27

CALIFORNIA DEPARTMENT OF WATER RESOURCES

A Non-Physical Barrier for Young Salmon in the Sacramento - San Joaquin Delta

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INTRODUCTION

In the Sacramento- San Joaquin Delta (Figure 1) and under the Temporary Barriers Project, a springtime Head of Old River (HOR) rock barrier may be installed at the confluence of the San Joaquin River and Old River (Figure 2). Since 1992, this barrier has generally operated from early in April until late May. This rock barrier (Figure 3) supports the Vernalis Adaptive Management Plan (VAMP) experiment and helps to keep out-migrating juvenile San Joaquin River Chinook salmon (smolts) from going down Old River, a longer and more dangerous path to the ocean. In 2008, the HOR rock barrier was not installed due to Delta smelt concerns and a court order preventing installation of the HOR rock barrier due to its potentially adverse impacts on Delta smelt. In 2009, while there was no longer a court order in effect, the 2008 U.S. Fish and Wildlife Service's Biological Opinion for the Central Valley Project (CVP) and State Water Project (SWP) Operations Criteria and Plan includes strict conditions under which the HOR rock barrier can be installed. Given the uncertainty of installing the HOR rock barrier, VAMP participants suggested exploring the possibility of installing a Non-Physical Barrier (NPB) instead of the HOR rock barrier normally used. The NPB was expected to help guide smolts away from entering Old River, keeping them in the San Joaquin River and on a less dangerous route to the ocean. In addition, the National Marine Fisheries Service (NMFS) 2009 Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project requires DWR to install a HOR barrier in April-May (Action IV.2.1) along with specific CVP and SWP export restrictions (Vernalis flow:export ratio). The NPB may provide sufficient protection to out-migrating salmon and steelhead and, therefore, reduce or eliminate the need for export restrictions. The NPB was planned to be a test project in 2009 and if it proved effective in improving out-migrating conditions for salmon smolts as well as steelhead, could become a reasonable alternative to the rock barrier or a future permanent gate facility.

BACKGROUND

Planning began in early 2009 and focused on testing the viability of a NPB using sound, bubbles, and strobe lights to guide out-migrating smolts in a manner that encourages them to stay in the San Joaquin River and out of Old River where they would be less likely to survive. The NPB was planned to be supported below the water surface and 45 cm above the channel bottom from four steel piles that secure the NPB in place. Unlike the rock barrier that is historically place at the HOR, the NPB would not change the hydrodynamics of the rivers, so it might have less adverse effects on other sensitive fish, particularly Delta smelt. Navigation would not be impacted because the NPB does not block the river channel. The NPB would be in place from April 15 through May 15 to support the VAMP experiment, similar to the time frame that the rock barrier would have been in place. A fish study was planned to collect data that would be gathered during the experiment. This data would be needed to determine the effectiveness of the NPB in improving the survivability of out-migrating salmon smolts and whether the NPB could be a viable alternative to a physical barrier at the Head of Old River.

