Quantifying the Abundance, Distribution, and Predation of Salmon by Non-Native Fish Predators in the San Joaquin River

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Understanding the factors that influence the survival of native resident and migratory species within the Sacramento-San Joaquin Delta is of great interest to researchers, managers, and stakeholders. The recent survival estimates of juvenile salmon emigrating from the Delta have been extremely low. One of the hypothesized causes of low survival rates is predation by non-native fishes but there has been insufficient research in the Delta to rigorously evaluate this hypothesis. To address this need, we conducted a study in a portion of the San Joaquin River with the following objectives: 1) examine the abundance, distribution, and movement of non-native fish predators, 2) quantify the magnitude of smolt predation with genetic analysis of predator stomach contents, 3) manipulate the density of predators to assess the influence of predator density on the predation rates of salmon smolts, and 4) determine how predation on salmon smolts may be influenced by physical habitat, water chemistry, and other environmental features. In 2014 and 2015 we estimated predator population sizes from electrofishing and hydroacoustics surveys, we described predator movement using acoustic telemetry, quantified predator diets using genetic analysis, relocated predators from removal reaches to addition reaches and determined relative predation rates with predation event recorders (PER) before and after relocation events, and mapped habitat among nine study reaches covering 25 river km of the San Joaquin River. Our results indicated that there were differences in relative abundance, movement patterns, and smolt consumption rates among different predator species. A total of 2,846 predators were removed and relocated but, surprisingly, these removals and additions had negligible influence on predation rates. However, PER predation was influenced by water velocity and other environmental conditions. Our study results will inform salmon life-cycle models and refine future study objectives.

Keywords: predator, salmon, diet, telemetry
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Insight into the Diets of the Primary Fish Predators of the California Delta using DNA Barcoding, and Implications for Salmonid Populations

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Few studies have been adequately equipped to find direct evidence of predation on salmon smolts. Novel DNA barcoding methods now allow definitive identification of predator stomach contents, even at trace levels. Predator stomachs from largemouth bass (LMB), striped bass (STB), white catfish (WHC), and channel catfish (CHC) were collected from nine 1-km long reaches of the lower San Joaquin River in the spring of 2014 and 2015, totaling 1030 samples. These stomachs were tested for presence of DNA from 12 different fish species, including imperiled native fish and common prey species. We found 46 stomachs containing Chinook salmon DNA, 9 containing steelhead, 9 containing delta smelt, and no detections of green sturgeon or longfin smelt. Focusing on salmonids, 19.2% of CHC, 6.0% of STB, 4.8% of WHC, and 2.8% of the LMB stomachs tested positive for salmonid DNA.

Additionally, we estimated population sizes of LMB and STB in the three primary 1-km collection reaches using electrofishing multi-pass depletion. Using the frequency of salmonid occurrence in LMB and STB diets, coupled with estimates of total metabolic demand of all STB and LMB in those reaches generated using a bioenergetics model, we are able produce an estimate of total salmonids eaten per predator species per reach. The window of temporal inference is approximately 2-4 days for STB, and unknown but likely similar for LMB. Preliminary estimates suggest STB were eating 1 to 160 smolts per reach, with wide variation being primarily due to the heterogeneous distribution of striped bass.

Our current understanding of predator-salmonid interactions in the Delta is largely based on highly localized studies. This study provides a methodology and region-specific results on the critical next step: estimating population-level impacts of predators. Furthermore, understanding the relative effects of different predator species on imperiled prey species can facilitate prioritization of management actions.

