Quantifying the Effects of Hatchery Management on the Portfolio Effect in Salmon

Allison Dedrick*, University of California Davis, agdedrick@ucdavis.edu
Marissa Baskett, University of California Davis, mlbaskett@ucdavis.edu
Amanda Faig, University of California Davis, afaig@ucdavis.edu
Michael Springborn, University of California Davis, mspringborn@ucdavis.edu

Diversity within populations can help buffer against collapse in a changing environment. This phenomenon, called the portfolio effect, is particularly applicable to salmon stocks because varied conditions in streams can create runs with diverse traits, such as outmigration timing. In Central Valley fall-run Chinook, which are heavily affected by humans through hatcheries, harvest, and habitat change, eroded diversity among runs could have contributed to the recent population collapse. In particular, hatchery release practices can change the amount of exchange among creeks: fish released closer to the ocean are more likely to stray and return to a non-natal creek as adults, eroding local adaptation. Using a quantitative genetic model with two creeks, one with a hatchery, we investigate the effect of hatchery management practices on the portfolio effect that arises from population dynamics and diversity across creeks. Specifically, we ask whether trucking hatchery fish downstream can drive the homogenization of outmigration timing across creeks and if so, what the consequences are for population dynamics.

We find that releasing hatchery fish closer to the ocean results in both genetic and demographic effects across the whole population, not just in the creek with the hatchery. As hatchery fish are released farther downstream, the mean traits become more similar between the two creeks and both the mean and the variance of annual total population size increase, presenting a tradeoff between average total run size and stability through time. These results indicate that hatchery release practices can drive homogenization among streams and weaken the portfolio effect, making returns larger on average but also more variable. Current management practices for the Central Valley fall-run Chinook involve hatcheries and trucking, including trucking to bypass the Bay-Delta, so the population-level tradeoffs due to trucking suggested by our study are relevant to future decisions about hatchery practices.

Keywords: hatcheries, trucking, Central Valley fall-run Chinook, outmigration, *Oncorhynchus tshawytscha*, portfolio
Session Title: Biology, Ecology and Management of Central Valley Salmonids I
Session Time: Wednesday 8:20 AM – 10:00 AM, Room 306

Salmon Strategies in the Central Valley Portfolio: Risk Spreaders vs. Risk Takers

Anna Sturrock, University of California, Berkeley, a.sturrock@berkeley.edu
Stephanie Carlson, University of California, Berkeley, smcarlson@berkeley.edu
Corey Phillis, Metropolitan Water District of Southern California, CPhillis@mwdh2o.com
Peter Weber, Lawrence Livermore National Laboratory, weber21@llnl.gov
Rachel Johnson, NOAA, Rachel.Johnson@noaa.gov

Life history diversity can buffer salmon populations over space (e.g. the use of natal and non-natal habitats for rearing) and time (e.g. variable outmigration timing resulting in a greater probability of meeting optimal ocean conditions). California Central Valley Chinook salmon display an extraordinary suite of life histories and migration strategies, but factors such as waterway channelization, modifications to the natural flow regimes, water diversions, and hatchery practices may function to truncate this diversity. For example, fall run Central Valley Chinook salmon are genetically homogeneous and exhibit correlated population dynamics that reveal a weak and deteriorating Portfolio Effect (PE), likely due, in part, to hatchery release practices. Managing for life history diversity in regulated rivers is a central element to many salmon recovery plans, yet it remains difficult to incorporate the PE into management objectives in part because it is a difficult phenomenon to quantify. Here, we have synthesized metrics of juvenile salmon life history diversity (size and time at outmigration, natal vs. non-natal rearing behaviors) from various data sources (rotary screw trap, beach seine and trawl sampling, and otolith chemistry reconstructions), rivers (Stanislaus, Tuolumne, Yuba, American and Sacramento River, Deer, Mill and Butte Creeks), and runs (spring, fall and winter run). We compare trait expression and success among years and populations, and attempt to integrate our findings with historical accounts and observations from other systems.

