Final

An Evaluation of Juvenile Salmonid Routing and Barrier Effectiveness, Predation, and Predatory Fishes at the Head of Old River, 2009–2012

Prepared by:

California Department of Water Resources

April 2015

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ACRONYMS AND OTHER ABBREVIATIONS

.RAT	raw acoustic tag file
.TAT	track acoustic tag file
°C	degrees Celsius
2D	two-dimensional
3D	three-dimensional
6YSS	Six-Year Steelhead Study
ACV	average channel velocity
AIC	Akaike's Information Criterion
AIC_c	Akaike's Information Criterion corrected for small sample sizes
ANOVA	analysis of variance
ATR	acoustic tag receiver
ATTS	Acoustic Tag Tracking System
BAFF	bio-acoustic fish fence
BDCP	Bay Delta Conservation Plan
BL/s	body lengths per second
$\hat{c}$	variance inflation factor
CCW	counter-clockwise
CDEC	California Data Exchange Center
CFR	Code of Federal Regulations
cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
cm	centimeters
cm/s	centimeters per second
CV	Central Valley
CVP	Central Valley Project
dB	decibels
D_E	deterrence efficiency
Delta	Sacramento–San Joaquin Delta
DGPS	Differential Global Positioning System
DL2D	two-dimensional velocity fields from DL-ADCP data
DL-ADCP	downward-looking acoustic Doppler current profiler
DPS	distinct population segment
DWR	California Department of Water Resources
ESA	federal Endangered Species Act

ACRONYMS AND OTHER ABBREVIATIONS

ESU	evolutionarily significant unit
FL	fork length
FR	*Federal Register*
GIS	geographic information system
GLM	generalized linear model
GPS	global positioning system
HD	Hydrophone
HOR	Head of Old River
HOR study site	Head of Old River, at the divergence of the San Joaquin and Old Rivers
HORB	Head of Old River Barrier
HR	High Residency
HTI	Hydroacoustic Technology Inc.
Hz	Hertz (cycles per second)
ID	identification
IML	Intense Modulated Light
IPLW	inverse path length weighting
J/g	Joules per gram
kg	kilogram
km	kilometer
kHz	kilohertz
LSZ	Low Salinity Zone
m	meter
m/s	meters per second
m^3/s	cubic meters per second
mm	millimeter
MSD	San Joaquin River at Mossdale
n	number of samples
NAVD	North American Vertical Datum of 1988
NFH	National Fish Hatchery
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Association
NTU	nephelometric turbidity units
OCAP	*Long-Term Central Valley Project and State Water Project Operations Criteria and Plan*
O_E	overall efficiency

ACRONYMS AND OTHER ABBREVIATIONS

OH1	Old River at Head
PAR	photosynthetically active radiation
PCC	percent correctly classified
P_E	protection efficiency
$QAIC_c$	the quasi-likelihood equivalent of Akaike's Information Criterion, corrected for small sample sizes
RBDD	Red Bluff Diversion Dam
Reclamation	U.S. Bureau of Reclamation
ROC	receiver operating characteristic
RPA	Reasonable and Prudent Alternative
SD	standard deviation
SE	standard error
SFPF	Skinner Delta Fish Protective Facility
SJL	San Joaquin River at Lathrop
SJR	San Joaquin River
SJRRP	San Joaquin River Restoration Program
SL2D	two-dimensional velocity fields from SL-ADCP data
SL-ADCP	side-looking acoustic Doppler current profiler
SWP	State Water Project
TFCF	Tracy Fish Collection Facility
TL	total length
Ua	main channel velocity
U-crit	critical swimming speed
Ue	fish escape velocity
Us	sweeping velocity
USFWS	U.S. Fish and Wildlife Service
UTC	Universal Coordinated Time
UTM	Universal Transverse Mercator
VAMP	Vernalis Adaptive Management Program

EXECUTIVE SUMMARY

ES.1 INTRODUCTION

ES.1.1 BACKGROUND AND PURPOSE

The California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (Reclamation) manage the State Water Project (SWP) and Central Valley Project (CVP), respectively, and are charged to do so in a manner that maintains the survival of anadromous salmonids subject to the terms of the National Marine Fisheries Service's (NMFS) 2009 Biological Opinion (BO) and 2011 amendments regarding the *Long-Term Central Valley Project and State Water Project Operations Criteria and Plan* (OCAP). Action IV.1.3 of the NMFS's 2009 BO instructs these agencies to "consider engineering solutions to further reduce diversion of emigrating juvenile salmonids to the interior and southern Delta, and reduce exposure to CVP and SWP export facilities." Specifically, one objective of Action IV.1.3 is to "prevent emigrating salmonids from entering channels in the south Delta (e.g., Old River, Turner Cut) that increase entrainment risk to Central Valley steelhead migrating from the San Joaquin River through the Delta."

Returning adult fish of the Distinct Population Segment (DPS) of California Central Valley steelhead (*Oncorhynchus mykiss*) and Central Valley fall-run Chinook salmon (*O. tshawytscha*) utilize the San Joaquin River and its connecting interior and south Sacramento-San Joaquin Delta (Delta) tributaries during their upstream spawning migration, while juveniles use these waterways to move downstream during their emigration to the Pacific Ocean. Increased susceptibility to entrainment and predation at DWR's and Reclamation's water export facilities has been associated with juvenile salmonids moving into Old River in comparison to those juveniles remaining in the mainstem of the San Joaquin River (Holbrook et al. 2009; SJRGA 2011). In an effort to reduce the movement of juvenile salmonids into Old River, engineering solutions (e.g., barriers) have been tested at the Head of Old River (HOR) pursuant to Action IV.1.3 of the NMFS BO. While a seasonal barrier in the fall has been part of California's protective fish management measures since 1968 (Hallock et al. 1970), deployment of a springtime barrier is more recent at this location (beginning in 1992) and uncertainties remain about its performance and effectiveness.

The purpose of this report is to contribute to the required BO Action IV.1.3 by evaluating and summarizing the effects of the non-physical barrier (2009, 2010), no barrier (2011), and physical barrier (2012) treatments and assess their effectiveness at retaining juvenile salmonids in the mainstem San Joaquin River. In addition to supporting Action IV.1.3, this report also provides critical information that improves understanding of how juvenile salmonids and predatory fish behave in the vicinity of the HOR and how effectively the tested barriers protect juvenile salmonids. This information can be used to improve barrier performance. The analyses included in the report focus on the barrier treatment effectiveness for juvenile salmonid route fate as influenced by the abiotic factors of ambient light level, water temperature, discharge, water velocity and turbidity. Additionally, predatory fish densities and predator fish interactions with the barrier treatments and juvenile salmonids were evaluated. Recommendations for future analyses and studies are identified.

ES.1.2 PHYSICAL PARAMETERS AND BARRIERS EVALUATION

The studies presented in this report were conducted during the spring (late April to May/June) of 2009–2012. San Joaquin River discharge (i.e., flow) varied among years. Discharge was lowest in 2009 and highest in 2011, and in the intermediate years, 2012 was less than in 2010 (Figure ES-1). The official water year classifications based on May 1 runoff forecasts were described as dry in 2009 and 2012, above normal in 2010, and wet in 2011 (State of California 2013).

In 2009 and 2010, a non-physical barrier (Bio-Acoustic Fish Fence [BAFF], Fish Guidance Systems Limited, Southampton, United Kingdom) was installed at the HOR. The BAFF comprised an acoustic deterrent stimulus enclosed within a bubble curtain and illuminated by strobe lights. In 2011, high-flow conditions precluded installing a barrier treatment. In 2012, an eight-culvert physical rock barrier was installed.

Discharge and barrier treatment influenced the proportion of San Joaquin River flow that entered Old River. In 2009, low discharge coupled with the resultant relatively strong tidal influence, including many flow reversals in the San Joaquin River and the non-physical barrier treatment caused a high proportion of discharge to enter Old River (0.6 to 0.8 [i.e., 60-80%] of total San Joaquin River flow at the Old River divergence). By contrast, the proportion of discharge entering Old River was lower, about 0.45 to 0.55 in 2010 (non-physical barrier) and 2011 (no barrier). In 2012, discharge proportion was recorded at 0.2 or less, demonstrating the effect of the presence of the rock barrier treatment (Figure ES-1).

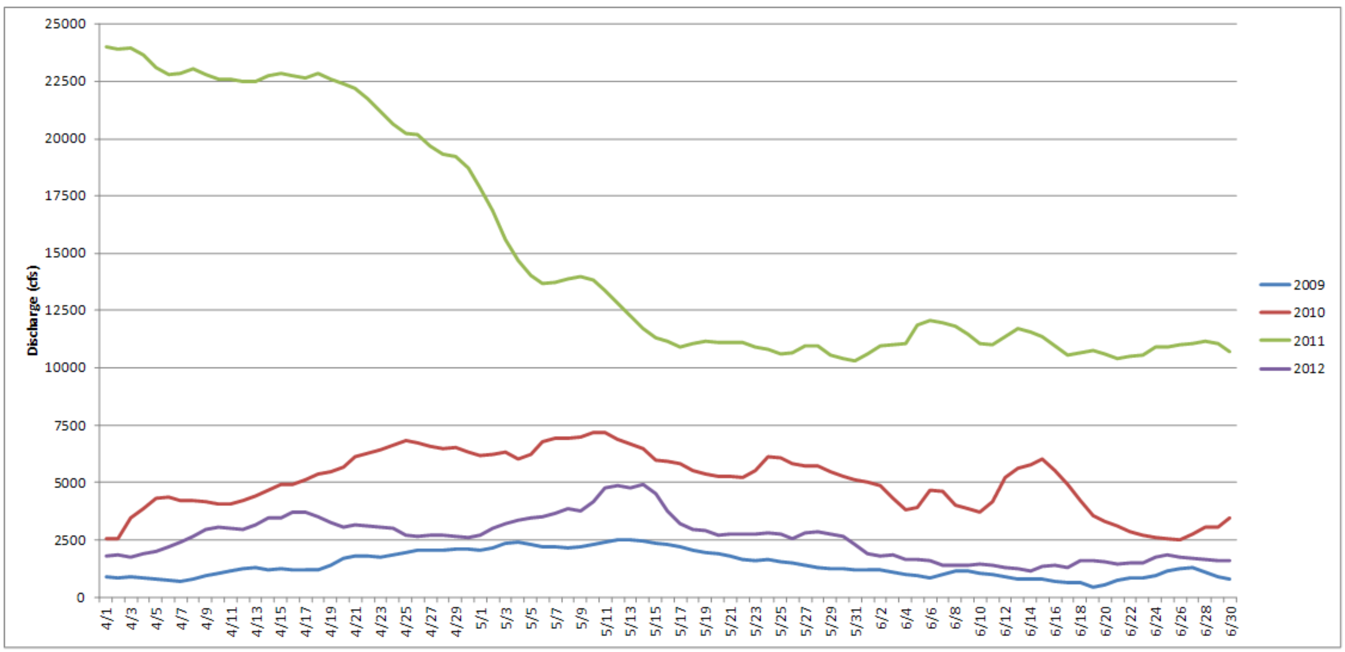


Figure ES-1 Mean Daily River Discharge (cubic feet per second) of the San Joaquin River at Mossdale (MSD), during the study period - April 1 to June 30, 2009–2012

ES.2 OBJECTIVES, METHODS, RESULTS, AND DISCUSSION

The present study included three main objectives, namely to conduct an evaluation at the Head of Old River of:

JUVENILE SALMONID ROUTING INCLUDING BARRIER EFFECTS

- Evaluate the effectiveness of different barrier treatments to influence the retention of acoustically tagged (tagged) juvenile Chinook salmon and steelhead in the San Joaquin River, under variable ambient light levels, water temperature, discharge, water velocity, and turbidity conditions.

PREDATION ON JUVENILE SALMONIDS INCLUDING BARRIER EFFECTS

- Evaluate predation on juvenile salmonids in response to a range of environmental conditions including barrier treatment effects.

BEHAVIOR AND DENSITY CHANGES IN PREDATORY FISHES

- Investigate behavior and density changes in predatory fishes in response to environmental conditions including residence time and assessment of areas occupied.

The following sections briefly summarize the methods used to evaluate the study objectives, the results, and their interpretation.

ES.2.1 EVALUATION OF JUVENILE SALMONID ROUTING INCLUDING BARRIER EFFECTS

STUDY FISH

Study fish were obtained from three hatcheries operated by the California Department of Fish and Wildlife. Chinook salmon juveniles were acquired from the Feather and Merced River hatcheries while the steelhead juveniles were acquired from the Mokelumne River Hatchery.

The number of juvenile Chinook salmon surgically implanted with Hydroacoustic Technology, Inc. (HTI; Seattle, Washington) tags was 933 in 2009, 504 in 2010, 1,915 in 2011, and 424 fish in 2012. The size of juvenile Chinook varied by year, but ranged from 80 millimeters (mm) to 140 mm in fork length. Steelhead juveniles implanted with HTI tags were released primarily in 2011 with a total of 2,208 fish which ranged from 149–396 mm fork length. Only 16 steelhead were released in 2012 and these fish ranged in size from 167–269 mm fork length. Juvenile salmonids implanted with VEMCO (Bedford, Nova Scotia, Canada) tags were released in 2012. These fish included 961 juvenile Chinook salmon (100–199 mm total length) and 1,435 juvenile steelhead (115–316 mm total length). Analyses presented in this report focus primarily on juvenile salmonids implanted with HTI tags, unless otherwise specified.

ROUTING AND FATE

The barrier evaluations described in this report were conducted as part of a coordinated suite of studies in the south Delta, which included the Vernalis Adaptive Management Program (VAMP) (SJRGA 1999) and the Six-Year Steelhead Study (6YSS) (NMFS 2009; SJRGA 2013). This coordinated suite of studies relied on one team (VAMP/6YSS) to conduct the surgical implantation, transport the fish to the release site (i.e., Durham Ferry on the San Joaquin River for all years), handle the fish to minimize effects on behavior, and release the telemetered juveniles according to the schedule.

Each juvenile salmonid entering the HOR study area was categorized based on its apparent fate from observations of two-dimensional tracks detected with a hydrophone array: (1) Released, but never arrived; (2) Remained in San Joaquin River; (3) Entered Old River; (4) Predation; or (5) Unknown. Only fish with fates 2-4 were included in the analyses. Fate was determined qualitatively based on a directed downstream movement for juvenile salmonids. Steelhead did not always move in a downstream direction which made subsequent analyses problematic. In contrast, predatory fish behavior typically included slower movements, looping patterns, and holding the same position.

Each fish was assigned to a sample based on its arrival time into the HOR study area. Samples were created by pooling fish that had arrived at a similar barrier state (BAFF on, BAFF off, no barrier, or rock barrier), ambient light level (< 5.4 lux or ≥ 5.4 lux), and average channel velocity (< 0.61 meter per second [m/s] or ≥ 0.61 m/s).

When barrier treatment status (off/on), ambient light level, or velocity changed, a new sample was created. For testing of BAFF effectiveness in 2009 and 2010, the BAFF was alternated between the "off" and "on" settings so that the BAFF was operational about 50% of the time. This time split in off/on operation allowed about 50% of the tagged juvenile Chinook salmon to experience the BAFF when in operation.

Table ES-1 provides an overview of the fate of tagged juvenile Chinook salmon that entered the HOR study area by year, barrier treatment, and ambient light level. The proportions shown are population proportions (note that population proportions differ from the sample proportions used in hypothesis testing; see Table ES-2). Across all years, the proportion of juveniles that remained in the San Joaquin River (nearly 0.41, i.e., 41%) was similar to the proportion that went down Old River; the remaining 0.19 (19%) were preyed upon. The proportion of juvenile Chinook salmon remaining in the San Joaquin River ranged from 0.09 (BAFF on in the dark, 2009) to 0.84 (rock barrier in the dark, 2012). The proportion of juvenile Chinook salmon entering Old River ranged from 0 (rock barrier, 2012) to 0.78 (BAFF off in the dark, 2009). The proportion of juvenile Chinook salmon that were preyed upon at the HOR study area ranged from 0.03 (no barrier in the dark, 2011) to 0.45 (rock barrier in the light, 2012). The fates of 525 tagged juvenile steelhead were determined in 2011–2012, although only five of these fish entered the study area in 2012. Of the 520 juvenile steelhead entering the study area in 2011, the grand overall efficiency was 38.3%, 199 remained in the San Joaquin River, 196 (37.7%) entered Old River, and 125 (24.0%) were preyed upon. There was little difference in routing or predation between light and dark conditions for juvenile steelhead.

Several primary objectives and hypotheses were associated with the evaluation of juvenile salmonid routing and barrier effectiveness (Table ES-2). The evaluation judged efficiency, defining "more efficient" as greater use by juveniles of the San Joaquin River route (over that of Old River) to leave the HOR study area. This definition reflects the general view that survival is lower down the Old River route (see review by Hankin et al. 2010 but see also SJRGA 2013). For each sample, three main metrics were calculated:

- *Overall efficiency* (O_E), the number of tags, surgically implanted in salmonid juveniles, exiting downstream from the study area via the San Joaquin River, divided by the number of tags entering the study area from upstream. This metric provided the most comprehensive measure of barrier effectiveness, as it integrated both routing and loss from predation.

Table ES-1
Fate of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River Study Area during 2009–2012

Year/Barrier/Light*	Total No. of Juveniles	San Joaquin River			Old River			Predation		
		Total	Proportion	SE	Total	Proportion	SE	Total	Proportion	SE
2009 BAFF	525	127	0.242	0.019	278	0.530	0.022	120	0.229	0.018
a. Off	292	68	0.233	0.025	176	0.603	0.029	48	0.164	0.022
i. dark	59	10	0.169	0.049	46	0.780	0.054	3	0.051	0.029
ii. light	233	58	0.249	0.028	130	0.558	0.033	45	0.193	0.026
b. On	233	59	0.253	0.028	102	0.438	0.033	72	0.309	0.030
i. dark	45	4	0.089	0.042	35	0.778	0.062	6	0.133	0.051
ii. light	188	55	0.293	0.033	67	0.356	0.035	66	0.351	0.035
2010 BAFF	451	114	0.253	0.020	220	0.488	0.024	117	0.259	0.021
a. Off	219	45	0.205	0.027	129	0.589	0.033	45	0.205	0.027
i. dark	77	25	0.325	0.053	41	0.532	0.057	11	0.143	0.040
ii. light	142	20	0.141	0.029	88	0.620	0.041	34	0.239	0.036
b. On	232	69	0.297	0.030	91	0.392	0.032	72	0.310	0.030
i. dark	60	28	0.467	0.064	28	0.467	0.064	4	0.067	0.032
ii. light	172	41	0.238	0.032	63	0.366	0.037	68	0.395	0.037
2011 No barrier	1,075	551	0.513	0.015	415	0.386	0.015	109	0.101	0.009
a. dark	306	162	0.529	0.029	135	0.441	0.028	9	0.029	0.010
b. light	769	389	0.506	0.018	280	0.364	0.017	100	0.130	0.012
2012 Rock barrier	193	117	0.606	0.035	0	0.000	0.000	76	0.394	0.035
a. dark	38	32	0.842	0.059	0	0.000	0.000	6	0.158	0.059
b. light	155	85	0.548	0.040	0	0.000	0.000	70	0.452	0.040
Total	**2,244**	**909**	**0.405**	**0.010**	**913**	**0.407**	**0.010**	**422**	**0.188**	**0.008**

Notes: BAFF = Bio-Acoustic Fish Fence (Fish Guidance Systems Ltd., Southampton, UK) (non-physical barrier); SE = Standard Error

* Dark < 5.4 lux, light ≥ 5.4 lux

Source: Present study

Table ES-2
Objectives, Hypotheses, and Results Related to Juvenile Salmonid Routing Including Barrier Effects

Year and Treatment	Objective	Hypothesis Number	Hypotheses	Results*
2009 BAFF	Determine whether barrier efficiency (O_E, P_E, and D_E) for juvenile Chinook salmon was improved by BAFF operation	$H1_0$	For juvenile Chinook salmon, barrier efficiency (O_E, P_E, and D_E) with the BAFF on was equal to barrier efficiency with the BAFF off.	O_E: Accept hypothesis (BAFF on [0.209] = BAFF off [0.184]) P_E: Accept hypothesis (BAFF on [0.338] = BAFF off [0.234]) D_E: Reject hypothesis (BAFF on [0.732] > BAFF off [0.311])
2010 BAFF	Determine whether barrier efficiency (O_E, P_E, and D_E) for juvenile Chinook salmon was improved by BAFF operation	$H2_0$	For juvenile Chinook salmon, barrier efficiency (O_E, P_E, and D_E) with the BAFF on was equal to barrier efficiency with the BAFF off.	O_E: Accept hypothesis (BAFF on [0.355] = BAFF off [0.245]) P_E: Reject hypothesis (BAFF on [0.441] > BAFF off [0.286]) D_E: Reject hypothesis (BAFF on [0.150] > BAFF off [0.012])
	Determine whether BAFF barrier efficiency with the BAFF on changed significantly between years	$H3_0$	For juvenile Chinook salmon with BAFF on, barrier efficiency (O_E, P_E, and D_E) in 2009 was equal to barrier efficiency in 2010.	O_E: Accept hypothesis (2009 [0.209] = 2010 [0.355]) P_E: Accept hypothesis (2009 [0.338] = 2010 [0.441]) D_E: Reject hypothesis (2009 [0.732] > 2010 [0.150])
	Determine whether with the BAFF off, barrier efficiency changed significantly between years	$H4_0$	For juvenile Chinook salmon with BAFF off, barrier efficiency (O_E, P_E, and D_E) in 2009 was equal to barrier efficiency in 2010.	O_E: Accept hypothesis (2009 [0.184] = 2010 [0.245]) P_E: Accept hypothesis (2009 [0.234] = 2010 [0.286]) D_E: Reject hypothesis (2009 [0.312] > 2010 [0.012])
2011 No Barrier	Determine whether and to what extent the BAFF infrastructure affected O_E and P_E when the BAFF was turned off	$H5_0$	For juvenile Chinook salmon, O_E and P_E were equal for 2009 BAFF off, 2010 BAFF off, and 2011 no barrier conditions.	O_E: Reject hypothesis (2011 [0.519] > 2010 [0.245] = 2009 [0.184]) P_E: Reject hypothesis (2011 [0.574] > 2010 [0.286] = 2009 [0.234])
	Determine whether juvenile Chinook salmon and steelhead had the same O_E and P_E through the HOR study area	$H6_0$	O_E and P_E were the same for juvenile Chinook salmon and steelhead.	O_E: Reject hypothesis (Chinook salmon [0.519] > steelhead [0.368]) P_E: Accept hypothesis (Chinook salmon [0.574] = steelhead [0.490])
2012 Rock Barrier	Compare O_E and P_E across treatments to determine whether any barrier was more effective than no barrier and which produced the highest efficiency at retaining juvenile Chinook salmon in the San Joaquin River	$H7_0$	For juvenile Chinook salmon, O_E and P_E were equal for 2009 BAFF on, 2010 BAFF on, 2011 no barrier, and 2012 rock barrier treatments.	O_E: Reject hypothesis (2012 [0.618] = 2011 [0.519] > 2010 [0.355] = 2009 [0.209]) P_E: Reject hypothesis (2012 [1.000] > 2011 [0.574] > 2010 [0.441] = 2009 [0.338])

Table ES-2
Objectives, Hypotheses, and Results Related to Juvenile Salmonid Routing Including Barrier Effects

Year and Treatment	Objective	Hypothesis Number	Hypotheses	Results*

Notes: BAFF = Bio-Acoustic Fish Fence (Fish Guidance Systems Ltd., Southampton, UK) (non-physical barrier); D_E = deterrence efficiency; O_E = overall efficiency; P_E = protection efficiency

* Numbers in brackets indicate sample-based mean efficiency estimates, with statistically significant differences indicated by “<” or “>” and no significant difference indicated by “=.”

Source: Present study

- *Protection efficiency* (P_E), the number of juveniles exiting downstream from the study area via the San Joaquin River, divided by the number of juveniles exiting via the San Joaquin River plus the number of individuals exiting via Old River, but considering only those juveniles that were not eaten at the HOR study area. This metric provided a measure of salmonid juvenile routing through the study area, excluding salmonid juveniles that were eaten.

- *Deterrence efficiency* (D_E), the number of juveniles approaching the BAFF that were deterred from continuing their approach or were guided along past the end of the BAFF, divided by the total number of juveniles approaching the BAFF. This metric was specific to the BAFF and evaluated its efficacy in producing stimuli noxious to the juvenile salmonids approaching it, as shown by their lack of desire to cross the BAFF.

The analyses of barrier effectiveness found that the BAFF effectively deterred juvenile Chinook salmon from approaching the BAFF in both 2009 and 2010 - that is, D_E was significantly higher with BAFF on than with BAFF off (Table ES-2; Hypotheses $H1_0$ and $H2_0$). D_E was significantly higher in 2009 than 2010 (Table ES-2; Hypothesis $H3_0$), possibly because in 2010 the discharge was higher, a lower proportion of the water column was occupied by the BAFF, and the barrier alignment was different. D_E was also higher in 2009 than 2010 with the BAFF off (Table ES-2; Hypothesis $H4_0$).

Although the BAFF's noxious stimuli were successful in deterring fish from approaching, the BAFF was not efficient in terms of allowing more juvenile Chinook salmon to leave the HOR study area via the San Joaquin River route. There was no significant difference in O_E between BAFF-on and BAFF-off treatments in either 2009 or 2010, and only in 2010 was P_E significantly higher with the BAFF on. These results reflected rates of predation that occurred during BAFF operations (discussed further in Section ES.2.2). There was no significant difference in O_E and P_E between 2009 and 2010, although O_E was close ($P = 0.0563$) to being significantly greater in 2010 (0.36) than in 2009 (0.21). With the BAFF off, O_E and P_E also were not significantly different between 2009 and 2010 (Table ES-2; Hypotheses $H3_0$ and $H4_0$).

The influence of the BAFF's infrastructure alone on survival through the HOR study area was assessed by comparing efficiency (O_E and P_E) with the BAFF off in 2009 and 2010 to efficiency in 2011 (Table ES-2; Hypothesis $H5_0$). Although both O_E and P_E were significantly lower in 2009 and 2010 than in 2011, this comparison was confounded by the very high discharge in 2011, which may have affected the comparison regardless of the presence of a BAFF.

The availability of tracking data for tagged juvenile steelhead moving through the HOR study area in 2011 allowed a comparison of juvenile Chinook salmon and steelhead efficiencies in that year (note that this was not a test of barrier efficiency, but of routing and survival [Table ES-2; Hypothesis $H6_0$]). The routing of juvenile Chinook and steelhead was similar (i.e., no significant difference in P_E), providing evidence of proportional movement that was similar to the proportional split in discharge between the San Joaquin and Old rivers. Juvenile steelhead had significantly lower O_E than the juvenile Chinook salmon, suggesting higher rates of predation. However, this may have been an artifact of juvenile steelhead behavior being similar to predator behavior at times (discussed further in Section ES.2.2).

The analysis of primary importance for addressing management at the HOR study area was the comparison of the efficiencies of different barrier treatments in retaining the juvenile Chinook salmon in the San Joaquin River

(Table ES-2; Hypothesis $H7_0$). This analysis revealed no significant difference in O_E between the no barrier and rock barrier treatments in 2011 and 2012, respectively, and that O_E was significantly greater in both of these years than in 2009 and 2010. The fact that all surviving Chinook salmon juveniles remained in the San Joaquin River with the 2012 rock barrier caused the P_E to be significantly higher in 2012 than in all other years, whereas greater discharge in 2011 resulted in significantly greater P_E in that year than in 2009 and 2010.

The primary hypotheses (Table ES-2) were supplemented with supporting hypotheses that evaluated BAFF efficiencies at different levels of light and channel velocity. The light levels considered were dark (< 5.4 lux), and light (≥ 5.4 lux), reflecting the threshold above which light might have affected juvenile Chinook salmon reactions to the BAFF's strobe lights. The channel velocity levels considered were low (≤ 0.61 m/s average channel velocity), and high (> 0.61 m/s average channel velocity), reflecting the sustained swimming speed of small juvenile Chinook salmon, corrected for BAFF angle. The analysis considered these different light levels and channel velocities to account for potential differences in barrier effectiveness because of the visibility of the BAFF and the ability of juvenile salmonids to exhibit swimming avoidance behavior.

Of the three measures of efficiency examined (O_E, P_E, and D_E), only D_E showed a difference between light levels or velocities, and it was significantly higher with the BAFF on in high light conditions (in both 2009 and 2010). This result may reflect a greater ability of juvenile Chinook salmon to orient away from the BAFF's main noxious stimulus (the acoustic deterrent) in high light because of the increased visibility of the BAFF. However, predation increases with higher light level, thus reducing much of the benefit of the BAFF in providing deterrence (as noted in Section ES.2.2).

ES.2.2 Evaluation of Predation on Juvenile Salmonids Including Barrier Effects

The data on tagged juvenile salmonids described previously were used to address several objectives related to predation in the HOR study area. Those objectives were evaluated by testing univariate sample–based hypotheses in relation to the proportion of salmonids in each sample that were eaten in the study area (Table ES-3; Hypotheses $H8_0$, $H9_0$, and $H10_0$). These analyses generated the following findings:

- The proportion of juvenile Chinook salmon eaten was significantly greater with the BAFF on than with the BAFF off in 2009, but not in 2010 (Table ES-3; Hypothesis $H8_0$);
- In 2011, a significantly greater proportion of juvenile steelhead was eaten than Chinook salmon (Table ES-3; Hypothesis $H9_0$). However, some of the tagged juvenile steelhead categorized as "eaten" may not have been eaten because steelhead sometimes exhibited looping behavior or swam against the flow - behaviors that were used as criteria for determining predation. This would have resulted in an overestimate of the proportion of steelhead eaten; and
- A significantly lower proportion of juvenile Chinook salmon was eaten in 2011 (a high-flow year) than in 2012 (a low-flow year, with the rock barrier in place), whereas the proportion eaten in 2009 and 2010 with the BAFF on was intermediate to, but not statistically different from, the other two years (Table ES-3; Hypothesis $H10_0$).

Table ES-3
Objectives, Hypotheses, and Results Related to Predation on Juvenile Salmonids Including Barrier Effects

Year(s)	Objectives	Hypothesis Number	Hypotheses	Results*
2009	Provide a direct test that the BAFF operation had some influence on proportion eaten.	$H8_0$	The proportion of juvenile Chinook salmon entering the HOR study area that were eaten with the BAFF was on was equal to the proportion eaten when the BAFF was off.	Reject hypothesis: Significantly greater proportion eaten with BAFF on (0.290) than with BAFF off (0.138).
2010	Provide a direct test that the BAFF operation had some influence on proportion eaten.	$H8_0$	The proportion of juvenile Chinook salmon entering the HOR study area that were eaten with the BAFF was on was equal to the proportion eaten when the BAFF was off.	Accept hypothesis: No difference in proportion eaten between BAFF on (0.217) and BAFF off (0.212).
2011	Evaluate the proportion eaten for Chinook salmon and steelhead juveniles in 2011.	$H9_0$	The proportions of juvenile Chinook salmon and steelhead entering the HOR study area that were eaten were equal.	Reject hypothesis: Significantly greater proportion of juvenile steelhead eaten (0.243) than Chinook salmon (0.087).
2009–2012	Show whether there were differences in proportion eaten between treatments.	$H10_0$	The proportions of juvenile Chinook salmon entering the HOR study area that were eaten were equal for 2009-BAFF on, 2010-BAFF on, 2011-no barrier, and 2012- rock barrier.	Reject hypothesis: Significantly greater proportion eaten in 2012 (0.354) than in 2011 (0.087), with 2009 (0.290) and 2010 (0.217) intermediate and not significantly different from other years.
2009, 2010, 2012	Evaluate the influence of abiotic and biotic factors, including barrier type/status, on probability of predation of juvenile Chinook salmon.	H11	Probability of predation of juvenile Chinook salmon is negatively related to discharge (shorter travel time/distance at higher discharge), turbidity (lower visual range of predators with greater turbidity), size (larger juveniles less susceptible to predators), and small-fish density (availability of alternative prey for predators). Probability of predation is positively related to water temperature (higher bioenergetic demands of predators with higher temperature) and ambient light level (greater visual range of predators with more light). Probability of predation is unrelated to barrier treatment/status (BAFF on/off, rock barrier).	Hypothesis supported only for ambient light: greater predation probability at higher light level. No support for other hypotheses. Significantly greater probability of predation with BAFF on or rock barrier than with BAFF off. Probability of predation positively related to small-fish density.

Table ES-3
Objectives, Hypotheses, and Results Related to Predation on Juvenile Salmonids Including Barrier Effects

Year(s)	Objectives	Hypothesis Number	Hypotheses	Results*
2011, 2012	Evaluate the influence of abiotic and biotic factors on probability of predation of juvenile Chinook salmon.	H12	Probability of predation of juvenile Chinook salmon is negatively related to discharge, turbidity, juvenile size, and small-fish density. Probability of predation is positively related to water temperature, ambient light level, and density of predatory fish (greater predation pressure with more large fish).	Hypothesis supported only for ambient light and turbidity: greater predation probability at higher light levels and lower turbidity.
2011	Evaluate the influence of abiotic and biotic factors on probability of predation of juvenile steelhead.	H13	Probability of predation of juvenile steelhead is negatively related to discharge, turbidity, size, and small-fish density. Probability of predation is positively related to water temperature, ambient light level, and density of predatory fish (greater predation pressure with more large fish).	Model was a poor fit to the data; results inconclusive.

Notes: BAFF Bio-Acoustic Fish Fence (Fish Guidance Systems Ltd., Southampton, UK) (non-physical barrier); HOR = Head of Old River

* Numbers in parentheses indicate sample-based mean proportion eaten estimates.

Source: Present study

In addition to the univariate sample-based method, generalized linear modeling (GLM) was undertaken. This modeling assessed the potential influence of several environmental variables on the probability of predation of juvenile salmonids in the HOR study area. It also tested the null hypothesis of no difference in predation probability of juvenile Chinook salmon between barrier treatments (BAFF on/BAFF off/rock barrier) for data from 2009, 2010, and 2012 (Table ES-3; Hypothesis H11). The GLM suggested that the probability of predation was significantly greater for the BAFF-on and rock barrier treatments than for the BAFF-off treatment, and that the probability of predation was greater under higher light conditions (presumably because predators could see the juvenile Chinook salmon more easily). This may be the case because juveniles have longer travel distances through the HOR study area as they avoid the noxious stimulus of the BAFF (and may be disoriented by the stimulus) or they are entrained into the eddies created by the rock barrier.

Further analysis was conducted of the data from GLM of juvenile Chinook salmon predation in 2011 and 2012 (Table ES-3; Hypothesis H12) so that the density of large fish from hydroacoustic surveys could be included as a measure of the density of potential predatory fish. This analysis found that the probability of predation was greater at higher light levels and lower turbidities, again suggesting the importance of visibility to predators.

Discharge was not found to be an important predictor of predation probability. To some extent, this may reflect the difficulty in accurately assigning a discharge measurement when conditions are changing rapidly; the higher probability of predation with lower turbidities partly reflects differences in discharge. Relatively low predation at the HOR study area in 2011 may have reflected a downstream shifting of predatory fish (as observed by LeDoux-Bloom [2012] in the broader San Francisco estuary), and predation pressure in response to discharge, because the VAMP study did not find overall through-Delta survival to be greater in 2011 than in other years (SJRGA 2013).

Bioenergetics modeling was conducted to assess potential striped bass predation on juvenile Chinook salmon at the HOR study area. This modeling illustrated that in 2012, the relatively high density of predatory fish (with large fish assumed to be striped bass based on side-looking mobile hydroacoustics), coupled with relatively high water temperature, may have resulted in predation rates similar to those estimated by observing the tagged juvenile Chinook salmon tracks. Lower predatory fish densities and water temperature estimates in 2011 led to considerably lower estimated predation rates for that year from bioenergetics modeling, which agrees with the considerably lower observed predation rate for that year (Tables ES-1 and ES-3).

GLM of the probability of predation on juvenile steelhead in 2011 did not yield informative results. To some extent, this may reflect difficulties in assigning steelhead fate, because steelhead movement patterns are less directed than those of Chinook salmon, and steelhead movement patterns may be confused with movement patterns of predatory fishes (Table ES-3; Hypothesis H13).

ES.2.3 Evaluation of Behavior and Density Changes in Predatory Fishes

The behavior of predatory fishes at the HOR study area was studied with more than 80 striped bass (*Morone saxatilis*), largemouth bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*), and white catfish (*Ameiurus catus*) that were captured by hook and line angling and externally fitted with acoustic tags, primarily in 2011 and 2012. The acoustic detection data from these fish allowed objectives related to residence time and areas occupied by predatory fishes at the HOR study area to be addressed (Table ES-4). In addition, information from mobile hydroacoustic surveys conducted in 2011–2012 and the locations of stationary juvenile salmonids' acoustic tags were used to provide information about the areas occupied by predatory fishes. It was assumed that the density of fish estimated by hydroacoustic surveys to be at least 30 centimeters (cm) in total length would indicate the density of predatory fishes (recognizing that not all large fish detected would be predatory fishes).

Table ES-4 Objectives Related to Behavior of Predatory Fishes			
Years	Objective	Means of Study	Utility to Management
2009–2012	Describe residence time of predatory fishes at the HOR study area.	Tagged predatory fish	Indicates turnover of predatory fish, and therefore allows inference regarding the level of effort required for relocation of predatory fish, for example.
2009–2012	Describe areas (spatial and velocity) occupied by predatory fishes at the HOR study area.	Tagged predatory fish, mobile hydroacoustic surveys, tags from stationary juvenile salmonids (presumably eaten and defecated by predatory fishes)	Indicates where at the HOR study area to focus predator capture efforts for any contemplated relocation efforts, as well as indicating habitat areas that could be manipulated to reduce predator density and predation risk.

Note: HOR = Head of Old River
Source: Present study

The time spent at the HOR study area by tagged predatory fishes varied. Generally, however, channel catfish, white catfish, and largemouth bass spent appreciably longer amounts of time than striped bass (i.e., days or weeks, rather than hours). Most striped bass left the study area in a downstream direction. The significance of the present results for management is that turnover of striped bass generally is appreciable, with most fish spending a limited amount of time at the HOR study area. Thus, efforts to control fish numbers by removal/relocation would require a sustained effort (e.g., daily removal).

The scour hole at the HOR study area was confirmed as an important area for occupancy by predatory fishes. Tagged predatory fishes were found occupying portions of the HOR study area in the San Joaquin River downstream of the Old River divergence, both at the scour hole and in the immediately adjacent areas. Some differences existed in the areas occupied by the different species of tagged predatory fish. For example, striped bass generally were found more often in areas away from shore (although they also occurred near shore), whereas largemouth bass tended to occur more in the nearshore zones.

