Factors Affecting Juvenile Chinook (*Oncorhynchus tshawytscha*) Growth Variability in a Large Freshwater Tidal Estuary

Pascale Goertler, School of Aquatic and Fishery Sciences, University of Washington, pascale.goertler@water.ca.gov
Charles Simenstad, School of Aquatic and Fishery Sciences, University of Washington, simenstd@u.washington.edu
Dan Bottom, NOAA Fisheries, Northwest Fisheries Science Center, dan.bottom@noaa.gov
Susan Hinton, NOAA Fisheries, Northwest Fisheries Science Center, susan.hinton@noaa.gov
David Teel, NOAA Fisheries, Northwest Fisheries Science Center, david.teel@noaa.gov
Lia Stamatiou, School of Aquatic and Fishery Sciences, University of Washington, liastam@uw.edu

Estuarine rearing habitat has been shown to enhance within watershed biocomplexity and support growth and survival for juvenile salmon (*Oncorhynchus* sp.). However, less is known about how growth varies across different types of wetland habitats and what explains this variability in growth. This study examined juvenile fish growth over a range of wetland habitats in the freshwater tidal Columbia River estuary. We focused on the estuarine habitat use of Columbia River Chinook salmon (*Oncorhynchus tshawytscha*), which are listed under the Endangered Species Act. We employed a generalized linear model (GLM) to test three hypothesis: (1) juvenile Chinook growth was best explained by temporal factors, (2) juvenile Chinook habitat use was the most important driver of estuarine growth rate, and (3) demographic characteristics, such as stock of origin or the timing of seaward migration best explain juvenile Chinook salmon growth rate. This study examined juvenile Chinook estuarine growth rate, incorporating otolith microstructure, individual assignment to stock of origin, GIS habitat mapping and diet composition in three habitats (mainstem river, tributary confluence and backwater channel) along ~130 km of the upper estuary. These findings present a unique example of the complexity in understanding the influences of the many processes that generate variation in growth rate for juvenile anadromous fish inhabiting estuaries.

Keywords: juvenile Chinook salmon, Columbia River estuary, habitat, growth, diet
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Using Otolith Strontium Isotopes to Reconstruct Life History Portfolios within Salmon Populations: When Do Different Phenotypes Contribute?

Anna Sturrock, University of California, Santa Cruz, anna.m.sturrock@gmail.com
JD Wikert, US Fish & Wildlife Service, john_wikert@fws.gov
Tim Heyne, California Department of Fish and Wildlife, Tim.Heyne@wildlife.ca.gov
Carl Mesick, US Fish & Wildlife Service, carl_mesick@fws.gov
Alan Hubbard, University of California, Berkeley, hubbard@berkeley.edu
Peter Weber, Lawrence Livermore National Laboratory, Weber21@llnl.gov
George Whitman, University of California, Santa Cruz, gewhitman@ucdavis.edu
Justin Glessner, UC Davis Interdisciplinary Center for Plasma Mass Spectrometry, jjglessner@ucdavis.edu
Stephanie Carlson, University of California, Berkeley, smcarlson@berkeley.edu
Travis Hinkelman, Cramer Fish Sciences, travis.hinkelman@fishsciences.net

