Otolith microchemistry reveals the decline of wild fall-run salmon on the Feather River, California.

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Introduction

Chinook salmon (*Oncorhynchus tshawytscha*) populations have persisted in California's highly variable climate by exhibiting diverse, genetically distinct run types (spring, fall, late-fall, winter). Fall-run Chinook salmon from the Central Valley form the backbone of California's ocean salmon fishery and are an integral part of the present and past culture in this region.

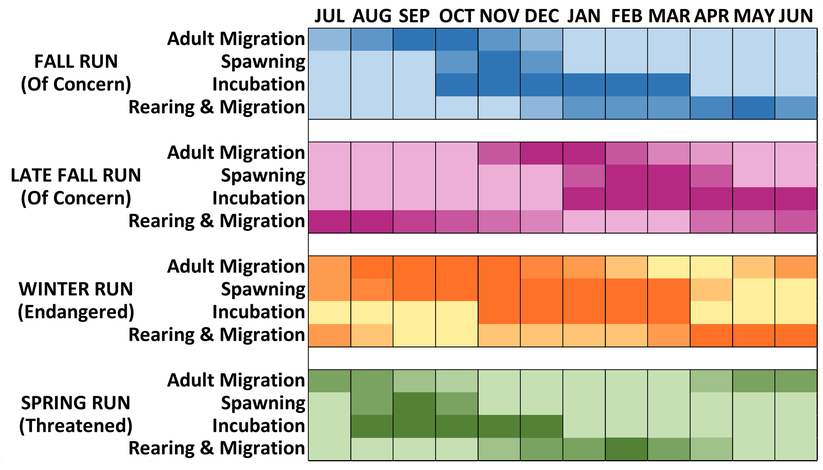


Fig. 1: Diversity in timing of the four run types of Chinook Salmon in the Central Valley of California, Data adapted from Vogel & Marine, 1991

Habitat loss, water diversions, fish harvest, and dam construction (blocking (>80% of spawning habitat) have resulted in significant population declines. Hatcheries were built to mitigate for dam construction and habitat loss, and many salmon populations are heavily subsidized. Consequently, wild stocks in several California rivers are now dominated by cultured fish, potentially eroding the long-term resiliency of locally-adapted populations by disrupting selection for heritable traits that improve life-time reproductive success.

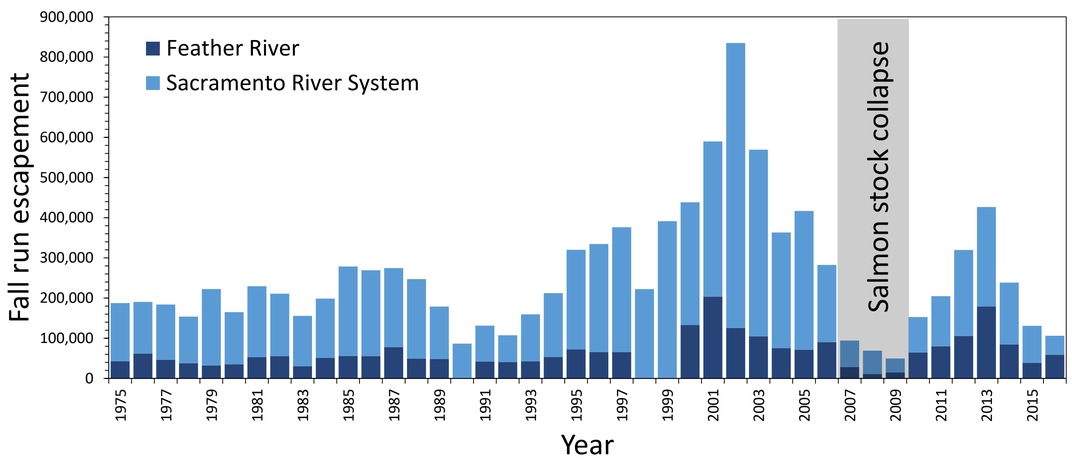


Fig. 2: Fall-run escapement estimates for the Sacramento River System and the Feather River from 1975-2016. *Note that there is no in-river escapement data available for 1990, 1998, and 1999 for the Feather River.

Aim

Determine the annual contribution of hatchery fish to the natural spawning grounds on the Feather River in the years 2002-2010, encompassing the salmon stock collapse and recovery using otolith $^{87}Sr/^{86}Sr$ isotope ratios

Study Site and sample collection

The Sacramento-San Joaquin River system in California's Central Valley (**Fig. 3**) is the foundation of California's water supply, providing water for approximately 35 million residents, supporting a multi-billion-dollar agriculture industry, and is home to the southernmost spawning runs of Chinook salmon in the northern hemisphere.