Keywords: Life history diversity, salmon, otolith, biocomplexity, synthesis, portfolio effect, outmigration
Session Title: Biology, Ecology and Management of Central Valley Salmonids I
Session Time: Wednesday 8:20 AM – 10:00 AM, Room 306

Identifying Hatchery Versus Wild Origin of Chinook Salmon (*Oncorhynchus tshawytscha*) on the Feather River Spawning Grounds using Otolith Strontium Isotope Ratios

Malte Willmes, Wildlife, Fish and Conservation Biology, University of California, Davis, malte.willmes@googlemail.com
Zachary Bess, Wildlife, Fish and Conservation Biology, University of California, Davis, zabess@ucdavis.edu
Anna M. Sturrock, Department of Environmental Science, University of California, Berkeley, a.sturrock@berkeley.edu
Ryon Kurth, Department of Water Resources, Division of Environmental Services, Feather River Special Studies, Ryon.Kurth@water.ca.gov
Jason Kindopp, Department of Water Resources, Division of Environmental Services, Feather River Special Studies, Jason.Kindopp@water.ca.gov
Rachel C. Johnson, NOAA Fisheries, rachel.johnson@noaa.gov
James A. Hobbs, Wildlife, Fish and Conservation Biology, University of California, Davis, jahobbs@ucdavis.edu

Chinook Salmon (*Oncorhynchus tshawytscha*) populations in California are heavily subsidized with the production of hatchery fish. However, the spawning of hatchery origin Chinook with wild fish has been found to compromise the genetic integrity of the wild origin populations through processes such as outbreeding, genetic homogenization and reduction of life history diversity. Determining the proportion of hatchery origin fish on the in-river spawning grounds is thus a direct prerequisite for the effective management of salmon populations. We used otolith strontium isotope (^{87}Sr:^{86}Sr) ratios of fish collected during carcass surveys for each year from 2002 to 2010 on the Feather River to reconstruct their life history patterns and determine their origin. Isotopically determined hatchery origin classifications were validated using otoliths of known hatchery origin from coded wire tag information and achieved an accuracy of 95%. Our results show, that a large proportion (~50-90%) of in-river spawning fish in the Feather River are of hatchery origin, with the proportion of hatchery fish dramatically increasing in 2009 and 2010. We also identified fish originating from other tributaries which contributed generally less than 10% to the spawning populations, with most strays originating from the near-by Yuba River. The high proportions of in-river spawning hatchery origin chinook salmon documented in this study indicate, that fitness of natural origin Chinook may be significantly impaired and suggest that introgression between hatchery and natural origin Chinook may be a factor contributing to the depressed status Central Valley Chinook salmon.

Keywords: Chinook Salmon, Otolith microchemistry, Feather River, Strontium isotopes
Session Title: Biology, Ecology and Management of Central Valley Salmonids I
Session Time: Wednesday 8:20 AM – 10:00 AM, Room 306

Adaptive Genetic Variation, Conservation, and Fisheries Management in the Age of Genomics

Devon Pearse, NMFS Southwest Fisheries Science Center, devon.pearse@noaa.gov

In anadromous fishes, expression of migratory life-history phenotypes is influenced by a combination of environmental, genetic, and developmental effects. Recent studies have identified specific genes and genomic regions under divergent natural selection for fitness-related phenotypes. This improved understanding of the genomic basis of life-history variation has extended our knowledge of adaptive evolution, and has the potential to provide useful data for species conservation and management decision-making, complimenting more typical conservation applications of population genetic data. However, careful consideration must be given to the implications of using marker-specific approaches to set conservation priorities. This is especially critical for hatchery supplementation programs and reintroduction projects because, unlike the practice of marker-assisted selection in captive plant and animal breeding, individuals in natural populations and hatchery broodstock programs must contend with natural selection in the environment in which they are released. Thus, marker-based selection of breeders to produce specific phenotypes in a conservation context has the potential to produce offspring with maladapted phenotypes for existing environmental conditions (e.g. anadromous migration through the delta). Here I use data on adaptive genomic variation associated with specific phenotypes in salmonids to hightlight the practical considerations and potential pitfalls of incorporating such information into conservation programs, describe conservation scenarios in which it could be misleading, and the importance of validating inferences drawn from new genomic data before applying them in conservation practice. Finally, I discuss ways to bridge the gap between newly developed genomic technologies and applied conservation practice.