An analysis of velocities occupied by tagged predatory fishes confirmed the main patterns shown by the spatial analysis of areas occupied. Catfishes and largemouth bass occupied areas with estimated near-surface velocities that were very low compared to all velocities available in the HOR study area. Striped bass differed from the other predatory fishes in occupying a range of velocities, with some individuals having median occupation velocities greater than the median velocities available at the HOR study area; this reflects the species' pelagic nature and occupation of a variety of habitats.

Down-looking mobile hydroacoustic surveys showed an extremely high concentration of large fish (presumably including many predatory fishes, but possibly also including large-bodied nonpredatory fish such as common carp [*Cyprinus carpio*]) in the scour hole; side-looking hydroacoustic surveys similarly showed many large fish in the scour hole, but also showed appreciable numbers in other nearby locations within the study area.

Stationary tags originally inserted into juvenile salmonids, provided a third source of information about areas occupied by predators. The tags also indicated the considerable importance of the scour hole and vicinity because most stationary tags were found there, with very few stationary tags found elsewhere (one tag was also found closely associated with the 2012 rock barrier).

With respect to the occurrence of predatory fish near the installed barriers, tagged largemouth bass that were released downstream of the rock barrier tended to remain at or close to the barrier much of the time, and therefore could have posed a predation threat to any fish passing through the barrier's culverts. A single largemouth bass tagged in 2009 spent an appreciable amount of time (nearly 50% of all detections) within 5 meters of the BAFF (at the upstream end, closest to shore). Little evidence existed of striped bass spending much time close to the BAFF in 2009/2010, although the number of tagged striped bass during these years was very low (n = 4). These findings have important implications for limiting predator abundance at the HOR study area, whether directly (through capture/relocation) or indirectly (through habitat manipulation, such as scour hole filling).

Data from mobile hydroacoustic surveys also were used to address several objectives related to changes in predatory fish density at the HOR study area caused by changes in environmental variables, and to compare density to several reference sites in the San Joaquin River (Table ES-5). GLM suggested that based on both down-looking and side-looking mobile hydroacoustic surveys, the main environmental predictors associated with changes in the density of large fish (greater than 30 cm total length) were same-day discharge and water temperature (Table ES-5; Hypothesis $H14_0$). Density increased as discharge decreased and water temperature increased.

To some extent, the correlation between density of large fish and discharge and water temperature reflected both differences between years and differences within years. The density of large fish was considerably less in 2011 than in 2012; discharge was considerably higher in 2011 than in 2012. The lower density of large fish, presumably including many predatory fish, in 2011 may reflect lower habitat suitability associated with higher water velocities. The 2012 surveys provided a contrast between very low abundance during March, which had low water temperatures (approximately 12–15°C), and higher abundance in May (18–22°C). This suggests seasonal migration to and through the HOR study area by large fish, such as striped bass that spawn in the river during the spring. Although density estimates were quite variable at all the sites, positive correlations in large-fish density existed between the HOR study area and the reference sites in approximately half of the comparisons (Table ES-5; Hypothesis $H15_0$). Large-fish density at the HOR study area was either greater than or not significantly different from large-fish density at the three reference sites (Table ES-5; Hypothesis $H16_0$).

Taken together, these results suggest that wide-ranging factors (e.g., discharge and water temperature) affect fish density over much of the San Joaquin River, and that the HOR study area has a relatively high density of large fishes compared to reference sites. These findings have management implications when prioritizing predator management efforts at the HOR study area and elsewhere in the interior and south Delta, both temporally (within and between years; e.g., there may be more need to capture/relocate predators in warmer years with lower discharge) and spatially (e.g., if the location of large concentrations of predatory fishes changes based on discharge).

Table ES-5
Objectives, Hypotheses, and Results Related to Density of Predatory Fishes

Year	Objectives	Hypothesis Number	Hypotheses	Results
2011–2012	Determine whether environmental variables are associated with changes in large-fish densities at the HOR study area.	$H14_0$	The density of large fish (> 30 cm in total length, i.e., potential predators) at the HOR site is not correlated with environmental variables (discharge, water temperature, turbidity, ambient light level, and small-fish density [representing availability of potential prey]).	Down-looking and side-looking hydroacoustics: Null hypothesis not supported for discharge (negative relationship with large-fish density) and water temperature (positive relationship with large-fish density). Null hypothesis accepted for other variables.
2011–2012	Determine whether there are broad-scale environmental influences on predatory fish densities at the HOR study area that result in similar changes in density to reference sites.	$H15_0$	Changes in the density of large fish (> 30 cm in total length, i.e., potential predators) at the HOR study area during the spring are not correlated with changes in density at three reference sites.	Down-looking hydroacoustics: Accept null hypothesis for two of three comparisons; reject null hypothesis for the remaining comparison (positive correlation in density between the HOR study area and the reference sites). Side-looking hydroacoustics: Reject null hypothesis for two of three comparisons (positive correlations in density between HOR study area and reference sites); accept null hypothesis for the remaining comparison.
2011–2012	Determine whether predatory fish density at the HOR study area is greater than at similar reference sites.	$H16_0$	The density of large fish (> 30 cm in total length, i.e., potential predators) at the HOR study area during the spring is not significantly different from density at three reference sites.	Down-looking hydroacoustics: Accept null hypothesis for two of three comparisons; reject null hypothesis for the remaining comparison (significantly greater density at the HOR study area than at one reference site). Side-looking hydroacoustics: Reject null hypothesis for two of three comparisons (significantly greater density at the HOR study area than at two reference sites); accept null hypothesis for the remaining comparison.

Notes: cm = centimeters; HOR = Head of Old River
Source: Present study

ES.3 RECOMMENDATIONS

Several recommendations for future study are provided to advance the findings of the present study (Table ES-6). With respect to juvenile salmonid routing and barrier effects, it is recommended that the cost and benefit of barriers at the HOR study area be studied relative to the cost and benefits of alternative management strategies, particularly non-engineering solutions such as habitat restoration (e.g., floodplain restoration and other actions proposed under the Bay Delta Conservation Plan [BDCP]). This recommendation is made for the following reasons:

- None of the barriers that were studied provided overall efficiency (O_E) greater than 62% and simultaneously - less than 22% proportion eaten (see Table ES-1 for the proportion of fish remaining in the San Joaquin River and Table ES-3 for the results of sample proportion eaten in 2009-2012); the only barrier (rock) that produced an O_E greater than 62% also showed a sample proportion eaten of 35.4% and the only barrier (BAFF on, 2010) that produced a proportion eaten of 21.7% yielded an O_E of only 29.4%; in other words, with respect to the barriers studied in the report, it is possible to have high overall efficiency (rock barrier) or relatively low predation (BAFF on), but both of these desirable qualities are not available from the same barrier.
- Recent studies concluded that the San Joaquin River may not necessarily be the best migration route for juvenile salmonid survival (SJRGA 2011, 2013; Buchanan et al. 2013); and
- Survival through the south Delta generally is low by any route, suggesting that habitat improvements and restoration are desirable regardless of any routing influenced by a barrier at the HOR.

Table ES-6
Recommendations for Future Study

Juvenile Salmonid Routing Including Barrier Effects
► Study the costs and benefits of barriers in relation to alternative (non-engineering) management strategies. ► Conduct additional integrated analysis of existing data using supplementary techniques. ► Investigate new physical barrier alternatives to the rock barrier and BAFF.
Predation on Juvenile Salmonids Including Barrier Effects
► Further examine predation classification. ► Study the feasibility of physical habitat reconfiguration. ► Conduct a pilot predatory fish relocation study. ► Study the effects of physical barriers on predation hotspots. ► Study potential effects of changing recreational fishing regulations.
Behavior and Density Changes in Predatory Fishes
► Assess movement patterns of predatory fish as part of a pilot predatory fish relocation study. ► Assess predatory fish density in relation to predation hotspots.
Notes: BAFF = Bio-Acoustic Fish Fence (Fish Guidance Systems Ltd., Southampton, UK) (non-physical barrier). Source: Present study

The generally limited effectiveness of the BAFF (Tables ES-1 and ES-2), coupled with what appeared to be relatively high predation with installation of the 2012 rock barrier, leads to the recommendation to study alternative barriers. In this regard, it is recommended to consider the suggestions made by the VAMP's review panel (Hankin et al. 2010) about the features of such a barrier, particularly because of the BDCP's proposal to construct an operable gate at the HOR. As part of such studies of physical barriers, it is recommended that juvenile Chinook salmon survival through the Delta by the San Joaquin and Old river routes be studied further. Historically, the San Joaquin River was the safer route (reviewed by Hankin et al. 2010) but survival by the Old River route has been similar to or higher than the San Joaquin River route since 2010 (SJRGA 2011, 2013; Buchanan et al. 2013).

Additionally, it is recommended that the existing juvenile salmonid routing data undergo additional analysis, using techniques supplementary to the univariate approach used in the present study (e.g., GLM). The purpose of such additional analysis would be to elucidate further barrier effectiveness across ranges of environmental variables and provide outputs that may support present analyses or provide a different interpretation than the current approach. It is also recommended that additional analyses be undertaken of data collected in 2013 (i.e., from the study similar to the VAMP's release of tagged juvenile Chinook salmon and from tagged steelhead released as part of the 6YSS mandated by the NMFS [2009] OCAP BO). Such analyses would allow comparison of juvenile salmonid routing and survival with a low-discharge, no-barrier treatment (i.e., 2013) with the other years (2009–2012) included in the present evaluation.

With respect to predation on juvenile salmonids, a key uncertainty warranting further research is the actual fate of fish that have been classified as having been preyed upon or having survived passage through the HOR study area. Therefore, it is recommended that the 2009–2012 data from the HOR study area be examined for the correspondence between qualitative fate classification (as used in the present investigations) and classifications based on mixture models that use data from tagged predatory fishes (e.g., from Georgiana Slough or, preferably, from the HOR study area). It is also recommended that predation classification in future studies (by mixture models, qualitative fate classification, or other means) at the HOR study area incorporate the use of the new predation tag technology (e.g., HTI's Predation Tag) that is currently being tested by DWR and its partners.

The preponderance of stationary juvenile salmonid acoustic tags in the scour hole and the association of predatory fishes with the scour hole and adjacent areas at the HOR study area leads to the recommendation that a study be undertaken of the feasibility of reconfiguring the physical habitat (e.g., modifying the scour hole's bathymetry by filling). Regardless of the presence or absence of a barrier at the HOR study area, predation was high in all years—bioenergetics modeling completed as part of this evaluation suggested that the estimated predation rates were reasonable—and a pilot predatory fish relocation study may be warranted. Such a study is already proposed for 2014–2017 and, together with any such future studies, will serve to inform management at the HOR study area and other predation hotspots.

At the broader scale, it is also recommended that changes to fishing regulations be studied to assess their potential for improving juvenile salmonid survival from the San Joaquin River region through the south Delta area, including the HOR study area. Associated with the pilot predator-relocation studies, it is recommended that broad-scale movement patterns of relocated predatory fishes also be studied. It is recommended that, at the broader scale of the south Delta, the study of the physical barriers recommended above be coupled with both the study of the locations of predation hotspots and the density of predatory fishes at hotspots, to assess the extent to which these vary under differing discharge conditions and the location of the tidal transition zone.

1 INTRODUCTION

1.1 BACKGROUND

The California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (Reclamation) manage the State Water Project (SWP) and Central Valley Project (CVP), respectively, with the goal of improving abundance, productivity, and diversity of anadromous salmonids subject to the terms of the National Marine Fisheries Service's (NMFS) 2009 Biological Opinion (BO) and 2011 amendments regarding the Long-Term Central Valley Project and State Water Project Operations Criteria and Plan (OCAP). Action IV.1.3 of the NMFS's 2009 BO instructs these agencies to "consider engineering solutions to further reduce diversion of emigrating juvenile salmonids to the interior and southern Delta,[1] and reduce exposure to CVP and SWP export facilities." Specifically, one objective of Action IV.1.3 is to "prevent emigrating salmonids from entering channels in the south Delta (e.g., Old River, Turner Cut) that increase entrainment risk to Central Valley steelhead migrating from the San Joaquin River through the Delta."

Returning adult fish of the Distinct Population Segment (DPS) of California Central Valley steelhead (*Oncorhynchus mykiss*) and Central Valley fall-run Chinook salmon (*O. tshawytscha*) utilize the San Joaquin River and its connecting interior and south Sacramento-San Joaquin Delta (Delta) tributaries during their upstream spawning migration, while juveniles use these waterways to move downstream during their emigration to the Pacific Ocean. Increased susceptibility to entrainment and predation at DWR's and Reclamation's water export facilities has been associated with juvenile salmonids moving into Old River in comparison to those juveniles remaining in the mainstem of the San Joaquin River (Holbrook et al. 2009; SJRGA 2011). In an effort to reduce the movement of juvenile salmonids into Old River, engineering solutions (e.g., barriers) have been tested at the Head of Old River (HOR) pursuant to Action IV.1.3 of the NMFS BO. While a seasonal barrier in the fall has been part of California' protective fish management measures since 1968 (Hallock et al. 1970), deployment of a springtime barrier is more recent at this location (1992) and uncertainties remain about its performance and effectiveness.

The purpose of this report is to contribute to the required BO Action IV.1.3 by evaluating and summarizing the effects of non-physical barrier (2009, 2010), no barrier (2011), and physical barrier (2012) treatments and assess their effectiveness at retaining juvenile salmonids in the mainstem San Joaquin River. Analyses include the effectiveness of the barrier treatments on juvenile salmonid route fate as influenced by the abiotic factors of light level, water temperature, discharge, and turbidity. These studies were augmented by investigations into the predation rates, predatory fish density, and predatory fish behavior that occurred in the vicinity of the HOR study area. Recommendations for future analyses and studies are identified.

1.1.1 SALMONID SPECIES MIGRATING PAST HEAD OF OLD RIVER

The two salmonid species of primary concern for the HOR studies were California Central Valley steelhead and Central Valley fall-run Chinook salmon (herein steelhead and Chinook salmon). For both species, the outmigrating juvenile life stage was most at risk at the study area. As the outmigrating juvenile salmonids pass the study area, they could remain in the San Joaquin River, shown by previous studies to be the safer route. Brandes

[1] Further detail of the study area is provided in Chapter 2, "Study Area and Focal Fish Species." Additional detail is provided in Appendix A, "Additional Background on the Study Area and Nearby Areas."

and McLain (2001) showed that recovery rates of tagged juvenile Chinook salmon at Chipps Island (Suisun Bay, Solano County, California) between 1985 and 1990 were higher if they were released in the mainstem San Joaquin River compared to being released in Old River. Additionally, they found that recovery rates from the Pacific Ocean were higher for these same fish released between 1986 and 1990 at Dos Reis (mainstem San Joaquin River downstream from the HOR study area) compared to those released in Old River (downstream from the HOR study area). Therefore, two sets of independent estimates appeared to indicate that migration down the San Joaquin River resulted in higher survival rates for juvenile Chinook salmon compared to those that migrated down Old River. Newman (2008) also found increased survival in the San Joaquin River over the Old River route.

Although juvenile salmonids taking the San Joaquin River route were documented to remain in the San Joaquin River at the HOR study area, they could also move into the interior Delta and to the Harvey O. Banks Pumping Plant (SWP) and C.W. "Bill" Jones Pumping Plant (CVP) through other downstream junctions (i.e., Turner and Columbia cuts, Old and Middle rivers). While referred to as the San Joaquin River route, it is acknowledged that fish can move from that route into Old River farther downstream. Alternatively, the juvenile salmonids could pass into Old River and traverse a route that would bring them closer to potential entrainment at the SWP and CVP pumping plants, both substantial water diversions. A third possible fate was that the juvenile salmonids could be subject to mortality (likely predation) near the HOR study area.

Chinook Salmon

The only Chinook salmon run in the San Joaquin River during the 2009–2012 study was the fall-run (see Section B.1.2, "Chinook Salmon—Fall-Run," in Appendix B, "Focal Fish Species Information"). Fall-run Chinook salmon are not listed under the federal Endangered Species Act (ESA). Fall-run spawn in Central Valley water courses primarily during October through December, and most of the juvenile Chinook salmon migrate to the Pacific Ocean in spring (NMFS 2013:Figure 1; Vogel and Marine 1991).

The San Joaquin River Restoration Program (SJRRP) conducted the first release of juveniles of an experimental spring-run juvenile Chinook salmon population in spring 2014 (NMFS 2013; Reclamation 2014; SJRRP 2012). Central Valley spring-run Chinook salmon were listed in 1999 as threatened under the ESA (Federal Register 64: 50394–50415; Federal Register 70: 37160-37204). A non-physical or physical barrier at the HOR could deter these spring-run juveniles from entering Old River. With the release of juveniles in 2014, spring-run adults may ascend the San Joaquin River passing through the HOR study area as early as 2016. The spawning migration of spring-run adult Chinook salmon may be affected by the operation of a barrier present at the HOR from April through June, the period during which barrier(s) would be installed.

Central Valley Steelhead

Steelhead were listed as threatened in 1998 (Federal Register 63: 13347–13371) (see Section B.1.4, "Steelhead," in Appendix B). Steelhead spawning peaks from December through April (McEwan 2001). Juveniles aged 1+ to 3+ move through the Delta (McEwan and Jackson 1996) toward the Pacific Ocean from November through June (Reclamation 2004b:Table 4-1). A barrier at HOR operated from April through June could affect juvenile steelhead migrating to the ocean during this period.

Because of its threatened status, interest in protecting juvenile steelhead has risen in recent years. Thus, the evaluation of the barriers installed at the HOR was extended to include steelhead in 2011. Two years (2011, 2012) of data collection and analyses included juvenile steelhead. These data allowed determination of the proportion of juvenile steelhead that remained in the San Joaquin River at the HOR study area when no barrier was present in 2011, and the proportion that remained in the San Joaquin River with a physical rock barrier installed in 2012.

1.1.2 Types of Barriers

Barriers that deter fish movement fall in two primary categories: non-physical and physical.

Non-physical barriers do not rely on physically obstructing fish from entering waterways, instead, these barriers take advantage of behavioral patterns of avoidance or attraction. Non-physical barriers offer the advantage of deterring fish from undesirable locations without physically blocking waterways (Noatch and Suski 2012) which can be important hydraulically, from a water quality perspective, and to navigation. Some types of behavioral barriers include electric (Savino et al. 2001), louvers (Kynard and Buerkett 1997), strobe lights (Anderson et al. 1998), bubble curtains (Sager et al. 1987), noise (Knudsen et al. 1992), or combinations of some of these stimuli (e.g., Perry et al. 2012).

Physical barriers do not rely on fish behavior, but exclude entry by obstructing passage. Physical barriers are the most commonly used type of fish barrier (Katapodis et al. 2004). Some physical barriers (e.g., wedgewire screens) have been important in demonstrating that fish protection can be provided at a screening location (State of Wisconsin 2003).

Non-physical Barriers

Perry et al. (2012) found that the OVIVO™ Bio-Acoustic Fish Fence (BAFF) (Fish Guidance Systems, Southampton, United Kingdom) comprising an acoustic deterrent stimulus enclosed within a bubble curtain and illuminated by strobe lights, decreased the entrainment of juvenile Chinook salmon into Georgiana Slough (Sacramento County, California). Entrainment was 22.3% with the BAFF turned off, but decreased to 7.7% with the BAFF on. The mainstem Sacramento River route previously was shown to be a safer route to the Pacific Ocean than emigrating via Georgiana Slough (Perry et al. 2010). Perry et al. (2012) also found that the effectiveness of the BAFF decreased with increasing river discharge, suggesting the concomitant increase in discharge velocity was more likely to force fish through the barrier compared to lower discharge/velocity conditions.

Elsewhere, Welton et al. (2002) found a large proportion of juvenile Atlantic salmon (*Salmo salar*) were deterred by a BAFF in the River Frome, United Kingdom. Furthermore, the BAFF diverted a higher proportion of juvenile Atlantic salmon at night than during the day.

Flammang et al. (2013) reported that a BAFF deterred walleye (*Sander vitreus*) and also suggested that the strobe light was not an important part of the deterrent. The sensitivity of walleye to a strobe light may be substantially different from other fish species. Chinook salmon deterrence may be enhanced by a strobe light (Bowen et al. 2010:Table 5).

Ruebush et al. (2012) concluded that a sound/strobe/bubble barrier (similar to the BAFF described herein) could be used as a deterrent for two Asian carp species: bighead carp (*Hypophthalmichthys nobilis*) and silver carp

(*H. molitrix*). However, those authors suggested the sound/strobe/bubble barrier should not be used as an "absolute" barrier to keep these carp species from extending their range.

PHYSICAL BARRIERS

The San Joaquin River Group Authority (SJRGA 2006) found that a physical barrier constructed of rock installed at the HOR appeared to increase juvenile Chinook salmon survival from Mossdale or Durham Ferry to Jersey Point, San Joaquin River, Contra Costa County, California (SJRGA 2006:Figure 5-19) using recapture recoveries of fish collected at Chipps Island and Antioch. However, it is difficult to determine conclusively whether the rock barrier improved survival using the Pacific Ocean recapture recovery information alone (SJRGA 2006).

The SJRGA (2006) evaluated survival data for south Delta releases to Jersey Point between 1989 and 2005, including three estimates with the rock barrier installed at the HOR in 1997. The recovery rate estimates for groups released upstream of the HOR study area (Mossdale) and downstream of the study area (Dos Reis) were similar. These results supported previous conclusions that survival was increased with the rock barrier installed. In addition, the SJRGA (2007) showed that an increase in juvenile Chinook salmon survival occurred with higher discharge of the San Joaquin River.

However, if management actions were implemented to increase the discharge of the San Joaquin River with a rock barrier installed, there might be unintended consequences on ESA-listed fishes. For example, there is evidence that positive Old River flows in April and May could benefit delta smelt (*Hypomesus transpacificus*) by reducing entrainment at south Delta diversions (Lichatowich et al. 2005). One compromise between these competing demands for discharge could be to increase the number or size of the culverts placed in the rock barrier installed at the HOR.

The physical rock barrier studied in 2012 that was included in the present study was similar to those investigated by Brandes and McLain (2001) and the SJRGA (2003, 2006, 2007). All of these physical barriers were temporary obstructions installed across the entire channel width of Old River in March or April and removed in June (see Chapter 4, "Barrier Descriptions").

1.2 STUDY DESIGN, OBJECTIVES, AND HYPOTHESES

1.2.1 STUDY DESIGN

BACKGROUND

The present study used a partially controlled experimental design with uncontrollable exogenous factors influencing the treatment conditions. The principal focus of the study was the effects of barriers to influence juvenile salmonid routing (see Section 1.2.2, "Juvenile Salmonid Routing Including Barrier Effects"). The controlled portion of the design was the selection of treatments for the March through June period in each of the years studied (2009 through 2012): a non-physical barrier (BAFF) in 2009 and 2010; no barrier in 2011; and a physical barrier (rock) in 2012. The "no barrier" condition provided information about the proportion of juvenile salmonids entering Old River in the absence of a barrier. Because no barrier was present, 2011 provided a reference condition, but it was not a control condition for 2009, 2010, or 2012 because of major differences in exogenous factors between those years, in particular, discharge.

A number of physical factors were identified as parameters that may have influenced salmonid behavior in the various treatments. These parameters were discharge, water velocity, water temperature, light level, and turbidity. Variability in discharge, water velocity, water temperature, and turbidity from 2009 through 2012 is discussed in Chapter 3, "Physical Parameters."

The effectiveness of retaining juvenile salmonids in the San Joaquin River between barrier treatments was evaluated through acoustic telemetry. In each year, acoustic transmitters (tags), either Hydroacoustic Technology, Inc. (HTI) (Seattle, Washington) or VEMCO (Bedford, Nova Scotia, Canada) were implanted into juvenile Chinook salmon and/or steelhead. Movement patterns of the tagged juvenile salmonids were tracked by hydrophone arrays deployed in or near the HOR study area.

For the HTI equipment, the hydrophone array was deployed within the HOR study area from April through June during all the study years (2009-2012). The tagged juvenile Chinook and steelhead were released 24.4 kilometers (km) upstream from the HOR study area at Durham Ferry State Recreation Area. As the tagged juvenile salmonids moved through the area of the divergence, the HTI hydrophones recorded two-dimensional (2D) tracks, and these tracks were used to derive measures of juvenile salmonid routing, including barrier effects and predation rates on juvenile salmonids.

Previous publications (Bowen et al. 2012; Bowen and Bark 2012) reported results of BAFF deterrence and efficiency at the HOR study area during 2009 and 2010. The present study provides reanalysis of these same data, but reclassifies all juvenile Chinook salmon fates into samples based upon the barrier status (i.e., BAFF on/off no barrier, rock barrier) and environmental conditions (i.e., light level and velocity). Earlier publications relied on analysis of experimental groups based on the release time of the tagged juvenile salmonids from Durham Ferry without respect to the abiotic environmental conditions encountered when the tagged salmonids arrived at the HOR study area. A reanalysis approach was applied to all data (2009-2012) evaluated in this report. All tagged juvenile salmonids were grouped into samples based on the conditions when the fish arrived at the HOR study area. This approach was applied to both HTI and VEMCO tag detection data sets.[2]

In association with the main studies of juvenile salmonid routing and predation, investigation of predatory fishes was also undertaken in 2011 and 2012, using acoustic tagging and mobile hydroacoustic surveys (see Section 1.2.4, "Behavior and Density Changes in Predatory Fishes").

METRICS OF EFFICIENCY

HTI equipment (i.e., transmitters, hydrophones, and receivers) was deployed from 2009-2012, and measures of barrier efficiency and salmonid behavior were derived from the time-stamped tag detections arriving at different hydrophones.

The first measure of barrier efficiency determined using HTI equipment for 2009-2012 was Overall Efficiency (O_E) (see equation in Chapter 5, "Methods"). O_E was defined as the total number of tags implanted into juvenile Chinook salmon determined to have passed by the HOR study area and continued down the San Joaquin River divided by the total number of tags that arrived at the HOR study area. O_E was calculated in the same manner for steelhead.

[2] Comparisons between HTI and VEMCO data are provided in Appendix C.

A second measure of barrier efficiency was developed for 2009-2012 because the 2D tracks made behavioral analysis possible, and was defined as Protection Efficiency (P_E). A set of rules was developed that defined when a 2D tag track exhibited very strong evidence that the juvenile salmon implanted with that tag had been eaten (Appendix E, "Fish Fate Determination Guidelines"). When a tagged juvenile salmonid was classified as having been eaten, it was removed from analysis of P_E. Only surviving "tags-in-salmonids" remained in the data sets. The P_E was calculated as the number of surviving tagged juvenile salmonids determined to have passed by the HOR study area and continued down the San Joaquin River, divided by the sum of surviving tags-in-salmonids that passed out of the HOR study area through either the San Joaquin or Old rivers.

A third measure of BAFF efficiency was developed using the 2D tracks for 2009-2010 and was termed Deterrence Efficiency (D_E). As each tagged juvenile Chinook salmon approached the BAFF line, its path was determined to have been either deterred or undeterred by the BAFF. The determination of deterrence was made with the status of the BAFF on and off. With the BAFF off, the physical infrastructure of the BAFF remained in the water but the BAFF was not in operation.

For the 2009 through 2012 data sets, a measure of predation was developed using the 2D tracks, termed proportion eaten. The fate of each tagged juvenile Chinook salmon was assessed according to the rules described in Appendix E, "Fish Fate Determination Guidelines." The determination of predation was made by the judgment of two experts. Uncertainties associated with the expert assessments are explored in Chapter 7, "Discussion." After the predation fate had been assessed, the population proportion eaten was determined and defined as the quotient of the number of juveniles eaten divided by the total number passing through the HOR study area. Next, the proportion eaten in each sample group (see "Grouping Juvenile Salmonid into Samples" in Section 5.2.1) was used for hypothesis testing.

In addition to the sample-based metrics of proportion eaten that was investigated with univariate hypothesis testing, analyses based on the fates of individual juvenile salmonids evaluated as the probability of predation also were conducted (see Section 1.2.3, "Predation on Juvenile Salmonids Including Barrier Effects").

1.2.2 Juvenile Salmonid Routing Including Barrier Effects

Primary Objectives and Hypotheses Related to Juvenile Salmonid Routing Including Barrier Effects

The objectives in this section relate to the effectiveness of the barriers as management tools to keep juvenile salmonids from entering Old River, in compliance with NMFS (2009, 2011) Action IV.1.3. The objectives are enunciated as hypotheses and they are listed in Table 1-1.

Non-physical Barrier - BAFF (2009 and 2010)

In 2009, a BAFF was operated from April 20 to May 26, and tagged juvenile Chinook salmon passed through the HOR study area from April 23 to May 18. The status of the BAFF alternated between off and on so that, approximately 50% of the time, it was operational. Exact BAFF operation times may be found in Bowen et al. (2012:Table 1). This time split between off/on operation also allowed approximately 50% of the tagged juvenile Chinook salmon to experience the BAFF when in operation.

In 2010, a BAFF was operated from April 15 to June 15, and tagged juvenile Chinook salmon passed through the HOR study area from April 27 to May 20. Similar to 2009, the status of the BAFF alternated between on and off so that it was operational approximately 50% of the time. Exact operation times may be found in Bowen and Bark (2012:Table 2). This time split between on/off operation allowed approximately 50% of the tagged juvenile Chinook salmon to experience the BAFF when in operation. In 2009 and 2010, no steelhead were surgically implanted or released.

The goal of the analysis was to determine if the BAFF was effective in retaining a significant proportion of the juvenile Chinook salmon in the San Joaquin River. If the BAFF retained a significant proportion, then it could be an effective deterrent. Hypotheses numbered $H1_0$, $H2_0$, $H3_0$, and $H4_0$ were tested to measure O_E, P_E, and D_E to determine BAFF efficiency (Table 1-1).

Table 1-1
Objectives and Hypotheses Related to Juvenile Salmonid Routing Including Barrier Effects

Year and Treatment	Objective	Hypothesis Number	Hypotheses
2009 BAFF	Determine whether barrier efficiency (O_E, P_E, and D_E) for juvenile Chinook salmon was improved by BAFF operation.	$H1_0$	For juvenile Chinook salmon, barrier efficiency (O_E, P_E, and D_E) with the BAFF on was equal to barrier efficiency with the BAFF off.
2010 BAFF	Determine whether barrier efficiency (O_E, P_E, and D_E) for juvenile Chinook salmon was improved by BAFF operation.	$H2_0$	For juvenile Chinook salmon, barrier efficiency (O_E, P_E, and D_E) with the BAFF on was equal to barrier efficiency with the BAFF off.
	Determine whether BAFF barrier efficiency with the BAFF on changed significantly between years.	$H3_0$	For juvenile Chinook salmon with BAFF on, barrier efficiency (O_E, P_E, and D_E) barrier efficiency in 2009 was equal to barrier efficiency in 2010.
	Determine whether with the BAFF off, barrier efficiency changed significantly between years.	$H4_0$	For juvenile Chinook salmon with BAFF off, barrier efficiency (O_E, P_E, and D_E) in 2009 was equal to barrier efficiency in 2010.
2011 No Barrier	Determine whether and to what extent the BAFF infrastructure affected O_E and P_E when the BAFF was turned off.	$H5_0$	For juvenile Chinook salmon, O_E and P_E were equal for 2009 BAFF off, 2010 BAFF off, and 2011 no barrier conditions.
	Determine whether juvenile Chinook salmon and steelhead had the same O_E and P_E through the HOR study area.	$H6_0$	O_E and P_E were the same for juvenile Chinook salmon and steelhead.
2012 Rock Barrier	Compare OE and PE across treatments to determine whether any barrier was more effective than no barrier and which produced the highest efficiency at retaining juvenile Chinook salmon in the San Joaquin River.	$H7_0$	For juvenile Chinook salmon, O_E and P_E were equal for 2009 and 2010 BAFF on, 2011 no barrier, and 2012 rock barrier treatments.

Notes: BAFF = Bio-Acoustic Fish Fence (Fish Guidance Systems Ltd., Southampton, UK); D_E = deterrence efficiency; HOR = Head of Old River; O_E = overall efficiency; P_E = protection efficiency; Barrier Efficiency = O_E, P_E, and D_E

Source: Present study

No Barrier (2011)

In 2011, no barrier was operated although both tagged juvenile Chinook salmon and steelhead passed through the HOR study area from May 4 to June 22. Using information collected by the hydrophone array, two measures of efficiency were obtained from the 2011 data. O_E and P_E were determined with exactly the same method mathematically (see Chapter 5, "Methods") as the barrier efficiency in years with barriers present.

Determining whether the BAFF infrastructure alone affected the routing of juvenile Chinook salmon is most appropriate when compared with the no barrier treatment (2011). Therefore, one hypothesis tested (Table 1-1: $H5_0$) if O_E and P_E varied between the status when the BAFF was installed but not in operation and when there was no barrier.

It also needed to be determined whether the routing of tagged juvenile Chinook salmon and steelhead were the same in a year in which no barrier was installed. Hence, hypothesis $H6_0$ tested if there was a difference between tagged juvenile Chinook salmon and steelhead for O_E and P_E (Table 1-1).

Physical Barrier - Rock (2012)

In 2012, a physical barrier made of rock was installed and operated from April 1 through May 31, and tagged juvenile Chinook salmon and steelhead passed through the HOR study area from April 28 through May 29. In contrast to BAFF operations, the physical barrier located at the HOR was always operational (on) because it could not be turned off or uninstalled.

It needed to be determined how the barrier treatments performed relative to each other and relative to no barrier. For example, if the physical rock barrier retained a significant proportion of the juvenile Chinook salmon in the San Joaquin River, then it might be an effective deterrent. Hence, one hypothesis tested measures O_E and P_E to determine the routing proportions with different treatments and discharge regime (Table 1-1:$H7_0$).

SUPPORTING HYPOTHESES RELATED TO JUVENILE SALMONID ROUTING INCLUDING BARRIER EFFECTS

DWR (2012) studied the effect of a BAFF under variable velocity conditions. A substantial proportion of the juvenile Chinook salmon were deterred by the BAFF under both low (<0.25 meters per second [m/s] "fish escape" velocity (Figure 4-2) and high (<0.25 m/s "fish escape" velocity) velocity (DWR 2012:Table 3-12). In addition, for the BAFF on status, O_E, P_E, and D_E were all greater under low-velocity compared to high-velocity conditions. These results suggest that the BAFF's effectiveness at the HOR study area might also be affected by discharge/velocity. As previously noted, Perry et al. (2012) also found that the effectiveness of the BAFF was inversely related to discharge. Perry et al. (2012) suggested that higher discharges and correspondingly higher velocities were more likely to force fish through the barrier compared to lower discharge/velocity conditions.

DWR (2012) described studies of a BAFF at Georgiana Slough (Sacramento County, California). This was the same BAFF studied by Perry et al. (2012). A significant proportion of juvenile Chinook salmon were deterred by the BAFF under both low (< 5.4 lux) and high (≥ 5.4 lux) light conditions (DWR 2012:Table 3-11). However, for the BAFF "on" status, D_E under high-light conditions was 13.7% greater than the D_E under low-light conditions. The results from the Georgiana Slough study suggest that the BAFF's performance at the HOR study area may be affected by ambient light level similar to the findings of Welton et al. (2002).

Because of these findings, the effects of light level and water velocity on O_E, P_E, and D_E were studied and are reported herein. For each hypothesis, where possible, analyses were conducted at various light and discharge/velocity levels. These analyses showed whether or not the O_E, P_E, and D_E were affected by these abiotic environmental variables and if so, to what extent.

1.2.3 Predation on Juvenile Salmonids, Including Barrier Effects

Several major objectives of the present study are related to predatory fish ecology and predation at the HOR study area. The HOR area and the scour hole downstream of the divergence of San Joaquin and Old rivers were previously noted as regional "hotspots" of high predation, although recent studies do not concur (e.g., SJRGA 2010, 2011, and 2013, and references therein). In the 2009 study of BAFF deterrence, Bowen et al. (2012) noted that predation was intense in the HOR area and appeared associated with the scour hole just downstream of the divergence of Old River from the San Joaquin River. They concluded the following (Bowen et al. 2012:20–21):

> The data suggest that much of the gains accomplished by the BAFF's determent of juvenile Chinook salmon are offset by the predatory fishes inhabiting the scour hole. We recommend that if the BAFF is installed in the future that predator relocation be employed near the Old River barrier area. For example, striped bass and largemouth bass could be moved from the HOR study area to San Luis Reservoir. Failure to do so could lead to a high predation rate situation and the highly efficient BAFF's deterrence may be offset by the heavy predation in the scour hole.
>
> It is possible that the high 2009 predation rates observed were a function of the low discharge (dry year) in the San Joaquin River. Juvenile Chinook salmon and predators might have been concentrated into a smaller habitat area due to the reduced volume of water than during average or wet years. Such a concentration could result in higher encounter rates between predators and juvenile Chinook salmon leading to an increased predation rate.

The predation rate on tagged juvenile Chinook salmon in the HOR was also high in 2010, despite greater river discharge (Bowen and Bark 2012).

In the present study, predation was examined using a sample-based, univariate approach (proportion eaten) and a generalized linear modeling (GLM) approach (probability of predation). Perspective on rates of predation suggested by tagged juvenile salmonids was provided with bioenergetics modeling of potential predatory fish consumption of prey fish (see Appendix H, "Illustrative Example of Striped Bass Predation Using Bioenergetics Modeling").

Objectives and Hypotheses Related to Proportion of Juvenile Salmonids Eaten

Because of the importance of predation in affecting the usefulness of a fish barrier, various hypotheses were tested regarding the proportion of juvenile salmonids entering the HOR study area that were determined to have been eaten based on the aforementioned "predation rules" (see Appendix E, "Fate Determination Guidelines"). In addition to this hypothesis testing approach based on proportions of juvenile salmonids entering the HOR study area that were eaten (grouping juvenile salmonids into samples, and using univariate statistics; see Section 5.2, "Evaluation of Juvenile Salmonid Routing Including Barrier Effects"), an approach based on the probability of predation of individual fish entering the HOR study area from GLM also was used (see "Objectives and Hypotheses Related to Probability of Predation" in the following section).

For 2009 and 2010 data analyses, it needed to be determined if the BAFF increased the proportion eaten when it was operating compared to when it was not operating. The outcome would be important in determining the effectiveness of the BAFF as a management tool. Thus, the proportion of those juvenile Chinook salmon eaten was tested as determined by expert opinion for 2009 and 2010 data separately, with the status of the BAFF on compared to BAFF off (Table 1-2: $H8_0$).

