Influence of Resident Rainbow Trout on Steelhead Production in the Yakima Basin

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ARTICLE

Resident rainbow trout produce anadromous offspring in a large interior watershed

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Abstract: Rainbow trout (*Oncorhynchus mykiss*) have diverse life histories, including both freshwater-resident and anadromous "steelhead" life-history forms. Here, we demonstrate that female resident rainbow trout produce anadromous offspring that survive and return to spawn as adult steelhead. This study represents the first successful attempt to quantify steelhead production rates from female resident rainbow trout across a large watershed. Otolith microchemistry ($^{87}Sr/^{86}Sr$) techniques were used to determine the maternal life history (resident or anadromous) of 498 emigrating steelhead kelts in the Yakima Basin, Washington. Five geochemically distinct freshwater rearing regions were identified within the basin. All five regions were predicted to produce steelhead with resident maternal life histories. Basin-wide, 20% and 7% of steelhead collected in 2010 and 2011, respectively, had resident maternal life histories. Cross-life-history form production may be critical to persistence of anadromous life histories within partially anadromous salmonid populations, particularly in areas where anadromous fish abundance is low due to natural or anthropogenic influences.

Résumé : Les truites arc-en-ciel (*Oncorhynchus mykiss*) présentent divers types de cycle biologique; elles comptent notamment une forme résidant en eau douce et une forme anadrome. Nous démontrons que des truites arc-en-ciel femelles résidentes peuvent produire des rejetons anadromes qui survivent en mer et retournent en eau douce pour frayer. L'étude constitue la première tentative fructueuse de quantifier les taux de production de truites arc-en-ciel anadromes issues de femelles résidentes à l'échelle d'un grand bassin versant. Des techniques de microchimie ($^{87}Sr/^{86}Sr$) des otolites ont été utilisées pour déterminer le cycle biologique (résident ou anadrome) maternel de 498 bécards de cette espèce émigrant du bassin de la rivière Yakima, dans l'état de Washington. Cinq régions d'alevinage en eau douce distinctes sur le plan géochimique ont été cernées dans ce bassin. Il avait été prédit que ces cinq régions produiraient des individus anadromes associés à des cycles biologiques maternels résidents. À l'échelle du bassin, 20 % et 7 % des truites anadromes prélevés en 2010 et 2011, respectivement, étaient associés à des cycles biologiques maternels résidents. La production de formes caractérisées par des cycles biologiques distincts d'une génération à l'autre pourrait être essentielle à la persistance des cycles biologiques anadromes dans les populations de salmonidés partiellement anadromes, en particulier dans les régions où l'abondance de poissons anadromes est faible en raison d'influences naturelles ou anthropiques. [Traduit par la Rédaction]

Introduction

Partial migration, when one portion of an animal population migrates while the other portion remains sedentary (Lundberg 1988), has been well documented in a variety of fish species, including salmonids (Jonsson and Jonsson 1993; Table 1). A related term, "partial anadromy", refers more specifically to a behavioral strategy whereby fish of the same population adopt divergent anadromous and resident freshwater life-history strategies (Hendry et al. 2004). Evolutionarily stable migration plasticity is thought to be a response to environmental stochasticity and density-dependent survival (Lundberg 1987; Kaitala et al. 1993). Life-history diversity, represented by these mechanisms, is believed to buffer against extinction (Hilborn et al. 2003; Greene et al. 2010). Such diversity may be particularly important to the perpetuation of salmonids facing a variety of natural and anthropogenic causes of mortality.

The term "steelhead", which has been conventionally used to identify anadromous rainbow trout, represents one of several potential life-history forms within *Oncorhynchus mykiss* populations (Pavlov et al. 2001). Stream residency is also common for this species, with resident individuals remaining in fresh water throughout their life cycle, often moving between suitable habitats (Gowan et al. 1994), but never venturing to the ocean. In watersheds with ocean access, researchers have found that in addition to interbreeding (McMillan et al. 2007), resident rainbow trout and steelhead can produce progeny of the alternate life-history form (Pascual et al. 2001; Thrower and Joyce 2004; Korman et al. 2010). These findings indicate that life-history trajectories of partially anadromous salmonid populations are driven by a combination of genetic predispositions and environmental cues (Jonsson and Jonsson 1993; Hendry et al. 2004).

The extent to which resident and anadromous *O. mykiss* life-history forms are reproductively mixed remains somewhat equivocal. In some cases, researchers have found evidence for reproductive isolation between the two forms (e.g., Zimmerman and Reeves 2000), while others have found evidence for substantial reproductive exchange (e.g., Pascual et al. 2001). There is need for resolution concerning the question of whether resident rainbow trout and steelhead are reproductively isolated in the majority cases (Behnke 2002) to inform whether population assessments should be expected to quantify the impact of resident rainbow trout on the persistence of steelhead.