Keywords: salmon, predation, diets, bioenergetics, DNA-barcoding
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Development of Predation Event Recorders (PERs) to Quantify Predation of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in a River Environment

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In an effort to evaluate predation as a cause of low survival among juvenile Chinook salmon we designed and tested autonomous, GPS-enabled, predation-event recorders (PERs) for use in a river environment. PERs were outfitted with temperature/light sensors, underwater cameras and predation-activated timers for the purposes of identifying individual predators, precise predation times and locations, and to capture environmental variables that may influence predation. PERs were baited with live juvenile Chinook salmon and were successfully tested and used on the lower San Joaquin River in the spring of 2014 and 2015. Preliminary results from one of the nine study sites suggest a positive relationship between water velocity and predation risk, and a negative relationship between water depth and predation risk. PERs proved to be an inexpensive and reliable tool that successfully quantified relative predation, identified predators, and allowed us to ascertain environmental conditions and locations that resulted in relatively higher predation risks. These studies will provide critical complementary information for acoustic telemetry and predator diet studies, as well as give resource managers the capability to predict the effect of different environmental conditions on the predation of imperiled fish species.

Keywords: Predation, Predation Event Recorder, PER, Chinook Salmon, Sacramento-San Joaquin Delta
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Do Barriers for Deterring Juvenile Salmonids Away from High-Risk Migration Pathways Affect Survival at Important Channel Junctions in the Sacramento-San Joaquin Delta, California?

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California's Department of Water Resources is mandated to investigate engineering solutions to reduce juvenile salmonid migration into the low-survival interior Sacramento-San Joaquin Delta. To this end, various barriers have been investigated at important channel junctions. Predation risk near such barriers could increase because of the predator habitat provided by the in-water structures or because of changed juvenile salmonid behavior. The present study investigated survival of acoustically tagged juvenile salmonids at the San Joaquin River-Head of Old River (HOR, 2009-2012) and Sacramento River-Georgiana Slough (GS, 2014) junctions. Predation probability of juvenile Chinook Salmon (CS) at HOR was significantly greater with a bioacoustic fish fence (BAFF) turned on (2009/2010) and a rock barrier (2012) in place than with the BAFF turned off, largely because the barriers guided the CS as intended away from the low-survival route, but inadvertently toward a predator-dense ambush location. In addition, predation probability was positively related to ambient light level, perhaps because visual predators were more successful by day. The estimated proportion of juvenile CS that were preyed upon at HOR ranged from 0.10 in 2011 (high flow, no barrier) to 0.39 in 2012 (lower flow, rock barrier). Bioenergetics modeling illustrated that the potential proportional consumption of CS entering HOR by Striped Bass could have been greater in 2012 (~0.17) than 2011 (<0.005) because 2012 had higher predator density, lower prey density, and higher temperature. At GS, predation probability was not related to the operation of a floating fish guidance structure, but was negatively related to turbidity, possibly because visual predators were more successful in clearer water. The present study illustrates that site-specific considerations are key because barriers and other factors can affect survival at important channel junctions. Additional studies with true no-barrier control conditions are essential to define potential barrier effects on predation.

Keywords: predation; barrier; junction; migration; Chinook Salmon; predator; Striped Bass; bioenergetics
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Shocking for Survival: An Overview of the Pilot Year Effort to Remove Non-Native Predatory Fish from Clifton Court Forebay

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The California Department of Water Resources (DWR) is conducting a research project to understand the effectiveness of using systematic non-native predatory fish removals as a tool for improving Chinook salmon and steelhead survival across Clifton Court Forebay (Forebay) to the John E. Skinner Delta Fish Protective Facility. Predatory fish are collected using boat based electrofishing and relocating them to Bethany Reservoir. The 2016 effort was a pilot effort to determine catch rates, fish distributions and logistics for the full scale effort which will occur in 2017 and 2018. Removals of non-native predatory fish occurred from April 20, 2016 to May 18, 2016 over 11 days of sampling. Timing is intended to coincide with Chinook salmon and steelhead outmigration period to improve their survival across the Forebay to the fish protective facility. To target different predatory fish species and increase effectiveness for different habitat types, three methods of boat-based electrofishing: 1) electrofishing along the banks and shallow areas focusing on structures that centrarchids tend to associate with, 2) stationary electrofishing with a low frequency (15 pulses per second) current for 5 minutes, a method effective for sampling catfish, 3) electrofishing open water environments which allowed for the capture of striped bass. Concurrent tagged Chinook salmon and steelhead releases at the Forebay radial gates will allow DWR to understand the relative effects that electrofishing will have on the survival of entrained salmonids. During the 2016 pilot study, 2059 striped bass, 594 black bass and 33 catfish were captured. Striped bass fork lengths ranged from 89 mm up to 1040 mm with an average of 290 mm, black bass fork lengths ranged from 99 mm to 625 mm with an average of 309 mm, and catfish fork lengths ranged from 135 mm to 664 mm with an average of 364 mm.

