Annotated Bibliography

Predation Workshop
July 22, 23 2013

Brown, L.R., and Michniuk, D. 2007. Littoral fish assemblages of the alien-dominated Sacramento-San Joaquin Delta, California, 1980-1983 and 2001-2003. Estuaries and Coasts 30(1): 186-200.

ABSTRACT: We analyzed monthly boat electrofishing data to characterize the littoral fish assemblages of five regions of the Sacramento–San Joaquin Delta (northern, southern, eastern, western, and central), California, during two sampling periods, 1980–1983 (1980s) and 2001–2003 (2000s), to provide information pertinent to the restoration of fish populations in this highly altered estuary. During the 1980s, almost 11,000 fish were captured, including 13 native species and 24 alien species. During the 2000s, just over 39,000 fish were captured, including 15 native species and 24 alien species. Catch per unit effort (CPUE) of total fish, alien fish, and centrarchid fish were greater in the 2000s compared with the 1980s, largely because of increased centrarchid fish CPUE. These differences in CPUE were associated with the spread of submerged aquatic vegetation (SAV), particularly an alien aquatic macrophyte *Egeria densa*. Native fish CPUE declined from the 1980s to the 2000s, but there was no single factor that could explain the decline. Native fish were most abundant in the northern region during both sampling periods. Nonmetric multidimensional scaling indicated similar patterns of fish assemblage composition during the two sampling periods, with the northern and western regions characterized by the presence of native species. The separation of the northern and western regions from the other regions was most distinct in the 2000s. Our results suggest that native fish restoration efforts will be most successful in the northern portion of the Delta. Management decisions on the Delta should include consideration of possible effects on SAV in littoral habitats and the associated fish assemblages and ecological processes.

Buchanan, R.A., J.R. Skalski, P.L. Brandes, and A. Fuller. 2013. Route Use and Survival of Juvenile Chinook Salmon through the San Joaquin River Delta, North American Journal of Fisheries Management, 33:1, 216-229.

Abstract: The survival of juvenile Chinook Salmon through the lower San Joaquin River and Sacramento–San Joaquin River Delta in California was estimated using acoustic tags in the spring of 2009 and 2010. The focus was on route use and survival within two major routes through the Delta: the San Joaquin River, which skirts most of the interior Delta to the east, and the Old River, a distributary of the San Joaquin River leading to federal and state water export facilities that pump water out of the Delta. The estimated probability of using the Old River route was 0.47 in both 2009 and 2010. Survival through the southern (i.e., upstream) portion of the Delta was very low in 2009, estimated at 0.06, and there was no significant difference between the Old River and San Joaquin River routes. Estimated survival through the Southern Delta was considerably higher in 2010 (0.56), being higher in the Old River route than in the San Joaquin route. Total estimated survival through the entire Delta (estimated only in 2010) was low (0.05); again, survival was higher through the Old River. Most fish in the Old River that survived to the end of the Delta had been salvaged from the federal water export facility on the Old River and trucked around the remainder of the Delta. The very low survival estimates reported here are considerably lower than observed salmon survival through comparable reaches of other large West Coast river systems and are unlikely to be sustainable for this salmon population. More research into mortality factors in the Delta and new management actions will be necessary to recover this population.

Cavallo, B., Merz, J., and Setka, J. 2012. Effects of predator and flow manipulation on Chinook salmon (*Oncorhynchus tshawytscha*) survival in an imperiled estuary. Environ. Biol. Fish. DOI 10.1007/s10641-012-9993-5: 1-11.

Abstract: We evaluated the effects of non-native, piscivorous fish removal and artificial flow manipulation on survival and migration speed of juvenile Chinook salmon, Oncorhynchus tshawytscha, emigrating through the eastern Sacramento-San Joaquin Delta of California (Delta) using a Before-After-Control-Impact study design. Acoustically-tagged salmon survival increased significantly after the first predator reduction in the impact reach. However, survival estimates returned to pre-impact levels after the second predator removal. When an upstream control gate opened (increasing flow and decreasing tidal effect) juvenile salmon emigration time decreased and survival increased significantly through the impact reach. Though a short-term, single season experiment, our results demonstrate that predator control and habitat manipulation in the Delta tidal transition zone can be effective management strategies to enhance salmon survival in this highly altered system.

California Department of Fish and Game. 2011. Report and Recommendation to the Fish and Game Commission in Support of a Proposal to Revise Sportfishing Regulations for Striped Bass. December.

Introduction: Striped bass are opportunistic predators, preying on a wide variety of fish, invertebrates, and other species. Among its prey are Sacramento River Winter-run Chinook salmon, Central Valley Spring-run Chinook salmon, coho salmon, Central Valley steelhead, delta smelt, longfin smelt, and tidewater goby (collectively the “listed species”). These species are all listed as “endangered” or “threatened” under either or both the federal Endangered Species Act and the California Endangered Species Act.

While predation by striped bass is only one of numerous stressors on the listed species, by previously stocking striped bass and by enacting the striped bass sport fishing regulations currently in effect, the Department of Fish and Game (Department) and the Fish and Game Commission (Commission) may have inadvertently contributed to this stressor by helping establish and maintain the current population of predatory striped bass. More importantly, this particular stressor not only has roots in the actions of the Department and the Commission, but standard fisheries management practices indicate it may be alleviated, at least in part, by further action on the part of the Department and Commission.

This staff report provides an overview of historic and current population trends for the listed species. This report further provides a brief overview of the striped bass fishery, historic and current population trends, the nature and extent of striped bass predation on the listed species, and key features of the recreational fishery for striped bass. While acknowledging uncertainty about the extent and impacts of striped bass predation, the Department concludes:

- The populations of each of the listed fish have declined, and some are at perilously low levels;
- Although striped bass abundance has declined in recent decades, the population remains substantial;
- Although studies of striped bass predation show each of the listed species to constitute a relatively small part of the striped bass diet, and although the actual level of striped bass predation on these species is unknown and likely unknowable, the enormous volume of fish (up to 110 million pounds annually) consumed by striped bass and the widespread distribution of striped bass within the geographic range of the listed species indicate the impact of striped bass predation on the listed species could be substantial; and
- The recreational fishery for striped bass is very popular, and many anglers will harvest substantially more striped bass if they are allowed to keep smaller fish.

For these reasons, the Department concludes that, notwithstanding uncertainty as to the extent and impact of striped bass predation on the listed species, the highly precarious state of the populations of the listed species warrant a change in sportfishing regulations to allow greater harvest of striped bass. Attached to this staff report as Exhibit A is a regulatory proposal to amend several sections of Title 14 with the goal of increasing the harvest of striped bass and thereby reducing predation by striped bass on the listed species. The Department recommends that the Commission:

- Direct the Department and Commission staff to prepare a regulatory packet for the attached regulatory proposal in accordance with the California Administrative Procedure Act; and
- Direct the Department and Commission staff to commence appropriate environmental review under the California Environmental Quality Act (CEQA) for the proposed regulation change.

Conclusions: Having studied striped bass for nearly a century and listed species for many decades, the Department recognizes that the consequences of management actions — past, present and future — are rarely certain. Although the impact of striped bass predation on the listed species is not certain, the Department has evaluated the large body of information and has determined that striped bass predation is an adverse impact, albeit one of unknown magnitude, that can likely be mitigated in part by promulgating a set of regulations that would authorize additional harvest by recreational anglers. The regulations would allow for the harvest of smaller and more striped bass in anadromous waters only. The Department expects that striped bass would become somewhat less abundant, the average size of striped bass would decline, and both fishing effort and fishing success would increase for a period of at least several years — resulting in a measure of protection for the listed species that would not cause the collapse of the striped bass fishery. For the foregoing reasons, the Department recommends that the Commission adopt the attached regulatory proposal. As a first step in that process, the Department recommends that the Commission direct the Department and Commission staff to prepare a regulatory packet for the attached regulatory proposal in accordance with the California Administrative Procedure Act and commence appropriate environmental review under CEQA for the proposed regulation change.

Clark, K. W., M. D. Bowen, R. B. Mayfield, K. P. Zehfuss, J. D. Taplin, and C. H. Hanson. 2009. Quantification of pre-screen loss of juvenile steelhead in Clifton Court Forebay. Fishery Improvements Section Bay-Delta Office CA Department of Water Resources In collaboration with: National Marine Fisheries Service Central Valley Fish Facilities Review Team Interagency Ecological Program Management Team.

Executive Summary: In response to the 2004 National Marine Fisheries Service (NMFS) biological opinion, the California Department of Water Resources (DWR) conducted a study in 2005, 2006, and 2007 to assess and quantify steelhead pre-screen losses within Clifton Court Forebay. Steelhead entrained in the Forebay are subject to predation, synonymous with pre-screen loss, as they traverse the Forebay toward the John E. Skinner Delta Fish Protective Facility (SFPF). The investigation was developed to provide useful information that could serve to reduce the potential vulnerability of steelhead to predation mortality in Clifton Court Forebay. Results from this study may be used in the calculation of Central Valley steelhead incidental take as a result of State Water Project (SWP) operations.

A pilot-scale telemetry experiment utilizing hatchery reared steelhead was conducted in April – June, 2005 to develop an understanding of the movement of juvenile steelhead through the Forebay and identify potential areas of increased vulnerability to predation mortality. The 2005 pilot study utilized thirty hatchery reared juvenile steelhead which were surgically implanted with acoustic tags prior to release into the Forebay. Three groups of ten tagged steelhead were released immediately upstream of the radial gates to expose them to the high water velocities and turbulence experienced by wild fish entrained into the Forebay.

