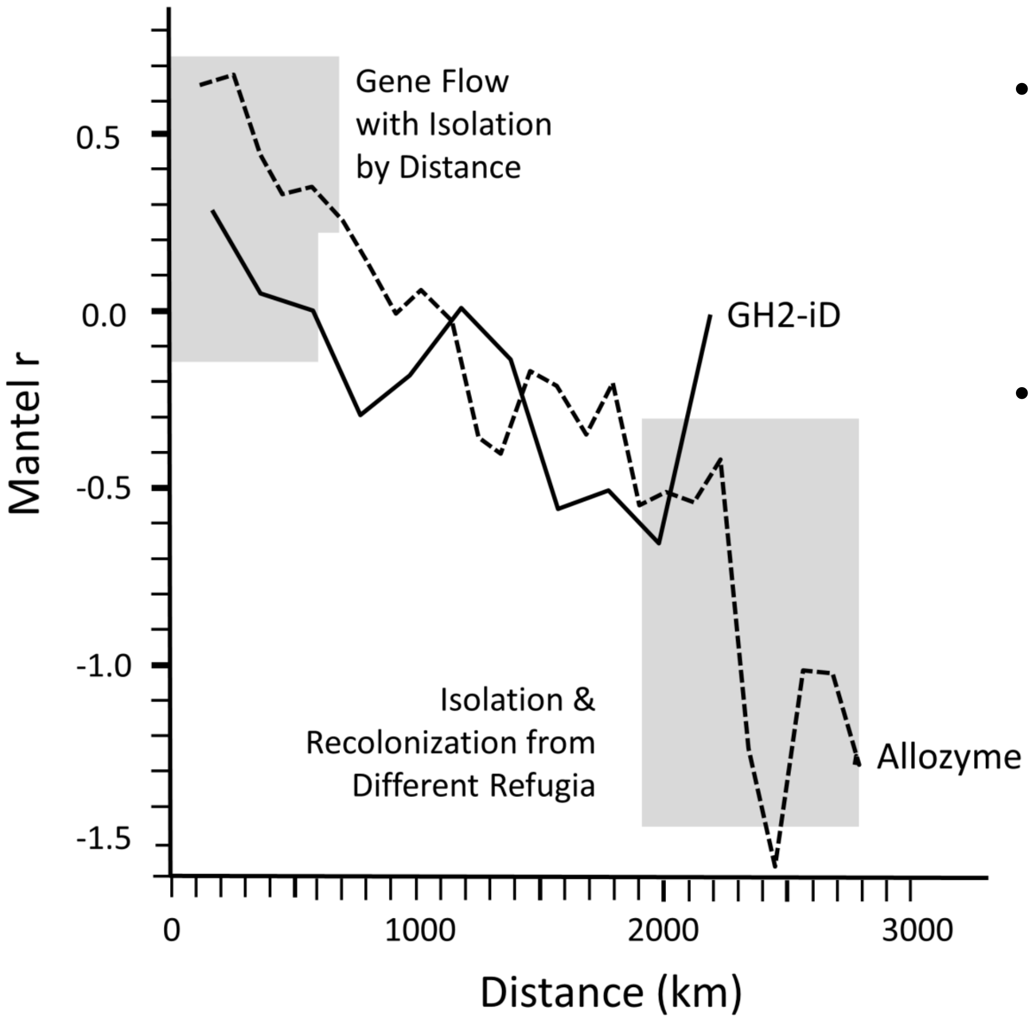




Four phenomena characteristic of coastal cutthroat trout inform these hypotheses concerning the combination of life-history diversity and dynamic landscape:

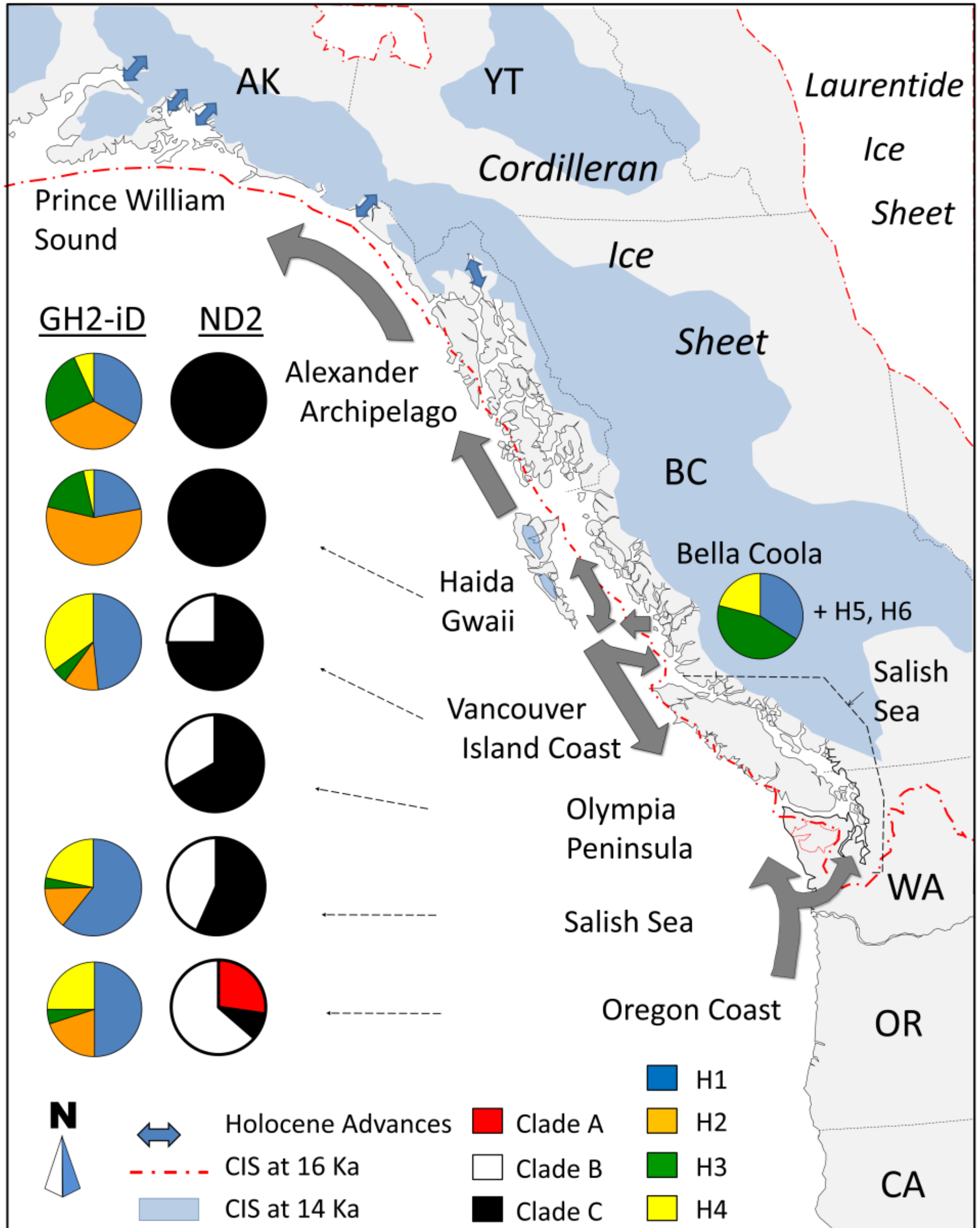
- a restricted scale of population connectivity and structure
- complex patterns of recolonization after glaciations
- maintenance of unexpectedly high levels of genetic diversity in small populations adapted to survive in highly dynamic environment
- threat of anthropogenic changes

A restricted scale of population connectivity and structure



- Geographical distribution of coastal cutthroat trout suggests different modes of population connectivity and organization
- The dominant pattern of genetic population structure observed includes:
  - Significant levels of genetic differentiation
  - Connectivity between populations decreasing as distances between increase

Complex patterns of recolonization after glaciations



Glacial Refugia

- south of Salish Sea along Washington, Oregon, and California coasts
- in the Haida Gwaii or Alexander Archipelago
- possibly near the central coast of British Columbia near Bella Coola

Information from haplotype variation in type 2 growth hormone gene (Costello 2006) and mitochondrial NADH dehydrogenase subunit 2 gene (Loxterman and Keely 2012)

Coastal Cutthroat Trout Paradox

High Genetic Variation in Small Populations

Maintenance of unexpectedly high levels of microsatellite DNA and allozyme diversity in populations with small, fluctuating abundances caused by dynamic environments

- most studies indicate that populations are small, are localized with limited dispersal, and fluctuate in abundance
- estimates of N_e support levels that would result in loss of genetic diversity (Costello 2006; Guy et al. 2008)
- maintain high genetic diversity (e.g., expected average heterozygosity, mean allelic richness), values similar to estimates for Chinook salmon and *O. mykiss* with abundances many times larger

Coastal Cutthroat Trout Paradox

High Genetic Variation in Small Populations

Several mechanisms offer possible hypotheses to explain this paradox

- gene flow – although apparently low and episodic, may maintain much of the variation
- rates of mutation – although assumed to be too low to add much new variation, episodic hybridization with *O. mykiss* might also influence genetic variation (Costello 2006)
- compensatory changes in mating behavior, such as iteroparity, sex ratio, and density-dependent dispersal (Costello 2006); could increase reproductive success while reducing variation of that success, increasing N_e and reducing genetic drift

Anthropogenic Changes and Threats to Coastal Cutthroat Trout Diversity

- anthropogenic hybridization with *O. mykiss*
- altered habitats
  - hybridization may be more common in degraded habitat
  - varies across the range, especially north to south
  - timber harvest, urbanization, and agriculture are the primary activities responsible that have altered and simplified physical habitat and ecological processes
  - coastal cutthroat trout especially sensitive to changes in pool depth and complexity

Summary

- Unique features of landscape have shaped the diversity in coastal cutthroat trout
- Extensive length and short breadth exposed coastal cutthroat trout over distance and millennia to large climate differences
- Life-history strategies that exploit migration in nearshore and marine waters allowing gene flow and colonization
- Natural co-occurrence with *O. mykiss* with which it can potentially hybridize