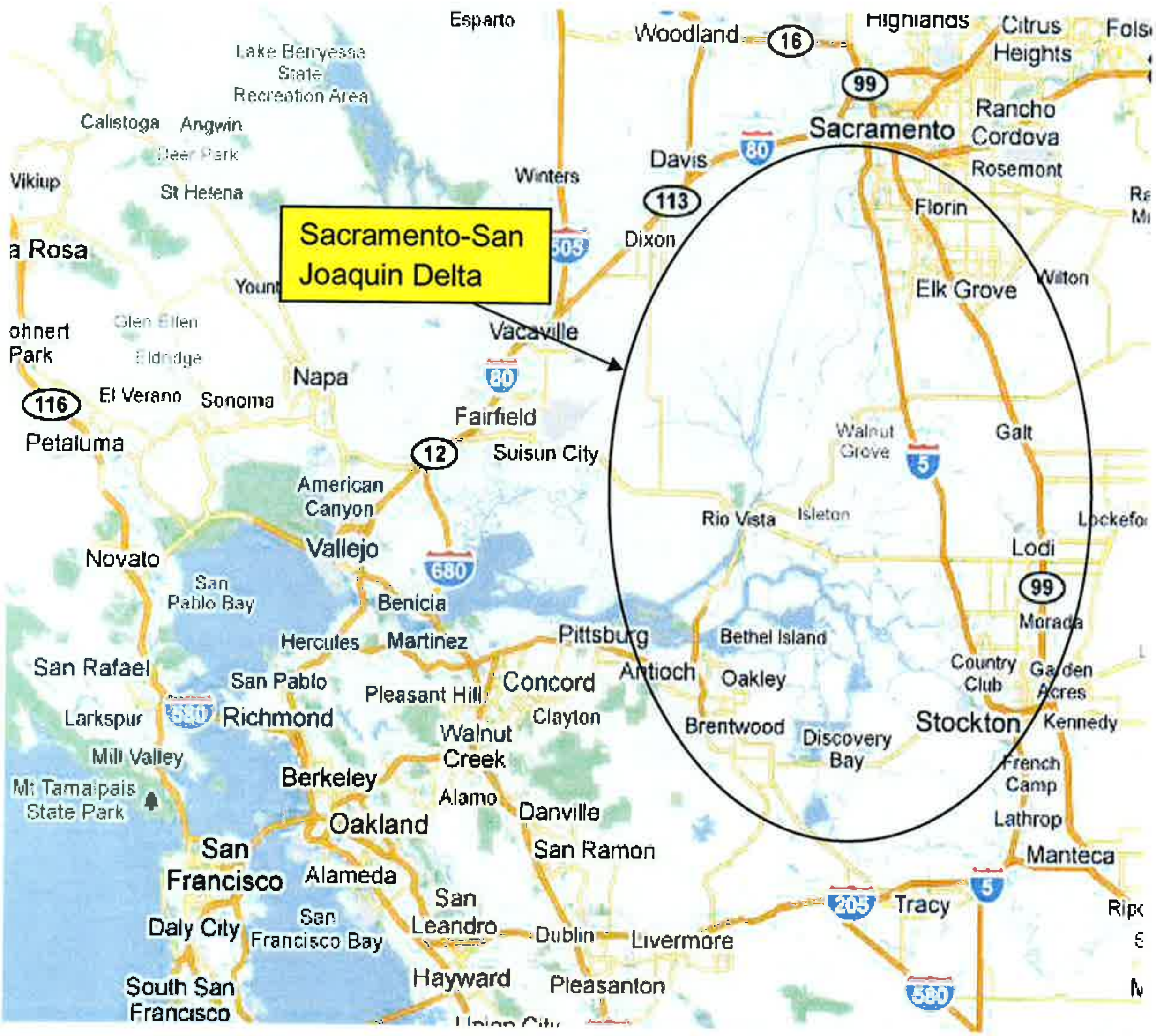

Figure 1. Location of California's Sacramento-San Joaquin Delta estuary

DESIGN

The NPB used is a proprietary design developed by Fish Guidance Systems, Ltd. (FGS). FGS has developed a multi-stimulus fish barrier, comprising a Bio-Acoustic Fish Fence (BAFF™) with sound, bubbles and strobe-lights. The BAFF™ is a patented device developed by FGS which combines acoustic stimuli with a bubble curtain to create a "wall of sound" at frequencies and levels that are repellent to fish. Sound is trapped by refraction within the bubble sheet, producing a sharply defined sound field that fish do not detect until within a few meters of the barrier. Hi-intensity light-emitting diode (LED) strobe lights are attached at the base of the BAFF™ to illuminate the bubble curtain, achieving a multi-stimulus barrier. Using this combination of technologies, a well defined barrier line can be created for optimum guidance of juvenile salmon away from the HOR.

Figure 2. Area map of Sacramento-San Joaquin Delta and location of non-physical barrier (NPB).