Additionally, the 2005 pilot study was conducted to identify movement patterns of predator-size striped bass and evaluate fundamental assumptions used in developing the experimental design for a full-scale mark-recapture survival study. Sixteen adult striped bass, the primary predator species thought to be responsible for the pre-screen loss of steelhead, were collected in the Forebay, externally tagged using acoustic tags, and subsequently released back into the Forebay. Movement of the juvenile steelhead and adult striped bass was monitored continuously using fixed-position acoustic receivers deployed adjacent to the radial gates, in the Forebay, in the SFPF salvage holding tanks, and in Old River. Mobile monitoring was also conducted to track the movements of these fish throughout the Forebay.

Telemetry results showed that of the thirty steelhead released upstream of the radial gates, twenty were last detected in the Forebay at the end of the tag's battery life (approximately 60 days), four were detected in the SFPF salvage holding tanks, four were detected emigrating through the radial gates into Old River, one was not entrained into the Forebay, and one tagged steelhead failed to be detected. Seventeen of the twenty-eight steelhead entrained into the Forebay were detected entering the intake canal leading to the SFPF. Thirteen of those seventeen were detected in the general vicinity of the trashboom, while only four of the tagged steelhead were detected in the SFPF salvage holding tanks.

Striped bass telemetry results revealed that adult striped bass moved throughout the Forebay. However, they were concentrated in the area immediately adjacent to the radial gates and within the intake canal leading to the SFPF. Adult striped bass were also observed to emigrate from the Forebay into Old River during periods when the radial gates were open. Recreational anglers within the Forebay harvested at least two of the acoustic tagged striped bass in 2005 illustrating that adult striped bass tagged for this study were actively seeking prey for consumption.

The 2005 pilot study provided useful information on movement patterns and residence time of juvenile steelhead and adult striped bass within the Forebay. Findings of the 2005 pilot study also documented emigration of both steelhead and striped bass from the Forebay during periods when the radial gates were open and identified areas within the Forebay where juvenile steelhead may have an increased vulnerability to predation. The 2005 pilot study indicated that the methods and technologies tested were appropriate and could be utilized in the full-scale study to evaluate the pre-screen loss rate of juvenile steelhead. The 2005 pilot study also indicated that a high percentage of steelhead remain in the Forebay longer than the battery life of the acoustic tagging technology utilized. To ascertain the fate of these fish, an additional tagging technology would need to be utilized in the full-scale study.

Another pilot-scale telemetry study was conducted in March – July, 2006 to further investigate the movements of juvenile steelhead through the Forebay and to refine the placement of acoustic tag receivers for optimal fish tag detections for the full-scale study. In 2006, changes were made to the fixed position acoustic receiver grid to address issues with signal overlap between the receivers as experienced in the 2005 pilot study. The new receiver grid covered the majority of Clifton Court Forebay rather than a center transect, as was covered in 2005. Similar to the 2005 pilot study, the 2006 pilot study utilized thirty hatchery reared juvenile steelhead. These steelhead were surgically implanted with acoustic tags and twenty-nine were released into the Forebay in three groups.

Results of the 2006 pilot study were similar to those in 2005. Juvenile steelhead monitoring revealed that of the twenty-nine steelhead released, twenty-two were last detected in the Forebay at the end of the tag's battery life (approximately 60 days), two were detected in the SFPF salvage holding tanks, and five were detected emigrating through the radial gates into Old River. The new acoustic receiver grid revealed that steelhead moved throughout the Forebay, including the most northern and southern areas not covered by the acoustic grid in 2005. The majority of the tagged steelhead released in the 2006 study were last detected in the Forebay, conceivably lost to predation.

A full-scale mark-recapture study was conducted between December, 2006 and June, 2007, and was designed to quantify steelhead pre-screen loss. Additionally, the 2007 full-scale study was designed to evaluate the behavior and movement patterns of steelhead and striped bass within the Forebay and identify environmental or operational factors that may contribute to steelhead pre-screen loss. In 2007, two tagging technologies, acoustic and Passive Integrated Transponders (PIT) tags, were utilized. Similarly to the 2005 and 2006 pilot studies, acoustic tags were used to gain information about the movement patterns of steelhead and striped bass within Clifton Court Forebay. In response to the 2005 pilot study recommendations, PIT tags were used to quantify the pre-screen loss rate and the SFPF loss rate. In contrast to acoustic tags, PIT tags do not have a battery and could be detected for the entire duration of the full-scale study. In addition, PIT tags are inexpensive when compared to acoustic tags and allowed for a larger sample size.

The movement patterns of steelhead and striped bass were examined using acoustic telemetry. Sixty-four steelhead were surgically implanted with acoustic tags and released immediately upstream of the radial gates between February – April, 2007. Fifteen acoustic tagged steelhead were also released directly into the SFPF primary louver bays. Twenty-nine striped bass collected in the Forebay were externally tagged and subsequently released back into the Forebay. Movements of the acoustic tagged juvenile steelhead and adult striped bass were monitored continuously using fixed-position acoustic receivers deployed in a similar grid to that of the 2006 pilot study.

Acoustic tagged steelhead entrained into Clifton Court Forebay through the radial gates showed varied movement patterns. Many steelhead remained near the radial gates for the duration of the study period and yet other steelhead moved into the northern and central portions of the Forebay. Of the 64 steelhead entrained into the Forebay, 12 (19%) steelhead were detected in the intake canal. Ten of the 12 steelhead detected in the intake canal were also detected at the trashboom. However, only two acoustic tagged steelhead were detected as having been successfully salvaged. No steelhead released directly upstream of the radial gates were lost through the primary louvers. Twenty of the acoustic tagged steelhead entrained were detected emigrating to Old River through the radial gates. However, it cannot be confirmed conclusively that the steelhead observed emigrating had not been preyed upon within the Forebay and their predators moved from the Forebay through the radial gates into Old River. Of the sixty-four juvenile steelhead entrained into the Forebay, 44 (69%) remained in the Forebay at the end of the study period. Twenty-nine of those 44 were last detected at the radial gates. Several of the steelhead last detected at the radial gates were stationary for a long period of time with no subsequent movements. These stationary tags may be attributed to steelhead that were consumed by striped bass with subsequent tag deposition.

Steelhead movement rates were calculated hourly and tested for correlation with environmental and operational conditions. Data analysis revealed that there was no correlation between steelhead movement rates and water temperature, export rate, turbidity, radial gate water velocities, or light intensity. However, steelhead movement rates were correlated to the length of time spent within Clifton Court Forebay. The longer steelhead remained within the Forebay the less they moved.

Similar to the steelhead telemetry results, striped bass telemetry results showed varied movement patterns. Striped bass were observed to move throughout the Forebay with a few striped bass spending considerable time in the northern portion of the Forebay. However, many of the tagged striped bass also spent long periods of time either near the radial gates or in the intake canal upstream of the SFPF. A few striped bass were observed to make many trips between the radial gates and the intake canal. However, neither radial gate operations nor Harvey Banks Pumping Plant operations had an effect on the proportion of time tagged striped bass spent near the radial gates or in the intake canal.

Striped bass were commonly observed emigrating from the Forebay. Eighteen of the 29 tagged striped bass were detected emigrating from Clifton Court Forebay into Old River. Three of these striped bass returned to the Forebay through the radial gates. Previous studies have documented striped bass emigration through the radial gates (Kano, 1990; Gingras and McGee, 1997). Thus, striped bass located within the Forebay are not isolated from the rest of the Delta population. The striped bass emigrating from the Forebay in the 2007 study were detected as far away as the Golden Gate Bridge and above Colusa on the Sacramento River.

Striped bass movement rates were calculated hourly and tested for correlation with environmental conditions. Data analysis indicated that there was no correlation between striped bass movement rates and water temperature, turbidity, or light intensity.

The 2007 full-scale study used nearly 1,200 juvenile steelhead obtained from the Mokelumne River Fish Hatchery for the PIT tag mark-recapture survival experiment. Pre-screen loss rate was quantified using 922 PIT tagged steelhead released immediately upstream of the radial gates. PIT tagged steelhead releases began in January and continued through April. SFPF loss rate, loss of fish within the SFPF due to predation or losses of fish through the primary louvers, was quantified using PIT tagged steelhead released directly into the SFPF primary louver bays. PIT tagged steelhead were detected post salvage by antennae installed at the SFPF salvage release sites.

Pre-screen loss rate was calculated from recoveries of the PIT tagged steelhead released immediately upstream of the radial gates and was 82 ±3% (mean ± 95% confidence interval). However, this estimate may have underestimated the number of steelhead emigrating from Clifton Court Forebay and into Old River leading to an overestimate of pre-screen loss rate. A second estimate of pre-screen loss rate, calculated from recoveries of the PIT tagged steelhead, included information gained about emigration based on acoustic tagged steelhead movements. This estimate of pre-screen loss rate was 78 ±4% (mean ± 95% confidence interval). However, this estimate may underestimate pre-screen loss rate given the uncertainty in the acoustic telemetry results for the steelhead emigrating from the Forebay to Old River. Statistical analysis showed that pre-screen loss rate did not differ by month of release. However, the time to salvage was greater for PIT tagged steelhead released at the radial gates in February than those released in January or April. In contrast to the high pre-screen loss rate, the SFPF loss rate was 26 ±7% (mean ± 95% confidence interval).