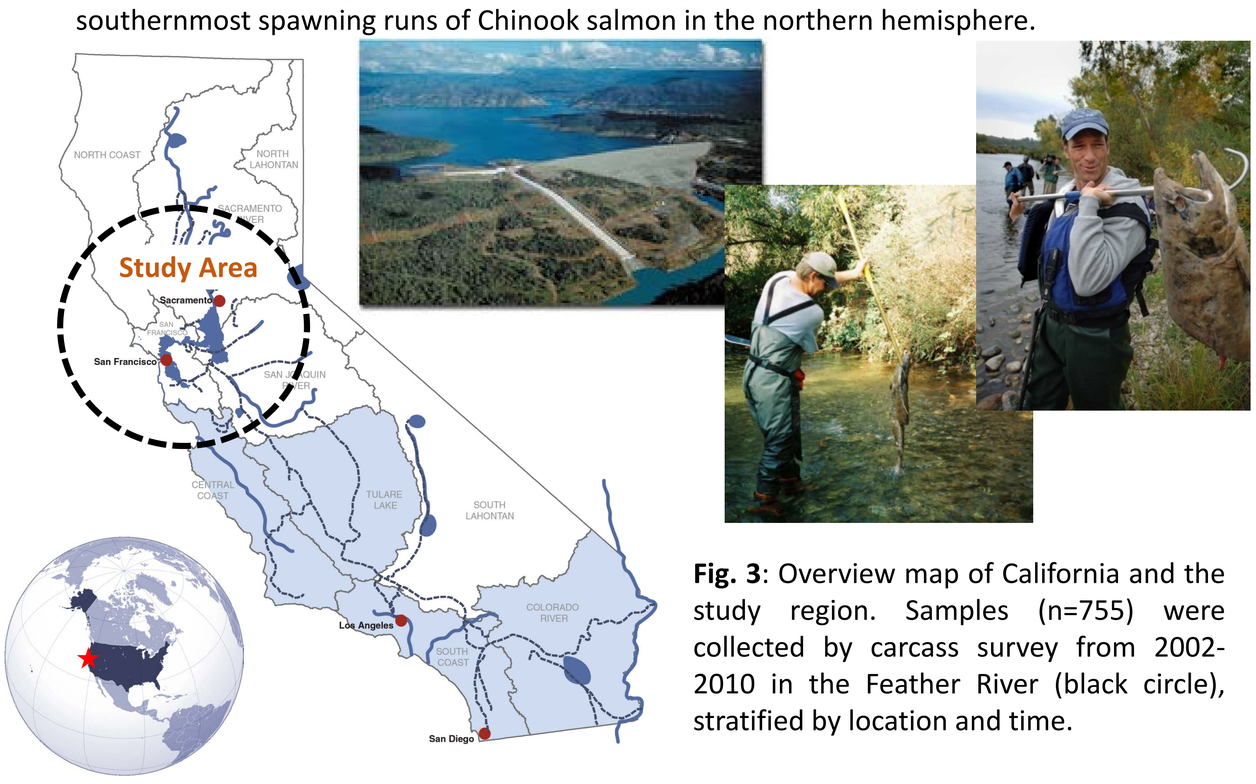


Fig. 3: Overview map of California and the study region. Samples (n=755) were collected by carcass survey from 2002-2010 in the Feather River (black circle), stratified by location and time.

Salmon stock collapse

In 2007, record low numbers of salmon returned to the CV (**Fig. 2**), resulting in the closure of the commercial ocean fishery in 2008 and 2009 for the first time in over 100 years. While the proximate cause of this stock collapse was attributed to low food availability in the coastal ocean in spring 2005 and 2006, the effect of hatchery practices contributed to a weakened salmon portfolio through increasing synchrony in population dynamics. After 2009, Chinook salmon fall-run escapement numbers rebounded, suggesting a quick and successful recovery of the salmon stock.

Insights from otoliths

Otoliths are a powerful archive of age, growth, and chemical composition of the surrounding water. In particular, strontium isotopes ($^{87}Sr/^{86}Sr$) in otoliths are a well-established tool in fish ecology for the retrospective determination of life history and origin

Otolith analyses (n=755)