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Partial Migration

- One portion of an animal population migrates while the other portion remains sedentary (Lundberg 1988)
- Well documented in a variety of fish species, including salmonids (Jonsson and Jonsson 1993)
- Evolutionarily stable (Kaitala et al 1993)

Partial Anadromy

brown trout	(Jonsson 1985)
cutthroat trout	(Zimmerman et al. 1997)
rainbow trout	(Pavlov et al. 2008)
bull trout	(Brenkman and Corbett 2005)
Dolly Varden char	(Koizumi et al. 2006)
brook char	(Curry et al. 2010)
Arctic char	(Nordeng 1983)
Atlantic salmon	(Fleming 1998)
sockeye salmon	(Wood 1995)
masu salmon	(Arai and Tsukamoto 1998)

Population structure of sympatric anadromous and nonanadromous *Oncorhynchus mykiss*: evidence from spawning surveys and otolith microchemistry

Christian E. Zimmerman and Gordon H. Reeves

Abstract: Reproductive isolation between steelhead and resident rainbow trout (*Oncorhynchus mykiss*) was examined in the Deschutes River, Oregon, through surveys of spawning timing and location. Otolith microchemistry was used to determine the occurrence of steelhead and resident rainbow trout progeny in the adult populations of steelhead and resident rainbow trout in the Deschutes River and in the Babine River, British Columbia. In the 3 years studied, steelhead spawning occurred from mid March through May and resident rainbow trout spawning occurred from mid March through August. The timing of 50% spawning was 9–10 weeks earlier for steelhead than for resident rainbow trout. Spawning sites selected by steelhead were in deeper water and had larger substrate than those selected by resident rainbow trout. Maternal origin was identified by comparing Sr/Ca ratios in the primordia and freshwater growth regions of the otolith with a wavelength-dispersive electron microprobe. In the Deschutes River, only steelhead of steelhead maternal origin and resident rainbow trout of resident rainbow trout origin were observed. In the Babine River, steelhead of resident rainbow trout origin and resident rainbow trout of steelhead maternal origin were also observed. Based on these findings, we suggest that steelhead and resident rainbow trout in the Deschutes River may constitute reproductively isolated populations.

Résumé : L'examen de la phénologie de la fraye et la localisation des frayères chez les Truites arc-en-ciel (*Oncorhynchus mykiss*) anadromes et résidantes de la rivière Deschutes, en Oregon, ont servi à étudier l'isolement génétique entre les deux formes. La microchimie des otolithes a permis de reconnaître la présence des rejetons des truites anadromes et résidantes dans les populations adultes de la rivière Deschutes et dans la rivière Babine, en Colombie-Britannique. Pendant les 3 années de l'étude, la fraye des anadromes s'étendait de la mi-mars jusqu'à la fin de mai et celle des résidantes de la mi-mars à la fin d'août. Le date où 50% de la fraye des anadromes s'est terminée précédait de 9 à 10 semaines le moment équivalent chez les résidantes. Les anadromes choisissaient des sites de fraye plus profonds et à substrat plus grossier que les résidantes. L'origine maternelle des poissons a pu être déterminée par l'étude des rapports Sr/Ca dans les primordiums et les zones de croissance en eau douce des otolithes au moyen d'une microsonde électronique à dispersion de longueur d'onde. Dans la rivière Deschutes, seules des anadromes originaires de mères anadromes et des résidantes nées de mères résidantes ont été observées. Dans la rivière Babine, il y avait en plus des anadromes issues de mères résidantes et des résidantes provenant de mères anadromes. Nous concluons donc à partir des ces observations qu'il y a un isolement reproductif entre les formes anadrome et résidante des Truites arc-en-ciel dans la rivière Deschutes.

[Traduit par la Rédaction]

Introduction

The term partial migration describes the phenomenon of populations divided into migratory and nonmigratory or resident individuals (Jonsson and Jonsson 1993). A variety of animal taxa from insects to birds and fish exhibit this phenomenon (Snyder and Dingle 1990; Berthold 1991; Wood 1995). Several species of salmonids exhibit partial migration. Within such populations, migratory behavior is diverse and well documented (Gross 1987; Thorpe 1987; Northcote 1992). Migrations exhibited by salmonids range from relatively short migrations between streams and lakes to long-distance migrations to the open ocean. Rainbow trout (*Oncorhynchus mykiss*; Neave 1944), coastal cutthroat trout (*Oncorhynchus clarki clarki*; Zimmerman et al. 1997), sockeye salmon (*Oncorhynchus nerka*; Wood 1995), Atlantic salmon (*Salmo salar*; Verspoor and Cole 1989), brown trout (*Salmo trutta*; Skaala and Nævdal 1989), and Arctic char (*Salvelinus alpinus*; Nordeng 1983) exhibit dual or multiple life-history forms that may reside in the same stream. Resident and migratory forms of a species may represent ecophenotypes within a

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“wild steelhead and resident rainbow trout co-occur and do not seem to be **reproductively isolated**.”

Pascual et al. (2001)

“This statement is unwarranted because it ignores studies such as Zimmerman and Reeves (2000); it can also be potentially harmful by providing a “scientific” basis for **anti-ESA rhetoric**.”

Behnke (2002)

Evidence For and Against Reproductive Isolation between Resident and Anadromous O. mykiss