In 2007 an avian point count survey was conducted to determine the prevalence of avian predation occurring in the Forebay. This survey focused on the abundance, distribution, and behavior of birds in the Forebay that were capable of preying on juvenile steelhead. The frequency of survey observation periods ranged from two to three times per week. A total of 87 observation periods were completed during the study. Observational data indicated that Double Crested Cormorants, gulls, and Great Blue Herons, were present within Clifton Court Forebay for the entire duration of the 2007 study period. Double Crested Cormorant numbers declined through time. Other avian predators, including Western Grebes, Clarke's Grebes, Great Egrets, and White Pelicans were also present within the Forebay, but not in high enough numbers to conduct any statistical analyses.

Avian predation on fishes was observed in the Forebay and was linked to radial gate operations for certain bird species. Data analysis showed that the percentage of Double Crested Cormorants foraging near the radial gates increased when the radial gates were open. The presence of stationary debris (i.e. tree branches) in the Forebay near the radial gates provides roosting habitat for Double Crested Cormorants and may be a contributing factor to the predation occurring near the radial gates.

Results of the steelhead pre-screen loss studies indicated that the pre-screen loss of steelhead is between 78 ±4% and 82 ±3% within Clifton Court Forebay. This result is similar to previous pre-screen loss studies of other fish species including Chinook salmon and juvenile striped bass (Schaffter, 1978;

Hall, 1980; and Kano, 1985). Radial gate operations may contribute to these losses as avian predators and striped bass are foraging near the radial gates. Additionally, striped bass are spending long periods of time in the intake canal leading to the SFPF potentially foraging on fish as they approach the SFPF.

A population risk analysis should be completed for the Central Valley Steelhead that takes into account this pre-screen loss rate. In addition, a management action plan (MAP) should be created that includes steps to reduce the pre-screen loss rate of Central Valley steelhead within Clifton Court Forebay. At this point no recommendations have been made for changes to radial gate or Harvey Banks Pumping Plant operations. However, if entrained fish could be moved to the SFPF sooner by altering the hydrodynamics within the Forebay or SFPF intake canal, then exposure time to predators could decrease and this may result in the reduction of pre-screen losses. Many steelhead were detected within the intake canal leading to the SFPF, but were never salvaged. Steelhead may perceive the trash rack as a barrier or there may be an attraction problem at the SFPF. Future studies should focus on the area directly in front of the trash rack to determine if modifications can be made to attract more steelhead from the intake canal into the SFPF louver bays and fish salvage holding tanks. Future studies should also focus on measuring the hydrodynamics within the Forebay and how it impacts fish movements. As striped bass continue to be linked to pre-screen loss, the predator removal investigations conducted in the 1990's should be revisited. Moderate reductions in predator numbers could yield an increase in steelhead survival. Facilitating greater public fishing pressure may assist in this regard. Additionally, as avian predation was shown to occur, further avian predation investigations should be conducted with an emphasis on diet composition and consumption-rate. Avian diet composition and consumption rate studies would provide information on prey selectivity of the avian predators near the radial gates and the magnitude of pre-screen loss rate due to avian predation.

Gingras, M. 1997. Mark/recapture experiments in Clifton Court Forebay to estimate pre-screening loss to juvenile fish: 1976-1993. Interagency Ecological Program for the San Francisco Bay/Delta Estuary, a cooperative program of California Department of Water Resources and California Department of Fish and Game. Technical Report 55.

Abstract: From October 1976 through November 1993, the California Department of Fish and Game conducted mark/recapture experiments at Clifton Court Forebay, designed to estimate pre-screen loss to entrained juvenile fishes. Ten studies were conducted; eight evaluated losses to hatchery-reared juvenile chinook salmon, and two evaluated losses to hatchery-reared juvenile striped bass. Pre-screen loss was calculated from the proportion of marked fish released at the radial gates that were subsequently recaptured during salvage operations at Skinner Fish Facility. The proportion was adjusted for handling mortality, fish facility louver efficiency, and any subsampling at the facility. Studies were conducted across a wide range of environmental conditions and State Water Project operations, with a wide range in the size of experimental fish. Pre-screen loss estimates for juvenile chinook salmon were 63-99%. Potential biases in estimates of pre-screen loss may be due to (1) the calculation for pre-screen loss, (2) under-representative and over-representative salvage of experimental fish at Skinner Fish Facility, and (3) the introduction of experimental fish directly into Clifton Court Forebay. A multiple-regression analysis of pre-screen loss to juvenile salmon showed that 91% of the variance in the pre-screen loss can be explained by export rate, experimental fish size, and water temperature.

W. Kimmerer and R. Brown. 2006. A Summary of the June 22-23, 2005 Predation Workshop, Including the Expert Panel Final Report. CBDA and CDWR.

Preface: In this report we provide a summary and commentary on the June 22-23, 2005 workshop convened by the CALFED Science Program and the California Department of Water Resources (DWR) to examine questions associated with the losses of Chinook salmon, steelhead, delta smelt, and other fish at the southern Delta intakes to the State Water Project and the federal Central Valley Projects pumping plants. More than 60 people attended the workshop including an expert panel consisting of:

- James Cowan, PhD, Louisiana State University, Baton Rouge. LA
- Kyle Hartman, PhD, West Virginia University, Morgantown, West Virginia
- Ed Houde, PhD, Chesapeake Biological Laboratory, University of Maryland, Solomons, MD
- James Peterson, PhD, Biological Resources Division, USGS, Cook, WA
- Andy Sih, PhD, University of California, Davis, CA

An interagency workshop planning committee helped organize the workshop with committee member Bruce Herbold (USEPA) moderating the workshop. The workshop format (attachment 3) provided considerable time for discussion, and for the expert panel to present and discuss their preliminary findings. We include the panel's final report as attachment 4. Finally, we also present our views of the reasonable next steps in predation related issues in the Delta.

Background: The workshop presentations and discussion focused on issues related to predation on fish species of concern in and near the water export facilities in the south Sacramento-San Joaquin Delta (Delta). The State Water Project Banks Pumping Plant and the federal Tracy Pumping Plant have a combined capacity to divert more than 15,000 cubic feet per second (cfs) to canals and pipelines that transport the water for use in the San Francisco Bay area, the San Joaquin Valley, the central coast and southern California. The intake canals to the pumps have fish protection facilities to separate many of the fish from the water being exported - the Skinner Fish Protective Facility and Tracy Fish Facility, respectively. The fish "salvaged" at these facilities are held in large tanks, and estimates are made of their numbers, before the fish are put into trucks and returned to the estuary.

The predation issue addressed at this workshop arises because the fish entrained are subject to predation by striped bass and other fish. This predation is exacerbated by the presence of physical structures and the configuration and operations of the facilities. Of particular interest are the losses of species listed as endangered (winter Chinook), threatened (delta smelt, spring Chinook, and steelhead), or otherwise of concern (for example Sacramento splittail). Since predation occurs before the salvaged fish are counted, it also complicates efforts to quantify losses of fish at the facilities because the predation losses of most fish are poorly known even for Chinook salmon and striped bass and unknown for other species.

The state and federal fish protection facilities are about one mile apart in the southern Delta near the town of Tracy and the village of Byron. They differ in their configuration: the federal facility takes its water from an adjacent channel, whereas the state facility draws water from a tidal impoundment, the Clifton Court Forebay (CCF). Radial gates at the southeast corner of the CCF are opened periodically to allow water from Delta channels to enter, usually near high tide. This intake configuration is believed to cause high predation losses at the state facility - mainly because fish entering the forebay have to transit it before encountering the fish screens. The estimated high predation losses at the SWP are supported by experimental results and predator abundance studies. The results, as discussed at the workshop, leave room for alternative interpretations. For purposes of calculating take, predators are assumed to remove 75% of the juvenile Chinook salmon entering the state facility, and 15% of those entering the federal facility. The state value is based on mark-recapture studies (Table 1, page 12) in which 63 to 99% of the juvenile Chinook salmon disappeared between the release point inside the forebay and the holding tanks, with the lost fish assumed to have been eaten.

The 75% was developed during 1986 negotiations leading the DWR-DFG Four Pumps Agreement (aka the 2-Agency Fish Agreement) and was the average of three most reliable estimated loss rates available at the time. The 15% loss rate for the federal facility was based on studies of predation at structures in water, not from studies conducted at the intake to the federal facility, and was considered a placeholder until biologists obtained an estimate based on actual loss data. The 15% is still a placeholder.

Workshop goal: With the help of an expert panel, determine if there are additional studies and or analyses needed to help managers agree on a course of action aimed at reducing predation losses at the water facility intakes.

Workshop objectives:

- Review the basis for current predation loss estimates for Chinook salmon at the fish facilities.
- Review new work and approaches for estimating losses of steelhead at the SWP intake and predation-related studies at the CVP intake.
- Develop an understanding of the hydrodynamic and operational system that leads to fish entrainment and losses.
- Develop an understanding of physical and operational changes being contemplated to reduce predation losses at the water facility intakes.

Workshop products: The workshop results, conclusions and recommendations, are documented in this summary report submitted to the CALFED Lead Scientist, attendees, and agency managers for their consideration. The expert panel's complete report is appended to this summary.