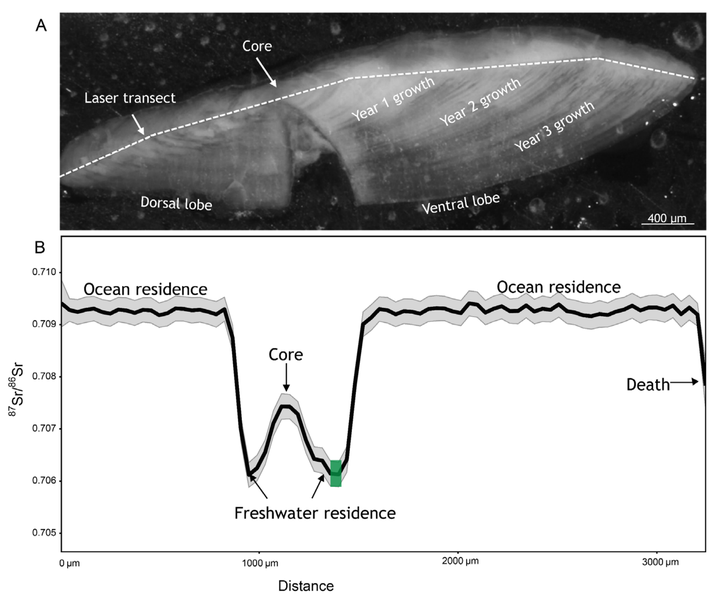


Fig. 4: (A) Image of a transverse section of an adult otolith in transmitted light, and (B) corresponding $^{87}Sr/^{86}Sr$ isotope profile measured by Laser Ablation MC-ICPMS, grey bands represent the 95% confidence intervals. Green box indicates the region used for the natal origin assignment.

Strontium Isoscape of the CV

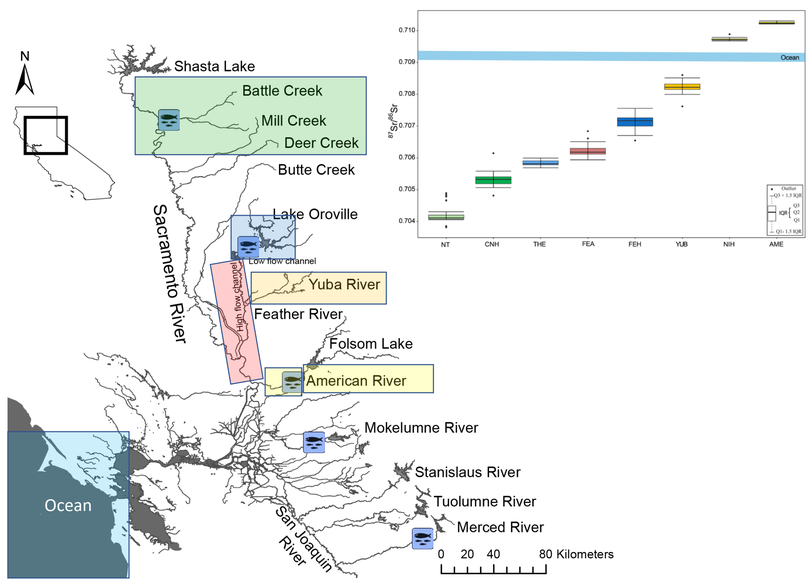


Fig. 5: $^{87}Sr/^{86}Sr$ isotope ratios of natal sources in the Sacramento River system. Using QDFA, we achieved a classification success rate of 96%, providing a robust baseline to determine natal origins in this river system. Furthermore, 95% of known-origin (coded wire tagged) fish were correctly assigned to the Feather River Hatchery.

Time series of fish origins

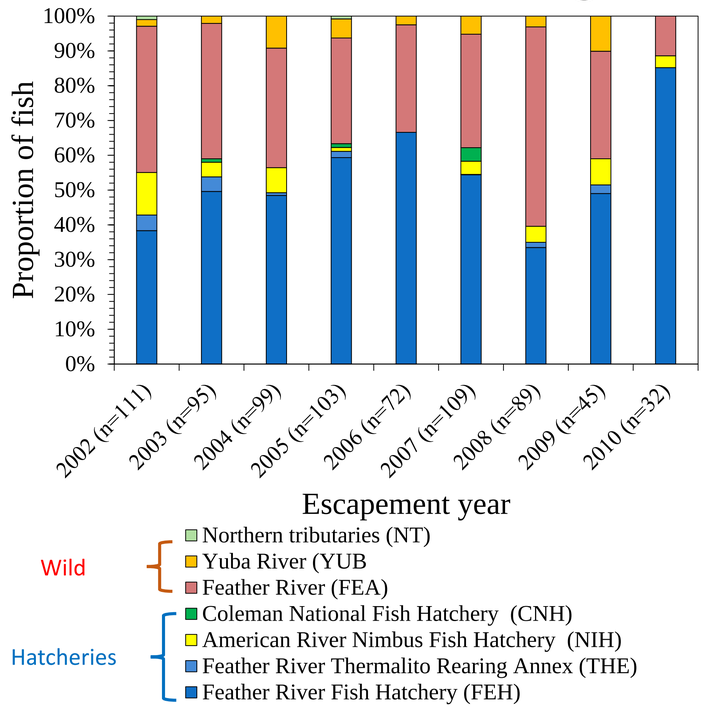
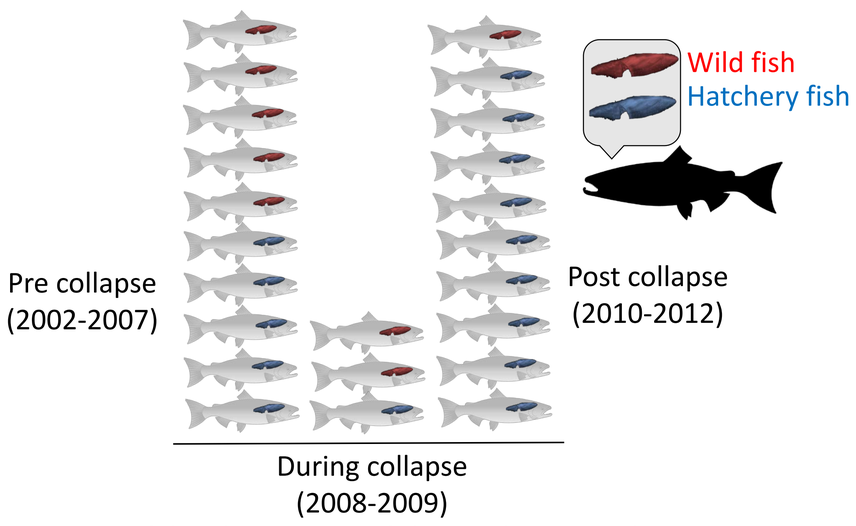