For 2011 data, it was possible to compare juvenile Chinook salmon and steelhead estimates of the proportion determined to have been eaten (Table 1-2: $H9_0$). It needed to be determined if species differences may have led to differential susceptibility to predation in the HOR study area. Differences between the species (described in Section 5.1.1, "Fish Sources and Tag Specifications," and Section B.1, "Focal Salmonid Species for Protection at Head of Old River" [Appendix B, "Focal Fish Species Information"]) in migration timing, size when in the vicinity of the HOR study area, and presumably swimming ability might all influence differences in predation probabilities.

For 2012 data analyses, the physical rock barrier was installed and all juvenile Chinook salmon that were determined to have been eaten were used to estimate the proportion eaten in each sample. It needed to be determined if the proportion eaten in each year was different, and what proportion might be eaten. For 2009 and 2010, BAFF-on observations of juvenile Chinook salmon determined to have been eaten were used. No BAFF-off observations were included. This approach simulated what would be expected if the BAFF were operated continuously. This hypothesis would identify if one of the barrier types caused a substantially higher proportion to be eaten (Table 1-2: $H10_0$).

OBJECTIVES AND HYPOTHESES RELATED TO PROBABILITY OF PREDATION

In addition to hypotheses related to proportion eaten that were tested with a univariate, sample-based approach (see "Objectives and Hypotheses Related to Proportion Eaten" previously presented), a GLM approach was used to address objectives and hypotheses related to probability of predation (Table 1-2: H11, H12, and H13). This approach allowed the probability of predation to be framed in terms of abiotic factors (light level, water temperature, turbidity, and discharge/velocity), biotic factors (juvenile size, density of large fish [assumed to be representative of predatory fish], density of small fish [assumed to be representative of alternative prey for predators]), and the presence/operational status of non-physical (BAFF) or physical barriers (rock) at the HOR study area. More detailed discussion of the underlying hypotheses is provided in Section 5.3.2 "Probability of Predation (Generalized Linear Modeling)."

Table 1-2
Objectives and Hypotheses Related to Predation on Juvenile Salmonids Including Barrier Effects

Year	Objectives	Hypothesis Number	Hypotheses
2009	Provide a direct test that the BAFF operation had some influence on proportion eaten.	$H8_0$	The proportion of juvenile Chinook salmon entering the HOR study area that were eaten with the BAFF on was equal to the proportion eaten when off.
2010	Provide a direct test that the BAFF operation had some influence on proportion eaten.	$H8_0$	The proportion of juvenile Chinook salmon entering the HOR study area that were eaten with the BAFF on was equal to the proportion eaten when off.
2011	Evaluate the proportion eaten for juvenile Chinook salmon and steelhead.	$H9_0$	The proportions of juvenile Chinook salmon and steelhead entering the HOR study area that were eaten were equal.
2009–2012	Show whether there were differences in proportion eaten between treatments.	$H10_0$	The proportions of juvenile Chinook salmon entering the HOR study area that were eaten were equal for 2009 and 2010 BAFF on, 2011 no barrier, and 2012 rock barrier.
2009, 2010, 2012	Evaluate the influence of abiotic and biotic factors, including barrier treatment/status, on probability of predation of juvenile Chinook salmon.	H11	Probability of predation of juvenile Chinook salmon is negatively related to discharge (shorter travel time/distance at higher discharge), turbidity (lower visual range of predators with greater turbidity), size (larger juveniles less susceptible to predation), and small-fish density (availability of alternative prey for predators). Probability of predation is positively related to water temperature (higher bioenergetic demands of predators with higher temperature) and ambient light level (greater visual range of predators with more light). Probability of predation is unrelated to barrier treatment/ status (BAFF on/off, rock barrier).
2011, 2012	Evaluate the influence of abiotic and biotic factors on probability of predation of juvenile Chinook salmon.	H12	Probability of predation of juvenile Chinook salmon is negatively related to discharge, turbidity, juvenile size, and small-fish density. Probability of predation is positively related to water temperature, ambient light level, and density of predatory fish (greater predation pressure with more large fish).
2011	Evaluate the influence of abiotic and biotic factors on probability of predation of juvenile steelhead.	H13	Probability of predation of juvenile steelhead is negatively related to discharge, turbidity, juvenile size, and small-fish density. Probability of predation is positively related to water temperature, ambient light level, and density of predatory fish (greater predation pressure with more large fish).

Notes: BAFF = Bio-Acoustic Fish Fence (Fish Guidance Systems Ltd., Southampton, UK); HOR = Head of Old River
Source: Present study

1.2.4 Behavior and Density Changes in Predatory Fishes

Objectives Related to Behavior of Predatory Fishes

Objectives related to predatory fish behavior at the HOR study area consisted of analyses based on acoustically tagged predatory fish and mobile hydroacoustics. These analyses generally did not test specific hypotheses (although see the following section on "Objectives and Hypotheses Related to Changes in Density of Predatory Fishes") and were more exploratory and descriptive. The objectives and their utility to management are summarized in Table 1-3.

Table 1-3
Objectives Related to Behavior of Predatory Fishes at the HOR Study Area

Year	Objective	Means of Study	Utility to Management
2009–2012	Describe residence time of predatory fish.	Acoustically tagged predatory fish	May indicate turnover of predatory fish, and therefore allows inference regarding the level of effort required for relocation of predatory fish.
2009–2012	Describe areas (spatial and velocity) occupied by predatory fish.	Acoustically tagged predatory fish, mobile hydroacoustic surveys, stationary tags from juvenile salmonid (presumably eaten and defecated by predatory fish)	May indicate location within the study area to focus predator capture efforts for any contemplated relocation efforts, as well as indicates habitat areas that could be manipulated to reduce predator density and predation risk.

Note: HOR = Head of Old River
Source: Present study

Objectives and Hypotheses Related to Changes in Density of Predatory Fish

Mobile hydroacoustic survey data from 2011 and 2012 were used to determine if there was evidence of changes in environmental variables associated with changes in density of large fish (>30 centimeters [cm] total length (TL), of which many are assumed to be predatory fish), by testing $H14_0$ (Table 1-4). Knowledge of the potential influence of these variables on density has the potential to guide management action (e.g., by allowing efforts such as predator relocation or reduction to be focused at times of potentially high density). In addition, two objectives related to $H15_0$ and $H16_0$ were intended to determine whether changes in density at the study area were similar to changes in the broader south Delta area, and whether the density at the study area was greater than at other areas. These objectives/hypotheses were examined by comparing density at the study area to three reference sites in the San Joaquin River (Table 1-4).

Table 1-4
Objectives and Hypotheses Related to Density of Predatory Fishes at the HOR Study Area

Year	Objectives	Hypothesis Number	Hypotheses
2011–2012	Determine if environmental variables are associated with changes in large-fish density at the HOR study area.	$H14_0$	Density of large fish (>30 cm TL) (i.e., potential predators) at the HOR site is not correlated with environmental variables (discharge, water temperature, turbidity, light level, and small-fish density [representing availability of potential prey]).
2011–2012	Determine if there are broad-scale environmental influences on predatory fish density at the HOR site that result in similar changes in density to reference sites.	$H15_0$	Changes in density of large fish (>30 cm TL) (i.e., potential predators) at the HOR site during the spring are not correlated with changes in density at three reference sites.
2011–2012	Determine if predatory fish density at the HOR site is greater than at reference sites.	$H16_0$	The density of large fish (>30 cm TL) (i.e., potential predators) at the HOR site during the spring is not significantly different from density at three reference sites.

Notes: cm = centimeters; HOR = Head of Old River; TL = total length
Source: Present study

2 STUDY AREA AND FOCAL FISH SPECIES

2.1 STUDY AREA

2.1.1 THE SACRAMENTO–SAN JOAQUIN DELTA

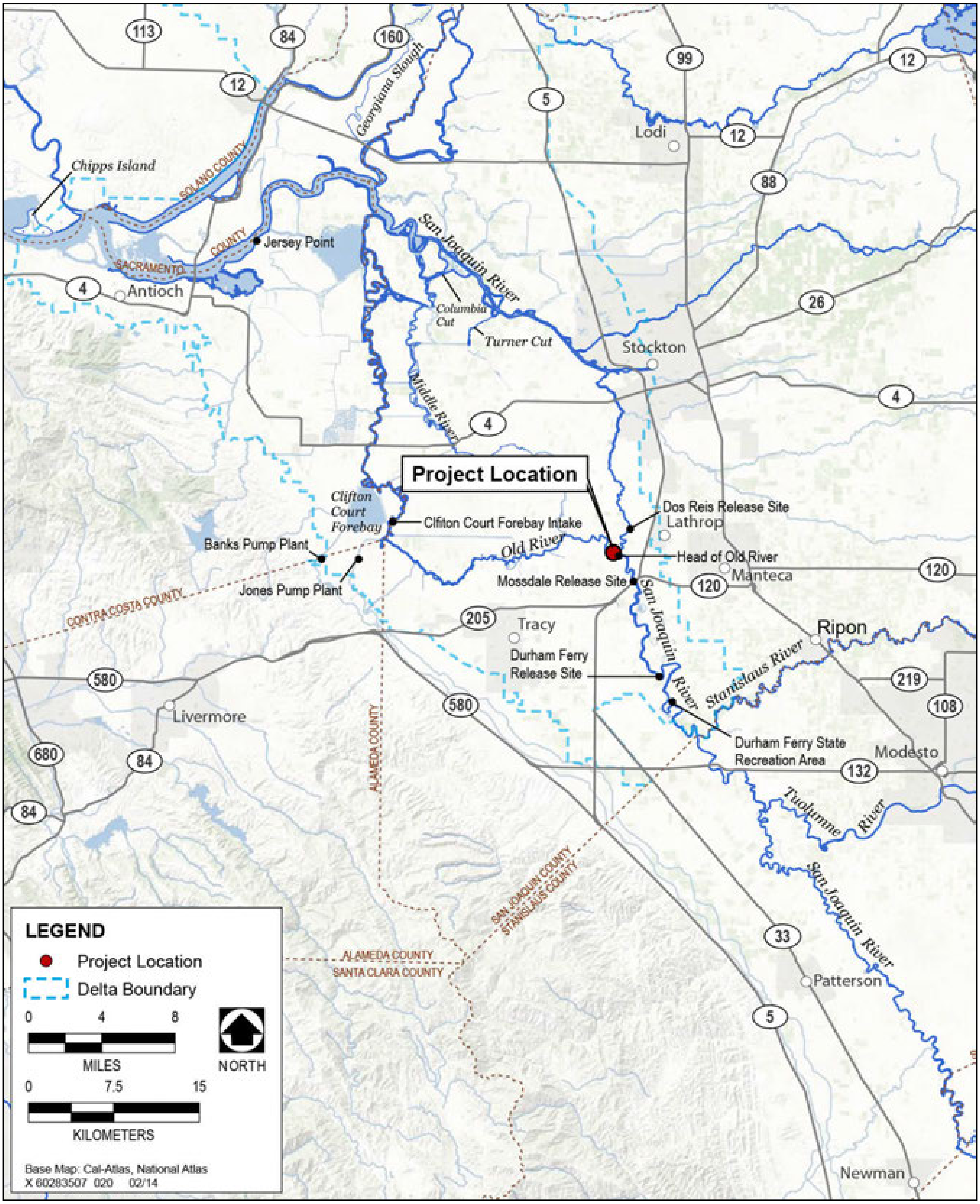
The Delta is a complex of reclaimed islands[1] and tidally influenced freshwater sloughs and channels at the confluence of the Sacramento and San Joaquin rivers. It is part of a larger estuary system to the west that includes Suisun, San Pablo, and San Francisco bays. The Delta watershed includes more than one-third of California's land surface area, and stretches from the eastern slopes of the Coast Range to the western slopes of the Sierra Nevada (Lund et al. 2007). The Delta is approximately 39 km wide and 77 km long. The Delta is located in an area roughly delimited by the cities of Sacramento, Stockton, Tracy, and Antioch (Thompson 1957) and includes portions of Sacramento, San Joaquin, Contra Costa, Solano, and Yolo counties. Before settlement and reclamation activities, the tidal basin included approximately 129,499 hectares, and another 82,961 hectares was subject to seasonal flooding (Thompson 1957).

Historically, the Delta was a natural wetland complex, fed by discharge from the Sacramento and San Joaquin rivers. The vast wetland complex consisted of tidal channels, sloughs, islands with tule (*Schoenoplectus* spp.) marsh plains, complex water channels characterized by dendritic branching, and natural levees colonized by riparian forests (Bay Institute 1998). A slow rise in sea level and gradual regional tectonic subsidence created an "accommodation space" that allowed for the continuous accumulation of large volumes of sediment within the Delta (Atwater et al. 1979; Orr et al. 2003). The Delta essentially was formed by a combination of upstream sediment deposition and the decay of large quantities of marsh vegetation (Lund et al. 2007). The formation of thick deposits of peat, capped by tidal marshes, kept up with a slow rise in sea level. Approximately 60% of the Delta land mass was flooded by daily tides, and spring tides could submerge it completely (Lund et al. 2007; Thompson 1957). Large areas frequently flooded during heavy winter rains. The interior waterways were primarily freshwater, although saltwater intrusion from the west occurred during summer months (Jackson and Paterson 1977).

Today, the Delta is a highly modified system when compared to conditions that existed before European settlement and reclamation activities. Many waterways are channelized and contained within riprap-stabilized levees. Floodplains, backwaters, and riparian vegetation are absent from many areas. The reduction of riparian vegetation and shaded riverine habitat through levee construction and protection activities has contributed to increased annual water temperatures (NMFS 2011). These changes have contributed to the decline of many native fish species while benefitting non-native fish species that are more adaptable to the highly altered environment (Lund et al. 2007; Moyle 2002). In addition, the simplified environment and loss of habitat complexity may have contributed to the success of non-native fish species and the decline of native fish populations (Moyle 2002).

Supplemental information is provided in Appendix A, "Additional Background on the Study Area and Nearby Areas," which includes information on the upstream tributaries leading to the HOR study area (Figures 2-1 and A-1).

[1] These "islands" are actually polders.



Source: Data compiled by AECOM in 2013

Figure 2-1 Location and Study Area Indicating Major Tributaries of the San Joaquin River

2.1.2 RESEARCH PROJECT STUDY AREA

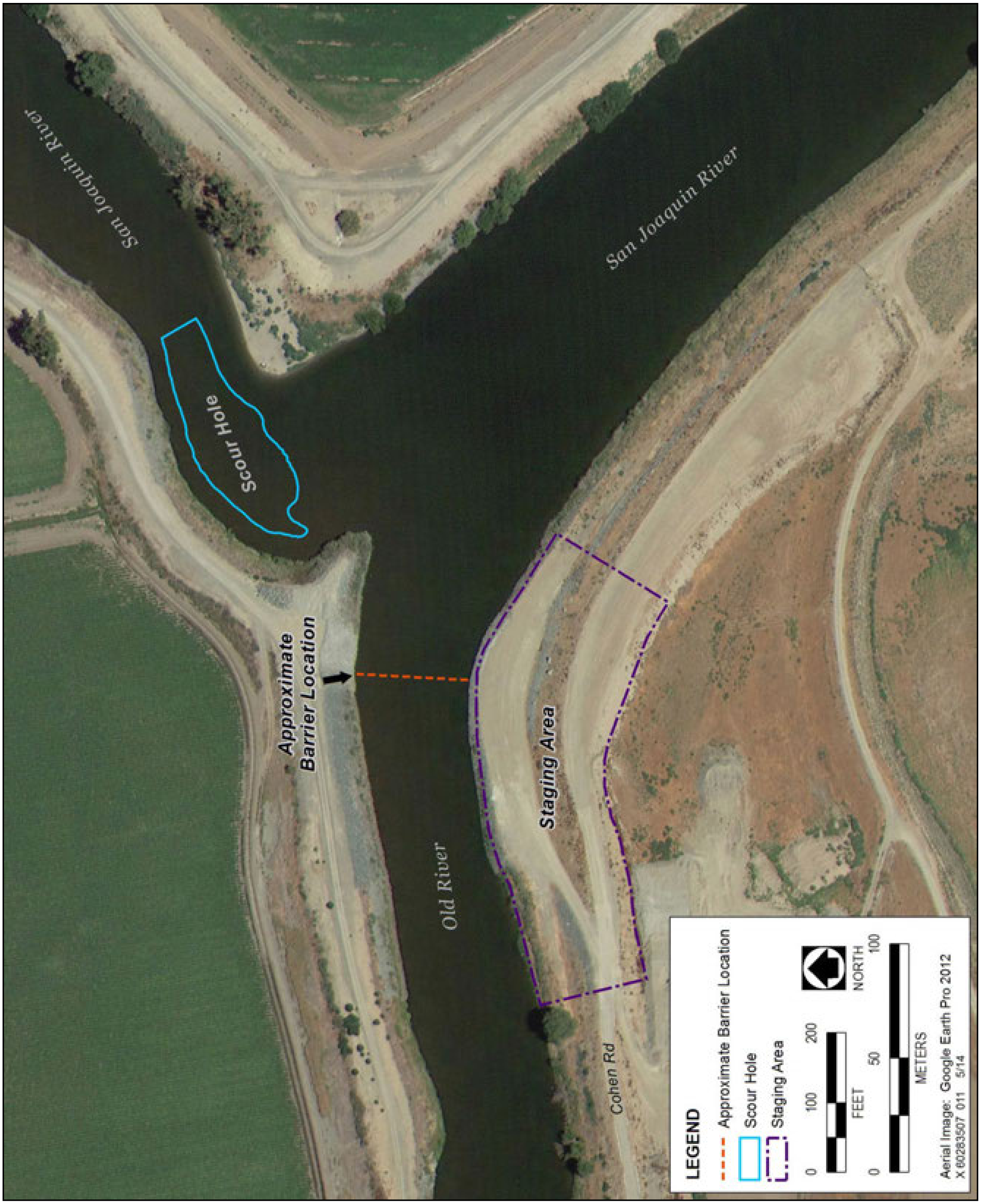
The field data collection activities of the research described in this report were conducted between April 1, 2009 and June 30, 2012, within a study area located in the southeast corner of the Delta at the divergence of the San Joaquin and Old rivers. The HOR study area boundary was delineated by the location of the most upstream and downstream hydrophones (discussed in further detail in Chapter 5, "Methods").

The primary land use is agricultural, including row crops, nut trees, dairies, and hay production. The banks of the San Joaquin River within the study area are heavily fortified with riprap with steep slopes that drop quickly to the river thalweg. Overstory riparian vegetation is absent. The river channel generally is featureless with an average depth of approximately 3 meters (m) and a maximum depth of 9 m, and the benthic substrate is composed primarily of fine sediments. Maximum depth occurs in a large scour hole, located just downstream from the divergence with Old River.

The Old River represents the first watercourse downstream of the convergences of the three main tributaries and the San Joaquin River (Figure 2-1). This divergence is the first potential migration fork for emigrating juvenile salmonids. If the Old River route is selected, it leads the juvenile salmonids into the interior Delta where susceptibility to predation and entrainment by the SWP and CVP intake pumps are increased. All emigrating juvenile salmonids produced in the San Joaquin River must pass by the HOR. Predation rates in this area may be comparatively high because:

- predatory fish densities can be particularly high in this location;
- the area is narrow and highly channelized;
- the area lacks littoral vegetation, instream structure and floodplain habitat;
- the river margins quickly become steep dropping into the river thalweg; and
- discharge patterns have created the fairly large, deep scour hole in the San Joaquin River just downstream of the divergence, which may attract predatory fish and increase their foraging opportunities (Figure 2-2).

These characteristics may create a predatory gauntlet, especially in the spring, when annual predictable high densities of juvenile salmonids are migrating downstream (Tables B-2 and B-4 in Appendix B, "Focal Fish Species Information"). Previous studies suggest that predation rates on juvenile Chinook salmon can be 12% to 40% at the HOR study area (Bowen et al. 2012; Bowen and Bark 2012). Appendix A, "Additional Background on the Study Area and Nearby Areas," briefly describes the three main tributaries of the San Joaquin River, including the current status of their steelhead and Chinook salmon populations.



Source: Data compiled by AECOM in 2013

Figure 2-2 **San Joaquin River–Old River Divergence, Scour Hole Location, Approximate Rock Barrier Line and Staging Area**

2.1.3 HEAD OF OLD RIVER

In 2009, DWR began assessing the deterrence capabilities of alternative barrier types to facilitate the retention of juvenile salmonids in the mainstem San Joaquin River during the downstream migration toward the Pacific Ocean. A non-physical BAFF barrier was installed in 2009 and 2010 at the divergence of Old and the San Joaquin rivers, approximately 5 km west of the City of Lathrop and 11 km northeast of the City of Tracy (Figure 2-3). No barrier was installed in 2011 because of very high discharge, and a physical rock barrier was installed in 2012 (Figure 2-4). Barriers were designed to improve migration conditions for juvenile salmonids that originated in the San Joaquin River watershed by blocking and/or deterring passage into Old River and directing movements to the mainstem San Joaquin River. Barrier descriptions, objectives, installation dates, and operations are summarized in Chapter 4, "Barrier Descriptions."

2.2 FOCAL FISH SPECIES

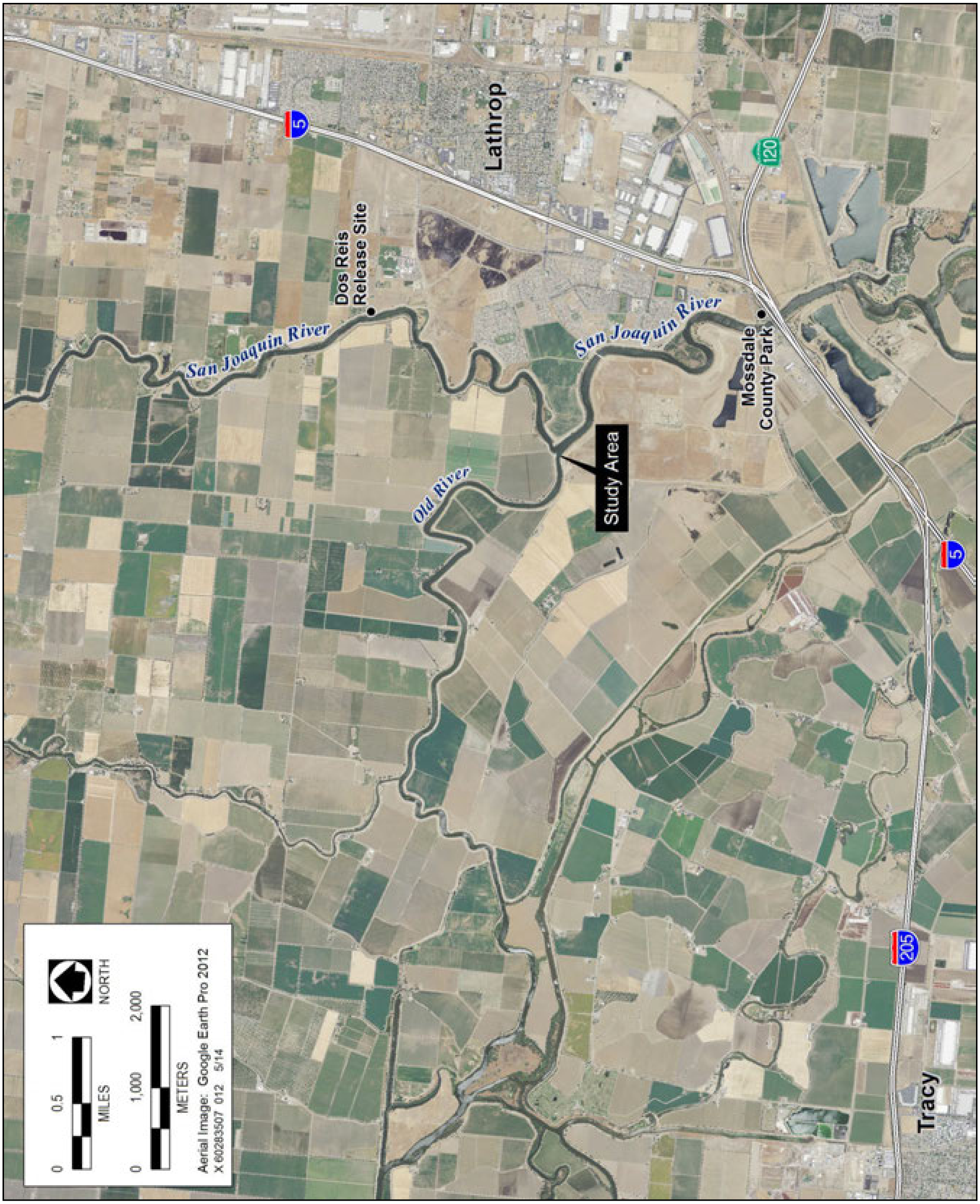
2.2.1 FOCAL FISH SPECIES FOR PROTECTION

The primary focal fish species that management intends to protect using barriers at the HOR are Chinook salmon and steelhead, both of which originate in tributaries of the San Joaquin River upstream of the HOR. Both Chinook salmon and steelhead are in long-term decline in California. Historically, the San Joaquin River supported three runs of Chinook salmon: fall, late fall, and spring (Fisher 1994). The late fall and spring-runs were extirpated in the 1940s (Fisher 1994). At present, the only Chinook salmon in the San Joaquin River region are fall-run, although spring-run are proposed for reintroduction under the San Joaquin River Restoration Program (SJRRP). Historically, steelhead were widely distributed throughout the Sacramento and San Joaquin river basins, and were composed of summer and winter-runs. Presently, only the winter-run steelhead persist in the Central Valley (Williams 2006) due to dam construction that prevents summer steelhead from reaching higher elevation stream reaches where they previously over-summered in deep, cool pools. An important period of interest for fish species protection is spring, when juvenile Chinook salmon and steelhead migrate downstream through the Delta. More detailed information on the status and life history of Chinook salmon and steelhead is presented in Section B.1, "Focal Salmonid Species for Protection at Head of Old River," in Appendix B, "Focal Fish Species Information."

In addition to the salmonid fish species for protection at the HOR, two other listed species are relevant for consideration of barrier operations: delta smelt (*Hypomesus transpacificus*) and green sturgeon (*Acipenser medirostris*). More detailed information on these two species is presented in Section B.2, "Other Species for Protection at Head of Old River," in Appendix B.

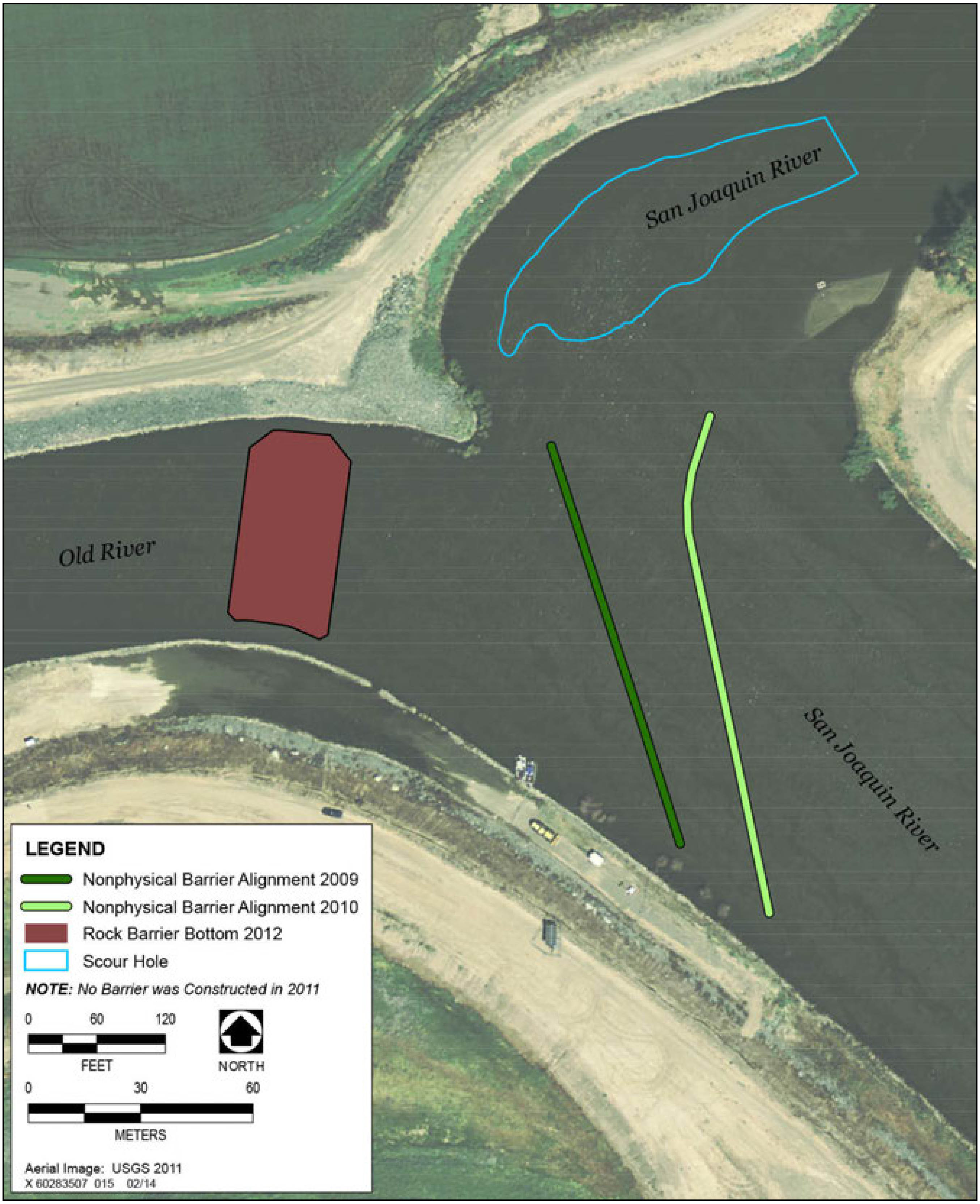
2.2.2 FOCAL PREDATORY FISH SPECIES

Several predatory fish species occur at the HOR study area and may influence barrier effectiveness if they are attracted to structures or capitalize on changed hydrodynamics or juvenile salmonid behavior that results from barrier deployment (see Bowen et al. 2012; Bowen and Bark 2012). The main predatory fish species that have been observed at the HOR study area during the studies from 2009 through 2012 are striped bass (*Morone saxatilis*), largemouth bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*), and white catfish (*Ameiurus catus*). A more detailed overview of the biology of the predatory fish species is provided in Section B.3, "Focal Predatory Fish Species at Head of Old River," in Appendix B.



Source: Data compiled by AECOM in 2013

Figure 2-3 Vicinity of the Head of Old River Study Area Depicting Salmonid Release Points



Sources: DWR 2012; Bianchini and Cane pers. comm. 2013; data compiled by AECOM in 2013

Figure 2-4 **Barrier Alignments near the Head of Old River, 2009–2012**

2.2.3 FOCAL FISH ASSEMBLAGE

A basic description of the spring (March through June) fish assemblage in the vicinity of the HOR study area is provided herein from three surveys: (1) trawling in the San Joaquin River at Mossdale which provides an indication of small fish relative abundance in the river channel (Dekar et al. 2013); (2) seining at three sites in the San Joaquin River which provides information on small fish in the nearshore, shallow water environment (Dekar et al. 2013); and (3) electrofishing in the San Joaquin River downstream from the HOR study area which samples small and large fish in the nearshore environment (Conrad, pers. comm., 2013). Of these surveys, Mossdale trawling occurs most frequently (near daily) at the highest intensity (generally 10 trawls per day) and is efficient at collecting the main salmonid species for protection at the HOR study area (i.e., juvenile Chinook salmon). For the summary presented next, trawl and seine data were limited to small fish (i.e., less than 150 millimeters [mm] fork length [FL]), because the trawling gear used was most suited for smaller fish. In addition, the Mossdale trawl estimates for small fish density were used in subsequent analyses of large fish abundance and salmonid juvenile predation probability, discussed in Chapter 5, "Methods." More information regarding the methods for trawling and seining is provided by Dekar et al. (2013). Electrofishing consisted of 300-meter-long transects from a survey vessel at 50 sites bimonthly from October 2008 through October 2010 (Conrad, pers. comm., 2013). Of this total effort, the spring (April and June, 2009 and 2010) data from the site (SAN_1) closest to the HOR study area are summarized herein.

RIVER CHANNEL (MOSSDALE TRAWL)

Thirty-five fish taxa were collected with trawling at Mossdale from March through June in 2009 through 2012, of which 12 were native species (Table 2-1). Daily abundance indices of small fish (less than 150 mm FL) from March through June 2009 were calculated as the geometric mean abundance per 10,000 cubic meters trawled at Mossdale. The mean abundance indices varied considerably among years. Sacramento splittail (*Pogonichthys macrolepidotus*) and juvenile Chinook salmon were the most abundant species collected. A very high abundance of Sacramento splittail in 2011 coincided with very high discharge in the San Joaquin River that probably provided a greater extent of spawning habitat; the species responds positively to increased availability of ephemeral habitats with inundated vegetation, such as floodplains (Sommer et al. 1997). Juvenile Chinook salmon mean abundance indices in 2011 and 2012 were appreciably greater than in 2009 and 2010. Threadfin shad (*Dorosoma petenense*) and inland silverside (*Menidia beryllina*) were the third and fourth most abundant small fish collected in the Mossdale trawl, and their mean abundance indices were greatest in 2009. Marked (i.e., adipose-fin-clipped or dyed for gear efficiency studies) juvenile Chinook salmon and striped bass were the only other taxa with mean daily abundance indices greater than 0.1 (Table 2-1).

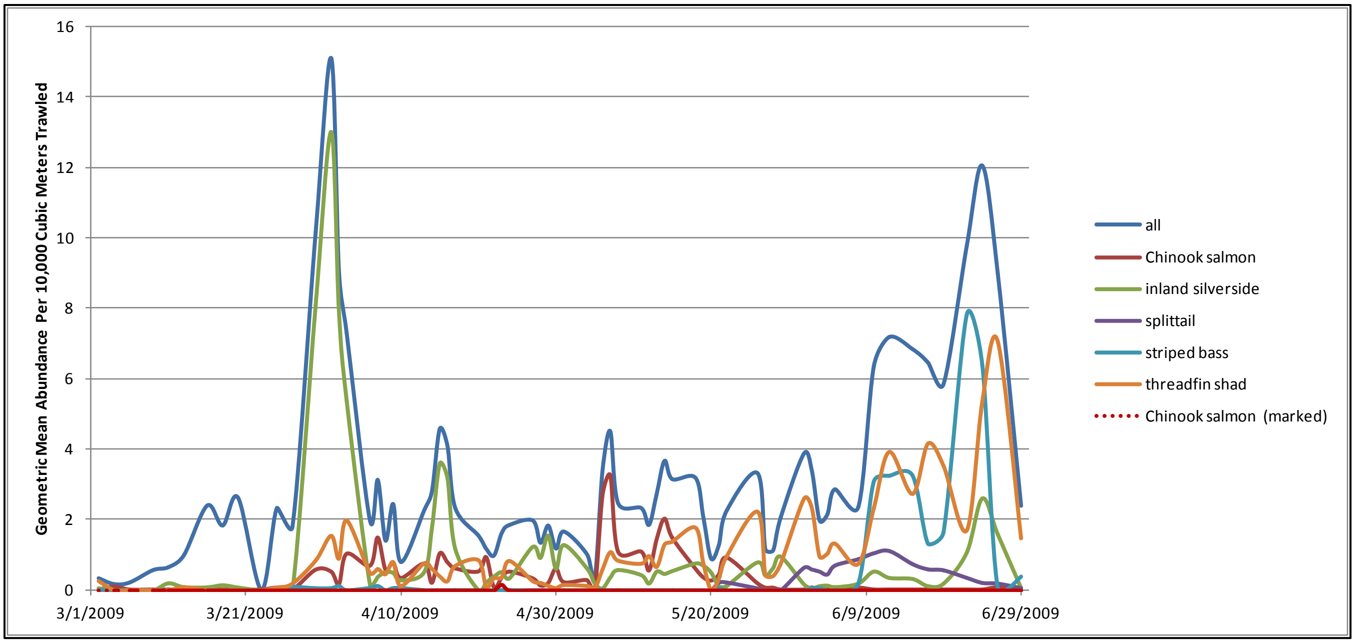
In 2009, high occasional catches of inland silverside occurred from April through June, and a relatively high abundance of threadfin shad and striped bass occurred in June (Figure 2-5). Juvenile Chinook salmon capture occurred from late March to late May, with greatest abundance generally in mid-May. In 2010, peaks in abundance of all fish combined were driven by a number of high catches of splittail from early May to mid-June (Figure 2-6). Catches of juvenile Chinook salmon in 2010 were sporadic, and they were low from early April to early June, but a large peak of marked fish occurred in early June. In 2011, very few fish were collected before late April (Figure 2-7). Subsequently, extremely high catches of splittail occurred in mid- to late May and mid-June, as well as appreciably high catches of juvenile Chinook salmon over the same period. In contrast, very few splittail were collected in 2012, whereas Chinook salmon (marked and unmarked) abundance was by far the highest of all fish, and occurred from early April to early June (Figure 2-8).