Lindley, S. T. and M. S. Mohr. 2003. Modeling the effect of striped bass (*Morone saxatilis*) on the population viability of Sacramento River Winter-run Chinook salmon (*Oncorhynchus tshawytscha*). Fish. Bull. 101:321-331.

Abstract: We estimated the impact of striped bass (*Morone saxatilis*) predation on winter-run chinook salmon (*Oncorhynchus tshawytscha*) with a Bayesian population dynamics model using striped bass and winter-run chinook salmon population abundance data. Winter-run chinook salmon extinction and recovery probabilities under different future striped bass abundance levels were estimated by simulating from the posterior distribution of model parameters. The model predicts that if the striped bass population declines to 512,000 adults as expected in the absence of stocking, winter-run chinook salmon will have about a 28% chance of quasi-extinction (defined as three consecutive spawning runs of fewer than 200 adults) within 50 years. If stocking stabilizes the striped bass population at 700,000 adults, the predicted quasi-extinction probability is 30%. A more ambitious stocking program that maintains a population of 3 million adult striped bass would increase the predicted quasi-extinction probability to 55%. Extinction probability, but not recovery probability, was fairly insensitive to assumptions about density dependence. We conclude that winter-run chinook salmon face a serious extinction risk without augmentation of the striped bass population and that substantial increases in striped bass abundance could significantly increase the threat to winter-run chi-nook salmon if not mitigated by increasing winter chinook salmon survival in some other way.

Loboschefsky, Erik; Benigno, Gina; Sommer, Ted; Rose, Kenneth; Ginn, Timothy; Massoudieh, Arash; et al.(2012). Individual-level and Population-level Historical Prey Demand of San Francisco Estuary Striped Bass Using a Bioenergetics Model. San Francisco Estuary and Watershed Science, 10(1).

Abstract: Striped bass are both a major predator of native fishes and support a recreational fishery in the San Francisco Estuary (the estuary). Quantifying their demands on their prey is important for understanding long-term trends of fish in the estuary. In this study, we: (i) applied a bioenergetics model of sub-adult (age 1 and age 2) and adult (age 3+) striped bass (*Morone saxatilis*) to quantify long-term consumption patterns from 1969 through 2004 in the estuary; (ii) developed a method to estimate the abundances of sub-adult striped bass; (iii) evaluated how consumption varied by age and gender; and (iv) identified factors that affect the resulting consumption estimates. On a 'per capita' basis, modeled individual prey fish consumption increased after 1990, and individual total and prey fish consumption by age-2 striped bass increased after 1994. Conversely, individual total and prey fish consumption by adult striped bass decreased over the period analyzed. This decline in individual consumption over the study period was related to a decline in mean length at age of adults. As expected, long-term trends in population consumption (total and prey fish) by all ages of striped bass (ages 1 through 6) closely followed their respective population- abundance trends. Population total consumption and prey fish-specific consumption by sub-adult striped bass was found to be similar to the population consumption by adult striped bass, largely because of the high abundance of sub-adults. Unlike adult striped bass that may emigrate and forage in the Pacific Ocean, the majority of sub-adult striped bass reside within the estuary; hence, consumption by the relatively abundant sub-adult population may have significant effects upon their estuarine prey species.

Michel, C. 2010. River and estuarine survival and migration of yearling Sacramento River Chinook Salmon (*Oncorhynchus Tshawytscha*) smolts and the influence of environment. Master of Arts, Ecology and Evolutionary Biology, University of California, Santa Cruz.

Abstract: Identifying where sources of enhanced mortality of outmigrating Chinook salmon (smolts) occur, and the movement patterns associated with this life stage, are critical steps in the preservation and conservation of imperiled salmonids in California's Sacramento River system. To that end, 200-300 late-fall run Chinook salmon yearling smolts were acoustically tagged per year and tracked during their outmigration in California's Sacramento River during 2007-2009. Total outmigration survival to the ocean environment varied from 3.1% (± 1.5 S.E.) to 5.5% (±1.2 S.E.), depending on the release year, with an all year total outmigration survival of 3.9% (±0.6 S.E.), substantially lower than published survival of other West Coast yearling Chinook salmon smolt emigrations. The migration rates of the smolts that successfully reached the ocean varied significantly based on release location, from an average of 14.32 km·day-1 (± 1.32 S.E.) to 23.53 km·day-1 (± 3.64 S.E.). The high spatial resolution of survival estimates of Chinook salmon (*Oncorhynchus tshawytscha*) revealed that smolts exhibited relatively low survival (92-97% survival·10km-1) in the upper reaches of the Sacramento River, as well as in the Sacramento River Delta and San Francisco Estuary (67-94% survival·10km-1). No significant inter-annual variation in survival, total river migration rates, or smaller scale movement rates were found, potentially due to similar hydrographic conditions among the three years. Survival did fluctuate significantly depending on month of release and river reach. Several natural and anthropogenic factors that are known to affect smolt survival rates were assessed; variables associated with river channelization, turbidity and sinuosity were all found to have positive relationships with survival within the river, suggesting increases in these variables may increase survival (likely by means of reducing predation). Smolts exhibited strong nocturnal movements while in the less turbid and channelized upper regions of the river which dissipated to temporally uniform movements in the more turbid and channelized lower regions of the river, suggesting that eased predatory action may have caused smolts to discontinue the nocturnal strategy. Survival data suggests a refocusing of fisheries and resource managers' efforts, specifically with regards to hatchery release strategies and the current concentration of mitigation efforts in the delta.

Nobriga, M. L., M. Chotkowski, and R. Baxter (2003). "Baby steps toward a conceptual model of predation in the delta: preliminary results from the Shallow Water Habitat Predator-Prey Dynamics Study." IEP Newsletter 16(1): 19-27.

Study Background: The Shallow Water Habitat Predator-Prey Dynamics Study is an ongoing IEP study designed to update and expand our understanding of piscivore-prey interactions in the Delta. Field work for this project occurred in 2000-2001 and is scheduled to continue in 2003. This article provides preliminary data on the feeding ecology and habitat use of striped bass and largemouth bass. A subsequent newsletter article currently in preparation will provide further details on the sampling opportunities and limitations that guided the analyses we present here.

Scope: Any study of piscivory in shallow water habitats (SWHs) needs to include definitions of (1) which habitats were considered "shallow", and (2) which fishes were considered piscivorous (Sheaves 2001). We sampled near shore within river channels and flooded islands (Table 1) in water less than 4 m deep. Therefore, we define SWH as less than 4 m deep. As described below, this definition is based on our gear choices rather than any ecological phenomena. Most fish species will opportunistically prey on smaller fishes (Johnson and Ringler 1998). Since the IEP primarily monitors the distribution and abundance of juvenile and small adult fishes, we were interested in focusing our data collection efforts on species that commonly prey on juvenile and small adult fishes. Moyle (2002) identifies 20 extant species that occur in the Delta and at least occasionally eat juvenile and small adult fishes (Table 2). During our 2000-2001 sampling, striped bass and largemouth bass accounted for 88% of the individuals of these 20 species. Each of the remaining 18 species accounted for at most 4% of individuals collected. In addition to being the most abundant, striped bass and largemouth bass also were on average the most frequently piscivorous (Table 1). Based on these observations, we limited our analyses to striped bass and largemouth bass. In this excerpt, we provide preliminary answers to the following questions, which provide the basis for developing a conceptual model of predation in Delta SWHs:

- What are the diet compositions of striped bass and largemouth bass?
- Do striped bass and largemouth bass switch prey based on changes in abundance?
- Which Delta SWHs are used by striped bass and largemouth bass, and what are some important characteristics of these habitats?
- In 2001, did estimated fish consumption by striped bass and largemouth bass inhabiting SWH vary over space and time, and if so, why?

Nobriga, M.L. 2009. Bioenergetic modeling evidence for a context-dependent role of food limitation in California's Sacramento-San Joaquin Delta. California Fish and Game 95(3): 111-121.

Abstract: Striped bass, *Morone saxatilis*, and largemouth bass, *Micropterus salmoides*, are two of the top piscivores in California's San Francisco Estuary. The relative abundance of age-0 striped bass has plummeted since the late 1960s, whereas the abundance of largemouth bass has increased since the early 1990s. Major changes to the estuarine food web have made it a likely place for significant striped bass food limitation, and despite their population increase, there is evidence that young largemouth bass might also be chronically food-limited. Food limitation can be thought of as a context-dependent stressor, meaning that population-level consequences of food limitation are discernable only when they are severe enough to override other factors influencing the growth and mortality of young fishes. The purpose of this study was to clarify the role that food limitation plays in the early life history of striped bass and largemouth bass. I used a combination of previously published beach seine data and bioenergetic modeling (BEM) to evaluate the question, which species is likely more food-limited during its first growing season? I hypothesized that age-0 striped bass would show evidence of greater food limitation than largemouth bass (as indexed by realized vs. potential growth). The BEM simulations predicted that largemouth bass would grow larger than striped bass given the water temperature histories these fish experienced in the Sacramento-San Joaquin Delta during summer-autumn 2001 and 2003. However, the striped bass collected during autumn were larger than the largemouth bass and had thus performed better relative to BEM predictions. I conclude that age-0 striped bass were less food limited than age-0 largemouth bass in these recent years. As discussed, the upsurge of largemouth bass is likely the outcome of low survival in an expanding area of suitable habitat, whereas striped bass food limitation covaries in time with high entrainment loss and declining abiotic habitat suitability. This contrast provides a counter-intuitive example of the context-dependence of food limitation in these sympatric fish populations.

