State of California
The California Natural Resources Agency
Department of Water Resources

Quantification of Pre-Screen Loss of Juvenile Steelhead in Clifton Court Forebay

March 2009

Arnold Schwarzenegger	Mike Chrisman	Lester Snow
Governor	Secretary	Director
State of California	California Natural Resources Agency	Department of Water Resources

State of California
The California Natural Resources Agency
Department of Water Resources

Quantification of Pre-Screen Loss of Juvenile Steelhead in Clifton Court Forebay

Prepared by:

Kevin W. Clark[1], Mark D. Bowen[2], Ryan B. Mayfield[3], Katherine P. Zehfuss[4], Justin D. Taplin[5], and Charles H. Hanson[6]

[1] *Bay-Delta Office/Fishery Improvements, California Department of Water Resources, 1416 9th Street, Sacramento, CA 95814, USA*
[2] *Fisheries and Wildlife Resources Group, US Bureau of Reclamation, P.O. Box 25007, 6th and Kipling, Bldg. 56, Denver, CO 80225, USA*
[3] *Bay Delta Region, California Department of Fish and Game, 4001 North Wilson Way, Stockton, CA 95205 USA*
[4] *Science Applications International Corporation, P.O. Box 25007, 6th and Kipling, Bldg. 56, Denver, CO 80225, USA*
[5] *Former Employee, Hanson Environmental, Inc., 132 Cottage Lane, Walnut Creek, CA 94595 USA*
[6] *Hanson Environmental, Inc., 132 Cottage Lane, Walnut Creek, CA 94595 USA*

Fishery Improvements Section
Bay-Delta Office
CA Department of Water Resources
1416 9th Street
Sacramento, CA 95814

In collaboration with:
National Marine Fisheries Service
Central Valley Fish Facilities Review Team
Interagency Ecological Program Management Team

Prepared under the supervision of

Zaffar Eusuff
Chief, Fishery Improvements Section

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ANOVA	Analysis of Variance
CHTR	Collection, Handling, Transport, Release
CIMIS	California Irrigation Management Information System
CPUE	Catch Per Unit Effort
CVFFRT	Central Valley Fish Facility Review Team
Delta	Sacramento-San Joaquin Delta
DFG	(California) Department of Fish and Game
DMR	Daily Movement Rate
DO	Dissolved Oxygen
DWR	(California) Department of Water Resources
EC	Electrical Conductivity
ESA	Endangered Species Act
FCCL	(UC Davis) Fish Conservation and Culture Laboratory
GPS	Global Positioning System
ID	Identification
MAP	Management Action Plan
MD	Maximum Hourly Sum of Detections
MR	Movement Rate
NMFS	National Marine Fisheries Service
No.	Number
OCAP	Operations Criteria and Plan
PAR	Photosynthetically Available Radiation
PIT	Passive Integrated Transponder
PST	Pacific Standard Time
SAIC	Science Application International Corporation
SFPF	John E. Skinner Delta Fish Protective Facility
SWP	State Water Project
TD	Total Number of Detections
TFCF	Tracy Fish Collection Facility
USFWS	United States Fish and Wildlife Service
UV	Ultraviolet
VAMP	Vernalis Adaptive Management Plan

This page intentionally left blank.

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.

This page intentionally left blank.

1.0 Introduction

Clifton Court Forebay (Figure 1) is operated as a regulating reservoir within the tidally influenced region of the Sacramento-San Joaquin Delta (Delta) to improve operations of the State Water Project (SWP) Harvey Banks Pumping Plant and water diversions to the California Aqueduct. The Forebay was created in 1969 by inundating a 8.9 km^2 (2,200 acre) tract of land approximately 4.2 km (2.6 miles) long and 3.4 km (2.1 miles) across (Kano, 1990).

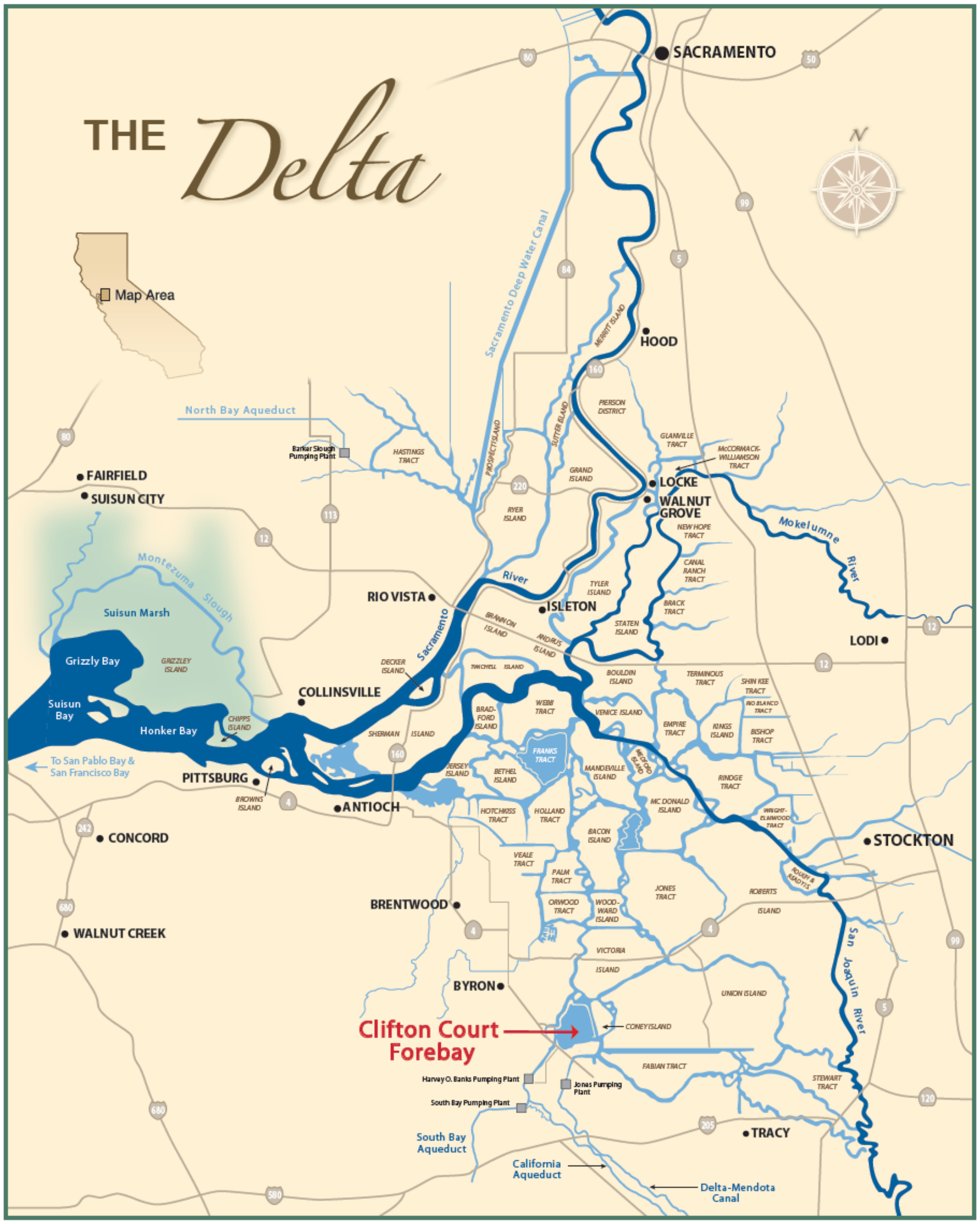

Figure 1. Location of Clifton Court Forebay in the Sacramento-San Joaquin Delta. (Source: DWR Graphic Services)

During high tide cycles when water elevation in Old River is greater than the water elevation in Clifton Court Forebay, water is diverted from the Delta into the Forebay via five radial gates (each 6.1m (20 ft) by 6.1 m (20 ft)) located in the southeast corner of the Forebay (Figure 2). Daily operation of the gates depends on scheduled water exports, tides, and storage availability within the Forebay (Le, 2004). Typically, diversions into the Forebay occur during the ebb stage of a tidal cycle (Kano, 1990) and only when a stage differential occurs between Old River and the Forebay. Water velocities passing through the gate openings typically approach 4.3 m/s (14 ft/s) at maximum stage differential. These high velocities have resulted in an approximately 18.3 m (60 ft) deep scour hole located immediately downstream of the radial gates, surrounded by a shallow shoal, revealed in recent bathymetry mapping (Figure 3).

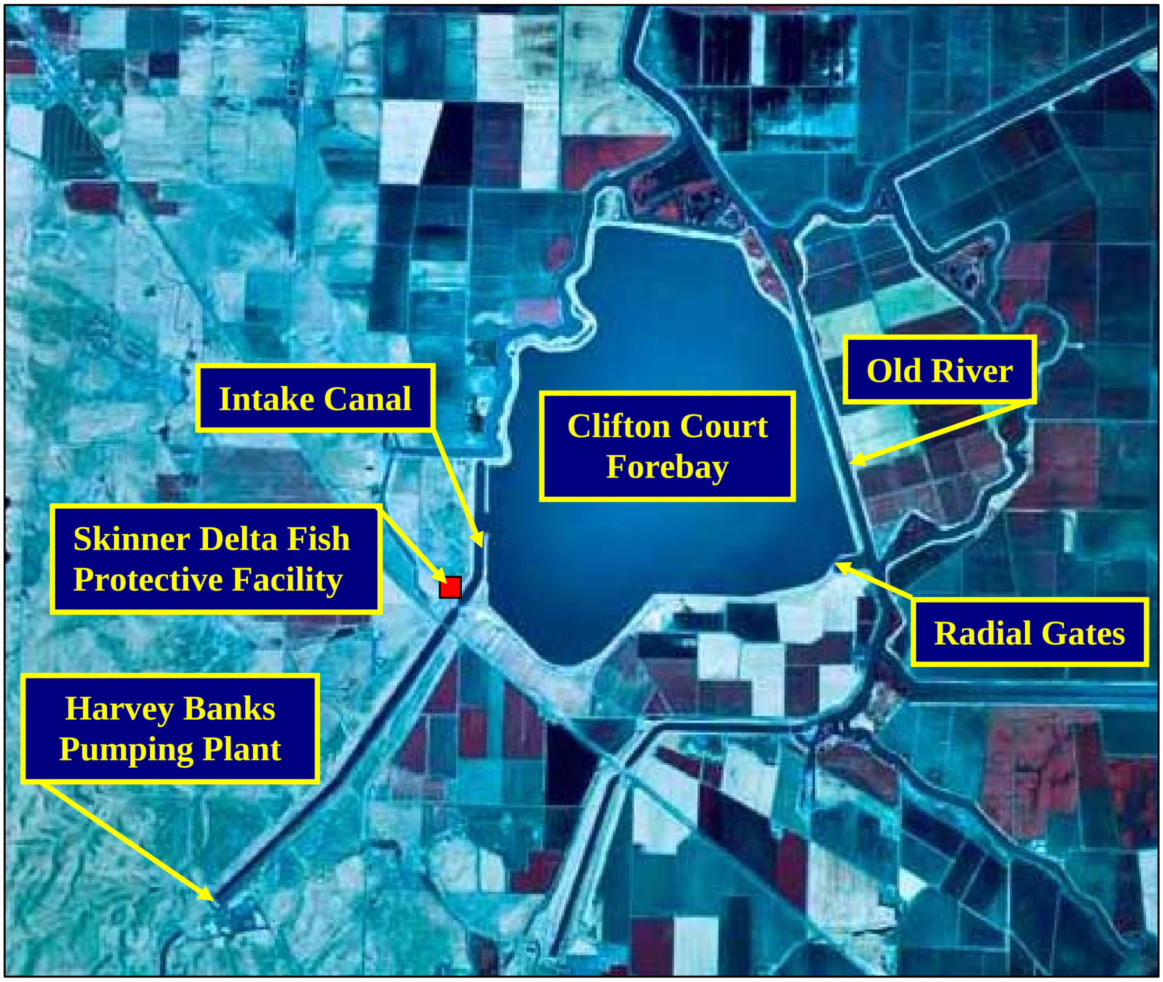

Figure 2. Aerial photograph of Clifton Court Forebay showing the locations of Old River, radial gates, intake canal, Harvey Banks Pumping Plant, and the John E. Skinner Delta Fish Protective Facility. (National High Altitude Photography courtesy of the United States Geological Survey)

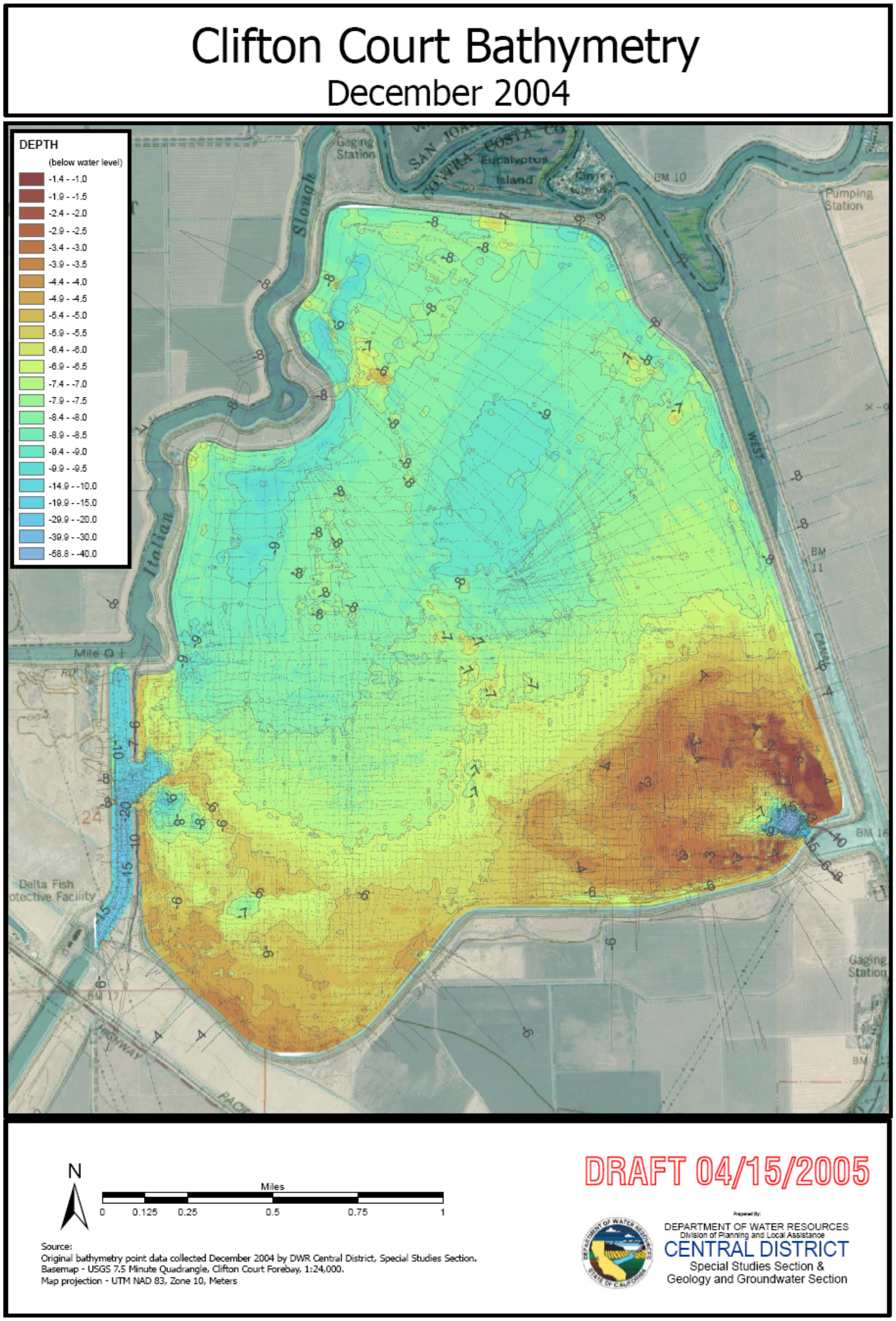

Figure 3. Clifton Court Forebay bathymetry map. (Source: DWR Central District)

Numerous fish, including Central Valley steelhead (*Oncorhynchus mykiss*), delta smelt (*Hypomesus transpacificus*), and Chinook salmon (*O. tshawytscha*), all of which have been listed under the California and/or Federal Endangered Species Acts (ESA), are entrained into the Forebay as water is diverted from Old River through the radial gates. Operation of the SWP, therefore, is necessarily performed in compliance with the terms and conditions of the National Marine Fisheries Service (NMFS) and United States Fish and Wildlife Service (USFWS) biological opinions and incidental take permits.

Fish entrained in the Forebay must make a minimum 3.4 km (2.1 mile) crossing of the Forebay before reaching the John E. Skinner Delta Fish Protective Facility (SFPF). The SFPF was designed to protect fish from entrainment into the California Aqueduct, and to safely return salvaged fish to the Delta. Water is drawn to the SFPF from Clifton Court Forebay through the intake canal (Figure 2) to a floating trashboom. The trashboom is designed to intercept floating debris and guide it to a trash conveyor on shore. Water and fish then flow through a trash rack, equipped with a trash rake, to a series of louvers arranged in a Vee pattern. Fish are "screened" via the louvers, kept in salvage holding tanks, and ultimately transported and released into the Delta.

Losses of fish during movement from the radial gates to the SFPF, termed pre-screen loss, include predation by fish and birds. A series of mark/recapture experiments (Table 1; cf. Gingras, 1997) were conducted by the California Department of Fish and Game (DFG) within Clifton Court Forebay between 1976 and 1993 to determine pre-screen loss of juvenile Chinook salmon and juvenile striped bass (*Morone saxatilis*). Of the 10 studies 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 as a function of the proportion of marked fish released at the radial gates and at the trashboom that were recaptured during salvage operations at the SFPF (Gingras, 1997). Proportions of recovered fish were adjusted for handling mortality, louver efficiency, and any sub-sampling at the facility. These studies showed the range of pre-screen juvenile Chinook salmon losses to be 63-99%. Striped bass pre-screen loss ranged from 70-94%. The high mortality rates have been largely attributed to predation by fish, particularly by adult and sub-adult striped bass (Gingras, 1997; Gingras and McGee, 1997), and birds. Kano (1990) and Brown and others (1995) have described pre-screen loss as synonymous with predation by striped bass.

Although predation of juvenile salmon and juvenile striped bass by predatory fish in the Forebay has been well documented (Kano, 1990; Brown and others, 1995), current literature lacks information on avian predation on fishes in the Forebay. Avian predation can be a source of significant mortality for juvenile salmonids. Birds have high metabolic rates and require large quantities of food relative to their body size (Ruggerone, 1986). Ruggerone estimated that 2% of the outmigrating salmonids on the lower Columbia River were lost to gulls. Various avian species are present within and around Clifton Court Forebay that could potentially prey on juvenile steelhead including: Great Blue Heron (*Ardea herodias*), Western Grebe (*Aechmophorus occidentalis*), Clark's Grebe (*Aechmophorus clarkia*), White Pelican (*Pelecanus erythrorhynchos*), Great Egret (*Ardea albus*), Double-crested Cormorant (*Phalacrocorax auritus*), and several species of gulls.

Table 1. Summary of pre-screen loss estimates within Clifton Court Forebay based upon mark-recapture experiments using juvenile Chinook salmon and striped bass.

Year-Month	Species	Pre-Screen Loss (%)	Mean Fork Length (mm)
1976-Oct	Salmon	97	114
1978-Oct	Salmon	88	87
1984-Apr	Salmon	63	79
1984-Jul	Striped bass	94	52
1985-Apr	Salmon	75	44
1986-Aug	Striped bass	70	55
1992-May	Salmon	99	77
1992-Dec	Salmon	78	121
1993-Apr	Salmon	95	66
1993-Nov	Salmon	99	117

Source: Gingras, M. 1997. Mark/recapture experiments at Clifton Court Forebay to estimate prescreening loss to juvenile fishes: 1976-1993.

Investigations have not been conducted to assess the potential predation mortality by fish and birds on juvenile steelhead within the Forebay. Since pre-screen loss within Clifton Court Forebay is included in the incidental take calculations for salvage losses of salmonids, the NMFS Operations Criteria and Plan (OCAP) biological opinion (2004) required investigations to (1) quantify predation losses (pre-screen loss) on juvenile steelhead within Clifton Court Forebay, and (2) identify potential management actions to reduce predation mortality of juvenile steelhead. The steelhead predation investigation is a pre-condition to the construction of the South Delta Improvements Program's permanent operable gates.

In response to the biological opinion requirements, the California Department of Water Resources (DWR) conducted a study over several years to evaluate steelhead predation mortality within the Forebay. A pilot-scale telemetry experiment using hatchery steelhead was conducted in April and May, 2005 to develop an understanding of the movement of juvenile steelhead through the Forebay and identify potential areas of increased vulnerability to predation mortality. Additionally, the 2005 pilot study was developed 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 steelhead survival study. Another pilot-scale telemetry study was conducted in March and April, 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. The full-scale mark-recapture and telemetry experiments were conducted December, 2006 – June, 2007 and were designed to meet the study objectives.

2.0 Objectives

In compliance with the requirements of the 2004 NMFS OCAP Biological Opinion, DWR designed and initiated an experimental field investigation to:

1. Evaluate predation losses (pre-screen loss) and the behavior/movement patterns of juvenile steelhead during passage through Clifton Court Forebay;

2. Evaluate behavior and movement patterns of adult striped bass which were identified as the primary predatory fish species that could potentially prey on juvenile steelhead within Clifton Court Forebay;

3. Identify physical locations and environmental and operational factors that contribute to increased vulnerability of juvenile steelhead to predation within the Forebay;

4. Determine the prevalence of avian predation within the Forebay; and

5. Develop quantitative estimates of pre-screen loss of juvenile steelhead within the Forebay.

3.0 Previous Studies

Gingras (1997) summarized the results of mark/recapture experiments conducted by DFG as part of the Interagency Ecological Program (IEP). These studies, conducted between 1976 and 1993, were designed to estimate pre-screen loss of juvenile Chinook salmon and juvenile striped bass entrained into Clifton Court Forebay. The average pre-screen loss of the three earliest studies was integrated into the Four-Pumps Agreement as mitigation for direct fish losses due to operation of the State Water Project. The following describes the previous pre-screen loss research conducted within Clifton Court Forebay.

Kano (1990) published data on the abundance of predatory fish inhabiting Clifton Court Forebay. This study, conducted between March 1983 and February 1984, provided important information on the composition and abundance of predatory fish within the Forebay that could contribute to pre-screen loss of juvenile fish entrained in the Forebay. White catfish and striped bass were found to be the two most abundant predators. The possibility of predation accounting for the loss of fish crossing the Forebay was strong due to the numbers of predatory fish observed inhabiting the Forebay.

Kano (1990) hypothesized that striped bass may impact losses of fish within the Forebay in two ways. First, striped bass schooling behavior may increase predation effects on fish. Schooled predators could increase the number of encounters between striped bass and fish entering the Forebay. The confusion resulting from schooled predators might also enhance predation success. Second, striped bass are highly mobile. Striped bass may track the sources of prey throughout the Delta, moving to the locations of highest prey availability.

Population abundance of striped bass fluctuated throughout the year with the lowest abundance occurring in early summer and highest abundance occurring in late fall (Kano, 1990). Levels of angler harvest and salvage of large fish by the SFPF were not high enough during the study to account for removal of significant numbers of striped bass. Emigration through the radial gates was hypothesized as a likely explanation for seasonal decreases in striped bass abundance. Before this study, fish emigrating from the Forebay were assumed to be prevented by the high water velocities passing through the radial gates. Velocities of less then 0.6 m/s (2.0 ft/s) were observed for short periods when the radial gates were open and suggested that flow through the gates may not act as a barrier to movement by larger fish during such times. Although fish emigrating through the radial gates was not monitored, anglers reported catching tagged striped bass from the study outside the Forebay. Recent studies utilizing radio and/or acoustic tagged adult striped bass have confirmed these earlier speculations. Gingras and McGee (1997) conducted telemetry studies using striped bass and documented emigration from Clifton Court Forebay through the radial gates. The implication that striped bass are not isolated from the rest of the Delta population complicates the task of regulating the population size of this species in the Forebay through traditional fisheries management techniques.

A number of studies were conducted between 1976 and 1993 to estimate predation losses of fish moving through Clifton Court Forebay. Studies evaluating predation losses of juvenile Chinook salmon within Clifton Court Forebay revealed pre-screen loss rates of 97% and 88% (Schaffter, 1978; Hall, 1980; cited in Kano, 1985). Kano (1985) conducted further studies to estimate pre-screen loss rates of juvenile Chinook salmon and juvenile striped bass within the Forebay. Survival of salmon from the radial gates to the trashboom was estimated at 37%. This evaluation was consistent with results of previous experiments conducted to determine pre-screen losses within Clifton Court Forebay. Pre-screen loss rate for juvenile Chinook salmon was estimated to be 63% between the radial gates and the SFPF trashboom. This pre-screen loss rate was lower than in previous studies (Schaffter, 1978; Hall, 1980). Kano (1985) conducted the study in the spring and used salmon that were smaller than the fish used in the earlier studies. The earlier studies were conducted in the fall. This seasonal difference was suggested as a major contributor to the difference in pre-screen loss rates.

In summarizing results of the mark/recapture studies conducted in Clifton Court Forebay, Gingras (1997) suggests there may be common biases throughout the studies due to the experimental methods used. Despite the biases, the results still identify predation as a major underlying mechanism that influences pre-screen loss rate. Tillman (1993a; cited in Gingras, 1997) suggests evaluating the relationship between pre-screen loss and factors such as experimental fish size, water export rate, water temperature, and predator-sized striped bass abundance in Clifton Court Forebay to better understand the mechanisms contributing to pre-screen loss in Clifton Court Forebay.

4.0 Regulatory Compliance

The experimental design was developed to avoid the potential take of listed species which resulted in minimal take of ESA-listed species. Hatchery steelhead were used as surrogates for wild steelhead and neither PIT tag nor acoustic telemetry monitoring required recapture sampling or modifications to the SFPF's normal fish salvage operations. However, the study intended to use a small number of wild juvenile steelhead (less than 20 individuals) to validate the telemetry results seen with hatchery steelhead. To properly address this issue, NMFS extended the ESA 4(d) research limit take exemption to include 20 wild steelhead potentially to be given to the pre-screen loss principle investigators. To facilitate the collection of these fish, DFG issued a Scientific Collecting Permit, which allowed for the collection of wild steelhead as bycatch through predator removal procedures of the secondary louvers at the Tracy Fish Collection Facility (TFCF). One wild steelhead was collected during a predator removal and was turned over to the DFG lead biologist. The take of this one wild steelhead was reported to DFG in an annual report and subsequently reported to NMFS. The wild steelhead had sustained a physical injury prior to collection and was held for treatment until succumbing to its injuries.

Another potential take issue of ESA-listed species was the use of gill nets and angling to acquire striped bass to be used for predator behavior studies. Incidental take for gill netting was covered through coordination and collaboration between the DFG lead biologist and NMFS. No ESA-listed species were taken during angling and/or gill net sampling.

Installation of the PIT tag detection systems at the SFPF salvage release sites required that the two sites be temporarily taken offline. Regulatory agencies require that the SFPF alternate fish releases between the two sites. Therefore, NMFS and DFG were contacted and the SFPF operators were given permission to release fish solely at one release site during the time the PIT tag detection system was installed at the second release site. Each site was taken offline for less than one work week. Releases resumed per normal operating procedures, once installation of the PIT tag detection system antennae was completed at both sites.

To conduct tagged steelhead releases immediately upstream of the radial gates, safety improvements to the site needed to be made. Uneven walkways, due to large rocks, and a slippery levee slope posed safety hazards for those conducting steelhead releases. DWR conducted a site survey and found no species of concern. DWR submitted a 1600 Notification of Streambed Alteration to DFG as gravel was proposed to fill in the uneven walkway and a concrete interlocking mat was proposed to alleviate the slipperiness of the levee. DFG reviewed the notification, conducted a site survey, and found it was not necessary to issue an agreement, therefore, DWR filed a Notification of Exemption with the State Clearinghouse. Safety improvements to the site were subsequently completed.

5.0 SWP Pumping and Radial Gate Operations

Clifton Court Forebay hydrodynamics can vary substantially within and among days depending on factors such as water export rates, radial gate operations, tidal conditions, weather conditions, and water storage within the Forebay. These variables, along with other physical factors such as debris, could affect salvage rates of fish at the SFPF. Harvey Banks Pumping Plant mean daily pumping (export) rates were variable in 2005, 2006, and 2007, ranging from approximately 0 to 226 m^3/s (0 to 8,000 cfs) (Figure 4). In all three study years, there was a marked decline in mean daily export rates beginning in mid to late-April with initiation of the Vernalis Adaptive Management Plan (VAMP). During May 2007, pumping was stopped for several days to protect delta smelt.

Flow rates and velocities of water entering the Forebay are regulated by operation of the five radial gates and export pumping rates. Gate operations are constrained by a scouring limit at the gates and south Delta water level concerns (Le, 2004). The radial gates are tidally operated with water flowing into the Forebay during high tide cycles when the water elevation in Old River is greater than the Forebay surface elevation. Flows were calculated using gate opening height and stage differential between Old River and the Forebay (Le, 2004). The water velocities for the intake channel leading to the radial gates, radial gate intake channel velocities, were calculated according to the equation $V_{ic}= Q/A$ where Q equals the calculated flow and A equals the area of the channel. The area of the channel was estimated from V and Q values published in the DWR Bulletin 200 (1974) where V_{ic} equals 0.9 m/s (3 ft/s) and Q equals 453 m^3/s (16,000 cfs). Therefore, the area of the channel was estimated at 495.5 m^2 (5,333 ft^2). The water velocities at the radial gate openings, radial gate water velocities, were calculated according to the equation $V_{rg}= Q/A$ where Q equals the calculated flow and A equals the sum of the areas of the radial gate openings. Because the radial gate water velocities are calculated from computed flows rather than measured flows, they should be treated as estimates.

Maximum hourly water flow, maximum hourly radial gate intake channel water velocities, and maximum hourly radial gate water velocities during the three study periods do not show much variation (Figure 5, 6, and 7). When the radial gates were open, the water flow into the Forebay typically averaged approximately 283 m^3/s (10,000 cfs) with typical maximum flows of approximately 425 m^3/s (15,000 cfs) (Figure 5). The fluctuation in flow and water velocity can be attributed to either changes in gate height operations or the change in differential head as the water surface elevations equalize between the Forebay and Old River. Historical data records show that there are times when the water surface elevations are almost equal and the gates are partially open, resulting in either very low flow into the Forebay or, at times, negative flow out of the Forebay and into Old River. As the radial gates are opened, water flow and water velocity rapidly increase and is dependent on the stage difference between the Forebay and Old River. As the water surface elevations begin to equalize, flow and water velocity decrease (Figure 8). However, the radial gates can be lowered or raised to change the amount of water flow and/or water velocity entering the Forebay. One extreme flow event occurred on April 16, 2007 with calculated flows approaching 600 m^3/s (21,200 cfs) (Figure 9). However, the spreadsheet developed to calculate water flow was not calibrated at high flows and thus may overestimate the true flow. Nonetheless, water flow through the gates was observed to be higher on April 16, 2007 than all other days during the study period.

Extremely high flow events, such as the one occurring on April 16, 2007, are rare and do not persist for long durations. After the first hour, the calculated flow during this event was greatly reduced as the radial gates were lowered from approximately 4 m (13 ft) to approximately 3 m (10 ft). Additionally, high water velocities through the radial gates did not always correspond with high flows. There were times during low flows when the radial gate water velocities were elevated due to relatively small gate openings (Figure 10).

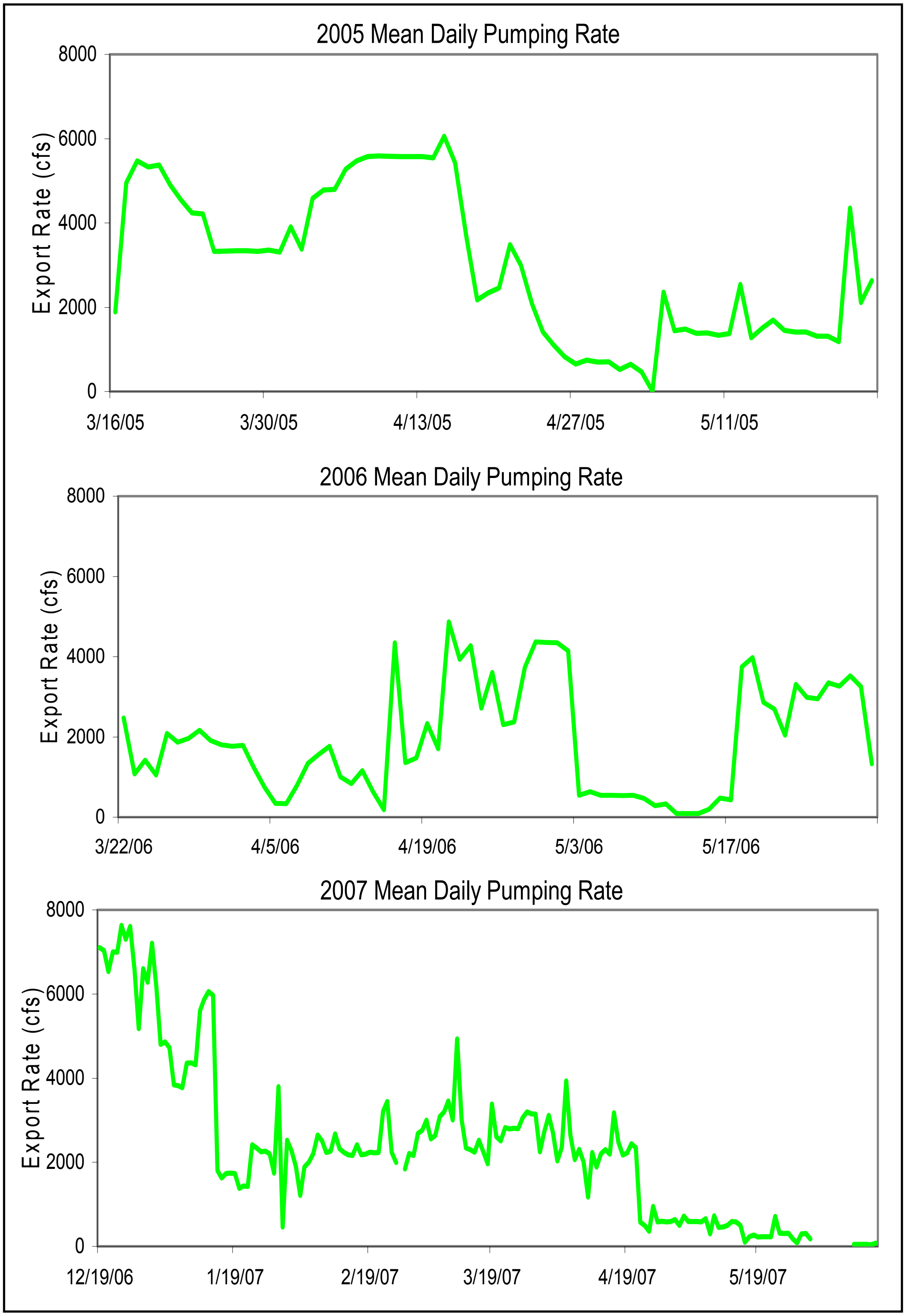

Figure 4. SWP mean daily export rates (cfs) during the 2005 and 2006 pilot studies and the 2007 full-scale study.

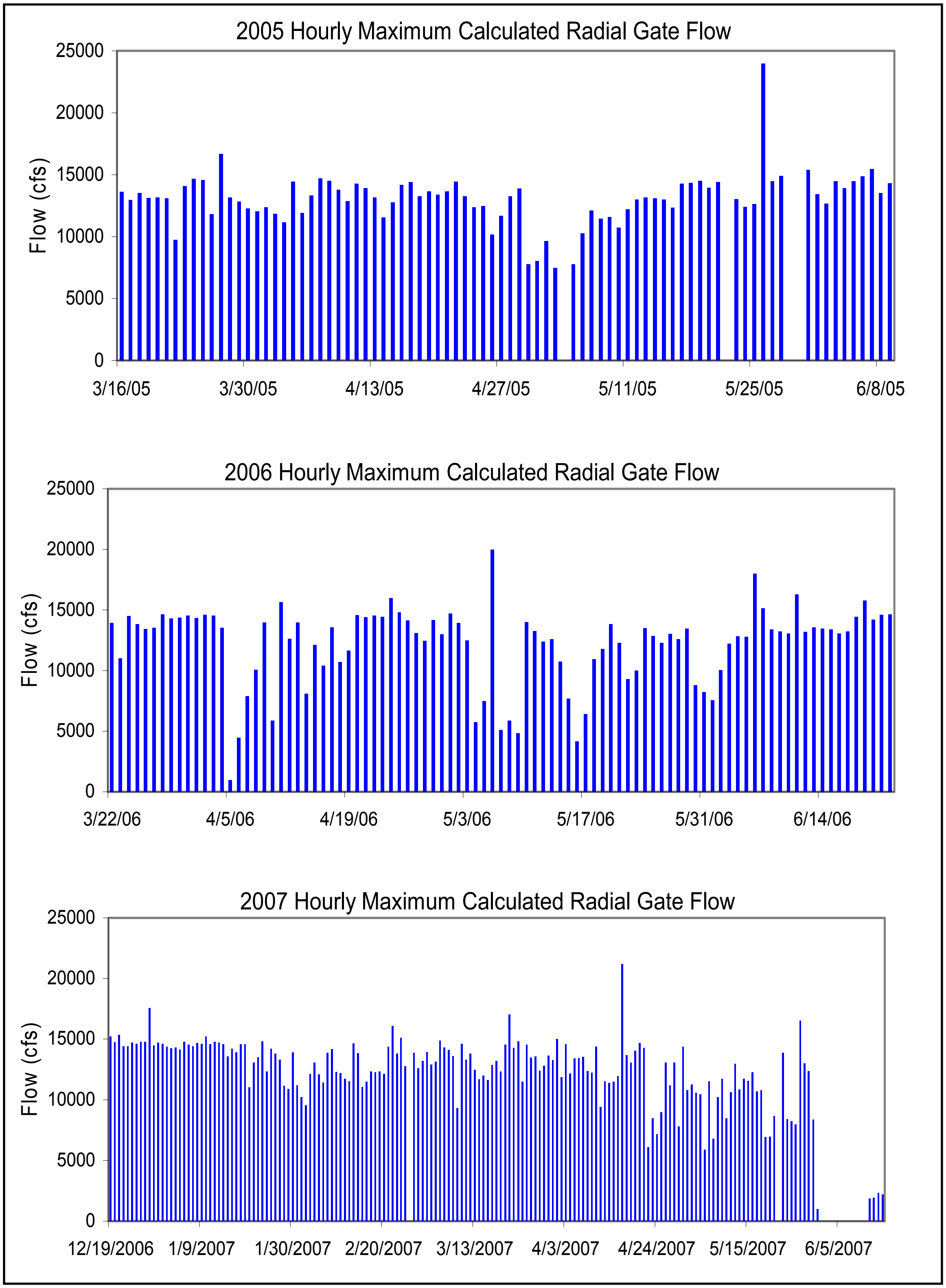

Figure 5. Estimated hourly maximum flow (cfs) at the radial gates during the 2005 and 2006 pilot studies and the 2007 full-scale study.

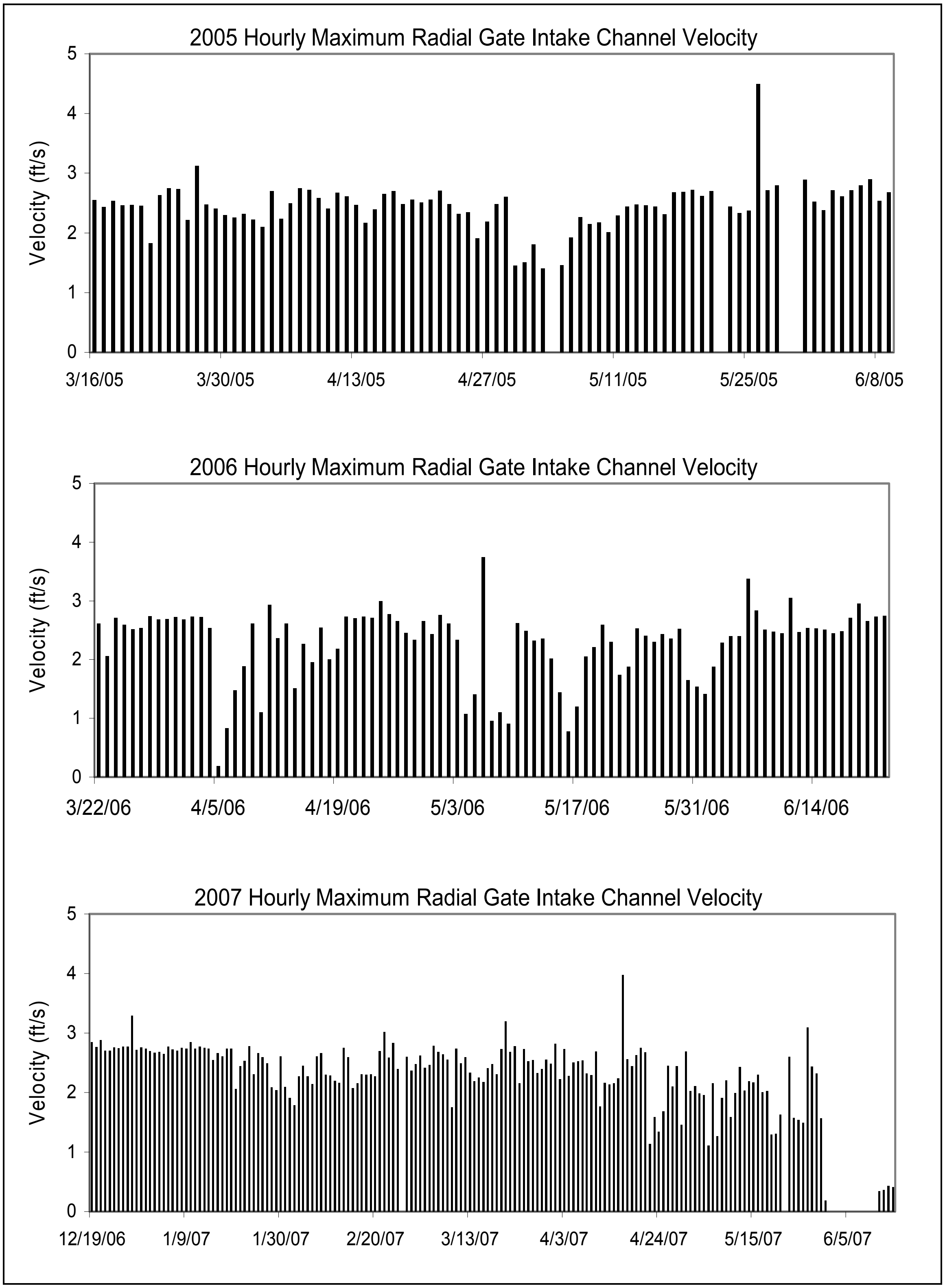

Figure 6. Estimated hourly maximum intake channel velocities (ft/s) directly upstream of the radial gates during the 2005 and 2006 pilot studies and the 2007 full-scale study.