Keywords: predator, fish, salmon
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Mobile Acoustic Methods to Survey Salmon Smolt Predators and their San Joaquin River Habitat

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Predation is thought to be one of the major sources of salmon smolt mortality in the San Joaquin River (SJR) because there are many non-native predatory fishes (e.g. striped bass, largemouth bass, white catfish, and channel catfish). The distributions and abundances of these fish are unknown. To survey these predators and their riverbed habitats an array of sonars was deployed from a small boat. The array included one or two multibeam sonars (500 kHz Simrad M3), one down-looking sonar (200 kHz Simrad ES15 or EK60), and one side- or forward-looking sonar (120 kHz Simrad EK60). Surveys were conducted between March and May 2014 and 2015 spanning nine reaches in the SJR between Port of Stockton and Lathrop as part of an associated predator removal study. The multibeam sonar data were used to measure bathymetry and track fishes. The echosounder data were used to detect, track, and enumerate fishes beneath, to the side, and in front of the survey boat. All of the acoustic data were geolocated using differential GPS positioning, and the bathymetry was compensated for pitch, roll, heave, and tide. The interpretation of backscatter from fishes was aided by the fish length and weight data collected as part of the predator removal study and X-ray images taken from representative specimens of the dominant species and sizes. The shapes of the fish and their swimbladders supported a Kirchoff-Ray Mode model used to estimate frequency-specific backscatter versus fish length. These relationships were used to refine the acoustical survey detections of salmon-smolt predators and the estimations of their numbers and sizes.

Keywords: salmon smolt predation, mobile active acoustic surveys, predator abundance
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Multibeam Mapping of Bathymetry, Riverbed Type, and Predator Habitats in the San Joaquin River

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Characteristics of bathymetry and submerged aquatic vegetation (SAV) may be conducive to predation by non-native fish on salmon smolt in the San Joaquin River (SJR). Here, we use multibeam acoustics to map these riverbed habitat characteristics from Port of Stockton to Lathrop, March through May 2014 and 2015. One (2014) or two (2015) Mesotech M3 multibeam sonars were used to fully insonify this shallow river, typically <4 m with holes as deep as 10 m. Full-coverage, 1-by-1-m grid-cell bathymetric maps were generated despite low grazing angles, high-reverberation and clutter, and strong second bottom returns induced by this environment. Riverbed habitats were discriminated by morphology metrics and backscatter intensity. Bathymetry data were used to constrain echosounder detections of fish and convert fish densities to abundances. Novel signal processing of M3 water-column data was used to detect fish among clutter, and patches of SAV. Resulting maps of bathymetry and SAV characterize conditions associated with high salmon-smolt predation along this migration route.