Nobriga, M. L. and F. Feyrer. 2007. "Shallow-water piscivore-prey dynamics in California's Sacramento-San Joaquin Delta." San Francisco Estuary and Watershed Science 5(2): Article 4.

Abstract: Predation is one mechanism that could lead to low native fish abundance in macrophyte dominated shallow-water habitats in the Sacramento-San Joaquin Delta. We used beach seine and gill net sampling to identify and compare the distribution and feeding ecology of three piscivores (striped bass, *Morone saxatilis*, largemouth bass, *Micropterus salmoides*, and Sacramento pikeminnow, *Ptychocheilus grandis*) at five nearshore sites in the Sacramento-San Joaquin Delta. Sampling was conducted March-October 2001 and 2003. We addressed the following questions. What are the spatial and temporal distributions of age-1 and older striped bass, largemouth bass, and Sacramento pikeminnow? What prey are eaten by these predators? What is the relative importance of predator size versus seasonal prey availability on incidence of piscivory for these predators? What is the likely per capita impact of each piscivore on prey fishes, particularly native fishes? All 76 of our individual station visits yielded at least one of the three species, suggesting that piscivorous fishes frequently occur in Delta shallow-water habitats. All three piscivores had diverse diets. There were noticeable seasonal shifts in prey fish for each of the three piscivores. In general, most native fish were consumed during spring (March-May) and the highest prey species richness occurred during summer (June-August). Largemouth bass likely have the highest per capita impact on nearshore fishes, including native fishes. Largemouth bass preyed on a greater diversity of native fishes than the other two piscivores and consumed native fishes farther into the season (July versus May). Based on binomial generalized additive models, incidence of piscivory was predominantly a function of size for largemouth bass and Sacramento pikeminnow. Largemouth bass became predominantly piscivorous at smaller sizes than Sacramento pikeminnow; about 115 mm versus about 190 mm respectively. In contrast, incidence of piscivory was predominantly a function of season for striped bass. Striped bass were typically most piscivorous during summer and fall regardless of size. We conclude that shallow water piscivores are widespread in the Delta and generally respond in a density-dependent manner to seasonal changes in prey availability.

Perry, R. W., P. L. Brandes, J. R. Burau, A. P. Klimley, B. MacFarlane, C. Michel, and J. R. Skalski, 2013. Sensitivity of survival to migration routes used by juvenile Chinook salmon to negotiate the Sacramento-San Joaquin River Delta. Environmental Biology of Fishes 96:381-392.

Abstract: Populations of juvenile salmon emigrating from natal rivers to the ocean must often traverse different migratory pathways that may influence survival. In regulated rivers, migration routes may consist of a network of channels such as in the Sacramento-San Joaquin River Delta, or of different passage structures at hydroelectric dams (e.g., turbines or spillways). To increase overall survival, management actions in such systems often focus on altering the migration routing of fish to divert them away from low-survival routes and towards high-survival routes. Here, we use a 3-year data set of route-specific survival and movement of juvenile Chinook salmon in the Sacramento-San Joaquin Delta to quantify the sensitivity of survival to changes in migration routing at two major river junctions in the Sacramento River. Our analysis revealed that changes in overall survival in response to migration routing at one river junction depended not only differences in survival among alternative routes, but also on migration routing at the other river junction. Diverting fish away from a low-survival route at the downstream river junction increased population survival by less than expected, given the difference in survival among routes, because part of the population used an alternative migration route at the upstream river junction. We also show that management actions that influence only migration routing will likely increase survival by less than actions that alter both migration routing and route-specific survival. Our analysis provides an analytical framework to help fisheries managers quantify the suite of management actions likely to maximize increases in population level survival.

San Joaquin River Group. 2013. Salmon smolt survival investigations. Ch. 5 in 2011 Annual Technical Report on implementation and monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP), Prepared for California Water Resources Control Board in compliance with D-1641.

The 2011 VAMP is the 6th year that acoustic technology was used to estimate juvenile salmon survival in the southern Sacramento-San Joaquin Delta (2006-2011), and the third year where survival was estimated through the Delta to Chipps Island (2008, 2010 and 2011). Prior to 2007, coded wire tag studies were used to estimate survival through the Delta. As part of the background for reporting the results of the 2011 study, the previous coded wire tag studies conducted in the south Delta and through the Delta prior to the VAMP (1994-1999), during the VAMP (2000-2006) and results of the previous acoustic studies (2006-2010) are summarized below. More detail on each annual study is provided in previous reports and specific references are shown in Table 5-1.

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Comparison of 2011 Results to Past Years: Smolt survival through the Delta from Mossdale or Durham Ferry to Jersey Point has been extremely low over the past 10 years regardless of flow, exports, or operation of the HORB. Since 2003, at flows ranging from approximately 2,000 to 27,000 cfs, survival was consistently less than or equal to 12%. In contrast, survival between 1994 and 2001 was much higher and generally ranged between approximately 15 and 50% (Figure 5-1). These present survival levels will not produce a sustainable population. The reason for the change in survival in the last decade is unclear and more study is needed to better define what is happening.

Estimated survival in 2011 through the Southern Delta was consistent with the 2010 estimate (0.56, SE < 0.03 in both years) and considerably higher than the 2009 estimate (0.06, SE=0.01) (without predator-like detections). Differences in survival between years may be due to flow, with 2009 a low-flow year and 2010 and 2011 above normal and wet flow years, respectively (Buchanan et al., 2013). However, differences between years, could also be due to differences in tag weight to body weight ratios as the minimum fish size criteria were not met in 2009; or due to differences in fish origin since Feather River Hatchery fish were used in 2009 while in 2010 and 2011 the smolts came from Merced River Hatchery. Any one or all of these factors may have contributed to the apparent differences in survival between 2009 and other years.

Between 1985 and 1991, CWT studies were conducted to estimate survival in the two main routes through the Delta; Old River and the San Joaquin River. The results of these studies indicated survival was generally higher for the fish released on the San Joaquin River at Dos Reis, downstream of Old River, than for fish released into Old River (Brandes and McLain, 2001). These studies were the basis for installing a physical rock barrier at the head of Old River (HORB) prior to and during the VAMP studies. The physical HORB kept the majority of CWT fish (SJRGA, 2005) and flow in the San Joaquin River.

Starting in 2008, the use of acoustic tags facilitated estimating the proportion of fish taking each route (route entrainment) and estimating survival in each route. In 2008, tag failure prevented unbiased survival estimates, but survival still appeared to be higher on the San Joaquin route than for the Old River route (Holbrook et al., 2009). In contrast, the results in 2010 were mixed about which route through the Delta had higher survival. Although, survival for each of the separate release groups was not significantly different between the Old River and San Joaquin routes, with the exception of the first release group, where survival in the San Joaquin River was higher, pooling all the release groups together suggested survival was higher in the Old River route in 2010 (SJRGA, 2011). In 2011, survival appeared to be higher in Old River than in the San Joaquin River. It is not clear if survival in the San Joaquin route decreased in 2010 and 2011 or whether survival in Old River has increased, for the relative survival to be higher in Old River.

Route entrainment analysis in 2011 found that the probability of remaining in the San Joaquin River at the head of Old River was positively associated with flow and water velocity at Lathrop, with higher flows and water velocities corresponding to more salmon migrating in the San Joaquin River route. Because survival to Chipps Island in 2011 was estimated to be lower in the San Joaquin River route than in the Old River route, this meant that overall survival was lower to Chipps Island for higher flows and velocities at Lathrop.

This year was the last year for the VAMP studies. The VAMP agreement has ended and it is clear additional salmon survival monitoring is needed to estimate survival through the Delta and between the two major routes. It is clear that survival is low for juvenile salmon migrating between Mossdale and Chipps Island and has potentially gotten lower over time. Without a structured set of flow and export targets providing survival estimates in several years under the same flow and export targets, it would not have been possible to detect the shift in survival in 2003 and 2004, relative to 2002 (Figure 5-1). Estimating survival with a structured set of test conditions over a number of years allowed results from annual studies to build on one another to improve our understanding of the complexities of juvenile salmon survival in the Delta.

In addition, the change to acoustic tag methodology allows us to measure route and reach specific survival to better understand what is causing the low observed survival. There is uncertainty in estimating survival using acoustic tags due to the uncertainty of smolts being eaten by predators and tags being detected inside the predator. However, this uncertainty tends to bias survival high, and even without removing predator-type detections survival to Chipps Island has been low. There is also uncertainty of how these tags may affect the survival of acoustic-tagged fish and whether such fish are more prone to predation than untagged salmon would be. Although an effort was made to adhere to the 5% tag weight to body weight ratio, doing so has resulted in releasing the experimental fish later in the season than if smaller tags or CWTs had been used. Additional studies are needed. Pairing acoustic studies with CWT studies may help validate the survival estimates observed with the acoustic tags. In addition, there is still much to learn about what is causing, and what might reduce, the mortality through the Delta of juvenile salmon originating from the San Joaquin River basin.

Shoup, D.E. and Wahl, D.H. 2009. The effects of turbidity on prey selection by piscivorous largemouth bass. Transactions of the American Fisheries Society 138: 1018-1027.