Figure 3. Aerial of spring Head of Old River temporary rock barrier

The BAFF technology was tested in a lab setting in 2008 by Dr. Mark Bowen and his team at the US Department of the Interior/Bureau of Reclamation (Reclamation), Denver, Colorado. Tests focused on Chinook salmon and delta smelt. The laboratory BAFF fish barrier combined a number of stimuli and operating principles to maximize fish guidance into a designated channel. These include customized sound signals, directional strobe lighting and an air bubble curtain (Figure 4).

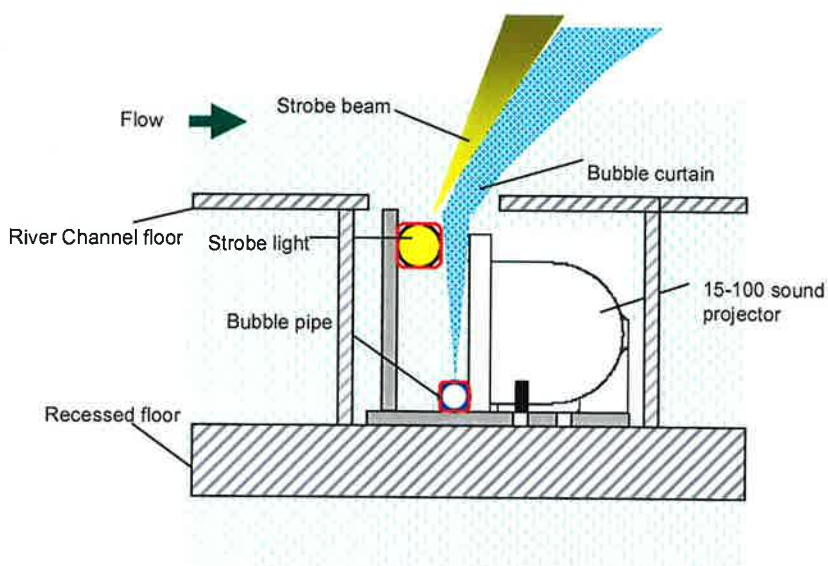

Figure 4. Laboratory BAFF barrier system set-up

The sound system and strobe light flash rate were tuned to known sensitivities of these species. The barrier was shown to be particularly effective against Chinook salmon smolts.

For the 2009 NPB test project, the California Department of Water Resources worked with Reclamation in coordination with FGS (Southampton, England), Jacobs Engineering (Southampton, England), EIMCO Water Technologies (Salt Lake City, UT), Hydroacoustic Technology Inc. (Seattle, WA), and the San Joaquin River Group Authority (Davis, CA) to design, implement, and monitor the NPB using the BAFF technology. The BAFF was deployed upstream of the divergence (Divergence) of the San Joaquin River (SJR) and Old River in the western half of the SJR channel and was angled approximately 24 degrees toward the east bank of the SJR. The length of the barrier was 112 meters (Figure 5). This NPB acted to intercept downstream-moving Chinook salmon smolts and guide them in a north-east direction away from the HOR, reducing their chances of continuing down the Old River.

Figure 5. Aerial of Non-Physical Barrier (NPB) installation

The BAFF components—sound, air, and light—were attached to a truss style frame. This frame was suspended 0.45 m off the bottom of the river (Figures 6 and 7). This distance was deemed sufficient to allow sturgeon, green and white, to pass under the NPB.

Acoustic Stimulus

FGS investigated the sensitivities of different fish species and found the most effective acoustic deterrents for multiple species applications fall within the sound frequency range of 5 to 600 Hz. The NPB generated frequencies within this range at source levels near 160 dB. The signals were delivered by electromechanical transducers, or "sound projectors." For the NPB installation, FGS sound projectors were used, allowing fine control of sound levels within the experimental arena. The sounds were generated by an FGS Signal Control Unit which fed an FGS Power Amplifier, which was linked by cable to the sound projectors.