Table 2-1
Mean Daily Abundance Index of Fish Species Caught by Mossdale Trawling, Site SAN_1, March–June, 2009–2012

Species	2009	2010	2011	2012	All Years
Sacramento splittail	0.16	2.46	34.52	0.10	10.10
Chinook salmon	0.52	0.23	1.53	1.98	1.10
Threadfin shad	1.22	0.20	0.03	0.03	0.35
Inland silverside	1.09	0.04	0.18	0.10	0.34
Chinook salmon (marked)	0.00	0.25	0.34	0.71	0.33
Striped bass	0.49	0.00	0.00	0.01	0.12
Common carp	0.00	0.00	0.20	0.00	0.06
Goldfish	0.00	0.03	0.10	0.00	0.03
Red shiner	0.04	0.00	0.01	0.07	0.03
Bluegill	0.07	0.01	0.00	0.01	0.02
Largemouth bass	0.00	0.04	0.00	0.01	0.01
Channel catfish	0.01	0.00	0.00	0.03	0.01
Golden shiner	0.02	0.00	0.00	0.01	0.01
White catfish	0.00	0.01	0.00	0.02	0.01
Hardhead	0.00	0.00	0.00	0.03	0.01
Sacramento sucker	0.00	0.00	0.01	0.01	0.01
Pacific lamprey	0.01	0.01	0.00	0.00	0.00
American shad	0.00	0.00	0.00	0.01	0.00
Bass unknown	0.01	0.00	0.00	0.00	0.00
Spotted bass	0.00	0.00	0.00	0.01	0.00
Smallmouth bass	0.00	0.00	0.00	0.00	0.00
Redear sunfish	0.00	0.00	0.00	0.00	0.00
White crappie	0.00	0.00	0.00	0.00	0.00
Black crappie	0.00	0.00	0.00	0.00	0.00
Hitch	0.00	0.00	0.00	0.00	0.00
Tule perch	0.00	0.00	0.00	0.00	0.00
Sacramento pikeminnow	0.00	0.00	0.00	0.00	0.00
Longfin smelt	0.00	0.00	0.00	0.00	0.00
Bigscale logperch	0.00	0.00	0.00	0.00	0.00
Delta smelt	0.00	0.00	0.00	0.00	0.00
Green sunfish	0.00	0.00	0.00	0.00	0.00
Prickly sculpin	0.00	0.00	0.00	0.00	0.00
Wakasagi	0.00	0.00	0.00	0.00	0.00
Lamprey unknown	0.00	0.00	0.00	0.00	0.00
Shimofuri goby	0.00	0.00	0.00	0.00	0.00
Sacramento blackfish	0.00	0.00	0.00	0.00	0.00

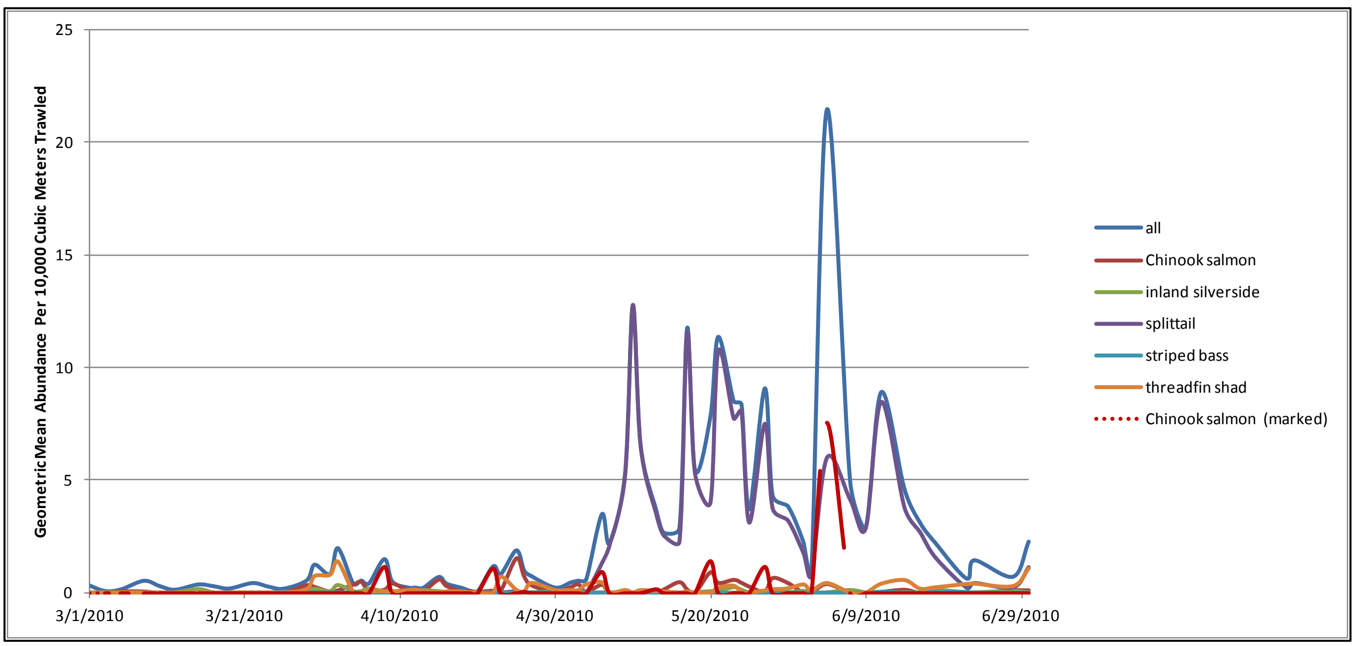
Note: Abundance index = geometric mean number of fish per 10,000 cubic meters trawled each day (typical sampling effort = 10 trawls per day).

Source: Compiled from data provided by Speegle, pers. comm., 2011–2012



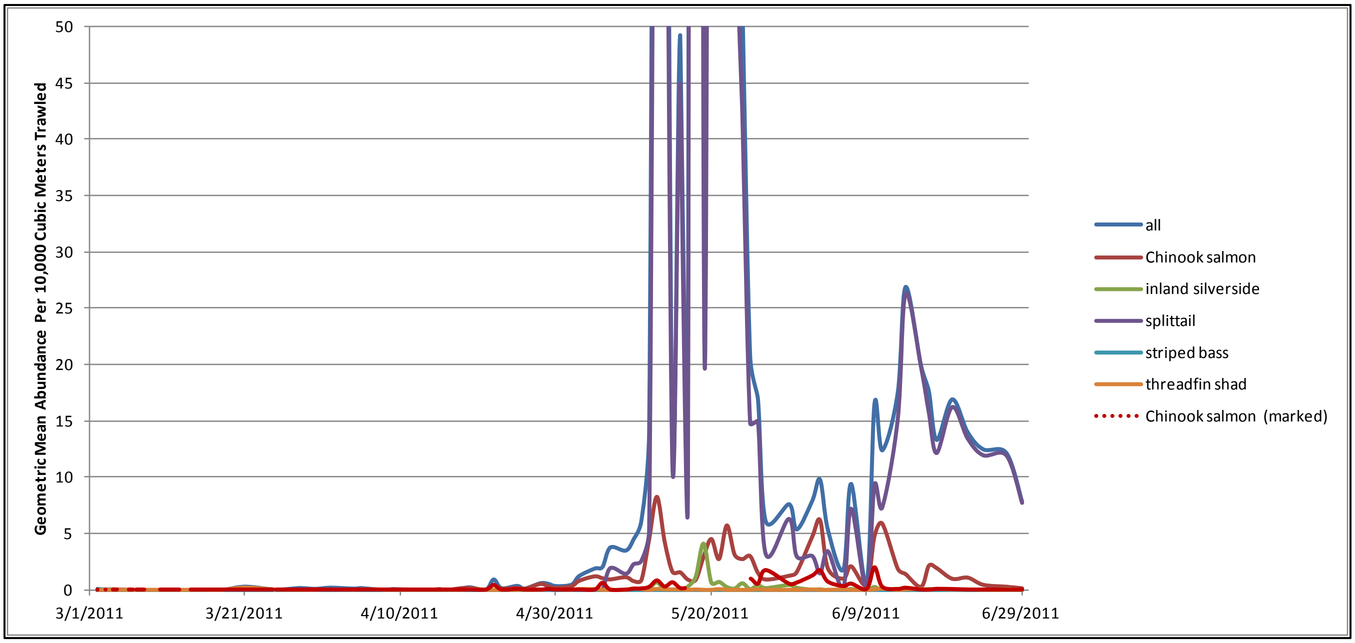
Source: Compiled from data provided by Speegle, pers. comm., 2011–2012

Figure 2-5 **Common Fish Species Geometric Mean Abundance per 10,000 Cubic Meters from Mossdale Trawling, Site SAN_1, March–June 2009**



Source: Compiled from data provided by Speegle, pers. comm., 2011–2012

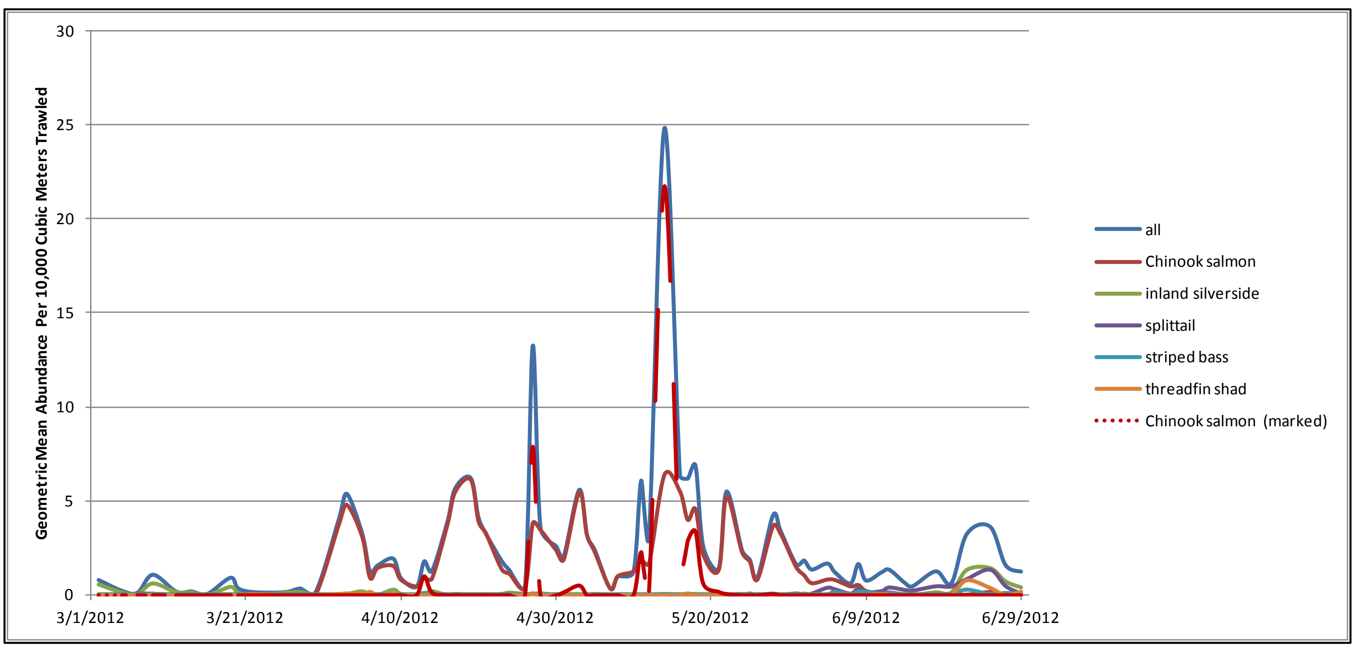
Figure 2-6 **Common Fish Species Geometric Mean Abundance per 10,000 Cubic Meters from Mossdale Trawling, Site SAN_1, March–June 2010**



Note: Y-axis is truncated; maximum abundance was greater than 600.

Source: Compiled from data provided by Speegle, pers. comm., 2011–2012

Figure 2-7 Common Fish Species Geometric Mean Abundance per 10,000 Cubic Meters from Mossdale Trawling, Site SAN_1, March–June 2011



Source: Compiled from data provided by Speegle, pers. comm., 2011–2012

Figure 2-8 Common Fish Species Geometric Mean Abundance per 10,000 Cubic Meters from Mossdale Trawling, Site SAN_01, March–June 2011

NEARSHORE (SEINING AND ELECTROFISHING)

Seining at three stations in the general vicinity of the HOR study area from March through June, 2009 through 2012, collected 25 fish taxa of less than 150 mm FL, of which nine were native (Table 2-2). The introduced species inland silverside and red shiner (*Cyprinella lutrensis*) dominated the catch (approximately 70% of all fish collected), with two native species (Sacramento sucker [*Catostomus occidentalis*] and splittail) constituting nearly 18% of all fish collected.

Table 2-2
Number of Fish Collected at San Joaquin River Beach Seining Stations SJ051E, SJ056E, SJ058W, March–June, 2009–2012

Species	2009	2010	2011	2012	All Years
Inland silverside	746	708	365	336	2155
Red shiner	442	750	301	273	1766
Sacramento sucker	54	194	74	232	554
Sacramento splittail	6	206	230	2	444
Largemouth bass	18	20	17	57	112
Bluegill	26	37	6	41	110
Threadfin shad	58	8	0	6	72
Prickly sculpin	0	1	6	52	59
Common carp	0	2	52	2	56
Western mosquitofish	15	19	7	3	44
Black crappie	1	0	0	36	37
Golden shiner	5	6	8	14	33
Chinook salmon	0	7	14	10	31
Redear sunfish	6	3	0	10	19
Sacramento pikeminnow	0	13	3	0	16
Striped bass	7	2	0	6	15
Tule perch	2	1	0	11	14
Chinook salmon (marked)	0	0	9	2	11
Bigscale logperch	0	2	0	7	9
Yellowfin goby	8	0	0	0	8
Spotted bass	0	1	1	4	6
Fathead minnow	1	0	4	0	5
Pacific staghorn sculpin	0	0	0	3	3
American shad	0	0	0	2	2
Hardhead	0	0	1	0	1
Sacramento blackfish	0	0	0	1	1

Source: Speegle, pers. comm., 2011–2012

Thirteen fish species were collected during four electrofishing samples in the San Joaquin River downstream from the HOR study area in April and June 2009 and 2010 (Table 2-3). The most abundant fish collected were bluegill (*Lepomis macrochirus*) (35% of total catch), white catfish (18%), threadfin shad (9%), and striped bass (8%). Native fish (Sacramento sucker and prickly sculpin [*Cottus asper*]) made up only 3% of the total catch. Of the four focal predatory fish species from the present study, white catfish (68–301 mm FL) were most abundant, followed by striped bass (115–459 mm FL), largemouth bass (160–385 mm FL; 7% of total catch), and channel catfish (199–447 mm FL; 5% of total catch). Other potential predatory fish collected during electrofishing (smallmouth bass [*Micropterus dolomieu*] and prickly sculpin) were a very minor part of the catch (Table 2-3).

Table 2-3
Number and Size of Fish Collected By Electrofishing in the San Joaquin River Downstream from the HOR Study Area, April and June, 2009–2010

Species	Number					Fork Length (mm)		
	4/21/2009	6/17/2009	4/15/2010	6/23/2010	Total	Min.	Mean	Max.
Bluegill	9	48	8	27	92	52	133.0	231
White catfish	20	6	6	15	47	68	246.0	301
Threadfin shad	0	20	1	4	25	84	100.1	126
Striped bass	9	6	2	3	20	115	190.8	459
Largemouth bass	3	3	8	4	18	160	262.5	385
Redear sunfish	4	9	1	4	18	44	178.8	293
Channel catfish	7	3	0	3	13	199	334.3	447
Common carp	4	0	2	4	10	NA	NA	NA
Green sunfish	3	1	1	1	6	119	146.8	171
Inland silverside	3	2	1	0	6	71	80.3	95
Sacramento sucker	1	0	4	1	6	428	466.8	510
Spotted bass	1	1	0	0	2	190	195.5	201
Prickly sculpin	1	0	0	0	1	128	128.0	128

Notes: HOR = Head of Old River; mm = millimeters
Data are for site SAN_1 (UTM Zone 10 N, Northing: 4187551.004; Easting: 648320.84).
Source: Conrad, pers. comm., 2013

3 PHYSICAL PARAMETERS

Data summarized in this chapter for physical parameters during the 2009 through 2012 study years were from local monitoring stations and generally consisted of 15-minute observations (discharge, water temperature, and turbidity). These data were from the California Data Exchange Center (CDEC) (Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013). In addition, water velocity data were modeled, as described herein.

3.1 DISCHARGE AND TIDAL REGIME

3.1.1 2009 DISCHARGE

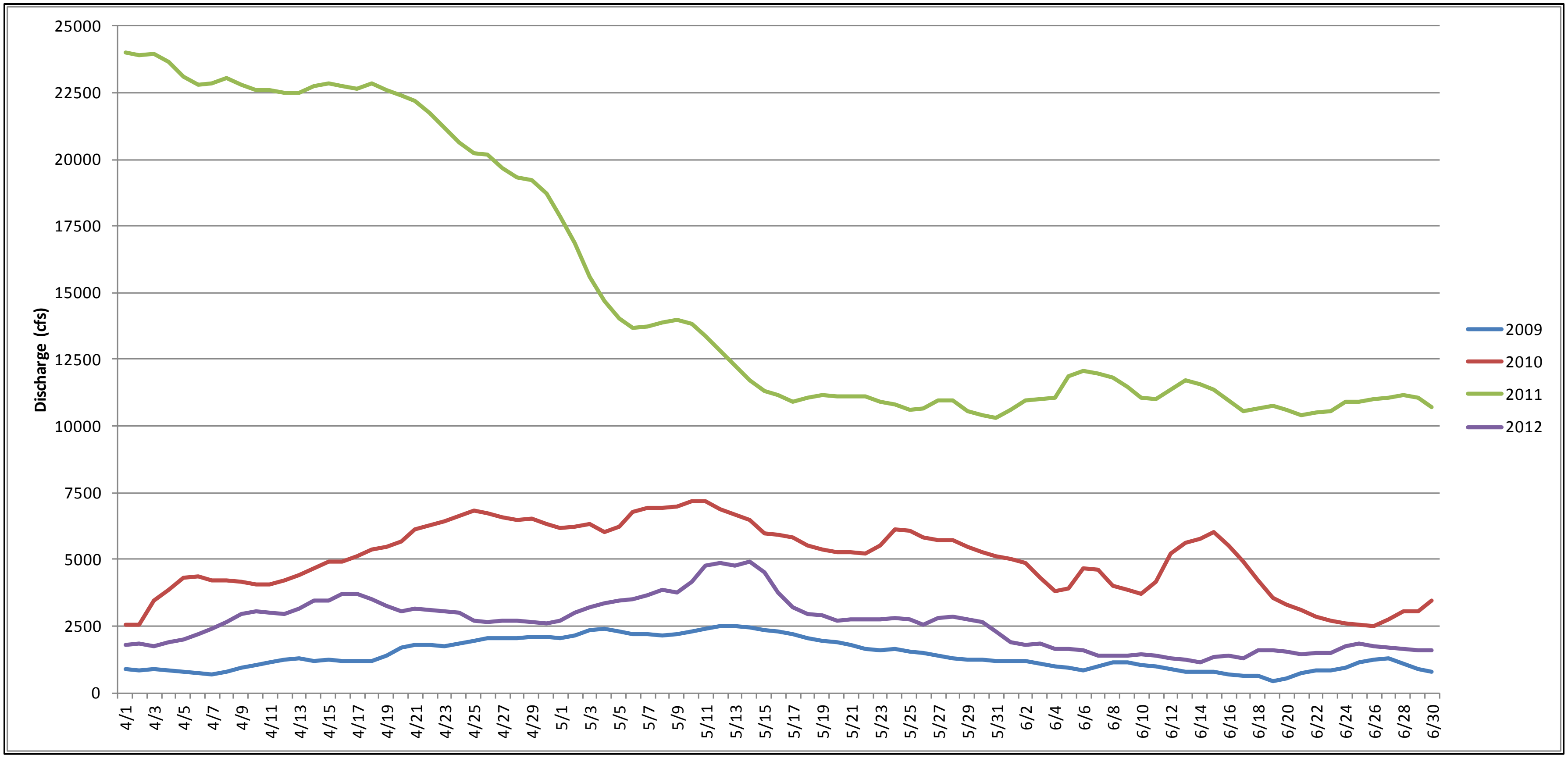
Within the study area, discharge from April through June 2009 was the lowest during the 4-year study period (Figure 3-1). The official water year classifications based on May 1 runoff forecasts were dry in 2009 and 2012, above normal in 2010, and wet in 2011 (State of California 2013). In 2009, low discharge in the San Joaquin River at Mossdale (MSD) led to frequent flow reversals at that location, and the San Joaquin River at Lathrop (SJL), just downstream of the HOR study area, was close to fully tidal much of the time (Figure 3-2). Ebb tide discharge rarely exceeded 2,000 cubic feet per second (cfs) at SJL, and flood tide discharge was nearly as low at -2,000 cfs. SJL flows during the period in which tagged juvenile Chinook salmon arrived into the HOR study area generally were within the range of -1,000 to 2,000 cfs (Figure 3-2).

The division of discharge at the HOR between Old and San Joaquin rivers is of considerable relevance to the analyses of barrier effectiveness described later in this chapter. Estimates of the proportion of discharge entering Old River tend to be extremely variable when made at the 15-minute scale, so summaries were created by calculating daily sums of 15-minute readings of discharge at the Old River at Head (OH1) and dividing by the corresponding daily sums of 15-minute San Joaquin River at Mossdale (MSD) discharge. From April through June 2009, daily discharge at OH1 averaged 0.81 (81%) of daily discharge at Mossdale (range: 0.60 to 1.18), suggesting that the great majority of discharge had entered Old River during this time (Figure 3-3). During the period from April 23 through May 18 in which tagged juvenile Chinook salmon arrived at the HOR study area, daily discharge at OH1 averaged 0.65 of the daily discharge at MSD (range 0.60 to 0.73) (Table 3-1).

3.1.2 2010 DISCHARGE

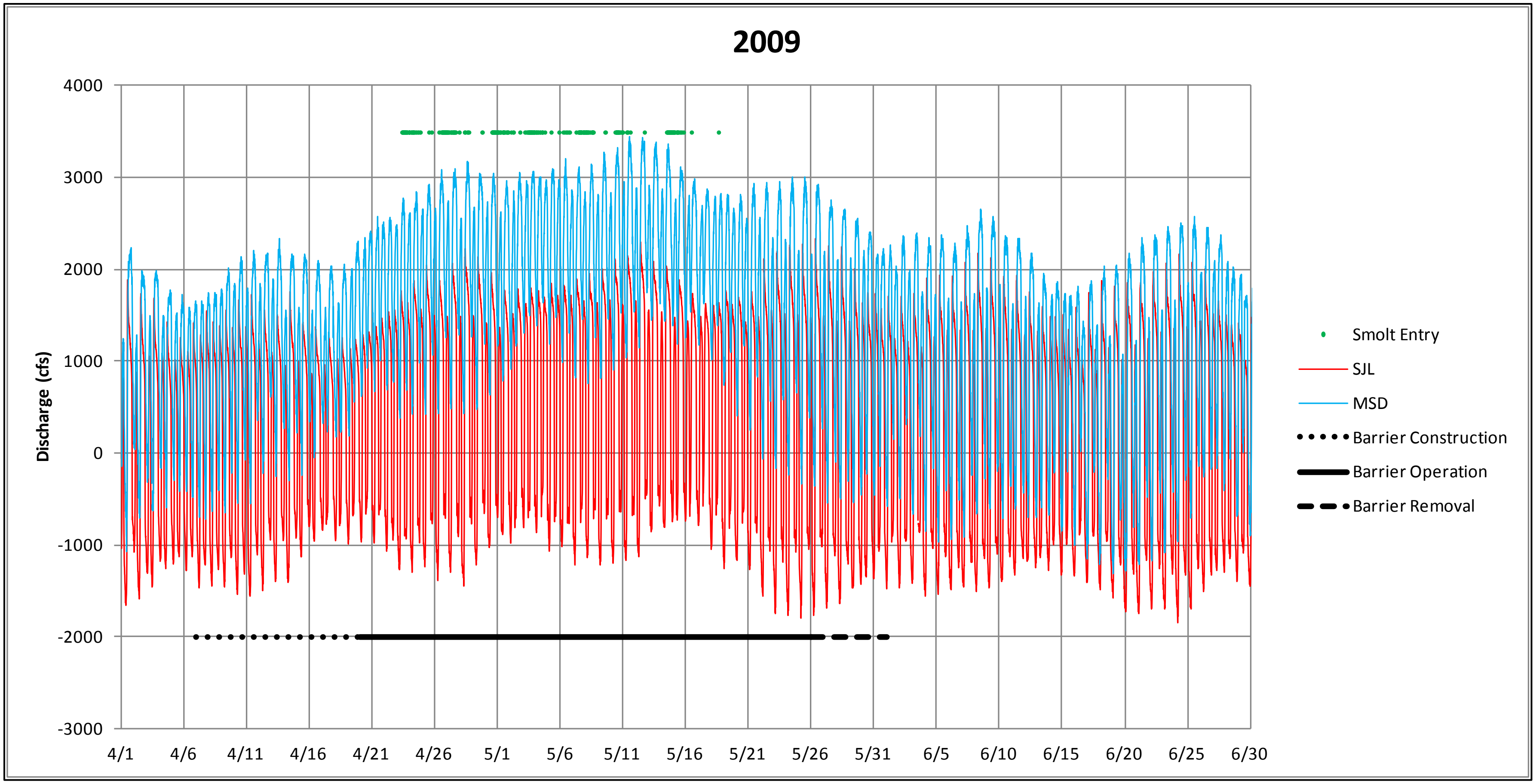
The April through June discharge in 2010 was appreciably higher than in 2009 (Figure 3-1), with the MSD discharge varying between a low of approximately 650 cfs in early April and a high of nearly 7,900 cfs during the period of tagged juvenile Chinook salmon entry in May (Figure 3-4). The SJL discharge exhibited tidal reversals in April, late May, and June, but during the period of juvenile entry, discharge was higher and generally ranged from 1,000 cfs to 3,000 cfs.

From April through June 2010, daily discharge at OH1 averaged 0.54 (54%) of daily discharge at MSD (range: 0.43 to 0.80), suggesting that just more than one-half of discharge had entered Old River during this time (Figure 3-3). During the period from April 27 through May 20, in which tagged juvenile Chinook salmon entered the area, daily discharge at OH1 averaged 0.44 of the daily discharge at MSD (range 0.43 to 0.45) (Table 3-1).



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

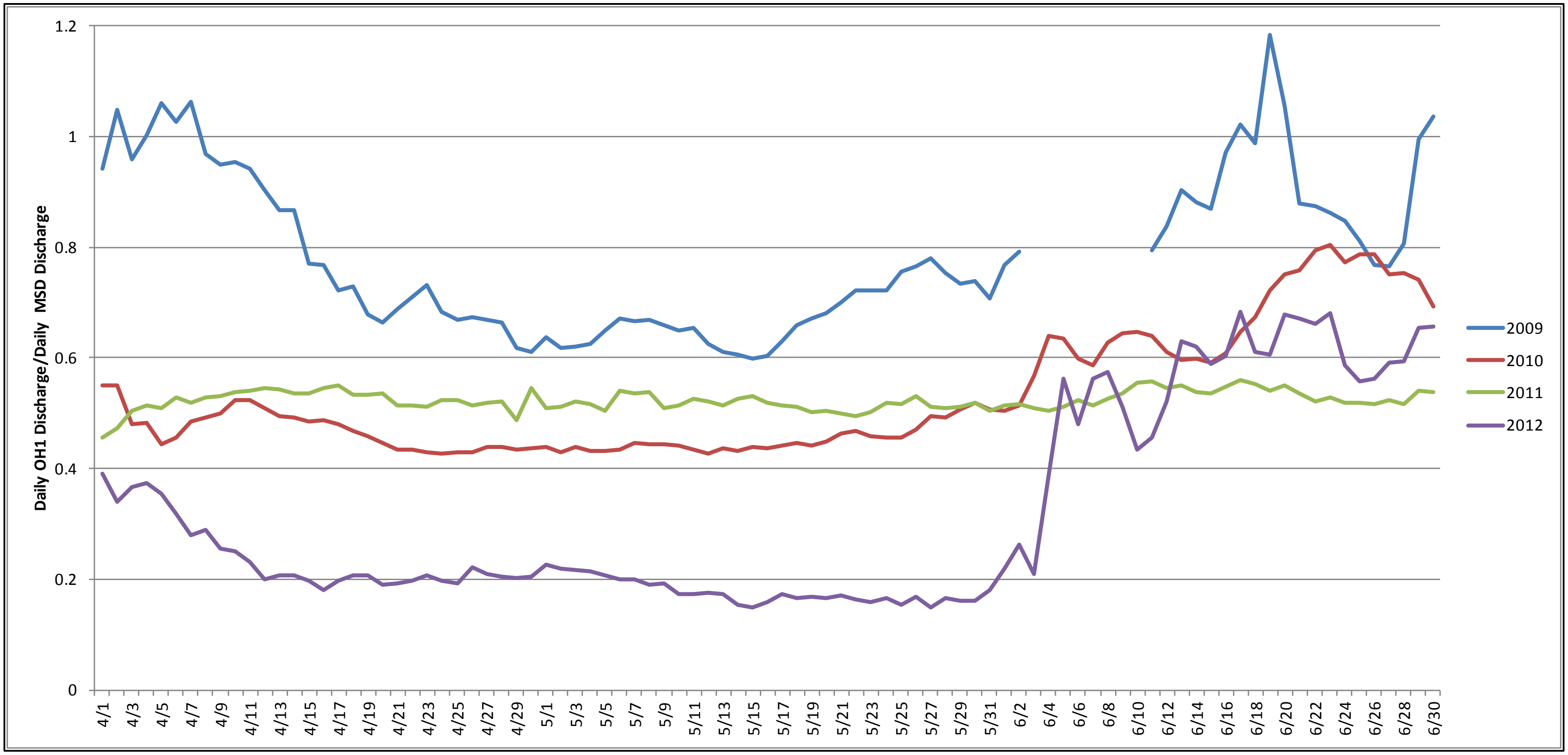
Figure 3-1 **Daily Mean River Discharge in the San Joaquin River at Mossdale (MSD), 4/1 through 6/30, 2009–2012**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

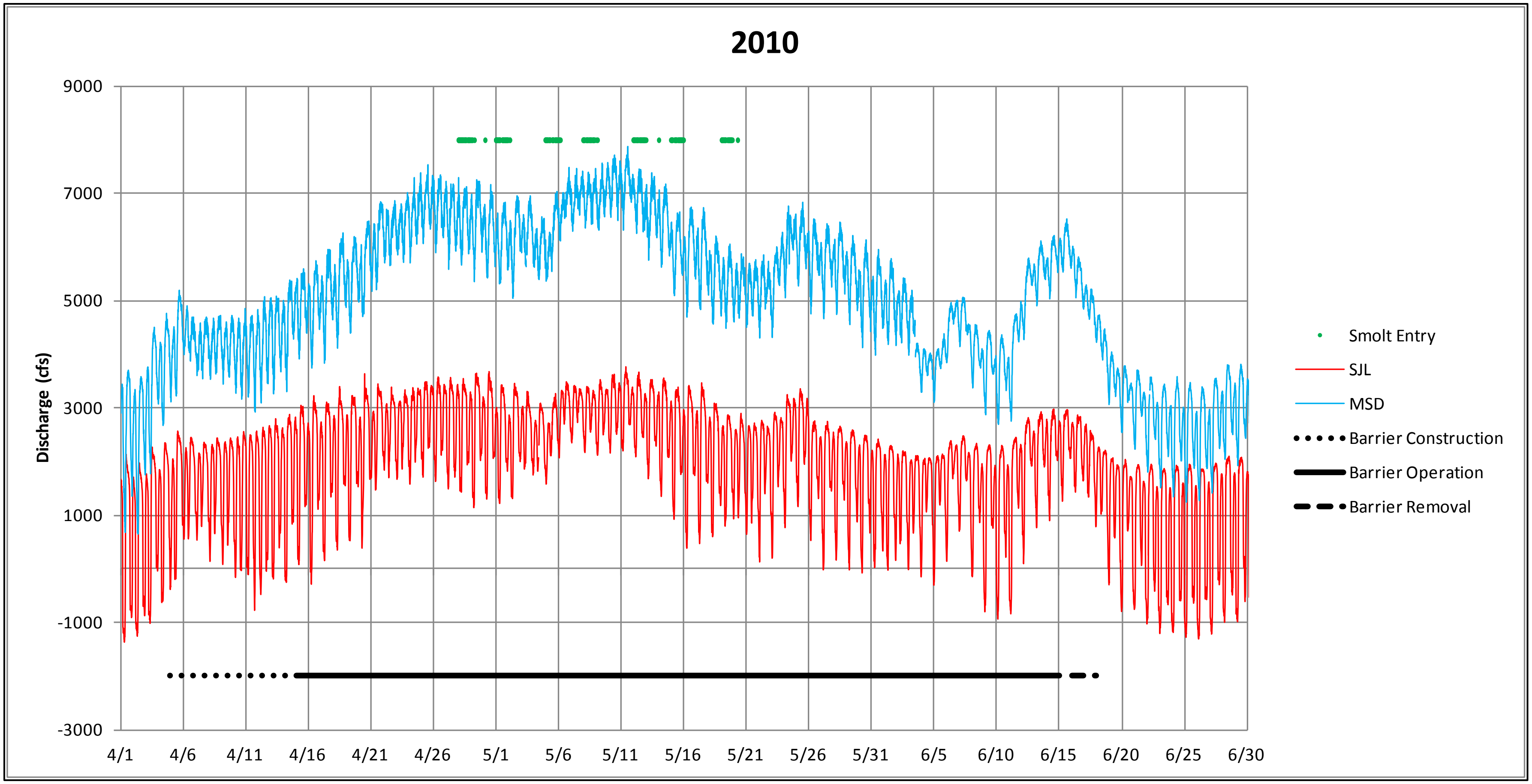
Note: The barrier referred to in the legend was a non-physical fish barrier called a BAFF (Fish Guidance Systems Ltd., Southampton, UK). Barrier operation was not continuous, with the BAFF off approximately 50% of the time during the period of BAFF operation.

Figure 3-2 **15-Minute River Discharge in the San Joaquin River at Mossdale (MSD) and Lathrop (SJL), 4/1/09 through 6/30/09, in Relation to Acoustically Tagged Juvenile Chinook Salmon Arrival into the Head of Old River Study Area (Green Dots)and Non-physical Barrier Construction/Operation/Removal (Black Lines)**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Figure 3-3 **Old River Head (OH1) Daily Discharge as a Proportion of San Joaquin River at Mossdale, Daily Discharge, April-June, 2009-2013**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Note: The barrier referred to in the legend was a non-physical fish barrier called a BAFF (Fish Guidance Systems Ltd., Southampton, UK). Barrier operation was not continuous with the BAFF off approximately 50% of the time during the period of BAFF operation.

Figure 3-4 15-Minute River Discharge in the San Joaquin River at Mossdale (MSD) and Lathrop (SJL), 4/1/10 through 6/30/10, in Relation to Acoustically Tagged Juvenile Chinook Salmon Entry into the Head of Old River Study Area (Green Dots)and Non-physical Barrier Status (Black Lines)

Table 3-1
Descriptive Statistics for 2009–2012 HOR Average Daily Discharge as Proportion of San Joaquin River at Mossdale Average Daily Discharge during Periods when Tagged Juvenile Chinook Salmon Arrived at the HOR Study Area

			Daily OH1 Discharge/Daily MSD Discharge				
Year	First Fish[1]	Last Fish[2]	Mean	Standard Deviation	Minimum	Maximum	Count
2009	4/23/09; 8:24	5/18/09; 13:48	0.65	0.03	0.60	0.73	26
2010	4/27/10; 22:25	5/20/10; 5:54	0.44	0.01	0.43	0.45	24
2011	5/4/11; 2:51	6/22/11; 4:24	0.52	0.02	0.49	0.56	50
2012	4/28/12; 4:13	5/29/12; 16:35	0.18	0.02	0.15	0.23	32

Notes: HOR = Head of River; OH1 = Old River at Head; MSD = San Joaquin River at Mossdale
The OH1 gauge is 0.25 km downstream of the HOR site; the MSD gauge is ~4.5 km upstream of the HOR site. The periods reported here are based on values observed during the period between first and last detections of fish.
1 Date/time when the first tagged salmonids was nearest the BAFF line.
2 Date/time the last tagged salmonids was nearest the BAFF line.
3 SJR Flow Proportion = 1 - (Mean of (Daily OH1 Discharge/Daily MSD Discharge)); therefore SJR Flow Proportion = 0.35 (2009), 0.56 (2010), 0.48 (2011), and 0.82 (2012).
Source: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

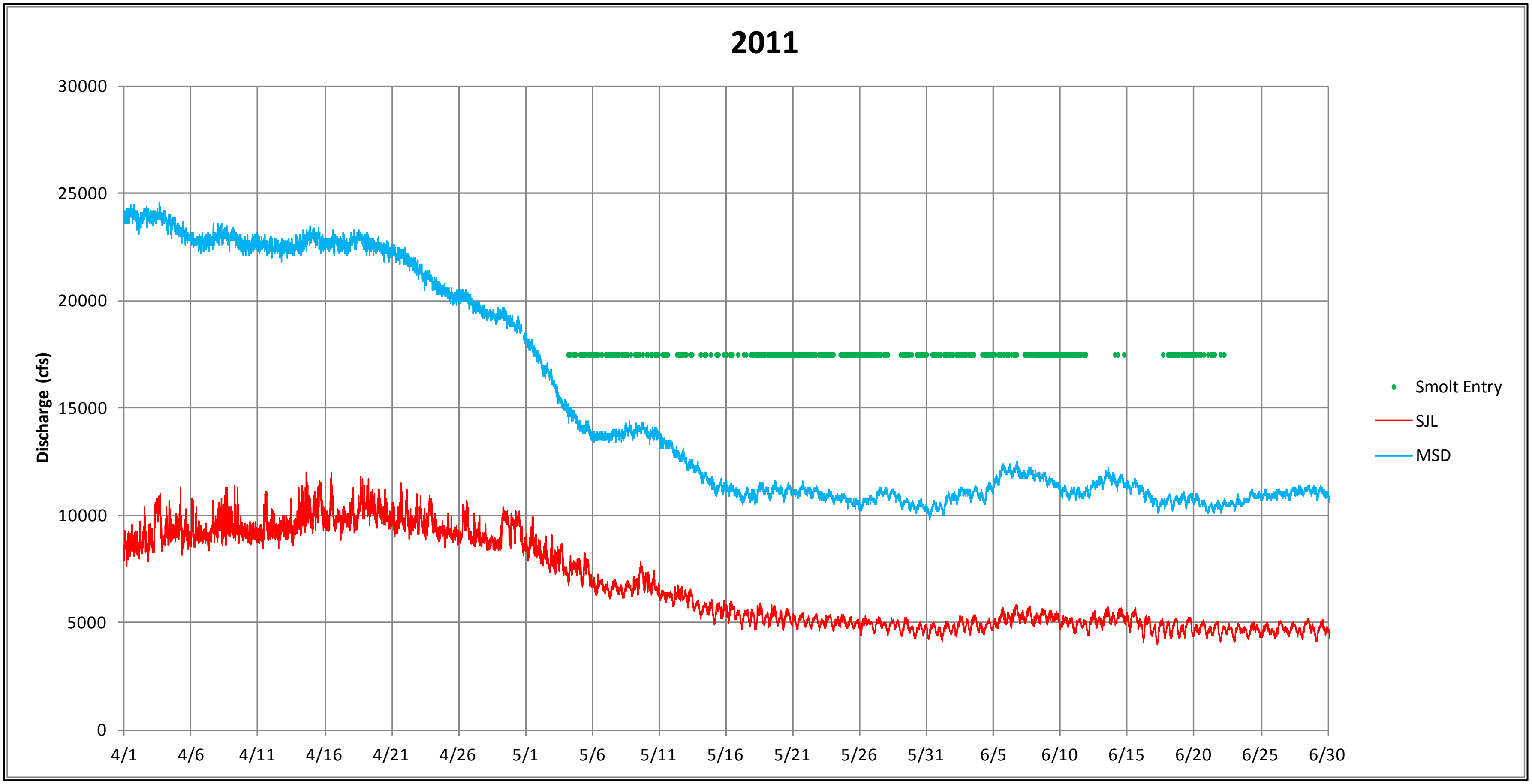
3.1.3 2011 Discharge

Discharge from April through June 2011 was exceptionally high as a result of unseasonably high precipitation (Figure 3-1). Discharge at MSD exceeded 24,000 cfs in early April and remained higher than 10,000 cfs for most the entire 3-month period (Figure 3-5). The discharge at the SJL gauge was higher than 10,000 cfs during much of April, and was approximately 7,500 cfs at the beginning of tagged juvenile salmonid entry into the HOR study area in early May, before decreasing to approximately 5,000 cfs from approximately mid-May thru the end of June. The tidal signal was appreciably muted in 2011 because of the high river discharge.