Abstract.—Turbidity in aquatic systems can change rapidly, affecting the visual ability of predators. Increased turbidity is known to reduce the reactive distance and foraging success of some planktivores and insectivores, leading to decreased growth rates. However, little is known about the effects of turbidity on prey selection by piscivores. We examined the interactions between largemouth bass *Micropterus salmoides* and their prey in 1.8-m-diameter tanks (58 cm deep) at four turbidity levels (0, 5, 10, and 40 nephelometric turbidity units [NTU]). Prey selectivity was significantly affected by turbidity. At lower turbidity levels (0 and 5 NTU), largemouth bass consumed mostly gizzard shad *Dorosoma cepedianum* and bluegills *Lepomis macrochirus* and had negative selectivity for northern crayfish *Orconectes virilis*. At 10 NTU, all three prey types had similar selectivity, presumably because the largemouth bass had more difficulty in capturing rapidly moving fish prey as their reactive distances decreased. At 40 NTU, the overall foraging rate was much lower and bluegills were selected significantly more often than the other prey types. Low light levels at the bottom of the tanks combined with reductions in visual clarity from clay sediments probably made it difficult for largemouth bass to feed effectively on virile crayfish at higher turbidities. Our results suggest that trophic interactions may be altered as turbidity levels change.

Stevens, D. L. 1963. Food habits of striped bass, *Roccus saxatilis* (Walbaum) in the Sacramento-Rio Vista area of the Sacramento River. University of California.

Introduction: The purpose of this study was to determine the food habits of the striped bass, *Roccus saxatilis* (Walbaum) and the extent of predation by this species upon young king salmon, *Oncorhynchus tshawytscha*, in the Sacramento River between Rio Vista and Sacramento. Previous studies in the California of the food of striped bass have been concentrated in the area between Antioch in the lower Sacramento-San Joaquin Delta and San Francisco Bay.

The striped bass is an anadromous member of the family Serranidae and is an important game and food fish throughout its range. Mature striped bass normally ascent the Sacramento and San Joaquin Rivers for spawning in the spring months, then descent to the bay and coastal ocean waters for the summer and fall months. Some bass, however, can usually be found in the river throughout the year. During the course of this study, bass ranging from 10 to 15 inches in size were found to be particularly abundant in the area from May through September.

The striped bass was native on the Atlantic Coast from the Gulf of St. Lawrence to northern Florida with centers of abundance including the Chesapeake and Delaware Bay Regions, and the waters of New York and southern New England. Striped bass were introduced to California in 1879. The initial plan t was transported from New Jersey waters and released in Carquinez Straits at Martinez. Three years later a second plant of 300 New Jersey fish was made in Suisun Bay near Army Point (Scofield and Bryant, 1926). The present Pacific Coast range of the striped bass lies between the Columbia River, Washington, and southern California. The main center of distribution in the west is San Francisco Bay and the Sacramento-San Joaquin Delta. An abundant population also occurs in Coos Bay in Oregon.

Conclusions:

1) Six hundred seventy stomachs of striped bass, *Roccus saxatilis*, taken in the Sacramento River between Rio Vista and Sacramento were examined. Of these stomachs, 36.7 % contained natural food items.
2) The diet was found to vary according to time of year and locality sampled.
3) Crayfish, *Pacifastacus leniusculus*; freshwater smelt, *Hypomesus olidus*; and king salmon, *Oncorhynchus tshawytscha*, were the most important food items. Young striped bass; carp, *Cyprinus carpio*; splittail, *Pogonichthys macrolepidotus*; tule perch, *Hysterocarpus traskii*; Pacific lamprey, *Entosphenus tridentatus*; shad, *Alosa sapidissima*; goldfish, *Crassius auratus*; myscid shrimp, *Neomysis mercedes*; amphipods, *Corophium* sp.; and chironomids, fam. Tendipedidae formed the remainder of the diet.
4) The absence of chironomids in stomachs of bass over 13 inches in length was the only indication of selective feeding by bass of different sizes.
5) Salmon formed a greater portion of the diet of bass caught with a gill net and by artificial lures than of those taken on sardine bait during the month of July. This difference may be accounted for by depth of feeding and time of capture.
6) The daily peak of surface feeding upon seaward migrant salmon at the Paintersville Bridge during the summer months was found to occur after the period of minimum current and prior to the period of maximum current.
7) Counts of splashes made by schools of bass chasing young salmon revealed the bridge shadow to be a definite factor in determining the area of surface predation.
8) The number of salmon preyed upon by striped bass at the Paintersville Bridge during June, July, and August was determined to be between 39,000 and 78,000.
9) Surface feeding upon fingerling salmon at the Paintersville Bridge does not occur until after the main portion of the seaward migrants have already passed through this area.
10) Occurrence of surface predation upon young salmon by striped bass at the Paintersville Bridge seems to be related to releases of salmon fingerlings from Nimbus Hatchery into the American River.

11) Salmon have not previously been found in the striped bass diet in the Sacramento-San Joaquin River system because food studies have been centered in areas where salmon are probably dispersed and less abundant than other prey.

Stevens, D. L. 1966. Food habits of striped bass (*Roccus saxatilis*) in the Sacramento-San Joaquin Delta. Pages 68-96 in J.L. Turner and D.W. Kelley, eds. Ecological studies of the Sacramento-San Joaquin Estuary, part II: fishes of the Delta. California Department of Fish and Game. Bull.136.

Abstract: This paper describes the food habits of striped bass older than three months, in the Delta of the Sacramento and San Joaquin rivers. Most of the older descriptions (Smith, 1896; Scofield, 1910; Scofield and Coleman, 1910; Scofield and Bryant, 1926; Scofield, 1928, 1931; Shapovalov, 1936; Hatton, 1940; Johnson and Calhoun, 1952) of striped bass food habits in the Sacramento-San Joaquin estuary are merely qualitative or fragmentary. More recently, Heubach, Toth, and McCready (1963) examined a large number of stomachs of bass younger than 6 months from the Delta, but they examined few stomachs of older bass. Ganssle (1966) has described striped bass food habits in the estuary between the Delta and the lower end of San Pablo Bay, and Thomas (1967) has studied the diet of striped bass from the Sacramento and San Joaquin rivers above the Delta down to San Francisco Bay. To avoid duplication of my work, Thomas did not attempt Delta-wide coverage. This paper is based on an analysis of stomach contents of 8,628 striped bass from eight types of Delta environments. The stomachs were collected from September 1963 through August 1964. The mysid shrimp, *Neomysis awatschensis,* and the amphipods, *Oorophi1tm stimpsoni* and *Oorophi1tm spinicorne,* were the most important foods of young bass. As bass grew their diet shifted to forage fishes, primarily small striped bass and the threadfin shad, *Dorosoma petenense.* Thc composition of the diet yaried by season and area. There is some evidenc~ that *N. awatschensis* was a preferred food of young bass. Stomach contents differed for bass collected by different sampling gear. The amount of food in stomachs of year-old bass decreased significantly from the lower to the middle to the upper San Joaquin River. Differences in the length and coefficient of condition of bass from these same zones may be a direct result of the differences in food intake.

Thomas, J. L. 1967. The diet of juvenile and adult striped bass, Roccus saxatilis, in the Sacramento-San Joaquin river system. California Department of Fish and Game 53(1):49-62.

Abstract: More than 4,500 striped bass stomachs were examined during the period 1957-1961. About half contained natural food items. Comparisons were made between size of bass and size of organisms eaten. Major foods were northern anchovies, shiner perch, striped bass, king salmon, carp, crayfish, bay shrimp, mysid shrimp, isopods, scuds, and insect larvae.

Tucker, M. E., C. M. Williams and R. R. Johnson. 1998. Abundance, food habits and life history aspects of Sacramento squawfish and striped bass at the Red Bluff Diversion Complex, including the Research Pumping Plant, Sacramento River, California, 1994-1996. Red Bluff Research Pumping Plant Report Series, Volume 4. U.S. Fish and Wildlife Service, Red Bluff, California.

Abstract: The Red Bluff Research Pumping Plan (RPP) is being evaluated by the Bureau of Reclamation (Reclamation) to determine if pumping water through either Archimedes or internal helical pumps is a viable method for meeting water delivery requirements to the Tehama-Colusa Canal system. The U.S. Fish and Wildlife Service (Service) is contracted to determine the in-river biological implication of the Research Pumping Facility.

This report summarizes Sacramento squawfish *Ptychocheilus granis* and striped bass *Morone saxatilis* monitoring activities around Red Bluff Diversion Dam (RBDD) and the RPP on the Sacramento River, California, from April, 1994, through July, 1996. Both Sacramento squawfish and striped bass were

sampled by angling and electrofishing. The main areas targeted for sampling included RBDD, the RPP, the bypass outfall structure, and a relatively undisturbed area downstream. Sampling occurred weekly, with intermittent periods of higher frequency (2 to 3 times per week). Data and tissues were collected to determine growth rate, age structure, reproductive condition (relative gonad weight), and diet of Sacramento squawfish and striped bass. Most of the fish were tagged and released to estimate population size, movement patterns and actual growth. Data are also presented from the 1st and 2nd Annual Red Bluff Squawfish Derbies.