Bubble Curtain

The primary function of the bubble curtain was to contain the sound generated by the sound projectors. Using a unique principle patented by FGS, the sound was encapsulated within the bubble curtain, allowing a linear sheet of sound to be developed. The bubble curtain was generated by passing compressed air into a perforated rubber pipe running along the base of the barrier. Air flow rate was typically around 2.0 liters per second per 1 meter length of barrier. The alignment of the bubble curtain determined the guidance line of fish, enabling them to be directed toward the San Joaquin River. Trapping the sound signal within the air curtain prevented any saturation of the experimental area with sound—levels typically falling to ambient at a range of 3 meters from the bubble curtain axis.

Strobe Lighting

FGS Linear Strobe Light Arrays were used to generate the visual stimulus. The strobe lights were LED powered devices that created white light in a vertically-oriented beam of 22-degree beam width. The light arrays were used in the barrier and were aligned such that the beam projects onto the rising bubble curtain. This served to reflect the beam and improved visibility from the direction of approaching fish. The narrow vertical beam angle minimized light saturation within the experimental arena. The strobe light system was driven by a low voltage source at a flash rate of 360 per minute.

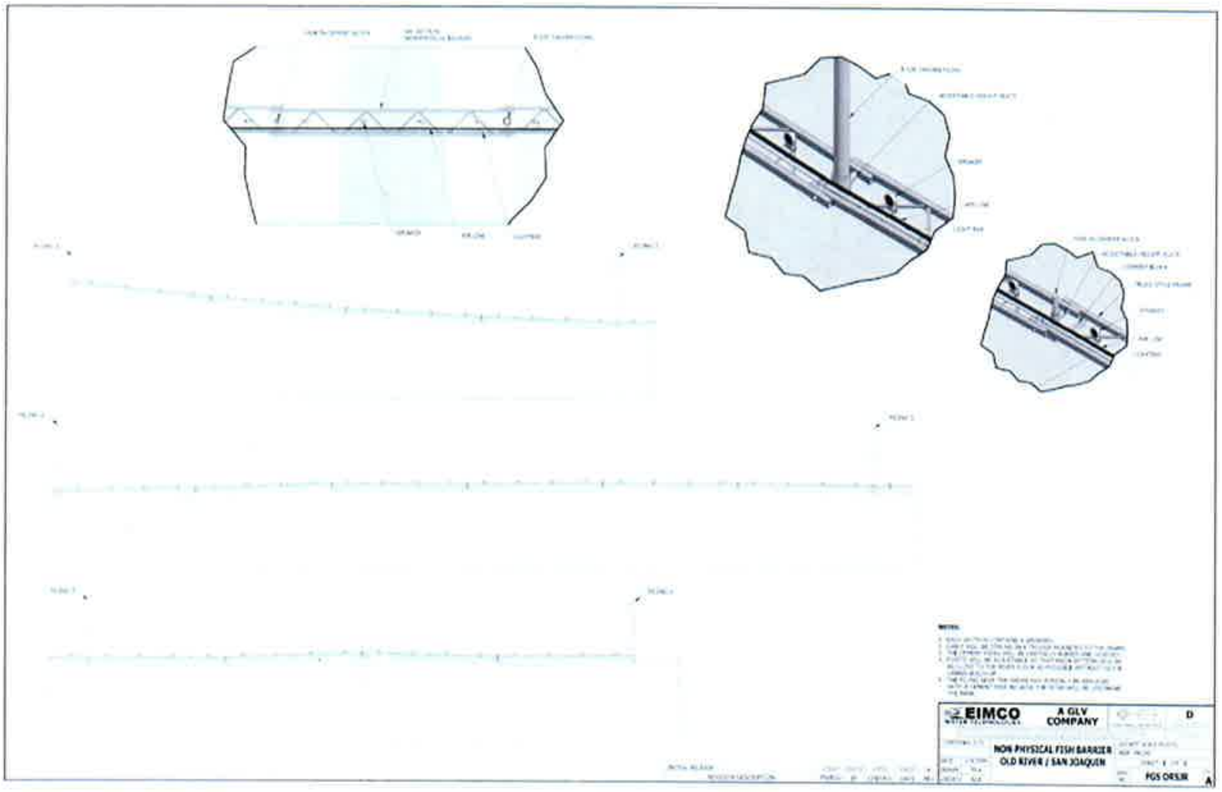

Figure 6. Non-physical barrier design in the San Joaquin River just upstream of the Old River divergence. The truss-style frame was supported 0.45 m off the bottom for the entire length of the barrier by pilings and concrete piers.