Keywords: genetics, genomics, adaptation, evolution, life-history, management, hatcheries, salmon, steelhead
Session Title: Biology, Ecology and Management of Central Valley Salmonids I
Session Time: Wednesday 8:20 AM – 10:00 AM, Room 306

Selection of Donor Stock for Salmonid Reintroduction Projects

John Carlos Garza, NOAA Southwest Fisheries Science Center and the University of California Santa Cruz, carlos.garza@noaa.gov
Devon Pearse, NOAA Southwest Fisheries Science Center and the University of California Santa Cruz, devon.pearse@noaa.gov
Anthony Clemento, University of California Santa Cruz and NOAA Southwest Fisheries Science Center, anthony.clemento@noaa.gov

Much of the historically available spawning and rearing habitat for salmon and steelhead in the Sacramento/San Joaquin basin is now behind dams and reservoirs, or otherwise not suitable for successful life cycle completion. As efforts accelerate to restore fish populations to achieve ESA recovery and stabilize ecosystems, many reintroductions of salmonids are either underway or being planned. Yet, it is often not clear where to obtain fish for such reintroductions and how to go about selecting and releasing them. We describe the biological factors that need to be taken into account for such donor stock collection, including considerations of local adaptation, genetic diversity, life history and population viability. We further discuss the biological criteria and logistical issues involved in selecting individual fish for reintroductions and in release strategies. We illustrate the complex issues involved in restoring fish populations in newly available habitat with examples from the current reintroduction of Chinook salmon to the San Joaquin River and planned reintroductions of salmon to the McCloud and North Fork Yuba Rivers.

Keywords: Reintroductions, Salmon, Steelhead, Donor stock, Biological criteria
Session Title: Biology, Ecology and Management of Central Valley Salmonids I
Session Time: Wednesday 8:20 AM – 10:00 AM, Room 306

Timing of Hatchery and Wild Winter-run Chinook Salmon Caught in the Sacramento River and Chipps Island Trawls for the Implementation of Delta Management Actions.

Patricia Brandes, U.S. Fish and Wildlife Service, Pat_Brandes@fws.gov

Many management actions in the Sacramento-San Joaquin Delta are timed to be protective of juvenile winter-run Chinook salmon and use the detection of winter-run-sized fish or hatchery winter-run to trigger actions, but it is unclear how well these represent wild winter run. Winter-run-sized fish in Delta monitoring are identified using the river length-at-date-criteria (RLADC). Between 2007 and 2011, we collected tissues from juvenile Chinook salmon caught in the trawls at Sacramento and Chipps Island and determined that the RLADC over-estimated the abundance of winter-run at both locations because many fall, late-fall and spring-run Chinook salmon are designated as winter-run using the RLADC. While the winter-run RLADC does not estimate relative abundance well, it does appear to generally reflect the timing of genetic winter-run at both Sacramento and Chipps Island. In contrast, when comparing the timing of the genetic winter-run caught at Sacramento to the hatchery winter-run, we found in most cases that roughly half of the winter-run caught were caught before the hatchery fish were released, and in two of three years no winter-run hatchery fish were caught at Sacramento. This would suggest that the hatchery winter-run are poor surrogates for the early part of the wild winter-run migration into the Delta. At Chipps Island, the majority of the genetic winter-run do overlap with the hatchery winter-run catches because fewer winter-run appear to migrate past Chipps Island earlier in the season before hatchery release. Management actions that incorporate timing from both the RLADC and the winter-run hatchery fish are more likely to be successful in protecting all of the juvenile winter-run Chinook salmon in the Delta, than either method alone.