Sacramento squawfish relative abundance estimates were lower than those reported from previous studies of the area. The highest densities of both Sacramento squawfish and striped bass occurred in the spring and early summer when the dam gates were in and an apparent Sacramento squawfish spawning migration was underway. Nearly all striped bass were captured directly behind the dam while the gates were in (90%, N=89). Diet analysis showed that juvenile salmonids outweighed other food sources in Sacre3manto squawfish stomachs only during summer, gates in periods. In striped bass stomach samples, juvenile salmonids outweighed other food types by a three to one margin. Other life history parameters were examined and compared to the findings of other authors.

Turlock Irrigation District and Modesto Irrigation District. 2013. Predation Study Report. Don Pedro Project FERC NO. 2299. Prepared by FISHBIO. For S&AR-07 Predation.

Introduction: Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) are the co-licensees of the 168-megawatt (MW) Don Pedro Project (Project) located on the Tuolumne River in western Tuolumne County in the Central Valley region of California. The Don Pedro Dam is located at river mile (RM) 54.8 and the Don Pedro Reservoir formed by the dam extends 24-miles upstream at the normal maximum water surface elevation of 830 ft above mean sea level (msl; NGVD 29). At elevation 830 ft, the reservoir stores over 2,000,000 acre-feet (AF) of water and has a surface area slightly less than 13,000 acres (ac). The watershed above Don Pedro Dam is approximately 1,533 square miles (mi2).

Both TID and MID are local public agencies authorized under the laws of the State of California to provide water supply for irrigation and municipal and industrial (M&I) uses and to provide retail electric service. The Project serves many purposes including providing water storage for the beneficial use of irrigation of over 200,000 ac of prime Central Valley farmland and for the use of M&I customers in the City of Modesto (population 210,000). Consistent with the requirements of the Raker Act passed by Congress in 1913 and agreements between the Districts and City and County of San Francisco (CCSF), the Project reservoir also includes a “water bank” of up to 570,000 AF of storage. CCSF may use the water bank to more efficiently manage the water supply from its Hetch Hetchy water system while meeting the senior water rights of the Districts. CCSF’s “water bank” within Don Pedro Reservoir provides significant benefits for its 2.6 million customers in the San Francisco Bay Area.

The Project also provides storage for flood management purposes in the Tuolumne and San Joaquin rivers in coordination with the U.S. Army Corps of Engineers (ACOE). Other important uses supported by the Project are recreation, protection of the anadromous fisheries in the lower Tuolumne River, and hydropower generation.

The Project Boundary extends from approximately one mile downstream of the dam to approximately RM 79 upstream of the dam. Upstream of the dam, the Project Boundary runs generally along the 855 ft contour interval which corresponds to the top of the Don Pedro Dam. The Project Boundary encompasses approximately 18,370 ac with 78 percent of the lands owned jointly by the Districts and the remaining 22 percent (approximately 4,000 ac) is owned by the United States and managed as a part of the U.S. Bureau of Land Management (BLM) Sierra Resource Management Area.

The primary Project facilities include the 580-foot-high Don Pedro Dam and Reservoir completed in 1971; a four-unit powerhouse situated at the base of the dam; related facilities including the Project spillway, outlet works, and switchyard; four dikes (Gasburg Creek Dike and Dikes A, B, and C); and three developed recreational facilities (Fleming Meadows, Blue Oaks, and Moccasin Point Recreation Areas).

Vogel, D. 2010. Evaluation of acoustic-tagged juvenile Chinook salmon movements in the Sacramento-San Joaquin Delta during the 2009 Vernalis Adaptive Management Program. Natural Resource Scientists, Inc. Red Bluff, CA.

Executive Summary: The spring of 2009 was the fourth year of experiments evaluating the movements of acoustic-tagged juvenile Chinook salmon (*Oncorhynchus tshawytscha*) released in the San Joaquin River during the Vernalis Adaptive Management Program (VAMP). It was hypothesized that the study may provide salmon survival estimates in some key reaches of the Delta and fish route "selection" probabilities at critical flow splits (i.e., head of old River and Turner Cut). This plan was also intended to become adaptive by continuing the testing of the acoustic receiver network and equipment, refining logistical approaches to field implementation, and assessing other potential improvements should a study of this nature continue in future years. The project was considered to be an ongoing effort to determine the efficacy of using this technology for Delta Fish studies.

A total of 993 acoustic–tagged salmon was released in the lower San Joaquin River at Durham Ferry during sever separate releases in Late April and early May 2009. Passage of those fish at 19 acoustic receivers strategically positioned in various Delta channels was monitored from the time of first fish release until early June. Additionally, mobile telemetry was used in some of the key fish migration channels to potentially locate areas of high salmon mortality and where predatory fish may have defecated smolt tags. To improve our understanding of how potential effects of non-native fish predation may influence survival results and interpretation of smolt telemetry data, small numbers of predatory fish were also tagged with transmitters to monitor trends in behavior and movements within the VAMP acoustic telemetry array.

We employed elaborate, painstaking techniques to evaluate the extensive acoustic telemetry data and spatiotemporal history of each tagged fish acquired during the VAMP study. We chose this approach because simple reporting of fish tag presence/absence information may cause widespread misinterpretation and negate the potential for scientifically sound results. These highly detailed assessments of acoustic tag movements included: 1) a near-field environment within the fish transmitter detection range of each of the 19 acoustic hydrophones, 2) medium-field observations of tag movements in a fine-time scale between receivers in close proximity, and 3) far-field examinations of movements of transmitters throughout the study-wide telemetry array. Manual processing of the acoustic telemetry data, although time consuming, provided critically important information on fish behavior to assist in interpreting the 2009 study results.

All of the fish telemetry data were integrated with: 1) flow measurements recorded in relevant Delta channels; 2) site-specific characteristics in fish migration corridors; and 3) knowledge acquired form numerous prior juvenile salmon telemetry studies conducted in the Delta. Furthermore, the analyses included results of a concurrent independent evaluation of acoustic tag movements at a two-dimensional acoustic receiver with four hydrophones positioned at the head of Old River and a dual-frequency identification sonar camera to study a potential fish behavioral barrier ("bubble curtain"). This latter study provided a means to develop a separate independent method to estimate predation on VAMP study fish and compare with our analyses.

It appears that we were frequently tracking dead salmon (or the transmitters) inside predatory fish during the 2009 VAMP study, not the live salmon. Although reasonably accurate numerical estimates of salmon smolt survival were not feasible, fish survival as observed from all seven releases of acoustic-tagged salmon was extremely low. Both independent methods of data evaluation, although not definite, suggest that there was a very high level of predation on acoustic-tagged salmon. Mobile telemetry surveys found a total of 173 acoustic tags believed to be dead acoustic-tagged salmon or tags defecated by predatory fish in the reaches surveyed (approximately 19% of those fish released at Durham Ferry).

Although the proximal cause of the fish mortality appeared to be a result of predation, the circumstances causing predation remain unknown and warrant further study. While remaining speculative, some of the conditions enhancing predation on salmon are hypothesized to be a result of one or more of the following: 1) flow and/or water quality (including temperature) conditions; 2) in-channel artificial structures (e.g., bridge piers, pump stations, docks); 3) channel geometry (e.g., scour holes) providing favorable habitat conditions for predatory fish; and/or the possible substandard condition of tagged salmon.

Acoustic-tagged striped bass frequently moved throughout the telemetry array and empirical evidence corroborating assumption of predation on acoustic-tagged salmon was observed. These complex circumstances significantly affect how juvenile salmon telemetry data can be interpreted. Due to large number of acoustic-tagged salmon possibly being eaten by non-native predatory fish in the Delta, the ability to accurately estimate salmon survival is likely severely compromised because of incorrect assumption on tag detections (i.e., live salmon versus dead salmon). Differentiating between live acoustic-tagged salmon and predatory fish that had eaten acoustic-tagged salmon makes it very difficult to estimate overall salmon survival, salmon survival by reach, and fish route selection at key flow splits, all of which were (and continue to be) key objectives of the VAMP study.

Acoustic telemetry technology has been amply demonstrated to be a powerful analytical tool to study juvenile salmon movements in the Delta, but only if it is appropriately implemented and the results are properly analyzed and understood. Information developed form the 2009 VAMP study indicates that attempts to accurately estimate salmon survival in the Delta using acoustic telemetry will require a new approach, perhaps by seeking changes in the technology to determine predation. In the absence of a technological breakthrough, highly detailed data on the behavior of predatory fish movements as compared to juvenile salmon movements is critically necessary.

Most importantly, because of the well-documented low salmon smolt survival in the lower San Joaquin River and Delta, efforts should focus on determining site-specific cause of mortality with the objectives of developing and implementing remedial actions to increase fish survival. This report contains numerous recommendations to improve the execution and scientific integrity of future acoustic telemetry studies in the Delta.

Vogel, D. 2011. Evaluation of Acoustic-Tagged Juvenile Chinook Salmon and Predatory Fish Movements in the Sacramento – San Joaquin Delta during the 2010 Vernalis Adaptive Management Program. Natural Resource Scientists, Inc. Red Bluff, CA.