The maintenance of life history diversity within and among populations is thought to be critical for the persistence of salmon stocks. Preserving and restoring diversity in life history traits is thus central to many recovery efforts, but it is necessary to first understand how environmental factors affect their expression and success. Rotary-screw trap sampling in the California Central Valley has indicated that juvenile salmon outmigrate at different sizes, ages and times of the year. We used otolith strontium isotopes in adult Chinook salmon returning to the Stanislaus River, a regulated stream at the southern end of the species range, to determine how river conditions influence juvenile behavior and survival. Paired otolith and scale samples were used to reconstruct juvenile outmigration patterns of successful adults from cohorts emigrating between 1999 and 2011. For each adult, the size it had outmigrated from its natal tributary was reconstructed by coupling otolith strontium isotope and radius measurements. Size distributions and phenotype contributions were compared between the juvenile outmigrants and adult "survivors", and used to identify trends in selective mortality. Our seven focus years exhibited contrasting flow regimes as a result of differences in precipitation patterns and local water operations. In wetter years, the majority of juveniles outmigrated as fry, while in drier years, outmigrants tended to be fewer but larger. Metrics of outmigration behavior (abundance, size and phenology) varied primarily as a function of hydroclimatic regime, while relative survival rates appeared to be driven by conditions within the natal tributary, as well as size- and time-selective mortality. While fry survival is generally assumed to be negligible in this system, our data indicate that they can represent more than 20% of the reproductive population. Patterns in juvenile outmigration behavior and survival are discussed in the context of water and fisheries management, and the portfolio effect.

Keywords: Chinook salmon, life history diversity, juvenile outmigration, otolith strontium isotopes
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Genetic Analysis of Hatchery Steelhead from the Central Valley Reveals Patterns of Reproduction and Migration

John Carlos Garza, NOAA Southwest Fisheries Science Center/University of California, Santa Cruz, carlos.garza@noaa.gov
David Vendrami, Università degli Studi di Ferrara, Italy; University of California, Santa Cruz; NOAA Southwest Fisheries Science Center, david.vendrami@student.unife.it
Devon Pearse, NOAA Southwest Fisheries Science Center/University of California, Santa Cruz, devon.pearse@noaa.gov

Iteroparous salmonids are more difficult to study than semelparous ones because carcasses are rarely encountered and they are released alive from hatcheries after spawning. Single Nucleotide Polymorphism markers have been shown to be useful in pedigree reconstruction, investigations of stock structure and individual identification and provide biological information that is not available with traditional physical tags. We collected data for 95 SNP markers from more than 10,000 steelhead (the anadromous form of *Oncorhynchus mykiss*) used as broodstock between 2011 and 2014 in the four California Central Valley steelhead hatchery programs: Coleman, Feather River, Mokelumne River and Nimbus hatcheries. Assignment tests allowed us to estimate migration rates between hatcheries and to confirm the clear distinction of the Nimbus Hatchery population, which was founded with coastal steelhead stocks, from the other Central Valley hatcheries. Similarly, we confirmed that Mokelumne River Hatchery steelhead are genetically similar to Feather River Hatchery stock, from which they were derived. The identification of parents-offspring trios allowed us to evaluate age structure and variance in family size in all programs. We found a high proportion of age 2 spawners in three of these programs, but none at Nimbus. Finally, we matching genotypes were used to count how many fish spawned more than once in the same season and identified a significant number of fish that reproduced multiple times in the same season. We also used this approach to investigate iteroparity rates for each hatchery program separately. The comparison of the first spawning date with spawning dates in subsequent spawning events for iteroparous individuals identified a strong correlation, consistent with the heritability of spawning date. This study shows the power of SNP-based genetic tagging analysis to elucidate key life history variables and, as a consequence, it's utility in formulating effective conservation and management strategies.

Keywords: Steelhead, genetics, SNPs, migration, iteroparity, hatcheries, reproduction
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Large-Scale Genetic Tagging Experiment with Chinook Salmon from the Feather River Hatchery Allows for Pedigree-Based Inference

Anthony Clemento, NOAA Fisheries, anthony.clemento@noaa.gov
Eric Anderson, NOAA Fisheries, eric.anderson@noaa.gov
Carlos Garza, NOAA Fisheries, carlos.garza@noaa.gov