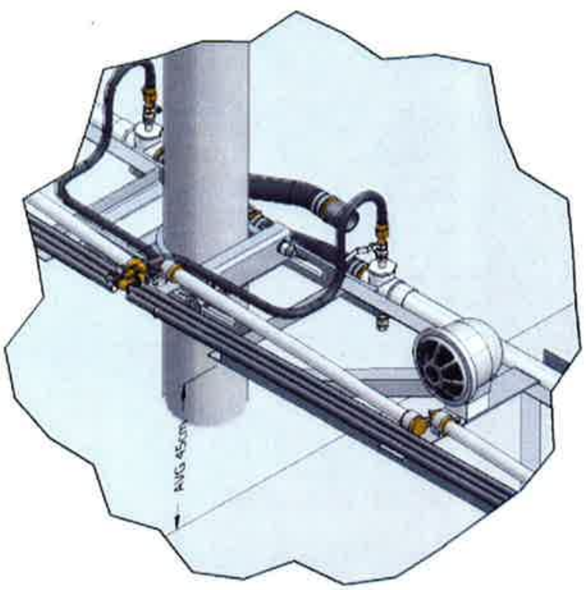

Figure 7. In this detailed drawing of the truss-style frame, with the BAFF components visible, the distance from the frame to the substrate is indicated as 45 cm. This was the space maintained between the BAFF components and the channel bottom along the entire 112 meters of the NPB

INSTALLATION

The NPB was installed beginning in early April 2009. The NPB was attached to four steel piles driven into the channel bed. Concrete piers were placed between piles to support the NPB and raise it off the channel bottom. The NPB truss framework was placed into the river by barge and crane using a steel pipe boom (Figure 8). Divers attached the frames to the piles and piers using u-bolts and nuts. Finally, power cables and air supply hoses were strung from the individual frames and routed back to equipment located on the south bank berm. The NPB was completed and ready (Figure 9) for the VAMP experiment that began on April 20, 2009.

Figure 8. Close-up of NPB assembled modular frames being installed

Figure 9. NPB in operation with bubbles breaking surface of river

EVALUATION

The effectiveness of the NPB was evaluated by field investigations in coordination with the VAMP participants. During the VAMP, conducted mid-April to mid-May, fish obtained from the Feather River hatchery were tagged with acoustic tags. Receivers were stationed along the out-migration path of the salmon at sites along the SJR and Old River. Data collected and analyzed will determine the effectiveness of the NPB and its future applications. The September 2009 draft Technical Memorandum prepared by Reclamation evaluating the NPB is attached. This document provides details to the summary that follows.

The monitoring of the NPB was conducted by Reclamation with the cooperation of the VAMP team. The VAMP team used acoustic telemetry to assess survival rate in several routes through the Sacramento-San Joaquin Delta.

The primary release point for the 2009 VAMP experiments was Durham Ferry, several miles upstream of the San Joaquin River-Old River Divergence. The Chinook smolts with acoustic transmitters that were released at Durham Ferry and survived to the Divergence were detected by an array of hydrophones deployed in the vicinity of the Divergence. These detections provided measures of efficiency of the NPB using BAFF technology to deter and protect salmon as the Chinook smolts passed through the Divergence area. Fish migrating down the San Joaquin River path are thought to be more likely to survive. Fish that are deterred by the NPB and remain in the San Joaquin River are, therefore, more likely to survive than fish that enter Old River. Chinook smolts that pass through the NPB undeterred are more likely to be exposed to increased predation due to a longer migratory path, greater number of agricultural diversions and possible entrainment into the Central Valley Project and State Water Project intakes that are located on Old River.