Summary

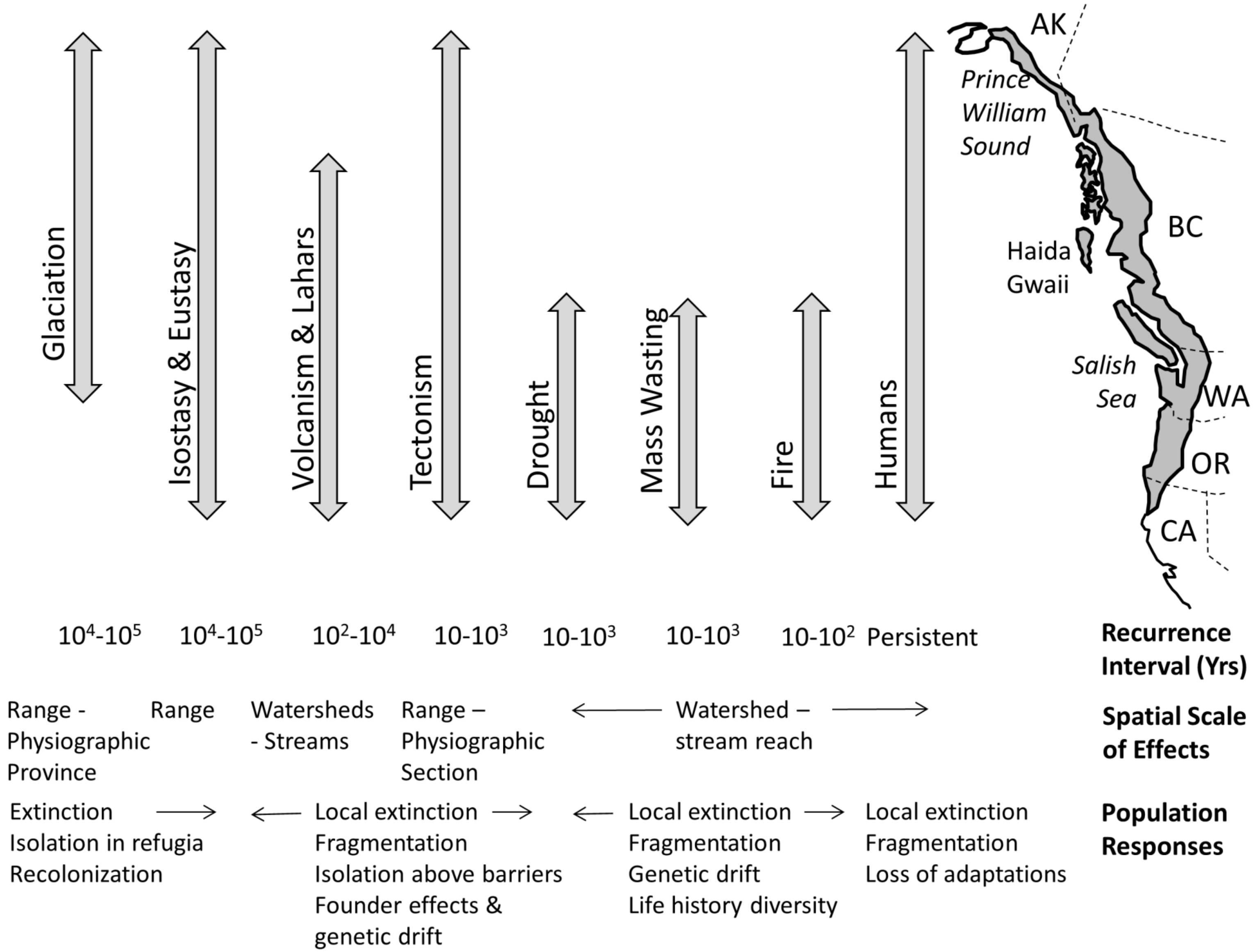
- Most studies indicate that populations are small, localized with limited dispersal, and fluctuate in abundance
- Individual populations show significant levels of genetic differentiation with limited connectivity among populations – decreasing with distance
- The role and importance of hybridization are complicated because both natural and hatchery hybridization has occurred

The big take home:

The persistence and genetic diversity of coastal cutthroat trout populations depends on the availability of appropriate habitat and the ability of populations to track and use available habitat.

Populations 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
- Non-anadromous ↔ anadromous life-history types