For

Zimmerman and Reeves 2000

Narum et al. 2004

Docker and Heath 2003

Against

McPhee et al. 2007

Olson et al. 2006

Pearsons et al. 2007

Berntson et al. 2011

Christie et al. 2011

Pascual et al. 2001

Pavlov et al. 2008

Zimmerman et al. 2008

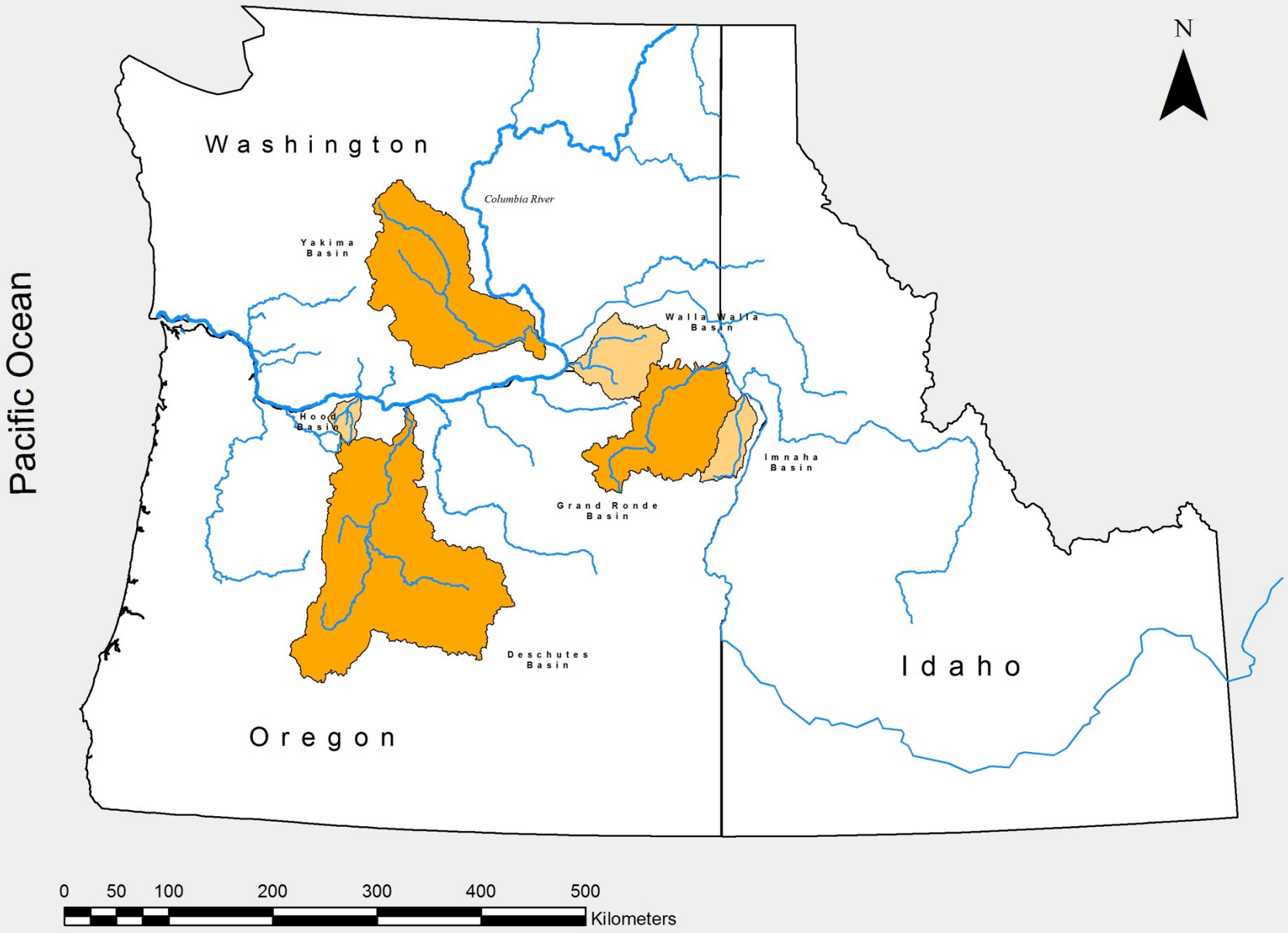