From April through June 2011, daily discharge at OH1 averaged 0.51 (51%) of daily discharge at MSD (range: 0.44 to 0.90), suggesting that approximately one-half of the discharge had entered Old River during this time (Figure 3-3). During the period from May 5 through June 22, in which tagged juvenile salmonids entered the area, daily discharge at OH1 averaged 0.52 of the daily discharge at MSD (range 0.49 to 0.56) (Table 3-1).

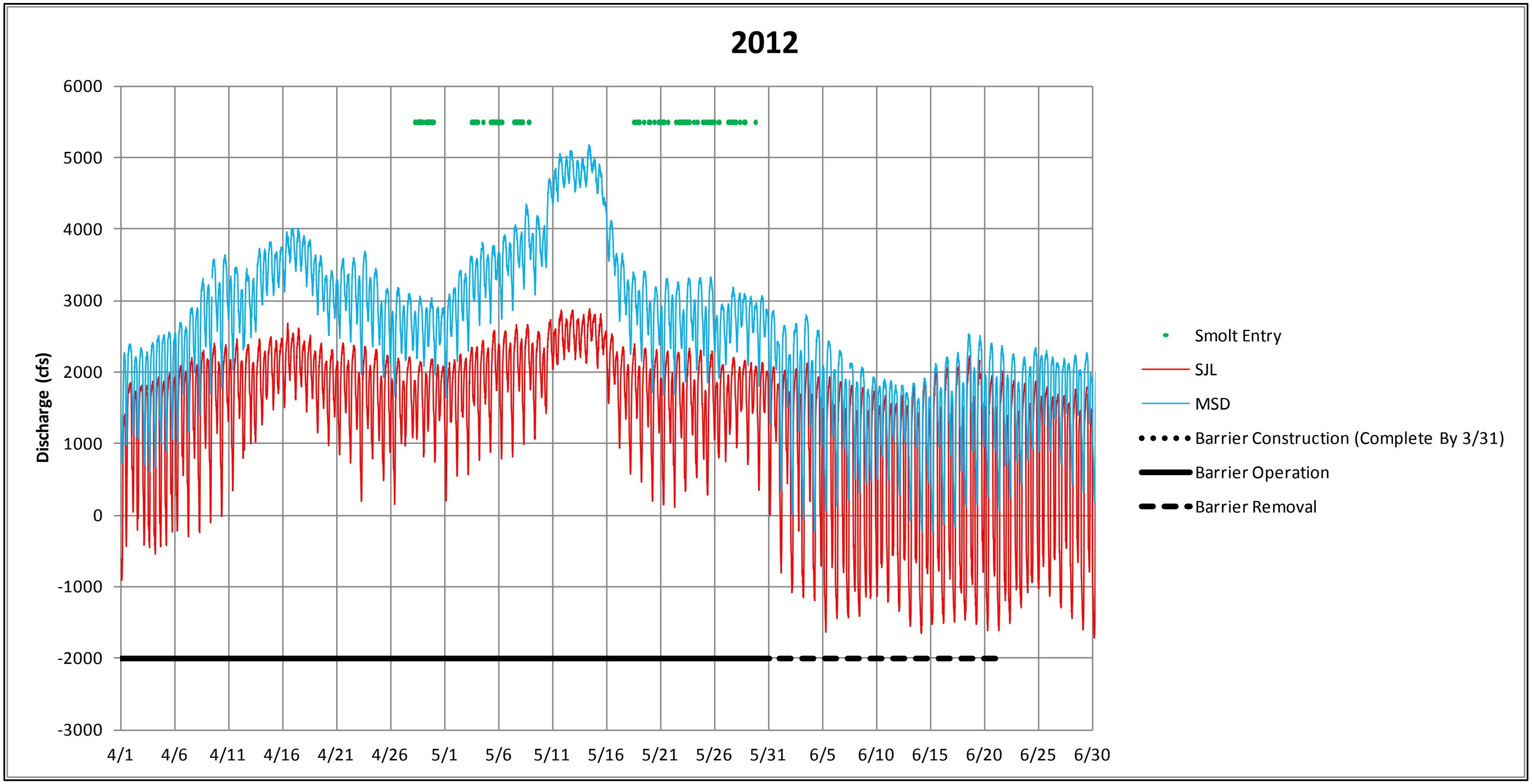
3.1.4 2012 Discharge

Discharge in 2012 from April through June was greater than in 2009, but less than 2010 (Figure 3-1). Tidal flow reversals occurred at SJL in April and June, with a handful of reversals at MSD in June (Figure 3-6). The SJL discharge during the period of tagged juvenile salmonid entry to the HOR study area generally varied from more than 1,000 to 2,500 cfs in late April/early May, and from less than 1,000 cfs to just more than 2,000 cfs from mid- to late June. No juveniles entered the area during elevated discharge of approximately 4,500 to 5,000 cfs at MSD from May 10 through 15 (Figure 3-6).



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Figure 3-5 15-Minute River Discharge in the San Joaquin River at Mossdale (MSD) and Lathrop (SJL), 4/1/11 through 6/30/11, in Relation to Acoustically Tagged Juvenile Chinook Salmon and Steelhead Arrival into the Head of Old River Study Area (Green Dots)



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Note: The barrier referred to in the legend was a rock barrier with eight culverts.

Figure 3-6 **15-Minute River Discharge in the San Joaquin River at Mossdale (MSD) and Lathrop (SJL), 4/1/12 through 6/30/12, in Relation to Acoustically Tagged Juvenile Chinook Salmon Entry into the Head of Old River Study Area (Green Dots) and Rock Barrier Status (Black Lines)**

From April through June 2012, daily discharge at OH1 averaged 0.44 (44%) of daily discharge at MSD (range: 0.15 to 1.05), suggesting that just less than one-half of the discharge had entered Old River during this time interval (Figure 3-3). During the period from April 28 through May 29, in which tagged juvenile salmonids entered the area, daily discharge at OH1 averaged 0.18 of the daily discharge at MSD (range 0.15 to 0.23) (Table 3-1). This relatively low proportion of discharge reflected the installation of the rock barrier that occurred from April 1 through May 31 (Figure 3-6), and represents the discharge either passing through the barrier's culverts or between the rocks that made up the barrier.

3.2 VELOCITY FIELD

Hydrodynamic data were collected in 2009, 2011, and 2012 to provide information on the velocity field at the HOR study area. These data sets provide a three-dimensional (3D) water velocity field at discrete time periods.

3.2.1 METHODS

In 2009 and 2011, hydrodynamic data were collected using a downward-looking acoustic Doppler current profiler (DL-ADCP) from a moving boat. Measurements were taken on February 2, March 3 and 13, May 29, and June 5, 2009, and on April 12, 2011. In 2012, near-surface hydrodynamic data were collected using side-looking (SL) ADCPs, deployed near the bank and profiling across the river at four locations for the duration of the study period, April 23 through May 30. The SL-ADCP data were interpolated to generate a near-surface 2D velocity field. On May 8 and 30, 2012, DL-ADCP measurements were taken to validate the 2D velocity interpolation.

DL-ADCP DATA PROCESSING AND INTERPOLATION

The DL-ADCP measurements were made synoptically during the same time intervals for 8 days in each year (i.e., 2009, 2011, and 2012). The processing methods included correcting Differential Global Positioning System (DGPS) tracks, objectively filtering out suspect data, spatially smoothing based on a 3-point weighted average, and extrapolating velocity vectors to the bed (bottom substrate) (Dinehart and Burau 2005). The processed DL-ADCP measurements were interpolated to produce a 3D velocity field for each time interval in 2009, 2011, and 2012. The 3D interpolated velocity fields were generated using an algorithm that releases particles into the initial velocity field and interpolates velocities along the particle pathlines, using an inverse path length weighting (IPLW) function. This algorithm iterates until the changes in the velocity field are minimal.

SL-ADCP DATA PROCESSING AND INTERPOLATION

The SL-ADCP measurements were made continuously at 15-minute intervals from April 23 through May 30, 2012, except for an 18-hour period from April 29 through April 30 and a 27-hour period from May 5 through May 7 due to a technical malfunction that resulted in recording erroneous data. The data processing included merging the SL-ADCP data into a single file, geo-referencing the measurement locations, conducting visual quality assurance/quality control checks, and estimating (when possible) data gaps. The 2D interpolated velocity fields were generated for a 5-meter by 5-meter set of grid points every 15 minutes using an algorithm that releases particles into the processed velocity field and interpolates velocities along the particle pathlines using an IPLW function. This algorithm iterates until the changes in the mean velocity field are minimal.

3.2.2 RESULTS

Near-surface 2D velocity fields from the DL-ADCP and SL-ADCP data (hereafter referred to as DL2D and SL2D) were used to examine velocity fields and hydrodynamic features over a range of river discharges (Table 3-2). The discharge values (SJL) were chosen to represent reverse and typical flows from 2009; very high flows from 2011; and the 5th, 25th, 50th, 75th, and 95th percentile flows from 2012.

Table 3-2
Summary of Velocity Fields Generated from DL-ADCP Data in 2009 and 2011, and SL-ADCP Data from 2012

Discharge at San Joaquin near Lathrop (cfs)	-1,360	780	1,450	1,500	1,970	2,000	2,250	2,660	9,535
Timestamp (PST)	5/29/2009 09:25	2012[1]	6/05/2009 10:00	2012[1]	2012[1]	2012[1]	2012[1]	2012[1]	04/12/201 1 10:10
Rationale	Negative-flow condition (common occurrence in 2009)	5th percentile of 2012 flows	Common low-flow condition in 2009 (and 2010)	25th percentile of 2012 flows	50th percentile of 2012 flows	Intermediate discharge of interest	75th percentile of 2012 flows	95th percentile of 2012 flows	High-flow condition observed only in 2011

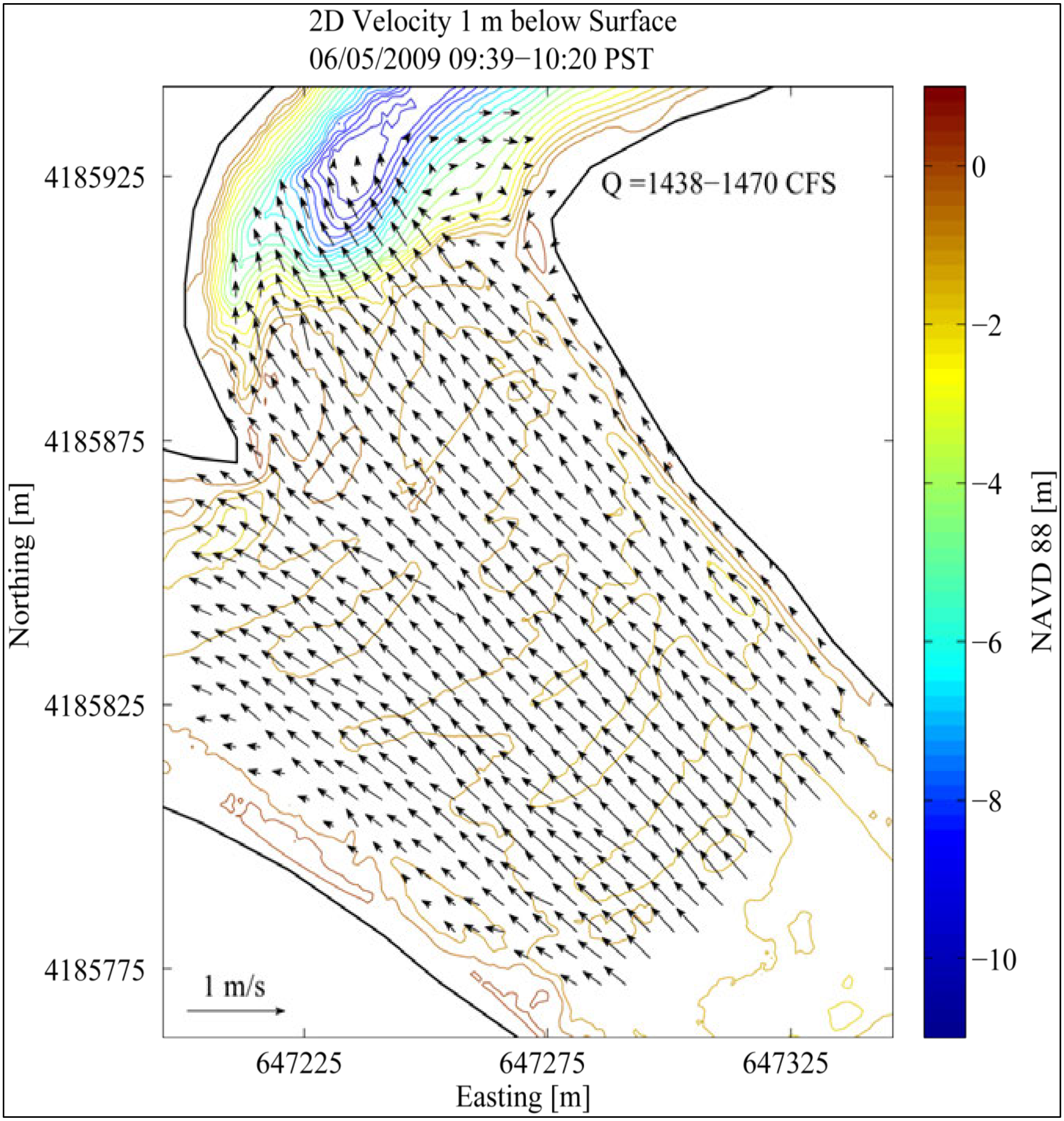
Notes: cfs = cubic feet per second; DL-ADCP = downward-looking acoustic Doppler current profiler; PST = Pacific Standard Time; SL-ADCP = side-looking acoustic Doppler current profiler
1 Multiple instances for specified discharge value.
Source: Present study

VELOCITY MODELING OF 2009 AND 2011 (NO ROCK BARRIER)

Data from 2009 and 2011 provided information on the HOR velocity field in the absence of a physical barrier. At a SJL discharge of approximately 1,450 cfs, a commonly observed discharge in 2009, near-surface velocity was primarily in a downstream direction and was greatest in the mid-channel San Joaquin River, close to the divergence with Old River (Figure 3-7).

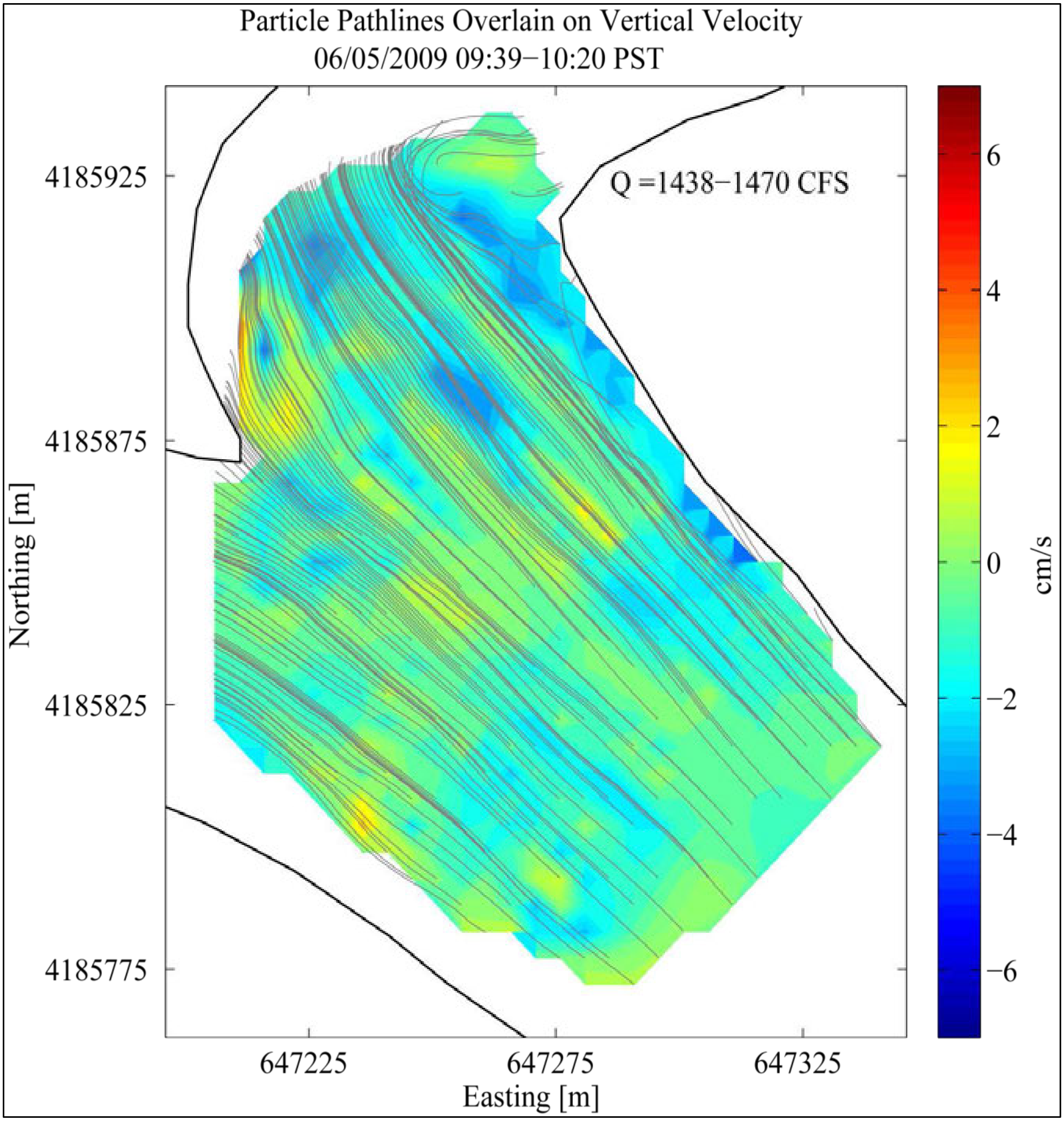
An eddy formed near a sand spit on the right bank of the San Joaquin River east of the deepest part of the scour hole (Figure 3-8). Vertical velocity primarily was downward at around 0 to 2 centimeters per second (cm/s). With reverse flows of approximately -1,360 cfs in 2009, a large eddy and related irregular velocities occurred on the right side of the San Joaquin River upstream of the divergence with Old River (Figures 3-9 and 3-10). Upstream velocity was of relatively high magnitude (approximately 0.33 m/s at discharge of approximately -1,300 to -1,450 cfs) (see Figure 3-9) on the left side of the San Joaquin River closest to the divergence with Old River. A low-velocity eddy also was apparent at the scour hole. Vertical velocity was primarily upward near the scour hole and mostly downward elsewhere.

Very high discharge in 2011 resulted in a downstream velocity of appreciable magnitude (e.g., >≥1 m/s) (Figure 3-11). Vertical velocity during this time was primarily downward, at more than 6 cm/s in many areas (Figures 3-7 through 3-12).



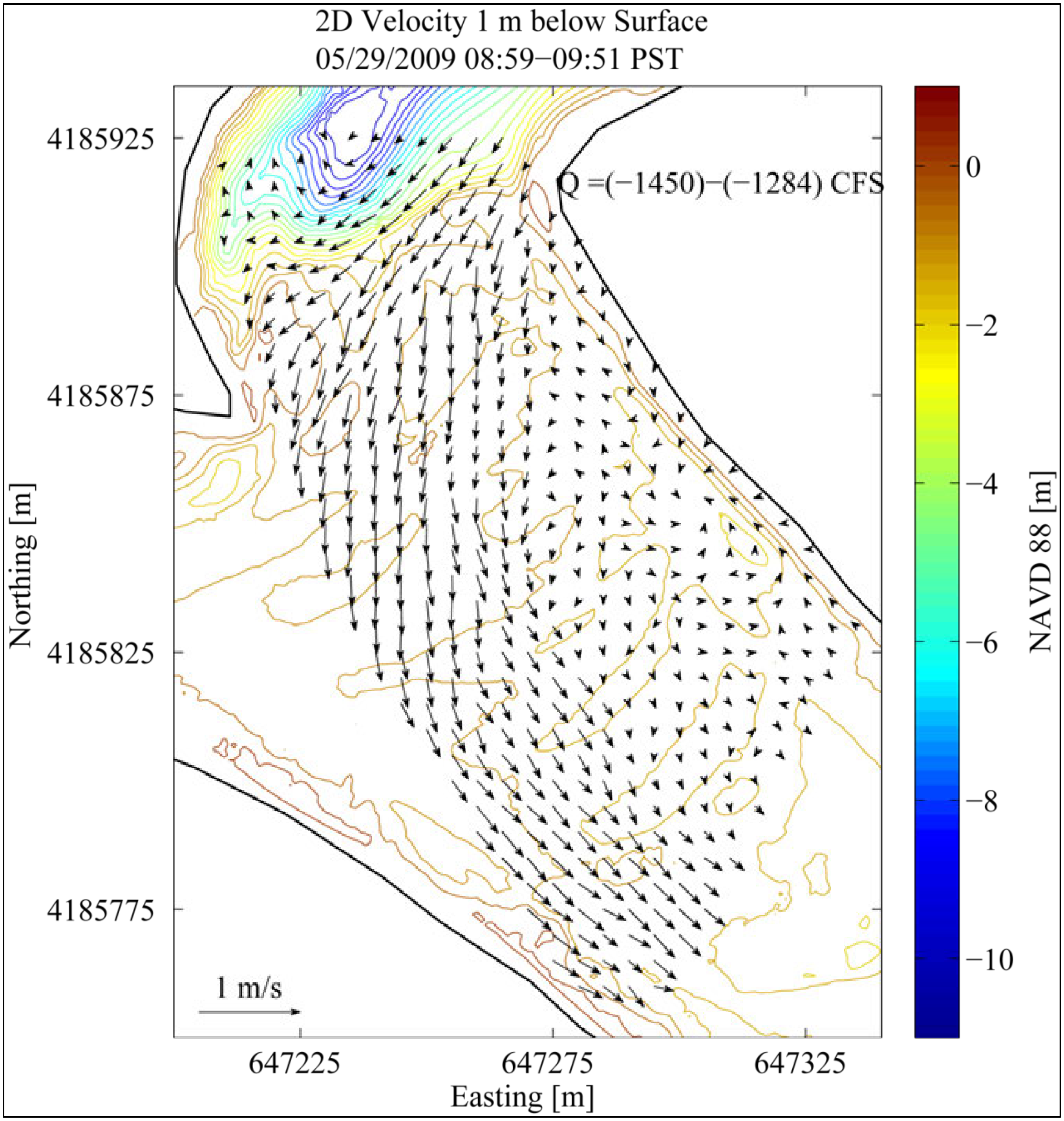
Source: Present study

Figure 3-7 Two-Dimensional Near-Surface Velocity Vectors (m/s) Estimated from Data Collected with a DL-ADCP at the Head of Old River, 6/5/2009, 0939–1020 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 1,438 to 1,470 cfs



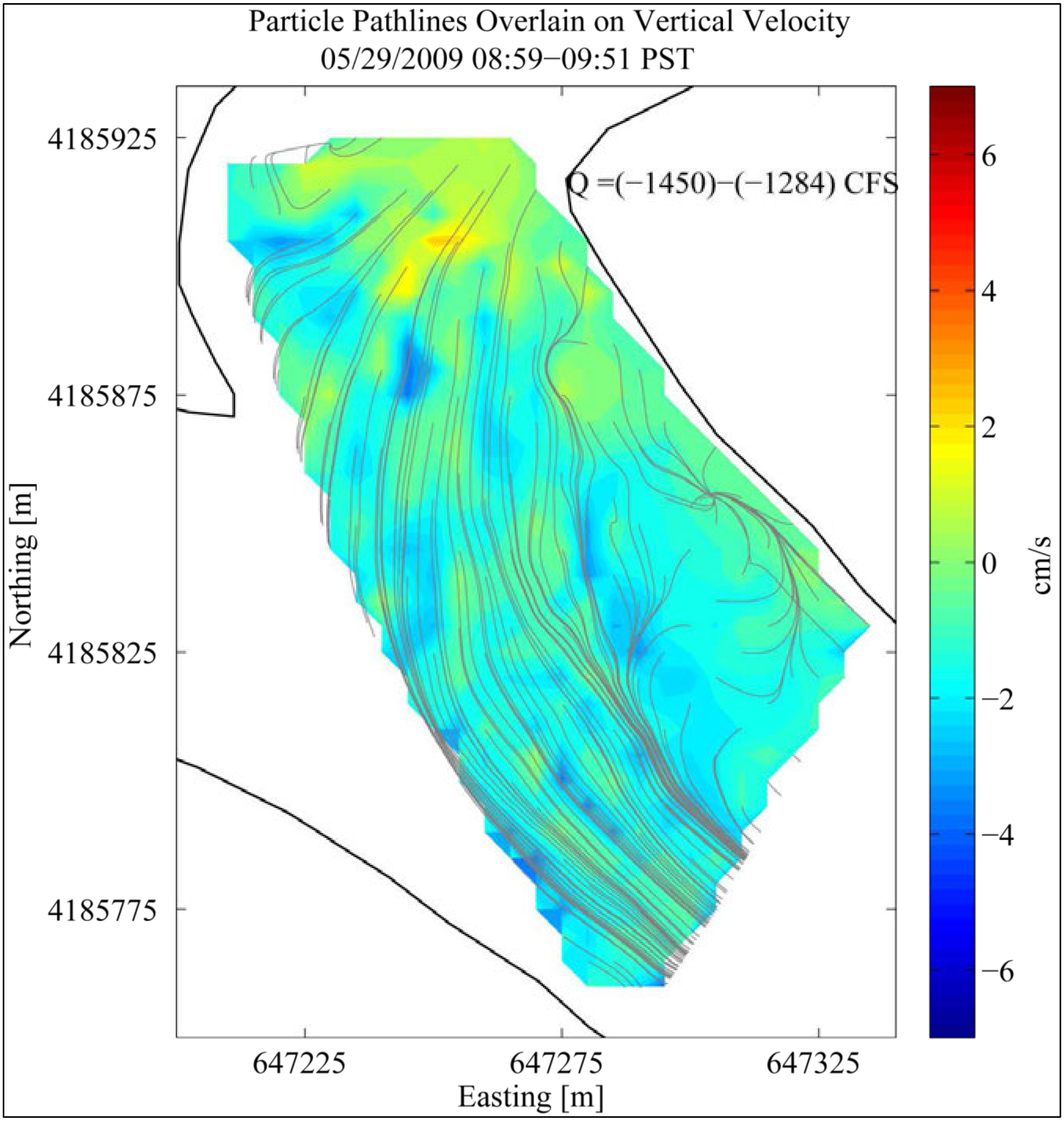
Source: Present study

Figure 3-8 Vertical Velocity (cm/s) and Particle Pathlines Estimated from Data Collected with a DL-ADCP at the Head of Old River, 6/5/2009, 0939–1020 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 1,438 to 1,470 cfs



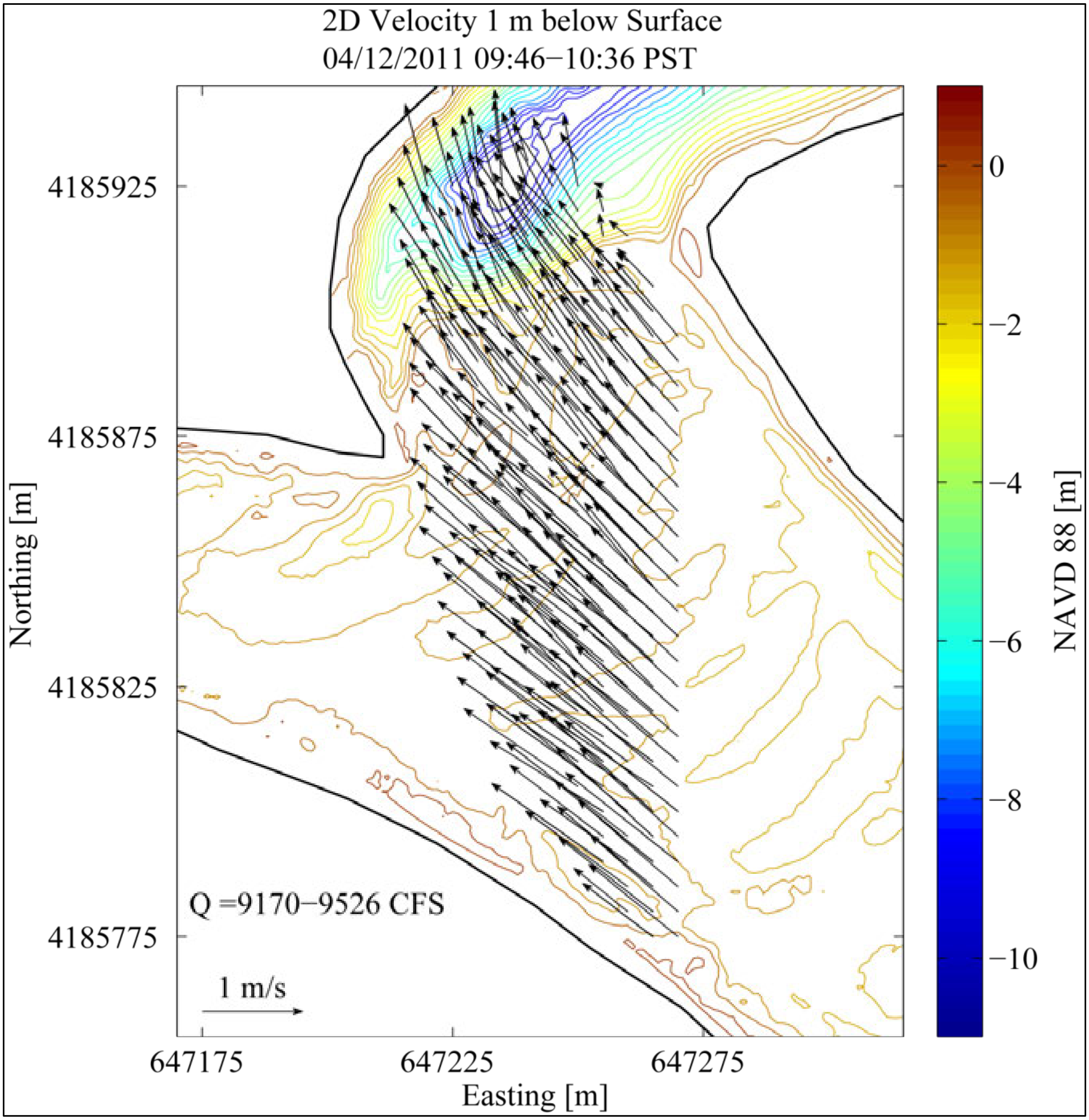
Source: Present study

Figure 3-9 Two-Dimensional Near-Surface Velocity Vectors (m/s) Estimated from Data Collected with a DL-ADCP at the Head of Old River, 5/29/2009, 0859–0951 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of -1,450 to -1,284 cfs



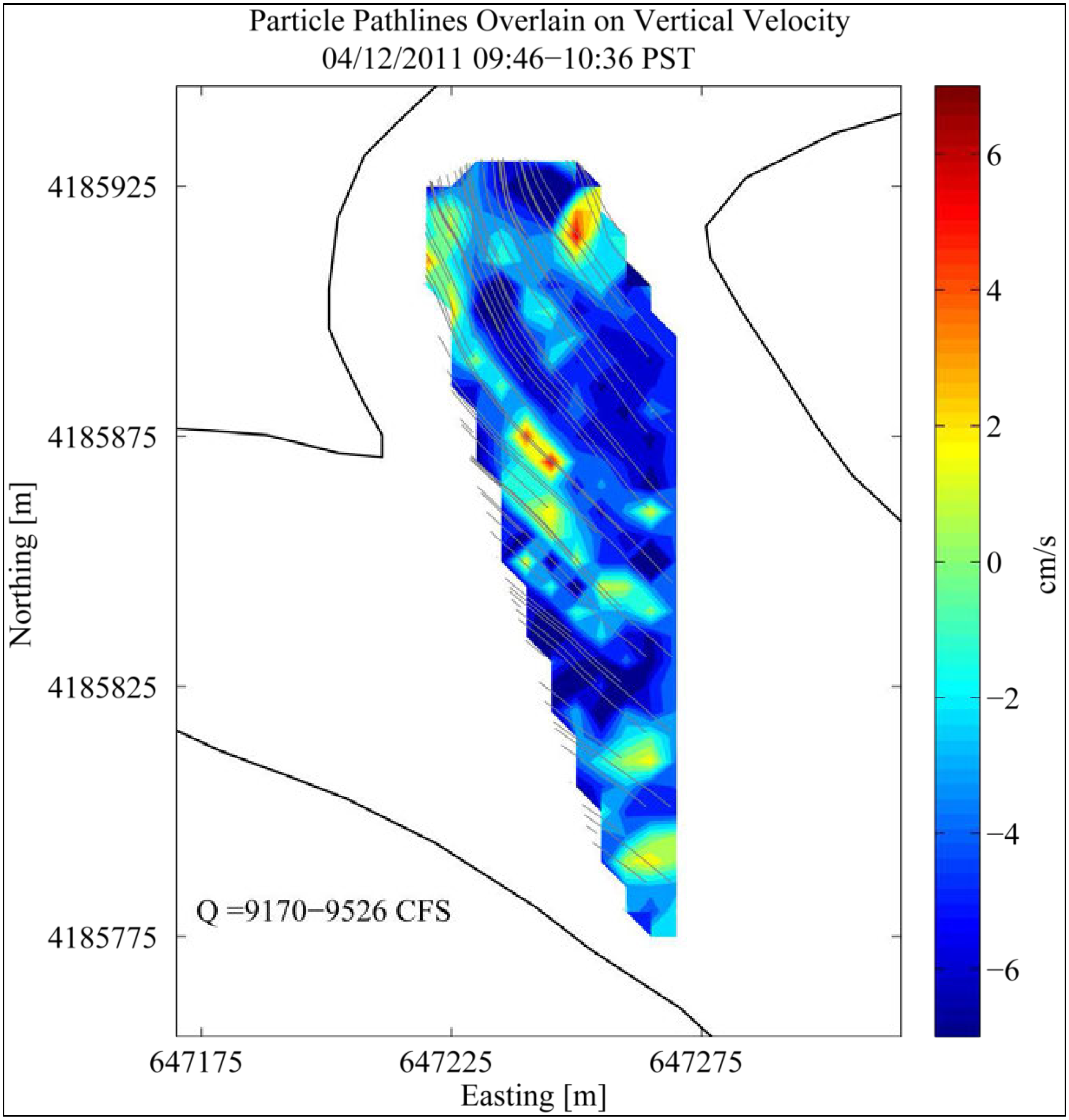
Source: Present study

Figure 3-10 Vertical Velocity (cm/s) and Particle Pathlines Estimated from Data Collected with a DL-ADCP at the Head of Old River, 5/29/2009, 0859–0951 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of -1,450 to -1,284 cfs



Source: Present study

Figure 3-11 Two-Dimensional Near-Surface Velocity Vectors (m/s) Estimated from Data Collected with a DL-ADCP at the Head of Old River, 4/12/2011, 0946–1036 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 9,170 to 9,526 cfs



Source: Present study

Figure 3-12 Vertical Velocity (cm/s) and Particle Pathlines Estimated from Data Collected with a DL-ADCP at the Head of Old River, 4/12/2011, 0946–1036 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 9,170 to 9,526 cfs

VELOCITY MODELING OF 2012 (PHYSICAL ROCK BARRIER)

The set of observations from the 2012 SL2D velocity fields are the most extensive available over a range of discharge values. The most notable observations are described herein. At low discharge (approximately 780 cfs; the 5th percentile discharge in 2012), the flow field does not exhibit much variability, and the velocity vectors near the barrier are low (Figures 3-13 and 3-14).

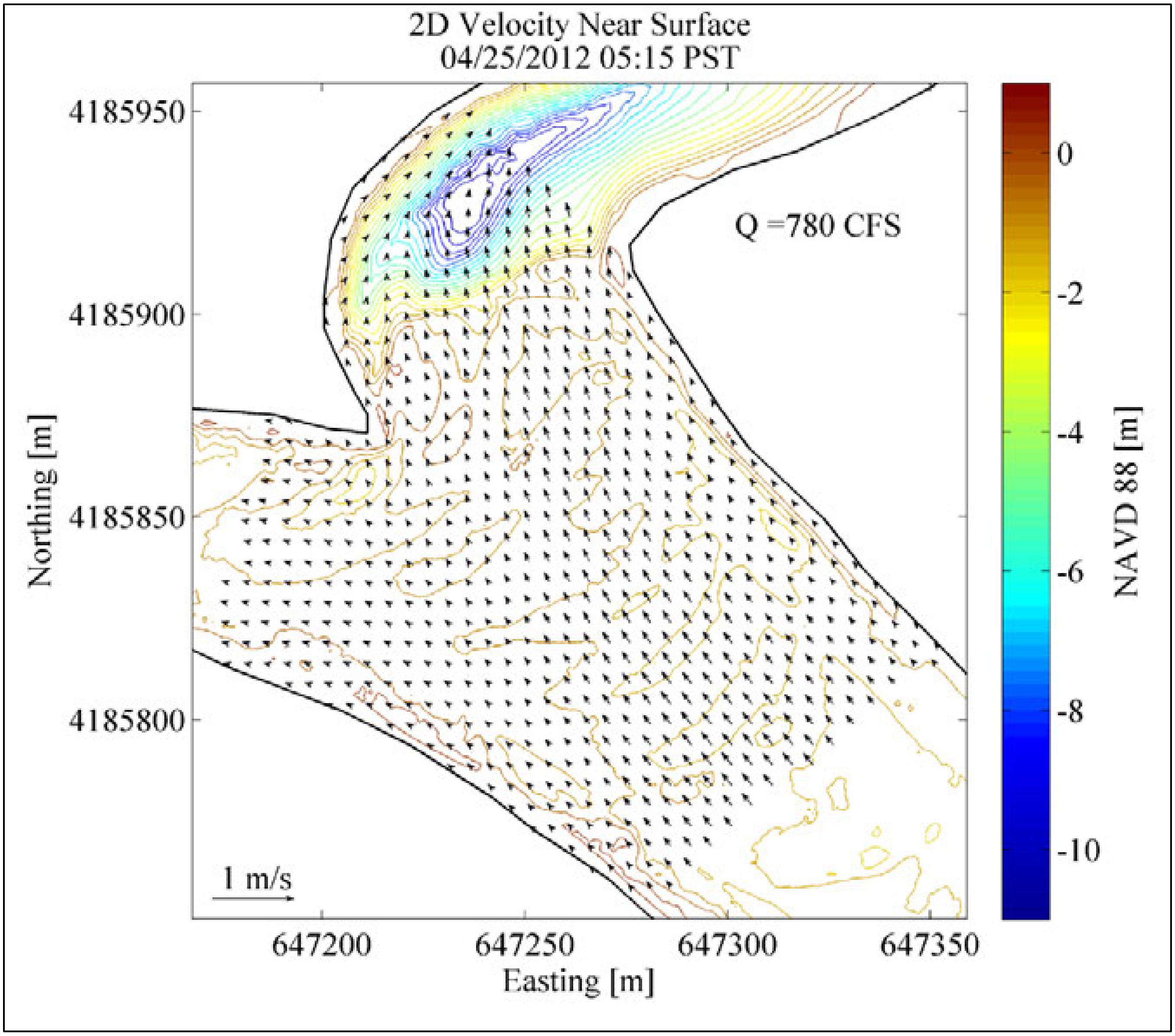
At moderate discharge values (1,500 to 1,970 cfs; the 25th to 50th percentile discharge in 2012), more variability occurred in the flow field, with higher velocities mid-channel and near the scour hole downstream of the divergence, and low velocities near the barrier (Figures 3-15, 3-16, 3-17, and 3-18). Two large-scale eddies appear at these discharge levels: one eddy forms near the barrier with a counter-clockwise (CCW) rotation, and a smaller eddy forms near the left bank adjacent to the scour hole, also with a CCW rotation.