In addition to acoustic telemetry, another evaluation methodology was used. A Dual-frequency Identification Sonar (DIDSON) camera was deployed immediately upstream of the barrier. The DIDSON recorded images throughout the period after each VAMP release. These DIDSON recordings were used primarily to observe the behavior of fishes in the vicinity of the barrier and are not easily quantifiable.

METHOD

After installation of the NPB, Reclamation installed a Hydroacoustic Technology, Inc. (HTI) 4-hydrophone, 2-Dimensional (2D) tracking system followed by the DIDSON camera. All installations were completed before the first VAMP Chinook smolt release occurred on 4/23/09. With this equipment the fish study team was able to monitor the seven experimental releases of telemetered Chinook smolts by the VAMP team.

ACOUSTIC TELEMETRY TRACKING

The NPB was deployed in the San Joaquin River immediately upstream of Old River. To monitor the acoustic tags implanted in the juvenile Chinook salmon, the fish study team deployed 4 hydrophones (Figure 10) in an array to provide for 2D tracking in the vicinity of the NPB. Each hydrophone was connected by cable to the HTI 4-port receiver.

The acoustic tag tracking system consisted of acoustic tags implanted in fish, hydrophones deployed underwater, and an on-shore receiver and data storage computer. Each acoustic tag transmitted an underwater sound signal or acoustic "ping" that sent identification information about the tagged fish to hydrophones. The hydrophones were deployed at known locations within the array to maximize spacing of the hydrophones in two (or three) dimensions. For three dimensional tracking, tags must be received on at least four hydrophones; for two dimensional tracking, tags must be received on at least three hydrophones.