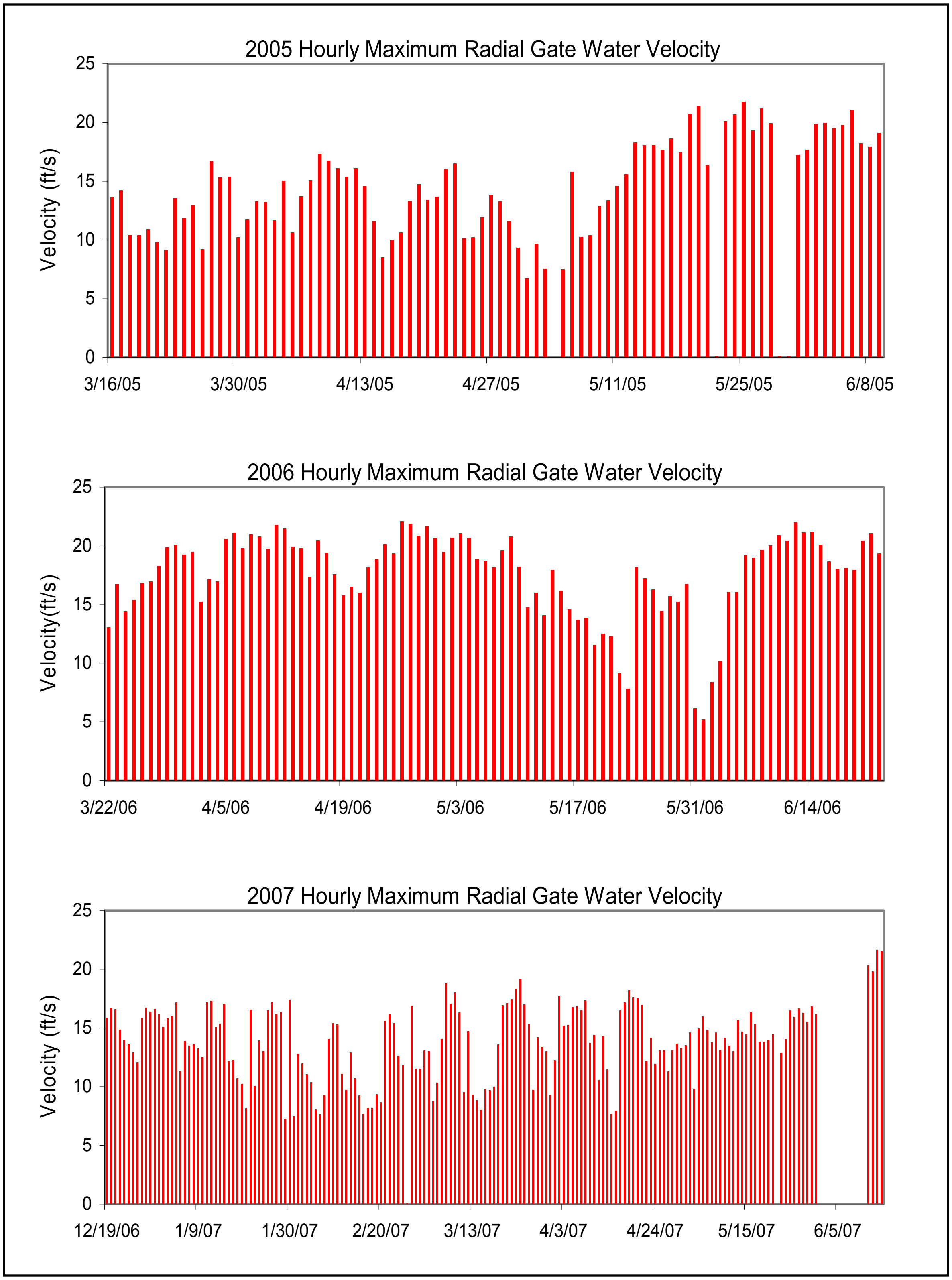

Figure 7. Estimated hourly maximum water velocity (ft/s) at the radial gates during 2005 and 2006 pilot studies and the 2007 full-scale study.

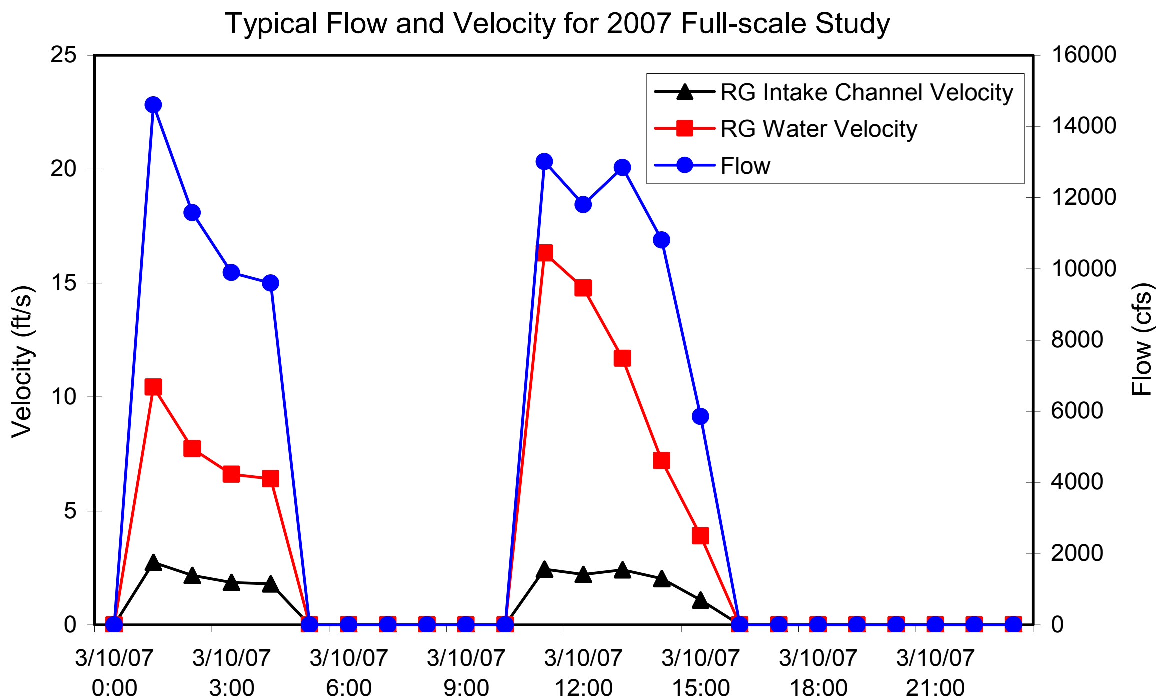

Figure 8. Flow (cfs) and velocity (ft/s) through the radial gates for a 24 hour period in 2007. The radial gates were open from 01:00 to 04:00 and from 11:00 to 15:00.

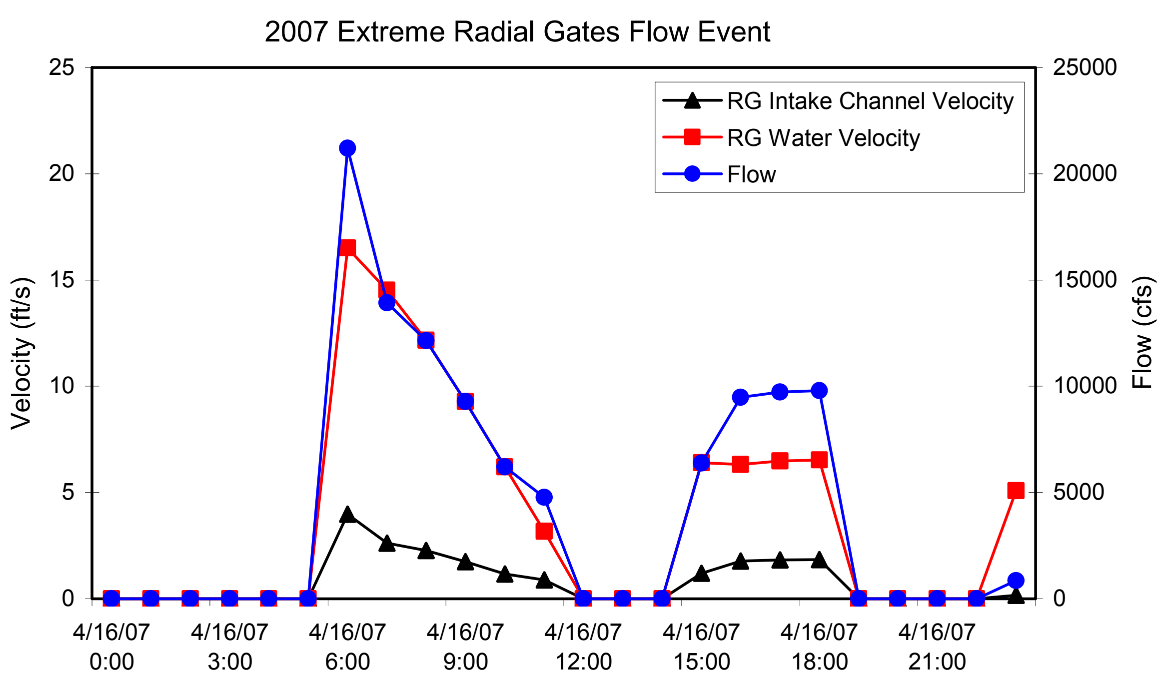

Figure 9. Radial gates extreme flow event April 16, 2007.

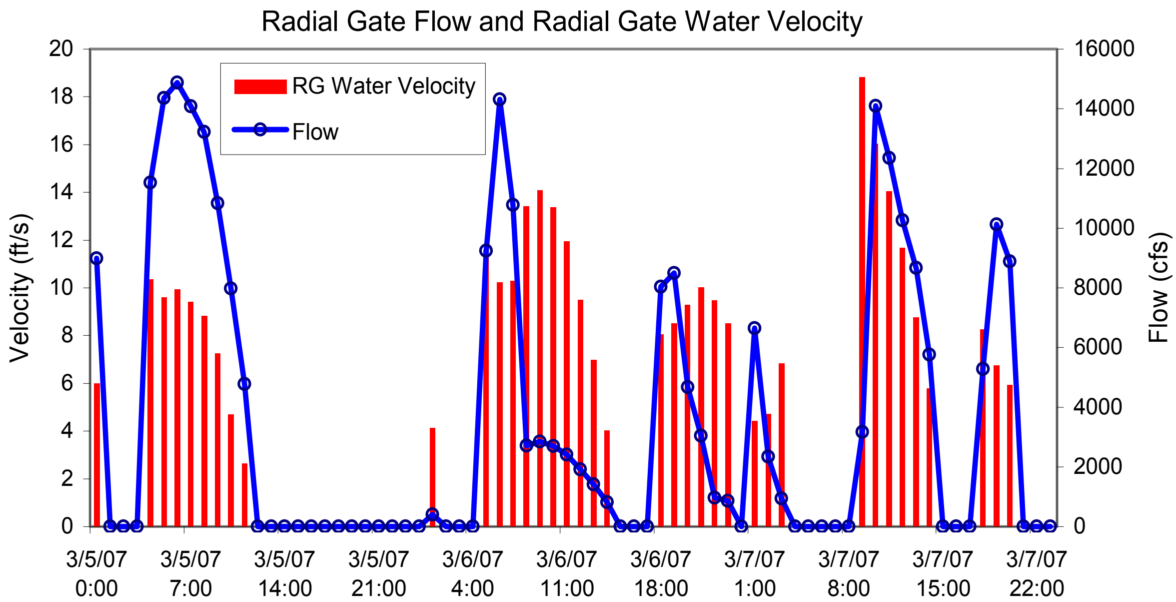

Figure 10. Radial gate flow (cfs) and radial gate water velocity (ft/s) for a 36 hour period during 2007.

6.0 2005 Pilot Study

6.1 Methods

A pilot-scale telemetry study was conducted April – May, 2005 to develop an understanding of the movement of juvenile steelhead through the Forebay and identify potential areas of increased vulnerability of steelhead to predation mortality. Additionally, the study was designed 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, steelhead survival study. To meet these objectives acoustic tags were utilized as steelhead and striped bass were tagged, released, and tracked within the Forebay.

6.1.1 Physical Parameters

Temperature was monitored at mid-depth using temperature recorders (Onset, model HOBO Water Temp Pro) from March to June, as water temperature may play an important role in the pre-screen loss of steelhead. Temperature recorders were deployed south-west of the radial gates approximately 61 m (200 ft) south of the southern wing wall within the Forebay and approximately 61 m (200 ft) upstream of the trash rack near the trashboom in the intake canal. Water temperatures at the radial gates and the intake canal increased from approximately 15 °C (59 °F) in March, 2005 to approximately 20 °C (68 °F) at the beginning of June, 2005 (Figure 11). Water temperatures monitored at the radial gates location increased to approximately 25 °C (77 °F) by the end of June (Figure 11). However, there was more variability in water temperature in the intake canal than at the radial gates. This difference in variability may be attributed to the surface area to volume relationship in the Forebay, bathymetry differences of the Forebay and intake canal, and/or variable pumping rates over time. Lethal water temperatures for steelhead have been reported to range between 21 to 24 °C (70 to 75 °F) (Nielsen and others, 1994; Coutant, 1970; cited in Richter and Kolmes, 2005). Therefore, lethal water temperatures for steelhead could have occurred in early June 2005.

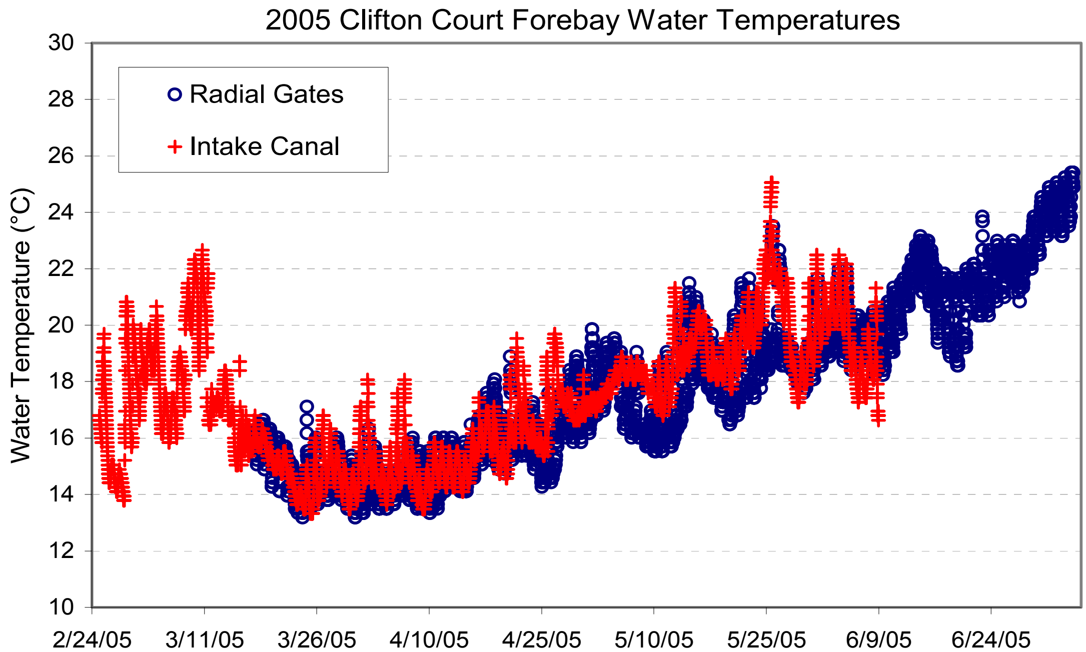

Figure 11. Water temperature (°C) at the radial gates and intake canal for the duration of the 2005 pilot study.

6.1.2 Acoustic Tagging of Striped Bass

Although a variety of predatory fish inhabit the Forebay, striped bass were thought to be the primary predatory fish species that could prey on juvenile steelhead because of their large size. The striped bass targeted for collection in 2005 were greater than 650 mm (26 in) in length. According to the literature (Walter and Austin, 2003; Manooch, 1973; Overton, 2002), this was near the lower size limit of striped bass capable of preying on juvenile steelhead 200 to 275 mm (7.8 to 10.8 in) in length. Walter and Austin (2003) reported that large striped bass consumed prey approaching 40% of their body length. This equaled the mean maximum forage length to striped bass length found by Manooch (1973). Overton (2002) predicted the optimal prey size to be 21% of the striped bass length. Manooch (1973) found that the mean forage length to striped bass length was 21%, but that striped bass are capable of eating fish approximately 60% of their total length. For purposes of the 2005 investigation we assumed a predator to prey length ratio of 30%.

In 2005, striped bass were captured by hook and line sampling in close proximity to the radial gates, trash rack, intake canal, and at various other locations throughout the Forebay. However, sampling effort at all locations was not equal, as the majority of the sampling effort was concentrated near the radial gates and within the intake canal. Water depth immediately adjacent to the radial gates ranged from approximately 18 m (60 ft) within the scour hole, with depth declining to approximately 1.5 m (5 ft) on the shoal surrounding the scour hole (Figure 3). There was a visually, well-defined velocity and turbulent zone around the gates and scour hole when the radial gates were open. The highest success for striped bass collection occurred around the perimeter of the scour hole and turbulent mixing zone either when the radial gates were open with water flowing into the Forebay, or within one hour of the gates closing. Only the striped bass captured near the radial gates met the 30% predator to prey length ratio and were of a sufficient size for inclusion in the 2005 pilot study.

Each striped bass captured that met the minimum size criterion was tagged with a coded acoustic transmitter (VEMCO, model V16) and released back into the Forebay. Each striped bass that was captured was transferred to an aerated holding tank onboard the sampling boat using a soft mesh dip net. Each fish was observed for signs of stress (loss of equilibrium). When the fish was no longer showing signs of stress from capture and handling, the fish was then transferred to a canvas cradle where the fish could be measured for length and tagged. External tagging of striped bass was similar to the method described by Chadwick (1963), Gray and Haynes (1979), and Gingras and McGee (1997). For respiration, a soft tube attached to a pump was used to irrigate the gills and was held in the mouth of the fish for the duration of the tag operation. No anesthesia was used. The acoustic tag, mounted on a soft rubber plate with thin stainless steel wire attachments, was externally attached by passing the wires through the body of the fish under the dorsal fin using hypodermic syringe needles. Another soft rubber plate was attached to the tag wires protruding through the fish to minimize tissue damage and irritation. The wires and tag were then secured in place by twisting the wires and trimming any excess (Figure 12). The tagged striped bass was placed back into the aerated tank and observed for signs of stress, then released into the Forebay at approximately the same location as capture. The external tagging operation lasted approximately four minutes per fish. The time, date, fish length, and Global Positioning System (GPS) coordinates were recorded for each striped bass captured, tagged, and released.

The size distribution for the 16 striped bass tagged as part of the 2005 pilot study ranged in total length from 625 to 940 mm (24.5 to 37 in) with a mean of 726 ±40 mm (28.6 ±1.6 in), Figure 13). Herein, all means are reported as mean ±95% Confidence Interval. One striped bass was tagged that was smaller than the minimum size requirement of 650 mm (26 in). Based on the length-weight relationship (Clark, 1938) for striped bass, the predators tagged and monitored during the 2005 pilot study ranged in size from 2,722 to 5,216 g (6.0 to 11.5 lb) with a mean of 3,799 g (8.4 lb) and ranged in age from 6 to 10 years old. Ideally, tag to body weight ratio should be approximately 2% or less to avoid impairing the swimming ability and behavior of the fish (Winter, 1983; 1996; Nielson, 1992; and Brown and others, 1999). The tag to body weight ratio was below 0.40% for all tagged striped bass during the 2005 pilot study.

Figure 12. Striped bass captured, externally tagged, and released in 2005.

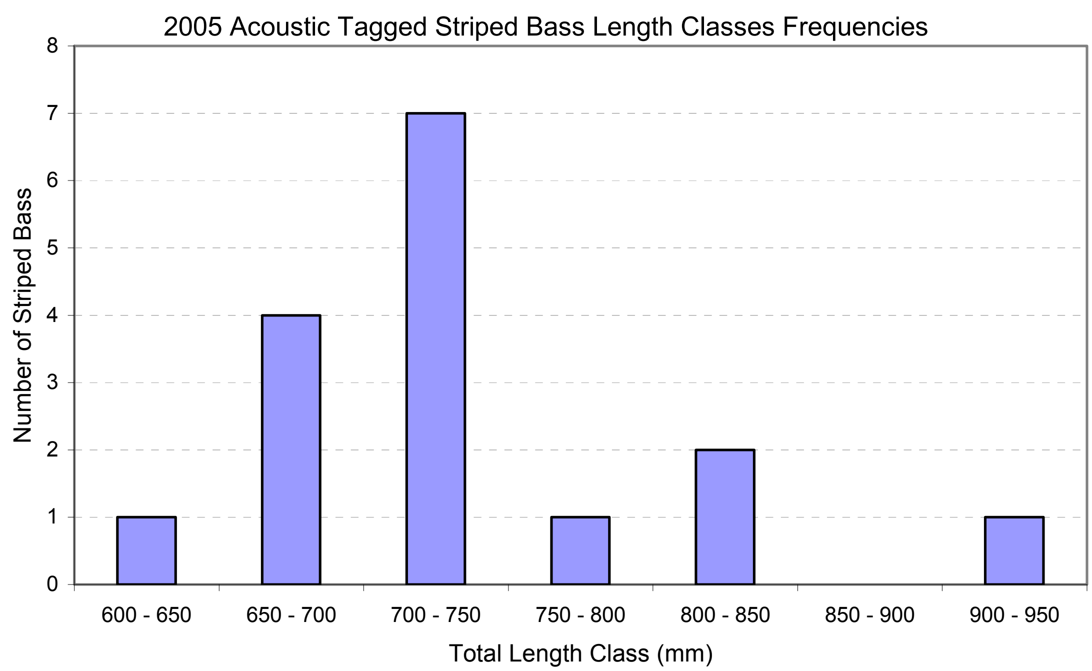

Figure 13. Externally tagged striped bass size class frequencies, for fish captured and tagged March 16 through March 18, 2005.

6.1.3 Acoustic Tagging of Steelhead

To determine the timing and size of steelhead entrained in the Forebay SFPF salvage data (DFG, 2008) was examined. SFPF salvage data shows that juvenile steelhead are present in the fish salvage from January to June, with peak abundance observed during February (Figures 14 and 15). Juvenile steelhead observed in the SFPF salvage typically range in length from approximately 200 to 300 mm (7.9 to 11.8 in) (Figure 16). The steelhead used in this study were representative of the general size distribution of juvenile steelhead entrained into the Forebay and recorded in the salvage data. The 30 juvenile steelhead selected for surgical implantation of acoustic tags ranged in total length from 221 to 275 mm (8.7 to 10.8 in) with a mean of 245 ±5 mm (9.6 ±0.2 in).

Juvenile steelhead used in the 2005 pilot study were obtained from the Mokelumne River Fish Hatchery and used as surrogates for wild fish. These juvenile steelhead were transported from the hatchery and held at the UC Davis Fish Conservation Culture Lab (FCCL) and the Collection, Handling, Transport and Release (CHTR) Study Facility (adjacent to the Forebay) for a one-week period to recover from transportation and handling stress and to acclimate to water quality conditions at the site. Thirty juvenile steelhead were tagged with acoustic coded transmitters (VEMCO, model V8SC) and released into the Forebay during April to coincide with the seasonal period that steelhead have been observed in the SFPF salvage.

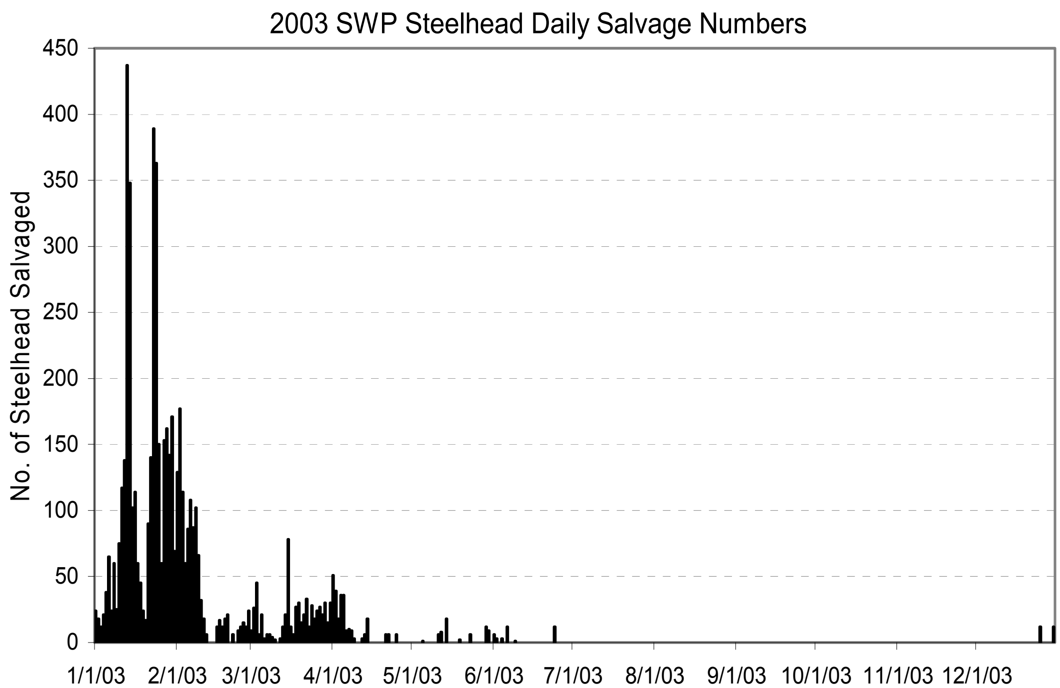

Figure 14. Steelhead salvaged at the SFPF, 2003.

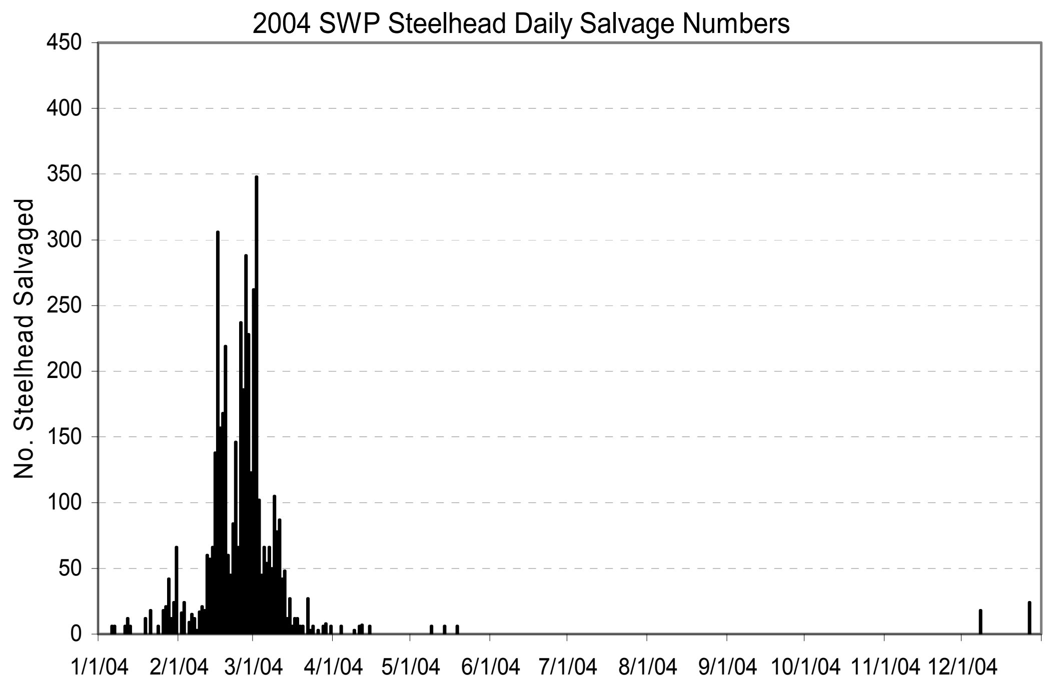

Figure 15. Steelhead salvaged at the SFPF, 2004.

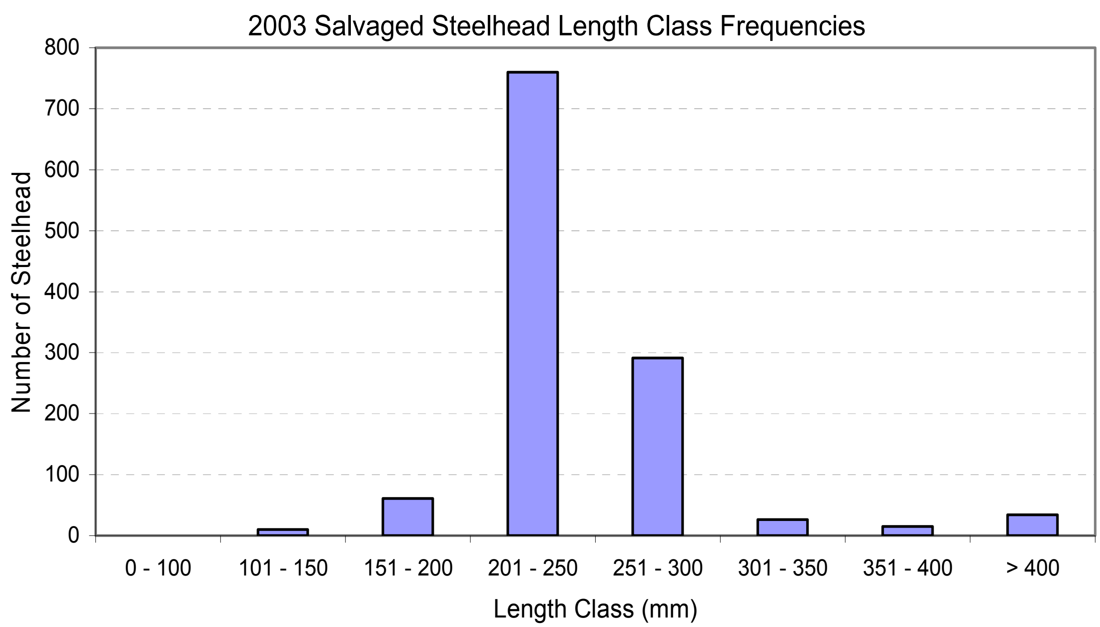

Figure 16. Length class frequencies for steelhead salvaged at the SFPF, 2003.

Surgical implantation of the acoustic tags took place between March 22 and April 5 according to the following procedure. Each juvenile steelhead was netted from the holding tank and measured for length and a sub-sample of steelhead was weighed. After measurement each steelhead was placed in a 18.9 L (5 gal) bucket that contained 106 mg/L (0.014 oz/gal) of MS-222. The juvenile steelhead was left in the bucket for approximately one minute until anesthetized. At this point the juvenile steelhead was placed into a holding cradle treated with Stress Coat®. Handling of the fish causes damage to the slime coat of the fish and Stress Coat® replaces the fish's natural slime coat with a synthetic one, thereby reducing stress. The gills were irrigated with water containing 53 mg/L (0.007 oz/gal) of MS-222 through a soft rubber tube to maintain anesthesia during surgery. The incision area near the posterior end of the abdominal cavity was swabbed with a Betadine Solution containing 10% povidone-iodine and a 25 mm incision was made along the linea alba immediately posterior to the pelvic fins. Antibiotic solution, containing oxytetracycline, was injected into the incision to avoid infection and the acoustic tag, coated in beeswax to slow rates of foreign body rejection, was inserted into the abdominal cavity. The incision was then closed with three to five synthetic absorbable sutures and the suture area was treated with a povidone-iodine ointment. During insertion of the last suture the gill irrigation water supply was switched from the MS-222 maintenance solution to fresh water to begin the recovery process. Once the surgical procedure was completed the juvenile steelhead was moved to a recovery bucket and then transferred to the holding tank for observation and recovery. The total surgical procedure took approximately four minutes in duration from initial measurement through recovery. A new pair of sterile surgical gloves and a new, sterile scalpel blade were used during each surgery to minimize infection and cross contamination. All instruments were kept in cold sterile solution. After surgery the tagged juvenile steelhead were observed in the holding tank for a minimum of two days to ensure recovery and suture stability prior to experimental release.

Just prior to tagging, a sub-sample of steelhead (7 of the 30 tagged fish) was weighed using a digital scale to estimate the tag percentage of body weight. The tag percentage of body weight for the sub-sample ranged from 1.94% to 2.73% with a mean of 2.18% ± 0.24%. It has been suggested in the literature that fish should not be tagged with transmitters that weigh more than 2% of the fish's body weight (Winter, 1983; 1996; Nielson 1992; Brown, and others 1999). The tag percentage of body weight was slightly higher than the suggested 2%. However, Brown and others (1999) found that swimming performance in juvenile rainbow trout was not affected by transmitters weighing up to 12% of the body weight. Also, Anglea and others (2004) found that juvenile Chinook salmon tagged with transmitters weighing up to 6.7% of the fish's body weight were not affected in terms of swimming performance or predation susceptibility.

6.1.4 Steelhead Surgical Procedure Control Group

To monitor the long-term effects of surgical implantation of acoustic tags on fish mortality, a group of 10 steelhead was surgically implanted with dummy acoustic tags and observed over a 30 day period. These steelhead were tagged following the same procedures as the steelhead tagged for release into the Forebay, described above. Also, a group of 10 steelhead randomly selected from the holding tank were kept as a control group for observation of long-term mortality. The 10 juvenile steelhead implanted with dummy tags and the 10 juvenile steelhead selected as a control group were kept in two separate aerated holding tanks and fed twice daily. Both groups were observed to have no mortality after a 30 day observation period. The control group experienced no mortality after a 46 day observation period at which point observations were ceased.

6.1.5 Acoustic Tagged Steelhead Releases

The live-car, shown in Figure 17, was constructed of aluminum perforated plate and steel tubing with a volume of 0.25 m^3 (9 ft^3) and was specially designed to release steelhead upstream of the radial gates. Prior to acoustic tagged juvenile steelhead release, the live-car was tested for potentially adverse effects. These adverse effects could include degradation of water quality associated with low flow through the live-car and/or overcrowding. During the tests, the live-car was placed in the radial gate intake canal and anchored to the shore allowing it to float naturally in the water via two boat bumpers. Ten juvenile steelhead with surgically implanted dummy tags were placed in the live-car and two water quality parameters were monitored over a 3 hr period. Dissolved oxygen and temperature were measured inside and outside the live-car to test for a significant reduction of water quality that would potentially stress steelhead during a pre-release acclimation period. No significant reduction in water quality within the live-car was detected for a 3 hr period with 10 tagged steelhead housed within the live-car (Table 2). Thus, the live-car was used to conduct all steelhead releases in 2005.

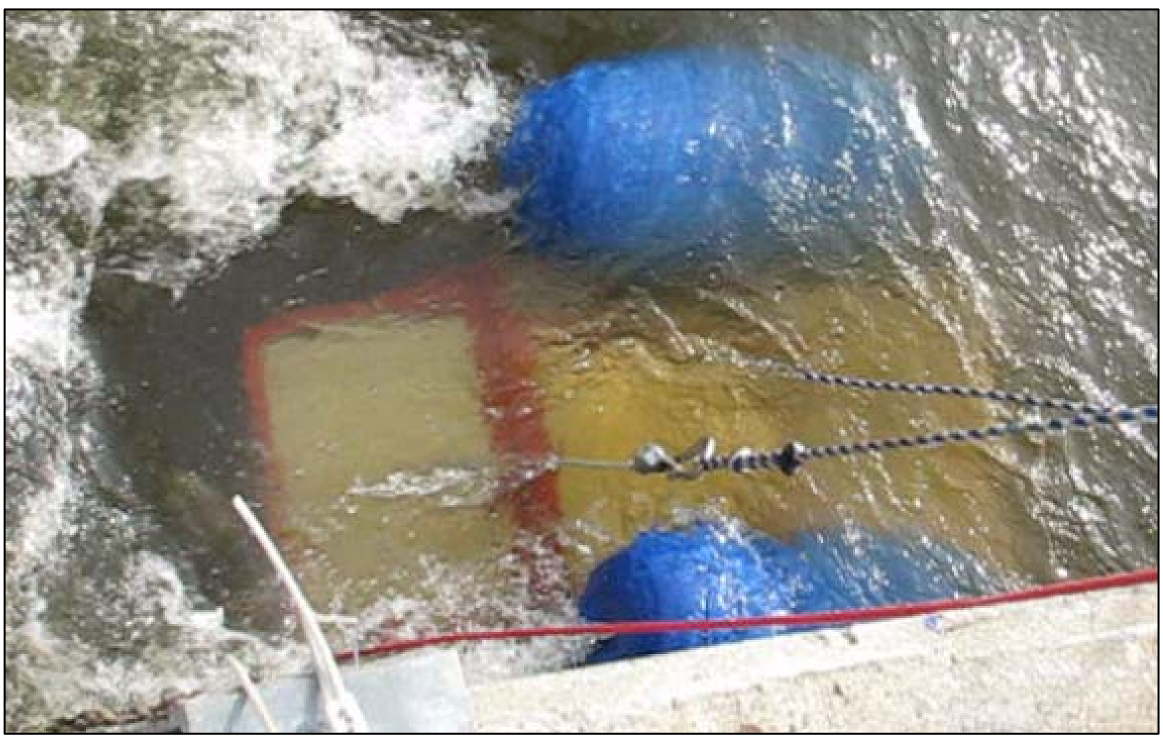

Figure 17. Release of tagged steelhead immediately upstream of the radial gates using the live-car. Two blue floats were attached to the live-car and used to float the live-car into position directly upstream of the radial gates.

Table 2. Live-car water quality conditions compared to ambient radial gate intake water quality conditions over time.

Live-car Water Quality			Radial Gate Intake Water Quality			
			Surface		Bottom	
Time	DO (mg/l)	Temp (°C)	DO (mg/l)	Temp (°C)	DO (mg/l)	Temp (°C)
1230	8.47	14.93	8.25	14.92	8.45	14.81
1330	8.24	15.03	8.42	15.07	8.37	14.88
1530	8.74	15.73	9.09	15.72	9.26	15.67

The 30 acoustic tagged juvenile steelhead were released immediately upstream of the radial gates over three days in groups of 10 fish each. Each group of 10 tagged steelhead was transported in an aerated tank to the release site. The acoustic tags were monitored to ensure correct operation using a mobile monitoring unit (VEMCO, model VR60) and the tag ID numbers for each release group were recorded. The group of 10 tagged steelhead was loaded into the live-car while the live-car was floating in Old River outside the Forebay. The live-car was positioned against the wing wall leading to radial gate number one and gate one was closed during the steelhead acclimation period. Prior to release, the tagged steelhead were acclimated in the live-car for a minimum of 2 hr to recover from transportation and handling stress. Once the acclimation period was complete, radial gate number one was opened. Once open, the downstream door of the live-car was released via remote cable. This allowed the tagged steelhead to exit the live-car into the flow passing through the radial gates from the velocity refuge of the live-car. After 10 minutes, the upstream door of the live-car was triggered to open and flush any remaining steelhead into the flow for entrainment into the Forebay. Releases of acoustic tagged steelhead via the live-car were conducted between April 5 and 7 with acclimation occurring from 06:30 to 08:15.

6.1.6 Fixed Station Receiver Grid

A network of fixed-station receivers (Vemco, model VR2) was placed throughout the Forebay to track the movement of tagged predator (striped bass) and prey (juvenile steelhead) within the Forebay, SFPF, Old River, and the intake canal leading to Harvey Banks Pumping Plant (Figure 18). The receiver array was installed in early March 2005 before either tagged striped bass or juvenile steelhead were released into the Forebay.

The VR2 is a submersible, multi-channel acoustic receiver capable of identifying VEMCO coded transmitters. The VR2 records the code number and date/time of each valid acoustic tag detection. This information is stored in memory until downloaded from the receiver using a VR PC interface and a computer running VR2PC software. The fixed station receivers were attached to a mooring line with the use of cable ties and kept in an upright position submerged completely in the water column between a mooring anchor and a float.

The fixed station receiver array was designed to achieve the following objectives:

1. Track steelhead movement patterns and transit times across the Forebay after entrainment through the radial gates;

2. Track steelhead movement through the intake canal to the trashboom and from the trashboom to the SFPF salvage holding tanks;
3. Track striped bass movement patterns and transit times in the Forebay;
4. Track striped bass accumulations within the Forebay;
5. Track potential emigration of steelhead and striped bass from Clifton Court Forebay into either Old River, through the radial gates, or into the Harvey Banks Pumping Plant intake canal through the primary louvers.