Introduction: The spring of 2010 was the fifth year of experiments evaluating the movements of acoustic tagged juvenile Chinook salmon (*Oncorhynchus tshawytscha*) released in the San Joaquin River during the Vernalis Adaptive Management Program (VAMP). The use of acoustic telemetry had been previously recommended as a useful analytical technique to acquire detailed biological data that was not possible with the more-traditional coded-wire tagging studies historically used for the VAMP program (Vogel 2005). In the fall and winter of 2009-2010, the VAMP Biology Committee formulated a plan for the 2010 fish study similar to 2009 (Vogel 2010a), but expanded in geographic scope, using a network of acoustic receivers1 deployed in the Delta to detect passage of acoustic-tagged juvenile salmon released in the San Joaquin River and Old River. The 2008 through 2010 studies were expanded from initial pilot acoustic-telemetry studies conducted in 2006 (Vogel 2006a) and 2007 (SJRGA 2008) where fewer acoustic receivers were deployed and fish samples were smaller. It was hypothesized that the study results may estimate fish route "selection" probabilities at critical flow splits (i.e., head of Old River and Turner Cut), fish survival in specific reaches and through the Delta to Chipps/Mallard Islands.

During the 2009 VAMP study, it was estimated that many of the acoustic tags detected by the fixed-station acoustic receivers were actually dead salmon (or the transmitters) inside predatory fish such as striped bass (Vogel 2010a). That conclusion was also corroborated through a separate study of fish behavior at the head of Old River using different analytical techniques (Bowen et al. 2009). This circumstance significantly complicated the ability to accurately estimate true juvenile salmon survival and migration route selection. Estimates of salmon survival using solely presence/absence data could be incorrect from true salmon survival with large error margins causing widespread misunderstanding of study results and negating the potential for scientifically sound decisions. It was therefore recommended that a better understanding of predatory fish behavior in comparison to juvenile salmon behavior was necessary to avoid misinterpretation of telemetry data (Vogel 2010a).

Small numbers of striped bass were also tagged with acoustic transmitters during the 2008 and 2009 VAMP studies to monitor fish movements and behavior concurrent with juvenile salmon monitoring. Results demonstrated that the striped bass were highly mobile during the study period moving large distances throughout the Delta, although some predators also exhibited strong affinity to certain regions (Vogel 2010a, 2010b). Empirical evidence was obtained which confirmed movements and behavior of predatory fish used in the evaluations of predation estimates on salmon smolts. These results also indicated that tag detections by the acoustic receiver array could easily result in incorrect assumptions on acoustic-tagged smolt movements due to similar swim patterns of salmon and predators with flow (e.g., ebb and flood tides). It became evident that, for future studies, collecting data on acoustic-tagged predatory fish movements would be invaluable.

To address the major problem with differentiating live acoustic-tagged salmon from dead salmon within the 2010 VAMP acoustic telemetry array, Natural Resource Scientists, Inc. proposed tagging predatory fish with acoustic transmitters for reasons similar to that recommended for an earlier north Delta telemetry study2 (CALFED 2008). A fundamental question associated with the salmon survival estimates in the Delta is the stationarity of the predator field and, by association, the stationarity of the survival estimates. If the predators are highly mobile or congregate in different regions in the Delta at different times of the year, then the survival estimates will vary depending on the spatial and temporal variability of the predator fields.

Wargo-Rub, A. M., L. G. Gilbreath, R. L. McComas, B. P. Sandford, D. J. Teel, and J. W. Ferguson. 2012. Estimated Survival of adult spring/summer Chinook salmon from the mouth of the Columbia River to Bonneville Dam, 2011. Report of the National Marine Fisheries Service, Northwest Fisheries Science Center. Seattle, Washington.

Introduction: Accurate estimates of adult salmon mortality from all sources during the upstream migration in freshwater are critical to management decisions. However, aside from mortality attributed to harvest, the proportion of adult migrants lost through any mechanism between the Columbia River mouth and Bonneville Dam (rkm 234) has not been measured in a scientifically rigorous manner until recently.

In spring 2010 and 2011, we conducted a pilot study of adult survival from the mouth of the Columbia River to Bonneville Dam. During these two study years, we collected and tagged a total of 962 adult spring Chinook salmon and released them to the Columbia River estuary near river kilometer (rkm) 45. This report details work conducted in 2011, the second year of the pilot study. Results from work conducted in 2010 are detailed in Wargo Rub et al. (2012).

Objectives of the pilot study were to:

- Establish protocols and equipment needs, including vessels and crews, for handling and tagging significant numbers of adult salmon (e.g., up to 100 fish per sampling day)
- Establish protocols for restraining fish to facilitate "best practices" for acoustic tagging with both gastric and surgical implantation methods and passive integrated transponder (PIT) tagging
- Provide a cursory evaluation of the effects of tagging on adult fish
- Obtain estimates of PIT- and acoustic-tag retention for migrating fish over a period of 2 weeks or longer
- Obtain preliminary estimates of survival to Bonneville Dam for adult spring Chinook salmon to inform sample-size selection for expanded survival studies

Wargo-Rub, A. M., B. P. Sandford, L. G. Gilbreath, M. S. Myers, M. E. Peterson, L. L. Charlton, S. G. Smith, and G. M. Matthews. 2011. Comparative performance of acoustic tagged and passive integrated transponder tagged juvenile Chinook Salmon in the Columbia and Snake Rivers, 2008. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Evaluation of Acoustic Tags in Migrating Yearling Chinook Salmon: Migration rates, detection and survival probabilities, and avian predation rates were compared between fish tagged with a passive integrated transponder (PIT) tag vs. those tagged with both a PIT-tag and Juvenile Salmonid Acoustic Telemetry System (JSATS) tag. During spring 2008, we collected migrating hatchery yearling Chinook salmon at Lower Granite Dam. We tagged 4,139 of these fish with both a JSATS tag and a PIT tag (JSATS-tagged fish) and 50,814 with a PIT tag only (PIT-tagged fish). Samples were designed to be of sufficient size to determine a minimum difference of 5% between tag groups in detection and survival over a distance of 348 km, and to provide statistical power of 80% (α=0.05). Fish were released to the tailrace of Lower Granite Dam on 10 d, from 24 April through 17 May.

Acoustic-tagged fish were implanted with the 2008 model JSATS acoustic tag, which weighed 0.42 g in air. Average tag burden experienced by JSATS-tagged fish was 2.3% of body weight (range 0.8-7.2%). For both tag treatments, travel times, detection probabilities, and survival were estimated from individual PIT-tag detections at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dam. For estimates of detection probability and survival, we also utilized detections of JSATS-tagged fish from acoustic arrays at multiple locations within the study area.

Mean detection probabilities were estimated for each PIT-tag detection site. Mean detection probability was higher for JSATS- than PIT-tagged fish at Little Goose, Lower Monumental, and John Day Dams. The difference in detection probability was 0.04 (P=0.005) at Little Goose Dam, 0.05 (P=0.002) at Lower Monumental, and 0.06 (P=0.006) at John Day Dam. Mean detection probability at Ice Harbor Dam was 0.03 higher for JSATS-than PIT-tagged fish, and the difference approached significance (P=0.067). There was no significant difference in detection probability between tag-treatment groups at McNary or Bonneville Dam (P=0.242, and 0.174, respectively).

In the Snake River, relative survival (ratio of survival estimates for JSATS-tagged/PIT-tagged groups) was not significantly different than one from release to Little Goose or Ice Harbor Dam (P=0.107 and 0.336 respectively). Relative survival was 0.95 from release to Lower Monumental Dam and approached significance (P=0.096). In the Columbia River, relative survival was 0.91 (P=0.095) to

McNary Dam, 0.72 (P=0.001) to John Day Dam, and 0.69 (P=0.021) to Bonneville Dam. A significant difference in travel time to John Day Dam was observed (P=0.019), with JSATS-tagged fish arriving 0.81 d (19.44 h) after PIT-tagged fish, but significant differences in travel time were not observed at any other detection site.

Overall mean PIT-tag recovery from upper river bird colonies was 2.0% for JSATS-tagged and 1.0% for PIT-tagged fish. Although this 1% difference in tag-recovery rate was statistically significant (P=0.016), it was not likely to have been biologically meaningful. From estuarine bird colonies, the overall mean PIT-tag recovery was rate 3.0% for JSATS-tagged and 4.0% for PIT-tagged fish, and the difference was not significant (P=0.881).

Zajanc, D., Kramer, S., Nur, N., and Nelson, P. 2013. Holding behavior of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) smolts, as influenced by habitat features of levee banks, in the highly modified lower Sacramento River, California. Environ. Biol. Fish. 96(2-3): 245-256.

Abstract: Using acoustic telemetry methods on large numbers of tagged fish, we studied how the holding behavior of Chinook salmon and steelhead smolts could be related to habitat features and spatial and temporal variables on a highly altered section of the Sacramento River. We viewed downstream migration as a process in which fish transition between moving and holding states, and used a binomial and negative binomial Generalized Linear Model to analyze two aspects of holding: 1) probability of holding, and 2) holding time. For Chinook salmon, the probability of holding increased as wood size and fine substrates increased; holding time increased as overhead shade increased. For steelhead, holding behavior was only weakly related to habitat variables, in contrast to the strong relationships with spatial and temporal variables. For both species, the probability of holding increased when distance from the release location decreased and instream flows decreased. We found support for three main findings: 1) spatial and temporal factors have considerably greater influence on Chinook salmon and steelhead smolt holding behavior than nearshore habitat features; 2) holding behaviors of Chinook salmon smolts are influenced more strongly by habitat features than steelhead smolts; and 3) incorporation of habitat features such as large woody material and overhead shade should be considered when conducting nearshore bank rehabilitation projects to increase cover from predators and provide velocity refuge, improving holding habitat during downstream migration.