McMillan et al. 2007

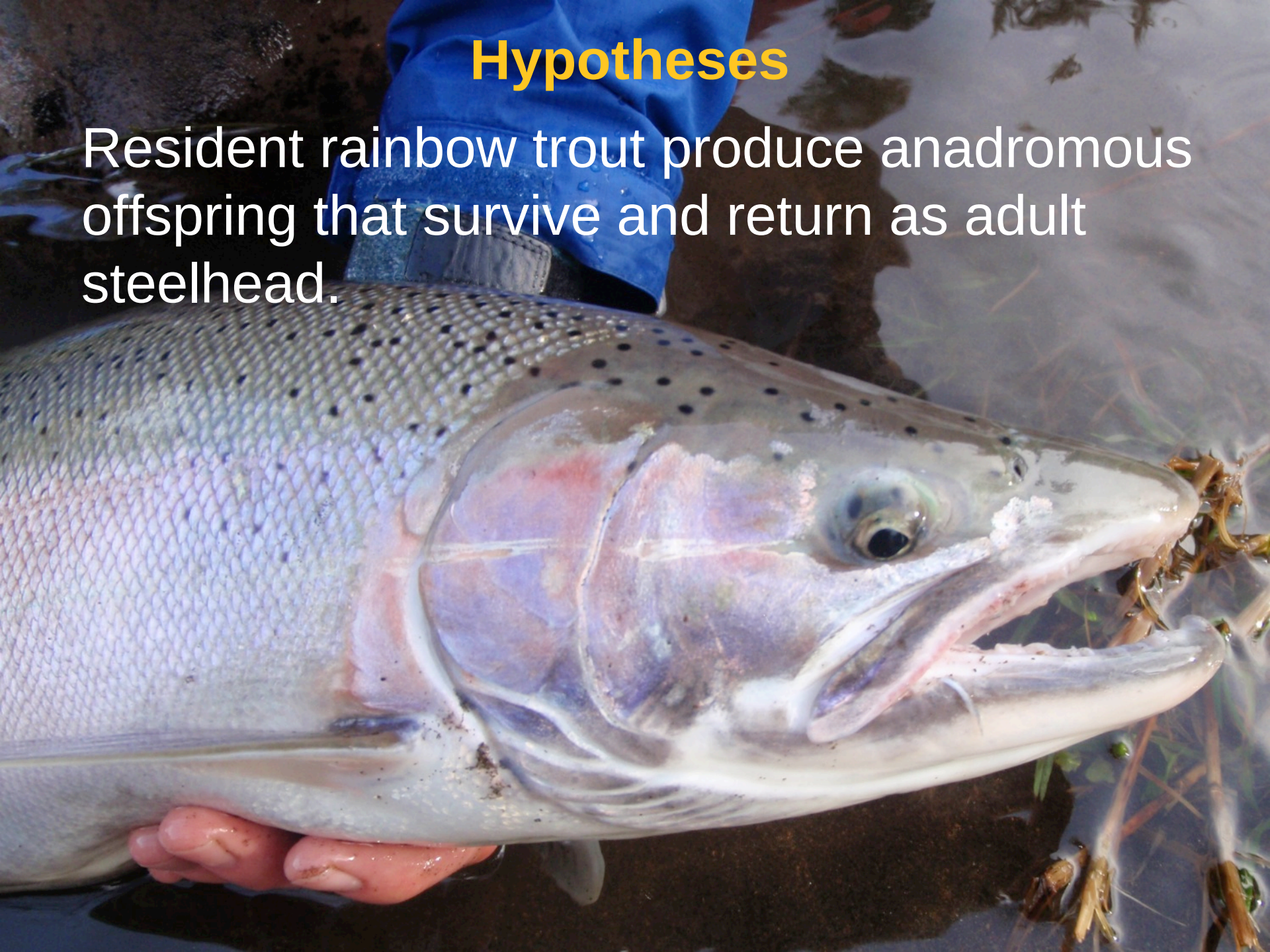
Korman et al. 2010

ODFW unpublished data

WDFW unpublished data

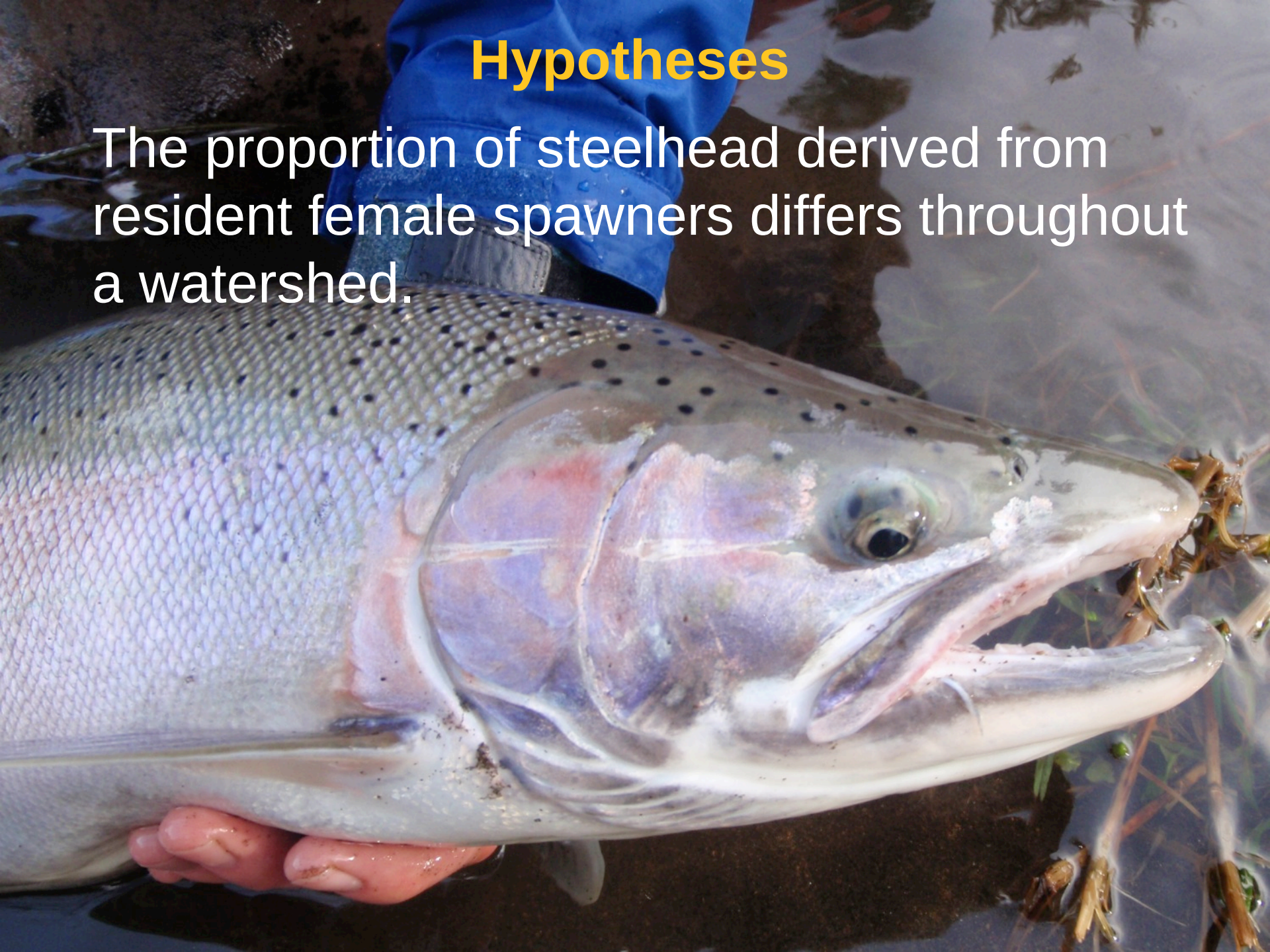

Pacific Ocean
Washington
Columbia River
Deschutes Basin
Oregon
Idaho
N
0 50 100 200 300 400 500
Kilometers