Studies of aquatic animals often require identifying individuals, groups or populations over a period of time. For Chinook salmon, the coded-wire tag, mechanically inserted in the skulls of juvenile fish, has been the primary tool for tracking cohorts and quantifying stock-specific fishery impacts. However, as the data needs of fishery managers have grown, alternative tagging strategies have gained prominence. One of the most promising technologies is parentage-based tagging (PBT), which uses genotypes collected from a parental breeding generation in a hatchery to tag the offspring cohort. Non-lethal sampling of offspring during their seaward migration, in fisheries, or upon return to spawn (either at hatcheries or instream) is followed by high-confidence parentage assignment, allowing identification of stock and cohort of origin, as well as the reconstruction of multiple pedigrees. Here, we report the results of an 8-year PBT experiment with spring-run Chinook salmon from the Feather River Hatchery. Reconstructed parent-offspring trios were used to assess inter-annual variability in the age structure of offspring cohorts as well as the age structure and relative reproductive success of spawning broodstock. Data on the physical characteristics of parents and offspring were used to estimate the heritability of length and age at maturity and to identify correlations between female body size and the number of her offspring returning to spawn. Inbreeding and relatedness in spawning populations was also assessed and the effect of parental relatedness on reproductive success evaluated. The offspring of hatchery spawners were also identified in a large mixed-stock fishery sample from the coastal ocean of California. This type of information is critical for understanding the population dynamics of hatchery stocks, the effects of hatchery practices and the distribution of specific cohorts in ocean fisheries.

Keywords: Chinook salmon California genetics SNP hatchery parentage-based-tagging heritability
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Application of Genetic Methods To Salvaged ESA-listed Chinook Salmon

Scott Blankenship, Cramer Fish Sciences - Genidaqs, scott.blankenship@fishsciences.net
Gregg Schumer, Cramer Fish Sciences - Genidaqs, greggs@fishsciences.net
Kevin Reece, California Department of Water Resources, kevin.reece@water.ca.gov

Water exports from the South Delta cause "incidental take" of juvenile salmonids, potentially contributing to jeopardy of ESA-listed species. While the export loss functions essentially estimate the total fish mortality given the number of fish observed at salvaged facilities, a foundational component of these calculations is the determination of which salvaged individuals are "older", as defined by length-at-date criteria (i.e., the "Delta Model"). NOAA's RPA define an "older" juvenile as an individual that resides above the lower boundary of winter run length-at-date criteria. Yet, the Delta Model is known to be ambiguous regarding race determination. The failure of the length-at-date model to accurately categorize race creates considerably uncertainty (variance) in the estimation of loss density. We were charged with using genetic methods to determine the population of origin for juveniles categorized as "older" by the Delta Model, as well as individuals that fell outside the winter run length-at-date criteria. The objectives of this genetic project are intended to directly target (and reduce) one source of uncertainty in the estimation of loss at salvage facilities. Accurate and rapid determination of population was performed using methods based on single nucleotide polymorphism (SNP) markers and fluidic chip technology. We compared our direct observations from genetically-partitioned salvage loss to current regulatory take determinations at both State Water Project and Central Valley Project South Delta export facilities for water years 2010-14. We observed statistically significant differences within-year between facilities, between-year within facility, and between tissue archive sampling strategies. Secondary analyses also found evidence for Sacramento River population survey deficiencies. The presentation will conclude with describing strategies to further integrate genetic information into salvage loss estimation processes.

Keywords: Genetic analysis, population assignment, Chinook salmon, salvage facilities
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What do We Need to Know about Juvenile Salmonids Entering the Delta and How Will We Know it?

Bradley Cavallo, Cramer Fish Sciences, bcavallo@fishsciences.net

Needs and opportunities for monitoring Central Valley salmonids differ considerably from other fish species inhabiting the Delta. While conservation biology recognizes only a single population of delta smelt, recovered populations of Central Valley Chinook (winter, spring and fall) are expected to consist of several to many sub-populations originating from tributaries up and down the Sacramento-San Joaquin Basin. Application of population genetics to juvenile salmon encountered in current Delta monitoring programs can estimate the proportion of fish matching a particular Chinook race genetic baseline. However, estimating the proportion of spring Chinook present in Delta fish samples, provides less value (for conservation, monitoring and management) than knowing how many juvenile spring Chinook were produced each from Clear Creek, Battle Creek, Butte Creek, the Feather River and the San Joaquin River along with knowing when and where individuals representative of these sub-populations are residing (or perishing) within the Delta. A monitoring program that detects spring run Chinook generally, but can't distinguish subpopulations specifically, would for example, allow the growth of one subpopulation to mask the decline of another. My presentation will describe a vision for Central Valley salmonid monitoring in which innovative sampling and tagging techniques are deployed to guide Delta management and to provide population metrics essential for guiding recovery of Central Valley salmonid populations.