Keywords: Salmon, winter-run, migration timing, Delta
Session Title: Biology, Ecology and Management of Central Valley Salmonids II
Session Time: Wednesday 10:20 AM – 12:00 PM, Room 306

Migration and Survival of Natural Juvenile Chinook Salmon in the Delta

Li-Ming (Lee) He, NOAA Fisheries, li-ming.he@noaa.gov

Problem Statement: The Sacramento-San Joaquin Delta serves as a migration corridor and rearing place for natural juvenile winter-run and spring-run Chinook salmon that enter from the Sacramento River to the Delta each year, before migrating into the San Francisco Bay and finally to the Pacific Ocean. Many studies have been done using a limited number of hatchery-origin juveniles, but much is unknown about the migration timing, migration duration, and survival of natural juveniles migrating through the complex waterway system of the Delta.

Approach: We developed a systematic approach for compiling and analyzing 21 years (1993-2013) of juvenile fish monitoring data at Sherwood Harbor and Chipps Island. Daily juvenile catch and trawl efficiency data were used to obtain daily and annual juvenile passages at the two monitoring locations.

Results/Conclusions/Relevance: I will present results for migration timing, migration duration, and survival rates for natural winter-run and spring-run Chinook salmon juveniles migrating through the Delta. I will discuss how inflow to the Delta, Delta outflow, or water export affects migration timing, duration, or survival. The findings may shed light on how to manage the Delta for endangered or threatened salmon species.

Keywords: Chinook salmon, migration timing, duration, abundance, survival, inflow, outflow, export
Session Title: Biology, Ecology and Management of Central Valley Salmonids II
Session Time: Wednesday 10:20 AM – 12:00 PM, Room 306

Comparing In-River Survival of Coleman National Fish Hatchery- and Nimbus Fish Hatchery-Origin Steelhead Smolts Released in the Lower American River

Annie Brodsky, Cramer Fish Sciences, annieb@fishsciences.net
Steven Zeug, Cramer Fish Sciences, stevez@fishsciences.net
Jonathan Nelson, California Department of Fish and Wildlife, Jonathan.Nelson@wildlife.ca.gov
John Hannon, United States Bureau of Reclamation, jhannon@usbr.gov

Steelhead reared at Nimbus Hatchery (NH) are not part of the Central Valley evolutionary significant unit and as such, do not contribute to recovery of the native stock. The reasonable and prudent alternative in the National Marine Fisheries Service biological opinion on operation of the Central Valley Project and State Water project included direction to investigate replacement of the NH stock. In 2015 steelhead eggs from Coleman National Fish Hatchery (CNFH) were reared at NH and in-river survival was monitored for both stocks released in the Lower American River as part of an evaluation of the CNFH stock's suitability for use at NH. Smolts from both stocks were implanted with acoustic transmitters and released on two occasions into the Lower American River. Forty seven NH-origin smolts and fifty CNFH-origin smolts were released on February 11, 2016 and forty six NH-origin smolts and 57 CNFH-origin smolts were released on February 24, 2016. The minimum survival estimate from release one was 83.0% for NH -origin fish and 82% for CNFH-origin fish. Minimum survival from release two was 95.7% for Nimbus Hatchery -origin fish and 75.4% for CNFH-origin fish. The data produced to date suggest that there is no detectable difference in the proportion of NH - and CNFH -origin smolts successfully migrating out of the Lower American River. These analyses suggest further studies should be performed to assess CNFH steelhead performance at NH during other life stages.

Keywords: Lower American River, acoustic monitoring, Nimbus, Coleman, steelhead, Central Valley
Session Title: Biology, Ecology and Management of Central Valley Salmonids II
Session Time: Wednesday 10:20 AM – 12:00 PM, Room 306

Where They Go and How They Grow: Using Otoliths to Reconstruct Habitat-Specific Growth Patterns for Endangered Winter-Run Chinook

Maya Friedman*, UC Santa Cruz, mfriedma@ucsc.edu
Eric Danner, NOAA fisheries, eric.danner@noaa.gov
Rachel Johnson, NOAA Fisheries, rachel.johnson@noaa.gov