At higher discharge values (2,250 to 2,660 cfs; the 75th to 95th percentile discharge in 2012), the flow field remains consistent, with higher velocity magnitudes (Figures 3-19, 3-20, 3-21, and 3-22). The eddy near the barrier becomes larger during moderate discharges. The eddy near the scour hole is not consistently present throughout the set of observations. As noted in the following section ("Comparison of DL2D and SL2D"), the SL2D velocity fields do not represent the eddy near the scour hole consistently in comparison to the DL2D.

COMPARISON OF DL2D AND SL2D

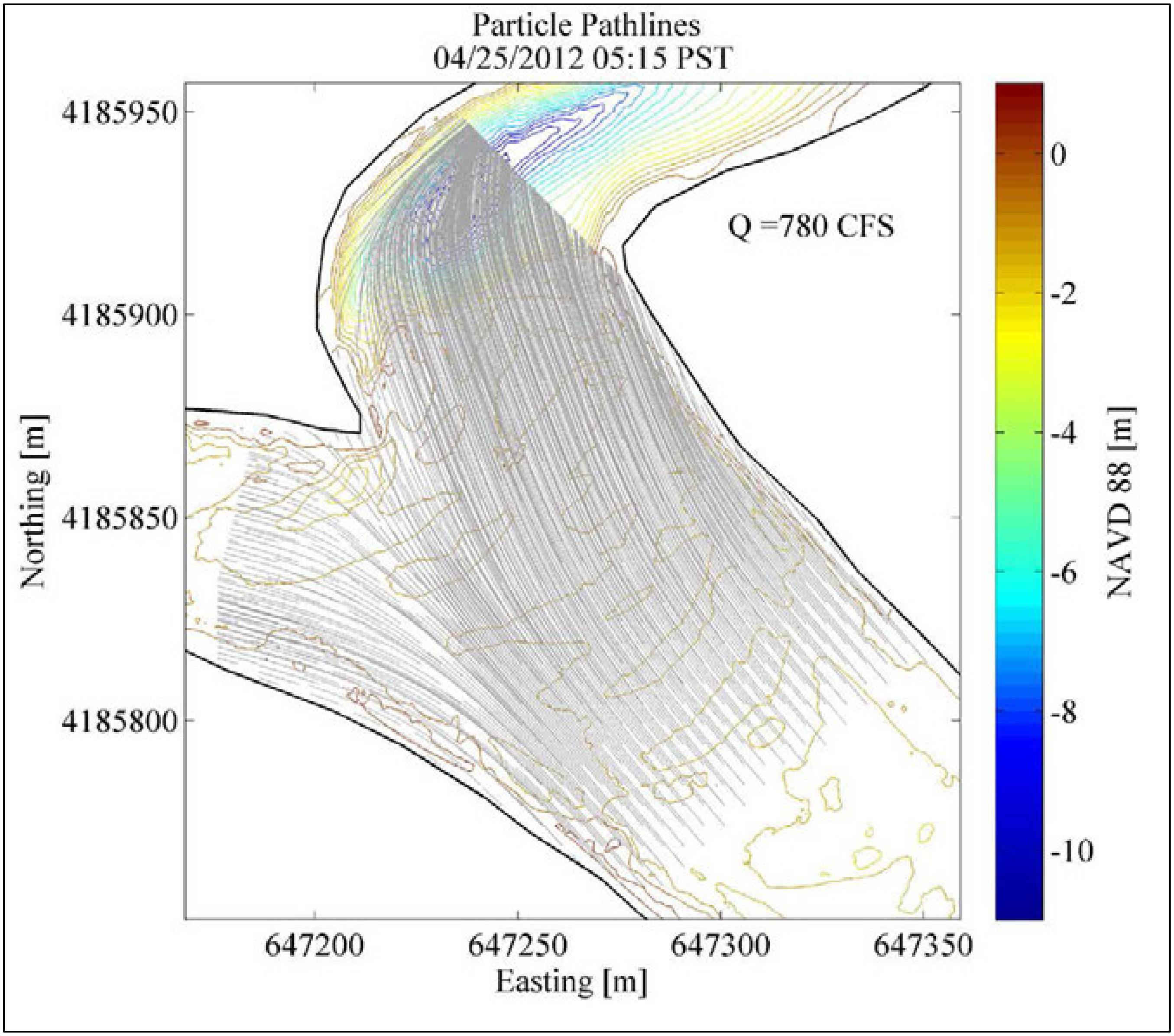
A comparison was made of the DL2D and SL2D velocity fields. The DL-ADCP data collected on May 8 and 30, 2012 were from a range of discharge values (1,840 to 2,660 cfs). These data were collected near the physical rock barrier and near the scour hole. The DL2D velocity field is considered more accurate because the interpolation was based on larger data density, but fewer observations exist over a smaller range of discharge. The most important observations from these comparisons are as follows:

- The SL2D velocity field accurately represented the velocity variability throughout the domain, except near the barrier, where the magnitude of the velocity vectors from the SL2D velocity field are smaller than those from the DL2D velocity field.
- The SL2D velocity field failed to capture or fully represent the eddy that was present near the scour hole for all observations, but this eddy was seen in nearly all of the observations of the DL2D velocity field.
- The eddy near the barrier appears to be accurately captured by the SL2D velocity field and was present in the DL2D velocity field.



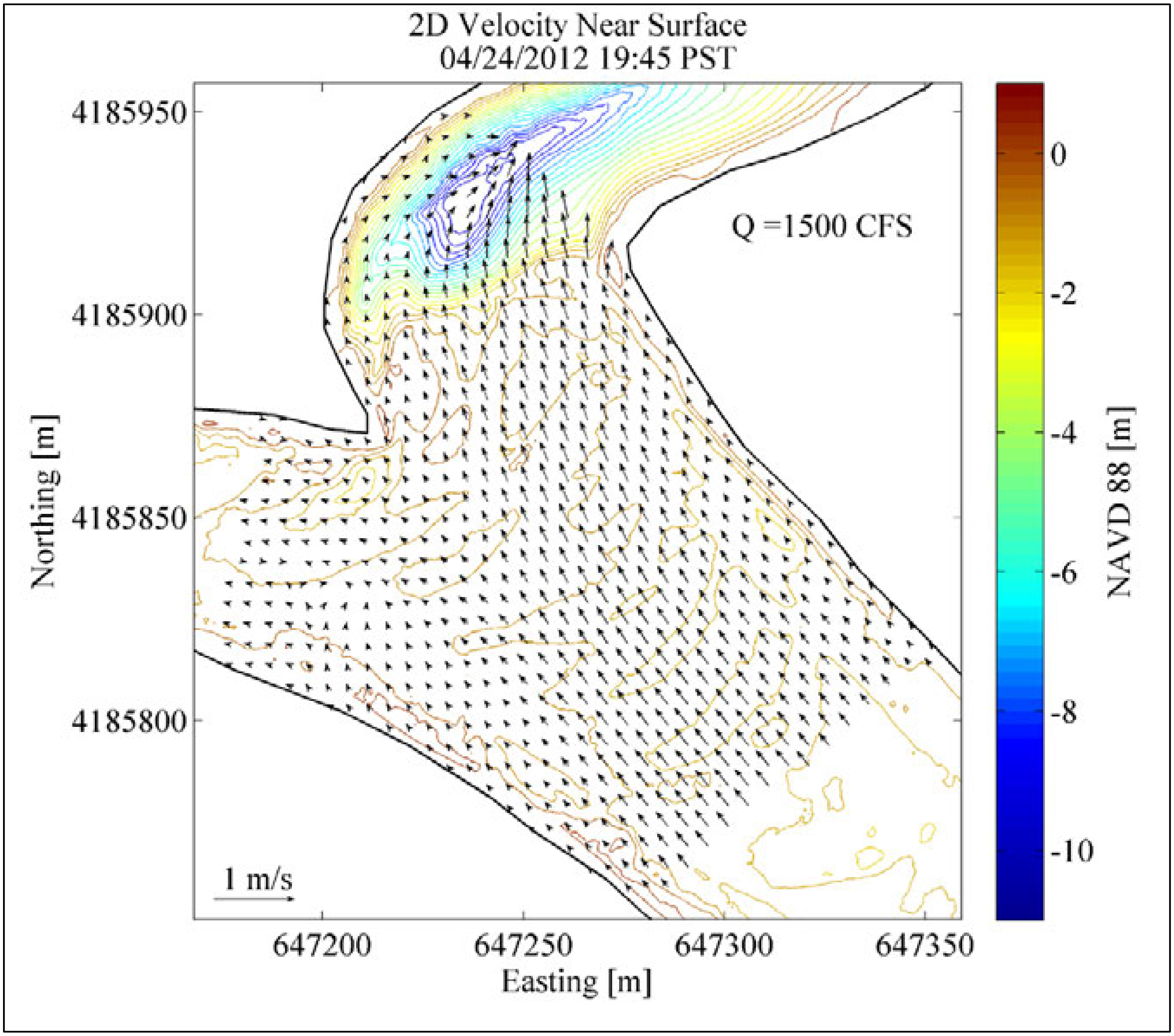
Source: Present study

Figure 3-13 Two-Dimensional Near-Surface Velocity Vectors (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 4/25/2012, 0515 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 780 cfs



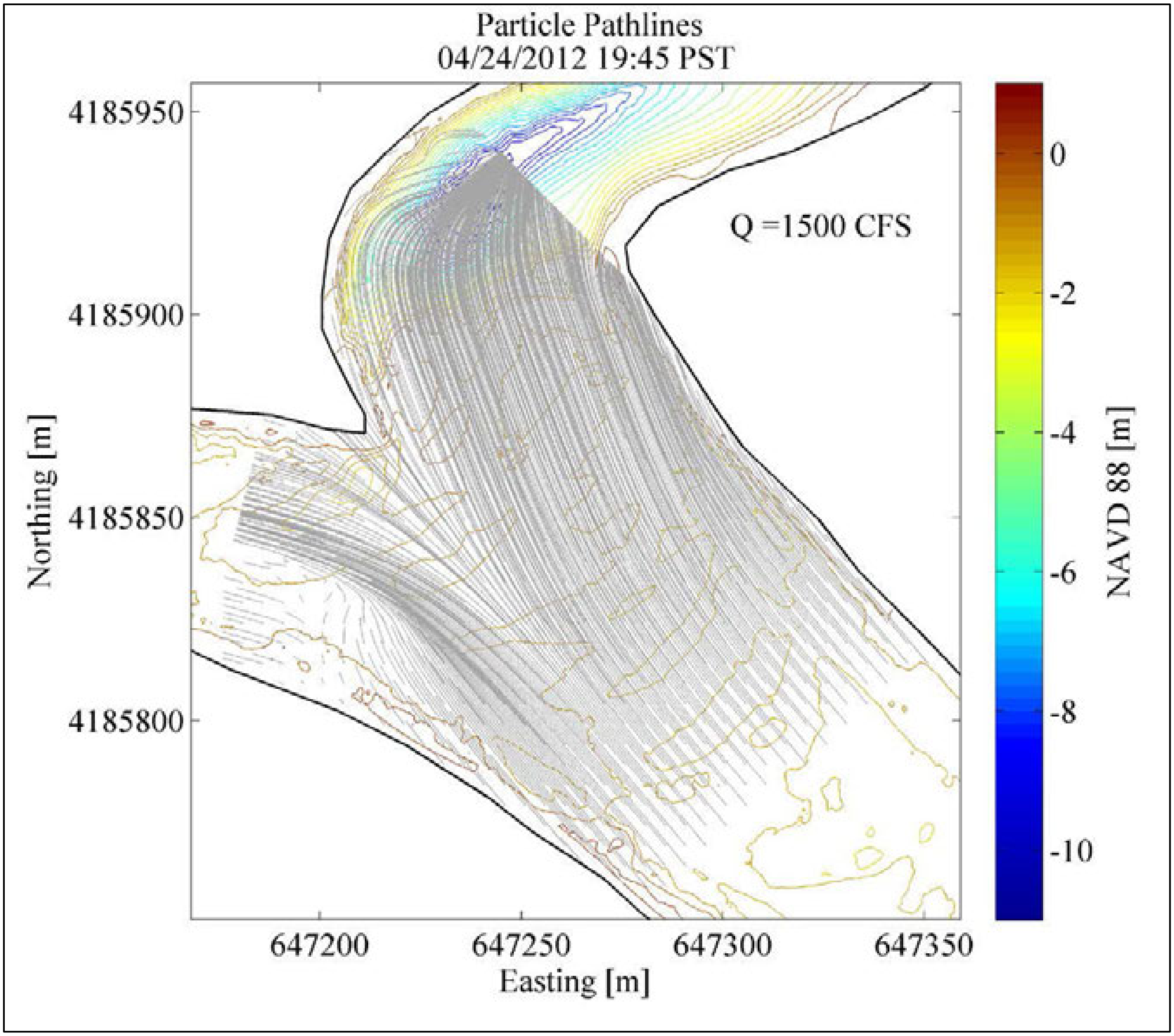
Source: Present study

Figure 3-14 Two-Dimensional Near-Surface Particle Pathlines (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 4/25/2012, 0515 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 780 cfs



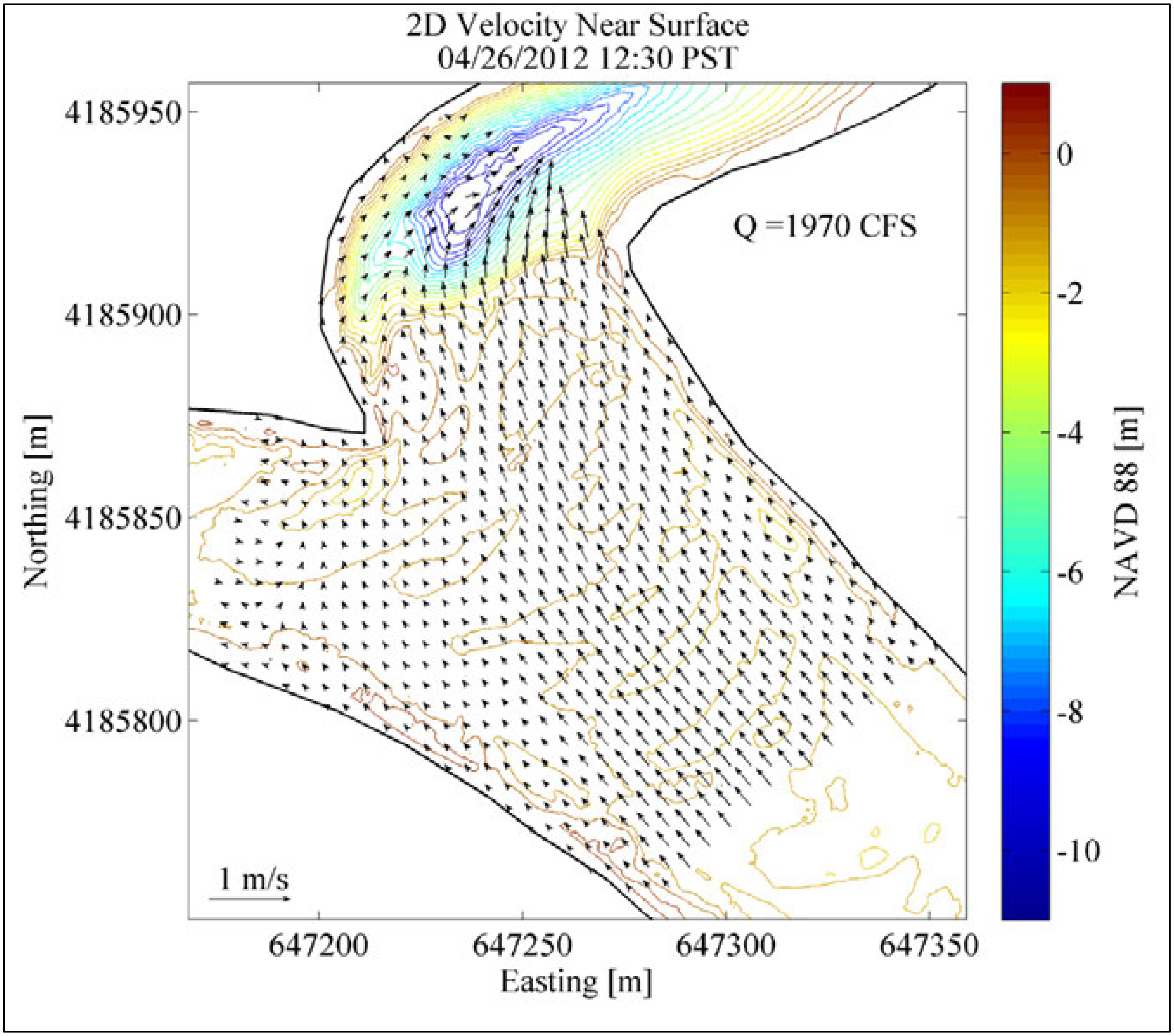
Source: Present study

Figure 3-15 Two-Dimensional Near-Surface Velocity Vectors (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 4/24/2012, 1945 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 1,500 cfs



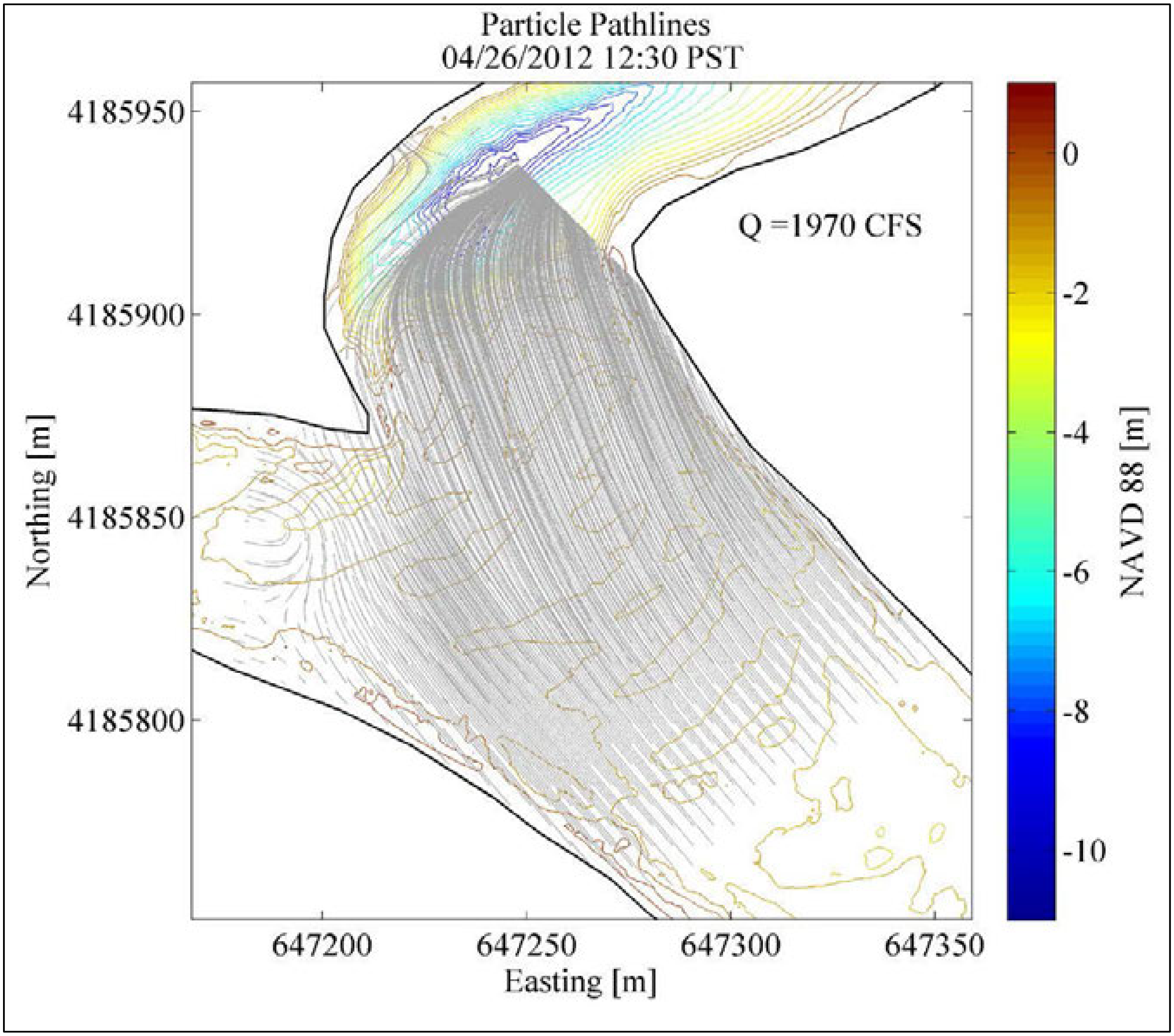
Source: Present study

Figure 3-16 Two-Dimensional Near-Surface Particle Pathlines (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 4/24/2012, 1945 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 1,500 cfs



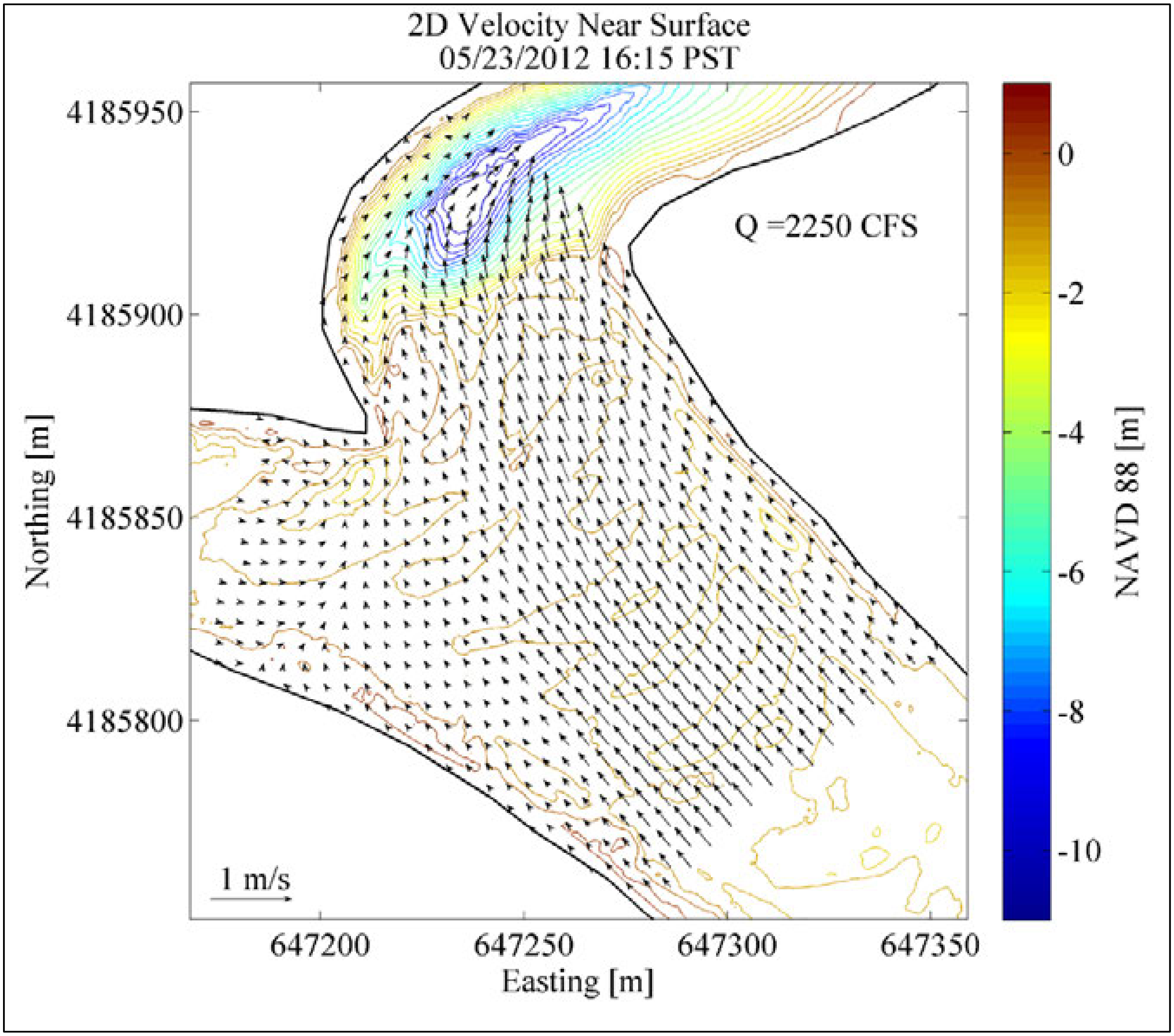
Source: Present study

Figure 3-17 Two-Dimensional Near-Surface Velocity Vectors (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 4/26/2012, 1230 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 1,970 cfs



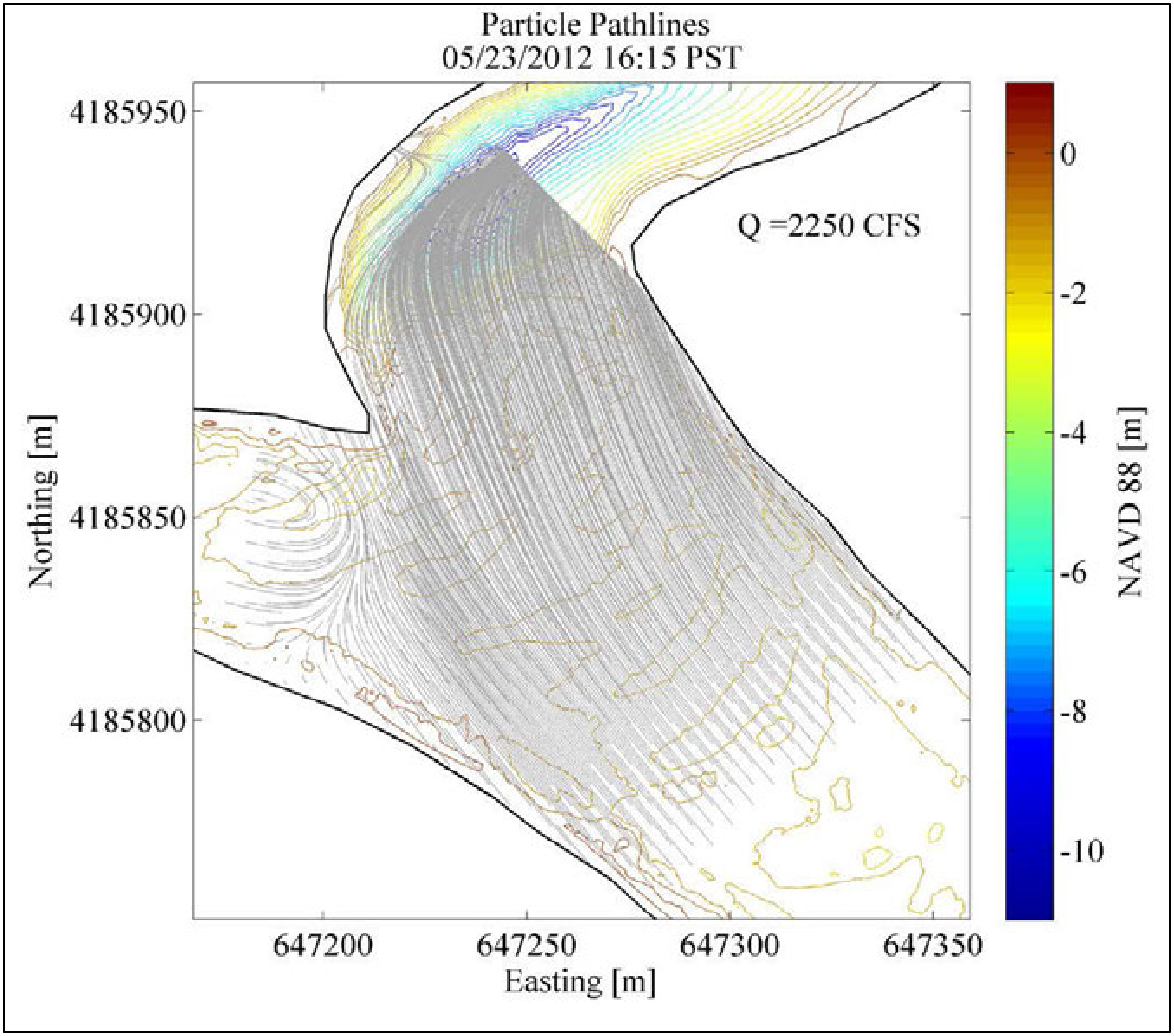
Source: Present study

Figure 3-18 Two-Dimensional Near-Surface Particle Pathlines (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 4/26/2012, 1230 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 1,970 cfs



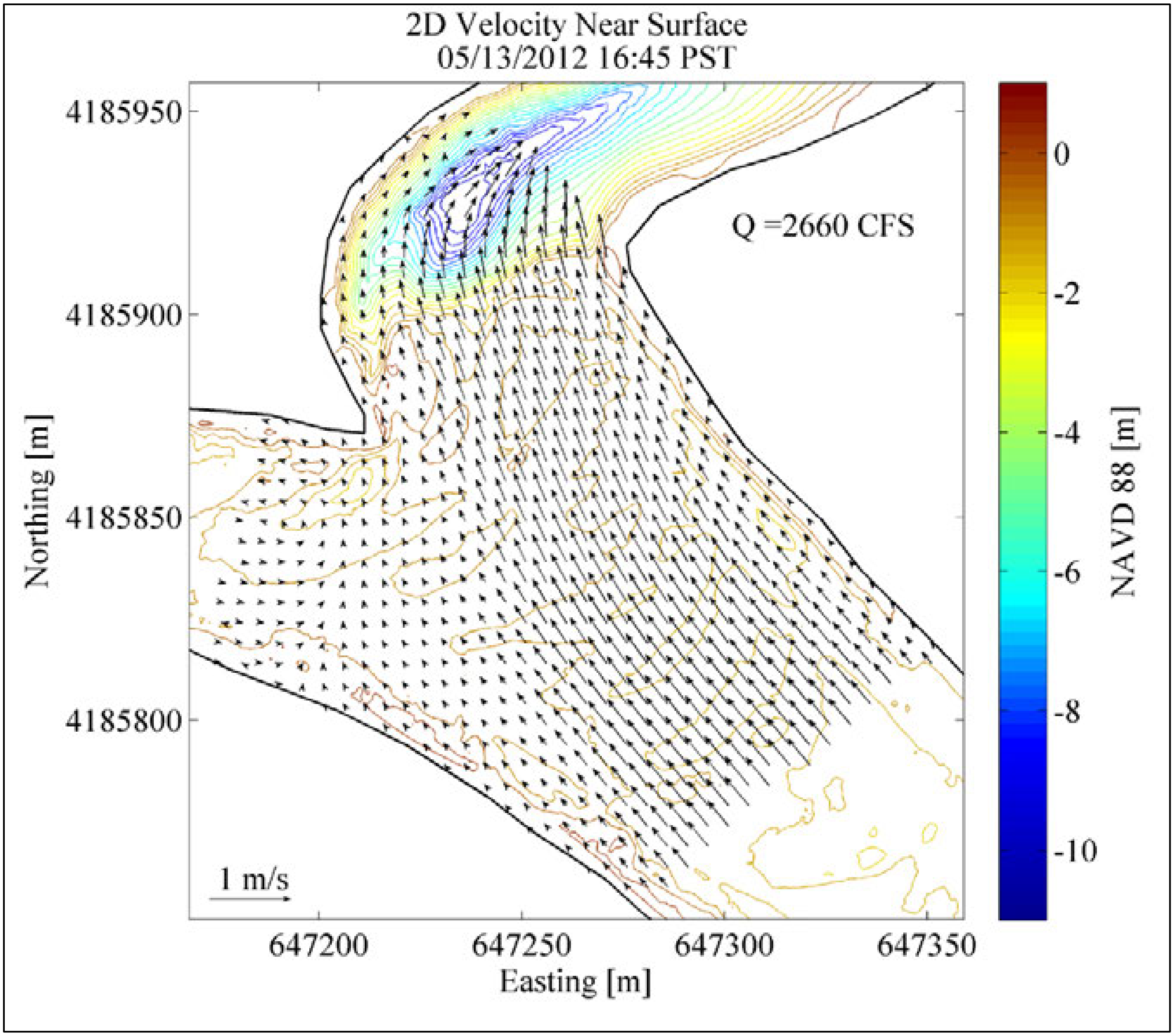
Source: Present study

Figure 3-19 Two-Dimensional Near-Surface Velocity Vectors (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 5/23/2012, 1615 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 2,250 cfs



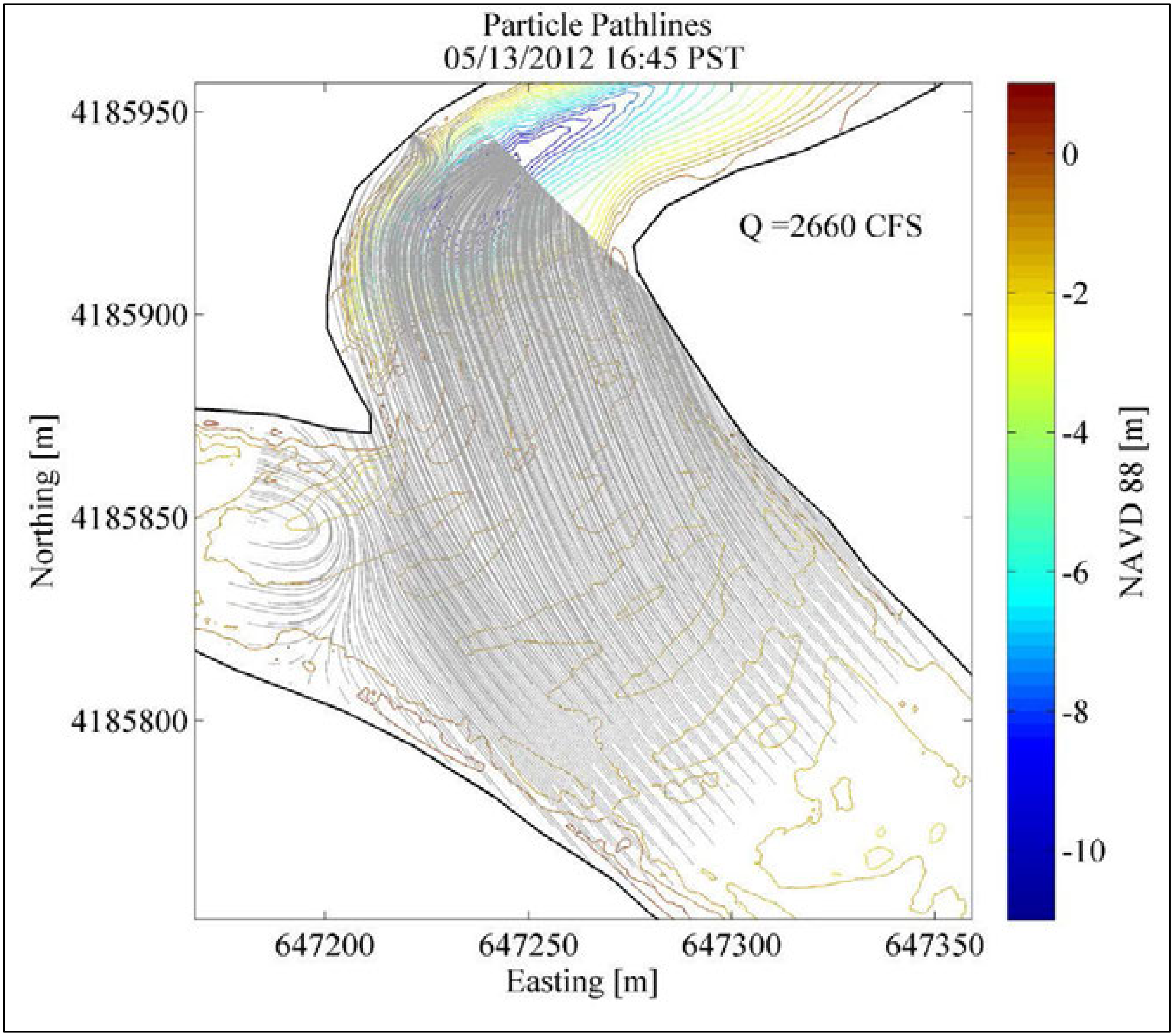
Source: Present study

Figure 3-20 Two-Dimensional Near-Surface Particle Pathlines (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 5/23/2012, 1615 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 2,250 cfs



Source: Present study

Figure 3-21 Two-Dimensional Near-Surface Velocity Vectors (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 5/13/2012, 1645 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of 2,660 cfs