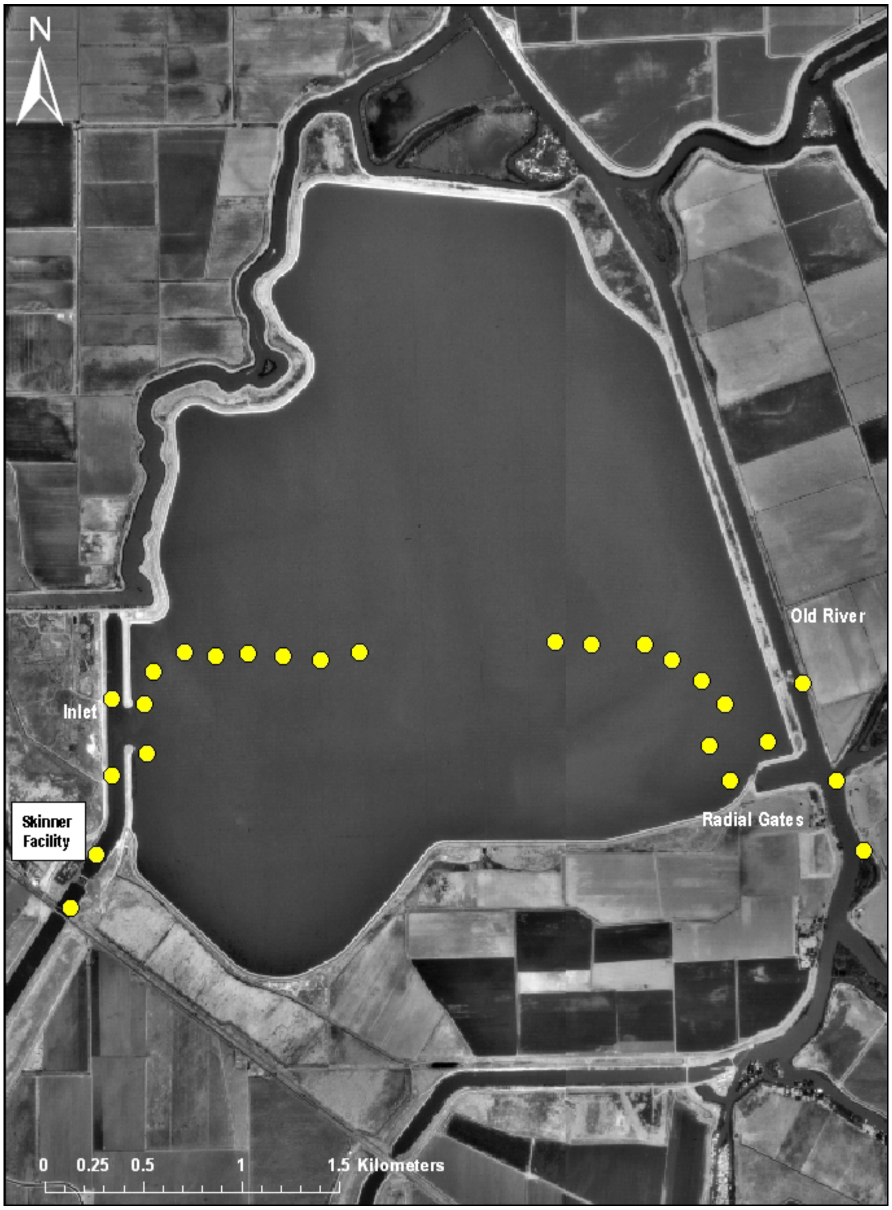

Figure 18. Fixed station receiver (29 total) locations within Clifton Court Forebay and Old River during the 2005 pilot study. The four receivers located within the SFPF are not shown. Locations of the receivers are indicated by yellow circles.

6.1.7 Mobile Monitoring

Mobile monitoring of acoustic tagged striped bass and juvenile steelhead was conducted within the Forebay to track fish movement patterns. The mobile monitoring transect patterns covered the areas of the Forebay outside the detection range of the fixed station receiver array (Figure 19). Mobile monitoring was also conducted along an additional transect between the trashboom and the radial gates (Figure 19). The data collected from the radial gates transect was used to validate the monitoring process by ensuring that both systems of data collection, fixed and mobile, recorded similar telemetry data when occurring simultaneously.

Mobile monitoring was conducted during the daylight hours on an almost daily basis from March 15 through April 30. Mobile monitoring was conducted from a boat within the Forebay using a handheld GPS unit (Garmin, model GPS 12) and a mobile monitoring unit (VEMCO, model VR60) equipped with an omni-directional hydrophone. The mobile monitoring was conducted following the transect patterns outlined in Figure 19 on a rotational daily basis (i.e. one portion of the Forebay was covered each day). Using GPS reference points and land based reference points, the transect pattern was traveled using the research boat. Approximately every 61 m (200 ft), the boat was fully stopped and the engines switched off to avoid signal contamination from noise and cavitation. The omni-directional hydrophone was submerged to a depth of approximately 0.9 m (3 ft) and left for tag detection for three to four minutes. Any coded tag detections received on the mobile monitoring unit were recorded onto data sheets identifying time, date, tag ID number, fish species, and GPS coordinates, with the approximate position within the Forebay marked on a field guide map. Also noted on the data sheets were the positions of the radial gates (open or closed) when possible.

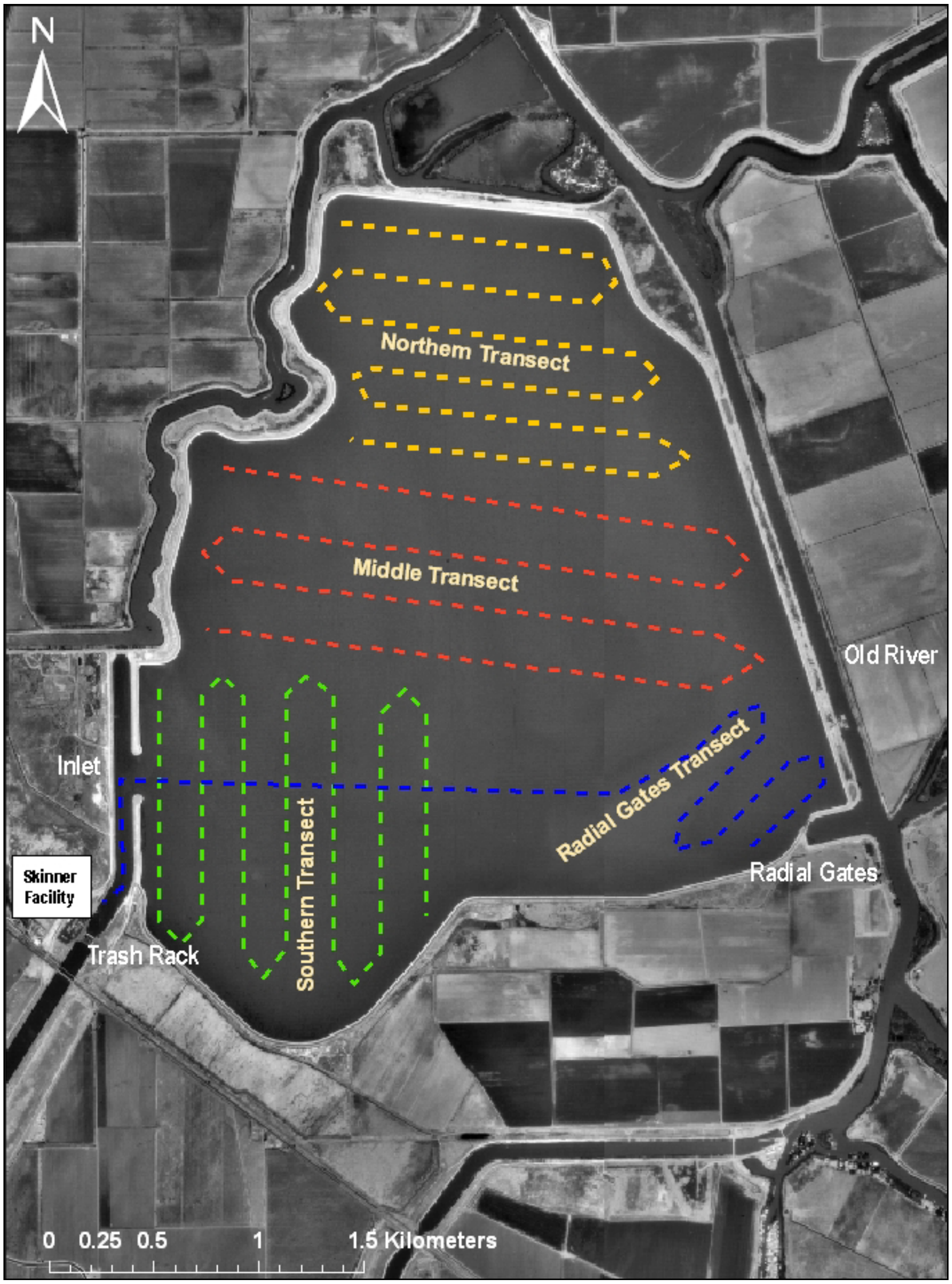

Figure 19. Mobile monitoring transect patterns for monitoring fish movement within the southern (green), northern (yellow), and middle (red) portion of the Forebay in 2005. An additional transect pattern (blue) was located near the radial gates.

6.1.8 Tag Signal Interference Testing

Testing was conducted to determine if the louvers of the SFPF interfere with the detection of a juvenile steelhead acoustic tag by a fixed station receiver. Tests were performed in July 2005 over two days. Weather conditions were similar for both days: sunny, air temperature above 38 °C (100°F), and winds out of the West at approximately

16 km (10 mph). The pumping rate for both tag signal interference testing days was identical at 234.6 m^3/s (8,285 cfs).

A fixed station receiver (VEMCO, model VR2) was placed downstream from the SFPF louvers, fastened to the railroad bridge, and submerged in approximately 6 m (20 ft) of water. The receiver was fastened at a location approximately 1 m (3 ft) from the bottom of the channel. An acoustic tag (VEMCO, model V8SC) was prepared for use as a mobile control tag. It was wrapped in netting with a 907 g (2 lb) weight with rope secured to the netting and a float placed on the rope approximately 1.5 m (5 ft) from the tag.

On day one of the tag signal interference testing, an acoustic tag was lowered into the water for approximately 10 minutes, followed by five minute intervals before the next reading. Within a 2 hr period, data from the following seven locations were collected: upstream of the trashboom, upstream of the trash rack, inside louver bay 1, inside louver bay 2, inside louver bay 3, inside louver bay 4, and the foot bridge immediately downstream from the louvers (Figure 20).

On day two of the tag signal interference testing, an acoustic tag was lowered into the water at the same starting location. The tag was lowered into the water for approximately 10 minutes, followed by five minute intervals before the next reading. Within a 2 hr period, data from the following seven locations were also collected: inside louver bay 1, outside louver bay 1, inside louver bay 2, outside louver bay 2, inside louver bay 3, outside louver bay 3, and the foot bridge immediately down stream from the louvers (Figure 20).

Figure 20. Acoustic tag signal interference testing positions within the SFPF louvers. The acoustic tag (VEMCO, model V8SC) was lowered into the water at the trashboom, at the trash rack, inside the louver bays (L1, L2, L3, L4), outside the louver bays (OL1, OL2, OL3), and at the foot bridge.

6.2 2005 Results and Discussions

6.2.1 Tag Signal Interference Testing Within the SFPF

Results from the tag signal interference testing demonstrated that the fixed station receiver, located at the railroad bridge downstream of the louvers, could not detect the acoustic tag within the SFPF. When the acoustic tag was lowered outside the louvers or off of the footbridge, the fixed station receiver detected a signal. At no other locations did the receiver detect the acoustic tag. When the acoustic tag was lowered into the water upstream of the trash rack or at the trashboom, no detection was recorded by the fixed station receiver downstream of the SFPF. Thus, fish moving within the SFPF primary louver bays and/or upstream of the SFPF would not be detected by the fixed station receiver deployed at the railroad bridge downstream of the SFPF.

6.2.2 Acoustic Tagged Striped Bass

Mobile monitoring data were analyzed separately from fixed station receiver data. Mobile monitoring detections were examined to determine the locations striped bass were located within the study area. For each day of mobile monitoring the monitoring time was recorded and the number of acoustic tagged striped bass detected was totaled and converted to a percentage of the total tagged striped bass assumed to be in the Forebay at the time (Table 3). As shown in Table 3, the number of tagged striped bass within the Forebay was reduced after a recreational angler harvested a tagged striped bass. The number of striped bass assumed to be in the Forebay was not adjusted for striped bass that possibly emigrated from Clifton Court Forebay and into Old River. All mobile monitoring events detected at least 1 striped bass within the Forebay. The percentage of tagged striped bass detected daily fluctuated throughout the monitoring period. However, the mobile monitoring daily coverage range typically was only approximately a quarter of the Forebay so movement out of the monitoring area could not be detected. The area of most frequent striped bass detection was directly between the radial gates and the intake canal, in line with the fixed station receivers. Striped bass were found to disperse into the extreme north and south of the Forebay, but generally only a low percentage of the tagged striped bass was observed in these areas. The majority of the tagged striped bass were detected either at the radial gates, within the intake canal near the trashboom, or in a direct line between these two areas within the Forebay. Figures 21 and 22 demonstrate detected striped bass from the mobile monitoring data.

Table 3. Daily mobile monitoring results for striped bass tracking.

Date	Start Time	End Time	No. Tagged Striped Bass Potentially in Forebay	No. Tagged Striped Bass Detected	% Tagged Striped Bass Detected
3/16	1430	1630	16	2	12%
3/17	1300	1500	16	4	24%
3/18	1130	1330	16	7	41%
3/22	0930	1330	16	10	59%
3/23	0930	1330	16	10	59%
3/25	0930	1330	16	1	6%
3/28	1300	1700	16	5	29%
4/1	1400	1600	16	4	24%
4/4	1230	1530	16	5	29%
4/5	0900	1500	16	6	38%
4/6	0900	1500	16	11	69%
4/7	0900	1500	16	6	38%
4/8	0800	1500	16	8	50%
4/12	1300	1800	16	2	13%
4/13	0730	1730	16	10	63%
4/18	0730	1530	15	5	31%
4/19	0900	1600	15	3	19%
4/20	0830	1730	15	4	25%
4/21	0830	1730	15	1	6%
4/22	0830	1730	15	5	31%
4/25	0830	1730	15	1	6%

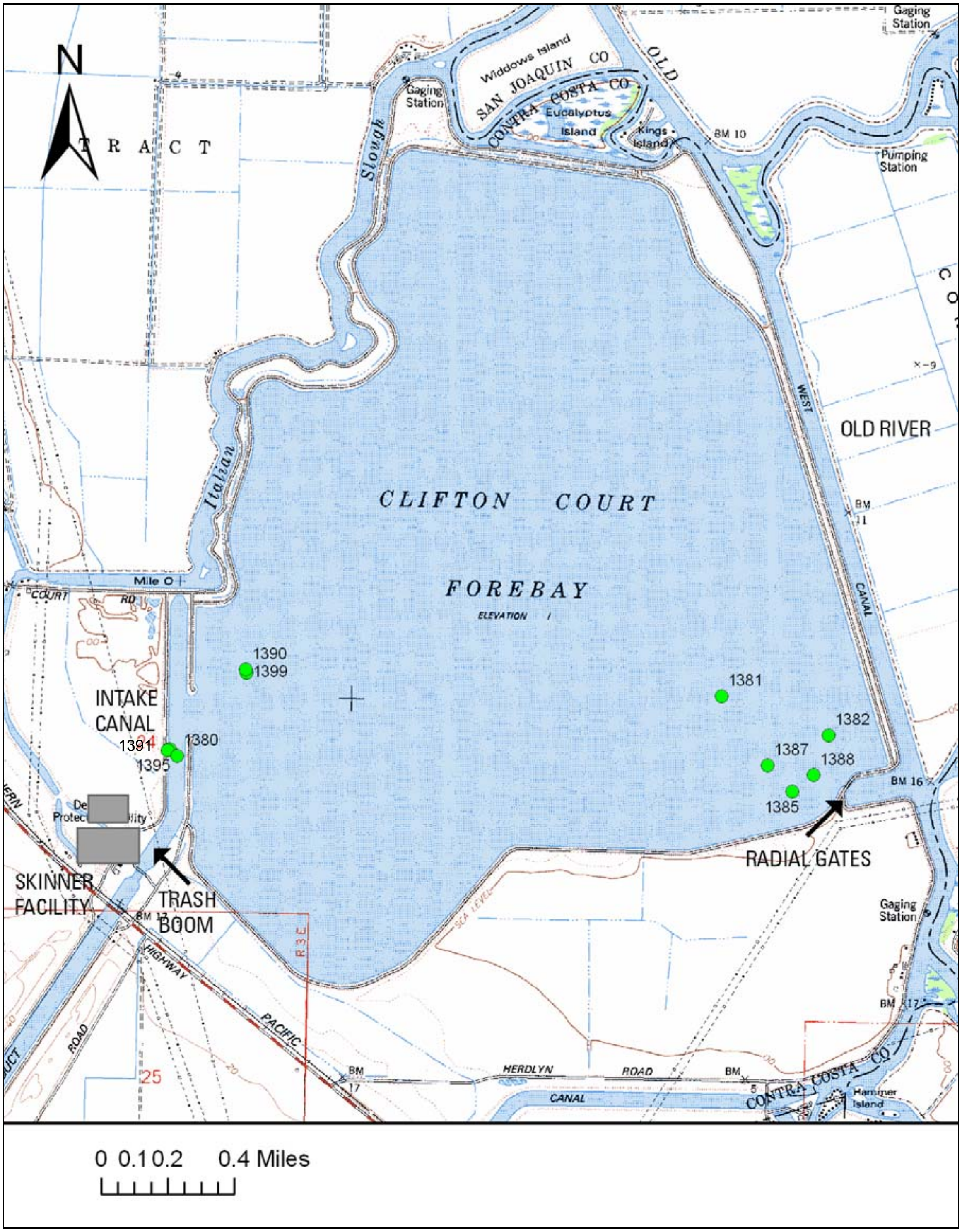

Figure 21. Striped bass locations on March 22, 2005, detected by mobile monitoring. The four digit codes next to the green location points indicate the tag identification number for each striped bass detected.

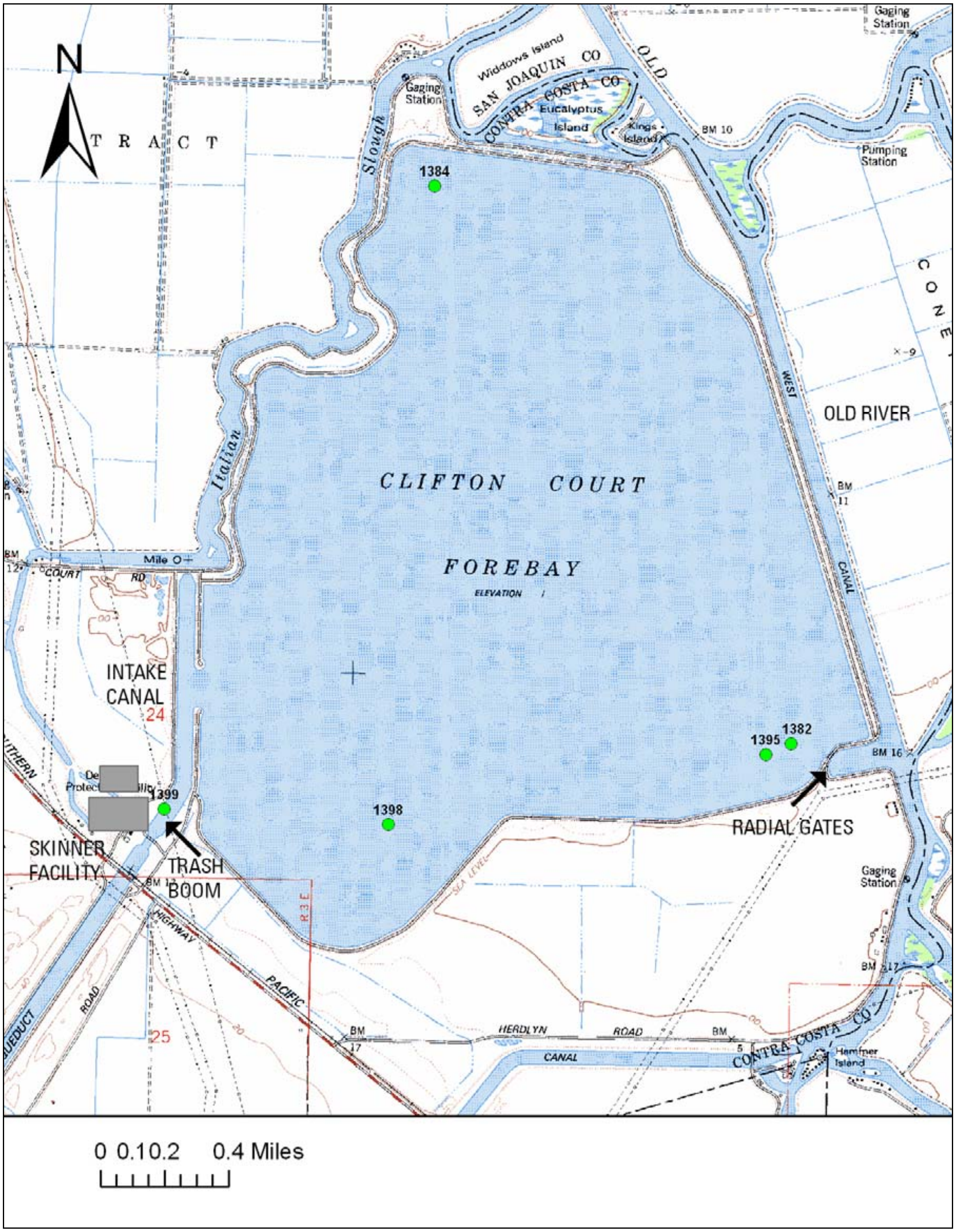

Figure 22. Striped bass locations on April 18, 2005 detected by mobile monitoring. The four digit codes next to the green location points indicate the tag identification number for each striped bass detected.

Fixed station receiver detections were summarized for the 16 acoustic tagged striped bass at selected locations within the Forebay and Old River. Fixed station receiver data showed that 11 (69%) of the tagged striped bass moved, at some time, from the release location at the radial gates to the intake canal entrance (Table 4). Furthermore, 10 (63%) moved from the release location at the radial gates to the trashboom immediately upstream of the SFPF (Table 4). Emigration from the Forebay was observed with 7 (44%) of the striped bass being detected in Old River after passing through the radial gates (Table 4).

Table 4. Fixed station receiver data summary for 12 of 16 acoustic tagged striped bass that were detected at either the intake canal, trashboom, and/or in Old River. Striped bass not detected at any of these locations were not included in the table. The total number of striped bass tagged and released was used to calculate the percentage of fish detected at the four locations.

Tag ID	Release Date	Intake Canal	Trash-boom	Old River
1380	3/16	X	X	-----
1381	3/18	X	X	-----
1382	3/18	X	-----	X
1383	3/18	X	X	-----
1389	3/17	X	X	-----
1390	3/18	X	X	X
1391	3/18	X	X	X
1394	3/17	X	X	-----
1395	3/18	X	X	X
1396	3/18	-----	-----	X
1398	3/17	X	X	X
1399	3/17	X	X	X
Fish Detected (% of total released)		11 (69%)	10 (63%)	7 (44%)

Analysis of all telemetry data for striped bass shows that striped bass moved throughout the Forebay and in some cases, moved multiple times between the radial gates and the trashboom. For example, striped bass tag ID 1398 was released at the radial gates on March 17 and was monitored moving from the radial gates to the intake canal and trashboom eleven times during the course of the monitoring period. Striped bass were also detected emigrating out of the Forebay, then re-entering the Forebay through the radial gates. Striped bass tag ID 1398 was detected moving out of the Forebay into Old River, returned to the Forebay and was monitored at the radial gates area, and then emigrated out of the Forebay to Old River in early June.

As part of the striped bass movement pattern analysis summarized in Table 4, transit times were calculated for striped bass movements. The transit times were calculated from the release date and time for each fish at the radial gate area to the first date time record of each striped bass at the intake canal entrance, the trashboom, and Old River using the fixed station receiver data. Of the eleven striped bass that moved from the radial gates to the intake canal, the mean transit time was 4 days, with a range in transit times from 7 hours to almost 17 days. Of the ten striped bass that moved from the radial gates to the trashboom, the mean transit time was 10 days with a range in transit times from approximately 1 to 45 days. Of the seven striped bass that were detected emigrating out of the Forebay into Old River, the mean transit time was 31 days with a range in transit times from 3 to 49 days.

Striped bass final detection locations were determined from a combination of mobile and fixed-position receiver monitoring data. Final destinations were determined as the last recorded detection location for each striped bass (Table 5). In the case of striped bass emigrating into Old River, these fish continued to disperse beyond the range of the study area. For the striped bass remaining in the Forebay in early June, the final detection locations were determined at the time the receivers were removed from the Forebay.

Table 5. Striped bass final detection summary for the 2005 pilot study.

Tag ID	Location Description	Date of Last Detection
1380	Trashboom	3/27
1381	Clifton Court Forebay	4/6
1382	Old River	4/21
1383	Clifton Court Forebay	4/20
1384	Clifton Court Forebay	4/20
1385	Clifton Court Forebay	5/4
1387	Clifton Court Forebay	6/9
1388	Clifton Court Forebay	4/29
1389	Trashboom	3/20
1390	Old River	4/15
1391	Old River	4/16
1394	Clifton Court Forebay	6/1
1395	Old River	4/21
1396	Old River	3/21
1398	Old River	6/6
1399	Old River	5/1

6.2.3 Acoustic Tagged Steelhead

Mobile monitoring of the steelhead produced varied results. Of the thirty steelhead released into the Forebay, one juvenile steelhead remained in Old River near the release site. Another juvenile steelhead was not detected after release either within the Forebay or in Old River and may have experienced a tag malfunction (tag 1987). Alternatively, this steelhead may have been consumed by an avian predator that left the study area. For the other 28 acoustic tagged steelhead mobile monitoring was able to capture the dispersion of tagged steelhead as they were entrained. Once entrained into the Forebay, steelhead displayed varied movement patterns (Figures 23, 24, and 25). Several moved to the intake canal within hours of entrainment (Figure 24). Others remained near the radial gates. While some steelhead dispersed to the extreme northern and southern areas of the Forebay (Figure 25).

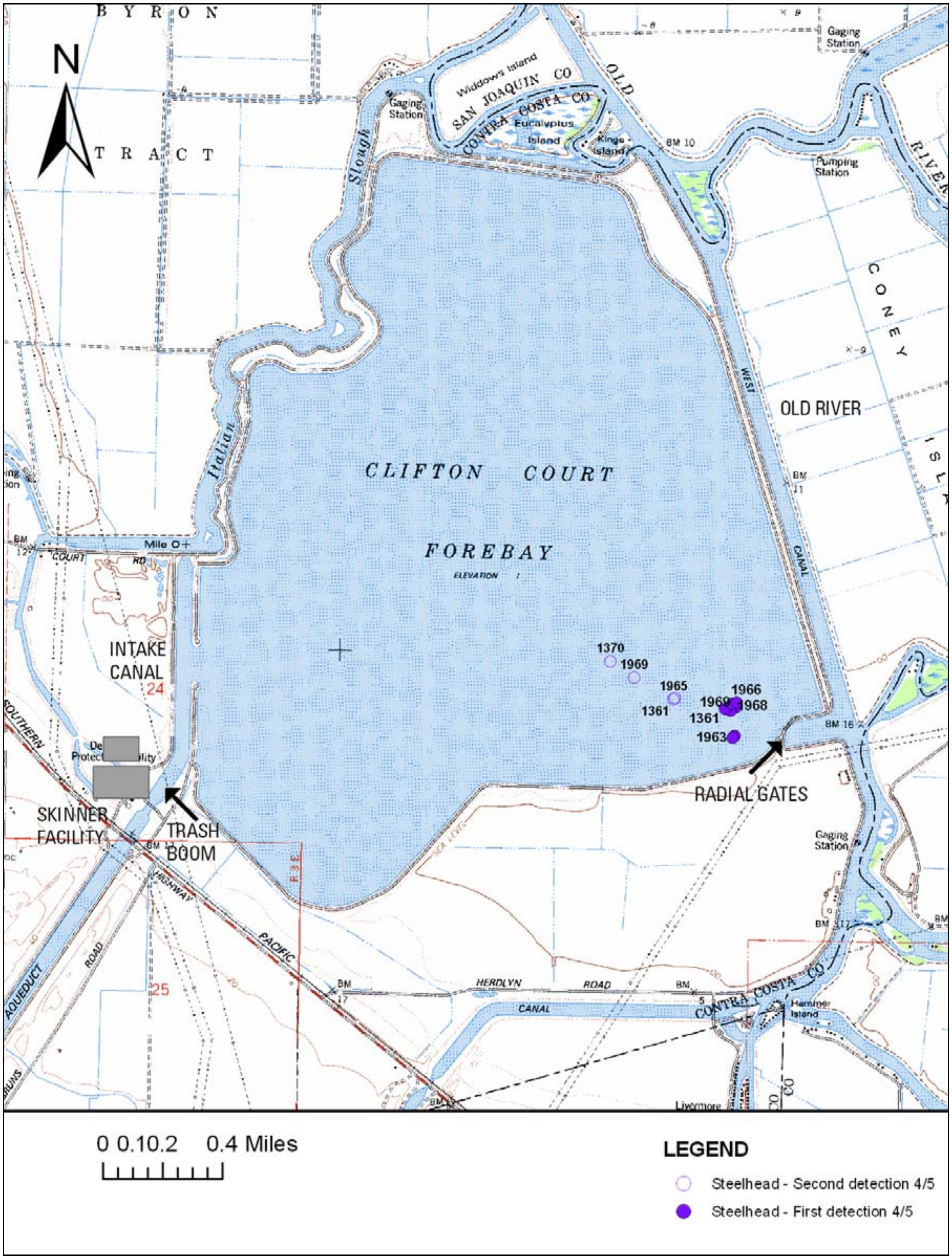

Figure 23. Steelhead locations on April 5, 2005 detected by mobile monitoring. The four digit codes next to the location points indicate the tag identification number for each steelhead detected.

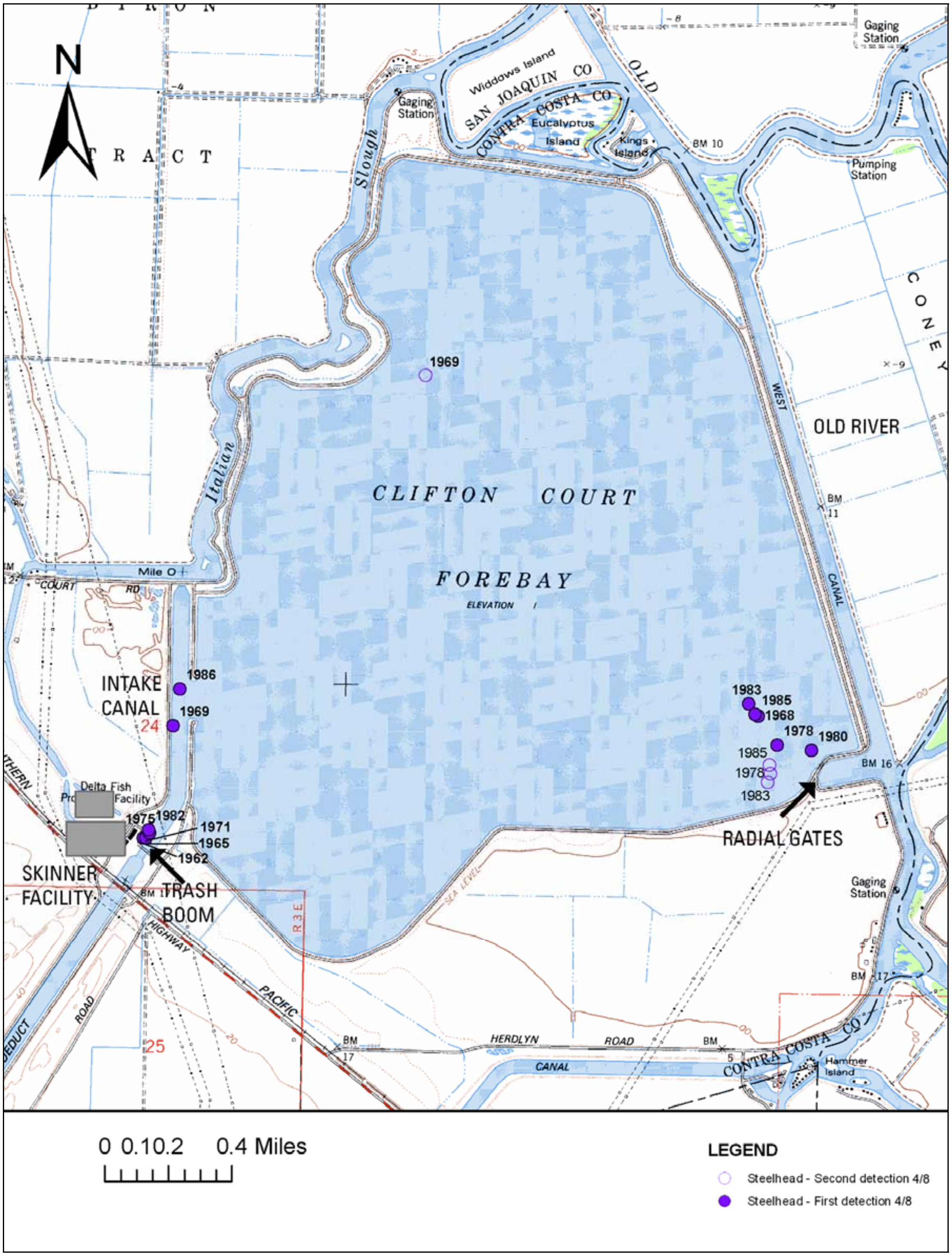

Figure 24. Steelhead locations on April 8, 2005, detected by mobile monitoring. The four digit codes next to the location points indicate the tag identification number for each steelhead detected.

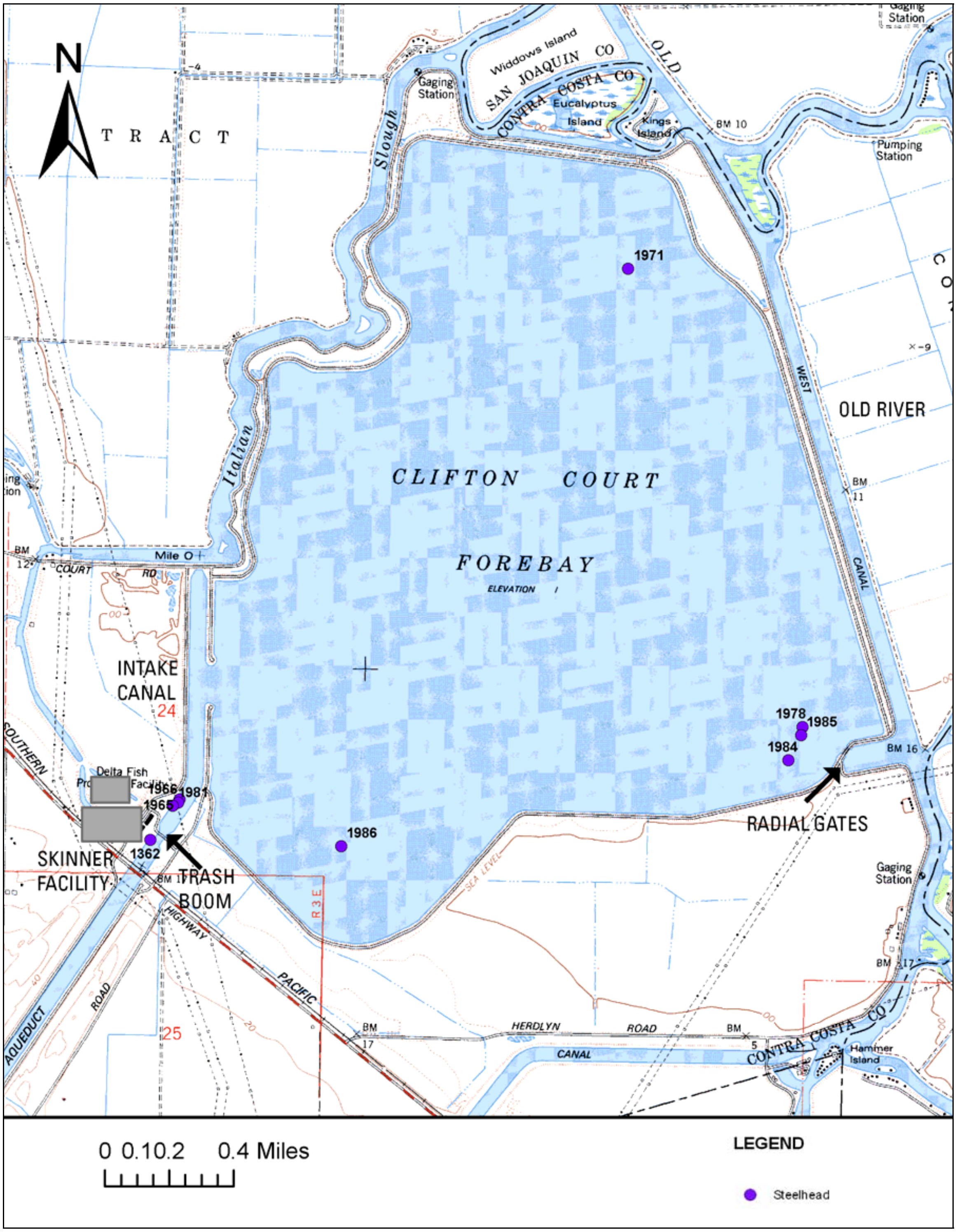

Figure 25. Steelhead locations on April 18, 2005, detected by mobile monitoring. The four digit codes next to the location points indicate the tag identification number for each steelhead detected.

Juvenile steelhead were also tracked by the fixed station receiver array deployed within the Forebay. Tracking by the array continued until June 1, after which the tag signals were unreliable due to battery extinction. Of the 30 acoustic tagged steelhead released, 17 (57%) were detected in the intake canal (Table 6). Twelve (71%) of the steelhead detected in the intake canal were also detected at the trashboom. Four (13%) of the tagged steelhead were detected as having emigrated from the Forebay into Old River (Table 6). Of the steelhead released, four (13%) were detected as having been successfully salvaged (Table 6). Even though only four steelhead were detected within the SFPF holding tanks, 17 steelhead reached the trashboom at least once. This may indicate that there is a delay problem and/or an attraction problem at the SFPF.

Table 6. Fixed station receiver data summary for 19 of 30 steelhead that were detected at either the intake canal, trashboom, salvage holding tank, and/or in Old River. Steelhead not detected at any of these locations were not included in the table. The total number of steelhead released was used to calculate the percentage of fish detected at the four locations.

Tag ID	Release Date	Intake Canal	Trash-boom	Salvage Holding Tank	Old River
1961	4/5	-----	-----	-----	X
1962	4/5	X	X	X	-----
1963	4/5	X	X	-----	-----
1965	4/5	X	X	-----	-----
1966	4/5	X	X	-----	-----
1968	4/5	X	X	-----	X
1969	4/5	X	X	-----	-----
1970	4/5	X	X	-----	-----
1971	4/7	X	X	-----	-----
1974	4/5	X	X	-----	-----
1975	4/6	X	X	X	-----
1976	4/6	X	X	X	-----
1980	4/6	X	-----	-----	-----
1981	4/6	X	X	-----	X
1982	4/6	X	-----	X	-----
1986	4/6	X	-----	-----	-----
1988	4/7	-----	-----	-----	X
1989	4/7	X	-----	-----	-----
1990	4/7	X	-----	-----	-----
Fish Detected (% of total released)		17 (57%)	12 (40%)	4 (13%)	4 (13%)

One steelhead was detected moving through the SFPF primary louvers into the aqueduct leading to Harvey Banks Pumping Plant, and was later detected moving back through the trash rack indicating that this fish was able to move both upstream and downstream through the SFPF louvers. This steelhead moved upstream through the primary louvers during the periods of time when Harvey Banks Pumping Plant export flows were reduced or during periods of time when there was a stoppage in pumping. This steelhead was last detected at the trashboom on April 19, 2005.

Transit times for steelhead were calculated from the release point at the radial gates to the intake canal, trashboom, SFPF salvage holding tanks, and Old River. From point of release to the intake canal, the mean transit time was 5 days. However, this mean time is skewed somewhat by two steelhead with transit times of 11 and 32 days. Nine of the seventeen steelhead detected at the intake canal had transit times of less than 1 day. The mean transit time from the release point to the trashboom was 9 days, however five of the thirteen steelhead detected at the trashboom had transit times less than 1 day. Mean transit time to the SFPF salvage holding tank from point of release was 14 days. However, only four of the twenty-nine active steelhead tags were detected as being salvaged with transit times ranging from 2 days to 31 days. Mean transit time for steelhead emigrating out to Old River was 9 days, but similar to the transit data for steelhead being salvaged, ranging from 1 days to 23 days. It is not possible to say with certainty whether these transit times were affected by striped bass predation.

Of the four steelhead salvaged, transit times from release to the trashboom varied widely. The progression from release to trashboom to salvage ranged from approximately 2 days up to 30 days from time of release. One steelhead moved from the trashboom to the salvage holding tank in a matter of hours, while two steelhead remained at the trashboom for over a week before being salvaged. The fourth steelhead was not detected at the trashboom before being detected in the salvage holding tank. Figure 26 illustrates the transit pattern for one of the salvaged steelhead. After release, the steelhead (tag 1962) moved from the radial gates at approximately 08:30 on April 5 to the trashboom at 02:22 on April 6, a transit time of approximately 18 hours. Between April 6 and April 18, the steelhead remained at the trashboom, a period of 12 days, before being salvaged on April 19. Of the four steelhead successfully salvaged, three were lost from the SFPF holding tank receivers in under eight hours from first contact, presumably as they were collected and released.

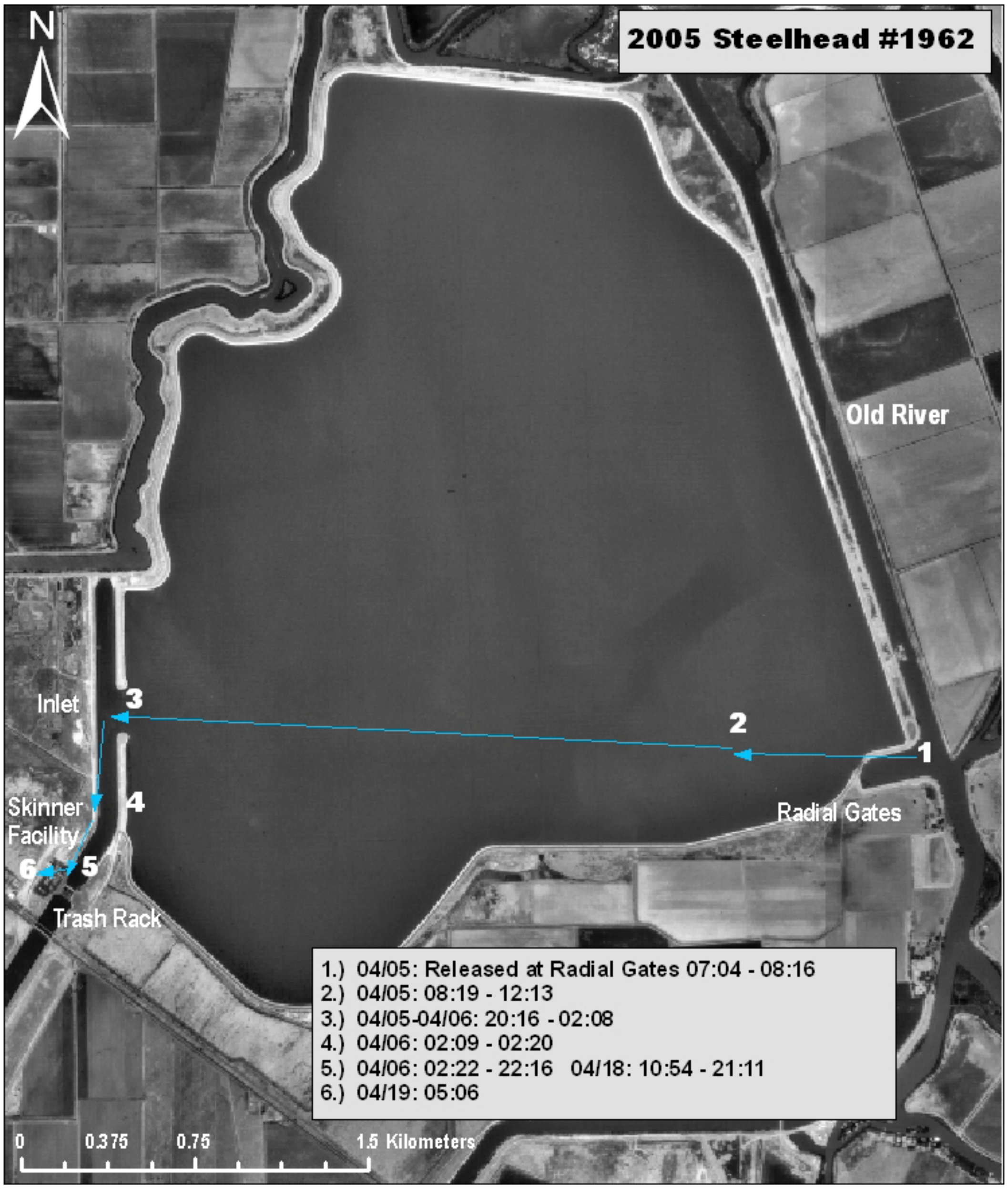

Figure 26. Steelhead tag ID 1962 path to the SFPF salvage holding tank.