As juvenile winter-run Chinook salmon migrate from the Sacramento River through the San Francisco Estuary into the Pacific Ocean, their growth, migration, and survival are heavily affected by water temperature and flow dynamics. Yet the relative importance and use of habitats within the winter-run migration corridor is poorly understood. Salmon otoliths provide an ideal tool to reconstruct fish condition and movement. Paired with unique chemical markers within the watershed, they are able to provide insight into the habitat use, migratory behavior, and growth patterns of juvenile salmonids. We used otolith strontium isotopes ($^{87}Sr/^{86}Sr$) in adult Central Valley Winter-run Chinook salmon that successfully returned to spawn, in order to determine how river conditions influence (1) freshwater growth, (2) migration behavior, and (3) habitat use of individuals that outmigrated during 2009-2011 and successfully returned to spawn. For each successfully spawned adult, analysis of otolith increment widths and strontium isotope ratios were used to reconstruct early life growth rates and duration of riverine and delta rearing. Otolith microchemistry was paired with a high-resolution model of water temperature and flow to generate isotopic landscapes (isoscapes) of strontium for the entire range of Winter-run habitat from the Sacramento River. Size distributions and phenotype contributions were compared between juvenile emigrants and adults that returned to spawn, and used to identify patterns in selective mortality. Our study years examined juvenile cohorts emigrating over a period of contrasting flow regimes as a result of differences in precipitation patterns and water operations. Outmigration behavior (size and phenology) varied primarily as a function of hydrologic regime, with important growth differences among habitats within the migration corridor. This information will provide valuable insights to aid future management decisions aimed at minimizing drought impacts to winter run, and to improving water supply reliability.

Keywords: Chinook salmon, life history diversity, juvenile outmigration, otolith strontium isotopes
Session Title: Biology, Ecology and Management of Central Valley Salmonids II
Session Time: Wednesday 10:20 AM – 12:00 PM, Room 306

Survival and Movement Rates of Wild Chinook Salmon Smolts from Mill Creek through the Sacramento River, Sacramento-San Joaquin River Delta and San Francisco Bay, 2013-2016

Jeremy Notch*, University of California, Santa Cruz, jeremy.notch@noaa.gov
Arnold Ammann, National Marine Fisheries Service, arnold.ammann@noaa.gov
Matt Johnson, California Department of Fish and Wildlife, matt.johnson@wildlife.ca.gov
Alex McHuron, National Marine Fisheries Service, alex.mchuron@noaa.gov

Populations of wild spring and fall-run Chinook salmon in California's Central Valley once numbering in the millions have dramatically declined in recent years to all-time low numbers. Dam construction, habitat degradation, predation, water diversions and hatchery stocks have largely wiped out populations of wild spring-run Chinook in the Central Valley, with just a handful of populations persisting in a few tributaries to the Upper Sacramento River Basin. Mill Creek is one of these tributaries which offer some of the most pristine spawning and rearing habitat currently available to Chinook salmon in the Central Valley. Despite this pristine habitat its populations of spring and fall-run Chinook salmon have declined in recent years, with spring-run escapement reaching a low of 127 adults in 2015. In order to address this issue and study the survival rates of out-migrating smolts from Mill Creek we used Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic tags surgically implanted into migrating smolts captured with a rotary screw trap and seine net. Acoustic receivers placed throughout the migration corridor allow us to track reach-specific survival and movement rates from Mill Creek to the Pacific Ocean. After four years of data collection (2013-2016) we have acoustic tagged 330 smolts during their spring out-migration, which experienced extreme drought conditions in 2013-2015 followed by a wet year in 2016. The data suggests survival for smolts emigrating from Mill Creek during drought conditions is very poor, with the majority of them dying in Mill Creek and the Upper Sacramento River. In 2016 these smolts experienced high water conditions which should lead to higher survival rates. Continued acoustic tagging studies on these stocks will allow us to better manage the dwindling populations and focus restoration efforts in key locations.

Keywords: Chinook salmon, acoustic telemetry, survival, movement, predators
Session Title: Biology, Ecology and Management of Central Valley Salmonids II
Session Time: Wednesday 10:20 AM – 12:00 PM, Room 306