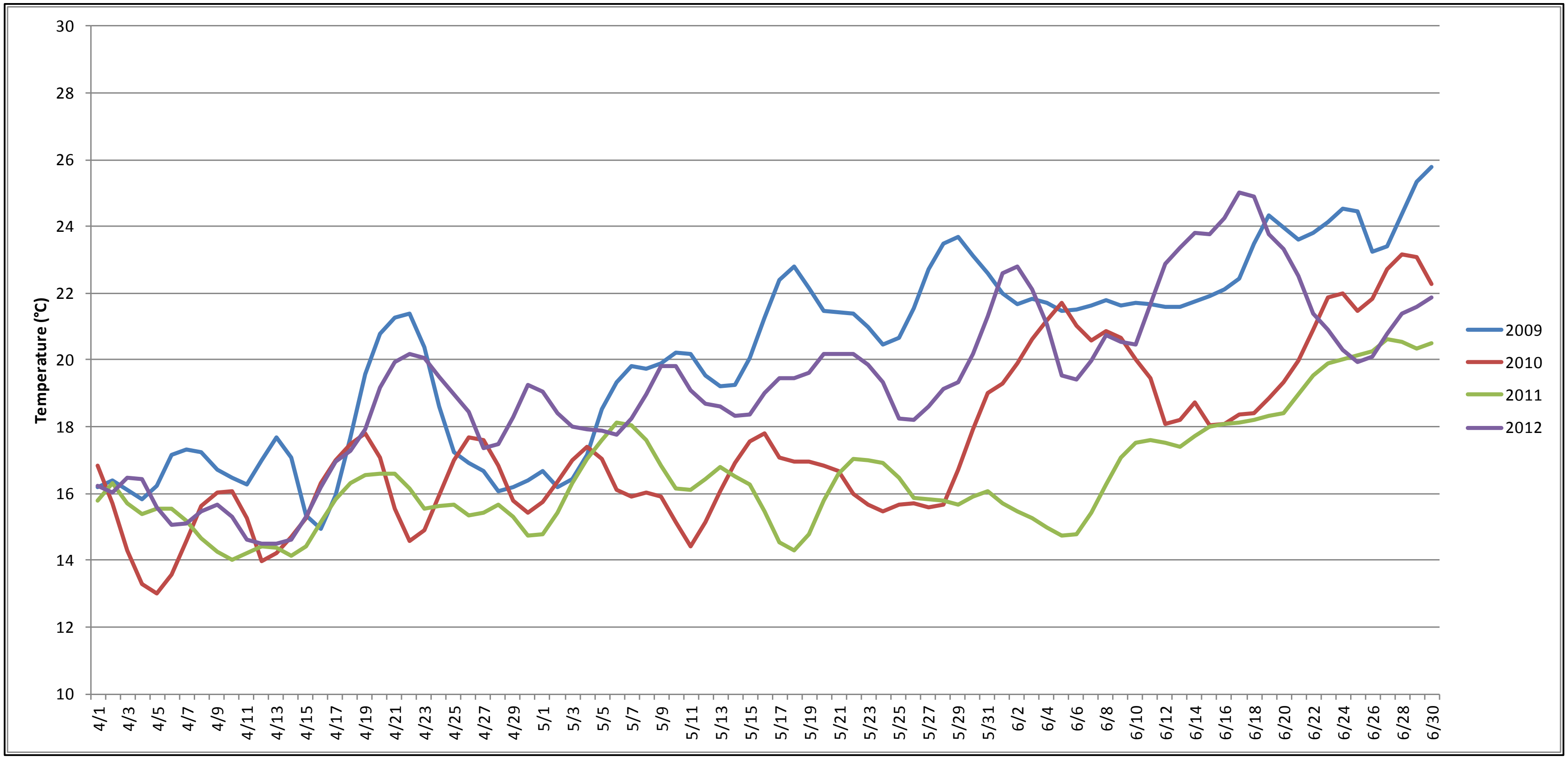
Source: Present study

Figure 3-22 Two-Dimensional Near-Surface Particle Pathlines (m/s) Estimated from Data Collected with a SL-ADCP at the Head of Old River, 5/13/2012, 1645 PST, with River Discharge in the San Joaquin River near Lathrop (Q) of cfs

3.3 WATER TEMPERATURE

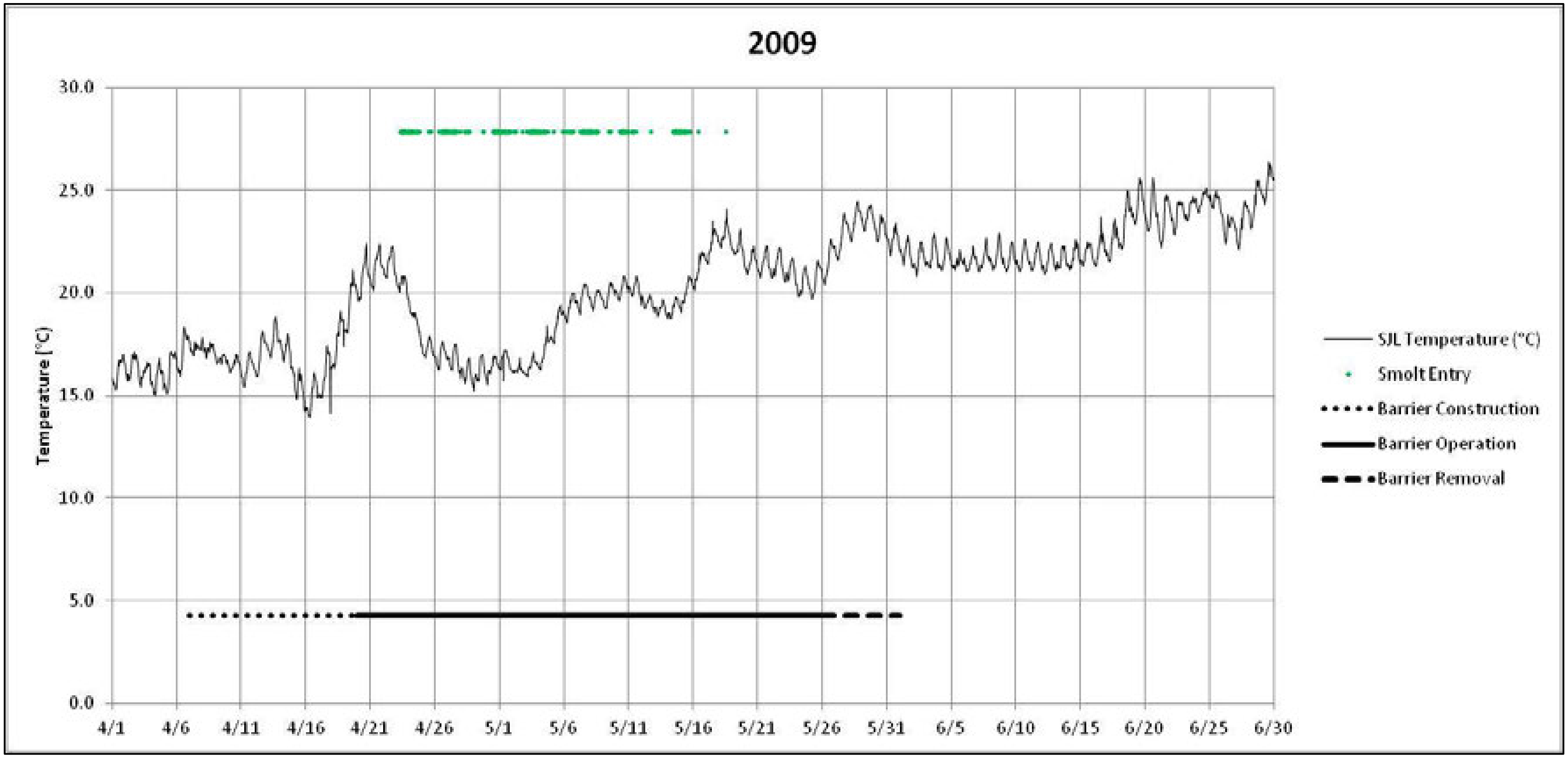
3.3.1 2009 TEMPERATURE

Mean daily water temperature between April 1 and June 30 was higher in 2009 compared to 2010 and 2011, but more similar to 2012 (Figure 3-23). Between April 1 and June 30, 2009, the water temperature in the San Joaquin River at the closest gauge in physical proximity (SJL) to the HOR study area ranged from 13.9 to 26.9 °C (Figure 3-24). When tagged juvenile Chinook salmon were in the water, the mean temperature in 2009 generally was warmer than in 2010 and 2011, but was similar to the mean temperature in 2012 (Table 3-3; Figures 3-24, 3-25, 3-26, and 3-27).



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

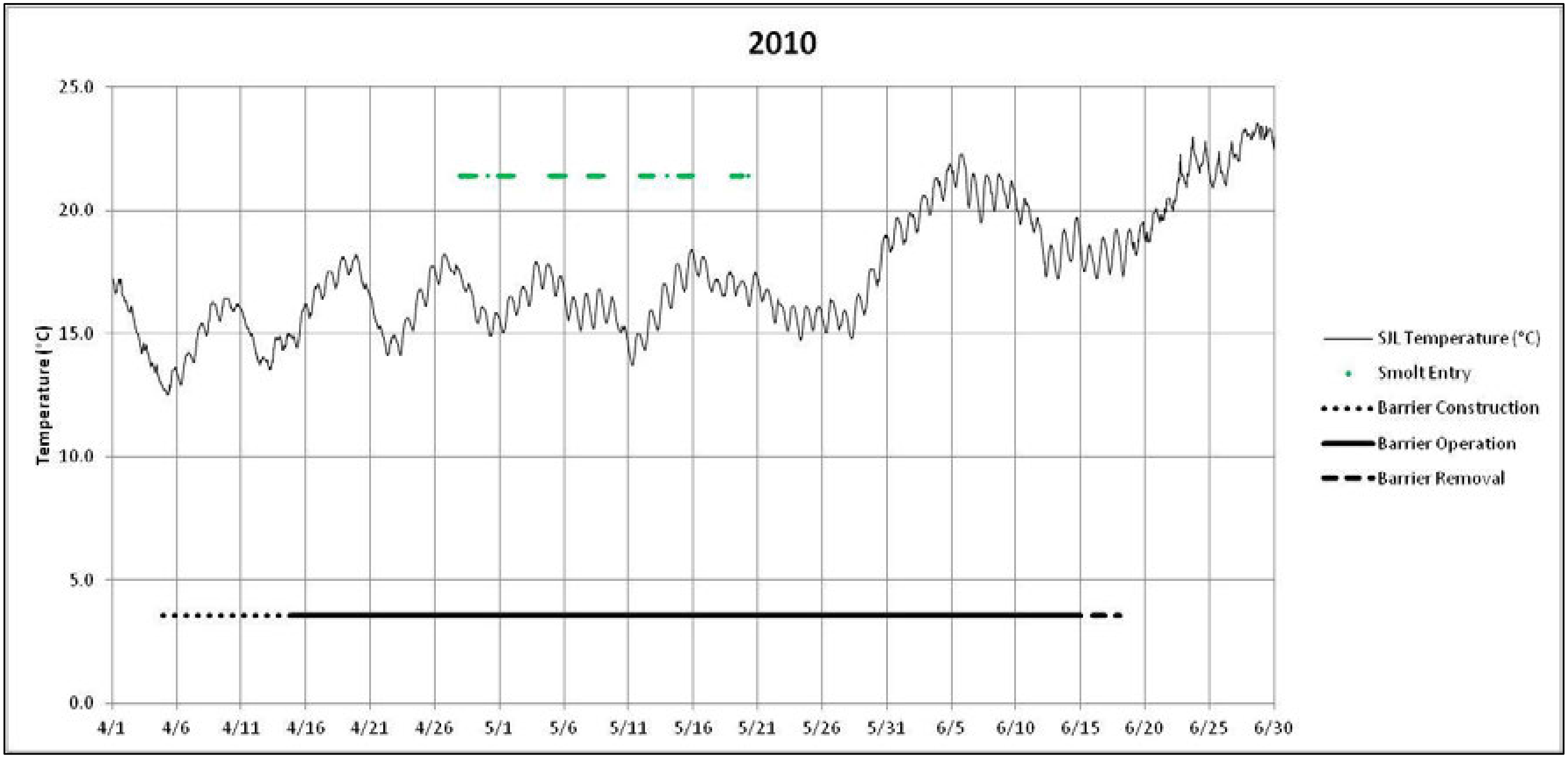
Figure 3-23 **Daily Mean Water Temperature (°C) in the San Joaquin River at Lathrop (SJL), 4/1–6/30, 2009–2012**



Sources: Baldwin, pers. comm.; 2013; Dempsey, pers. comm., 2013

Note: The barrier referred to in the legend was a non-physical fish barrier called a BAFF (Fish Guidance Systems Ltd, Southampton, UK). Barrier operation was not continuous, with the BAFF off approximately 50% of the time during the period of BAFF operation.

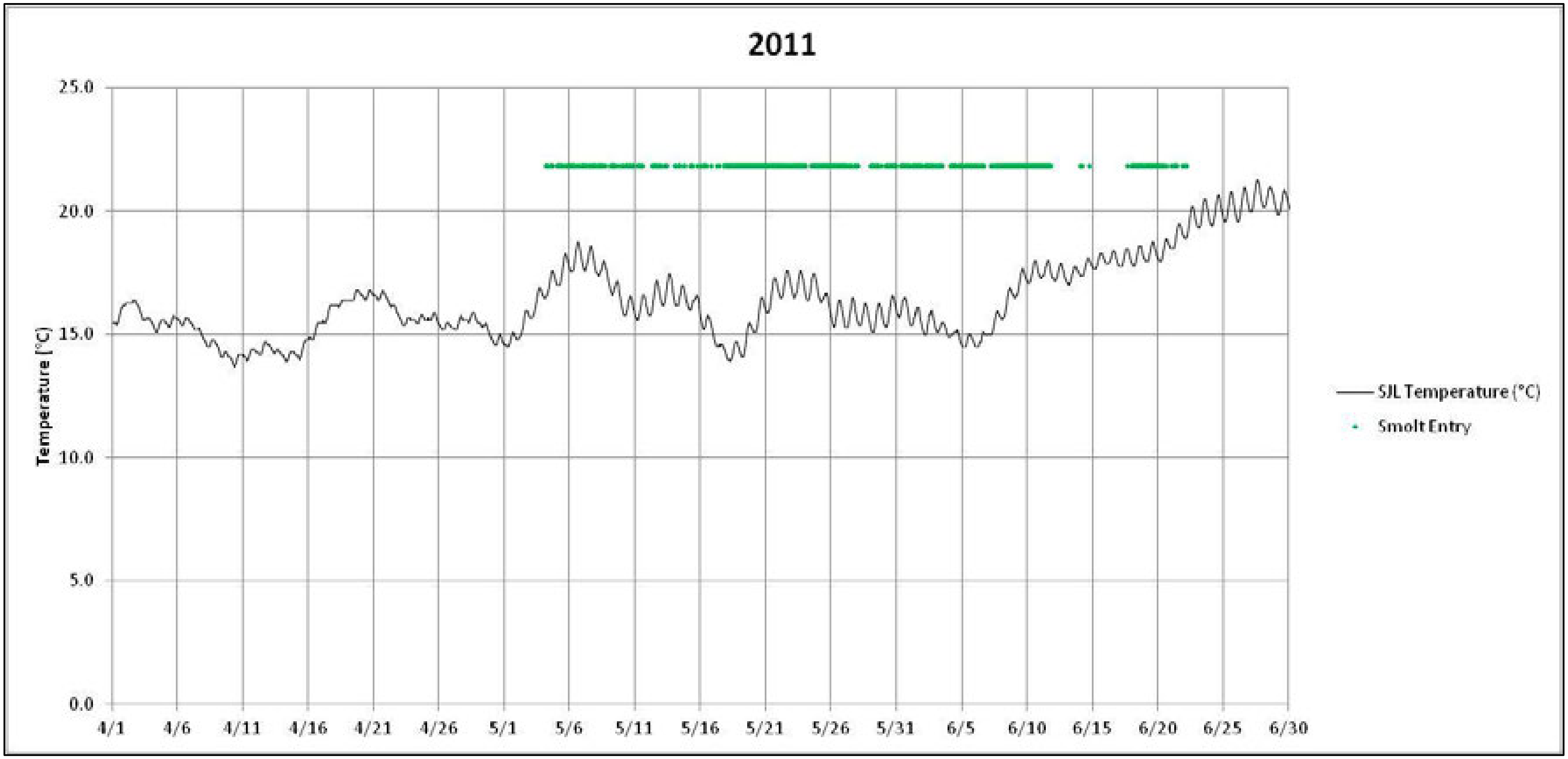
Figure 3-24 **Water Temperature (°C), Juvenile Chinook Salmon Releases and Barrier Status in the San Joaquin River at Lathrop Gauge from 4/1/09 through 6/30/09**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Note: The barrier referred to in the legend was a non-physical fish barrier called a BAFF (Fish Guidance Systems Ltd, Southampton, UK). Barrier operation was not continuous, with the BAFF off approximately 50% of the time during the period of BAFF operation.

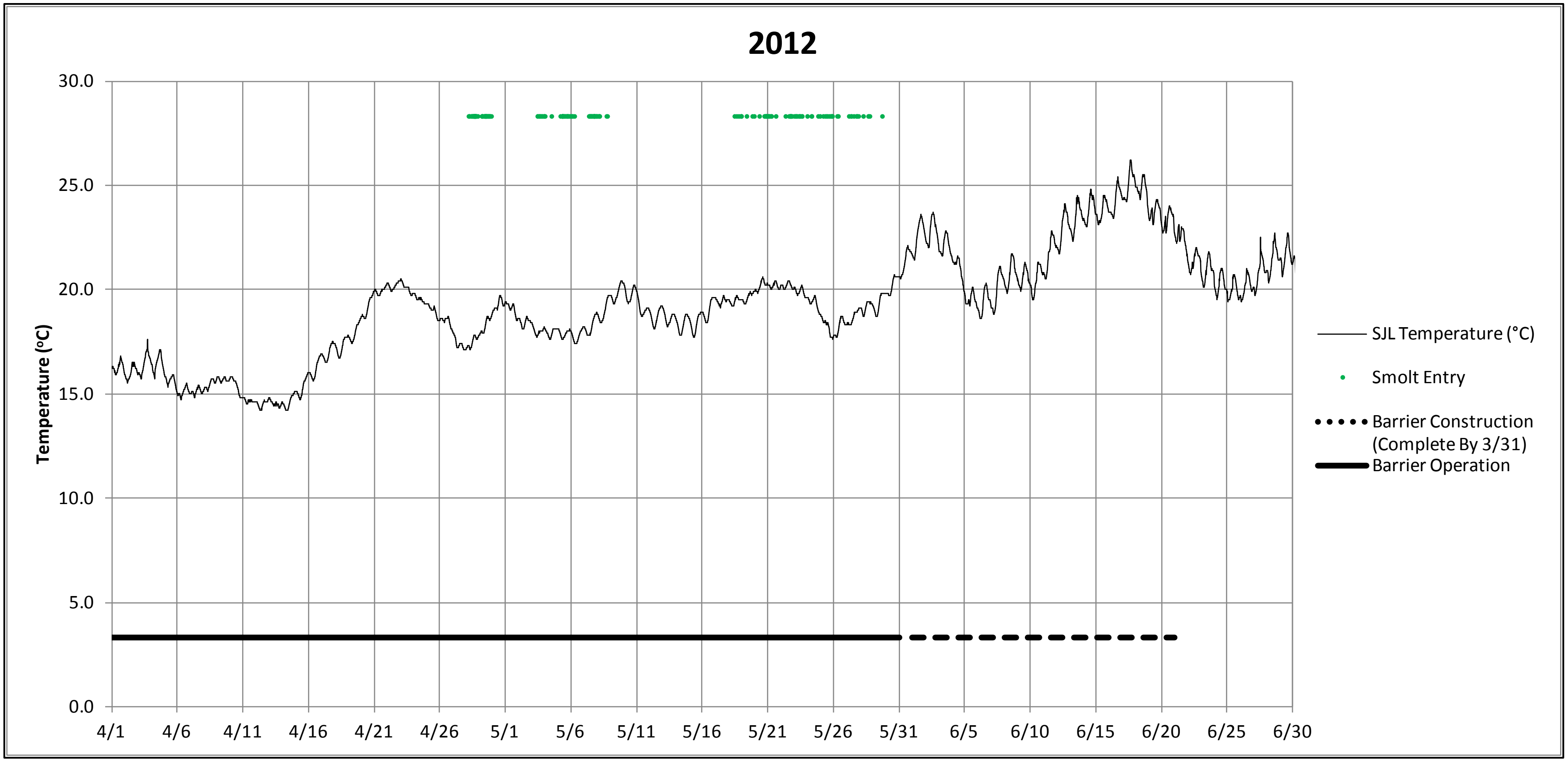
Figure 3-25 **Water Temperature (°C), Juvenile Chinook Salmon Releases and Barrier Status in the San Joaquin River at Lathrop Gauge from 4/1/10 through 6/30/10**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Note: No barrier was installed or operated during this period.

Figure 3-26 **Water Temperature (°C) and Juvenile Chinook Salmon Releases in the San Joaquin River at Lathrop Gauge from 4/1/11 through 6/30/11**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Note: The barrier installed during this period was a rock barrier with eight culverts.

Figure 3-27 **Water Temperature (°C), Juvenile Chinook Salmon Releases and Barrier Status in the San Joaquin River at Lathrop Gauge from 4/1/12 through 6/30/12**

Table 3-3
Descriptive Statistics for 2009–2012 Water Temperature in the San Joaquin River at the SJL Gauge when Tagged Juvenile Salmonids were at the HOR Study Area

Year	First Fish[1]	Last Fish[2]	SJL Temperature (°C) Mean	Standard Deviation	Minimum	Maximum	Count
2009	4/23/09 8:24	5/18/09 13:48	18.6	1.9	15.2	23.6	2422
2010	4/27/10 22:25	5/20/10 5:54	16.4	1.0	13.7	18.4	2143
2011	5/4/11 2:51	6/22/11 4:24	16.6	1.2	13.9	19.5	4712
2012	4/28/12 4:13	5/29/12 16:35	18.9	0.8	17.1	20.6	3026

Notes: HOR = Head of River; SJL = San Joaquin River at Lathrop
The SJL gauge is the closest gauge in physical proximity to the HOR study area, and was 0.5 km of the HOR site. The periods reported here are those when experimentally released fish were nearest the 2009 BAFF line (in 2009, 2011, and 2012) and nearest the 2010 BAFF line (in 2010).
1 Date/time when the first tagged salmonids was nearest the BAFF line.
2 Date/time the last tagged salmonids was nearest the BAFF line.
Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Although 2009 and 2012 were similar in mean water temperature, differences existed. During the tagged juvenile Chinook salmon release period, the water temperature in 2009 increased to 22 °C, a critical temperature that can cause major mortality in wild populations of Chinook salmon (Moyle 2002), for 30 hours during one interval; this never occurred in 2012 (see temperature maxima in Table 3-3). Furthermore, the standard deviation (SD) of water temperature was considerably higher in 2009 than in 2012 (Table 3-3).

Although juvenile steelhead were not released, by June 12, temperatures at the SJL gauge had risen to a point where the respiratory efficiency of steelhead would be affected (21 °C) (Hooper 1973). This date was earlier than in any other year studied (Table 3-4). Wild, non-hatchery steelhead could have been passing through the HOR study area (Table B-2 in Appendix B, "Focal Fish Species Information"). Experimental releases constrain the study juvenile fish to migrate at prescribed periods, whereas wild, non-hatchery fish may respond more strongly to environmental cues, such as water temperature.

Table 3-4
Day of the Year at which the Water Temperature in the San Joaquin River at SJL Gauge Reached and Remained at Least 15 Days at Two Critical Temperatures for Juvenile Salmonids

Year	Temperature > 21.0 °C[1]	Temperature > 23.9 °C[2]
2009	June 12	July 14
2010	July 5	July 10
2011	July 27	Not Exceeded
2012	June 29	July 7

Notes: SJL = San Joaquin River at Lathrop
For Chinook salmon, major mortality occurred at 22–23 °C in wild populations, and very few individuals survived temperatures greater than 24 °C (Moyle 2002).
1 Temperature at which steelhead juveniles had difficulty absorbing oxygen from the water, 21.0 °C (Hooper 1973)
2 Steelhead upper lethal thermal limit, 23.9 °C (Bell 1986)
Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

3.3.2 2010 TEMPERATURE

From April 1, 2010, through June 30, 2010, the water temperature at the SJL gauge ranged from 12.5 to 23.5 °C (Figure 3-25). When tagged juvenile Chinook salmon were present in the study area, the mean water temperature in 2010 was lower than in any other year, but was very similar to 2011 (Table 3-3; Figures 3-23, 3.24, 3-25, and 3-26). Furthermore, in 2010, it took longer to reach 21 °C and remain there for 15 days or more, longer than any year except 2011 (Table 3-4).

3.3.3 2011 TEMPERATURE

From April 1 through June 30, 2011, the water temperature at the SJL gauge ranged from 13.7 to 21.3 °C (Figure 3-26). The water temperature in 2011 was consistently cooler than in 2009 and throughout spring and summer of 2012 (Figure 3-23). Although 2011 did not have the lowest mean water temperature (Table 3-3), the temperature never increased to 23.9 °C, the upper lethal limit for steelhead (Bell 1986). Among the 4 years included in this study, the only year that the water temperature never exceeded 23.9 °C was 2011 (Table 3-4).

3.3.4 2012 TEMPERATURE

From April 1 through June 30, 2012, the water temperature in the San Joaquin River at Lathrop ranged from 14.2 to 26.2 °C (Figure 3-27). When tagged juvenile Chinook salmon and steelhead were present in the study area, the mean water temperature in 2012 was higher than in any other year. Furthermore, the mean 2012 water temperatures generally were warmer than 2010 and 2011, but similar to 2009 temperatures (Table 3-3; Figures 3-23 to 3-27). Also, by June 29, 2012, water temperatures at the SJL gauge had risen to a point where steelhead respiratory efficiency was affected (21 °C) (Hooper 1973).

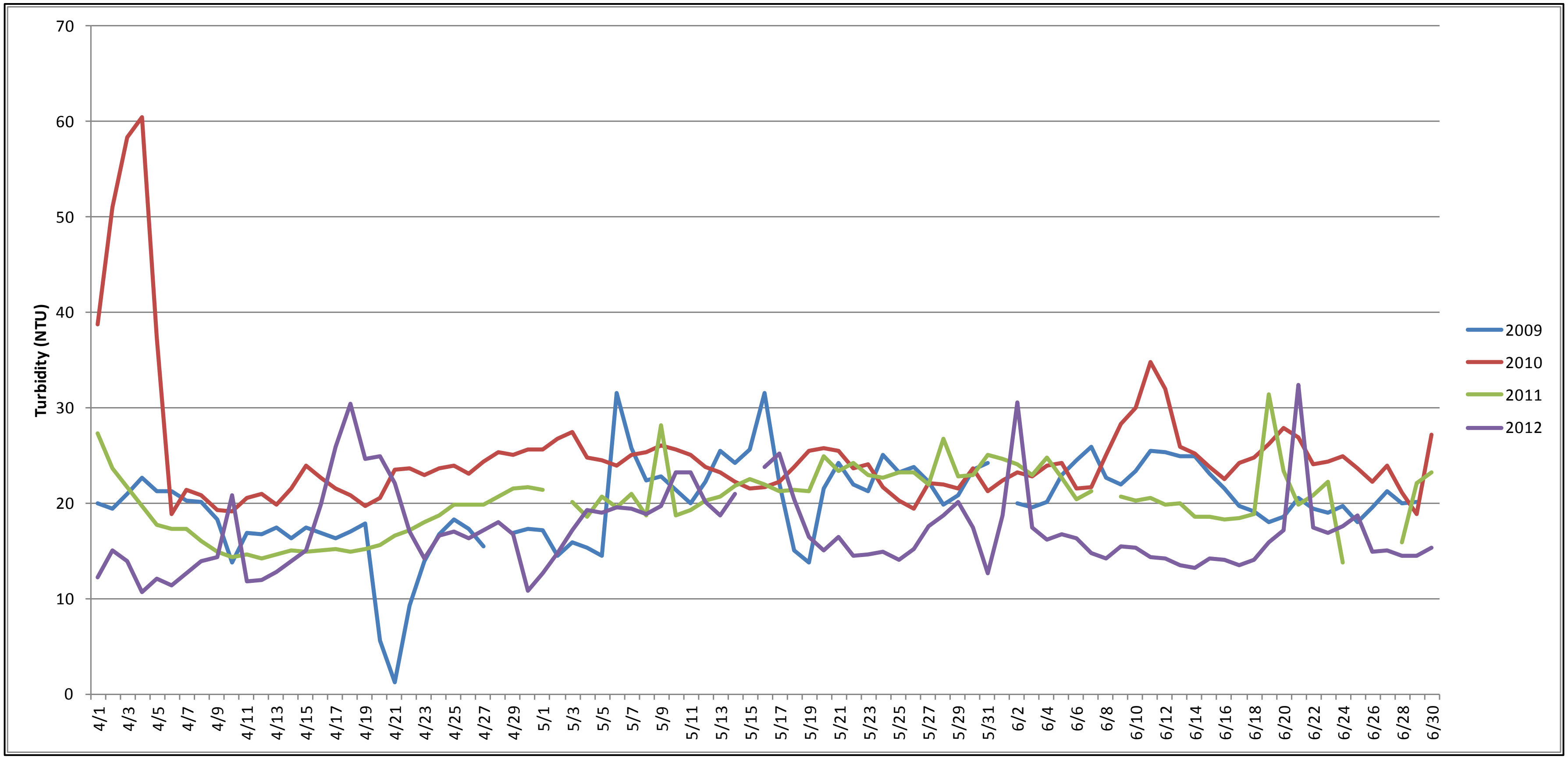
3.4 WATER CLARITY (TURBIDITY)

3.4.1 2009 TURBIDITY

Turbidity varied between years (Figure 3-28). From April 1 through June 30, 2009, the turbidity at MSD, the closest gauge in physical proximity to the HOR study area (4.6 km), ranged from 9.1 to 48.3 Nephelometric Turbidity Units (NTU) (Figure 3-29). When tagged juvenile Chinook salmon were recorded by the receivers, the mean turbidity in 2009 generally was lower than in 2010, but was similar to 2011 and 2012 turbidity (Table 3-5; Figures 3-28, 3-29, 3-30, 3-31, and 3-32). The turbidity also was more variable in 2009 than in any other year (Table 3-5).

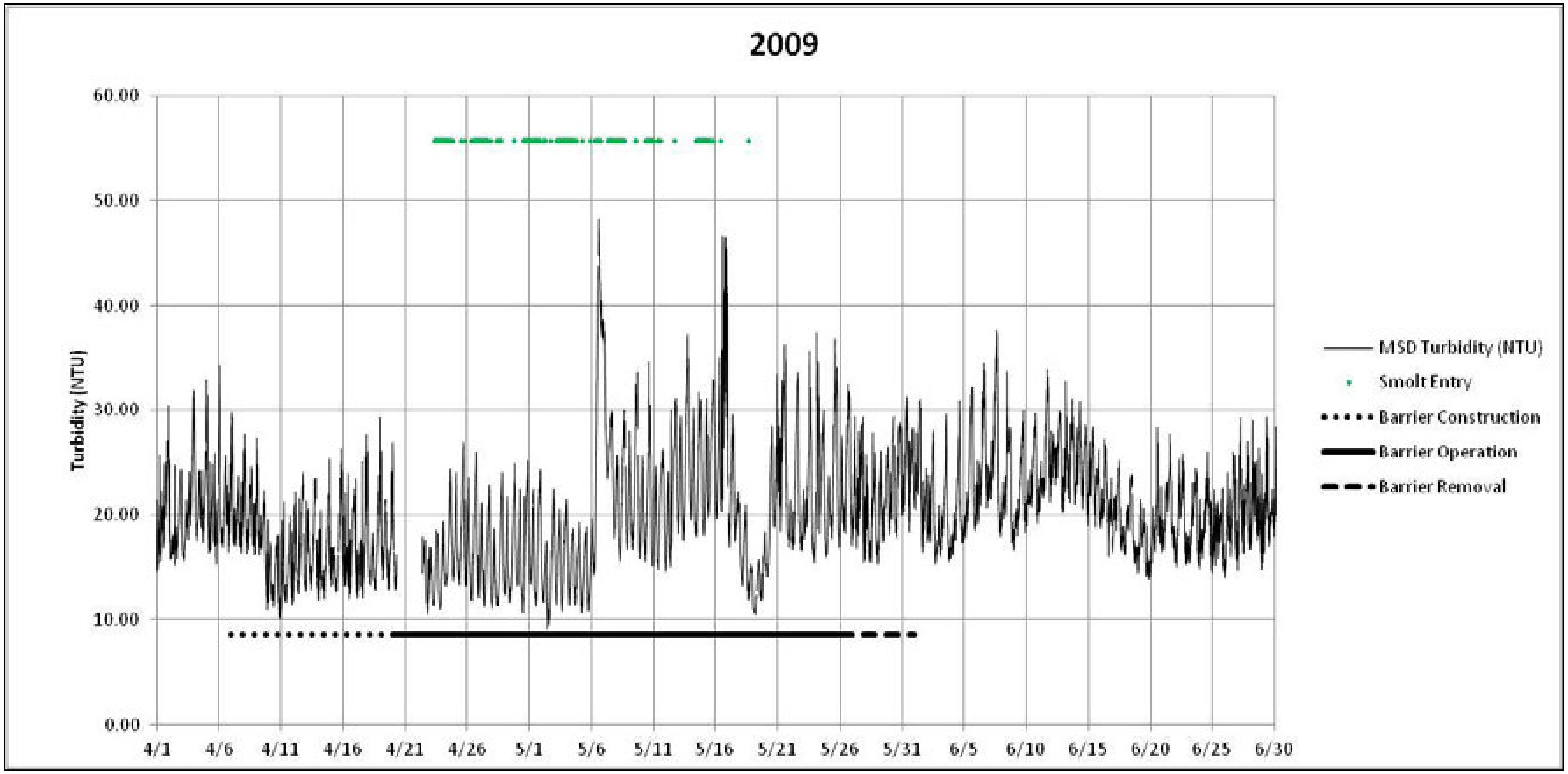
3.4.2 2010 TURBIDITY

From April 1 through June 30, 2010, the turbidity at the MSD gauge ranged from 12.1 to 42.9 NTU (Figure 3-30). When tagged juvenile Chinook salmon were recorded by the receivers, the mean turbidity in 2010 was higher than in any other year (Table 3-5; Figures 3-29, 3-30, 3-31, and 3-32). The turbidity also was the least variable in 2010 (Table 3-5; Figure 3-28).



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

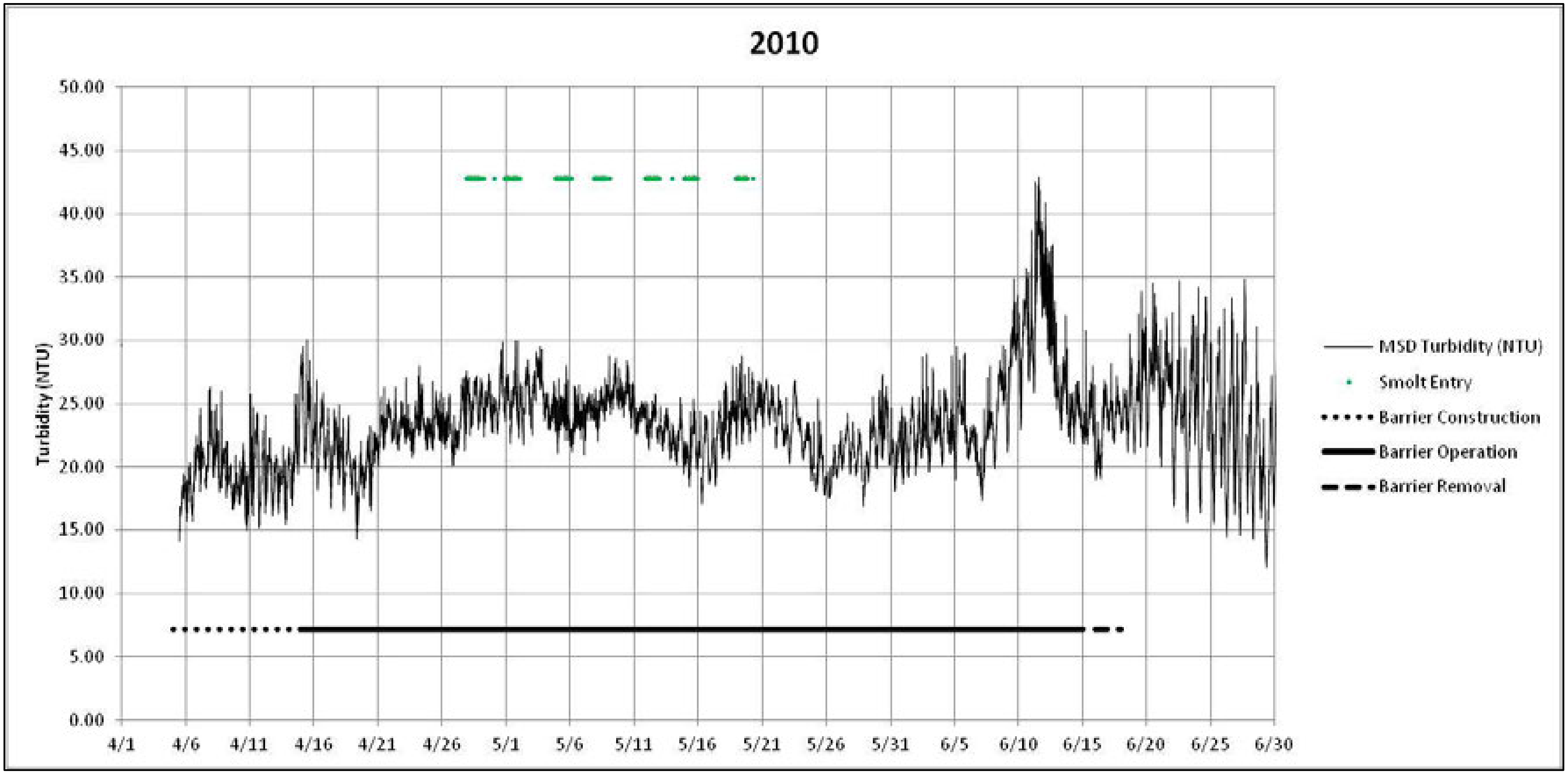
Figure 3-28 **Daily Mean Turbidity in the San Joaquin River at Mossdale (MSD), 4/1 to 6/30, 2009–2012**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Note: The barrier referred to in the legend was a non-physical fish barrier called a BAFF (Fish Guidance Systems Ltd, Southampton, UK). Barrier operation was not continuous, with the BAFF off approximately 50% of the time during the period of BAFF operation.