Keywords: salmon, steelhead, monitoring, viability, recovery, spawning, abundance, productivity
Session Title: Looking Ahead: Managing for Salmon
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2012 Georgiana Slough Non-Physical Barrier Performance Evaluation

Christopher Fitzer, Environmental Science Associates, cfitzer@esassoc.com
Ryan Reeves, California Department of Water Resources, Ryan.Reeves@water.ca.gov

The migration of juvenile salmonids into the interior Delta through pathways such as Georgiana Slough has been shown in previous studies to contribute to lower survival. In an effort to identify potential approaches to reduce the percentage of the juvenile salmonids that migrate from the Sacramento River into Georgiana Slough, a team led by DWR implemented a large-scale experimental testing program in 2011 and 2012 to assess the effectiveness of a non-physical barrier using Bio-Acoustic Fish Fence™ (BAFF) technology as a method for guiding outmigrating juvenile salmonids. The experimental design of the 2012 tests included the use of acoustically tagged juvenile late fall-run Chinook salmon and steelhead, released upstream of the non-physical barrier when the barrier was on and when it was off, to determine the effectiveness of the barrier. The BAFF reduced the percentage of Chinook salmon passing into Georgiana Slough from 24.8% when the BAFF was off to 10.3% when the BAFF was on, representing statistically significant overall reduction in entrainment into Georgiana Slough of 14.5 percentage points ($p=<0.0001$). This improvement produced an overall efficiency rate of 89.7%; that is, 89.7% of Chinook salmon that entered the area when the BAFF was on exited by continuing down the Sacramento River. Furthermore, the BAFF reduced the percentage of steelhead passing into Georgiana Slough from 25.6% when the BAFF was off to 12.3% when the BAFF was on, representing an overall reduction in entrainment into Georgiana Slough of 13.3 percentage points. The improvement produced an overall efficiency rate of 87.7%. A generalized linear model analysis of the data showed that the most important predictors of tagged salmonids remaining in the Sacramento River were cross-stream position and BAFF operation. The predation rate of tagged salmonids in the area of the BAFF did not differ between BAFF ON and OFF operations.

Keywords: salmon, barrier, Sacramento River, Delta, telemetry, acoustic, Chinook, steelhead, Georgiana
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A Method to Estimate the Annual and Daily Abundance of Salmonid Juveniles in the Delta

Li-Ming He, NOAA Fisheries, li-ming.he@noaa.gov
Jeff Stuart, NOAA Fisheries, j.stuart@noaa.gov

Problem Statement: The Sacramento-San Joaquin Delta serves as a migration corridor for salmonid juveniles outmigrating from the Sacramento River, San Joaquin River, and other eastside tributaries. Juvenile abundance in the Delta is a key variable contributing to fish entrainment and is fundamental to managing facility operations in the Delta. Currently, there is no method available for quantifying the annual or daily abundance of salmonid juveniles in the Delta, except for winter-run Chinook salmon that had annual abundance estimates.

Approach: The daily total number of juvenile fish in the Delta (Φ) can be estimated as:

$$\Phi = \Sigma\{\phi_{in} (1 - \gamma)\} - \phi_{out}$$

Where

ϕ_{in} = Number of fish entering the Delta

ϕ_{out} = Number of fish leaving the Delta

γ = Fish daily mortality rate in the Delta

n = Fish residence time in the Delta

The number of fish entering the Delta was estimated from juvenile trawl data in the Sacramento and San Joaquin rivers. The number of fish leaving the Delta was estimated from juvenile trawl data at Chipps Island. Data for juvenile mortality and residence time were obtained from recent acoustic tag studies in the Delta. The overall annual Delta survival rate was estimated from the total annual numbers of fish entering and leaving the Delta.