Steelhead final detection locations were determined from fixed station receiver grid data and/or mobile monitoring data. At the end of the pilot study (June 1, 2005), four (13%) of the steelhead had been salvaged and 20 (68%) steelhead remained in the Forebay (Figure 27). Of the steelhead tags remaining within the Forebay, seven tags were detected near the radial gates, five remained in the wider Forebay, five were located within the intake canal, and three were located at the trashboom (Table 7). One (3%) steelhead was never detected after release and one (3%) steelhead may not have been entrained and was last detected in the live-car (Figure 27). Four (13%) of the steelhead had emigrated to Old River (Figure 27).

Time periods exist when water surface elevations within the Forebay and Old River are similar and water velocities passing through the radial gates are reduced, or under extreme circumstances, water is actually flowing from the Forebay through the radial gates to Old River. Juvenile steelhead have been shown to have a critical swimming velocity of 7.90 bl/s (Hawkins and Quinn, 1996). Thus, juvenile steelhead that have been entrained into the Forebay would have the swimming performance capability to effectively swim out of the Forebay when either of these conditions occur or when water velocities at the radial gates are approximately below 1.2 m/s (4 ft/s). Acoustic tagged steelhead were detected as moving from the Forebay through the radial gates to Old River at periods of low velocity. However, it cannot be confirmed conclusively that these acoustic tagged steelhead had not been preyed upon within the Forebay and their predators moved from the Forebay through the radial gates into Old River.

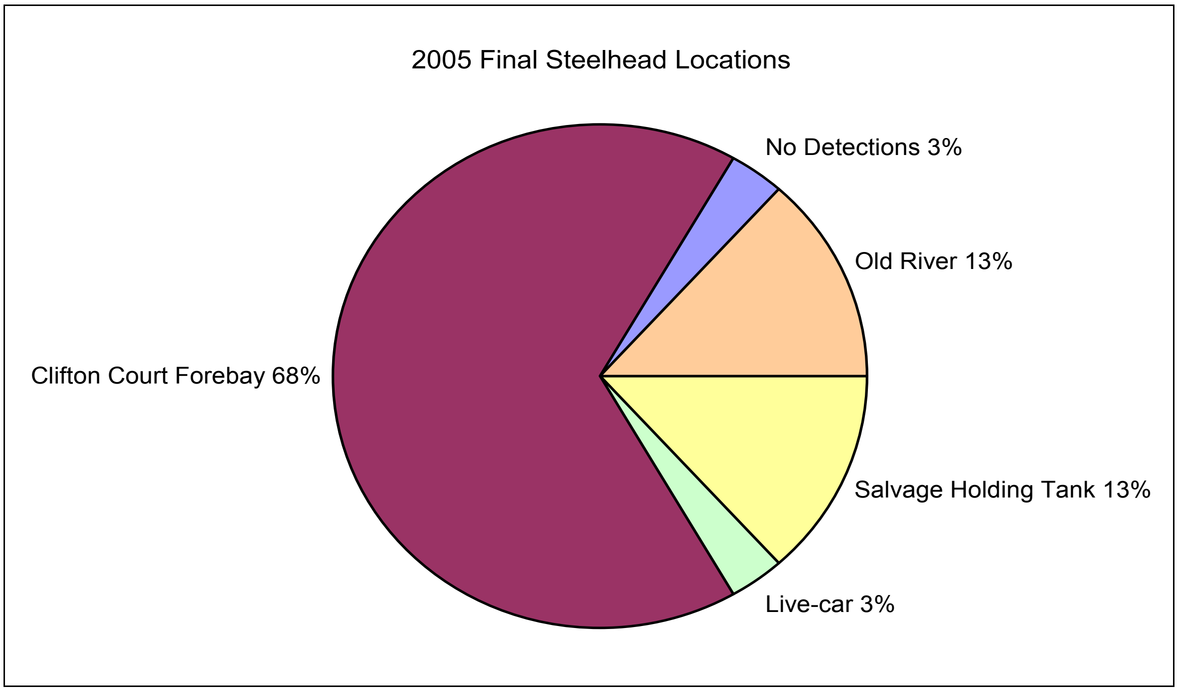

Figure 27. Percentages and locations for final detections of acoustic tagged steelhead released during the 2005 pilot study.

Table 7. Final detection locations for acoustic tagged steelhead in 2005.

Tag ID	Location Description	Date of Last Detection	Days After Release
1961	Old River	6-Apr	1
1962	**Salvage Holding Tank**	**20-Apr**	**15**
1963	Intake Canal	16-Apr	11
1964	East Side of Forebay	5-Apr	0
1965	Trashboom	1-Jun	57
1966	Trashboom	19-Apr	14
1967	East side of Forebay	7-Apr	0
1968	Old River	14-Apr	9
1969	Intake Canal Opening	26-May	21
1970	Intake Canal Opening	5-Apr	0
1971	Radial Gates	29-May	52
1972	Radial Gates	31-May	54
1973	West Side of Forebay	12-Apr	5
1974	Trashboom	7-May	32
1975	**Salvage Holding Tank**	**17-Apr**	**11**
1976	**Salvage Holding Tank**	**7-May**	**31**
1977	Radial Gates	1-Jun	56
1978	Radial Gates	1-Jun	55
1979	Live-car	7-Apr	0
1980	Middle of Forebay	16-Apr	10
1981	Old River	29-Apr	23
1982	**Salvage Holding Tank**	**8-Apr**	**2**
1983	East Side of Forebay	26-May	50
1984	Radial Gates	1-Jun	56
1985	Radial Gates	1-Jun	56
1986	Intake Canal	26-Apr	20
1987	No detections		
1988	Old River	9-Apr	2
1989	Radial Gates	1-Jun	55
1990	Intake Canal	27-May	50

Note: Bold lines are for steelhead recovered at the SFPF

6.3 Recommendations for the Full-scale Investigation

Based upon results of the 2005 pilot study, recommendations for the full-scale investigation included the following:

- The experimental investigation should occur coincident with the period of juvenile steelhead salvage extending from January through April.

- Seasonal variation in water temperatures and potential abundance and behavior of predatory striped bass during the winter and early spring should be taken into account in the experimental design by stratifying experimental design and recapture releases on a monthly basis, as well as evaluating the potential relationship between juvenile steelhead predation mortality and water temperatures within the Forebay. The experimental design should allow for calculating independent estimates of juvenile steelhead survival monthly over the January – April period.

- Juvenile steelhead ranging in length from approximately 200-300 mm were used successfully in the 2005 pilot study and represent the size distribution of juvenile steelhead actually observed in SFPF salvage. Juvenile steelhead used in the full-scale investigation should range in length from 200-300 mm.

- Juvenile steelhead that were used in the 2005 pilot study were obtained from the Mokelumne River Fish Hatchery. The 2005 pilot study was not designed to determine whether or not there was a difference in predation mortality between hatchery produced fish and wild fish. Given the difficulty of obtaining an adequate sample size of wild steelhead, as well as impacts to ESA listed species that may occur as a result of extensive in-river sampling, it is recommended that juvenile steelhead from the Mokelumne River Fish Hatchery, or other hatchery, be used as surrogates for determining pre-screen loss during the full-scale investigation.

- The live-car method of releasing juvenile steelhead directly into the flow passing through the radial gates proved to be an effective release technique in the 2005 pilot study. Releasing fish immediately upstream of the radial gates provides for a representative introduction of the juvenile fish into the Forebay and is thought to more accurately represent the vulnerability of juvenile steelhead entrained through the radial gates. The live-car release techniques developed during the 2005 pilot study should be employed as part of the full-scale investigation.

- Juvenile steelhead were effectively tagged using surgical implantation of individually coded acoustic transmitters during the 2005 pilot study. After developing these surgical techniques, there was no mortality among tagged fish prior to release or for a sub-sample of tagged fish held for a 30 day observation period. The VEMCO V8SC acoustic tag was within the 2% body weight guideline for most of the juvenile steelhead used in the pilot study. In addition, the acoustic tag does not require an external antenna that may affect the behavior or ability of a juvenile steelhead to avoid predation. The use of acoustic tags as part of the full-scale investigation offers the opportunity to quantify emigration of juvenile steelhead from Clifton Court Forebay through the radial gates, passage of juvenile steelhead through the louvers into the canal leading to the Harvey Banks Pumping Plant, and provides valuable information on behavior patterns of juvenile steelhead within the Forebay. The full-scale investigation should include proportional marking of juvenile steelhead using acoustic tags.

- Modifications to the fixed position receiver array should include locating additional receivers in the canal leading to the Harvey Banks Pumping Plant to document potential steelhead movement through the primary louvers, within Old River, and within the Forebay. Analysis of the 2005 fixed position receiver data was difficult due to simultaneous detections on multiple receivers. Methods for optimizing the acoustic tag detection array as suggested by Clements and others (2005) should be used in establishing the full-scale receiver array. Also, the sensitivity of the system for tag detection should be verified.

- Based on the residence time of juvenile steelhead within Clifton Court Forebay observed during the pilot study, PIT tags should be used to mark juvenile steelhead releases as part of the full-scale investigation, with subsequent monitoring using PIT tag detectors positioned on the release pipes at the SFPF salvage release sites. The use of PIT tags will substantially reduce manpower required for sampling, as well as avoid disruption to routine salvage operations and eliminate additional stress and impacts to salvaged fish. PIT tags are also cheaper than acoustic tags and will allow for larger sample sizes.

- Acoustic tagging of striped bass and the use of both fixed position and mobile acoustic monitoring provided valuable insight into the behavior and geographic distribution of adult striped bass within the Forebay. Additional acoustic tagging of adult striped bass should be included as part of the full-scale experimental design to provide further insight into the dynamics of predation in the Forebay and help identify specific locations, operations, or other factors influencing either the concentration of predatory fish or vulnerability of juvenile steelhead to predation.

- Avian predation has been noted as a significant source of mortality for juvenile downstream migrating Chinook salmon in other river systems (Ryan and others, 2001a; 2001b; 2003; Collis and others, 2001) and, therefore, as part of a rigorous experimental design systematic observations and documentation of potential avian predation should be included as part of the full-scale study design.

7.0 2006 Pilot Study

7.1 Methods

Another pilot-scale telemetry study was conducted March – June, 2006. This pilot study was conducted to further investigate the movements of juvenile steelhead through the Forebay, to refine the placement of telemetry receivers for optimal fish tag detections, and to facilitate the training of new project staff. To meet these objectives, steelhead were acoustic tagged, released, and tracked throughout the Forebay. However, the 2006 pilot study data were not completely analyzed until after completion of data collection for the 2007 full-scale study.

7.1.1 Acoustic Tagging of Steelhead

Juvenile steelhead used in the 2006 pilot study were obtained from the Mokelumne River Fish Hatchery and used as surrogates for wild fish. These juvenile steelhead were transported from the hatchery and held at the CHTR Study Facility for 10 days to recover from transportation and handling stress and to acclimate to water quality conditions at the site. The steelhead were selected to be representative of the general size distribution of juvenile steelhead entrained into the Forebay. The 30 juvenile steelhead selected for surgical implantation of acoustic tags ranged in total length from 235 to 280 mm (9.25 to 11.00 in) with a mean of 254 ±0.4 mm (10 ±0.016 in). These steelhead were tagged with acoustic coded transmitters (VEMCO, model V8SC) on March 17 following the same surgical procedure used in the 2005 pilot study. Unlike in 2005, all tagged juvenile steelhead were weighed in 2006 to determine the tag percentage body weight. Tag percentage of body weight ranged from 1.57 to 2.94% with a mean of 2.21 ±0.13%. Similar to the 2005 pilot study, the tag percentage of body weight in 2006 was slightly higher than the accepted 2% tag to body weight rule established by Winter (1983 and 1986). The tagged juvenile steelhead were kept for observation in a holding tank for a minimum of three days to ensure recovery and suture stability prior to experimental release. One acoustic tagged steelhead died and the remaining twenty-nine were released into the Forebay during March to coincide with the seasonal period that steelhead have been observed in the SFPF salvage.

7.1.2 Tagged Steelhead Releases

Similarly to the 2005 pilot study, a special designed live-car was used to release the acoustic tagged steelhead (Figure 17). Three releases of 10 acoustic tagged steelhead each were scheduled for March 2006. However, one acoustic tagged steelhead died prior to release. Therefore, twenty-nine acoustic tagged juvenile steelhead were released immediately upstream of the radial gates over three days in 2 groups of 10 fish and one group of 9 fish. Each group of acoustic tagged steelhead was transported in aerated 18.9 L (5 gal) buckets to the release site adjacent to the radial gates. The acoustic tags were monitored to ensure correct operation using a mobile monitoring unit (VEMCO model VR100) and the tag ID numbers for each release group were recorded. Each release group of acoustic tagged steelhead was loaded into the live-car while the live-car was floating in Old River immediately outside of the Forebay. The live-car was positioned against the wing wall leading to radial gate number one. The tagged steelhead were acclimated in the live-car for 2 hr to recover from transportation and handling stress prior to release. All radial gates were closed during the 2 hr acclimation period. Once the acclimation period was complete and after the radial gates were opened, the live-car was moved into position immediately upstream of the radial gates by pulling the floating live-car along the wing wall. Once in position, the front door of the live-car was released via remote cable. This allowed steelhead to exit the live-car into the flow passing through the radial gates from the velocity refuge of the live-car and become entrained into the Forebay. After a few minutes, the back door of the live-car was triggered to open and flush any remaining steelhead into the flow passing through the radial gates.

Releases of acoustic tagged steelhead via the live-car were conducted during the night on March 22 and March 23 and at dawn on March 28 with acclimation occurring from 00:00 to 02:00, 00:05 to 02:05, and 04:45 to 06:45 respectively. During the March 22 release, one acoustic tagged steelhead jumped out of the aerated bucket into the radial gate intake channel as the fish were loaded into the live-car. All acoustic tagged steelhead appeared to be in good health at the time of release with the exception of one fish showing signs of stress, tag ID 1694, released on March 28.

7.1.3 Fixed Station Receiver Grid

In 2006 a new network of fixed station receivers was designed to cover the entire Forebay and to track the movement of acoustic tagged juvenile steelhead near key locations within the Forebay, the SFPF, Old River, and the intake canal leading to the Harvey Banks Pumping Plant (Figure 28). The new network was designed to reduce the number of simultaneous detections on multiple receivers and to cover the entire Forebay.

The fixed station receiver array was installed in January 2006 before acoustic tagged steelhead were released and remained in the Forebay through the entire 2006 pilot study period. Fixed station receivers (VEMCO, model VR2) were attached to a mooring line with the use of cable ties and kept in an upright position submerged completely in the water column between a mooring anchor and a float. The fixed station receivers were removed from the study area in August 2006 and all data was uploaded for future analysis.

Two Vemco, model VR3-UWM units were utilized in addition to the VR2 receivers for the 2006 field season. One VR3-UWM was deployed from the trashboom upstream of the SFPF and the second VR3-UWM was deployed from the boat dock immediately upstream of the radial gates in Old River. The VR3-UWM is a submersible, multi-channel acoustic receiver capable of identifying VEMCO coded transmitters. The VR3-UWM records the code number and date/time of each valid acoustic tag detection. This information is stored in the VR3-UWM memory until the data is downloaded to a computer at the surface using an underwater modem. Thus, data can be retrieved without retrieving the VR3-UWM.

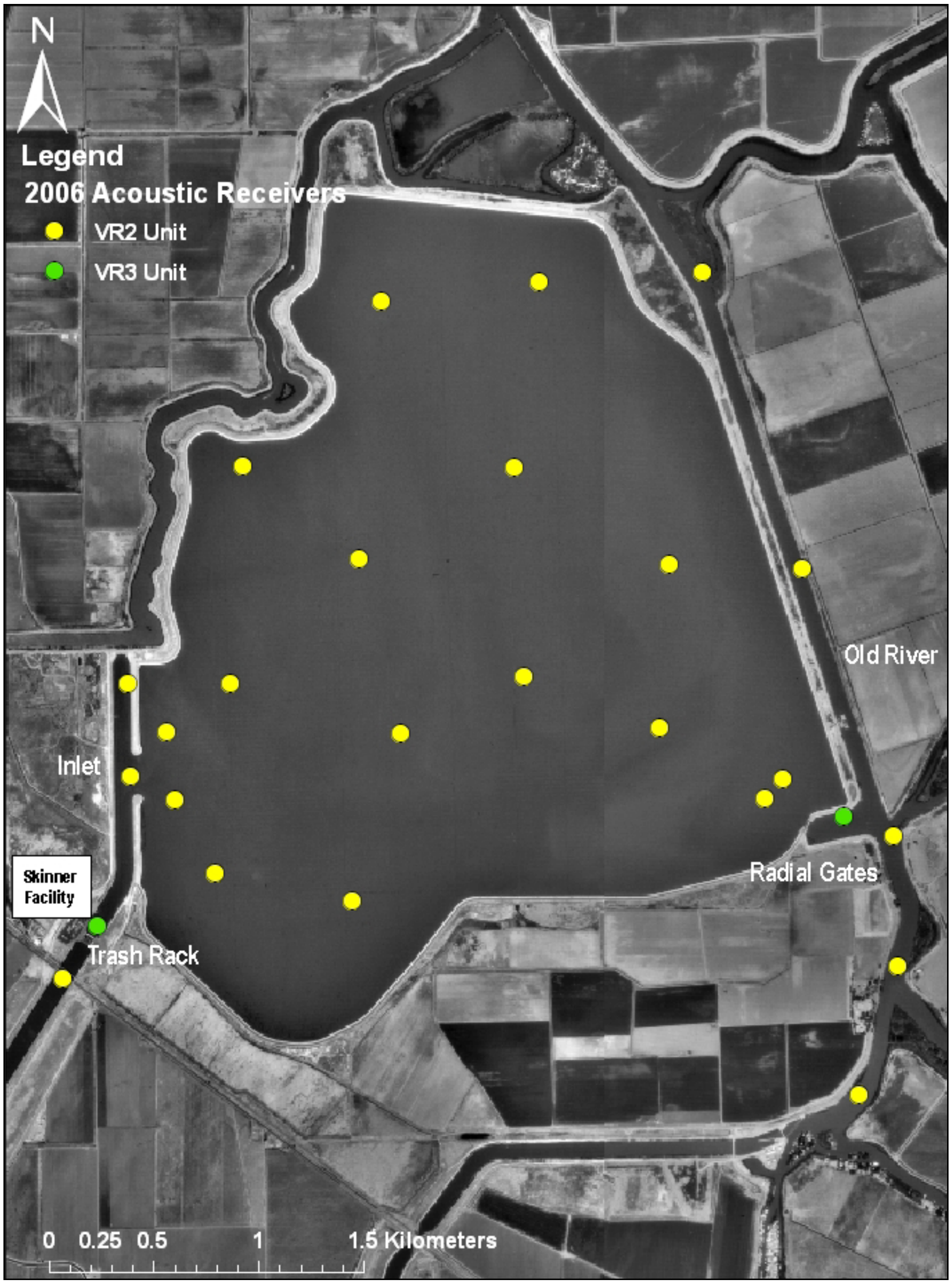

Figure 28. 2006 VR2 and VR3-UM acoustic fixed receiver locations within Clifton Court Forebay, Old River, and the John E. Skinner Delta Fish Protective Facility.

7.2 2006 Results and Discussions

7.2.1 Acoustic Tagged Steelhead

Similarly to the 2005 pilot study, acoustic tagged steelhead detection data was examined using VEMCO VR2 pc software. However, unlike the 2005 pilot study, the 2006 pilot study data was not analyzed using GIS techniques and no GIS graphics were produced. The following is a description of the raw detection data as examined.

All released steelhead were not initially detected as having been entrained. One steelhead, tag ID 1679, jumped out of the live-car prior to acclimation and was detected in Old River for six days with initial movements toward the TFCF. After initially moving towards the TFCF, this steelhead was later detected north of the radial gate intake channel. Ultimately, this steelhead was entrained through the radial gates six days after jumping out of the live-car. Thus, all 29 juvenile steelhead intended for release were entrained.

Entrained steelhead displayed varied movement patterns. Some steelhead were observed to move to the intake canal within hours of entrainment. Other steelhead were observed to remain near the radial gates. Yet, other steelhead dispersed to the extreme northern and southern areas of the Forebay. Of the 29 steelhead entrained into the Forebay, 17 (59%) steelhead were detected in the intake canal (Table 8). Thirteen (76%) of the 17 steelhead detected within the intake canal were also detected at the trashboom. Two (7%) acoustic tagged steelhead were detected as having been successfully salvaged and no steelhead were detected moving through the primary louvers towards Harvey Banks Pumping Plant (Table 9). Six (21%) steelhead tags were detected as having emigrated from the Forebay into Old River (Table 8).

Transit times for steelhead were calculated from the release point at the radial gates to the intake canal, trashboom, SFPF salvage holding tanks, and Old River. For those steelhead detected in the intake canal, the mean transit time was 5 days. However, this mean time is skewed somewhat by three steelhead with transit times of 27, 16, and 12 days. Eleven of the seventeen steelhead detected at the intake canal had transit times of fewer then 3 days. The mean transit time from the release point to the trashboom was 9.5 days. However, six of the thirteen steelhead detected at the trashboom had transit times less than 3 days. Mean transit time to the SFPF salvage holding tank from point of release was 12 days, however, only two of the twenty-nine steelhead tags were detected as having been salvaged with transit times of 4 days and 20 days. Mean transit time for steelhead emigrating out to Old River was 25 days with a wide range from less than 1 day to 57 days. However, the single steelhead detected in Old River immediately after the release time (less than 1 day) was attributed to the steelhead observed jumping out of the live-car prior to release. It is not possible to say with certainty whether any of the calculated transit times were affected by striped bass predation and subsequent striped bass movements.

Steelhead final detection locations were determined using the fixed station receiver data. The fixed station receivers were removed well after the expiration of the battery life of the steelhead tags. Thus, a tagged steelhead's final location was assigned at the location of last tag detection. Of the 29 juvenile steelhead entrained into the Forebay, 22 (76%) remained in the Forebay at the end of the study period (Figure 29). Of the steelhead tags remaining within the Forebay, 13 tags were detected near the radial gates, seven remained in the wider Forebay, and two were located within the intake canal (Table 9).

Several of the steelhead last detected within the Forebay were stationary for a long period of time at a single location. One steelhead was detected at the radial gates for 12 weeks continuously. Similar to the 2005 pilot study, these data demonstrate that either juvenile steelhead may remain resident within the Forebay for extended periods of time before salvage or that the steelhead tags lay on the bottom as a result of predation. A total of two (7%) juvenile steelhead were detected in SFPF salvage holding tanks, and five (17%) were detected in emigrating through the radial gates into Old River (Figure 29). However, these acoustic tagged steelhead seen emigrating from the Forebay may have been preyed upon within the Forebay and their predators moved from the Forebay through the radial gates into Old River. Striped bass were able to emigrate from the Forebay through the radial gates during the 2005 pilot study. However, no striped bass were acoustically tagged in 2006. There was some evidence of possible avian predation, as two steelhead were only detected for a single day with no subsequent detections. It could be possible for an avian predator to consume a steelhead and fly away with the tag in the bird's stomach, thus, accounting for never detecting the tag again. However, the possibility remains that the two tags simply malfunctioned.

Table 8. Fixed station receiver data summary for 19 of 29 steelhead that were detected at either the intake canal, trashboom, salvage holding tank, and/or in Old River. Steelhead not detected at any of these locations were not included in the table. The total number of steelhead released was used to calculate the percentage of fish detected at the four locations.

Tag ID	Release Date	Intake Canal	Trash-boom	Salvage Holding Tank	Old River
1672	3/28	X	-----	-----	X
1673	3/28	X	X	-----	-----
1674	3/22	X	X	-----	X
1675	3/28	X	X	-----	-----
1678	3/22	X	X	-----	-----
1679	3/22	X	X	-----	-----
1680	3/22	X	X	-----	-----
1683	3/28	X	-----	-----	-----
1684	3/22	X	-----	-----	-----
1686	3/22	X	-----	-----	-----
1687	3/22	X	-----	-----	X
1688	3/23	X	X	X	-----
1689	3/23	X	X	-----	-----
1690	3/23	X	X	X	-----
1693	3/23	-----	-----	-----	X
1694	3/28	X	X	-----	-----
1695	3/23	-----	X	-----	-----
1699	3/23	X	X	-----	X
1700	3/28	X	X	-----	X
Fish Detected (% of total released)		17 (59%)	13 (45%)	2 (7%)	6 (21%)

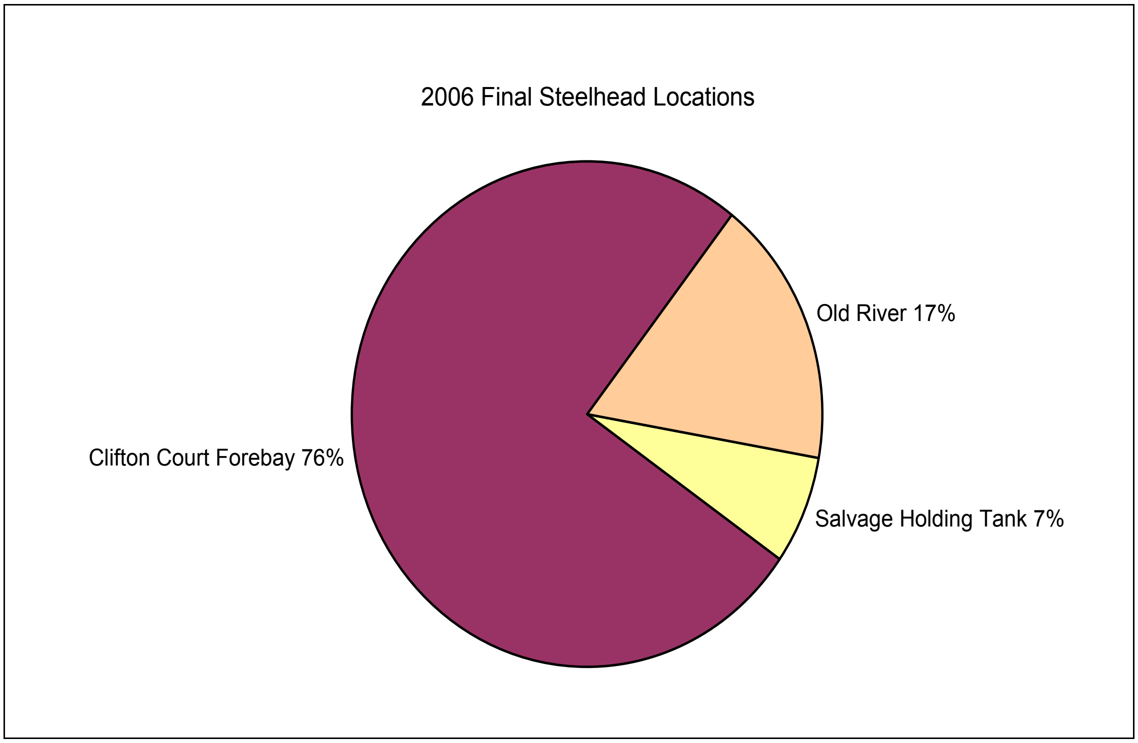

Figure 29. Percentages and locations for final detections of acoustic tagged steelhead released during the 2006 pilot study.

Table 9. Final detection locations for acoustic tagged steelhead in 2006.

Tag ID	Location Description	Date of Last Detection	Days After Release
1671	Radial Gates	6/3	74
1672	Old River	5/23	56
1673	Intake Canal Opening	5/21	54
1674	Old River	5/18	57
1675	Intake Canal Opening	4/3	7
1676	Radial Gates	6/22	86
1677	South Side of Forebay	3/23	1
1678	South Side of Forebay	4/30	39
1679	Radial Gates	5/18	57
1680	East Side of Forebay	4/18	28
1681	Radial Gates	6/3	73
1683	South Side of Forebay	5/5	38
1684	Radial Gates	5/23	63
1685	South Side of Forebay	3/23	1
1686	Radial Gates	6/3	74
1687	Radial Gates	5/3	42
1688	**Salvage Holding Tank**	**3/27**	**4**
1689	Radial Gates	5/30	68
1690	**Salvage Holding Tank**	**4/12**	**20**
1691	Radial Gates	5/24	63
1692	South Side of Forebay	4/12	22
1693	Old River	3/27	4
1694	Radial Gates	6/6	70
1695	South Side of Forebay	4/28	36
1696	Radial Gates	6/7	76
1697	Radial Gates	7/11	105
1698	Radial Gates	4/28	31
1699	Old River	3/27	4
1700	Old River	5/18	51

Note: Bold lines are for steelhead recovered at the SFPF

8.0 2007 Full-scale Study

8.1 Methods

Unlike the 2005 and 2006 pilot studies, the 2007 full-scale study was designed to quantify steelhead pre-screen loss within Clifton Court Forebay. Additionally, the full-scale effort 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. A mark-recapture and telemetry study was conducted December, 2006 – June, 2007 and utilized two tagging technologies, acoustic and Passive Integrated Transponders (PIT) tags. 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. PIT tags are also inexpensive when compared to acoustic tags and allowed for a larger sample size. In addition to the mark-recapture and telemetry study, an avian predation study was conducted to determine the prevalence of avian predation occurring in the Forebay. This study focused on the abundance, distribution, and behavior of birds in the Forebay that were capable of preying on juvenile steelhead.

8.1.1 Water Quality

As changes in water quality conditions may contribute to steelhead pre-screen loss, water quality measurements were recorded hourly for the duration of the 2007 study. Water temperature was monitored using temperature recorders (Onset, model HOBO Water Temp Pro V2) from January to June and by a mulitprobe water quality meter (HACH, model Hydrolab®). The water quality meter was deployed from the SFPF trashboom at mid-depth and the temperature recorders were attached to VR2 units located in the Forebay, Old River, and intake canal. Water temperatures at the trashboom increased from approximately 9 °C (48 °F) in January to approximately 25 °C (77 °F) at the beginning of June (Figure 30). However, in 2007 there was a cold weather event in January with a low water temperature of 5 °C (41 °F). Additionally there was a warm weather event in April with a high water temperature of approximately 20 °C (68 °F).

Additional water quality variables were also measured via the trashboom-installed, multiprobe water quality meter (HACH, model Hydrolab®). These were: electrical conductivity (EC), salinity, turbidity, and dissolved oxygen (DO) concentration. EC decreased from 0.64 mS/cm in December 2006 to 0.27 mS/cm in April 2007 and increased to 0.42 by June 2007. Likewise salinity decreased from 0.33 ppt in December 2006 to 0.13 ppt in April 2007 and increased to 0.22 ppt by June 2007. Turbidity fluctuated greatly, especially in April, May, and June 2007, and was probably dependent on wind patterns (Figure 31). The wind can cause surface currents and waves within the Forebay which can cause the deposited sediment to become suspended. Turbidity values were typically measured between 1 NTU and 200 NTU. DO slowly decreased from 14 mg/L in December 2006 to 5 mg/L in June 2007. This decrease in dissolved oxygen concentration corresponds with the increase in water temperature for the same time period.

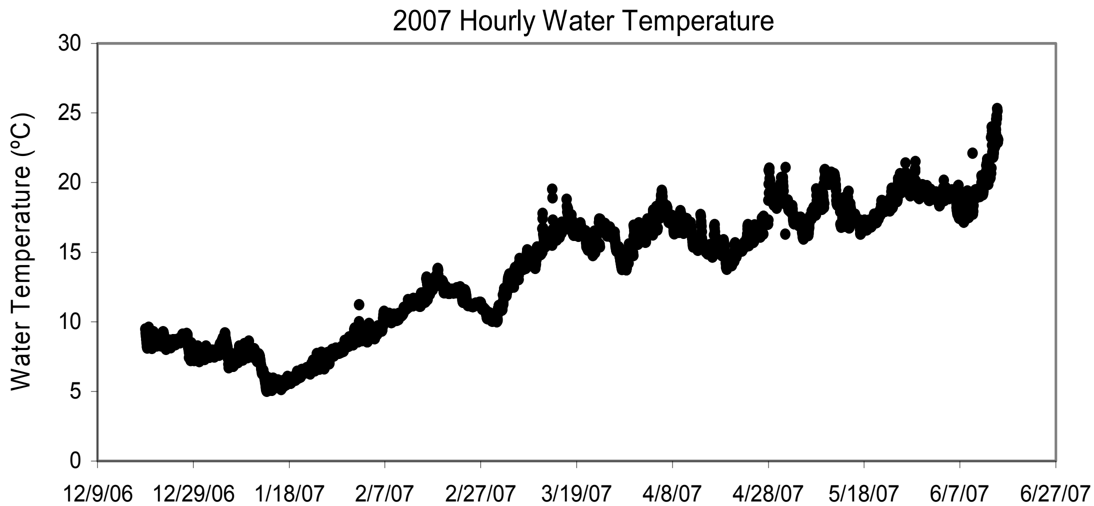

Figure 30. 2007 water temperatures measured hourly via a HACH Hydrolab at the SFPF trashboom and a HOBO temperature logger in the intake canal.

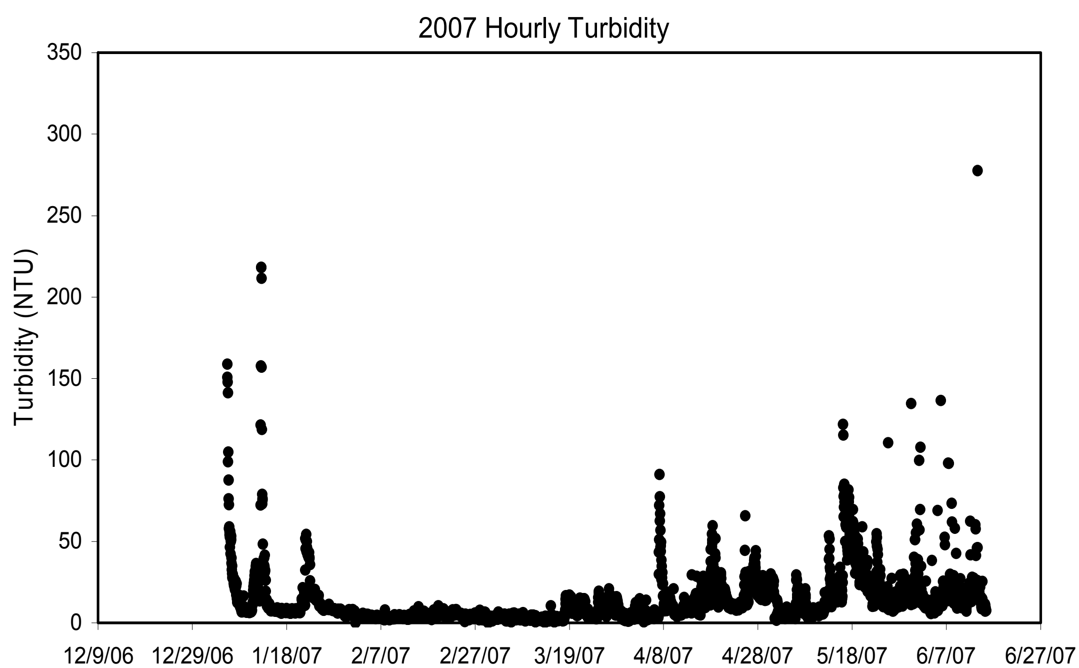

Figure 31. 2007 turbidity measured hourly via a HACH Hydrolab deployed at the SFPF trashboom.

8.1.2 Light Intensity and Day, Night, Crepuscular Classification

Light intensity may also contribute to the pre-screen loss of steelhead within Clifton Court Forebay and was recorded during the study. Light sensors measuring Photosynthetically Available Radiation (PAR) were chosen because striped bass have a peak spectral sensitivity in the 400 to 650 nm range (Horodysky, 2007). Light intensity in the 400 to 700 nm was measured by a light sensor (Onset, model S-LIA-M003) and data logger (HOBO®, model Micro Station) every five minutes starting January 11, 2007 at 11:00. The remote light sensing unit was setup near the CHTR Study Facility building which is adjacent to Clifton Court Forebay. The light sensor was pointed to the sky. Leading averages were calculated for each hour from the five minute light intensity measurements.

Light measurement data prior to January 11, 2007 was taken from the Brentwood #47 weather station (see appendices) in the California Irrigation Management Information System (CIMIS) database (CIMIS, 2007). This data was appended to the hourly light dataset recorded at the CHTR Study Facility. During the study, light intensity ranged from approximately 0 to 2,000 μmol/m^2/s (Figure 32), increasing from February 2007 through June 2007. Daily variation in the remote light sensor readings may be attributed to changes in weather, primarily by cloud cover or changes in density of fog. Weather observations were recorded daily by an observer starting January 10, 2007 and ending June 14, 2007. These observations included estimated percent cloud cover, presence or absence of fog, and light observations. Light intensity was also measured using a handheld light meter (LI-COR, model LI 250 Light Meter) with a PAR light sensor (LI-COR, model LI-190 Quantum Sensor). These additional light intensity measurements were used to verify the light intensity measurements taken by the fixed light station.

Light intensity measurements were used to classify night, crepuscular, and day. On January 5, 2008 an observer using the handheld light meter, measured light intensity every five minutes starting at sunrise and continuing until the observer determined that there was sufficient light to have the classification of day (Figure 33). The observer determined that crepuscular changed to day at 30 minutes post sunrise. Light was measured to be approximately 50 μmol/m^2/s at sunrise + 30 minutes, the observer's designation of day. These measurements were similar to measurements recorded by observers at the CHTR Study Facility while recording weather observations. Thus, categories for night, crepuscular, and day were established at 0-10 μmol/m^2/s, >10-50 μmol/m^2/s, and >50 μmol/m^2/s respectively.

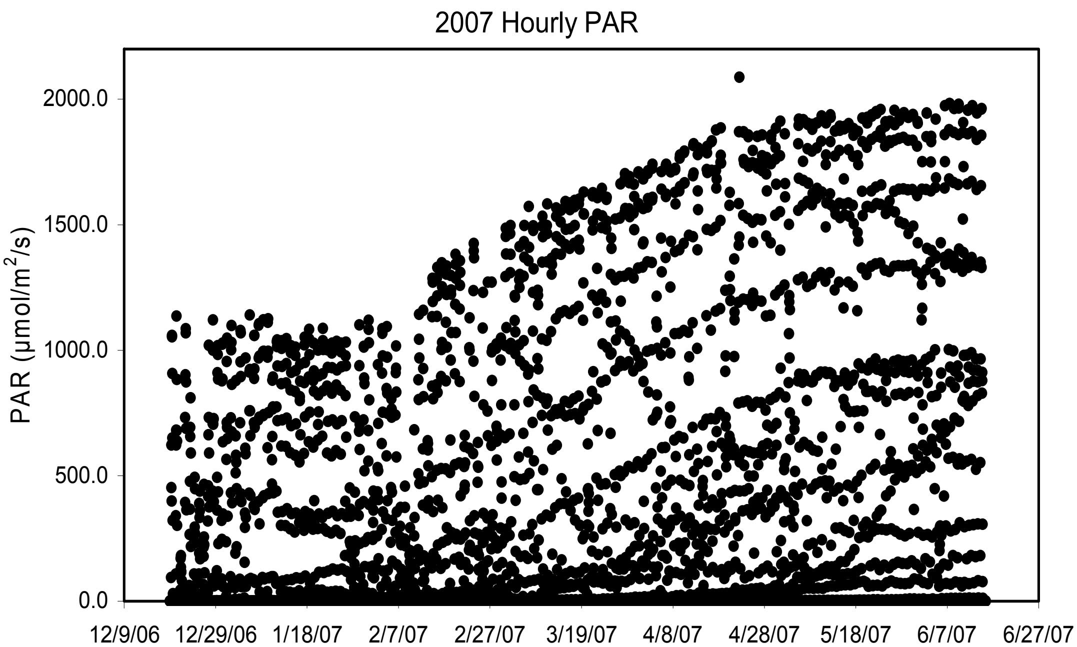

Figure 32. Hourly photosynthetically available radiation (PAR) measured via a remote station near the CHTR Study Facility including estimates from the CIMIS database in December.