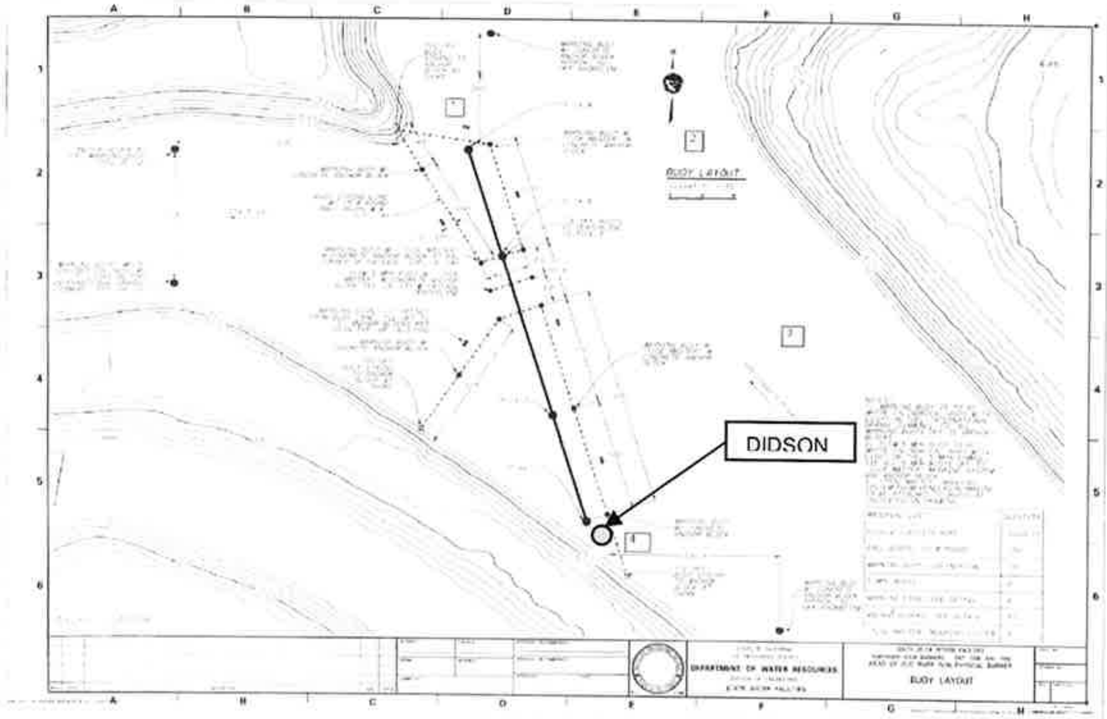

Figure 10. Divergence of Old River and San Joaquin River, CA. The bold black line indicates the NPB location. The red squares exhibit the locations of the four HTI hydrophones

DIDSON Observations

Reclamation deployed a DIDSON camera immediately upstream of the NPB. The camera was placed in the water near the shore and origin point of the NPB. The camera head was on a rotator and was 75 cm upstream of the NPB. The detection cone was aimed parallel to the NPB for recording.

Results

Predation Before and Near the Old River Barrier

For each release, Reclamation calculated the proportion of released fish that never appeared at the NPB area. In addition to fish that never appeared in the area, Reclamation also determined the number of fish that were eaten in the NPB area by inspecting every 2D trace for all 539 fish that appeared in the NPB area. The proportion that appeared and for which there was strong evidence of predation is found in Table 1. Table 1 also sums the predation before the NPB area and in the NPB area to find the total estimated predation proportion from Durham Ferry past the Divergence.

In addition to quantifying predation in the NPB area, Reclamation studied the behavior of predators at the site. Regular observation of the area upstream of Piles 1 and 2 with the DIDSON camera showed interesting behaviors. Striped bass could be identified with the DIDSON. These predators were in the 60-140 cm Total Length range and could be distinguished from sturgeon based on their silhouette. The striped bass would swim in looping patterns pursuing patrolling behavior throughout the NPB area. The striped bass would also swim along the NPB infrastructure. Another important difference between predators and smolts was their swimming speed. Generally, Reclamation found that predators swim more slowly than smolts.

Table 2. Mortality rate of Chinook smolts: 1) between Durham Ferry and the San Joaquin/Old River Divergence, 2) in the Divergence area, and 3) sum of predation (1 and 2) from Durham Ferry past the Divergence area.

Release	Number Released	Proportion Never Arrived at NPB	Proportion Consumed in NPB area	Total Dead Combined Proportion (before and in NPB area)
1	136	0.478	0.118	0.596
2	136	0.279	0.346	0.625
3	135	0.252	0.400	0.652
4	136	0.485	0.279	0.765
5	136	0.360	0.353	0.713
6	133	0.616	0.135	0.752
7	135	0.385	0.296	0.681

These extremely high predation rates before the NPB ranged from 25.2 to 61.6 percent for each release group of approximately 135 smolts led to low numbers of fish available to evaluate the NPB. In addition, the BAFF was operated approximately half the time with the barrier off and barrier on leading to lower sample sizes in each division. This pattern of operation however led to N=7 observations of deterrence efficiency with barrier off and seven with barrier on. This effectively doubled the sample size and considerably improved statistical power.

DISCUSSION

A highly statistically significant proportion of Chinook salmon were deterred by the BAFF. The deterrence rate was 81.4%. However, many smolts that were deterred by the BAFF were eaten by predators in the vicinity of the scour hole that was just downstream of the NPB on the San Joaquin River.

When the barrier was on, the percentage of smolts that continued past the NPB and the scour hole and proceeded down the San Joaquin River was 30.8%. When the barrier was off, the percentage of smolts that continued past the NPB and the scour hole and proceeded down the San Joaquin River was 24.5%. There was no statistical difference between these two sets of observations. So it appears that most smolts are deterred from entering the Old River but many of those are consumed by predators.

The 2D traces of acoustic tags suggest that much of the gains accomplished by the BAFF's determent of smolts is offset by the predators in the scour hole; many of the tag traces end in the scour hole. Reclamation recommends that if the BAFF is installed in the future that predator relocation be employed. Failure to do so could lead to a similar situation to that observed in 2009. That is, the highly efficient BAFF's deterrence may be offset by the heavy predation in the scour hole.