Keywords: multibeam sonar, shallow-water bathymetry, riverbed mapping, riverbed habitats
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Acoustic Detection, Tracking, and Enumeration of Salmon Smolt Predators

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Salmon smolt mortality in the Sacramento-San Joaquin River (SJR) system is impacted by predatory fish. To quantify the abundance, distribution, and habitats of these predators, we devised and implemented a novel active-acoustic method to sample the fish and bathymetry in this shallow-water environment. Acoustic surveys were conducted during March through May, 2014 and 2015 from the Port of Stockton to Lathrop in the area of complementary fish tethering and tagging studies. The survey deployed vertically- and horizontally-oriented split-beam and multi-beam echosounders on a small vessel. Individual fish were acoustically detected using single-target detection and echo-track processing methods with target strength thresholds determined by scattering models developed using specimens from the river. Counts of fish per sampled volume were estimated from fish tracks found within river segments defined by 1- to 100-m distance intervals along the river centerline. Aggregated fish counts were converted to densities by compensating for the integrated sampled volumes of the acoustic beams weighted by the probability of target detections. Assuming uniform densities within river segments, fish abundances were estimated by compensating for river volume. Data provide evidence of temporal and spatial trends of predator abundances and suggest associations with the river environment. Results provide important information for management by elucidating potential areas, times, and conditions where predators and smolt interact.

Keywords: active-acoustic fish detection, predator density/abundance, split-/multi-beam sonars
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Linking Predation Mortality to Predator Density and Survival for Out-Migrating Chinook Salmon in the Lower San Joaquin River and Delta

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It is currently not clear what proportion of juvenile salmonid mortality can be directly attributed to fish predation and it is difficult to interpret results regarding population-level survivorship in the Bay-Delta because the data have limited spatial scales, used various tagging methodologies, and do not clearly connect tag loss or mortality to predation. It is essential to improve the linkage between mortality events and predation. We will address this research need through the use of baited tethers as predation event recorders and enclosure experiments. Tether experiments allow estimation of relative predation rates in various environments, and reveal information about mortality produced by different species of fish predators. Enclosure experiments allow for controlled manipulation of predator density and habitat type to quantify predation rates and will provide information on how consumption changes as a function of density which is essential for evaluating predation effects on salmon survival while passing hotspots and predicting the benefits and effectiveness of predator control activities. Initial results and lessons learned from a pilot study to build the experimental enclosures, secure them in a tidally influenced channel, design of PIT antennas, and trials of releasing PIT tagged fish through the enclosures will be shared. The full study will be conducted in the spring 2017. These data will be used to identify and characterize statistical relationships between predation mortality rates and other factors to determine how environmental conditions and predator density affect predation mortality. This study will couple survivorship with predation mortality estimates to quantify if fish predation is a substantial component of total mortality in the Bay-Delta and under which circumstances this occurs.

Keywords: salmonid predation
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Predator Diet and Movement Patterns in the Lower Feather River and their Effects on Hatchery Smolts

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Full in-river release of hatchery origin salmonids, as close to the hatchery as possible, was one of several reforms recommended by the California Hatchery Scientific Review Group (CAHSRG 2012), and a goal of draft Hatchery and Genetic Management Plans for the Feather River Fish Hatchery. However, results from acoustic studies on hatchery origin spring run Chinook salmon and Central valley Steelhead (CVST) smolts in the Feather River (and out to the ocean) reveal their downstream migration success is very poor. Such high mortality is problematic for advancing toward our goal of full in-river release. Various release techniques have been implemented to improve migration success, however very little improvement has been observed and the direct cause of mortality has not been identified. Predation is one likely source of mortality that may explain poor outmigrating smolt survival in the Feather River. In an effort to better understand the role of predation, we conducted a fish predator study, focusing on movements and diet. Predators such as striped bass, largemouth bass, smallmouth bass, white catfish, channel catfish and Sacramento pikeminnow were tagged with Vemco acoustic tags and monitored over the course of two years. Stomachs from these species were also collected and compared to identify prey selection in the Lower Feather River throughout the entire year. We compared seasonal diets and noted presence and absence of certain species found in the stomach contents. Using angling and acoustic tag data we were able to identify 'predator hotspots'. Identifying these hot spots may provide opportunity to adjust release strategies to minimize predator success.

Keywords: Predator Diet Movement Patterns Feather Effects Hatchery Smolt
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