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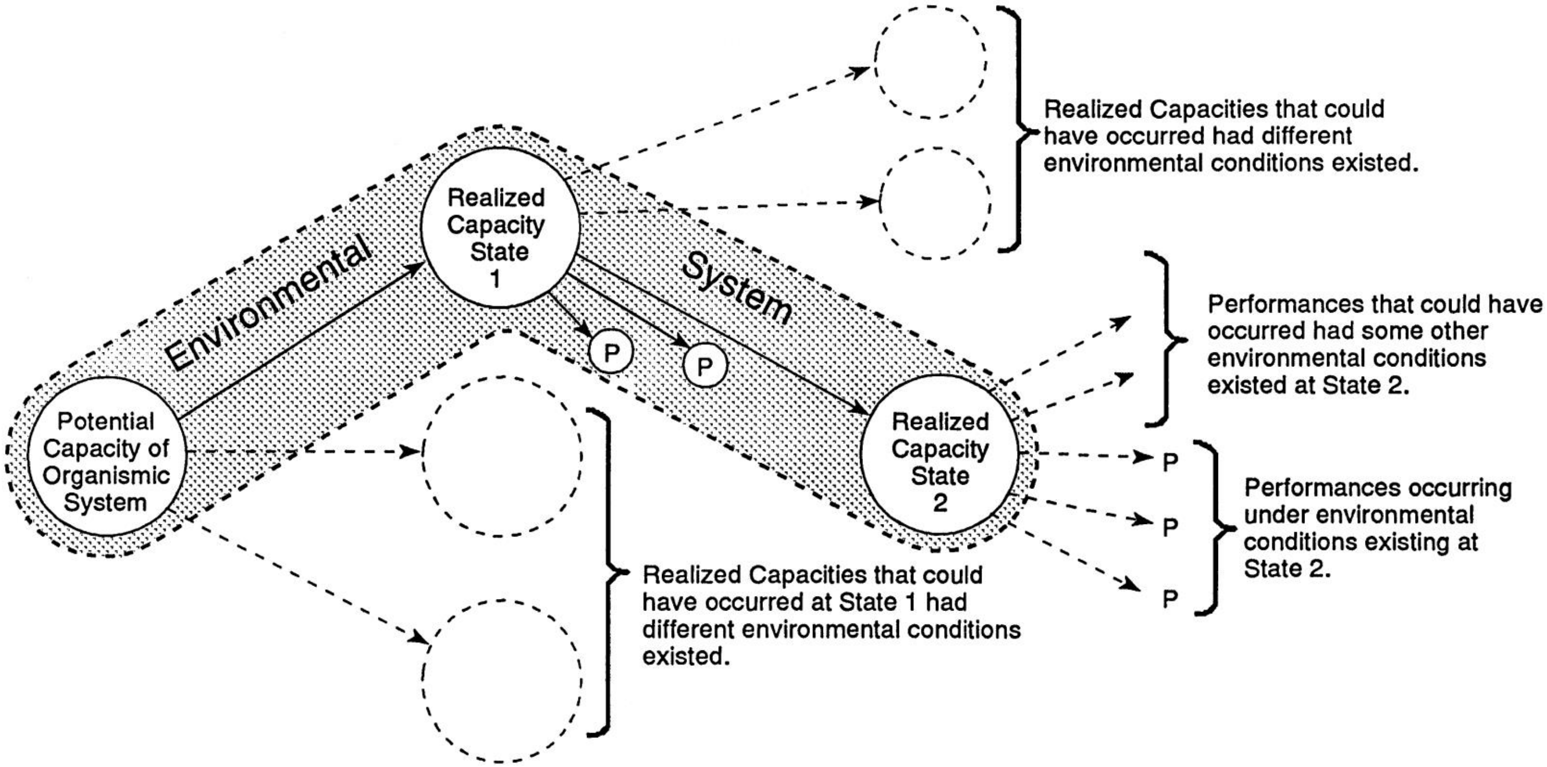

From Ebersole et al. 1997. Envir. Mgt. 21:1-14.

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, agriculture)**
- **fire (magnitude, frequency)**
- **flooding (magnitude, frequency)**

Fresno Bee (9/27/2009)

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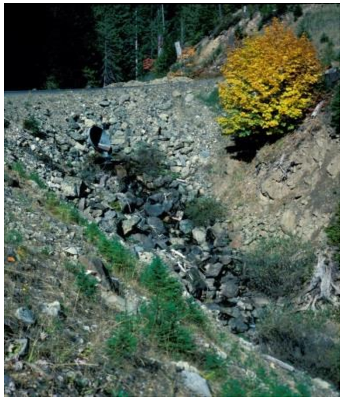