Pacific Ocean
Washington
Columbia River
Yakima Basin
Walla Walla Basin
Hood Basin
Imnaha Basin
Grand Ronde Basin
Deschutes Basin
Idaho
Oregon
N
0 50 100 200 300 400 500
Kilometers



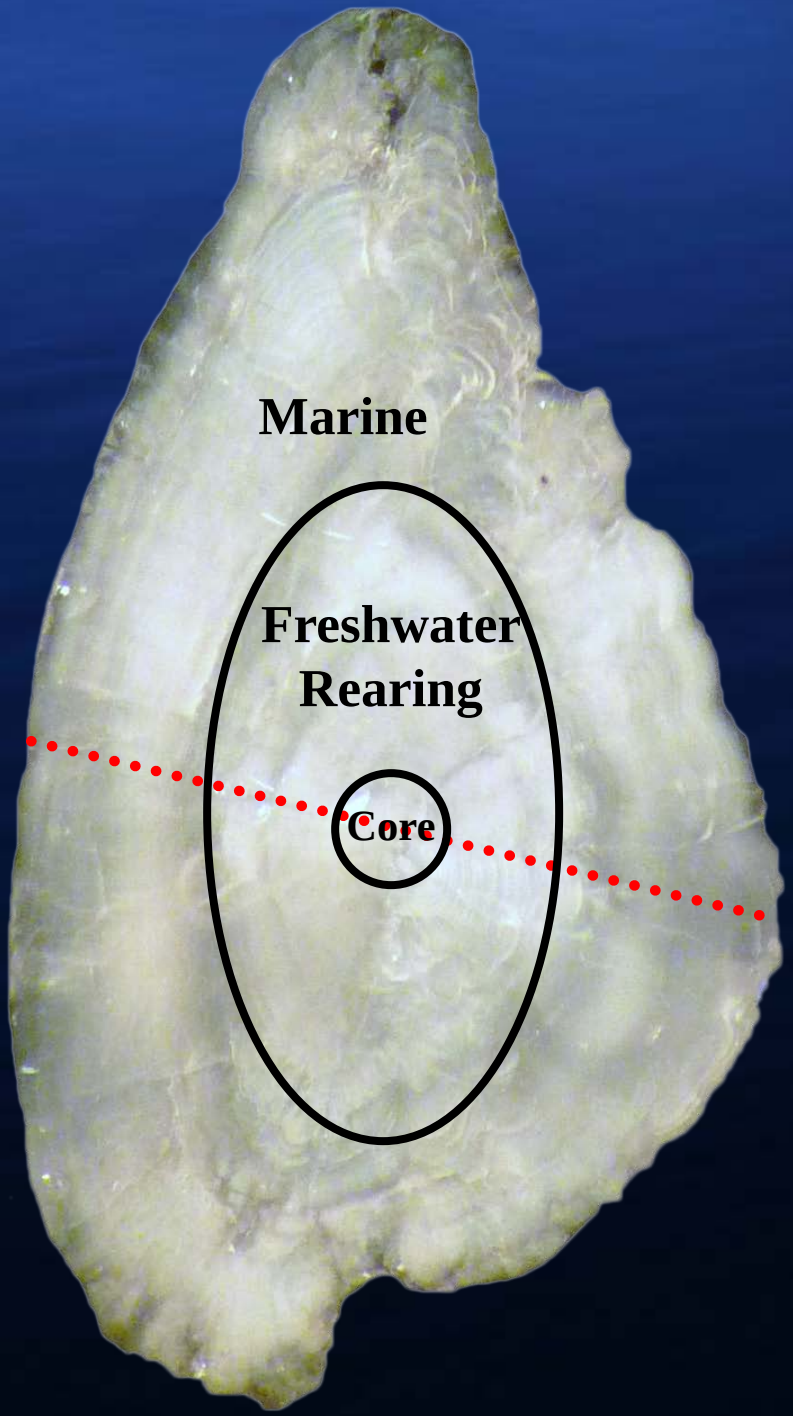
Hypotheses

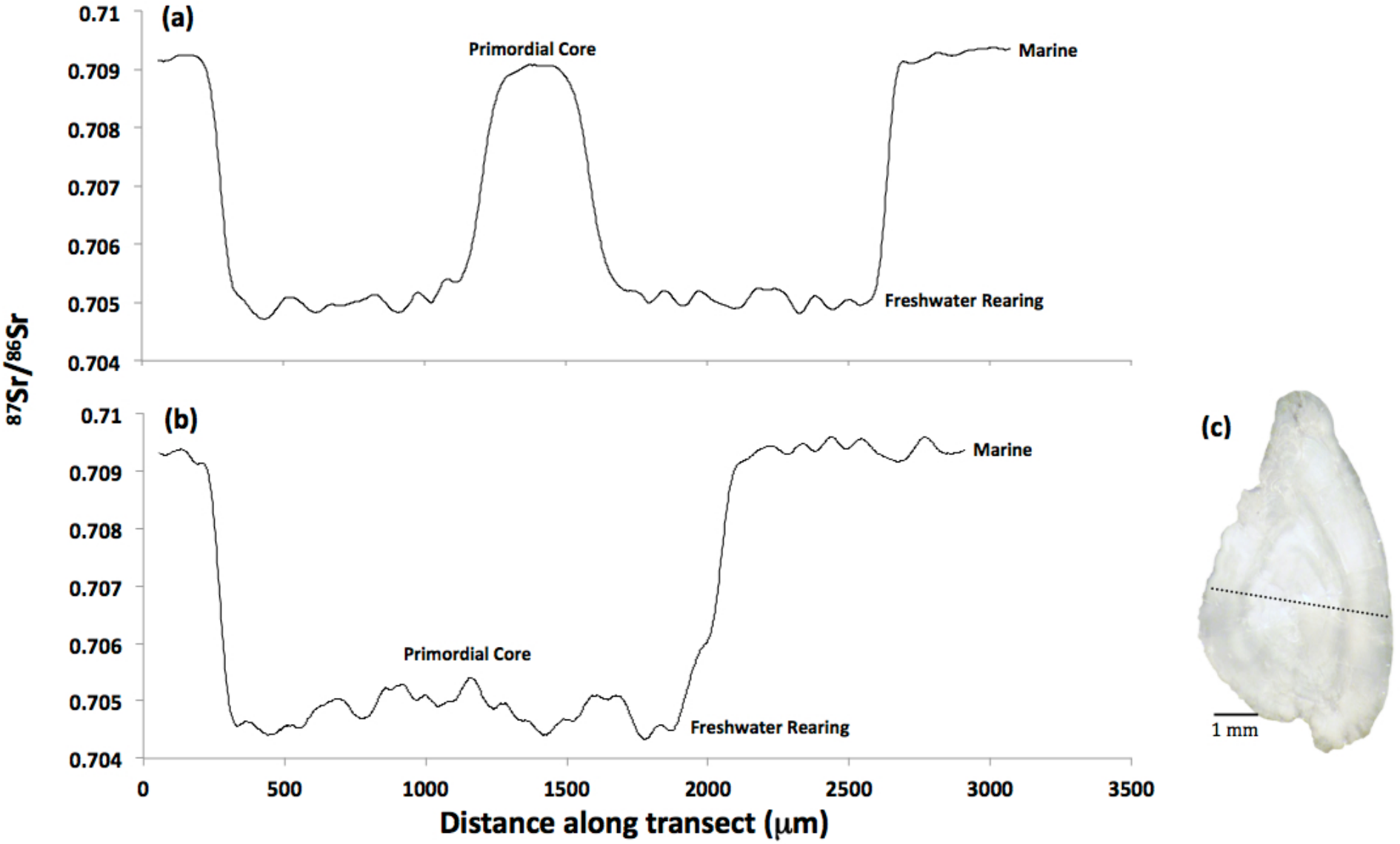
Resident rainbow trout produce anadromous offspring that survive and return as adult steelhead.