Results/Conclusions/Relevance: The daily abundance of natural winter-run Chinook salmon juveniles in the Delta was highest (423,000) in 1996 and has been relatively low (below 50,000) since 2008. The daily abundance of natural spring-run Chinook salmon juveniles has been low since 1998 except for 2003, 2005, and 2011. The daily abundance of natural steelhead juveniles has been consistently low since 1998. The median overall Delta survival rates were estimated for juveniles of natural steelhead (0.47), and natural winter-run (0.41) and spring-run (0.26) Chinook salmon.

Keywords: Fish flux, juvenile abundance, Chinook salmon, steelhead, Delta survival
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Impacts of Interior Delta Flows on Salmonid Species

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

Problem Statement: Every year large quantities of salmonid juveniles, including steelhead and winter-run, spring-run, and fall-run Chinook salmon, are entrained to the Federal and state water export facilities in the south Delta; yet it has been in dispute on factors that most likely impact the entrainment.

Approach: We analyzed the available data of 19 years (1993-2011) on juvenile fish salvage/loss, inflows to and outflows from the Delta, water exports, juvenile abundance, Old and Middle rivers (OMR) flow, and tide height, using Pearson's correlation and multiple linear regression methods.

Results/Conclusions/Relevance: The fish salvage of natural juvenile winter-run and spring-run Chinook salmon and natural juvenile steelhead was positively correlated to water exports, juvenile abundance, Sacramento River flow, or tide height; but negatively correlated to the San Joaquin River flow, OMR flow, the inflow-to-export (I:E) ratio, or Delta outflow. The multiple linear regression results indicate that water export and juvenile abundance are the most important variables impacting the number of juveniles salvaged at the fish facilities. To a lesser degree, tide height, inflow, outflow, the I:E ratio, or OMR flow played a role in controlling fish salvage. In addition, juvenile fish survival decreases from the mainstem Sacramento River to interior North Delta to South Delta. Measures to reduce juvenile fish entrainment to interior N. Delta and S. Delta (*e.g.*, DCC gates closure and restriction of OMR flow or water export) will increase their overall Delta survival.

Keywords: salvage, loss, abundance, inflow, water export, OMR flow, tide height
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Chinook Salmon Rearing in the Lower Sacramento River: Effects of Physical Variables on Near-Shore Habitat Use

Michael Hellmair, FISHBIO, michaelhellmair@fishbio.com
Brian Mulvey, USACE, Brian.M.Mulvey@usace.army.mil

Factors driving habitat use by juvenile Chinook salmon in large, main stem habitats such as the Sacramento River remain poorly understood, yet information pertaining thereto is needed to guide restoration and mitigation approaches intended to enhance rearing opportunities for the species. We used point-based boat electrofishing to sample juvenile Chinook during the spring rearing and outmigration season in the middle section of the Sacramento River, and collected a suite of biologically relevant habitat characteristics at each sampled location, including localized temperature, depth, current velocity, substrate, bank slope and available in-stream cover. Using logistic regression analysis, we evaluated the effects of physical variables on occupancy probability by juvenile Chinook, and found that a number of habitat characteristics - including temperature, cover, depth, velocity, and others - significantly affect near-shore habitat use. In addition, we document drift abundance and diet composition of juvenile Chinook salmon in the middle Sacramento River (vicinity of Knights Landing), which is suggestive of active rearing and foraging as fish emigrate through this reach of the Sacramento River. While some of our findings agree with habitat requirements established on smaller watersheds, others may warrant a reconsideration of restoration and mitigation designs intended to benefit juvenile salmonids in the Sacramento River and the Bay-Delta.

Keywords: Chinook salmon; smolt; fry; habitat; rearing' Sacramento River; restoration; mitigation
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