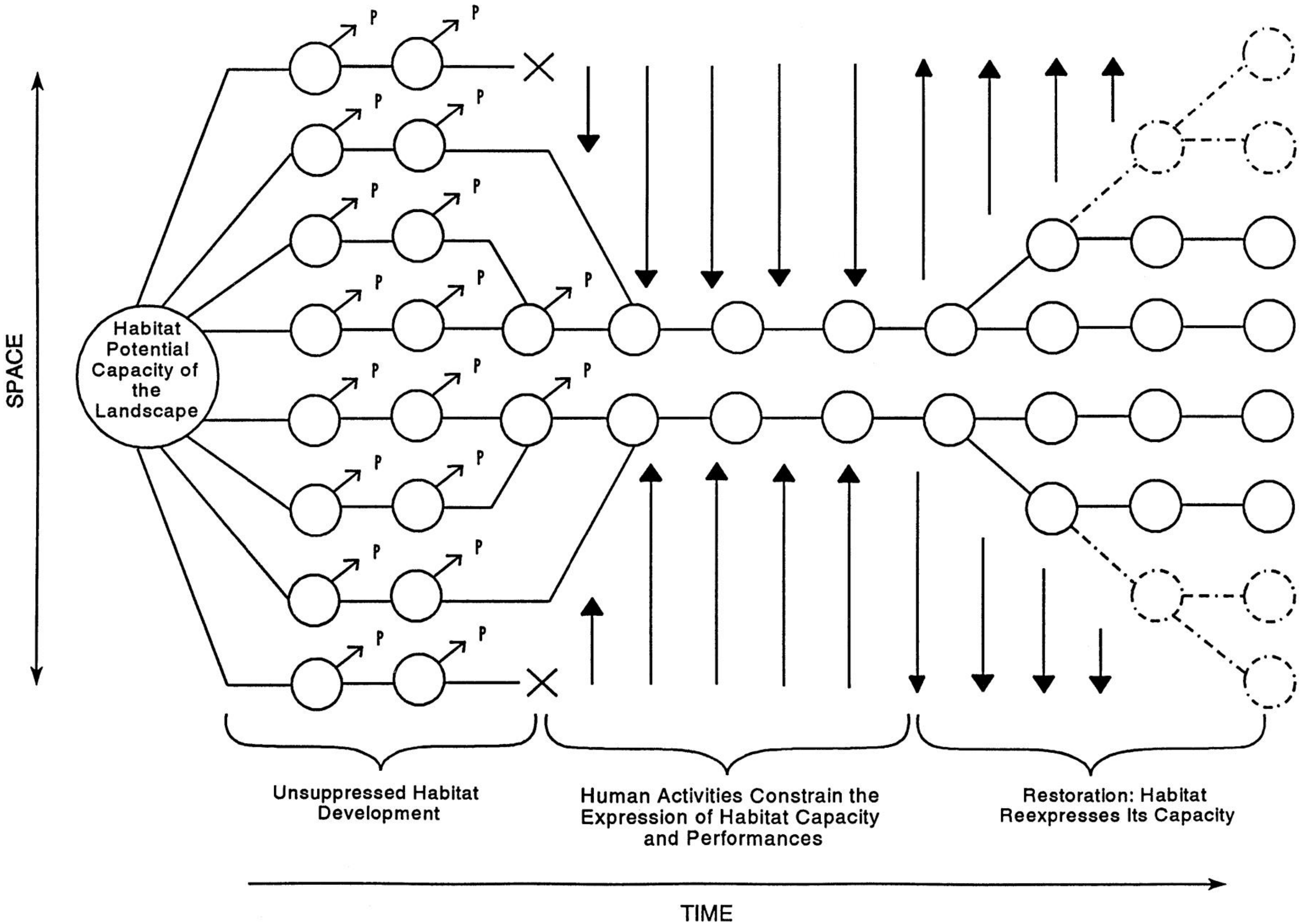

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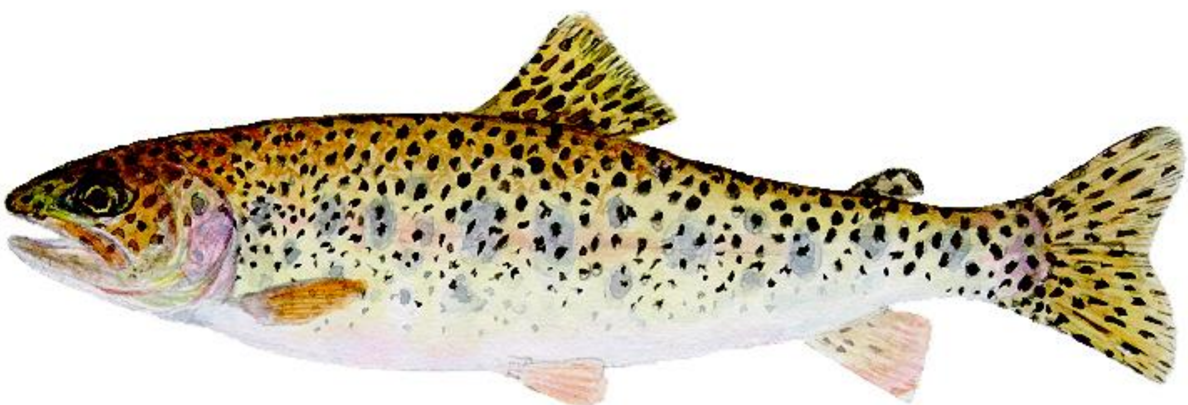
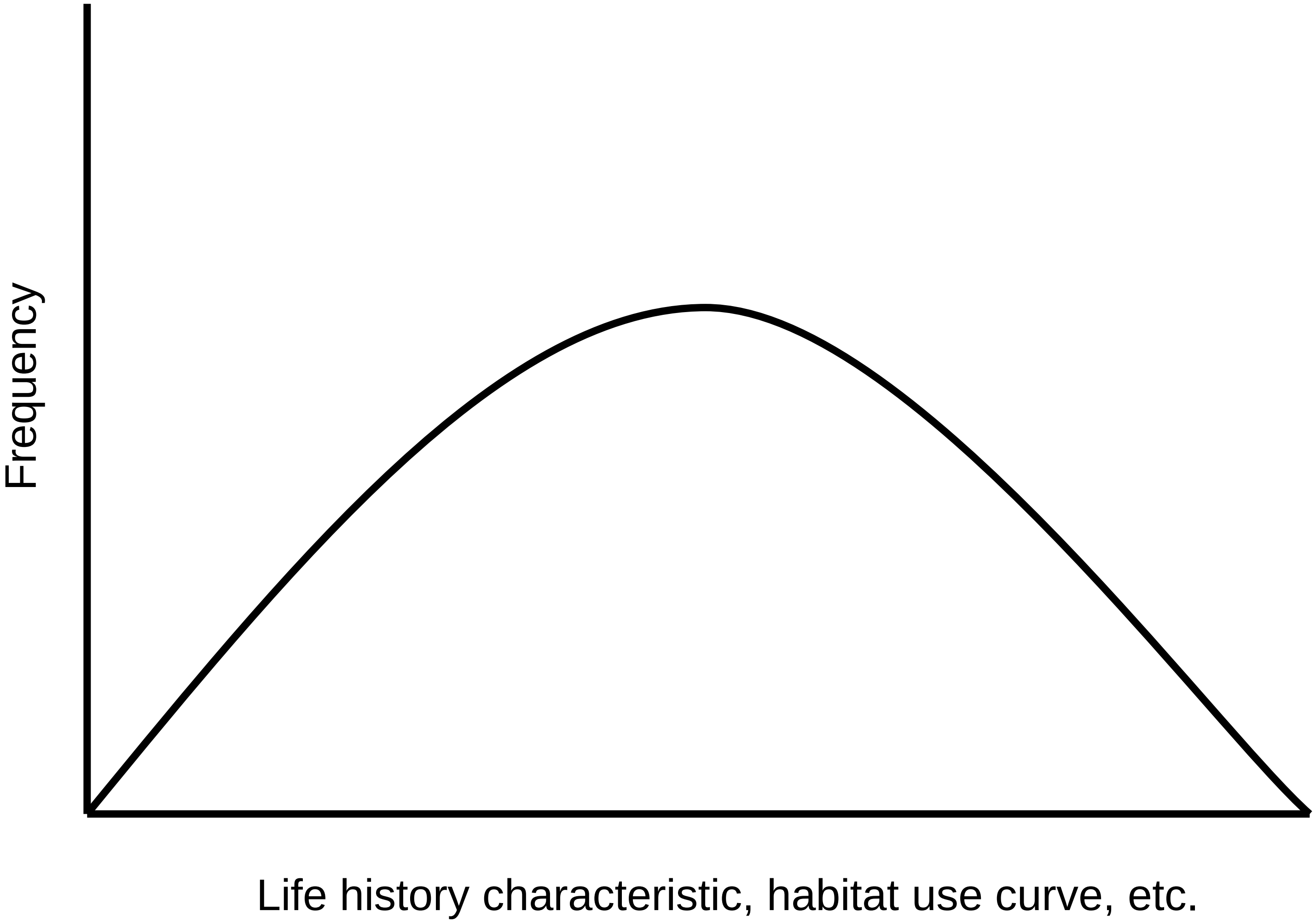
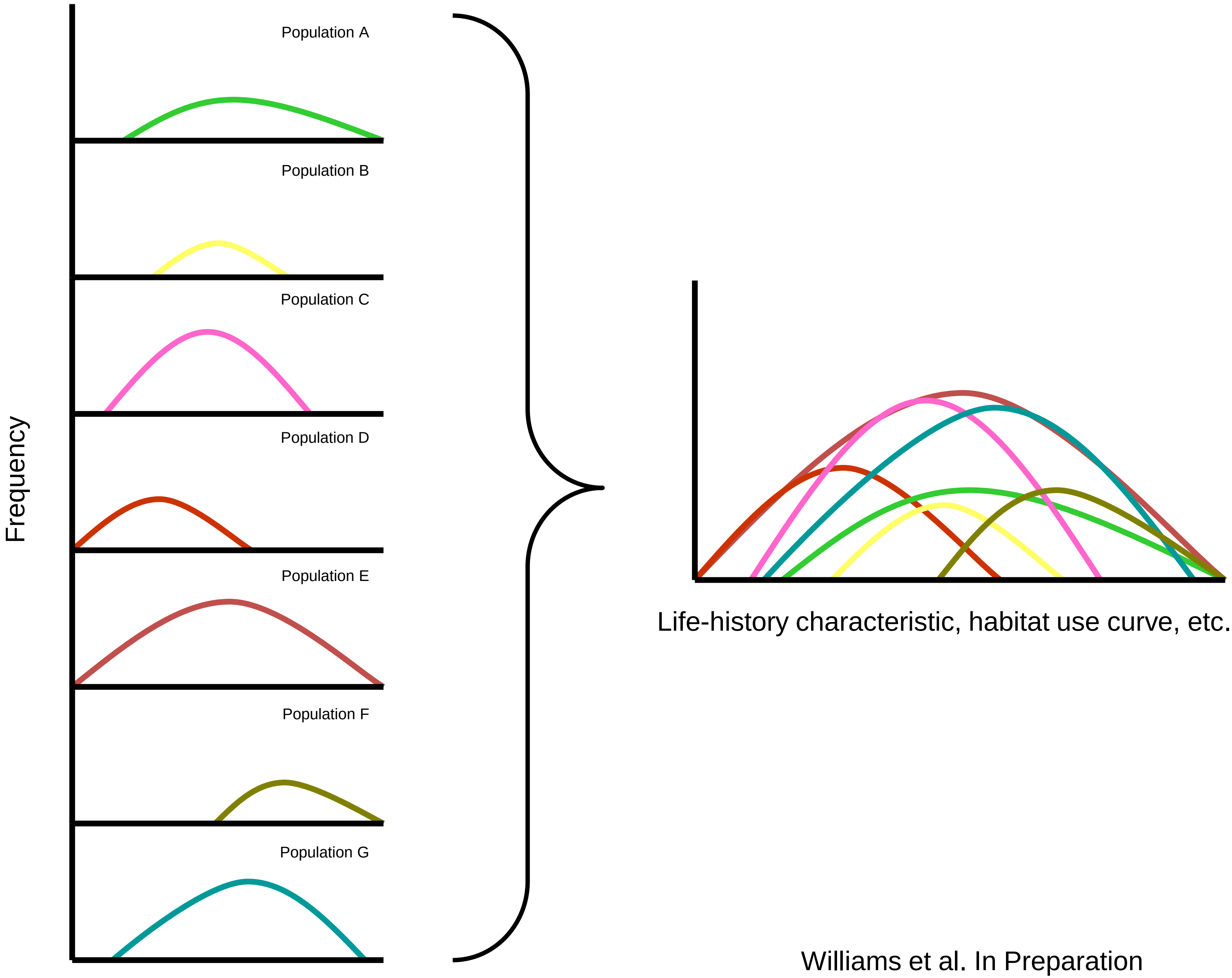
“*In this day of detailed research, surprisingly little is known of the cutthroat, especially in his sea-running phase. Life history, migration stages, feeding habitats, stream preferences, all are matters of vague surmise and angler’s observation. Even his peak spawning time remains a matter for debate, although it probably varies a good deal from one watershed to another*.”