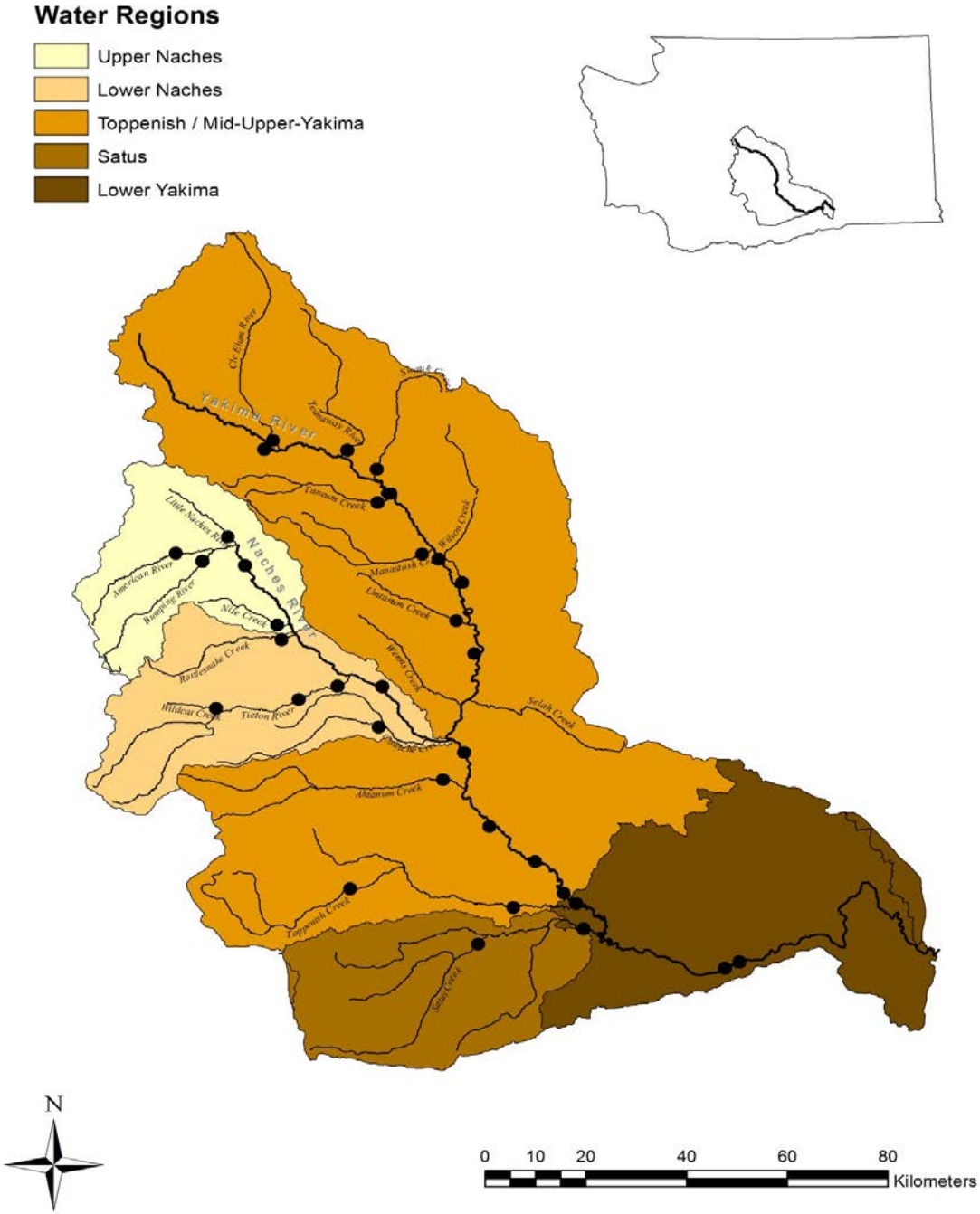
Hypotheses

The proportion of steelhead derived from resident female spawners differs throughout a watershed.