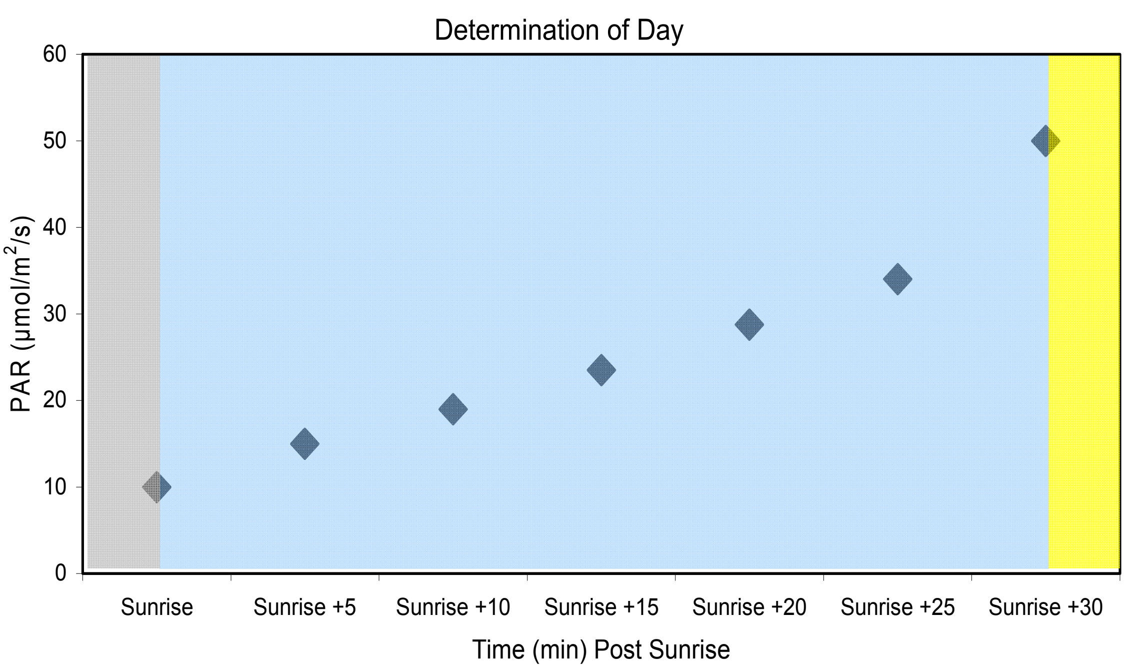

Figure 33. Day determination by an observer on January 5, 2008 during a 30 minute observation period using a handheld light meter. Grey, blue, and yellow represent night, crepuscular, and day, respectively.

8.1.3 Acoustic Tagging of Striped Bass

To gain telemetry information on striped bass, the predatory fish species of particular interest in this study, 29 striped bass were captured, acoustic tagged and released. Striped bass were captured by hook and line sampling and gill netting in close proximity to the radial gates and within the intake canal. Sampling effort at all locations was not equal. The minimum size requirement for tagging was reduced from 650 mm (26 in) (2005 pilot study criteria) to 550 mm (22 in) in order to maximize the number of striped bass tagged. Manooch (1973) and Walter and Austin (2003) found that striped bass commonly consumed prey up to 40% of the striped bass length. Thus, a 550 mm (22 in) striped bass could consume a 220 mm (8.5 in) steelhead. Manooch (1973) also found that some striped bass are capable of consuming fish that are up to 60% of the striped bass length.

Acoustic tagging of striped bass followed a similar procedure to that used in the 2005 pilot study. Each striped bass collected that was greater than 550 mm (22 in) was transferred to an aerated holding tank located onboard the sampling boat using a large rubber dip net. Each striped bass was observed for signs of stress (loss of equilibrium). When the fish was no longer showing signs of stress from capture and handling, the fish was weighed using a Boga-Grip (spring loaded suspension scale with fish lip grip) and transferred to a canvas cradle. The fish was then measured for length and was externally tagged with an acoustic transmitter (VEMCO, model V13) following the same procedure used in 2005 with minor modifications to the way in which the stainless steel wires were attached to the acoustic tag. Prior to tagging, stainless steel wires were attached to each acoustic tag by surrounding the wire and tag with heat shrink rubber tubing. The heat shrink tubing was used to replace the soft rubber backing plate used in the 2005 pilot study. The tagged striped bass was released into the Forebay at approximately the same location as capture. The external tagging operation lasted approximately four minutes per fish. The date, total length, weight, and collection location were recorded for most striped bass captured, tagged, and released. The tagged striped bass ranged in length from 550 mm (22 in) to 810 mm (32 in) with a mean of 653 ±32 mm (26 ±1.26 in) and ranged in weight from 1,360 to 6,349 g (3 to 14 lb) with a mean of 3,038 ±546 g (6.7 ±1.2 lb). The tag to body weight ratio was below 0.8% for all tagged striped bass.

8.1.4 Steelhead Fish Husbandry

Juvenile steelhead used in the 2007 full-scale study were obtained from the DFG Mokelumne River Fish Hatchery. The steelhead provided by the hatchery were selected to be representative of the general size distribution of juvenile steelhead entrained into the Forebay. These juvenile steelhead were transported in three separate events using a 1,700 L (449 gal) hauling tank and held at the CHTR Study Facility to recover from transportation and handling stress and to acclimate to water quality conditions at the site. Upon arrival at the CHTR Study Facility, fish were transferred to a 4,500 L (1189 gal) D-shaped, indoor tank with a center wall. The D-shaped tank with center wall simulated water flow in a hatchery raceway. This tank was part of a flow through system with water supplied from the intake canal. Water supplied from the intake canal was mechanically filtered via a sand filtration system and sterilized via ultraviolet (uv) sterilizers. The steelhead were held in this tank until they were tagged and moved to one of three tanks. The tagged steelhead were held in the CHTR Study Facility in two 1,500 L (396 gal) white fiberglass tanks and one 1,500 L (396 gal) black fiberglass tank. These three tanks were also part of the flow through system with water supplied from the intake canal. Air pumps delivered air to the fish tanks. The steelhead were fed a floating pellet via belt feeders daily, except when fasted for 24 hr before and after tagging. The fish tanks were cleaned and checked for mortalities daily. Water temperature was generally kept at ambient, however, a chiller was used to buffer water temperatures and keep tagged fish from experiencing stress due to elevated water temperatures. The chiller was used when water temperatures were approaching 18ºC (64.4 ºF). Even with a chiller buffering the water system, the water temperatures within the fish tanks reached 18.5 ºC (65.3 ºF) for a duration of 2 days in April.

Midway through the 2007 study (March 14th), a low DO event in the D-shaped tank was observed and a large die-off of untagged steelhead occurred over several weeks. During this die-off, several internal parasites were observed floating in the water column of the D-shaped tank. The internal parasites appeared to be an intestinal tapeworm (*Eubothrium salvelini*), but a positive identification was not obtained. Generally, tapeworms do not cause mortalities in their host, but can reduce growth and reduce condition factor. All mortalities observed were dissected and approximately 20% were infested with the internal parasites. Internal parasites were not limited to untagged steelhead. A small number of PIT tagged steelhead were found dead in the CHTR Study Facility fish tanks and upon dissection only a small percentage of those contained internal parasites.

Due to the high number of mortalities of untagged steelhead in the D-shaped tank, a new group of steelhead was procured from the Mokelumne River Hatchery. The replacement fish were held at the UC Davis Fish Conservation and Culture Laboratory (FCCL) in an outdoor rectangular tank. The tank was part of a flow through system with water supplied from the intake canal. The water was mechanically filtered via a sand filtration system and sterilized via ozonation. A chiller was used to keep water temperatures below ambient and was successful at preventing stress and mortalities due to increasing water temperatures in April 2007.

8.1.5 Acoustic Tagging of Steelhead

As part of the telemetry component of the full-scale study, juvenile steelhead were tagged with acoustic coded transmitters (VEMCO, modelV9). These transmitters were identical to the VEMCO, model V8SC used in 2005 and 2006 pilot studies, but renamed by the manufacturer. The juvenile steelhead selected for surgical implantation of acoustic tags ranged in fork length from 195 to 363 mm (7.6 to 14.3 in) with a mean of 237 ±4.81 mm (9.3 ±0.19 in). These juvenile steelhead were tagged following a similar surgical procedure to that used in the 2005 and 2006 pilot studies. Three to five surgical skin staples (3M Precise™, model Vista 35W) were used to close the incision rather than the sutures used in the 2005 and 2006 pilot studies. This change in the surgical procedure was made to reduce the time the steelhead were kept in anesthesia. The surgical procedure typically took less than two minutes from initial incision through recovery.

The use of skin staples to close the incision effectively reduced the surgical procedure by two to three minutes per fish. The acoustic tagged steelhead ranged in weight from 75.3 to 310.8 g (0.17 to 0.68 lb) with a mean of 146.0 ±8.1 g (0.32 ±0.02 lb). Tag percentage of body weight ranged from 0.93% to 3.85% with a mean of 2.16 ± 0.10%. The acoustic tagged steelhead were kept for observation in a holding tank for a minimum of 25 days to ensure recovery prior to experimental release. A few mortalities occurred and the tags were taken from those mortalities and reused. Including those reused tags, a total of 130 juvenile steelhead were acoustically tagged.

8.1.6 PIT Tagging of Steelhead

In response to the recommendations developed in the 2005 pilot study, PIT tags (Destron, model TX1411ST) were utilized as the major marking method in 2007. The juvenile steelhead selected for PIT tag implantation ranged in fork length from 111 to 310 mm (4.4 to 12.2 in) with a mean of 216.9 ±1.4 mm (8.5 ±0.05 in). These juvenile steelhead were tagged following a PIT tagging procedure manual prepared by the Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee (1999). Each juvenile steelhead was netted from the holding tank and placed into a 18.9 L (5 gal), rectangular tub that contained 106 mg/L (0.014 oz/gal) of MS-222. The juvenile steelhead was left in the tub for approximately one minute until anesthetized. The juvenile steelhead was measured for length and weight. A PIT tag implanter (Biomark, model MK7) was used to inject the PIT tag into the abdominal cavity and New-Skin liquid bandage was applied to the puncture wound to aid the healing process (Figure 34). The time to PIT tag each steelhead was less than one minute. To ensure proper disinfection the implanters were held in a 91% isopropyl alcohol for a minimum of 10 minutes before use. The PIT tagged juvenile steelhead were kept for observation in a holding tank to ensure recovery prior to release.

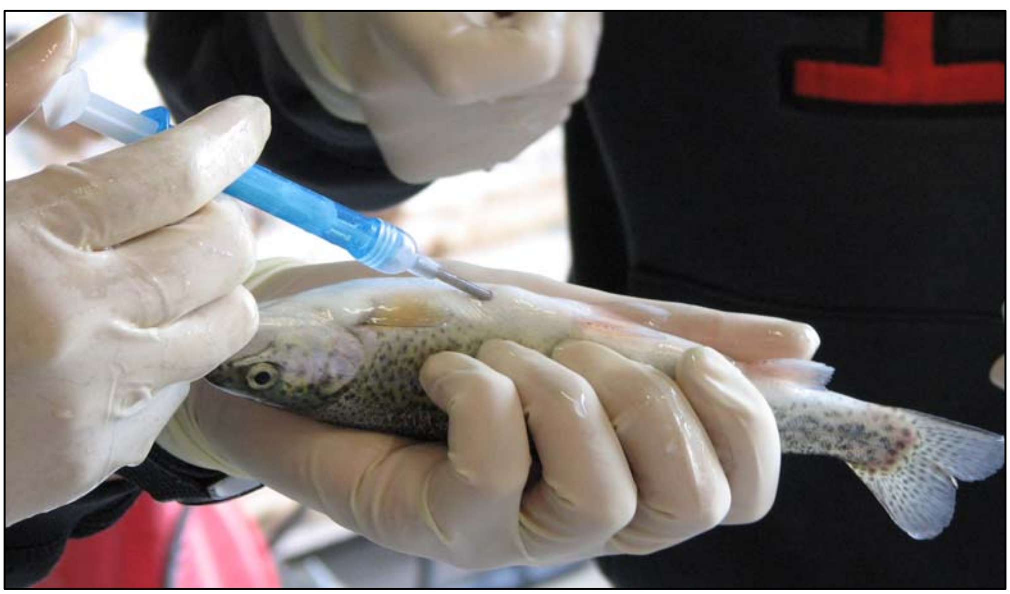

Figure 34. A MK7 implanter was used to insert PIT tags into steelhead in 2007.

8.1.7 Tagged Steelhead Releases

8.1.7.1 Radial Gate Releases

To simulate the exposure to the high water velocity and turbulence experienced by wild fish entrained into the Forebay, small groups of tagged steelhead were released immediately upstream of the radial gates using a specially constructed live-car. Prior to transportation of the tagged steelhead to the radial gates release site, all PIT and acoustic tags were checked for proper operation and the tag identification recorded. Each group of tagged steelhead was transported in aerated 18.9 L (5 gal) buckets to the release site. Releases were scheduled to target the time when the radial gates were initially opened. The timing of the releases varied with the daily changes in routine radial gate operations. Each release group of tagged steelhead was loaded into the live-car in Old River immediately outside of the Forebay. The live-car was positioned against the wing wall leading to radial gate number one. The tagged steelhead were acclimated for 2 hours to recover from transportation and handling stress prior to release. The radial gates were closed during the acclimation period. Once the acclimation period was complete and after the radial gates were opened, the live-car was moved into position immediately upstream of the radial gates by manually pulling the floating live-car along the wing wall. Once in position, the front door of the live-car was released via remote ropes (Figure 17). This allowed the tagged steelhead to exit the velocity refuge of the live-car, into the flow passing through the radial gates, and become entrained into the Forebay. After a few minutes, the back door of the live-car was triggered to open and flush any remaining steelhead from the live-car. Figure 8 shows an example of the typical calculated flow rates passing through the radial gates at the time of steelhead release. However, there was one extremely high flow event on April 16, 2007 (Figure 9).

PIT tagged steelhead were released using the live-car as part of the mark-recapture experiment. PIT tagged steelhead releases began on January 8, 2007 and were generally conducted 5 days or nights per week through April 16, 2007 with alternating release group sizes of 10 or 20 fish. However, there were two weeks in which releases were not conducted due to equipment failure and safety concerns. In total, 922 PIT tagged steelhead were released upstream of the radial gates, with 220, 260, 260, 182 PIT tagged steelhead released in January, February, March, and April, respectively.

Acoustic tagged steelhead were released as part of the telemetry component of the experiment. The acoustic tagged steelhead were released into the Forebay during February – April, 2007 to coincide with the seasonal period that steelhead have been observed in SFPF salvage data. January releases were precluded by the steelhead received from the hatchery not yet being of taggable size. Releases of acoustic tagged steelhead began on February 7, 2007 using the live-car method described above. However, the last radial gate release of acoustic tagged steelhead was conducted using 18.9 L (5 gal) buckets rather than the live-car due to safety concerns with the high flow event observed on April 16, 2007 (Figure 9). During the last radial gate release the acoustic tagged steelhead were lowered to the water surface utilizing a bucket with a rope attached to the handle. A second rope was attached to the bottom of the bucket and was used to subsequently tip the bucket into the flow and release the fish. Therefore, there was no acclimation period. Acoustic tagged steelhead were generally released in groups of 10 or 20 fish. Not all acoustic tagged steelhead were released. In comparison to the 2005 and 2006 pilot studies, the standard for the quality of acoustic tagged steelhead was raised in 2007. Those acoustic tagged steelhead showing abnormal swimming behavior or appearing stressed were not released. In total, 64 acoustic tagged steelhead were released upstream of the radial gates, with releases of 30, 30, and 4 acoustic tagged steelhead in February, March, and April, respectively.

8.1.7.2 Tagged Steelhead Releases Within the SFPF

To estimate the salvage efficiency of the SFPF tagged steelhead were released within the SFPF immediately downstream of the trash rack which is immediately upstream of the primary louvers in the primary louver bays. Beginning January and February 2007, PIT and acoustic tagged fish, respectively, were released using a bucket release technique. These releases were generally conducted 5 days or nights per week and were scheduled to coincide with the releases conducted at the radial gates. Generally, 25 PIT tagged steelhead per week or 10 acoustic tagged steelhead per week were released within the SFPF coinciding with the type of tagged steelhead being released upstream of the radial gates. Tagged steelhead were released at the SFPF in smaller groups than at the radial gates, but consisted of a daily ratio consistent with the daily ratio at the radial gates. For example, if on Monday 20 PIT Tagged fish were released upstream of the radial gates (25% of the week's scheduled radial gate released fish) then 6 PIT tagged fish were released inside the SFPF (~25% of the week's scheduled fish releases within the SFPF). Similarly, acoustic tagged steelhead were released according to a daily ratio. Tagged steelhead were lowered to the water surface utilizing a bucket with a rope attached to the handle. A second rope was attached to the bottom of the bucket and was used to tip the bucket into the water and release the fish. Again, not all tagged steelhead were released. Those showing abnormal swimming behavior or appearing stressed were not released. During the 2007 study, 239 PIT tagged steelhead were released within the primary louver bays, with releases of 12, 86, 81, 60 PIT tagged steelhead in January, February, March, and April, respectively. During the 2007 study, 15 acoustic tagged steelhead were released within the primary louver bays, with releases of 9 and 6 acoustic tagged steelhead in February and March, respectively.

8.1.8 Acoustic Fixed Station Receiver Grid

To track acoustic tagged striped bass and steelhead throughout the Forebay, a similar receiver network to that used in the 2006 pilot study was employed in 2007. The network of fixed station receivers (VEMCO, VR2) was designed to cover the entire Forebay, SFPF, Old River, and the intake canal leading to the Harvey Banks Pumping Plant (Figure 35). The receiver array was installed November - December 2006 before acoustic tagged steelhead were released and remained in the Forebay through the entire 2007 study period. The VR3-UM receivers used in the 2006 pilot study were not used in the 2007 full-scale study. The fixed station receivers were attached to a mooring line with the use of cable ties and kept in an upright position while submerged completely underwater between a mooring anchor and a float. Downloads of the receivers' internal memory were conducted monthly to ensure that the units were working properly. The monthly receiver interrogation also prevented the receiver's internal memory from becoming full and thus prevented the loss of tag detection data. During the study, two fixed station receivers were found to be malfunctioning and were replaced. All receivers were removed from the study area June 15, 2007.

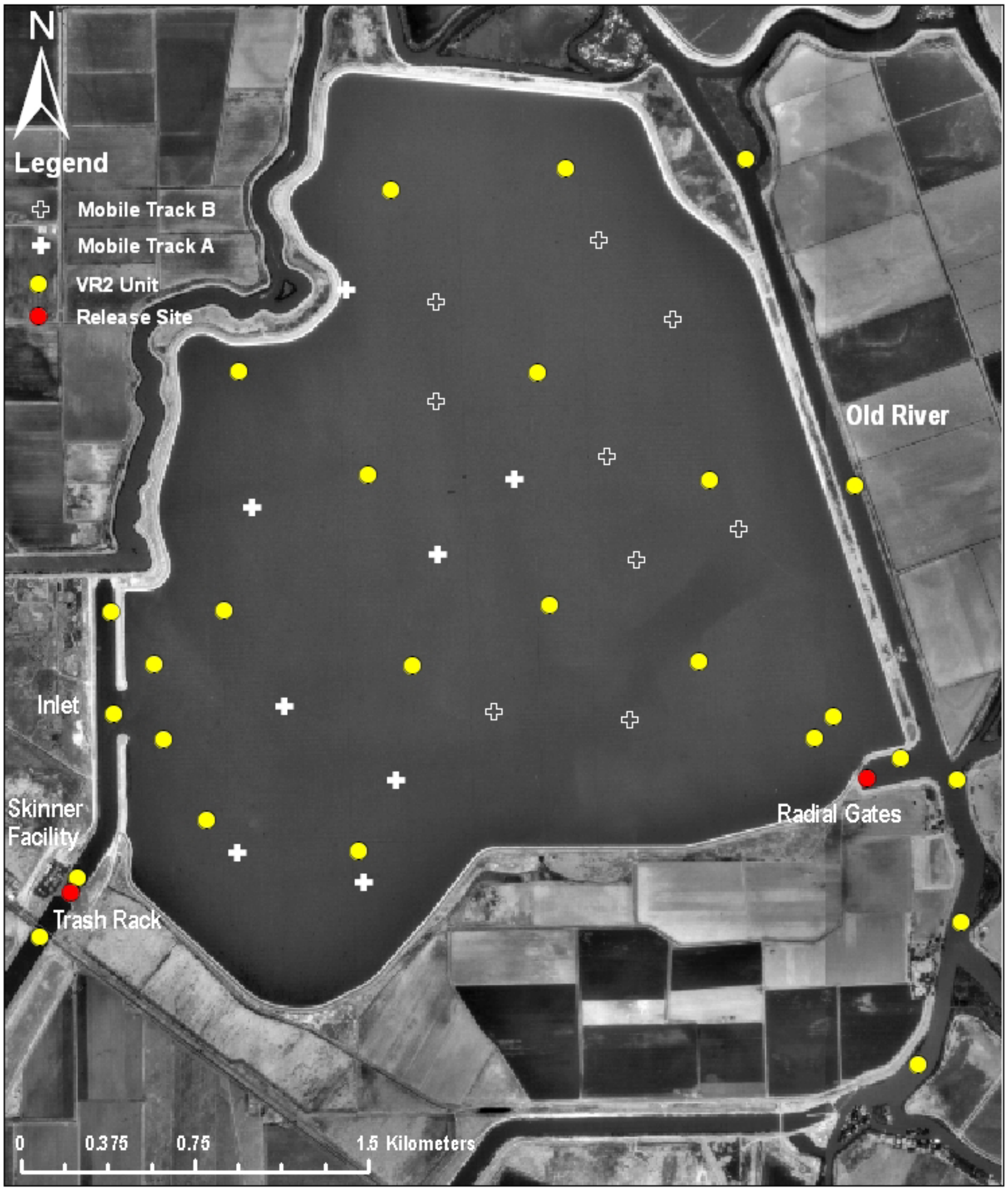

Figure 35. 2007 fixed station receiver array and mobile monitoring locations. Yellow circles indicate the VR2 locations. The plus symbols indicate the mobile monitor locations. The red circles indicate the steelhead release locations.

8.1.9 Mobile Monitoring

Mobile monitoring of acoustic tagged steelhead and acoustic tagged striped bass was conducted within the Forebay to track fish movement patterns throughout the Forebay and to validate the fixed receiver data. Mobile monitoring began in February and continued through early June 2007. Mobile monitoring was conducted from two boats using handheld GPS units and two mobile monitoring units (VEMCO, model VR100) equipped with omni-directional and/or directional hydrophones. In 2007, mobile monitoring stations were established creating two mobile monitoring transects, transects A and B. The mobile monitoring stations were setup to fill in the areas between fixed station receivers and were no closer than 530 m (0.33 mile) to the closest VR2 unit (Figure 35). Numbered buoys were deployed at each mobile monitoring station and GPS positions for these stations were recorded for easy identification by mobile monitoring crews. Using GPS reference points and the numbered buoys, a transect pattern was traveled using the research boats covering the entire Forebay in a single day. When using a mobile monitoring unit, the boat was fully stopped and the engine was switched off to avoid signal contamination from noise and cavitations. The omni-directional hydrophone was submerged to a depth of approximately ½ the distance to bottom or a maximum of 1.5 m (5 ft). Any coded tag detections received on the mobile monitoring unit were recorded onto data sheets identifying time, date, tag ID number, GPS coordinates and the approximate position within the Forebay was marked on a field map. Also noted were the positions of the radial gates (open or closed) and weather conditions when possible.

8.1.10 Central Valley Fish Tacking Consortium Database

The Central Valley Fish Tracking Consortium (CVFTC) database was used to track acoustic tagged juvenile steelhead and adult striped bass that emigrated from Clifton Court Forebay either via the radial gates or through the salvage process in 2007. The CVFTC is a collaboration between several academic, government, and private organizations working together to answer questions regarding anadromous fish life histories. The CVFTC fixed station receivers (VEMCO, VR2) cover the Sacramento River directly below Lake Shasta to the Golden Gate Bridge. VR2 receivers are also located within the Sacramento-San Joaquin Delta and Carquinez Straits. The CVFTC receiver grid is primarily used to track the movement of acoustic tagged anadromous fish and to estimate mortality of those fish in the Sacramento River watershed. UC Davis and NMFS researchers maintain the database of acoustic tag detections and receiver deployment locations for those receivers that are maintained by CVFTC scientists. The database is available to all members of the CVFTC.

8.1.11 Acoustic Tag Detection Analysis

VEMCO VR2pc software and Microsoft Excel were used to analyze the downloaded fixed station receiver detections. Using the VEMCO VR2pc software, all receiver detections were "searched" for each steelhead's and striped bass' tag ID and a "search" file was created containing the receiver serial IDs and the dates and times of detection for each acoustic tagged fish. Once "searched", the detection locations and times were examined to determine the movement of each acoustic tagged steelhead and striped bass.

8.1.12 Steelhead Acoustic Data Consolidation

To further analyze the steelhead acoustic data, Microsoft Excel was used to consolidate and summarize the telemetry data. The fixed station receivers were capable of detecting a fish approximately every 10 to 20 seconds, therefore there could be as many as 180 detections per hour per fish at each location. Within a one minute period, several juxtapositioned receivers could simultaneously detect an individual fish, resulting in significant tag signal overlap and hence difficulty in determining fish position among receivers. In addition, because the environmental, physical, and operational conditions were sampled or recorded hourly, a consolidated hourly fish position for each fish was needed for comparison to those recorded conditions.

To determine a consolidated hourly position for each fish, each acoustic tagged steelhead's detection history was first tabulated, with the number of detections at each receiver for each one hour study period summed. Next, these hourly sums for each receiver were totaled across the hour period to yield the Total Number of Detections across receivers per hour (TD). Then a maximum hourly sum of detections (MD) was determined across the receivers for each hour, yielding the receiver location with the most detections for that hour. Finally, a ratio was calculated between the MD and the TD for each hour. If the MD/TD ratio was greater than 50%, and the TD was greater than 2 detections, then the MD receiver location was selected as the fish position for that hour. Hence the spatial location of that fish for that hour was assigned to the location of the MD receiver. If the MD receiver consisted of less than 50% of the total number of detections (MD/TD<0.50), then no fish position was recorded for that hour. It was assumed that the fish stayed at the previous hour's location for that hour. False detections were low and were usually indicated by a receiver with less than two detections per hour, thus the need for the requirement of more than two detections for positive location identification. For an example of the consolidation process, if one steelhead was detected twice in hour number one at VR2 #11 and was not detected at any other receiver within that hour, then no location was assigned for that hour. However, if that same steelhead was detected ten times at VR2 #6, and five times at VR2 #2 in hour number two, then that steelhead was assigned a position at VR2 #6. If that same steelhead was detected five times at VR2 #6, seven times at VR2 #2, and three times at VR2 #11 in hour number three, then the steelhead was not assigned a location for hour number three, because less than 50% of the total detections were at VR2 #2, the receiver with the maximum summed detections (MD).

A limitation of the employed telemetry equipment included tag signal collisions between acoustic tags (Pincock, 2008). As more and more steelhead tags were located for long durations of time at the radial gates (VR2 #27 and VR2 #28), tag signal collisions and tag detections became an issue. Signals being detected from one tag could prevent the detection of signals from other tags in the same location. VEMCO has a tag collision calculator for their tags located at http://www.vemco.com/education/collision.php. Using this calculator one could see that if ten tags were in close proximity to each other, then it could take 60 minutes for all of the tags to be detected. Thus, in our data consolidation process, when summing detections over an hourly period and comparing those sums across receivers, VR2 #27 and VR2 #28 could have been underrepresented as those receivers were the two closest receivers to the radial gates within the Forebay. To address this issue, VR2 #27 and VR2 #28 detection files were merged into one file and treated as having been recorded on a single fixed station receiver. By merging these two files, the radial gate location was weighted to alleviate the tag signal collision limitation. At no other location was signal collision deemed an issue.

8.1.13 Steelhead Acoustic Trimming

Another limitation of telemetry equipment is that the behavior of a predator cannot be distinguished from that of the prey, if a tagged prey fish is consumed (Beland and others, 2001). In other words, if an acoustic tagged steelhead was consumed by a striped bass the steelhead's tag would still be received by the fixed station receivers. Thus, there was the potential to have "steelhead" detections that really belonged to a striped bass. To account for these possible striped bass movements as a result of predation on the acoustic tagged steelhead, the steelhead acoustic tag detection data were "trimmed". Evacuation rates for predated steelhead tags in striped bass were considered a function of water temperature (Johnson and others, 1992). The temperature at the last received detection was therefore inputted to an evacuation rate regression equation derived from estimated striped bass stomach evacuation rates (Johnson and others, 1992) (Figure 36). The result of which predicted time between predation and evacuation. For the purpose of this analysis, it was assumed that unless the tag was stationary for a long period of time (several days), the last received detection of each steelhead was that of an evacuated tag. In the case where a steelhead tag was stationary for several days, the date and time of the first stationary detection was recorded as the last received detection. Therefore, the outputted number of hours after predation until evacuation for each steelhead was used as the number of records (hours) to trim off the end of each acoustic tagged steelhead's detection data. For purposes of this analysis, the remaining data (unpredated steelhead records) were called "Remain", and the records that were trimmed off (predated steelhead records) were called "Trim". Thus, "trim" records correspond to the records when the steelhead acoustic tags could have been in a striped bass intestinal tract.

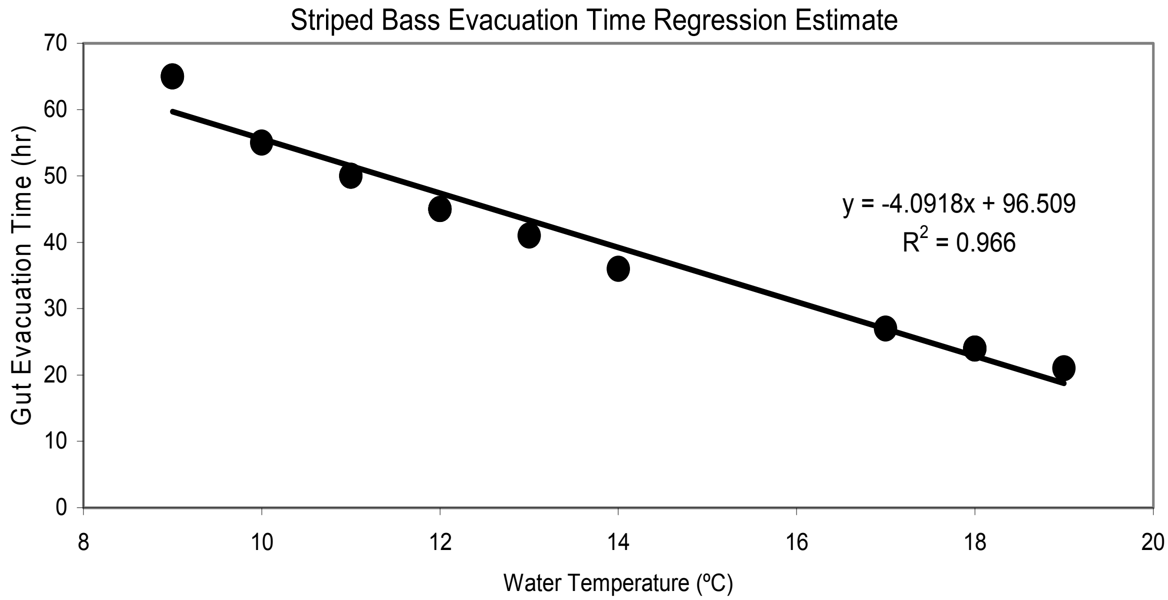

Figure 36. Linear regression of striped bass gut evacuation rates from data derived from Johnson and others 1992.

8.1.14 Striped Bass Acoustic Data Consolidation

The hourly position for each striped bass was determined in the same manner as was used for the acoustic tagged steelhead. Striped bass acoustic tag detections were recorded via the fixed station receiver network deployed in Clifton Court Forebay, Old River, SFPF salvage holding tanks, and the intake canal. Several juxtapositioned receivers could simultaneously detect an individual fish, resulting in significant tag signal overlap that made it difficult to determine fish position among receivers. In addition, because the environmental, physical, and operational conditions were sampled or recorded hourly, a consolidated hourly fish position was needed for comparison to those recorded conditions.

8.1.15 PIT Tag Detection System

To detect salvaged, PIT tagged steelhead released as part of the mark-recapture experiment, a PIT tag detection system was installed at the two SFPF salvage release sites. The detection system consisted of three custom made, circular antennae at the Horseshoe Bend release site (Figure 37) and two custom made, circular antennae at the Curtis Landing release site. Fish salvaged were trucked to the release sites and released through these pipes outfitted with PIT antennae according to the SFPF standard operating procedures. Thus, all detections of PIT tagged steelhead were made post salvage. All PIT tagged steelhead detected during the salvage release process were considered successfully salvaged and alive. Striped bass of the size required to consume the PIT tagged steelhead are rarely seen within the SFPF fish hauling truck. Attached to each antenna was a tuning box and a reader (Destron, model FS2001F-ISO), capable of storing 4400 tag detections each with a time and date stamp. Once the equipment was installed, the antennae were tuned according to manufacturer specifications. Multiple antennae and readers were used at a single site to create redundancy lest one antenna reader combination missed a tagged steelhead moving through the pipe. As a precautionary measure, the PIT tag detection system data was uploaded frequently to prevent loss of data due to possible equipment failure.

Eight tag detection efficiency tests were conducted throughout the 2007 study with four at each of the two SFPF salvage release sites. The efficiency tests utilized groups of 10 PIT tagged steelhead which were placed directly into the SWP fish hauling truck tank or the SFPF salvage holding tank. These fish were subsequently taken to the release site during a routine fish haul and were released through the release pipe outfitted with the PIT tag detection system antennae. Results of the tag detection efficiency test indicated that the efficiency of the two systems was a combined 98.75%.

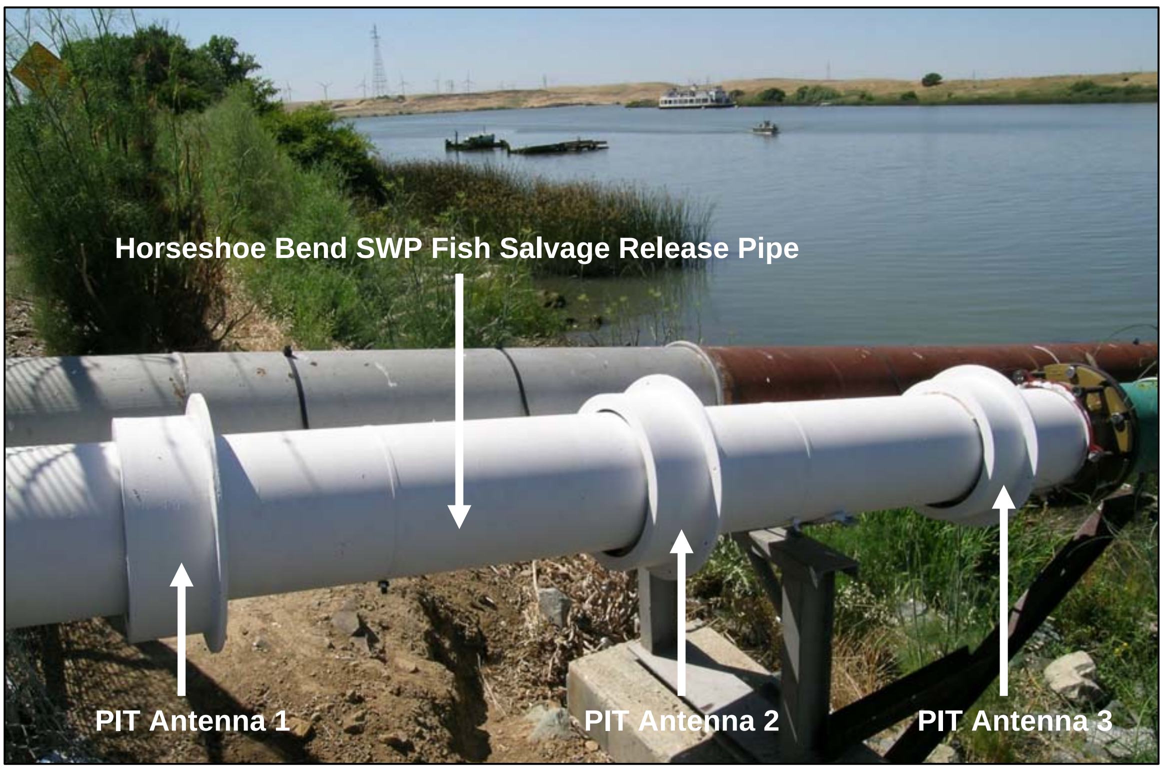

Figure 37. PIT antennae installed around the release pipe at the Horseshoe Bend, SFPF salvage release site.

8.1.16 Avian Predation Monitoring

A predatory bird point-count survey was completed to discover if avian predation on juvenile steelhead in Clifton Court Forebay was occurring. This survey focused on the abundance, distribution, and behavior of birds in the Forebay. Specific focus was given to birds that were capable of preying on juvenile steelhead 200 to 300 mm FL (7.9 to 11.8

in) during the period when steelhead emigrate through the Delta. The Forebay was divided into 3 zones (Figure 38), each with a corresponding vantage point. Vantage points were located on a road that surrounds the Forebay and collectively provided visual coverage of the entire reservoir surface area. A survey consisted of one observation at each of the vantage points. Bird observations were aided with a 20 X 60-power spotting scope and 8 X 42-power binoculars. Birds were identified to species with the aid of a field guide (Peterson, 1998). Each observation was 5 to 15 minutes per zone depending on bird densities present. Surveys were completed 2 to 3 times per week with a total of 87 surveys for the entire sampling season. Typically, one survey was performed per sampling day, although two surveys were conducted on a small number of sampling days. Timing of these surveys was fairly random and predominantly during daylight hours, with occasional attempts to target crepuscular periods.

During each observation the following data were recorded: zone number, bird location within a particular zone, time of observation, abundance/species or taxa, and general behavior. Behavior fell into 4 categories: roosting, flying, floating, and foraging. Foraging strategies varied among species and ranged from diving below the water's surface (Double Crested Cormorant and grebe) to slowly walking along the shoreline (Great Blue Heron). Foraging data were expressed as the percentage of a species foraging in a particular zone during a single observation.

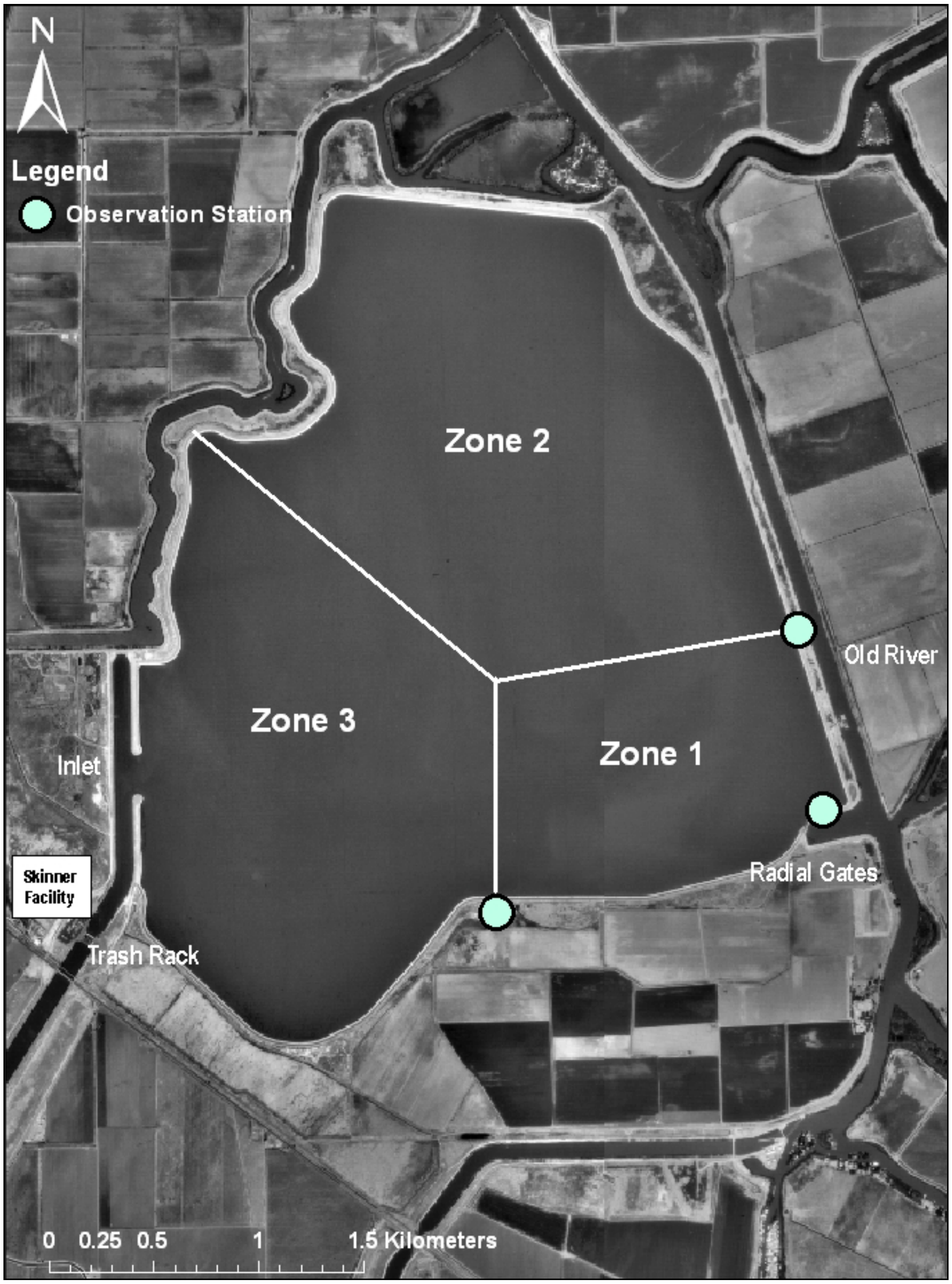

Figure 38. Avian point count zones within Clifton Court Forebay. The circles denote the three observation stations.

8.1.17 Statistical Methods

Microsoft Excel®, SigmaStat® 3.5, SigmaPlot® 10.0.1, and Systat® 11 software were used to perform statistical analyses. Descriptive statistics were used to characterize samples. For all hypothesis tests, the following procedure was followed: determine if the data met the assumptions of parametric statistical testing procedures (independence of observations, normality, and homogeneity of variance). If the data met these assumptions a parametric hypothesis test was used. If the data did not meet these assumptions the appropriate non-parametric equivalent was used.

8.2 Results

8.2.1 Acoustic Tagged Steelhead Movements

Once entrained into the Forebay, the 64 acoustic tagged steelhead displayed varied movement patterns. A few steelhead were observed to move to the intake canal within hours of entrainment (Figure 39). Many steelhead were observed to remain near the radial gates for the duration of the tags' battery life (Figure 40). Yet, other steelhead dispersed to the extreme northern and southern areas of the Forebay (Figures 41 and 42). Of the 64 steelhead entrained into the Forebay, 12 (19%) steelhead were detected in the intake canal (Table 10). Ten of the 12 steelhead detected in the intake canal were also detected at the trashboom (Table 10). However, six of the steelhead detected at the trashboom were subsequently detected in Old River indicating that they had emigrated through the radial gates (e.g. Figure 42) (Table 10). Only two (3%) acoustic tagged steelhead were detected as having been successfully salvaged (Figures 39 and 41) (Table 10). Of the 64 entrained steelhead, none were detected moving through the primary louvers towards Harvey Banks Pumping Plant. Twenty (31%) of the acoustic tagged steelhead entrained were detected in Old River with two of those steelhead being entrained a second time.