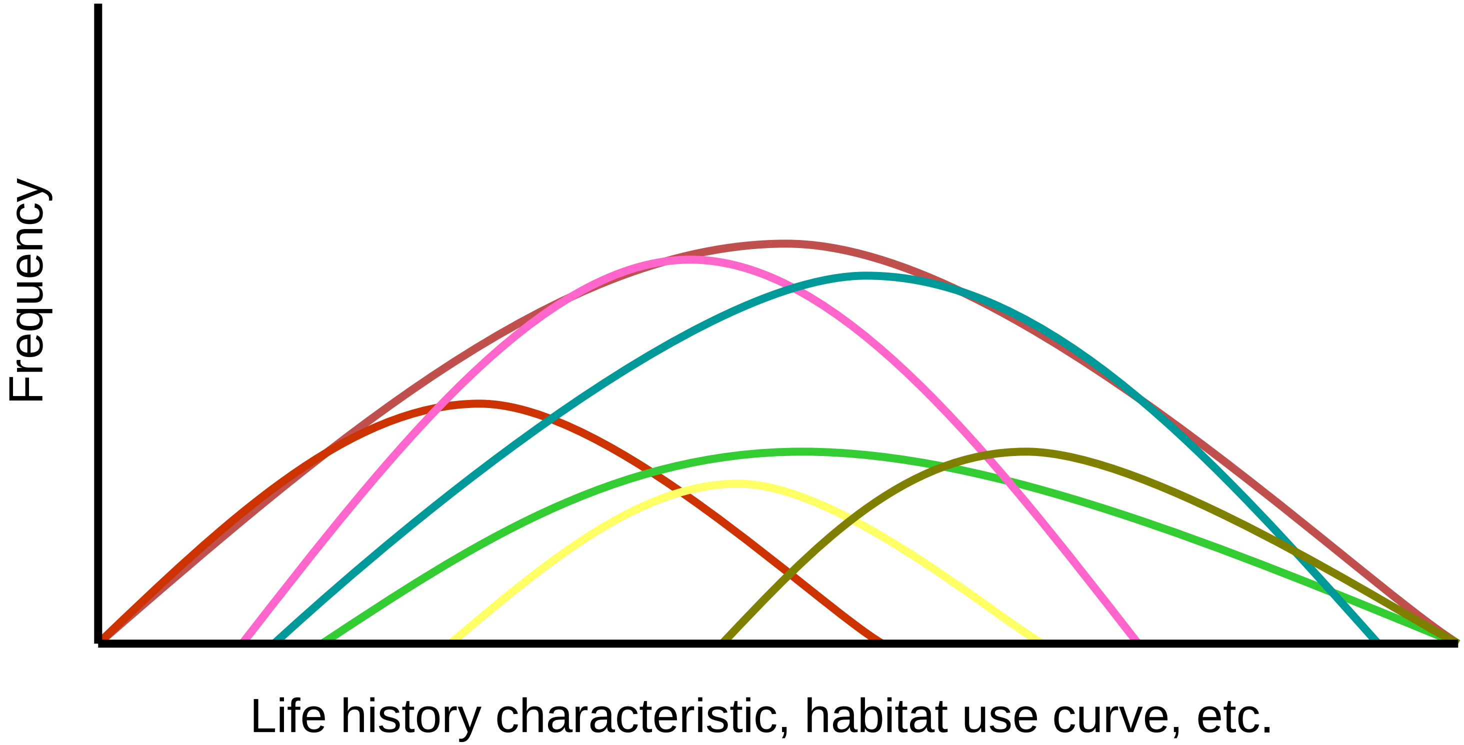
R. Haig-Brown 1964 – Fisherman’s Fall




Frequency
Life history characteristic, habitat use curve, etc.



Williams et al. In Preparation



Williams et al. In Preparation

NRC Research Press

ARTICLE

Fish ladder installation across a historical barrier asymmetrically increased conspecific introgressive hybridization between wild winter and summer run steelhead salmon in the Siletz River, Oregon

William Hemstrom, Stan van de Wetering, and Michael Banks

Abstract: Managing intraspecific hybridization is crucial for maintaining a balance between inbreeding and outbreeding depression in winter and summer run steelhead (*Oncorhynchus mykiss*). While spatial distance is a common factor in maintaining reproductive isolation between these two ecotypes, physical barriers may also prevent hybridization, particularly in short river systems. To determine the effect of barriers and their removal on hybridization, we studied winter and summer steelhead populations in the Siletz River of northern coastal Oregon, which were historically separated by a physical barrier that was removed in the 1950s. We observed a large degree of admixture in the summer run population but little in the summer hatchery or wild winter populations, the former of which was established shortly after the removal of the barrier. This suggests that the high level of admixture in the wild summer run may be due to the removal of the barrier. We also found reduced genetic diversity in the wild summer run and in both hatchery populations. This highlights the need to balance inbreeding and outbreeding depression in hybridizing subpopulations.