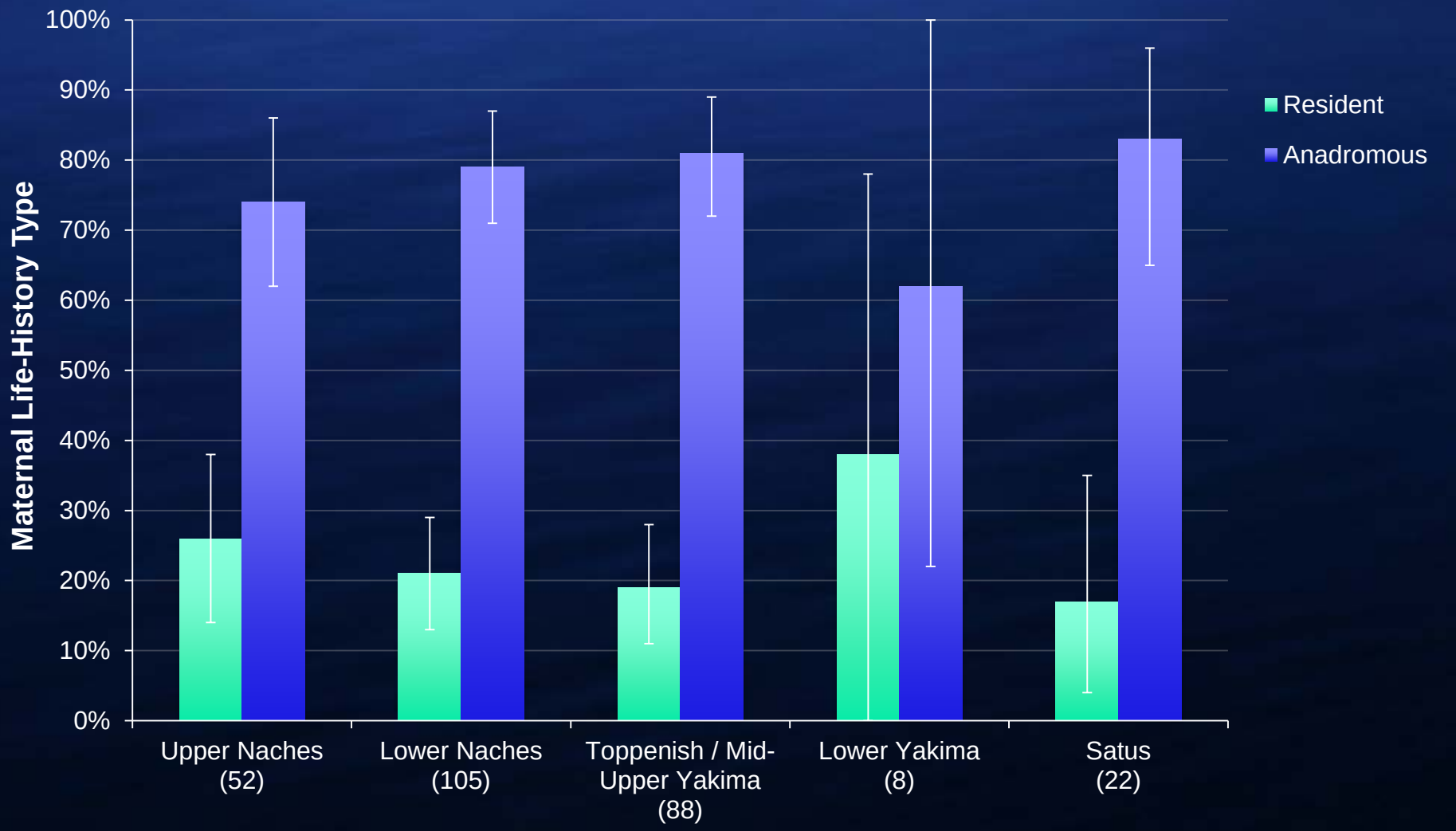

Marine
Freshwater
Rearing
Core



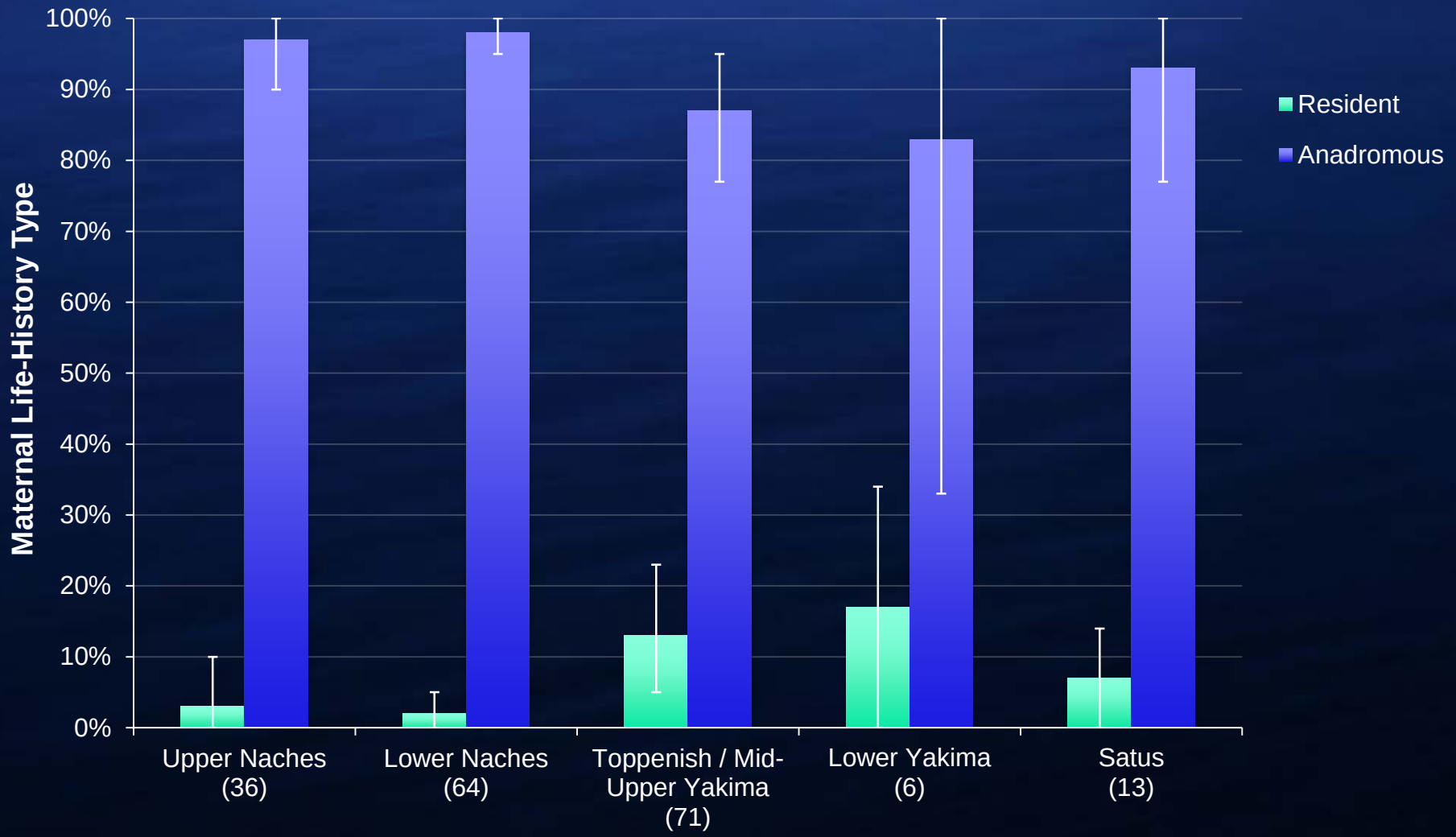
Courter et al. 2013


Water Regions
Upper Naches
Lower Naches
Toppenish / Mid-Upper-Yakima
Satus
Lower Yakima
Yakima River
Naches River
Cle Elum River
Teanaway River
Tucquala Creek
Wilson Creek
Manastash Creek
Umtanum Creek
Wenas Creek
Selah Creek
Ahtanum Creek
Toppenish Creek
Satus Creek
Little Naches River
American River
Bumping River
Rattlesnake Creek
Wildcat Creek
Tieton River
Nile Creek
N
0 10 20 40 60 80
Kilometers

2010


Maternal Life-History Type
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Resident
Anadromous
Upper Naches (52)
Lower Naches (105)
Toppenish / Mid-Upper Yakima (88)
Lower Yakima (8)
Satus (22)

2011


Maternal Life-History Type
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Resident
Anadromous
Upper Naches (36)
Lower Naches (64)
Toppenish / Mid-Upper Yakima (71)
Lower Yakima (6)
Satus (13)

Conclusions

- Yakima Basin *O. mykiss* are partially anadromous
- Resident Maternal Origin
  - 20% in 2010
  - 7% in 2011
- A large sample is needed to detect cross life-history production.

Naturally reproducing populations of anadromous and resident rainbow trout are <u>not reproductively isolated</u>.

Future Plans

1. Expand this unique dataset

2. Examine effects of environmental conditions on anadromous steelhead production