Salvage of the 15 acoustic tagged steelhead released directly into the primary louver bay was high. Twelve (80%) of the steelhead released directly into the SFPF primary louver bays were detected within the SFPF holding tanks. However, one (7%) steelhead released within the primary louver bays was detected moving through the louvers and downstream of the SFPF. Two (13%) of the steelhead released within the primary louver bays were detected moving upstream through the trash rack and past the trashboom. Neither of these two steelhead was subsequently salvaged and one (tag ID # 1351) of the two was detected directly under the trashboom without movement for nearly two months.

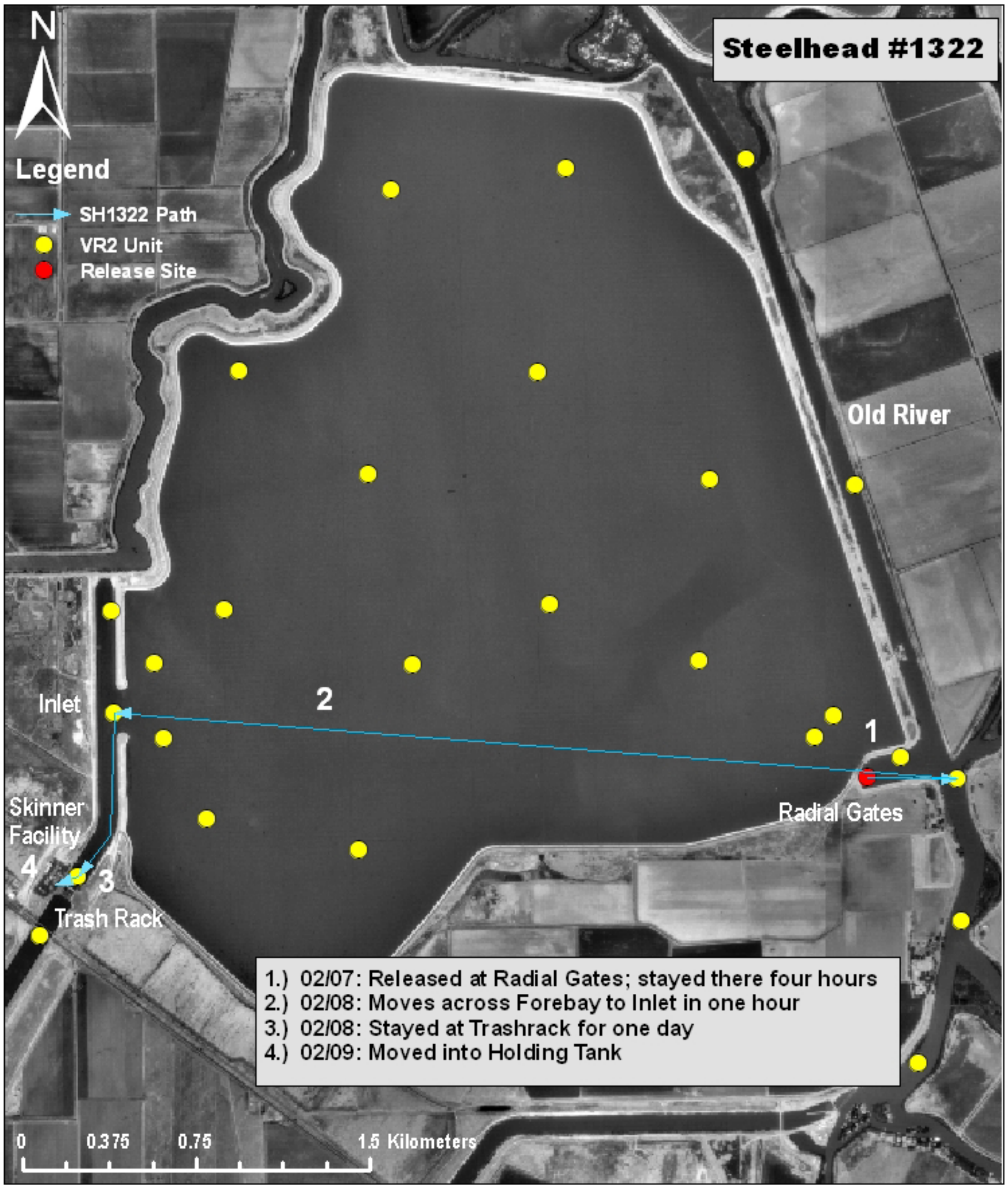

Figure 39. Steelhead tag ID 1322 path to the SFPF holding tank.

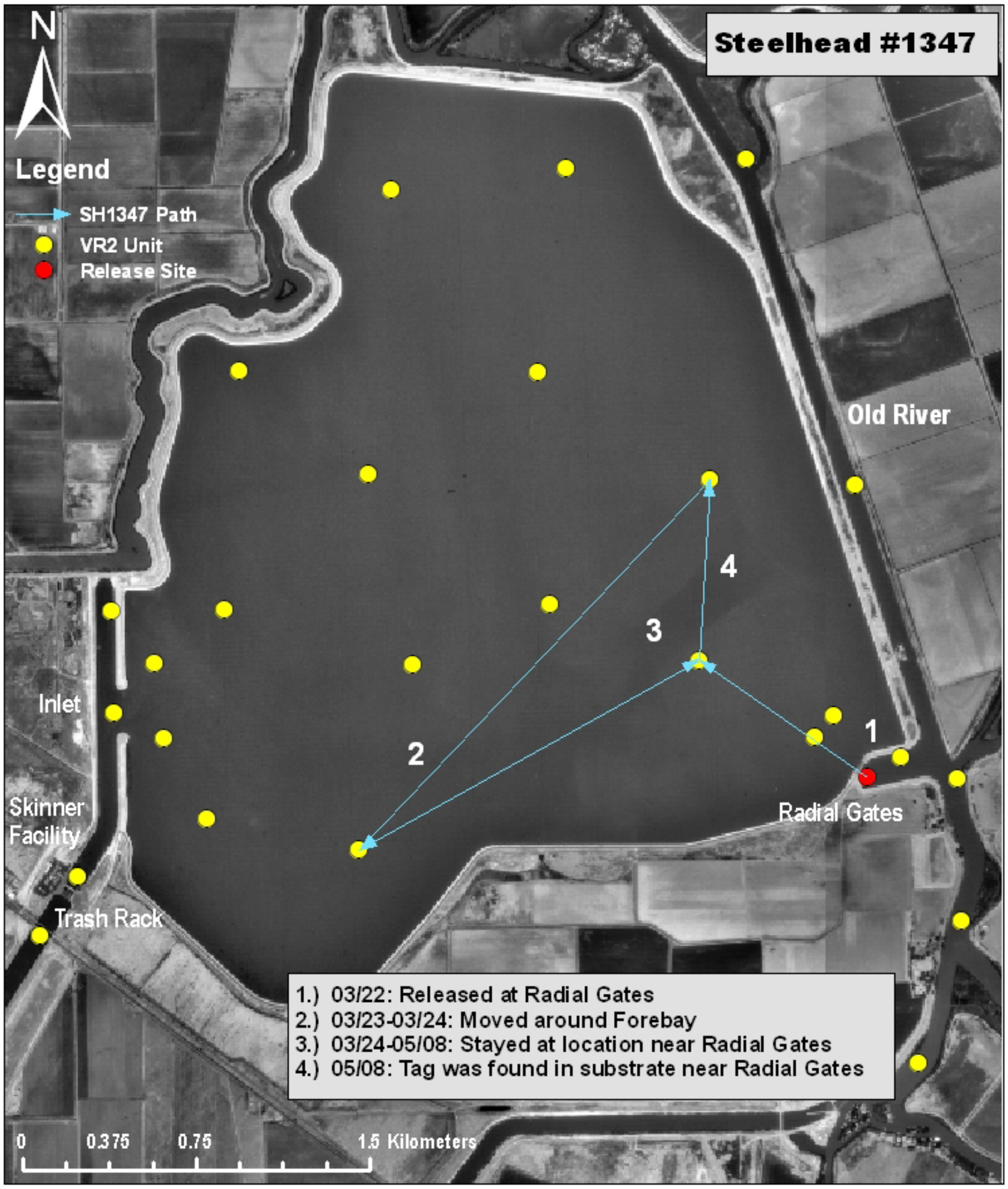

Figure 40. Steelhead tag ID 1347 was detected near the radial gates for 45 days. The acoustic tag was recovered from the bottom of the Forebay while conducting mobile monitoring.

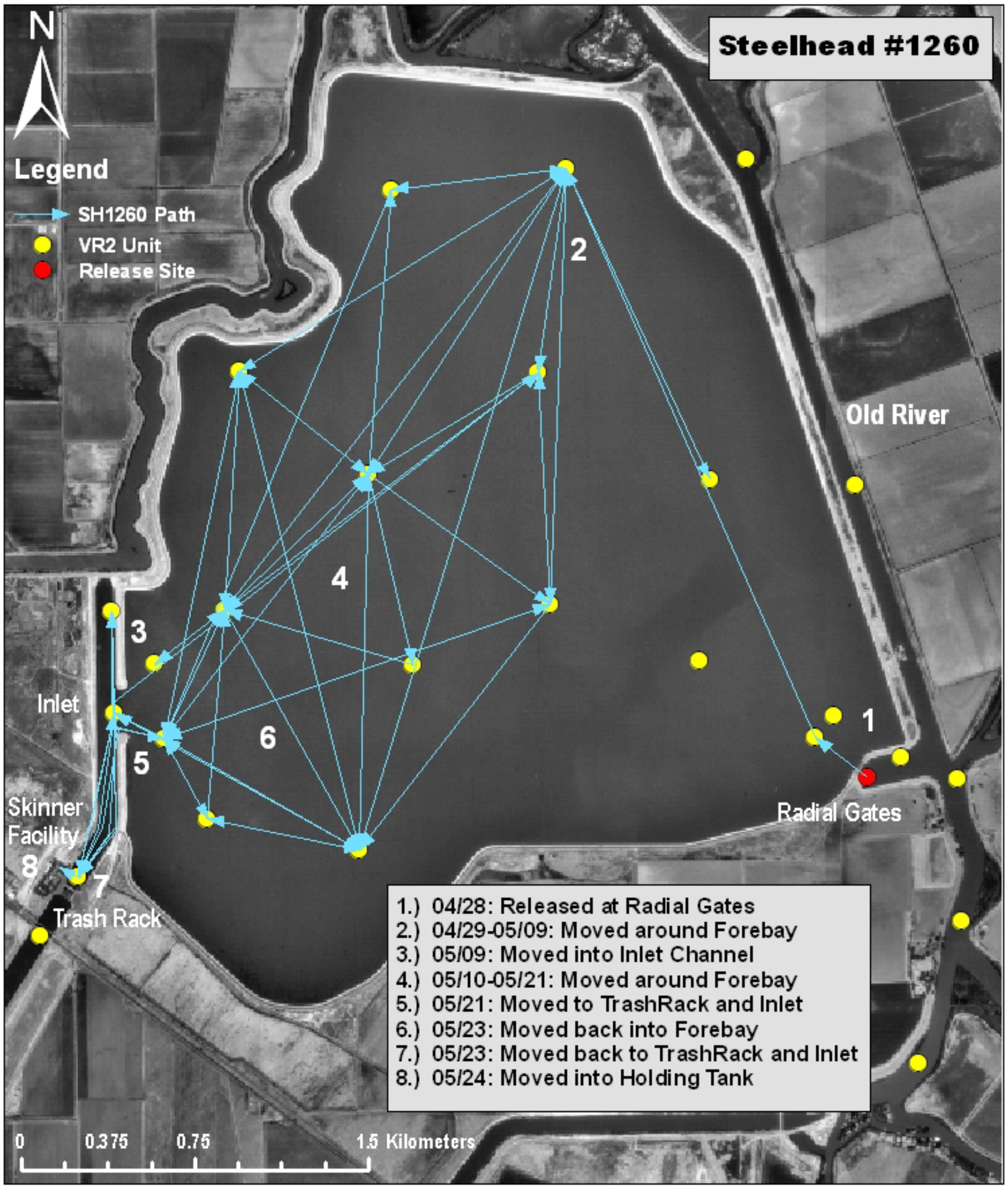

Figure 41. Steelhead tag ID 1260 path to the SFPF salvage holding tank.

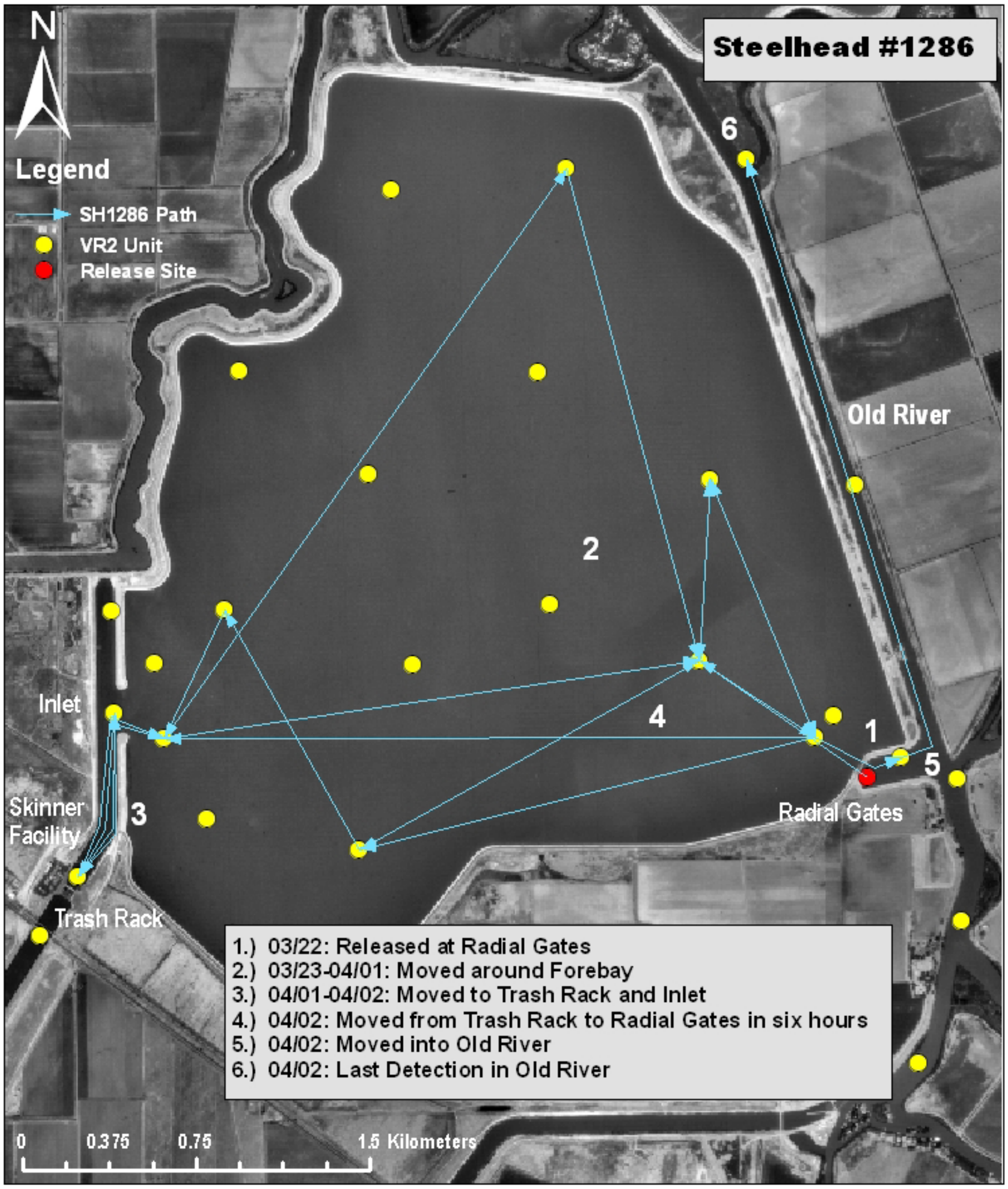

Figure 42. Steelhead tag ID 1286 was detected moving into the intake canal leading to the SFPF and then moved across the Forebay and emigrated into Old River.

Table 10. Fixed station receiver data summary for 25 of 64 steelhead entrained that were detected at either the intake canal, trashboom, SFPF, and/or Old River. Steelhead not detected at any of these locations were not included in the table. The total number of acoustic tagged steelhead released was used to calculate the percentage of fish detected at the four locations.

Tag ID	Release Date	Intake Canal	Trash-boom	Salvage Holding Tank	Old River
1236	3/22	-----	-----	-----	X
1260	4/28	X	X	X	-----
1285	3/23	-----	-----	-----	X
1286	3/22	X	X	-----	X
1288	4/28	X	X	-----	-----
1294	3/23	-----	-----	-----	X
1296	3/23	-----	-----	-----	X
1297	2/8	X	X	-----	X
1299	2/7	X	-----	-----	-----
1300	2/7	X	X	-----	X
1301	2/8	X	X	-----	-----
1304	2/8	-----	-----	-----	X
1322	2/8	X	X	X	-----
1332	2/7	-----	-----	-----	X
1336	2/8	-----	-----	-----	X
1339	3/23	-----	-----	-----	X
1346	3/23	X	X	-----	X
1349	3/23	-----	-----	-----	X
1353	3/22	-----	-----	-----	X
1360	3/23	-----	-----	-----	X
1368	3/23	-----	-----	-----	X
1369	3/22	-----	-----	-----	X
1371	3/22	X	-----	-----	X
1372	3/23	X	X	-----	X
1373	3/23	X	X	-----	X
Fish Detected (% of total released)		12 (19%)	10 (16%)	2 (3%)	20 (31%)

Transit times for steelhead were calculated from the release point at the radial gates to the first detection at the intake canal, trashboom, SFPF salvage holding tanks, and Old River. For those steelhead detected in the intake canal, the mean transit time was 7.2 days. Three of the 12 steelhead detected at the intake canal had transit times of fewer then 1 day. The mean transit time from the release point to the trashboom was 12.4 days, however 3 of the 9 steelhead detected at the trashboom had transit times greater than 20 days. Mean transit time to the SFPF salvage holding tank from point of release was 13.5 days, however, only 2 of the 64 steelhead tags were detected as having been salvaged with transit times of 1 day and 26 days. Mean transit time for the steelhead released at the radial gates observed emigrating out of the Forebay and into Old River was 10.4 days with a wide range of transit times from less than 1 to 46 days. Thirty percent of the steelhead emigrating from Clifton Court Forebay through the radial gates were earlier detected at the SFPF trashboom.

Fixed receiver tracking within Clifton Court Forebay ended at the time the receivers were removed from the water, June 25, 2007. Steelhead final detections were based on those receivers' data. Of the 64 juvenile steelhead entrained into the Forebay, 44 (69%) remained in the Forebay at the end of the study period (Figure 43). Of the 44 steelhead tags remaining within the Forebay, 29 tags were last detected at the radial gates and one was located at the trashboom. Several of the steelhead last detected within the Forebay were stationary for a long period of time with no subsequent movements. For example, one steelhead was detected at the radial gates for 17 weeks continuously. Similar to the 2005 and 2006 pilot studies, these data demonstrate that either juvenile steelhead may remain resident within the Forebay for extended periods of time before salvage or that the steelhead tags lay on the bottom of the Forebay as a result of tag shedding or predation. A total of two (3%) of the juvenile steelhead were detected in SFPF salvage holding tanks and 18 (28%) were last detected in Old River (Figure 43). One of the steelhead last detected in Old River was detected at a single fixed receiver location within Old River for five weeks.

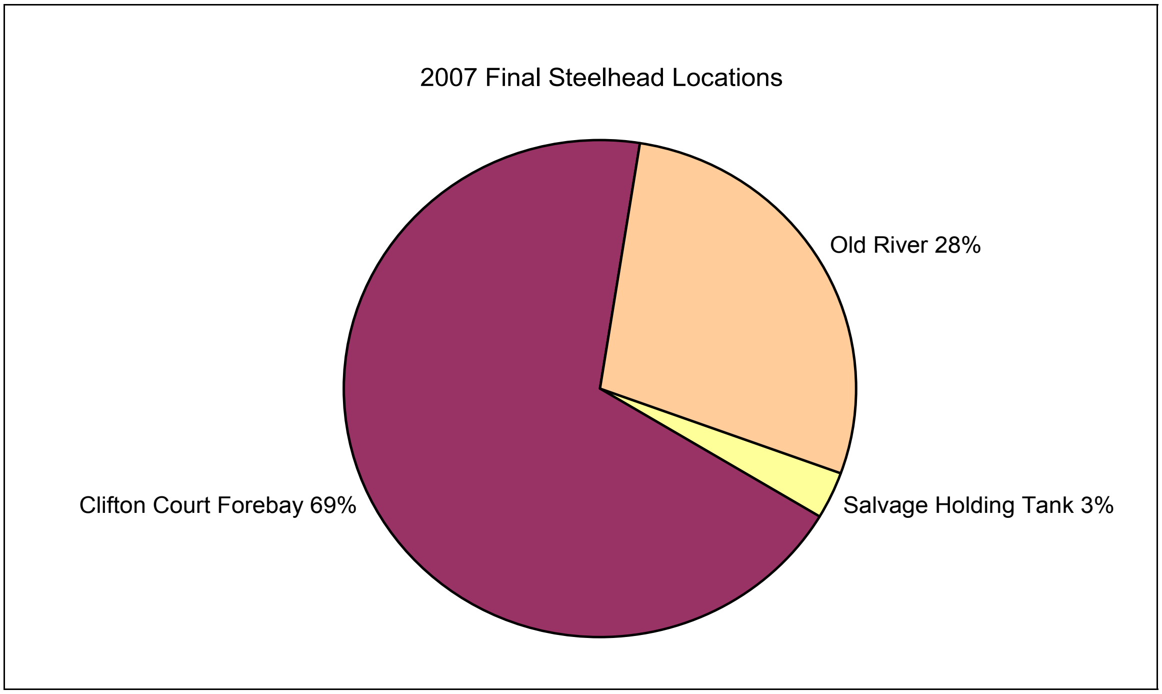

Figure 43. Percentages and locations for final detections of acoustic tagged steelhead released during the 2007 full-scale study.

The Central Valley Fish Tracking Consortium (CVFTC) database was also searched for records of the steelhead that were last detected in Old River or were salvaged at the SFPF. Of the two steelhead released at the radial gates and salvaged, one was not detected on the CVFTC network of receivers. The other salvaged steelhead was detected moving downstream from the SWP fish release site past Chipps Island, the Benicia Bridge, Carquinez Bridge, Richmond Bridge, Bay Bridge and last detected in the Port of Oakland. Of the eighteen last detected in Old River, several were observed near Decker Island and Horseshoe Bend. Two steelhead last detected in Old River were detected on the CVFTC network of receivers moving rapidly upstream on the Sacramento River as far as the confluence of the Feather and Sacramento Rivers. These rapid, lengthy movements are indicative of possible predation of the tagged steelhead while in the Forebay. However, it cannot be confirmed that any of the acoustic tagged steelhead emigrating from the Forebay had been preyed upon, and that their predators moved from the Forebay through the radial gates and into Old River.

Steelhead released within the SFPF primary louver bays and salvaged displayed similar movement patterns. Of the 12 steelhead released within the SFPF primary louver bays and salvaged one was detected moving rapidly upstream from the SWP fish release site and eventually passed the confluence of the Feather and Sacramento Rivers. Another steelhead released within the SFPF and salvaged was detected moving downstream from the SWP fish release site and eventually passed the Golden Gate Bridge.

8.2.2 Acoustic Tagged Steelhead Movement Rates

Remain and Trim steelhead movement rates (MR) were estimated hourly by calculating the distance moved between two receivers in one hour for the duration of the study period. To compare the MR between the Remain and Trim datasets for all steelhead, a Mann-Whitney Rank Sum test was used as data were not normally distributed. Remain MR was significantly different ($U = 15950645.0$; $T = 19594216.0$; $p < 0.001$) from the Trim MR, with the mean Trim MR being greater than the mean Remain MR (Table 11). This suggests the Trim MR contains many movements by striped bass and that striped bass move considerably more than steelhead. Both Remain MR and Trim MR contained many movement rate records of 0 m/hr (fish remained at same location) as indicated by the median MR of both datasets.

Table 11. Summary statistics for steelhead hourly Remain movement rate (m/hr) (steelhead alive) and hourly Trim movement rate (m/hr) (steelhead presumed eaten by predator).

	Remain Movement Rate	Trim Movement Rate
N	17830	1893
Minimum	0.0	0.0
Mean	86.5	145.9
Median	0.0	0.0
Standard Deviation	302.8	421.1
Maximum	3745.2	3651.1

Because of the high variance inherent to hourly movement rates, steelhead acoustic data were analyzed as “pooled”. To pool the data, for each study day, all steelhead received at VR2s on that day had their Remain movement rate data for that day pooled together and averaged to obtain a mean daily movement rate (DMR). For example, if twelve fish were received in hours 0:00 through 23:00 then there was a total of 288 movement rates, one per hour per steelhead. The 288 movement rates were summed and divided by 288 to calculate mean DMR. If no steelhead were received during a study day, DMR was recorded as missing. Pooled mean daily movement rate was variable and ranged from 0 m/hr to 282 m/hr. Variation in mean DMR increased after acoustic tagged steelhead were released in March.

Mean DMR could be influenced by a number of factors including but not limited to water temperature, turbidity, light intensity, radial gate water velocity, and Harvey Banks Pumping Plant export rate. To statistically test the relationship between each of these factors and DMR, Spearman Rank Order Correlation was used as the data were not normally distributed. Neither water temperature ($R_S = 0.0872$; $n = 121$; $p = 0.341$), turbidity ($R_S = 0.0841$; $n = 121$; $p = 0.358$), light intensity ($R_S = 0.131$; $n = 121$; $p = 0.152$), radial gate water velocity ($R_S = -0.0872$; $n = 120$; $p = 0.343$), nor Harvey Banks Pumping Plant export rate ($R_S = -0.117$; $n = 120$; $p = 0.203$) had a significant relationship with DMR.

The time between when a steelhead was released and when it was detected, or "Days Out", may have an effect on Mean DMR. Days Out were rounded to the nearest day (ex. 1.23 days = 1 day) and for each Day Out, all steelhead received at VR2s during that period of time had their movement rate data pooled together and averaged to obtain a mean Days Out movement rate. A maximum Days Out movement rate was calculated as well. As the Days Out data were normally distributed, a Pearson Product Moment Correlation was used to test the relationship between mean Days Out movement rate and Days Out. Mean Days Out movement rate was significantly ($R = -0.889$; $n = 59$; $p < 0.001$) related to Days Out. An R value close to -1 indicates a negative relationship between the two variables with Days Out movement rate decreasing with increasing Days Out (Figure 44). Also, a Pearson Product Moment Correlation was used to test the relationship between mean maximum Days Out movement rate and Days Out. Maximum Days Out movement rate was significantly ($R = -0.880$; $n = 59$; $p < 0.001$) related to Days Out. Again, an R value close to -1 indicates a negative relationship between the two variables with maximum Days Out movement rate decreasing with increasing Days Out (Figure 45).

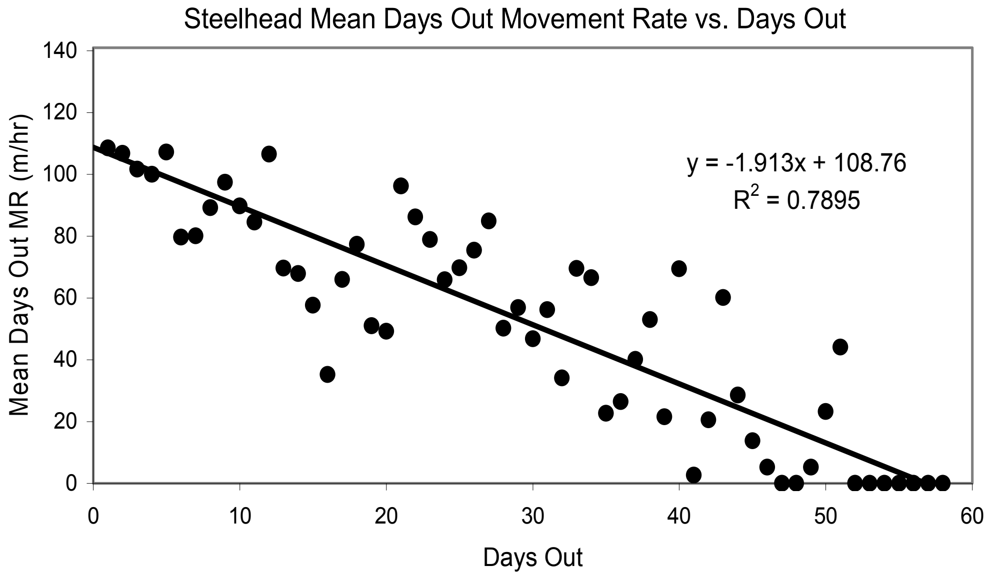

Figure 44. Plot of linear relationship between steelhead mean Days Out movement rate (MR) and time in days since release (Days Out).

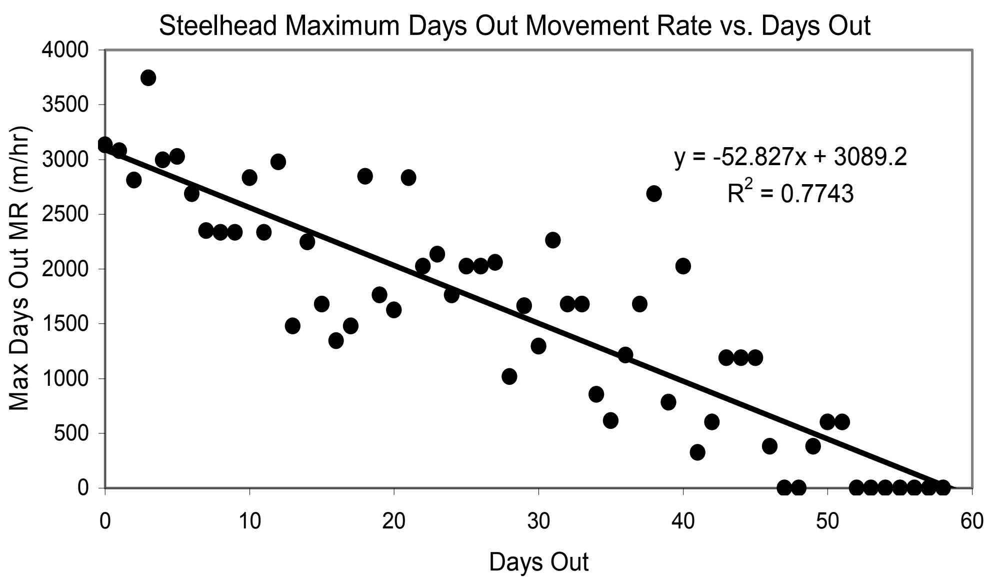

Figure 45. Plot of linear relationship between steelhead maximum Days Out movement rate (MR) and time in days since release (Days Out).

8.2.3 Acoustic Tagged Striped Bass Movements

Striped bass utilized the entire Forebay, but many of the striped bass spent long periods of time near either the radial gates or the trashboom or both. A few striped bass were observed to make trips between the radial gates and the trashboom with one striped bass (tag 1375) making 23 such trips. Striped bass were also observed to move from the radial gates to other areas within the Forebay only to return to the radial gates several times (Figure 46). One striped bass was never detected and another striped bass was found dead and impinged on the SFPF trash rack. Eighteen of the 29 tagged striped bass were detected emigrating from Clifton Court Forebay into Old River (e.g. Figure 46). Three striped bass, observed emigrating into Old River, returned to the Forebay through the radial gates. Surprisingly, one striped bass (tag 1420) was detected in a SFPF salvage holding tank. The striped bass detected in the holding tank was 686 mm (25.9 in) in total length and weighed 2267 g (5 lb). In order to be detected in the SFPF holding tank, this striped bass had to move through the SFPF trash rack with a bar spacing of approximately 50.8 mm (2 in).

The Central Valley Fish Tracking Consortium (CVFTC) database was also searched for records of the striped bass that were last detected in Old River. The striped bass emigrating from the Forebay were detected on the CVFTC receiver grid as far away as the Golden Gate Bridge and above Colusa on the Sacramento River. One striped bass (tag 1413) was observed to emigrate through the radial gates into Old River and was subsequently detected near Decker Island and Rio Vista. Eight days later this striped bass was detected moving through Threemile Slough to Franks Tract and subsequently Old River near the radial gates. The striped bass emigrating through the radial gates were detected in Old River in the same time span as the steelhead emigrating through the radial gates. However, those striped bass and steelhead moving through the Delta were not detected simultaneously at the same locations, so it is unlikely that any of the tagged striped bass were transporting any of the tagged steelhead in their stomachs.

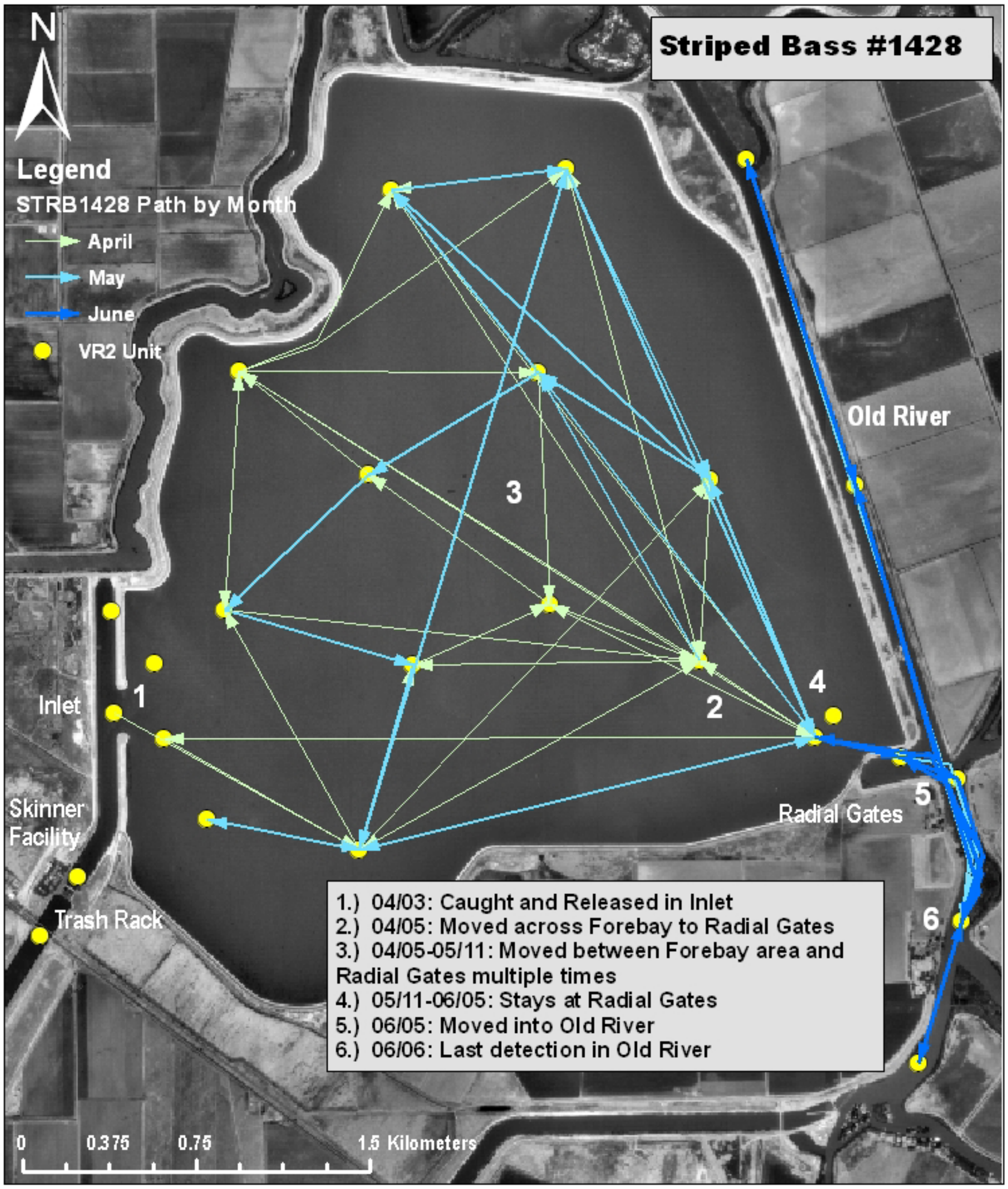

Figure 46. Striped bass #1428 moved throughout the Forebay and emigrated into Old River in June, 2007.

8.2.4 SWP Operation Effects on Striped Bass Time Spent at the Radial Gates and the Intake Canal

SWP operations could have an effect on striped bass behavior and movement patterns, as striped bass spent a majority of time at the radial gates and in the intake canal, which are two areas affected by operations. To determine if SWP operations affect the proportion of time striped bass spent at the radial gates, the hourly detection data was separated into two categories: "gates open" and "gates closed". Once separated, the proportion of hours spent at the two VR2 receivers located at the radial gates was calculated for gates open and gates closed time periods. Also, the proportion of hours spent at all other VR2 receivers was calculated for gates open and gates closed time periods. To test the null hypothesis that gate operations (gates open and gates closed) had no effect on the proportion of time striped bass spent at the radial gates, a Chi-square test was used. The Chi-square test ($\chi^2 = 1.481$; n = 33581; df = 1; p = 0.224) suggested that radial gate operations had no effect on the amount of time striped bass spent near the radial gates (Figure 47).

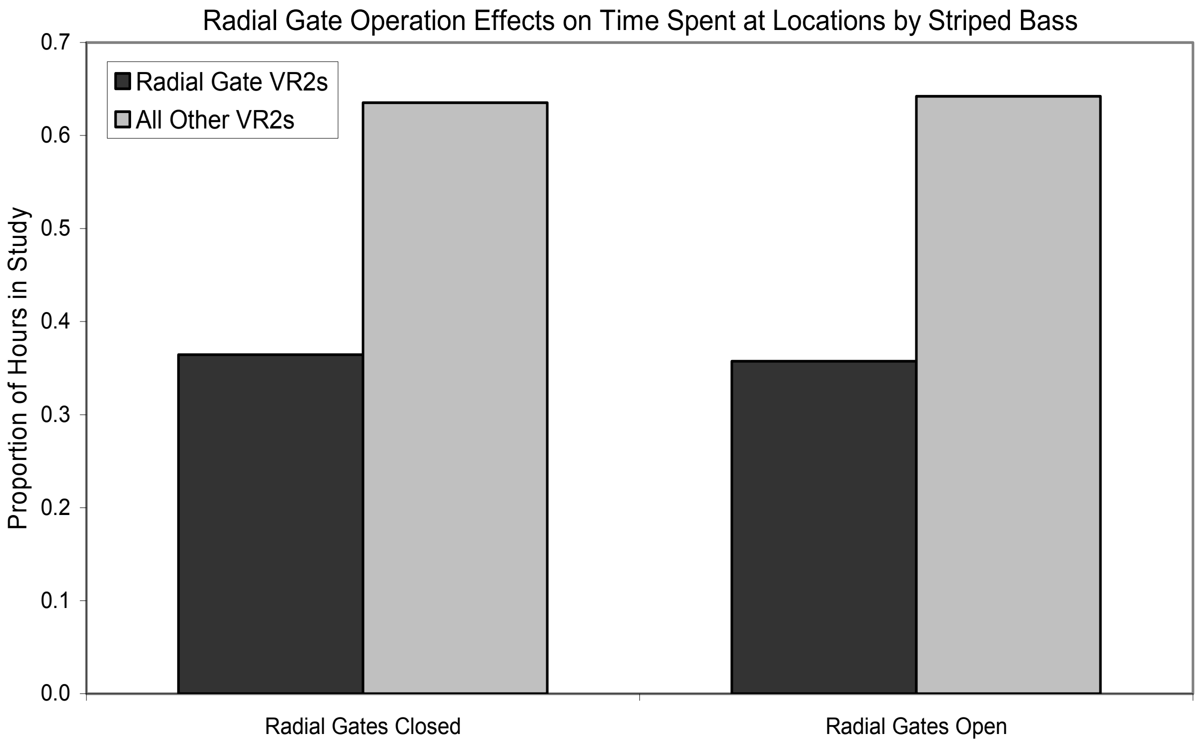

Figure 47. Proportion of study hours striped bass spent near the radial gates when the radial gates were closed or open.

To determine if SWP operations affect the proportion of time striped bass spent in the intake canal, the hourly detection data was separated into two categories: "pumping" and "not pumping". Once separated, the proportion of hours spent at the three VR2 receivers located in the intake canal and at the trashboom was calculated for pumping and not pumping time periods. Also, the proportion of hours spent at all other VR2 receivers was calculated for pumping and not pumping time periods. To test the null hypothesis that pumping operations had no effect on the proportion of time striped bass spent in the intake canal to the SFPF, a Chi-square test was used. The Chi-square test ($\chi^2 = 0.004$; n = 33581; df = 1; p = 0.949) suggested that pumping operations had no effect on the proportion of time striped bass spent in the intake canal (Figure 48).

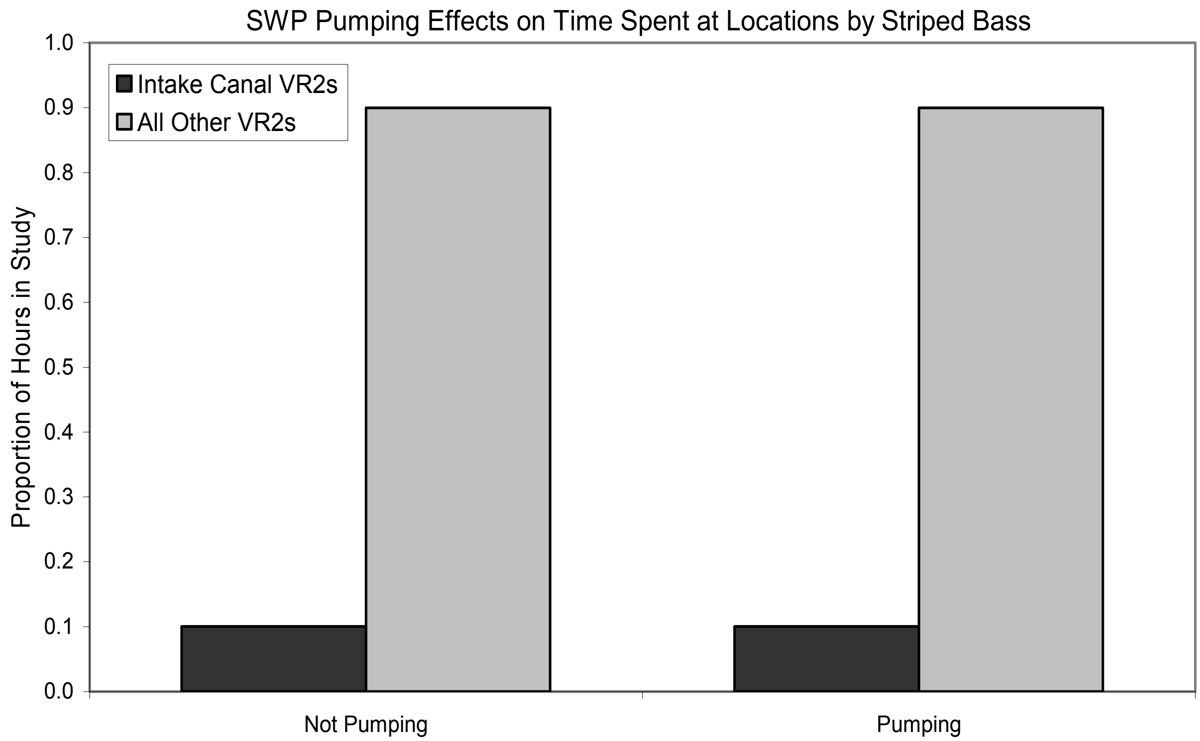

Figure 48. Proportion of study hours striped bass spent in the intake canal when Harvey Banks Pumping Plant was not pumping or pumping.