Fig. 6: Time series of the proportions of fall-run Chinook salmon on the Feather River assigned to each of the 7 natal habitats.

The Cryptic decline of wild fall-run Salmon on the Feather River



- The proportion of hatchery origin fish on the natural spawning grounds increased significantly after the stock collapse.
- Hatchery fish have effectively replaced wild stocks on the Feather River and dominate most rivers in this system.
- Hatchery release practices (constrained release timing and off-site releases) increase vulnerability of the stock complex to future collapse.

"Central Valley salmon are at a critical juncture, with many populations close to extinction and facing an increasingly unpredictable climate. Hatcheries can play a key role in the recovery of wild stocks, supplementing the fishery and the re-establishment of natural areas, but only with cautious and appropriate management"

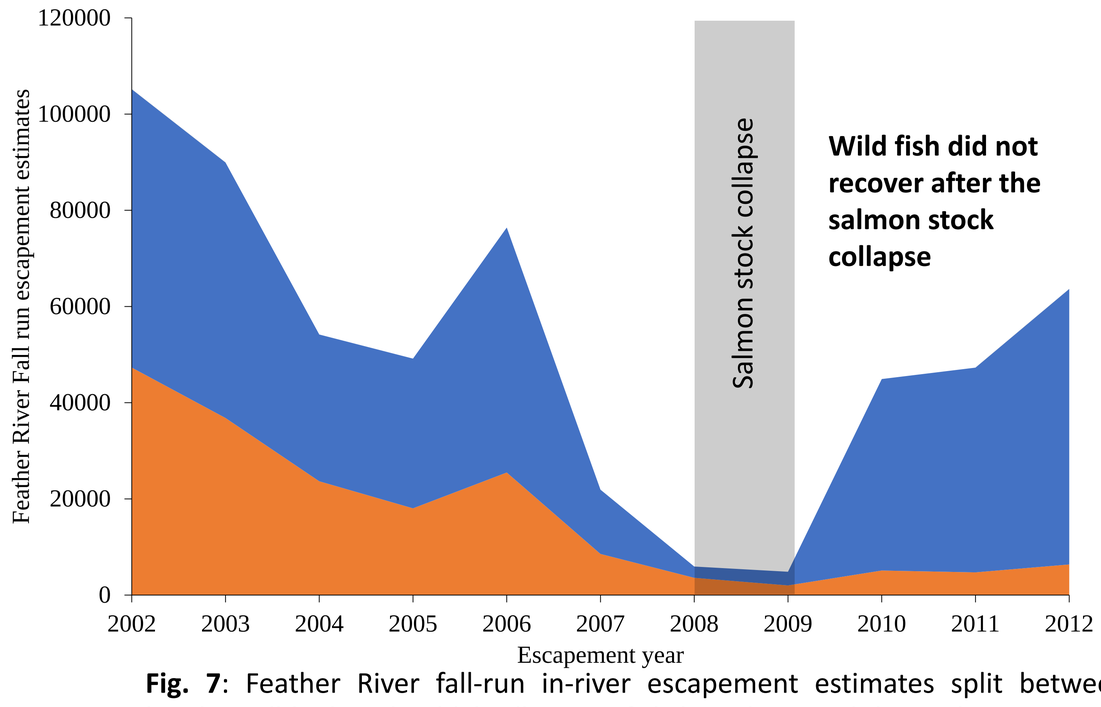


Fig. 7: Feather River fall-run in-river escapement estimates split between hatchery (blue) and wild (red) origin fish based on otolith natal assignments (2002-2010) and from a large-scale tagging program (2011-12).

Acknowledgements

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