It is possible that the high 2009 predation rates observed were a function of the dry year in the San Joaquin River. Smolts and predators might have been concentrated into a smaller volume of water than in average or wet years. Such a concentration could result in higher encounter rates between predators and smolts leading to an increased predation rate.

Why does the barrier work for Chinook salmon? It is Reclamation's opinion that the sound deterred the fish and the bubble curtain contained the sound. The strobe lights enabled the fish to identify the source of the sound. The fish saw the barrier because of the strobe lights and they heard the sound as they approached the BAFF. The risk of passing through the barrier to an uncertain future was greater than the risk of swimming away and passing into a different uncertain future but avoiding the source of that sound.

2010 NPB Planning

Design/Installation

Preliminary planning for the 2010 NPB installation includes provision for an additional frame on the downstream end of the NPB that extends eastward toward the east bank of the San Joaquin River. This "kicker" frame is expected to help move smolts further away from the scour hole that was located near the end of the NPB during the 2009 installation. Reclamation's fish study indicated that the scour hole may be a significant source of predators, particularly striped bass, which took a large toll on the smolts that entered the NPB area. The 2010 NPB design may rely on heavy concrete piers to hold the frame structure in place instead of the four steel piles that were used in 2009. This would simplify the installation and reduce hazards to boat navigation at the site. Modifications to the electrical and air supply hoses and harnesses will be done to ensure easier assembly on the site and improved reliability and maintenance.

Fish Study

The 2010 fish study for the NPB is expected to be similar to the 2009 study and will be accomplished again by Reclamation. Reclamation is considering increasing the number of fish tagged for the releases to ensure a sufficient number of smolts reach the NPB area to improve the strength of the statistical analysis and findings. Additional tags and fish will need to be purchased and secured from the hatcheries. Also, more hydrophones are planned for locations necessary to determine the fate of smolts in the vicinity of the scour hole and further downstream.

PREDATION CONTROL

Based upon study observations using acoustic telemetry with hatchery Chinook smolts, predation control is recommended for 2010. Reclamation observed the non-physical barrier, NPB, had an extremely high efficiency with a mean of 81.4 percent of smolts deterred toward the San Joaquin River channel. Yet, the percentage of smolts that successfully continued down the San Joaquin River was only 30.8. Reclamation showed the proportion of the smolts consumed in the immediate vicinity of the San Joaquin/Old River Divergence ranged from 11.8 to 40.0% for the seven hatchery smolt releases, while acknowledging that these observed consumption rates may be higher for hatchery smolts than for naturally produced smolts. It appears there is considerable room for improvement of smolt survival through predator relocation/reduction; however Reclamation is unable to predict the amount of improvement possible because of too many sources of variation determining the smolt percentage continuing down the San Joaquin such as predator biomass, openness of the predator population, and predator-prey encounter rates.

The 2010 study is expected to be able to quantify the percentage of smolts consumed in the immediate vicinity of the Divergence as was done in 2009. Therefore, a contrast can be made between 2009 and 2010: 1) the percentage of telemetered smolts that successfully continued down the San Joaquin River in a year without predator relocation (2009) and a year with predator relocation (2010), 2) differences in size and origin of hatchery smolts, 3) differences in hydraulic conditions, 4) differences in water quality (e.g. turbidity) and 5) other factors as deemed necessary.

One method for predator relocation would involve the state agency responsible for fish management in the Delta, the California Department of Fish and Game (DFG). DFG could lead the predator relocation effort. The relocation effort could include at least four important components: 1) begin predator capture one week before the beginning of the NPB operation and continue through the last day of NPB operation, 2) capture as many striped bass and largemouth bass as possible, 3) maintain in net pens until sufficient to fill a transport truck, and 4) transport and release to a remote location from where they cannot return to the Divergence.