8.2.5 Acoustic Tagged Striped Bass Movement Rates

Similarly to steelhead, striped bass acoustic data were "pooled" to reduce the high variance in the hourly MR. For each study day, all striped bass received at VR2s on that day had their movement rate data for that day pooled together and averaged to obtain a mean daily movement rate (DMR). Pooled mean daily movement rate was variable and ranged from 21 m/hr to 365 m/hr.

Variables such as water temperature, turbidity, and light intensity could have an effect on Mean DMR. To statistically test the relationship between each of these variables and DMR, Spearman Rank Order Correlation was used as the data were not normally distributed. Neither water temperature ($R_S = -0.106$; $n = 177$; $p = 0.162$), turbidity ($R_S = -0.0794$; $n = 162$; $p = 0.315$), nor light intensity ($R_S = -0.113$; $n = 177$; $p = 0.134$) had a significant effect on DMR.

8.2.6 PIT Tagged Steelhead Total Loss, SFPF Efficiency, and Pre-screen Loss

Pre-screen loss rate for this study was defined as the proportion of steelhead released at the radial gates that are lost within Clifton Court Forebay as they travel to the SFPF. Pre-screen loss rate could not be directly determined, but was calculated by finding the Total

Loss (TL_P) from radial gate to SFPF fish release pipe and the SFPF loss. Total Loss estimates for juvenile steelhead were based upon detections (recoveries) of PIT tagged steelhead at the SFPF salvage release sites. Total Loss was calculated for each of the 58 radial gate release groups as:

$$TL_P = \left(1 - \left(\frac{Rec_{rg}}{Rel_{rg} \text{ x } A}\right)\right) \text{ x } 100$$

Rec_{rg} = # PIT tagged steelhead recovered from radial gate releases
Rel_{rg} = # PIT tagged steelhead released at the radial gates
A = PIT antennae detection efficiency (98.75%)

Based on PIT tagged steelhead detections, TL_P was estimated to be 87 ±2.5% (mean ±95% Confidence Interval). TL_P estimates ranged from 59 to 100% for the 58 release groups. Summary statistics for TL_P are summarized in Table 12. Only one PIT tagged steelhead was directly measured as having emigrated from Clifton Court Forebay into Old River. This single PIT tagged steelhead was detected in a TFCF 10 minute count and this steelhead was subtracted from its release group. TL_P is a conservative estimate because emigration may be grossly underestimated given the acoustic telemetry results.

A second estimate of Total Loss (TL_{PA}) was calculated using an estimate of emigration. Emigration was estimated from the results of the 64 acoustic tagged steelhead released directly upstream of the radial gates. TL_{PA} was calculated for each of the 58 radial gate release groups as:

$$TL_{PA} = \left(1 - \left(\frac{Rec_{rg}}{(Rel_{rg} - (Rel_{rg} \text{ x } E_{rg})) \text{ x } A}\right)\right) \text{ x } 100$$

Rec_{rg} = # PIT tagged steelhead recovered from radial gate releases
Rel_{rg} = # PIT tagged steelhead released at the radial gates
A = PIT antennae detection efficiency (98.75%)
E_{rg} = Emigration rate through the radial gates assumed constant at (28%)

Based on PIT and acoustic tagged steelhead detections, TL_{PA} was estimated to be 82 ±3% (mean ±95% Confidence Interval). TL_{PA} estimates ranged from 44 to 100% for the 58 release groups. Summary statistics for TL_{PA} are summarized in Table 12. TL_{PA} is a liberal estimate because emigration may be overestimated given the uncertainty of the acoustic telemetry results. Many of the acoustic tagged steelhead seen emigrating from the Forebay may have been in the stomach of a striped bass. Thus, the error in the emigration constant may be large.

SFPF salvage efficiency (F_P) was defined as the proportion of PIT tagged steelhead released within the SFPF primary louver bays that were successfully salvaged. F_P was calculated for each of the 47 trash rack release groups as:

$$F_P = \left(\frac{Rec_{tr}}{Rel_{tr} \times A} \right) \times 100$$

Rec_{tr} = # PIT tagged steelhead recovered from trash rack releases
Rel_{tr} = # PIT tagged steelhead released at the trash rack
A = PIT antennae detection efficiency (98.75%)

Based on PIT tagged steelhead detections, SFPF efficiency (F_P) was estimated to be 74 ±7% (mean ±95% Confidence Interval) for the 2007 study period. F_P ranged from 17 to 100% for the 47 release groups. Summary statistics for SFPF efficiency can be found in Table 12. F_P is a conservative estimate because emigration out of the primary louver bay and into the Forebay may have occurred.

PIT tagged steelhead emigrating through the trash rack and into the Forebay were not included in the SFPF efficiency test. Direct measurements of emigration through the trash rack by PIT tagged steelhead was not possible. However, acoustic tagged steelhead released within the SFPF primary louver bays were observed to emigrate through the trash rack and into the Forebay. Thus, a second estimate of SFPF efficiency (F_{PA}) was calculated using an estimate of emigration. Emigration was estimated from the results of the 15 acoustic tagged steelhead released within the primary louver bays. F_{PA} was calculated for each of the 47 trash rack release groups as:

$$F_{PA} = \left(\frac{Rec_{tr}}{(Rel_{tr} - (Rel_{tr} \times E_{tr})) \times A} \right) \times 100$$

Rec_{tr} = # PIT tagged steelhead recovered from trash rack releases
Rel_{tr} = # PIT tagged steelhead released at the trash rack
A = PIT antennae detection efficiency (98.75%)
E_{tr} = Emigration rate through trash rack assumed constant (13.33%)

Based on PIT and acoustic tagged steelhead detections, SFPF efficiency (F_{PA}) was estimated to be 82 ±7% (mean ±95% Confidence Interval) for the 2007 study period. F_{PA} ranged from 19 to 100% for the 47 release groups. Summary statistics for SFPF efficiency can be found in Table 12. F_{PA} is a liberal estimate because emigration out of the primary louver bay and into the Forebay was based on two acoustic steelhead releases. Therefore, the error associated with the emigration constant may be large.

Table 12. Summary statistics for total loss (%) and SFPF efficiency (%) estimates.

	Total Loss (TL_P)	Total Loss (TL_{PA})	SFPF Efficiency (F_P)	SFPF Efficiency (F_{PA})
No. of Release Groups	58	58	47	47
Minimum	59	44	17	19
Mean	87	82	74	82
Median	90	86	76	88
Standard Deviation	10	13	24	24
Maximum	100	100	100	100

Pre-screen loss rate (PSL_P) estimates were calculated based upon recoveries of PIT tagged steelhead. PSL_P was calculated for each of the 58 radial gate release groups as:

$$PSL_P = \left(1 - \left(\frac{Rec_{rg}}{Rel_{rg} \times A \times F_P}\right)\right) \times 100$$

Rec_{rg} = # PIT tagged steelhead recovered from radial gate releases
Rel_{rg} = # PIT tagged steelhead released at the radial gates
A = PIT antennae detection efficiency (98.75%)
F_P = Facility efficiency estimated by trash rack releases (74%)

Based on PIT tagged steelhead detections, PSL_P was estimated to be 82 ±3% (mean ±95% Confidence Interval). PSL_P release group estimates ranged from 45 to 100% for the 58 release groups. Summary statistics for PSL_P are summarized in Table 13.

Because PSL_P may not accurately account for emigration into Old River, PSL_P may overestimate loss. In addition, the SFPF efficiency (F_P) used to calculate PSL_P does not account for steelhead that emigrated from the SFPF into the Forebay through the trash rack. Thus, a second estimate of pre-screen loss rate (PSL_{PA}) was calculated using an estimate of emigration and F_{PA}. Emigration was estimated from the results of the 64 acoustic tagged steelhead released directly upstream of the radial gates. PSL_{PA} was calculated for each of the 58 radial gate release groups as:

$$PSL_{PA} = \left(1 - \left(\frac{Rec_{rg}}{(Rel_{rg} - (Rel_{rg} \times E_{rg})) \times A \times F_{PA}}\right)\right) \times 100$$

Rec_{rg} = # PIT tagged steelhead recovered from radial gate releases
Rel_{rg} = # PIT tagged steelhead released at the radial gates
A = PIT Antennae detection efficiency (98.75%)
F_{PA} = Facility efficiency estimated by trash rack releases including emigration (82%)
E_{rg} = Emigration rate through the radial gates assumed constant at (28%)

Based on PIT and acoustic tagged steelhead detections, PSL_{PA} was estimated to be 78 ±4% (mean ±95% Confidence Interval). PSL_{PA} release group estimates ranged from 31 to 100% for the 58 release groups. Summary statistics for PSL_{PA} are summarized in Table 13. PSL_{PA} may underestimate pre-screen loss given the uncertainty in the acoustic tagged steelhead results. As a result, NMFS recommended the use of pre-screen loss (PSL_P), the most conservative estimate, for all subsequent data analysis of PIT tagged steelhead losses within Clifton Court Forebay.

Table 13. Summary statistics for pre-screen loss rate (%).

	Pre-screen Loss (PSL_P)	**Pre-screen Loss (PSL_{PA})**
No. of Release Groups	58	58
Minimum	45	31
Mean	82	78
Median	86	83
Standard Deviation	13	16
Maximum	100	100

8.2.7 Comparing Pre-screen Loss Rate to SFPF Loss Rate

SFPF loss rate for this study was defined as the loss of PIT tagged steelhead within the SFPF. SFPF efficiency (F_P) was converted to a loss rate by 1-F_P. SFPF loss rate ranged from 0 to 83% with a mean of 26 ±7% (Table 14).

Table 14. Summary statistics for the SFPF loss rate (%) and pre-screen loss rate (%).

	SFPF Loss Rate	Pre-screen Loss (PSL_P)
No. of Release Groups	47	58
Minimum	0	45
Mean	26	82
Median	24	86
Standard Deviation	24	13
Maximum	83	100

The SFPF loss rate observed for the groups of PIT tagged steelhead released into the primary louver bays was dissimilar to that observed for the acoustic tagged steelhead released at the same location. Of the 15 acoustic tagged steelhead released into the primary louver bays, 12 were recovered in a SFPF salvage holding tank. Of the three acoustic tagged steelhead not salvaged, one was detected downstream of the SFPF having been lost through the louvers and two were detected moving upstream through the trash rack. A SFPF loss rate of 8% was calculated for the acoustic tagged steelhead released in the primary louver bays. However, this SFPF loss rate was based on only two acoustic tagged steelhead release groups.

To determine if there was a statistically significant difference between the SFPF loss rate and the pre-screen loss rate (PSL_P) for PIT tagged steelhead, the non-parametric Mann-Whitney Rank Sum test was used as data were not normally distributed. There was a significant difference ($U = 2623.0$; $T = 1231.0$; $p < 0.001$) found between the two medians. Median pre-screen loss rate (PSL_P) was greater than the median SFPF loss rate (Table 14). Although, SFPF loss rate was on occasion as high as the pre-screen loss rate.

8.2.8 Monthly Pre-screen Loss Rate Estimates and Time to Salvage for PIT Tagged Steelhead

Monthly adjusted pre-screen loss rate estimates were determined by taking the calculated pre-screen loss rate (PSL_P) for each radial gate release group and pooling them by release month. Summary statistics for the monthly pre-screen loss estimates are summarized in Table 15. ANOVA was used to determine if there was a statistically significant difference in monthly pre-screen loss estimates. There was no significant difference ($F = 1.382$; $df = 3$; $p = 0.258$) between monthly pre-screen loss estimates. Therefore, pre-screen loss rate estimates did not differ between months during the 2007 full-scale study and can be pooled for a single pre-screen loss rate (PSL_P) estimate.

Table 15. Summary statistics for monthly pre-screen loss rates (%).

	January	February	March	April
No. of Release Groups	13	16	16	12
Minimum	66	46	73	46
Mean	84	83	86	76
Median	86	83	86	73
Standard Deviation	10	13	10	17
Maximum	100	100	100	100

Although there were no differences in monthly pre-screen loss rate estimates, time to salvage by month of release may vary. The first observation of a salvaged PIT tagged steelhead occurred on January 12, two days after release at the radial gates. The last observation of a salvaged PIT tagged steelhead occurred on April 30, seventeen days after release at the radial gates. Time to salvage (number of days) was calculated for each PIT tagged steelhead released. Time to salvage ranged from 1 day to 84 days with a mean of 12.5 ±3 days.

For statistical analysis, time to salvage was pooled for each release month. Mean monthly time to salvage estimates for January and February appear different from March and April (Figure 49). However, median monthly time to salvage estimates for January, March and April appear different from February. This discrepancy can be explained by several outliers observed in January (Figure 49). The outliers observed may be due to the difference in the number of observation days. PIT tagged steelhead released in April did not have an equal number of observation days compared to other months. The time between April's last radial gate release to the last possible observation day (June 15) was 63 days. Therefore, months were also compared where "observation days" was set at a maximum such that any PIT tagged steelhead salvaged at more than 63 days was removed from the dataset. Based on this criteria, four steelhead released during the month of January were removed for statistical comparison. Monthly time to salvage means and medians still appear to be different (Table 16) (Figure 50).

A Kruskal-Wallis One Way ANOVA on Ranks test was used to determine if median time to salvage significantly differed by month of release, as data was not normally distributed. The median time to salvage significantly differed ($H = 15.364$; $df = 3$; $p = 0.002$) between release months. To determine which months differed a multiple comparison procedure (Dunn's Method) was employed. Steelhead released at the radial gates in February had a different time to salvage than those released in April or January; but not for those released in March (Table 17). Steelhead released at the radial gates in March did not have a different time to salvage than those released in April. No comparison was made between January and March or January and April.

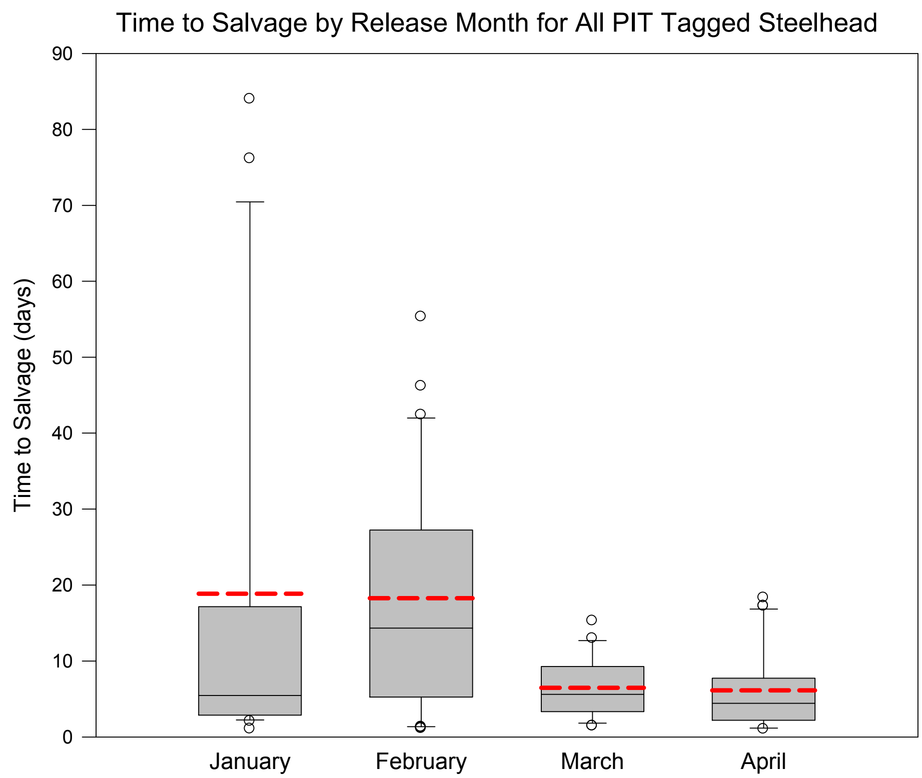

Figure 49. Box plot of monthly time to salvage for all salvaged PIT tagged steelhead released at the radial gates. The red dashed lines indicate the monthly means.

Table 16. Summary statistics for time to salvage in days for PIT tagged steelhead released at the radial gates salvaged in less than 63 days.

	January	February	March	April
No. Steelhead Salvaged	22	33	24	33
Minimum	1	1	1	1
Mean	9	18	6	6
Median	5	14	6	4
Standard Deviation	12.5	14.9	4.0	5.2
Maximum	60	55	15	18

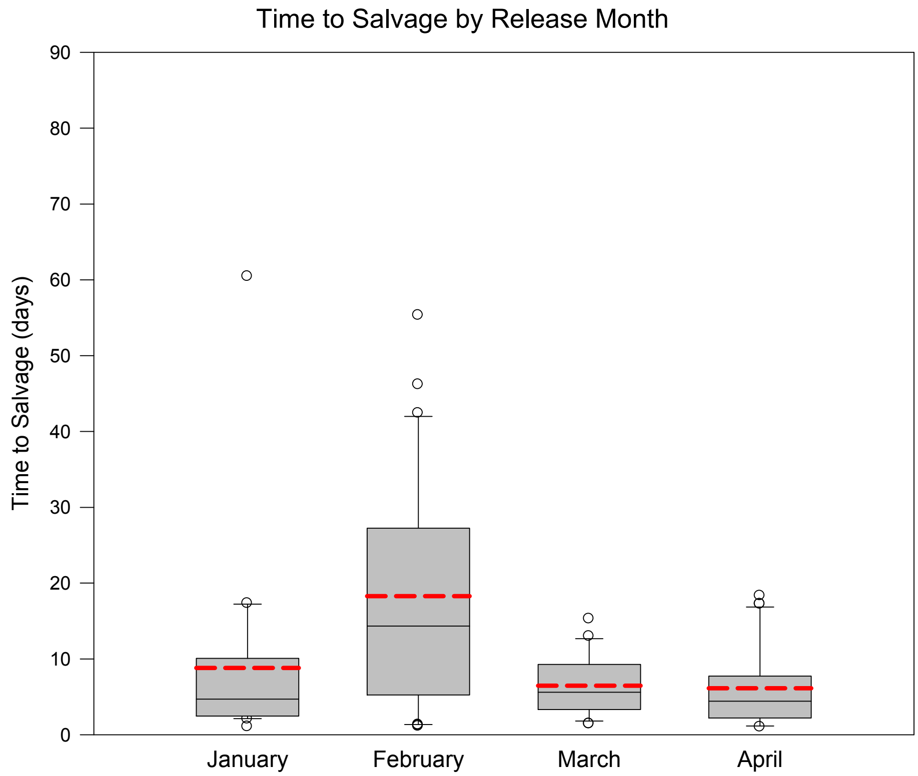

Figure 50. Box plot of monthly time to salvage for PIT tagged steelhead released at the radial gates salvaged in less than 63 days. The red dashed lines indicate the monthly means.

Table 17. Summary of multiple comparison procedure (Dunn's Method) to determine differences in time to salvage by release month.

Comparison	Difference of Ranks	Q	p < 0.05
February vs April	29.318	3.667	Yes
February vs January	24.000	2.685	Yes
February vs March	22.536	2.587	No
March vs April	6.782	0.778	No
January vs March	1.464	0.153	Not Tested*
January vs April	5.318	0.595	Not Tested*

* A result of not tested appears for those comparison pairs whose difference of rank means is less than the differences of the first comparison pair which is found to be not significantly different.

8.2.9 Effect of Temperature on Pre-screen Loss Rate of PIT Tagged Steelhead

To test the effect of the water temperature observed at time of release of PIT tagged steelhead on the pre-screen loss rate (PSL_P), a Spearman Rank Order Correlation was used as data were not normally distributed. Water temperature at time of release was found to have no significant effect on pre-screen loss rate ($R_S = -0.087$; n = 57; p = 0.517).

8.2.10 Effect of Light on Pre-screen Loss Rate of PIT Tagged Steelhead

To test the effect of light intensity observed at time of release for PIT tagged steelhead on the pre-screen loss rate (PSL_P) a Spearman Rank Order Correlation was used as data were not normally distributed. Light intensity at time of release was found to have no significant effect on pre-screen loss rate ($R_S = 0.069$; $n = 57$; $p = 0.608$). In addition, light intensity measurements were categorized into night or day according to the 2007 full-scale light methods section of this report. To test if there was a significant difference in pre-screen loss rate (PSL_P) between night and day releases, a Mann-Whitney Rank Sum test was used as data were not normally distributed. There was no significant difference ($U = 248.5$; $T = 441.5$; $p = 0.469$) in median pre-screen loss rates between night ($n = 38$) and day ($n = 15$) releases of PIT tagged steelhead at the radial gates (Figure 51). This result could occur if the initial release period, and predation during that period, did not drive the pre-screen loss rate for a steelhead release group.

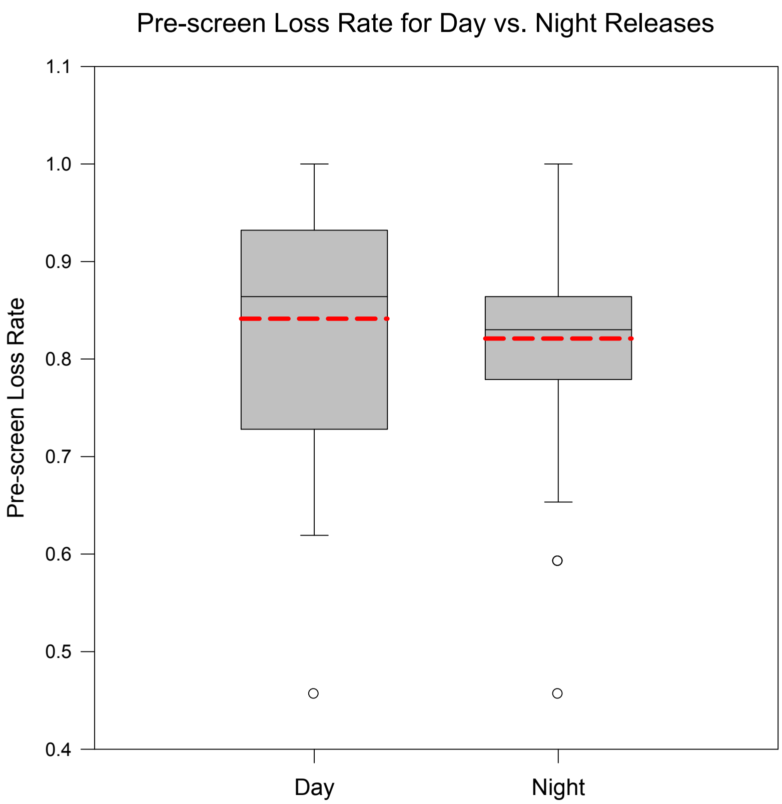

Figure 51. Box plot of pre-screen loss rates for day and night radial gate releases of PIT tagged steelhead. The red dash lines indicate the day and night means.

8.2.11 Avian Predation

Clifton Court Forebay is located along a major migratory pathway for many waterfowl species and harbors thousands of birds at a time during the winter and spring. When the full-scale study began in January 2007, waterfowl of various species were estimated to be in the thousands. Based on their published feeding habits, only a few of these bird species were considered predators of juvenile steelhead. Observational data for bird species that not only exhibited signs of foraging, but were large enough to prey on fish from 200 to 300 mm (7.8 to11.8 in) in length was summarized (Table 18). Western Grebes and Clarke's Grebes were difficult to differentiate at times, so they were grouped as "grebes" for the analyses. For this study period, only Double Crested Cormorants (cormorants), gulls, and Great Blue Herons (herons) had sufficient numbers to perform any statistical analysis.

Cormorants, grebes, gulls, herons, and Great Egrets were present in the Forebay prior to and during the 2007 study. Monthly indices of abundance of these avian predators were calculated for the point-count surveys conducted January through June 2007 (Table 19). Birds were most abundant in zones 1 and 2. Zone 3 consistently had the overall lowest abundance of birds (Table 19). Cormorants were the only species in relatively high total numbers that foraged consistently (Table 18). The mean monthly abundance of cormorants peaked in January, declined through March, and was at a low level for the remainder of the study (Figure 52). Zone 1 had higher numbers of cormorants than zones 2 and 3 for the entire study period (Figure 52). Cormorants were observed consistently foraging in the area near the radial gates, i.e. zone 1. During observations, some cormorants would fly away while others would rest on a nearby tree branch or "snag". Herons presence was much more sporadic and they occurred in relatively low numbers during the 2007 study (Figure 53). Unlike cormorants, herons are solitary fishers. Also, grebes were not common. Gulls were extremely abundant with numbers consistently in the hundreds for a single zone (Figure 54). Gull abundance was markedly higher at zone 1 (Figure 54) during January, followed by higher numbers in zone 3 during February and March. Gulls were almost completely absent from April through June. Gulls were observed briefly poking their heads below the water's surface and pecking at floating objects. It could not be determined if these gulls were feeding.

Table 18. Occurrence and behavior of predatory birds within Clifton Court Forebay.

Species Observed	**No. Observed**	**No. Observations**	**% Behavior Observed**			
			Foraging	Floating	Roosting	Flying
Double Crested Cormorant	2337	264	11.1	13.7	54.8	20.2
Great Blue Heron	552	188	32.4	0.0	48.9	18.3
Gulls	20214	99	0.1	77.5	15.5	6.9
Great Egret	62	37	16.1	0.0	37.1	46.8
Western Grebe	196	77	51.5	50.0	0.0	0.5
Clarke's Grebe	40	18	67.5	32.5	0.0	0.0
White Pelican	2	1	0.0	100.0	0.0	0.0

Table 19. Monthly indices of relative abundance (monthly count/number of surveys) of avian predators within Clifton Court Forebay.

Species	Zone	Jan	Feb	Mar	Apr	May	Jun
Double Crested Cormorant	1	0.0	22.1	19.4	11.2	12.7	11.5
Double Crested Cormorant	2	11.0	14.5	12.8	3.5	3.5	5.2
Double Crested Cormorant	3	0.0	0.9	1.4	0.8	0.6	1.3
Gulls	1	0.0	56.0	241.2	0.2	1.5	8.7
Gulls	2	0.0	7.4	6.4	1.7	0.9	1.3
Gulls	3	27.3	391.0	287.2	7.4	2.5	0.0
Great Blue Heron	1	0.0	1.3	4.4	1.5	2.4	3.3
Great Blue Heron	2	1.3	1.9	4.4	2.7	2.7	7.8
Great Blue Heron	3	0.3	0.7	1.4	0.5	0.6	0.3
Grebes	1	0.0	1.6	0.2	0.2	0.4	0.3
Grebes	2	4.3	0.7	0.1	0.4	1.0	1.2
Grebes	3	0.7	0.2	0.2	0.3	4.0	3.5
Egrets	1	0.0	0.2	0.1	0.0	0.1	0.5
Egrets	2	1.7	0.2	0.8	0.5	0.3	0.2
Egrets	3	0.0	0.1	0.1	0.1	0.1	0.3

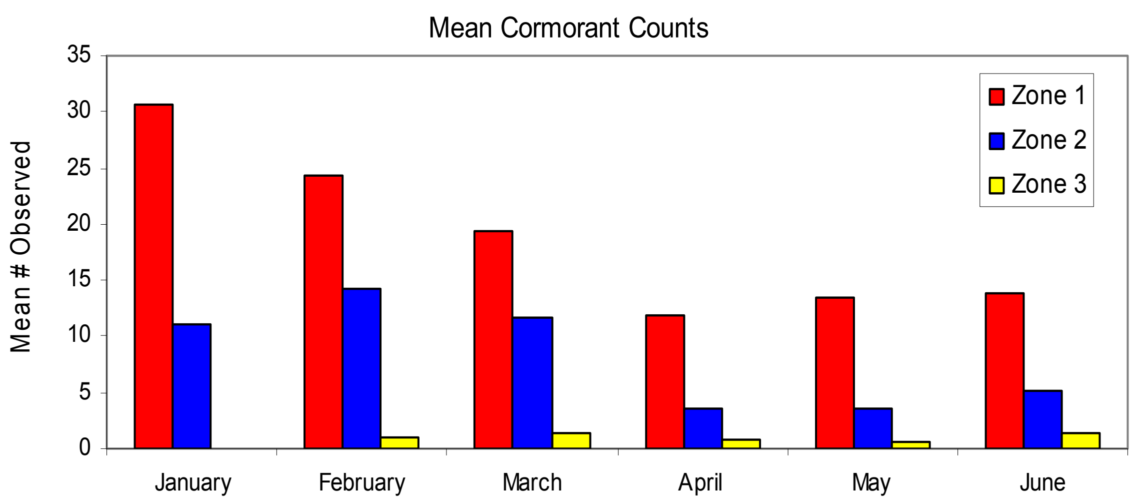

Figure 52. Mean monthly counts of Double Crested Cormorants by Clifton Court Forebay zone.

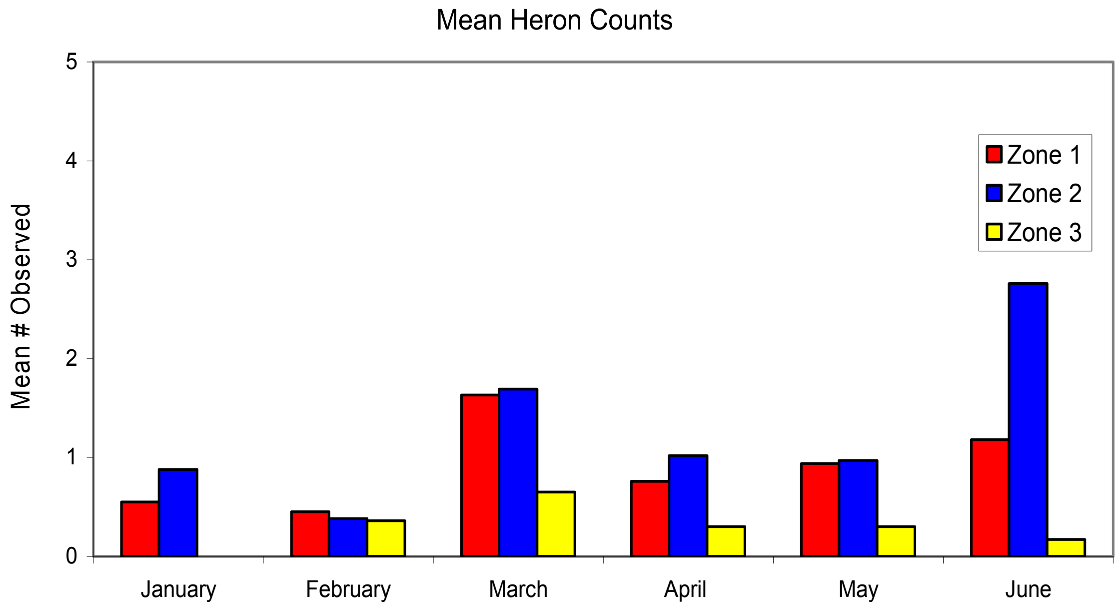

Figure 53. Mean monthly counts of herons by Clifton Court Forebay zone.

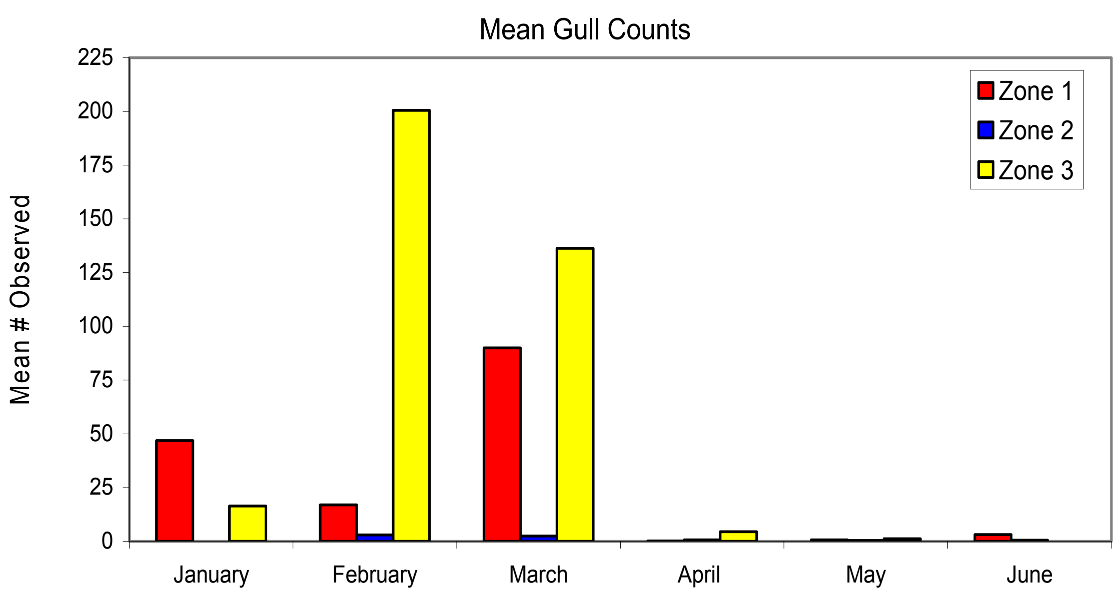

Figure 54. Mean monthly counts of gulls by Clifton Court Forebay zone.

The percentage of cormorants foraging near the radial gates could be influenced by radial gate operations seeing that cormorants were consistently foraging in the area and cormorant distribution was centered near the radial gates (Zone 1). This study was designed to be descriptive and the study design was not sufficient for rigorous statistical analysis. However, to test the null hypothesis that radial gate operations had no effect on the percentage of cormorants foraging in zone 1, a Mann-Whitney Rank Sum test was used. Results of the Mann-Whitney Rank Sum test (U = 479.0; T = 1302.0; p = 0.014) suggests that radial gate operations influenced the percentage of cormorants foraging near the radial gates (Figure 55).

The amount of time the radial gates were either opened or closed at the time of observations could act as a covariate on percent foraging. For example, a survey taking place ten hours after the gates had been opened could have low bird numbers and foraging percentages due to the fact that satiated birds left the Forebay. Because radial gate operations and their temporal proximity to an observation could affect the presence and/or behavior of birds, a logistic regression was performed on percent foraging. However, a logistic regression showed that the amount of hours the radial gates were opened or closed had no significant affect (p = 0.182) on percent foraging.

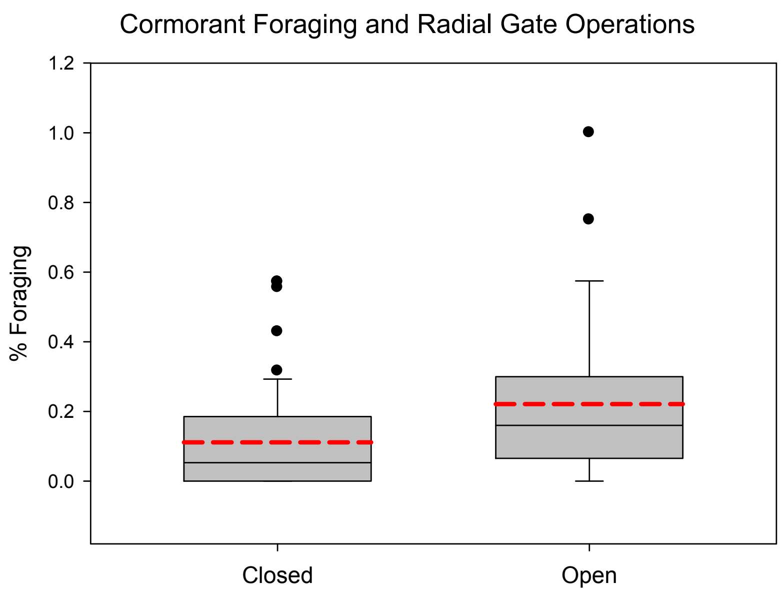

Figure 55. Percent foraging of Double Crested Cormorants located in Zone 1 as a function gate operations. The red dashed lines indicate the closed and open means.

8.3 Discussion and Conclusions

8.3.1 Steelhead Pre-screen Loss

Results of the 2007 full-scale study are consistent with the results of the 2005 and 2006 pilot studies. Steelhead appear to be moving throughout the entire Forebay with only a few steelhead making it from the radial gates into the SFPF salvage holding tanks. Predation by striped bass and piscivorous birds appears to be the primary cause for such losses. Steelhead pre-screen loss rate within Clifton Court Forebay is greater than 74% which is within the range of pre-screen loss rates (63 to 99%) found in other studies for other marked fishes released into the Forebay (Gingras, 1997). The juvenile steelhead released as part of the steelhead pre-screen loss studies were larger and had a higher swimming capacity than the juvenile salmon released in previous studies. Thus, the steelhead might be expected to have a higher predatory avoidance ability than the juvenile salmon released in the previous studies. However, even with these advantages, juvenile steelhead are still being lost at a very high rate within Clifton Court Forebay.

Steelhead pre-screen loss rate within the Forebay is substantially greater than the SFPF loss rate. This is not surprising as the SFPF has a relatively high capture efficiency for juvenile salmonids (Skinner, 1974, Odenweller and Brown, 1982). The SFPF is operated to maximize louver efficiency for salmonids during the times of the year that salmon or steelhead are usually present. Also, the amount of predation occurring within the SFPF is assumed low given the low likelihood of the presence of predators capable of consuming a 200+ mm (7.8+ in) juvenile steelhead. Pre-screen loss rate (> 74%) is much greater than SFPF loss rate (26%). Therefore, efforts to reduce predation within Clifton Court Forebay, rather than improvements within the SFPF, are likely to a produce a greater number of steelhead salvaged. Although the relative losses suggest that DWR management may want to focus on reductions in pre-screen loss rather than facility loss, SFPF improvements may be more feasible. For example, many steelhead were detected within the intake canal and yet were not salvaged. These results may indicate that there is an attraction problem at the SFPF or that the trash rack is perceived as a barrier by the fish. Perhaps changes to SFPF operations or changes in the design of the trash rack may yield higher salvage of steelhead.

Food intake by fishes, including striped bass, increases with water temperature (Brett, 1979; cited in Kestemont and Baras, 2001). Therefore, one would expect pre-screen loss rate to increase with increasing water temperature. However, water temperature at the time of PIT tagged steelhead release had no significant effect on steelhead pre-screen loss rate. Likewise light observed at the time release had no significant effect on steelhead pre-screen loss rate. Striped bass and piscivorous birds located in the Forebay are visual predators and should have increased prey capture success during the crepuscular and day than at night. It is possible that pre-screen loss rate did not change with water temperature or light observed because the number of predators within Clifton Court Forebay is great enough that the majority of juvenile steelhead are consumed regardless of water temperature or light intensity. On the other hand, water temperature and light intensity at the time of release may not influence pre-screen loss if most of the tagged steelhead survived the initial entrainment period. If predation is not immediate, environmental factors would be more relevant at or near the time of death and not at the time of entrainment. Many other factors could influence steelhead pre-screen loss rate. With many variables potentially influencing steelhead pre-screen loss rate such as radial gate operations, barometric pressure, etc, a large variance in that rate may occur and mask the influence of any single factor. Thus, the influence of only one variable may be difficult to detect statistically, but could be important biologically.

In 2007 there was no significant difference in monthly pre-screen loss estimates. However, there was a difference in time to salvage by month of release for PIT tagged steelhead. Steelhead released in February had greater times to salvage than steelhead released in January and April. SWP operational conditions were different in January and April than in February and March. In January, the Harvey Banks Pumping Plant was generally pumping continuously which led to higher average daily pumping rates than in February, March, and April. The Harvey Banks Pumping Plant was not continuously pumping and there was a reduction in average daily pumping rate during those months in comparison to January. Additionally, beginning at the end of April operational conditions changed in response to Vernalis Adaptive Management Plan (VAMP). The Harvey Banks Pumping Plant had significant pumping rate reductions or a zero pumping rate in early May. Perhaps because of this, no PIT tagged steelhead released at the radial gates were salvaged after April 30, 2007, even though water temperatures did not become lethal until June. Thus, operational conditions, such as pumping rate and duration of pumping, may effect the time it takes for steelhead to move from the radial gates to the SFPF. However, analysis of the movement rates of acoustic tagged steelhead did not show any statistical differences in steelhead movement rates that could be attributed to SWP operational conditions.

Steelhead movement rates were not related to changes in water temperature, turbidity level, light intensity level, radial gate operational conditions, or export rate. However, the acoustic telemetry equipment used was not designed to quantify movement rates of tagged fish. Generally movement rate information requires faster pinging tags with specialized 3D tracking equipment or 2D mobile monitoring equipment. Even with the equipment limitations steelhead movement rate was shown to be negatively correlated with time since release, or entrainment, for acoustic tagged steelhead. The longer steelhead remained in the Forebay the slower the movement rate. It is hypothesized that steelhead may become residualized within the Forebay. Residualism occurs when steelhead juveniles do not outmigrate as smolts with the rest of their cohort (McMichael and others, 1997; Sharpe and others, 2007). The water flow entering the Forebay through the radial gates may provide a consistent food supply for steelhead. However, this hypothesis is counter intuitive to what one would expect given that the steelhead used in the study appeared to be smolts and thus, should be looking to move downstream. Perhaps there is no directional flow for steelhead to detect within the Forebay and therefore no motivation to move toward the SFPF.