Résumé : Gérer l'hybridation intraspécifique est d'importance capitale pour maintenir un équilibre entre le croisement consanguin et la dépression découlant de croisements distants chez les truites arc-en-ciel (*Oncorhynchus mykiss*) à migrations hivernales et estivales. Si l'écart spatial est un facteur courant de maintien de l'isolement reproductif entre ces deux écotypes, des barrières physiques peuvent également prévenir l'hybridation, particulièrement dans les réseaux hydrographiques courts. Afin d'établir l'effet des barrières et de leur retrait sur l'hybridation, nous avons étudié des populations hivernales et estivales de truites arc-en-ciel dans la rivière Siletz, du nord de la côte de l'Oregon, qui, historiquement, étaient séparées par une barrière physique retirée dans les années 1950. Nous avons observé un degré élevé de mélange dans la population à migration estivale, mais peu de mélange dans la population hivernale sauvage ou la population estivale issue d'écloseries, cette dernière ayant été établie peu après le retrait de la barrière. Cela donne à penser que le degré élevé de mélange dans la population sauvage à migration estivale pourrait découler du retrait de la barrière. Nous avons également noté une diversité génétique moindre dans la population sauvage à migration estivale et dans les deux populations issues d'écloseries. Ces résultats soulignent la nécessité d'un équilibre entre le croisement consanguin et la dépression découlant de croisements distants dans les sous-populations qui s'hybrident. [Traduit par la Rédaction]

Introduction

While local adaptation may be mediated by genetic drift, gene flow, and phenotypic plasticity, this phenomenon likely plays an important role in bolstering the relative fitness of salmonid fish subpopulations to their respective environments over a large range of spatial scales (Fraser et al. 2011; Hand et al. 2016; Matala et al. 2014; Narum et al. 2008, 2013; Taylor 1991). Intraspecific hybridization between subpopulations in salmonids and other species can result in outbreeding depression and reduce overall fitness (Rhymer and Simberloff 1996), particularly when hybrids are less fit than their parents (Crispo et al. 2006). Hybridization between locally adapted populations can therefore be of major conservation concern, particularly when it is caused by anthropogenic environmental alterations such as the removal of dispersal barriers or the introduction of hatchery populations (Rhymer and Simberloff 1996).

In steelhead salmon (*Oncorhynchus mykiss*), hybridization between salmonid subpopulations with different run timings may cause outbreeding depression. Most winter run steelhead populations typically return to the river as sexually mature adults between November and May and breed relatively quickly thereafter (Withler 1966). Summer run populations return earlier in the year, typically from April to June, and hold in cool microhabitats before breeding synchronously with winter steelhead (Moyle 2002; Withler 1966). Reproductive isolation between the two runs is typically ensured by spatial distance, since fish that return earlier often breed farther upstream (Arciniega et al. 2016; Briggs 1953; Smith 1969). As a result, as in other salmonid species (Waples et al. 2004), steelhead subpopulations with different run timings are typically genetically distinct (Arciniega et al. 2016; Clemento 2006). Very different environmental conditions experienced by winter and summer run steelhead promotes local adap-

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W. Hemstrom* and M. Banks. Oregon State University Department of Fisheries and Wildlife, Hatfield Marine Science Center, Coastal Marine Experiment Station, 2030 SE. Marine Science Drive, Newport, OR 97365, USA.
S. van de Wetering. Confederated Tribes of Siletz Indians Natural Resources, 201 S.E. Swan Avenue, P.O. Box 549 Siletz, OR 97380, USA.
Corresponding author: William Hemstrom (email: whemstrom@ucdavis.edu).
*Present address: Graduate Group in Ecology, 2251 Meyer Hall, UC Davis, One Shields Ave., Davis, CA 95616, USA.

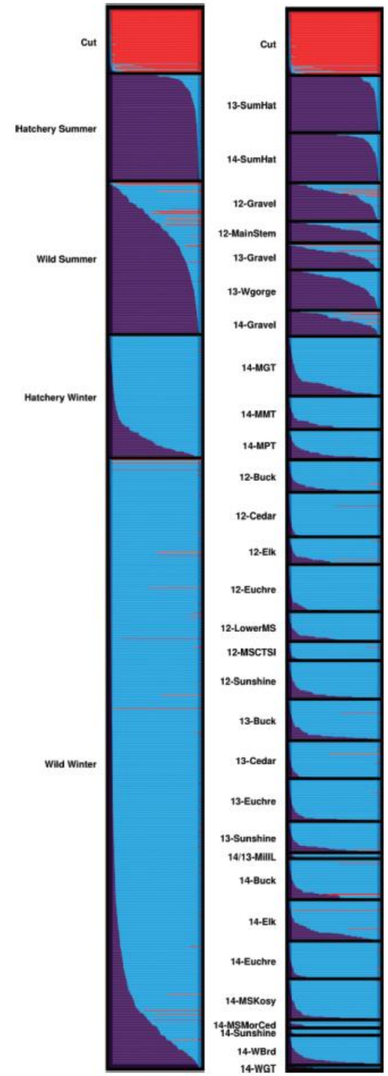

Fig. 2. STRUCTURE plots (k = 3) after removal of all but one individual from each full-sibling family with an inclusive probability of greater than 0.9, organized by proportion assignment into the winter cluster and grouped by either sampling location (top) or putative subpopulation (bottom). Black demarcations indicate sets of samples, with sample location codes or subpopulation names below. Blue indicates assignment to the winter cluster, purple to the summer cluster, and red to the cutthroat cluster. [Colour online.]