Results of the 2007 full-scale study and the 2005 and 2006 pilot studies show that steelhead emigrate from Clifton Court Forebay through the radial gates. A few steelhead observed emigrating in 2007 were also observed moving downstream towards the Pacific Ocean. However, a few of the steelhead observed emigrating in 2007 were also observed moving rapidly upstream following a similar movement pattern to that of striped bass seen emigrating from the Forebay. Thus, it is likely that some of the steelhead seen emigrating from the Forebay through the radial gates were actually in the stomach of a striped bass and were not actual steelhead movements. Without further information, it is difficult to say how many of the steelhead observed emigrating were actually steelhead. The method used for trimming steelhead detections may not have been adequate to remove all confounding striped bass movements. Given the uncertainty in the number of live steelhead emigrating from the Forebay, NMFS recommended that the pre-screen loss rate not be adjusted for the percentage of steelhead acoustic tags observed emigrating from Clifton Court Forebay into Old River. Regardless of the confounding results, steelhead possess the swimming capacity to effectively navigate the water velocities at the radial gates. At least one PIT tagged steelhead emigrated and was recovered at the TFCF.

8.3.2 Striped Bass Contributions to the Steelhead Pre-screen Loss Rate

Although there were many striped bass captured less than 550 mm (22 in) in length, it was difficult to capture large numbers of striped bass greater than 550 mm (22 in) in length. Those striped bass that were tagged and released had movement patterns that included multiple trips to the radial gates and the intake canal. Striped bass spent considerable time at both locations and a few striped bass made multiple trips between the radial gates and the intake canal. These results may be biased given that the striped bass were only collected in two locations: near the radial gates and within the intake canal. However, Bolster (1986) also found that striped bass utilized the area near the radial gates predominantly during the winter and spring when the density of prey in the Forebay is low. Even though striped bass spent considerable time near the radial gates and within the intake canal, neither radial gate operations nor Harvey Banks Pumping Plant operations had a significant effect on the proportion of time spent in those locations. Thus, striped bass may not be cuing in on the direct operations, but rather have learned that if they stay long enough a meal will become available. Pikeminnow exhibit a similar behavior on the Columbia River as they are commonly observed immediately downstream of dams (Beamsederfer and Rieman, 1991, Gadomski and Hall-Griswold, 1992). Furthermore, the occurrence of striped bass may be more dictated by prey abundance than by short term changes in water operations.

Striped bass movement rates were not related to changes in water temperature, turbidity level, or light intensity level. However, the acoustic telemetry equipment used was not designed to quantify movement rates of tagged fish. Even with the equipment limitations it is likely that water temperature and turbidity did not influence the movement rates of striped bass as most of Clifton Court Forebay is not stratified and the frequent winds observed at the Forebay keep the water well mixed. However, temperature stratification was measured on a non-windy day in the 18.3+ m (60+ ft) deep hole adjacent to the radial gates during the 2007 full-scale study. Given the frequency of windy days observed during the 2007 study period it is unlikely that a thermal refuge persisted.

Although this study focused on striped bass as the primary predator fish species, other predators were captured within the Forebay during striped bass sampling. A small number of white catfish were captured by gill netting near the radial gates. However, the white catfish were likely too small to consume a juvenile steelhead. Additionally, a small number of largemouth bass were captured in the intake canal during hook and line sampling events, but like the white catfish were likely too small to consume juvenile steelhead. Thus, other predatory fish species are residing within the Forebay, but may or may not be contributing to steelhead pre-screen loss. As the predatory fish sampling methods were designed specifically to capture striped bass, it is impossible to quantify the effect that these other predator fish species may be having on steelhead entrained within the Forebay.

8.3.3 Avian Predation

Avian predation on fishes was observed in the Forebay and can be linked to SWP operations. The avian predation component of this study showed that Double Crested Cormorants tend to feed when the radial gates are open. This is not surprising, given the large numbers of fish entering the Forebay through the radial gates as shown via historical fish salvage data. When the radial gates are open, a turbulent plume of water extends from the opening of the radial gates into zone 1 (Figure 38). As fish pass through this area, they could be disoriented and become more susceptible to predation. Furthermore, cormorants are efficient, deep water predators. This area of turbulence near the gates is approximately 15.2 m to 18.3 m (50 to 60 ft) deep and cormorants appear to be exploiting this area effectively.

Interestingly, cormorant abundance decreased as steelhead abundance increased in the Forebay. SWP operations may have been a reason for this discontinuity between abundance of cormorants and steelhead. Water exports in late April decreased substantially due to implementation of the Vernalis Adaptive Management Plan (VAMP), which may have contributed to decline of entrained and salvaged steelhead (DFG, 2008) (Figure 56). However, this reduction in pumping and the resulting decrease in steelhead occurred well after the cormorants' abundance decline (Figure 52).

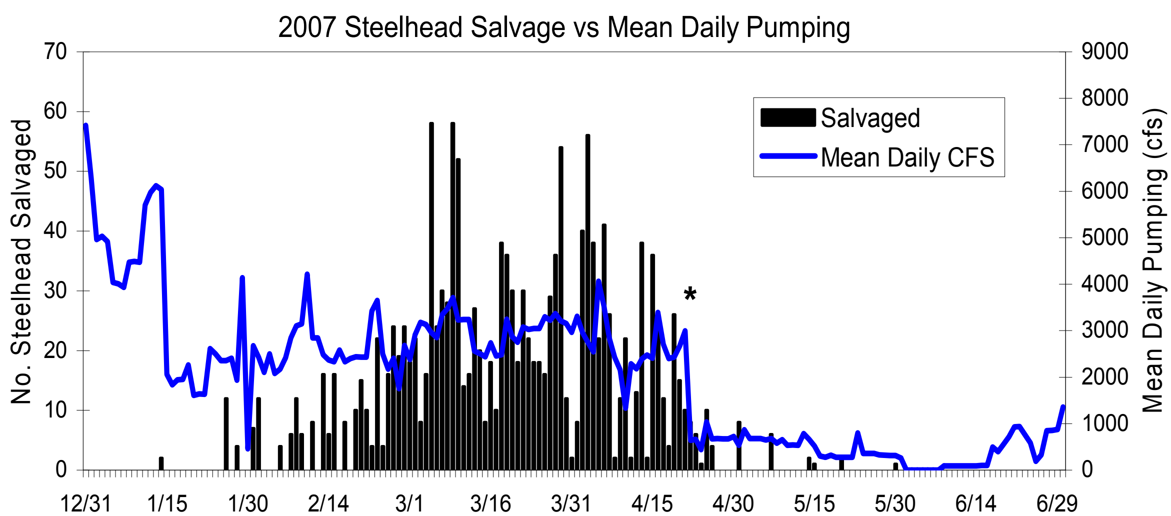

Figure 56. Relationship between 2007 daily total salvage of juvenile steelhead and mean daily pumping exports from the Harvey Banks Pumping Plant. The asterisk denotes the beginning of pumping restrictions during VAMP.

Cormorant life history may explain the lack of overlap in abundance between cormorants and steelhead in the Forebay. Double Crested Cormorants are opportunistic predators (Tommy King, Personal Communication), prey on an array of different fish species, and are able to shift between species based on availability. Fish collection data (DFG, 2008) from the SFPF showed that juvenile striped bass and American shad were the most abundant fishes entrained into the Forebay and salvaged during January and February 2007 (Figure 57). Salvage numbers for these two species dropped considerably in February and they were in negligible numbers for the rest of the 2007 study period. Declines in American shad and striped bass coincided with the cormorant abundance decline (Figure 52). Therefore, it is plausible that these birds were preying on more abundant fishes, American shad and striped bass, entering the Forebay and moved when these fishes became relatively scarce.

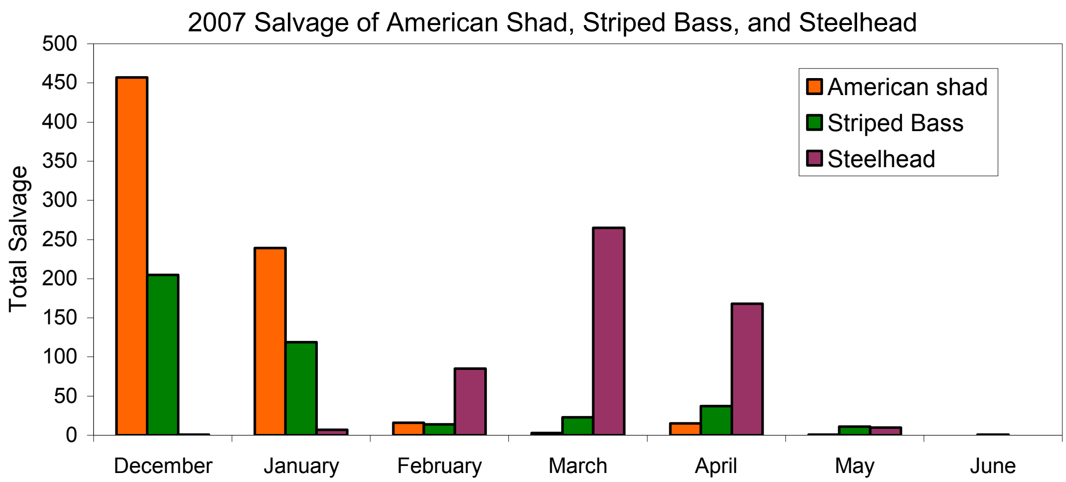

Figure 57. Monthly total salvage for American shad, striped bass and steelhead (100-300 mm fork length) at the John E. Skinner Delta Fish Protective Facility.

Another plausible reason for the difference in timing of cormorant and steelhead abundances in the Forebay is the migratory nature of the birds themselves. Double Crested Cormorants usually arrive at their wintering grounds in November and remain there until April, then move back to their home range (Aderman and Hill, 1995). In this case, much of the cormorant decline may be due the birds migrating from the area. The few cormorants observed during April and May might have been a residential population (Dan Anderson, UC Davis, Personal Communication).

Cormorants are widely recognized as being an efficient avian piscivore. In aquaculture, many fish farms suffer major losses of their stocks due to cormorant predation. People have capitalized on their proficiency as a piscivore by domesticating them in Southeast Asia to catch fish for human consumption. In the wild, cormorants can have large negative impacts on local fish numbers. These birds are capable of consuming up to 1/3 of their body weight per day (Robertson, 1974). One study estimated the number of subadult trout taken by cormorants during their 8 month study to be greater than the number of fish observed during a 12 month creel census nearby (Modde and Wasowicz, 1996). The same study found that cormorants’ strong affinity for salmonids is exhibited by distributing themselves wherever trout fingerlings were in a reservoir and by consuming mostly trout despite presence of many other fish. Based on the relevant literature and our observations, we conclude that cormorants almost certainly consume steelhead in Clifton Court Forebay. However, the magnitude of this consumption has not been established. Without stomach content analyses or bioenergetics modeling, determination of the magnitude of juvenile steelhead consumption would be a difficult task. Evidence of avian predation on fishes belonging to the juvenile steelhead size range comes from approximately 10 occasions during this study where cormorants were observed swallowing fish that were estimated to be between 200 to 300 mm (7.8 to 11.8 in) long (Figure 58). There was additional evidence of possible avian predation, as a few acoustic tagged steelhead were only detected for a short time near the radial gates with no subsequent detections. It could be possible for an avian predator to consume a steelhead and fly away with the tag in the bird's stomach, thus, accounting for no subsequent detections. However, the possibility remains that the tags simply malfunctioned and the steelhead were not consumed by a bird.

Figure 58. Photograph of a Double Crested Cormorant with an unidentified fish in its mouth taken after the radial gates were open and immediately following an acoustic tagged steelhead release in 2007.

Low numbers of herons made it difficult to test for any effects or observe any trends or patterns in their abundance and distribution in the Forebay. With regards to radial gate operations, it is unlikely that percent foraging in herons would be affected due to their life history. Herons are wading birds and would not be able to take forage in the deep and often turbulent water near the radial gates. Opening the radial gates nevertheless provides an influx of water and presumably prey to even the shallow portions of the Forebay. As steelhead were shown to utilize the majority of the Forebay, it may be possible for herons to consume steelhead in the shallows.

It was difficult to determine what factor(s) may be contributing to the vulnerability of fish to avian predation within the Forebay. However, one such factor was identified. The presence of stationary debris in the Forebay (e.g., tree branches called ‘snags’) provides refuge for cormorants. Snags allow cormorants to rest after foraging and remain nearby to forage when the radial gates are open again. A search effort was conducted for acoustic tags that may have been excreted by cormorants close to snags, but no tags were found.

9.0 Findings

The following findings are based on the results from the pilot studies conducted in 2005 and 2006 and the 2007 full-scale study:

Steelhead

1. Many entrained steelhead remained within the Forebay for extended periods of time, i.e. greater than 60 days.
2. Steelhead utilized much of the Forebay and exhibited random movement patterns.
3. Steelhead were shown to emigrate from the Forebay through the radial gates.
4. Many steelhead, 19% of the acoustic tagged steelhead released at the radial gates in 2007, were detected within the intake canal leading to the SFPF.
5. 3% of the acoustic tagged steelhead released at the radial gates in 2007 were salvaged.
6. In 2007, the PIT tagged steelhead pre-screen loss rate within Clifton Court Forebay was between 78 ±4% and 82 ±3% (Mean ±95% Confidence Interval).
7. PIT tagged steelhead pre-screen loss rate estimates were not significantly different by month in 2007.
8. Time to salvage changed by month of entrainment with increased time to salvage by PIT tagged steelhead entrained in February.
9. Acoustic tagged steelhead movement rates were not related to water temperature, turbidity, export rate, radial gate water velocity, or light intensity.
10. Water temperature or light observed at the time of release had no significant effect on PIT tagged steelhead pre-screen loss rate.
11. The large amount of variability in acoustic tagged steelhead movement rates may indicate a great number of variables influence steelhead movement behavior.
12. As time since entrainment increased, acoustic tagged steelhead movement rates decreased.

Striped Bass

1. Striped bass were captured in areas with the highest water velocity, the intake canal and near the radial gates.
2. Striped bass spent long periods of time near the radial gates and in the intake canal. However, the time spent at these locations was not related to SWP operations.
3. Striped bass were observed to make several trips between the radial gates and the trashboom.
4. Striped bass movement rates were not related to water temperature, turbidity, or light intensity.
5. Striped bass were observed to emigrate from Clifton Court Forebay through the radial gates and then re-enter the Forebay again at a later time.

Avian Predation

1. Of the numerous bird species that frequent the Forebay from January-June, the following species or taxa were thought to be capable of eating 200 to 300 mm (7.8 to 11.8 in) sized fish: Double Crested Cormorant, Western Grebe, Clarke's Grebe, Great Blue Heron, gulls, Great Egret, and White Pelicans.
2. The west side of Clifton Court Forebay had consistently lower bird densities.
3. Cormorants were the second most numerous predatory bird species observed.
4. Cormorant counts were higher near the radial gates.
5. Cormorants were observed preying on fish approximately 200 to 300 mm (7.8 to 11.8 in) long.
6. Cormorants displayed a higher percent of foraging behavior in the area adjacent to the radial gates when the radial gates were open.

10.0 Recommendations for Future Work

Central Valley Steelhead are listed as threatened under the Endangered Species Act. A population risk analysis should be completed for these fish that takes into account this pre-screen loss rate. In addition, a management action plan (MAP) should be created that includes the steps to be taken to reduce the pre-screen loss rate of Central Valley steelhead within Clifton Court Forebay. One step could include a predator removal program. Predator removals could reduce pre-screen loss within Clifton Court Forebay. When survival is low (< 25%) due to predation by high numbers of predators, a reduction in predator numbers (> 50%) can yield a doubling in survival rate (Ricker, 1952). Predator removals along with other steps should be explored as part of the MAP.

Steelhead and striped bass movement rate information was inconclusive in the 2007 study. Steelhead may use water flow patterns to determine where and when to move. However, water flow patterns within the Clifton Court Forebay were not investigated. Collecting hydrodynamics data within the Forebay may give insight into the uncertainty of steelhead movements within the Forebay. The hydrodynamics data could be used to construct a hydrodynamics model to test different hypothesis regarding water flow and fish movement patterns within the Forebay. SWP operational changes could be modeled to see if any changes in SWP operations result in beneficial flow patterns within the Forebay.

The employed acoustic telemetry equipment for these studies had limitations that made interpretation of results difficult. Future studies should evaluate the use of other telemetry technologies e.g. three-dimensional tracking systems. Also, future telemetry studies would highly benefit from a striped bass gut evacuation rate experiment. Gut evacuation rate studies have been conducted to determine the rate at which organic material is evacuated. However, studies have not been performed to determine the evacuation rates for inorganic materials, such as acoustic tags. A striped bass gut evacuation experiment should be conducted to determine the time it takes to evacuate an acoustic tag after consuming an acoustic tagged steelhead. Results from a gut evacuation study would provide a better gut evacuation estimate, than the estimate used for the 2007 full-scale study data analysis, to back calculate the date and time that acoustic tagged steelhead were consumed given a tag deposition date and time.

Feasibility studies should be conducted to determine if changes to the configuration of Clifton Court Forebay could reduce the entrainment of fishes. Feasibility studies could also determine if the configuration of Clifton Court Forebay could be changed to shorten the time it takes entrained fish to reach the SFPF.

Although there was not any conclusive evidence that any birds preyed upon tagged steelhead, the 2007 study observations suggest that avian predation is occurring and can be traced to the operation of the radial gates. To achieve greater certainty of avian predation, diet composition and consumption-rate analyses would be necessary. A bioenergetics approach may provide useful information in those regards. Furthermore, a radio telemetry study would help characterize movement of predatory birds. Further investigations should characterize the benefit of removing bird refuges from Clifton Court Forebay and the installation of a non-lethal bird deterrent system.

11.0 Acknowledgements

California Department of Fish and Game

Bay-Delta Region:

Robin Carter, Earnest Chen, Sarah Dewees, Jason DuBois, Bob Fujimura, Dennis Michniuk, Ramiro Soto, Derek Stein, Eloise Tavares, Galen Tigan, Shannon Waters, and Julie Wolford

Mokelumne River Fish Hatchery:

Bob Anderson

Nimbus Fish Hatchery:

Bob Burks

California Department of Water Resources

Bay-Delta Office:

Javier Miranda, Roger Padilla, and Zaffar Eusuff

Delta Field Division:

Rhett Cotter, Sheryl Moore, and John Moe

Division of Engineering:

Bill Sutliffe

Division of Environmental Services:

Karen Enstrom and Laura Patterson

Division of Flood Management

Jay Kortuem and Mike Salvador

Hanson Environmental, INC.

Charles Hanson, Kristie Karkanen, and Justin Taplin

National Marine Fisheries Service

Bruce Oppenheim

Sonoma County Water Agency

Natural Resources Section:

Joshua Fuller and David Manning

United States Bureau of Reclamation

Fisheries and Wildlife Resources Group:

Raymond Bark, Steve Hiebert, Chuck Hueth, Evan Mickle, Brent Miller, Vince Riedman, and Matt Trese

Tracy Fish Salvage Facility:

Brad Baskerville-Bridges, Brent Bridges, Brandon Wu, Joe Pennino, René Reyes, Ron Silva, and Johnson Wang

University of California Davis

Fish Conservation and Culture Laboratory:

Brad-Baskerville-Bridges, Luke Ellison, and Joan Lindberg

12.0 Literature Cited

Aderman, A. R. and E. P. Hill. 1995. Locations and numbers of Double-Crested Cormorants using winter roosts in the delta region of Mississippi. Colonial Waterbirds 18 (Special Publication 1):143-151.

Anglea, S. M., D. R. Geist, R. S. Brown, and K. A. Deters. 2004. Effects of acoustic transmitters on swimming performance and predator avoidance of juvenile Chinook salmon. North American Journal of Fisheries Management 24: 162-170.

Anderson, Dan. PhD. Professor at U.C. Davis. Wildlife, Fish and Conservation Biology Department. Davis, CA.

Beamesderfer, R. C. and Rieman, B. E. 1991. Abundance and distribution of northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120: 439-447.

Beland, K. F., J. F. Kocik, J. vandeSande, and T. F. Sheehan. 2001. Striped bass predation upon Atlantic salmon smolts in Maine. Northeastern Naturalist 8(3): 267-274.

Bolster, B. C. 1986. Movement patterns of striped bass (*Morone saxatilis*) in Clifton Court Forebay, Contra Costa County, California. Masters thesis. California State University Sacramento.

Brett, J. R. 1979. Environmental factors and growth. In: Fish Physiology, volume 8. Academic Press, New York.

Brown, R., S. Greene, P. Coulston, and S. Barrow. 1995. An evaluation of the effectiveness of fish salvage operations at the intake to the California Aqueduct, 1979-1993. *in* J.T. Hollibaugh editor. San Francisco Bay: The Ecosystem, San Francisco: American Association for the Advancement of Science.

Brown, R. S., S. J. Cooke, W. G. Anderson, and R. S. McKinley. 1999. Evidence to challenge the “2% rule” for biotelemetry. North American Journal of Fisheries Management 19: 867-871.

California Department of Fish and Game. 2008. Salvage database. ftp://ftp.delta.dfg.ca.gov/salvage/ (February, 2008)

California Department of Water Resources. 1974. Bulletin 200. California State Water Project.

Central District, California Department of Water Resources. 2005. Bathymetry map created by the Special Studies Section and Geology and Groundwater Section of Division of Planning and Local Assistance. December 2004.

Chadwick, H. K. 1963. An evaluation of five tag types used in a striped bass mortality rate and migration study. California Fish and Game 49(2): 64-83.

Clark, G. H. 1938. Weight and age determination of striped bass. California Fish and Game 24: 176-177.

Clements, S., D. Jepsen, M. Karnowski, and C.B. Schreck. 2005. Optimization of an acoustic telemetry array for detecting transmitter-implanted fish. North American Journal of Fisheries Management 25:429–436.

Collis, K., D.D. Roby, D.P. Craig, B.A. Ryan, and R.D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130: 385-396.

Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee. 1999. PIT Tag Marking Procedures Manual. Version 2.0.

Fisher, T. R., A. B. Gustafson, G. M. Radcliffe, K. L. Sundberg, and J. C. Stevenson. 2003. A long-term record of photosynthetically available radiation (PAR) and total solar energy at 38.6ºN, 78.2ºW. Estuaries 26 (6): 1450-1460.

Coutant, C. C. 1970. Thermal resistance of adult coho (*Oncorhynchus kisutch*) and jack Chinook (*O. tschawytscha*) salmon, and adult steelhead trout (*Salmo gairdneri*) from the Columbia River. AEC Research and Development Report. Battelle Memorial Institute Pacific Northwest Laboratories. BNWL-1508.

Gingras, M. 1997. Mark/Recapture experiments at Clifton Court Forebay to estimate pre-screening loss to juvenile fishes: 1976-1993. Technical Report 55. Interagency Ecological Program.

Gadomski, D. M. and Hall-Griswold, J. A. 1992. Predation by northern squawfish on live and dead juvenile Chinook salmon. Transactions of the American Fisheries Society 121: 680-685.

Gingras, M. and M. McGee. 1997. A telemetry study of striped bass emigration from Clifton Court Forebay: implications for predator enumeration and control. Technical Report 54. Interagency Ecological Program.

Gray, R. H. and J. M. Haynes. 1979. Spawning migration of adult Chinook salmon (*Oncorhynchus tshawytscha*) carrying external and internal radio transmitters. Journal of the Fisheries Research Board of Canada 36: 1060-1064.

Hall, F. A. 1980. Evaluation of downstream migrant Chinook salmon, *Oncorhynchus tshawytscha*, losses in Clifton Court Forebay, Contra Costa County, California. California Department of Fish and Game Anadromous Fisheries Branch Administrative Report No. 80-4.

Hawkins, D. K. and T. P. Quinn. 1996. Critical swimming velocity and associated morphology of juvenile coastal cutthroat trout (*Oncoryhnchus clarki clarki*), steelhead trout (*Oncorhynchus mykiss*), and their hybrids. Canadian Journal of Fisheries and Aquatic Sciences 53:1487-1496.

Horodysky, A. Z. 2007. http://www.vims.edu/newsmedia/press_release/fish_vision.htm (May, 2008)

Johnson, J. H., A. A. Nigro, and R. Temple. 1992. Evaluating enhancement of striped bass in the context of potential predation on anadromous salmonids in Coos Bay, Oregon. North American Journal of Fisheries Management 12: 103-108.

Kano, R. M. 1985. 1984 Clifton Court Forebay evaluations of predation losses to juvenile Chinook salmon and striped bass. Memorandum, Clifton Court Forebay files. Department of Fish and Game, California.

Kano, R.M. 1990. Occurrence and abundance of predator fish in Clifton Court Forebay, California. Technical Report 24. Interagency Ecological Program.

Kestemont, P. and Baras, E. 2001. Environmental factors and feed intake: mechanisms and interactions. In: Food intake in fish. Blackwell Science Ltd Oxford.

King, Tommy. Research Wildlife Biologist. USDA/APHIS/WS, National Wildlife Research Center, Mississippi State University, Aphis, MS 39762

Le, K. 2004. Calculating Clifton Court Forebay Inflow. Chapter 12 *In:* Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 25th Annual Progress Report to the State Water Resources Control Board. October 2004. DWR.

Manooch, C. S. III. 1973. Food Habits of yearling and adult striped bass, *Morone saxatilis* (Walbaum), from Albemarle Sound, North Carolina. Chesapeake Science 14(2): 73-86.

McMichael, G. A., Sharpe, C. S., and Pearsons, T. N. 1997. Effects of residual hatchery-reared steelhead on growth of wild rainbow trout and spring Chinook salmon. Transactions of the American Fisheries Society 126(2): 230-239.

Modde, T., and Wasowicz, A. 1996. Cormorant and Grebe Predation on Rainbow Trout Stocked in a Southern Utah Reservoir. North American Journal of Fisheries Management 16: 388-394.

National Marine Fisheries Service (NMFS). 2004. Endangered Species Act Section 7 Consultation. Biological opinion on the long-term Central Valley Project and State Water Project operations criteria and plan. National Marine Fisheries Service, Southwest Region. October 2004.

Nielsen, L. A. 1992. Methods of marking fish and shellfish. American Fisheries Society Special Publication 23. American Fisheries Society, Bethesda, Maryland.

Nielsen, J. L., Lisle, T. E, and Ozaki, V. 1994. Thermally stratified pools and their use by steelhead in northern California streams. Transactions of the American Fisheries Society 123: 613-626.

Odenweller, D. B. and Brown, R. L. 1982. Delta Fish Facilities Program Report Through June 30, 1982. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary Technical Report 6 – FF/BIO-4ATR/82-6.

Overton, A.S. 2002. Striped bass predator-prey interactions in Chesapeake Bay and along the Atlantic Coast. Ph.D. dissertation, 226 pp. Univ. Maryland Eastern Shore, Princess Anne, Maryland.

Peterson, R. T. 1998. A field guide to western birds. Houghton Mifflin Company.

Pincock, D. 2008. Understanding the performance of VEMCO 69 kHz single frequency acoustic tags. Technical White Paper. Document #: XDOC-004372 Version 05.

Richter, A. and S. A. Kolmes. 2005. Maximum temperature limits for chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science 13(1): 23-49.

Ricker, W. E. 1952. Numerical relations between abundance of predators and survival of prey. The Canadian Fish Culturist. No. 13.

Robertson, I. 1974. The food of nesting double-crested and pelagic cormorants at Mandarte Island, British Columbia, with notes on feeding ecology. Condor 76: 346-348.

Ruggerone, G. T. 1986. Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. Transactions of the American Fisheries Society 115: 736-742.

Ryan, B.A., J.H. Glabek, J.W. Ferguson, E.P. Nunnallee, and R.D. Ledgerwood. 2001a. Detection of passive integrated transponder (PIT) tags on piscivorous bird colonies in the Columbia River basin, 2000. Report of Research, Northwest Fisheries Science Center, NMFS/NOAA, Seattle, Washington.

Ryan, B.A., E.P. Nunnallee, J.H. Glabek, and J.W. Ferguson. 2001b. Recovery of passive integrated transponder tag codes from piscivorous bird colonies in the Columbia River basin. 2001 Annual Research Review, Anadromous Fish Evaluation Program, U.S. Army Corps of Engineers, Portland, Oregon. (abstract only).

Ryan, B. A., S. G. Smith, J. M. Butzerin, and J. W. Ferguson. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with passive integrated transponders in the Columbia river estuary, 1998-2000. Transactions of the American Fisheries Society 132: 275-288.

Schaffter, R.G. 1978. An evaluation of juvenile king salmon (*Oncorhynchus tshawytscha*) loss in Clifton Court Forebay. California Department of Fish and Game Anadromous Fisheries Branch Administrative Report. 78-21.

Sharpe, C. S., Beckman, B., Cooper, K. A., and Hulett, P. L. 2007. Growth modulation during juvenile rearing can reduce rates of residualism in the progeny of wild steelhead broodstock. North American Journal of Fisheries Management 27(4): 1355-1368.

Skinner, J. E. 1974. A functional evaluation of a large louver screen installation and fish facilities research on California water diversion projects. *in* L. D. Jensen editor. Proceedings of the Second Entrainment and Intake Screen Workshop. The John Hopkins University Cooling Water Research Project, Report No. 15.

Temesgen, Bekele. PhD. CIMIS Program.

Tillman, T. 1993a. Estimates of Pre-Screen Mortality of Juvenile Chinook Salmon at Clifton Court Forebay, State Water Project, Byron, California. California Department of Fish and Game Memorandum Report. Bay-Delta Files. Stockton, California.

Walter, J.F. and H.M. Austin. 2003. Diet composition of large striped bass (*Morone saxatilis*) in Chesapeake Bay. Fishery Bulletin 101: 414-423.

Winter, J. D. 1983. Underwater biotelemetry. Pages 371-395 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Winter, J. D. 1996. Advances in underwater biotelemetry. Pages 555-590 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques. Second Edition. American Fisheries Society, Bethesda, Maryland.

13.0 Appendices

A.1 VEMCO Acoustic Tag Specifications

Table A- 1. VEMCO acoustic tag specifications for tags used to tag either steelhead or striped bass.

Tag	Battery Option	Submap ID	Length (mm)	Weight in Air (g)	Power Output (dB)	Min. Off Time (s)	Max. Off Time (s)
V8SC	6L	B	21	2.9	142	20	60
V9	6L	B	21	2.9	142	20	60
V13	1L	B	36	11.0	147	20	60
V16	3H	B	64	25.0	165	20	60

A.2 Acoustic Tagged Fish Released

Table A- 2. Acoustic tag identification numbers and release information for acoustic tagged steelhead and striped bass.

Tag ID	Species	Date Released	Release Location
1236	Steelhead	22-Mar-07	Radial Gates
1246	Steelhead	28-Apr-07	Radial Gates
1260	Steelhead	28-Apr-07	Radial Gates
1285	Steelhead	23-Mar-07	Radial Gates
1286	Steelhead	22-Mar-07	Radial Gates
1288	Steelhead	28-Apr-07	Radial Gates
1292	Steelhead	23-Mar-07	Trash Rack
1293	Steelhead	22-Mar-07	Radial Gates
1294	Steelhead	23-Mar-07	Radial Gates
1296	Steelhead	23-Mar-07	Radial Gates
1297	Steelhead	8-Feb-07	Radial Gates
1298	Steelhead	7-Feb-07	Trash Rack
1299	Steelhead	7-Feb-07	Radial Gates
1300	Steelhead	7-Feb-07	Radial Gates
1301	Steelhead	8-Feb-07	Radial Gates
1302	Steelhead	7-Feb-07	Radial Gates
1303	Steelhead	7-Feb-07	Radial Gates
1304	Steelhead	8-Feb-07	Radial Gates
1305	Steelhead	7-Feb-07	Radial Gates
1306	Steelhead	7-Feb-07	Radial Gates
1307	Steelhead	7-Feb-07	Trash Rack
1308	Steelhead	7-Feb-07	Trash Rack
1309	Steelhead	7-Feb-07	Radial Gates
1310	Steelhead	7-Feb-07	Radial Gates
1311	Steelhead	7-Feb-07	Radial Gates
1312	Steelhead	7-Feb-07	Radial Gates

1313	Steelhead	7-Feb-07	Trash Rack
1314	Steelhead	7-Feb-07	Radial Gates
1315	Steelhead	8-Feb-07	Radial Gates
1316	Steelhead	7-Feb-07	Radial Gates
1317	Steelhead	7-Feb-07	Radial Gates
1318	Steelhead	7-Feb-07	Trash Rack
1319	Steelhead	7-Feb-07	Trash Rack
1320	Steelhead	7-Feb-07	Trash Rack
1321	Steelhead	8-Feb-07	Radial Gates
1322	Steelhead	8-Feb-07	Radial Gates
1323	Steelhead	7-Feb-07	Trash Rack
1324	Steelhead	8-Feb-07	Radial Gates
1325	Steelhead	7-Feb-07	Radial Gates
1326	Steelhead	7-Feb-07	Radial Gates
1327	Steelhead	7-Feb-07	Radial Gates
1328	Steelhead	8-Feb-07	Radial Gates
1329	Steelhead	7-Feb-07	Radial Gates
1331	Steelhead	8-Feb-07	Radial Gates
1332	Steelhead	7-Feb-07	Radial Gates
1333	Steelhead	7-Feb-07	Trash Rack
1334	Steelhead	7-Feb-07	Radial Gates
1335	Steelhead	7-Feb-07	Radial Gates
1336	Steelhead	8-Feb-07	Radial Gates
1339	Steelhead	23-Mar-07	Radial Gates
1340	Steelhead	28-Apr-07	Radial Gates
1341	Steelhead	23-Mar-07	Radial Gates
1342	Steelhead	23-Mar-07	Radial Gates
1343	Steelhead	22-Mar-07	Trash Rack
1346	Steelhead	23-Mar-07	Radial Gates
1347	Steelhead	22-Mar-07	Radial Gates
1348	Steelhead	23-Mar-07	Radial Gates
1349	Steelhead	23-Mar-07	Radial Gates
1350	Steelhead	22-Mar-07	Radial Gates
1351	Steelhead	23-Mar-07	Trash Rack
1352	Steelhead	23-Mar-07	Radial Gates
1353	Steelhead	22-Mar-07	Radial Gates
1354	Steelhead	22-Mar-07	Radial Gates
1357	Steelhead	23-Mar-07	Radial Gates
1358	Steelhead	23-Mar-07	Trash Rack
1359	Steelhead	23-Mar-07	Radial Gates
1360	Steelhead	23-Mar-07	Radial Gates
1361	Steelhead	22-Mar-07	Trash Rack
1363	Steelhead	23-Mar-07	Radial Gates
1364	Steelhead	23-Mar-07	Radial Gates
1365	Steelhead	22-Mar-07	Trash Rack
1366	Steelhead	23-Mar-07	Radial Gates
1367	Steelhead	22-Mar-07	Radial Gates
1368	Steelhead	23-Mar-07	Radial Gates
1369	Steelhead	22-Mar-07	Radial Gates
1370	Steelhead	23-Mar-07	Radial Gates

1371	Steelhead	22-Mar-07	Radial Gates
1372	Steelhead	23-Mar-07	Radial Gates
1373	Steelhead	23-Mar-07	Radial Gates
1374	Striped Bass	5-Apr-07	Intake Canal
1375	Striped Bass	13-Apr-07	Intake Canal
1376	Striped Bass	13-Apr-07	Intake Canal
1377	Striped Bass	24-May-07	Radial Gates
1378	Striped Bass	3-Apr-07	Radial Gates
1379	Striped Bass	25-May-07	Radial Gates
1380	Striped Bass	16-Mar-05	Radial Gates
1381	Striped Bass	18-Mar-05	Radial Gates
1381	Striped Bass	24-May-07	Radial Gates
1382	Striped Bass	18-Mar-05	Radial Gates
1382	Striped Bass	24-May-07	Radial Gates
1383	Striped Bass	18-Mar-05	Radial Gates
1383	Striped Bass	24-May-07	Radial Gates
1384	Striped Bass	16-Mar-05	Radial Gates
1384	Striped Bass	25-Apr-07	Intake Canal
1385	Striped Bass	18-Mar-05	Radial Gates
1387	Striped Bass	18-Mar-05	Radial Gates
1388	Striped Bass	16-Mar-05	Radial Gates
1388	Striped Bass	13-Apr-07	Intake Canal
1389	Striped Bass	17-Mar-05	Radial Gates
1390	Striped Bass	18-Mar-05	Radial Gates
1391	Striped Bass	18-Mar-05	Radial Gates
1394	Striped Bass	17-Mar-05	Radial Gates
1395	Striped Bass	18-Mar-05	Radial Gates
1396	Striped Bass	18-Mar-05	Radial Gates
1398	Striped Bass	17-Mar-05	Radial Gates
1399	Striped Bass	17-Mar-05	Radial Gates
1409	Striped Bass	19-Dec-06	Radial Gates
1410	Striped Bass	21-Dec-06	Intake Canal
1411	Striped Bass	21-Dec-06	Intake Canal
1412	Striped Bass	9-Jan-07	Radial Gates
1413	Striped Bass	9-Jan-07	Intake Canal
1414	Striped Bass	9-Jan-07	Intake Canal
1415	Striped Bass	18-Jan-07	Radial Gates
1416	Striped Bass	18-Jan-07	Radial Gates
1417	Striped Bass	18-Jan-07	Radial Gates
1418	Striped Bass	18-Jan-07	Radial Gates
1420	Striped Bass	8-Mar-07	Radial Gates
1421	Striped Bass	8-Mar-07	Radial Gates
1422	Striped Bass	8-Mar-07	Radial Gates
1424	Striped Bass	8-Mar-07	Radial Gates
1425	Striped Bass	9-Mar-07	Intake Canal
1426	Striped Bass	8-Mar-07	Radial Gates
1427	Striped Bass	9-Mar-07	Intake Canal
1428	Striped Bass	3-Apr-07	Intake Canal
1671	Steelhead	22-Mar-06	Radial Gates
1672	Steelhead	28-Mar-06	Radial Gates

1673	Steelhead	28-Mar-06	Radial Gates
1674	Steelhead	22-Mar-06	Radial Gates
1675	Steelhead	28-Mar-06	Radial Gates
1676	Steelhead	28-Mar-06	Radial Gates
1677	Steelhead	23-Mar-06	Radial Gates
1678	Steelhead	22-Mar-06	Radial Gates
1679	Steelhead	22-Mar-06	Radial Gates
1680	Steelhead	22-Mar-06	Radial Gates
1681	Steelhead	23-Mar-06	Radial Gates
1683	Steelhead	28-Mar-06	Radial Gates
1684	Steelhead	22-Mar-06	Radial Gates
1685	Steelhead	23-Mar-06	Radial Gates
1686	Steelhead	22-Mar-06	Radial Gates
1687	Steelhead	22-Mar-06	Radial Gates
1688	Steelhead	23-Mar-06	Radial Gates
1689	Steelhead	23-Mar-06	Radial Gates
1690	Steelhead	23-Mar-06	Radial Gates
1691	Steelhead	22-Mar-06	Radial Gates
1692	Steelhead	22-Mar-06	Radial Gates
1693	Steelhead	23-Mar-06	Radial Gates
1694	Steelhead	28-Mar-06	Radial Gates
1695	Steelhead	23-Mar-06	Radial Gates
1696	Steelhead	23-Mar-06	Radial Gates
1697	Steelhead	28-Mar-06	Radial Gates
1698	Steelhead	28-Mar-06	Radial Gates
1699	Steelhead	23-Mar-06	Radial Gates
1700	Steelhead	28-Mar-06	Radial Gates
1961	Steelhead	5-Apr-05	Radial Gates
1962	Steelhead	5-Apr-05	Radial Gates
1963	Steelhead	5-Apr-05	Radial Gates
1964	Steelhead	5-Apr-05	Radial Gates
1965	Steelhead	5-Apr-05	Radial Gates
1966	Steelhead	5-Apr-05	Radial Gates
1967	Steelhead	7-Apr-05	Radial Gates
1968	Steelhead	5-Apr-05	Radial Gates
1969	Steelhead	5-Apr-05	Radial Gates
1970	Steelhead	5-Apr-05	Radial Gates
1971	Steelhead	7-Apr-05	Radial Gates
1972	Steelhead	7-Apr-05	Radial Gates
1973	Steelhead	7-Apr-05	Radial Gates
1974	Steelhead	5-Apr-05	Radial Gates
1975	Steelhead	6-Apr-05	Radial Gates
1976	Steelhead	6-Apr-05	Radial Gates
1977	Steelhead	6-Apr-05	Radial Gates
1978	Steelhead	7-Apr-05	Radial Gates
1979	Steelhead	7-Apr-05	Radial Gates
1980	Steelhead	6-Apr-05	Radial Gates
1981	Steelhead	6-Apr-05	Radial Gates
1982	Steelhead	6-Apr-05	Radial Gates
1983	Steelhead	6-Apr-05	Radial Gates

1984	Steelhead	6-Apr-05	Radial Gates
1985	Steelhead	6-Apr-05	Radial Gates
1986	Steelhead	6-Apr-05	Radial Gates
1987	Steelhead	7-Apr-05	Radial Gates
1988	Steelhead	7-Apr-05	Radial Gates
1989	Steelhead	7-Apr-05	Radial Gates
1990	Steelhead	7-Apr-05	Radial Gates

A.3 CIMIS Light Data

The "Brentwood #47" weather station in the CIMIS database has been in operation since Nov. 18, 1985 and is located at 37.93 North Latitude and -121.66 West Longitude (NAD83). This weather station is approximately 8.06 miles (using Google Earth version 4.2.0196.2018, Mountain View, CA., 2007) from the CHTR Study Facility. The Brentwood #47 CIMIS weather station operates on Pacific Standard Time (PST) and records hourly solar radiation in Langley's as an average of the previous 60 minute-by-minute readings whereas daily solar radiation is an average of the previous 1,440 minute-by-minute readings. The CIMIS data is an average of the previous hour also known as a trailing average. For example, if you have 561 Ly/d at 10:00, this value is an average of 60 minute-by-minute readings between 09:00 and 10:00 (Bekele Temesgen, Personal Communication).

The Langley data from the Brentwood #47 CIMIS website was used to estimate PAR for the period of December 19, 2006 01:00 to January 11, 2007 11:00. The CIMIS Langley data was converted to PAR using the following formula (Fisher and others, 2003):

$$\frac{\text{Lagley}}{\text{day}} \times \frac{\text{day}}{24\text{ hr}} \times \frac{\text{hr}}{60\text{ min}} \times \frac{698\text{ Watts/m}^2}{\text{Langley/min}} \times \frac{4.57\ \mu\text{mol/m}^2\text{/sec}}{\text{Watt/m}^2} \times 50\% = \text{PAR}$$

Therefore, Langley/day x 1.1076 = PAR (mol/m^2/sec)

PAR estimates were converted from a trailing average to a leading average by moving each hourly estimate back one hour. Once converted to a leading average, the December 19, 2006 through January 11, 2007 estimates were added to the hourly light dataset recorded at the CHTR Study Facility.