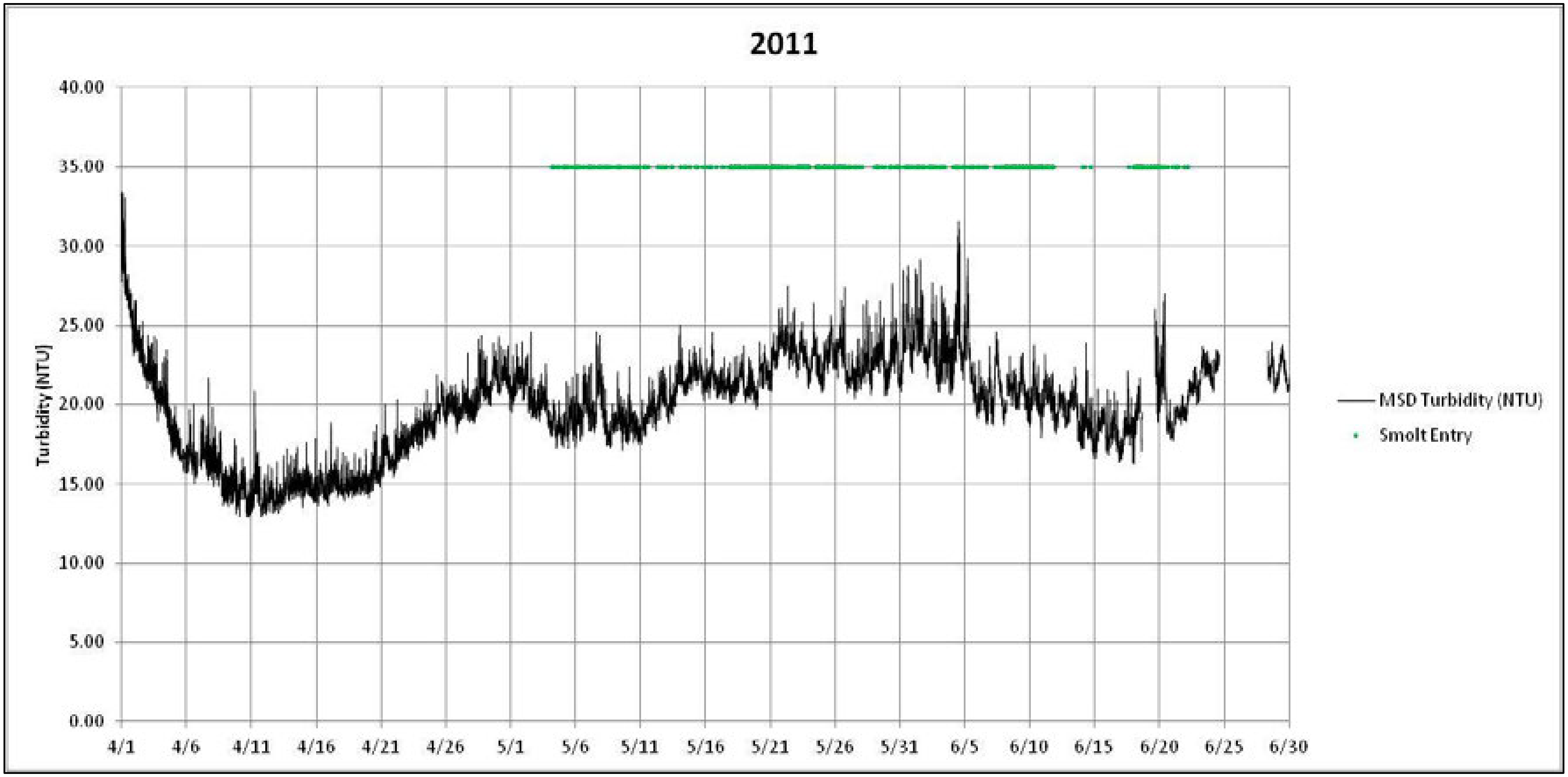
Figure 3-29 **Turbidity of the San Joaquin River at the Mossdale Gauge from 4/1/09 through 6/30/09 and Tagged Juvenile Chinook Salmon Presence**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Note: The barrier referred to in the legend was a non-physical fish barrier called a BAFF (Fish Guidance Systems Ltd, Southampton, UK). Barrier operation was not continuous, with the BAFF off approximately 50% of the time during the period of BAFF operation.

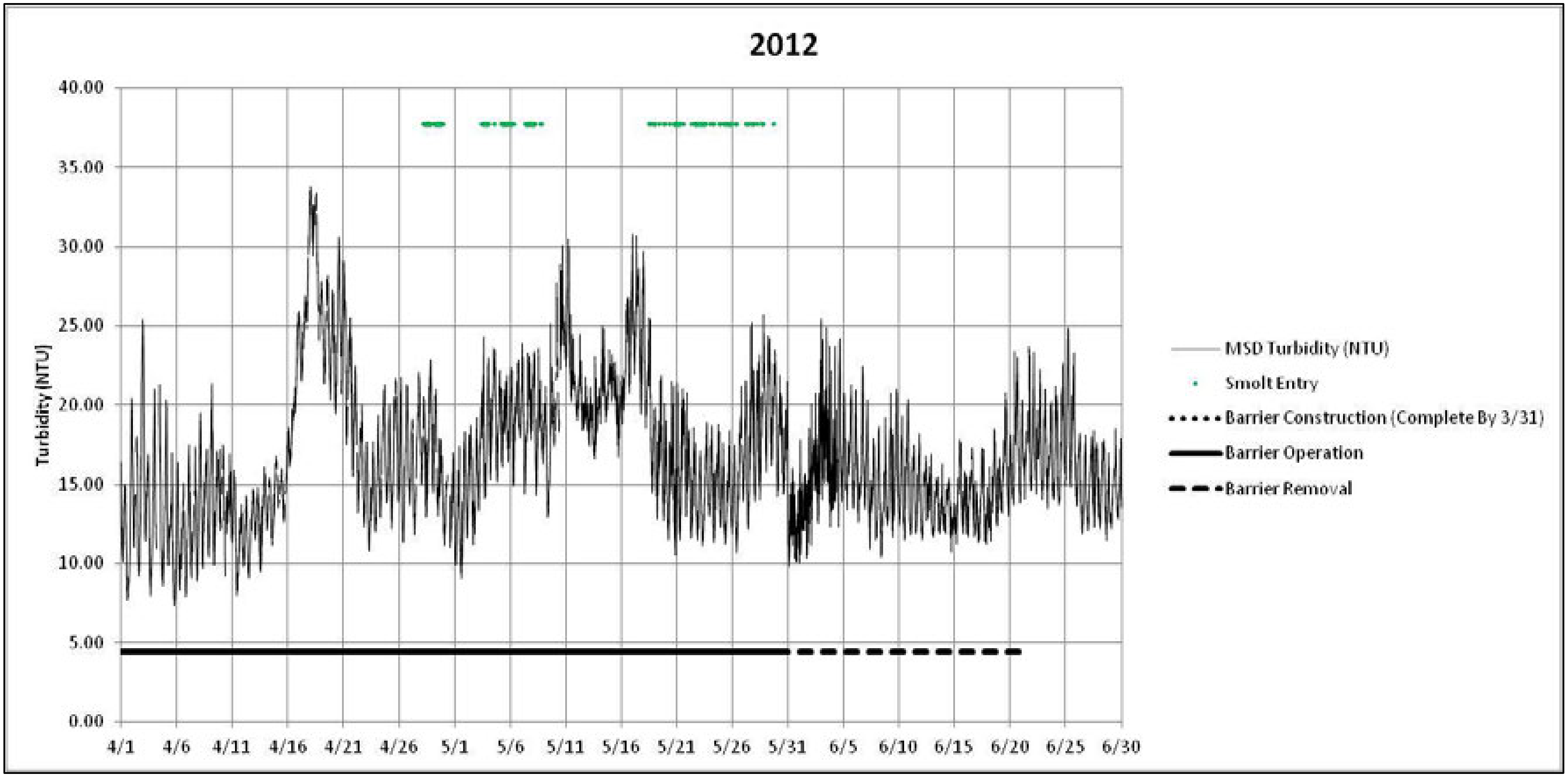
Figure 3-30 **Turbidity of the San Joaquin River at the Mossdale Gauge from 4/1/10 through 6/30/10 and Tagged Juvenile Chinook Salmon Presence**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Note: No barrier was installed or operated during this period.

Figure 3-31 **Turbidity of the San Joaquin River at the Mossdale Gauge from 4/1/11 through 6/30/11 and Tagged Juvenile Chinook Salmon and Steelhead Presence**



Sources: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Note: The barrier installed was a rock barrier with eight culverts.

Figure 3-32 **Turbidity of the San Joaquin River at the Mossdale Gauge from 4/1/12 through 6/30/12 and Tagged Juvenile Chinook Salmon and Steelhead Presence**

Table 3-5
Descriptive Statistics for 2009–2012 Turbidity at the MSD Gauge

Year	First Fish[1]	Last Fish[2]	MSD Turbidity (NTU)				Count
			Mean	Standard Deviation	Minimum	Maximum	
2009	4/23/09 8:24	5/18/09 13:48	19.9	6.6	9.1	48.3	2405
2010	4/27/10 22:25	5/20/10 5:54	24.1	1.9	17.1	30.0	2073
2011	5/4/11 2:51	6/22/11 4:24	21.1	2.1	16.3	31.6	4523
2012	4/28/12 4:13	5/29/12 16:35	18.0	3.8	9.1	30.8	2945

Notes: MSD = San Joaquin River at Mossdale; NTU = Nephelometric Turbidity Units
1 Date/time when the first tagged salmonids was nearest the BAFF line.
2 Date/time the last tagged salmonids was nearest the BAFF line.
Source: Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

3.4.3 2011 TURBIDITY

From April 1 through June 30, 2011, the turbidity at the MSD gauge ranged from 12.9 to 33.4 NTU (Figure 3-31). When tagged juvenile Chinook salmon and steelhead were present, the mean turbidity in 2011 generally was lower than in 2010, but was similar to 2009 turbidity (Table 3-5; Figures 3-28, 3-29, 3-30, and 3-31). The standard deviation in turbidity was similar in 2010 and 2011, and both of these years exhibited lower standard deviation than in other years (Table 3-5).

3.4.4 2012 TURBIDITY

From April 1 through June 30, 2012, the turbidity at the MSD gauge ranged from 7.3 to 33.8 NTU (Figure 3-32). Furthermore, in this same period, the mean turbidity was 16.6 NTU, the lowest recorded mean for the 4 years studied (Figure 3-28). The turbidities from April 1, 2012, until fish were released on April 28, 2012, represented the lowest turbidity of any 4-week period in the 4 years studied. In addition, when tagged juvenile Chinook salmon and steelhead were present, the mean turbidity in 2012 was lower than in than any other year (Table 3-5; Figures 3-29, 3-30, 3-31, and 3-32). Only 2009 exhibited a higher standard deviation in turbidity than 2012 while tagged juvenile Chinook salmon and steelhead were released (Table 3-5).

4 BARRIER TREATMENTS

4.1 NON-PHYSICAL BARRIER: THE BIO-ACOUSTIC FISH FENCE (BAFF)

Installation of the spring rock barrier has been controversial because of the area of habitat impacted and its potential effects on the risk of entrainment into the SWP and CVP export facilities for delta smelt, a species that is listed under the federal and California endangered species acts (see Section B.2.1 in Appendix B, "Focal Fish Species Information"). In 2008, a court order designed to protect delta smelt prohibited the installation of the spring rock barrier pending fishery agency actions or further order of the court. Subsequently, the U.S. Fish and Wildlife Service (USFWS) issued a BO for delta smelt and its critical habitat for the OCAP (USFWS 2008). USFWS determined that, as a result of its influence on the hydrodynamics of the Delta, the rock barrier potentially increases the vulnerability of delta smelt, particularly larvae and juveniles, to entrainment at CVP and SWP south Delta export facilities.

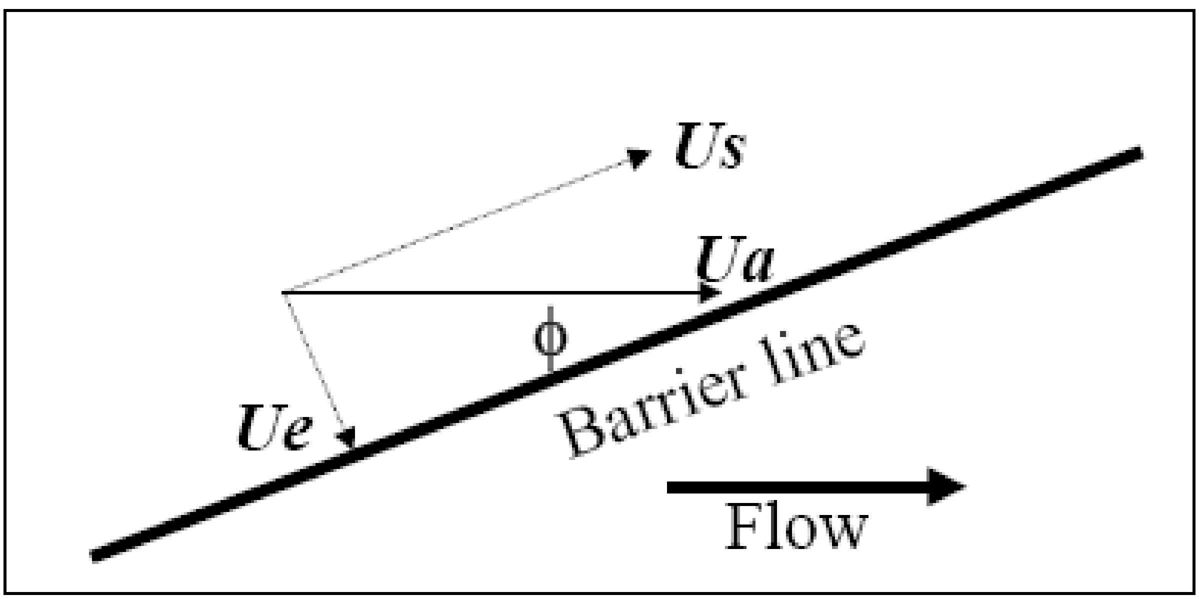
When the rock barrier is in place, a proportion of the water that would ordinarily flow down Old River is forced to flow down the San Joaquin River which benefits outmigrating juvenile salmonids. However, the rock barrier can also cause or augment net flow reversal in Old River. In addition, the barrier increases flows in Turner and Columbia cuts, two major central Delta channels that flow toward the south Delta. The result of these hydrodynamic changes is an increase in reverse flow in several channels, which has been noted to have coincided with increases in salvage of delta smelt (e.g., in 1996) (Nobriga et al. 2000). Therefore, DWR proposed use of a BAFF as an option at the HOR to meet the objective of excluding outmigrating salmonid juveniles from Old River while also minimizing the potential effects to delta smelt and Delta hydrodynamics. The BAFF allowed unobstructed flows into Old River, thus helping to lessen reverse flows in Old River as a result of SWP/CVP exports.

The BAFF is a multi-stimulus fish barrier that combines strobe lights, an air bubble curtain, and sound at frequencies and levels repellent to fish. The BAFF is intended to form a behavioral deterrent for juvenile salmonids in the San Joaquin River, rather than a physical barrier (e.g., rock barrier), to prevent entry into Old River. The sound system and strobe light flash rate can be tuned to known sensitivities of various fish species. Studies with Chinook salmon and delta smelt have shown that when the sound and strobe light flash rate are tuned according to these species' sensitivities, the barrier was effective as a deterrent for juvenile Chinook salmon (Bowen et al. 2009) and delta smelt (Bowen et al. 2010). The sound frequency range used was 50 to 600 Hertz (Hz). Audiogram studies (Oxman et al. 2007) have shown maximum hearing sensitivity at around 250 Hz for juvenile Chinook salmon. The BAFF's strobe lights flashed at 360 flashes per minute. Nemeth and Anderson's (1992) data showed a strong reaction to strobe lights at this flash rate.

Although future minor design adjustments may occur based on the 2010 design, the BAFF is 138 m long and made up of 17 separate 7.9-m sections. The barrier frame includes 64 Fish Guidance Systems Model 15-100 sound projectors, spaced approximately 2.0 m apart; 136 strobe lights (Fish Guidance Systems 100-centimeter-linear intense modulated lights [IMLs]), and perforated pipe. The sound projectors are driven by a signal generator (Fish Guidance Systems Model 1-08) and eight Fish Guidance Systems Model 400 power amplifier/control units, located in an onshore building. The strobe lights are powered from a "power supply accumulator," a unit that accumulates energy until it is discharged to the IML, positioned every 12 strobe lights; the flash rate is triggered from the Model 1-08 signal generator. The exact power rating for the IMLs and the wavelength of the light are proprietary (Fish Guidance Systems Ltd, Southampton, UK). However, on visual inspection at the barrier study area under low-light conditions, the IMLs could be detected, flashing in the water at a maximum of 10 m distance from the BAFF. This led to the 10-m line, developed under low-light conditions; it was assumed that if a human eye could perceive the IML at 10 m, then a juvenile Chinook salmon would definitely experience the IML at less than or equal to 10 m from the BAFF.

The barrier is positioned diagonally across the main river channel, upstream of the divergence, and is aligned to guide outmigrating juvenile Chinook salmon to the San Joaquin River (Figure 2-4, "Barrier Alignments near the Head of Old River, 2009–2012," in Chapter 2, "Study Area and Focal Fish Species"). In designing the barrier, the flow was assumed to split 50/50 at the divergence, and the streamlines were assumed to divide midway across the river. Therefore, the angled barrier was designed so that fish present in streamlines that were entering Old River would be guided into streamlines entering the San Joaquin River. Thus, the barrier was planned to extend from the left bank (Old River side) to beyond the mid-channel position upstream of the divergence (Figure 2-4 in Chapter 2).

The diagonal fish screen/barrier concept is well known (Turnpenny and O'Keeffe 2005). The velocity perpendicular to the barrier line must be kept at or below the maximum sustainable swimming speed of the fish. In 2009, during BAFF design, the critical swimming speed (U-crit) was estimated from swimming performance data given by Muir et al. (1993:Figure 3), who give a U-crit range of 3.4 to 3.9 body lengths per second (BL/s). For design purposes, a value of 3.4 BL/s was assumed. The smallest size of fish desirable to protect was assumed to be 58 mm FL based on the minimum of length range for juvenile Chinook salmon (58 to 100 mm FL) expected in the south Delta, reflecting salvage data at the Tracy Fish Collection Facility and the Skinner Fish Protection Facility (NMFS 2013). This gave a conservative design figure for escape velocity (*Ue*) of 0.2 m/s (Figure 4-1).



Note: Ua = main channel velocity; Ue = fish escape velocity; Us = sweeping velocity component along the face of the screen
Source: Turnpenny and O'Keeffe 2005

Figure 4-1 Flow Velocity Components in Front of an Angled Fish Barrier

Figure 4-1 shows the relevant velocity components for an angled fish barrier. The main channel velocity is denoted *Ua*. The velocity perpendicular to the screen face is the fish escape velocity, *Ue.* For a barrier angle φ, this is calculated as Equation 4-1:

$$Ue = Ua \sin \varphi$$

The sweeping velocity, *Us*, is the component parallel to the screen face. This can be used to calculate the time taken for the fish to traverse the screen from any given point when swimming at velocity *Ue*. It is calculated as Equation 4-2:

$$Us = Ua \cos \varphi$$

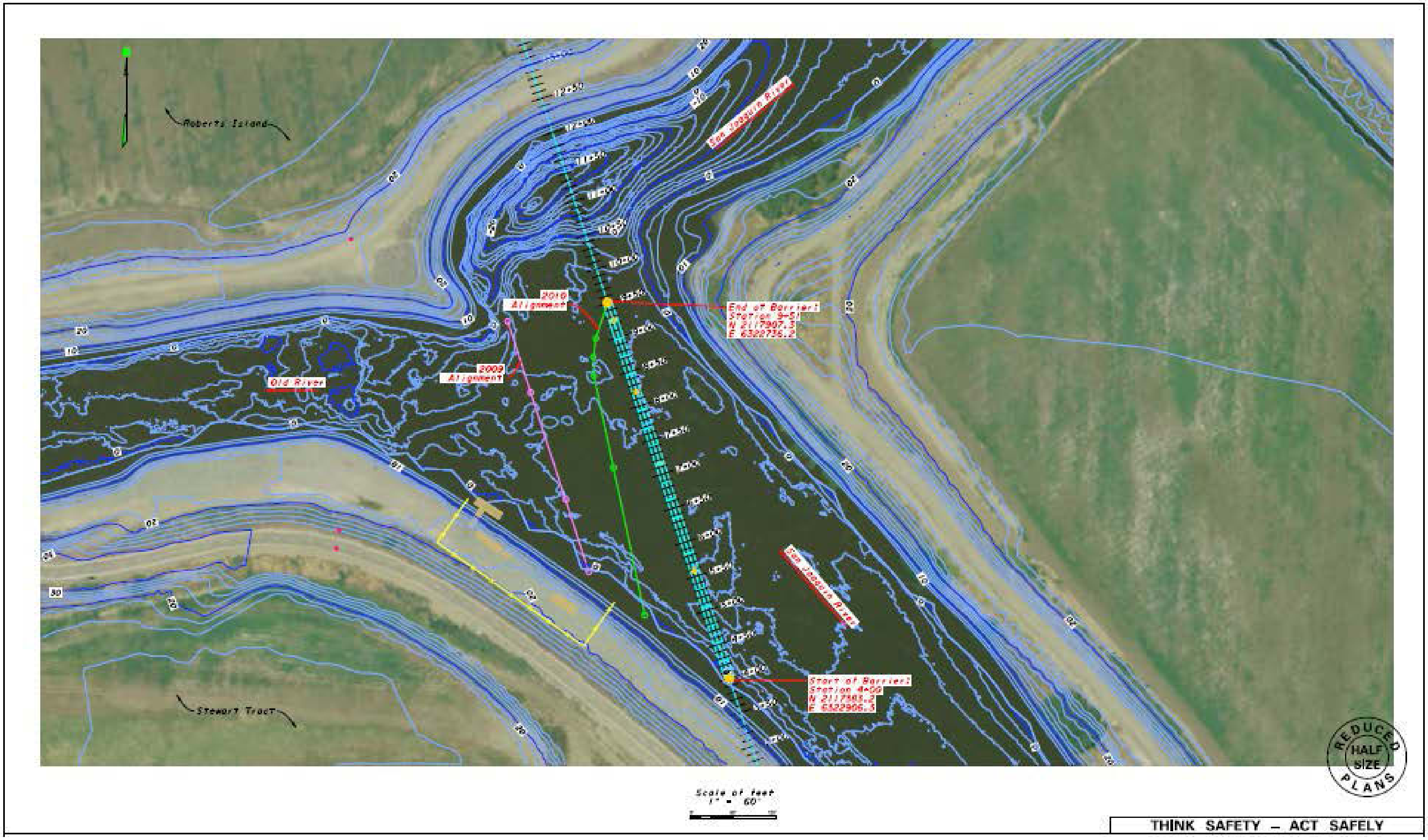
The BAFF design for the barrier study area was based on the following values:

- River width at barrier line equaled 91 m;
- Average velocity (data from the MSD gauge, approximately 4.5 km upstream of HOR junction) was 0.41 m/s. Therefore, the average velocity used for the design was 0.5 m/s. This value was slightly larger than the observed mean to provide a safety margin; and
- River depth along barrier line exhibited a maximum of 4.5 m, and averaged approximately 2.5 m.

To achieve *Ue* = 0.20 m/s perpendicular to the barrier, the barrier angle φ was arcsin (0.2/0.5) equals 24°. This is the angle relative to the centerline of the river flow at the upstream point of the barrier. This was the angle, 24°, of the BAFF as deployed in 2009 (Figure 4-2).

In 2010, the barrier length was increased from 114 m to 138 m to reduce the risk of diverting fish into the deep scour hole in the concave bend of the San Joaquin River limb at the HOR study area. Also, the angle of the BAFF incident to the left (west) bank was increased to 27° to allow more distance between a deterred juvenile Chinook salmon and the scour hole. Additionally, a "hockey-stick" bend was shaped toward the tip of the barrier, made up of the last four barrier units; this was angled at 30° to the main barrier angle. This bend was intended to deter juvenile Chinook salmon away from the deep scour hole, where predation events were observed in 2009. The alignment of the 2010 BAFF barrier is shown in Figure 4-2.

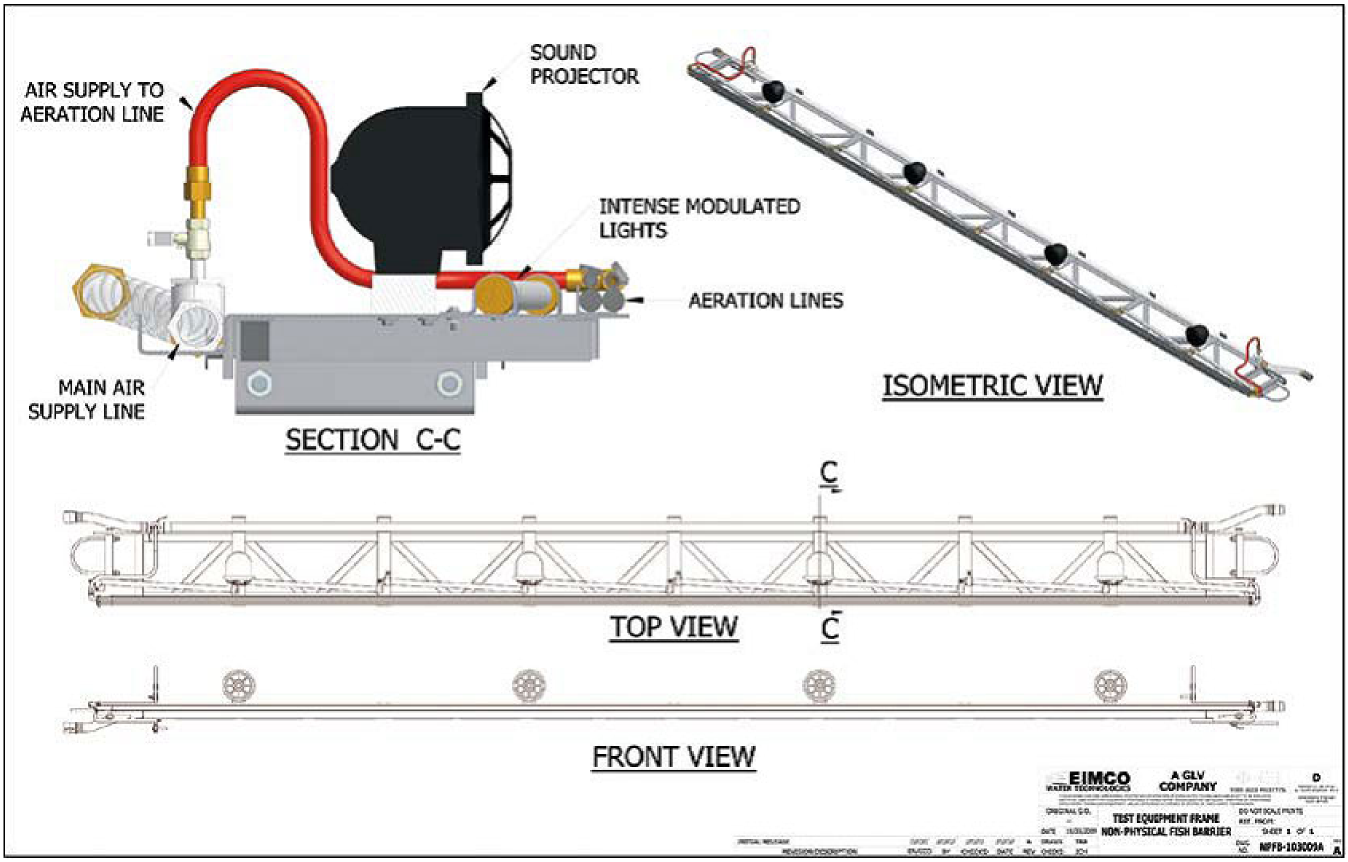
Consideration was given to two methods of barrier deployment: either suspending the barrier from the surface or mounting it rigidly on the riverbed. Surface mounting is simpler for a temporary barrier but less robust. Owing to the risk of high flows and debris, bed mounting was selected. The San Joaquin River could provide habitat for the protected green sturgeon (see Chapter 2, "Study Area and Focal Fish Species"), and a condition of permitting the installation was that a gap of 0.46 m should be left below the barrier infrastructure to allow sturgeon to pass. This was achieved by supporting the BAFF chassis with piles inserted for this purpose. This also facilitated free bedload movement and reduced the risk of equipment becoming inundated by fine sediments. The resulting gap below the BAFF meant that approximately 18% of the cross-sectional area of the barrier channel was not "screened" by the BAFF.



Source: DWR 2013

Figure 4-2 **Plan View of the Head of Old River Divergence (BAFF line in 2009 shown by pink line and in 2010 by green line)**

Each of the 7.9-m sections had adjustable height pivots to provide flexibility in lowering or raising each section to follow the riverbed contour. The barrier frame was supported by up to four piles in the river channel. Additionally, concrete piers were placed to support the frame above the riverbed in several locations so that the system would not move out of alignment and would allow for vertical adjustment of the barrier relative to the riverbed or water surface (Figure 4-3).



Source: Data provided by EIMCO

Figure 4-3 **Schematic of the Lattice Construction of the Barrier Support Frames (with sound projectors, strobes, and aeration lines)**

The air bubble curtain was generated by passing air (approximately 16.4 cubic meters per minute) through a uniformly perforated pipe attached to the barrier frame. The air was supplied by a trailer-mounted air compressor capable of an operating pressure up to 7 bar, although the actual operating pressure was lower, typically 2 to 3 bar. The air pipe was a rubberized construction, allowing the pores to open under pressure and self-seal when the air flow stopped. The primary function of the bubble curtain was to contain the sound that was generated by the sound projectors. The air bubble/water mixture acted as a pseudo-medium in which sound would travel at a velocity intermediate between that of air and water alone. Essentially, the sound was refracted and became encapsulated within the bubble curtain, which allowed a precise linear wall of sound to be developed (Bowen et al. 2009). Sound levels decayed very rapidly in the water outside of the bubble curtain, dropping to a few percent of the sound projector level within 3 m (Bowen et al. 2012:Appendix A). This led to the development of the 3-m line; a juvenile Chinook salmon would definitely experience the sound deterrent when it passed within 3 m of the BAFF. Therefore, during the day, a 3-m line was established, and at night a 10-m line was established (see

Section 5.2.2, “Calculation of Barrier Deterrence Efficiency”). These lines were used to determine if a tagged salmonid “experienced” the BAFF; if the tagged individual passed within 3 m of the BAFF during the day, or within 10 m at night, it was determined to have “experienced” the BAFF.

Up to 120 amps (115 volts, alternating current) of an inductively rated power supply was required to run the complete light and sound generating system. A small trailer housed the control units, signal generators, and amplifiers, because these units had to be kept dry.

4.2 HEAD OF OLD RIVER PHYSICAL ROCK BARRIER

The rock barrier is installed biannually, in spring and fall. The spring rock barrier is intended to prevent downstream-migrating juvenile salmonids in the San Joaquin River from entering Old River and, thereby, avoiding their exposure to SWP and CVP diversion operations and unscreened agricultural diversions. The spring rock barrier is constructed with approximately 9,560 cubic meters of rock to form a 68.5-meter-long by 25.9-meter-wide (at the base) berm. The spring rock barrier has a crest elevation of +3.8 m North American Vertical Datum of 1988 (NAVD) (Figure 4-4). The south end of this barrier has eight 1.2-meter-diameter culverts with slide-gates built into the barrier abutment, and a 22.9-m clay weir at an elevation of +2.5 m NAVD. Unlike the Old River at Tracy and Grant Line Canal barriers, no boat portage facility exists at this barrier.

The fall rock barrier is similar in design to the spring rock barrier, but smaller. The fall rock barrier is intended to benefit migrating adult salmon in the San Joaquin River by improving flow and dissolved oxygen conditions. The fall rock barrier has six 1.2-m culverts with slide-gates and a 6.1-m weir section at an elevation of +0.7 m NAVD. It is approximately 68.5 m long by 16.8 m wide at the base, and has a crest elevation of +2.5 m NAVD. The fall rock barrier is composed of approximately 5,730 cubic meters of rock.

Source: DWR 2013 and AECOM 2013

Figure 4-4 Physical Rock Barrier at the Head of Old River with Eight Culverts in 2012

5 METHODS

5.1 ANALYSIS OF TAGGED JUVENILE SALMONIDS

5.1.1 FATE OF TAGGED JUVENILE SALMONIDS

The analysis of tagged juvenile Chinook salmon and steelhead followed the methodology used for the 2011 analysis of the effects of a non-physical barrier at Georgiana Slough (DWR 2012). Acoustic transmitters were originally inserted in juvenile salmonids in accordance with the Vernalis Adaptive Management Program (VAMP) (SJRGA 1999, 2010, 2011, and 2013) and the Six-Year Steelhead Study (6YSS) (NMFS 2009; SJRGA 2013) by the VAMP/6YSS team. The fates of the tagged fish were classified as follows:

1. Released but never arrived;
2. San Joaquin River;
3. Old River;
4. Predation; or
5. Unknown.

These fates were used to estimate O_E, P_E, and D_E. These three metrics (O_E, P_E, and D_E) were evaluated through samples of tagged juvenile salmonid as they arrived at the HOR study area. If a tagged juvenile salmonid was determined to have been eaten, then that tag was evaluated in an analysis of proportion eaten. The possible errors that could have been made in determining the fate of being eaten are assessed for implications with respect to the proposed recommendations (Section 8.2.1, "Further Examine Predation Classification").

From 2009 through 2012, there were two types of acoustic telemetry gear used for evaluations of movement and behavior of acoustic tags: HTI and VEMCO. HTI gear provided sub-meter positioning and was used to evaluate behavior in the vicinity of the barrier location; this was the primary gear used in the analyses presented in this report. VEMCO gear provided one-dimensional information and collected route selection information and overall barrier effectiveness measures in 2012. Analyses related to VEMCO gear are presented in Appendix C, "Comparisons of HTI and VEMCO Data."

5.1.2 STUDY FISH SOURCES AND TAG SPECIFICATIONS

HTI EQUIPMENT

Three hatchery sources were used to provide juvenile Chinook salmon and steelhead for the study during the four study years, as shown in Table 5-1. For Chinook salmon, the Feather River Fish Hatchery and the Merced River Fish Hatchery supplied fish. All steelhead were from the Mokelumne River Fish Hatchery.

Table 5-1 Juvenile Salmonids Used for Head of Old River Barrier Evaluations Using HTI Gear						
Study Year	Species	Fish Hatchery	Run	Total Number Released	Minimum Size (mm FL)	Maximum Size (mm FL)
2009	Chinook Salmon	Feather River	Fall-Spring Hybrid	933	80	110
2010	Chinook Salmon	Merced River	Fall	504	99	121
2011	Chinook Salmon	Merced River	Fall	1,915	94	140
2011	Steelhead	Mokelumne River	Winter	2,208	149	396
2012	Chinook Salmon	Merced River	Fall	424	95	135
2012	Steelhead	Mokelumne River	Winter	16	167	269

Notes: FL = fork length; mm = millimeter
Sources: SJRGA 2010, 2011, 2013

The Chinook pre-smolts and smolts (referred to as "juveniles" in this report) from the Feather River and Merced River fish hatcheries for this study mimicked the ocean-type life history pattern (described in Appendix B, "Focal Fish Species Information"). These two hatcheries take ocean-type adults, spawn them between September and January, house the fry (30 to 55 mm TL) in raceways, where they are maintained for several months. At the Feather River Fish Hatchery, the target size is 96 mm TL by April (Kastner, pers. comm., 2013). At the Merced River Fish Hatchery, the target is to maximize growth by feeding approximately 3.5% of body weight per day (Kollenborn, pers. comm., 2013). The fry become parr in a few months and eventually begin to undergo the physiological and behavioral changes of smoltification. The ocean-type parr begin to smoltify in March or April. The largest individuals, a minimum of 102 mm TL, were selected in April for use in the study. These juveniles may be considered pre-smolt or smolt, depending on the state of smoltification in each individual. These juveniles were produced in the hatchery and used as surrogates for naturally produced (wild) juveniles. Chinook juveniles were surgically implanted with acoustic transmitters and released in the San Joaquin River 24.4 km upstream of the HOR study area.

In 2009, the HTI Model 795 *Lm* acoustic transmitter ranged in mass from 0.62 to 0.69 grams (in air) and were surgically inserted into the coelomic cavity of the juvenile Chinook salmon (Table 5-2). The target tag burden (i.e., tag:body mass ratio) of 5% (as recommended by Liedtke et al. 2012) was exceeded in 98% of cases (Table 5-3). The high number of exceptions existed because the spring/fall hybrids from the Feather River Fish Hatchery grew more slowly than expected once they were transferred to the Merced River Fish Hatchery (SJRGA 2010). From 2010 through 2012, juvenile Chinook salmon supplied for tagging were larger (Table 5-1) and the target tag burden was reduced and exceeded in 5.3 to 11% of the juvenile Chinook salmon tagged (Table 5-3).

Table 5-2 Acoustic Tag Models and Specifications Used in the Head of Old River Studies from 2009–2012						
Study Year	Tag Model Number	Quantity Used	Diameter (millimeters)	Length (millimeters)	Mass in Air Mean (grams)	Used for Sampling
2009	795*Lm*	950	6.8	16.5	0.65	Juvenile Chinook Salmon
2010	795*Lm*	508	6.8	16.5	0.65	Juvenile Chinook Salmon
2011	795*Lm*	1,089	6.8	16.5	0.65	Juvenile Chinook Salmon
	795*LD*	540	6.8	21.0	1.0	Juvenile Steelhead
	795*LX*	36	16	45.0	13.0	Predator Species
	795*LG*	13	11	25.0	4.5	Predator Species
2012	M800	76	6.7	16.4	0.50	Juvenile Chinook Salmon
	795*Lm*	348	6.8	16.5	0.65	Juvenile Chinook Salmon
	795*LD*	16	6.8	21.0	1.0	Juvenile Steelhead
	795*LX*	3	16.0	45.0	13.0	Predator Species
	795*LG*	45	11.0	25.0	4.5	Predator Species
Source: Data compiled by AECOM and Turnpenny Horsfield Associates in 2013.						

Table 5-3 Range of HTI Tag Burdens Experienced by Salmonid Juveniles in 2009–2012						
Study Year	Tag Model Number	Minimum Tag Burden	Mean Tag Burden	Maximum Tag Burden	Percentage of Tags Exceeding 5% of Body Mass	Species
2009	795*Lm*	0.044	0.071	0.102	98.0	Chinook Salmon
2010	795*Lm*	0.028	0.042	0.058	6.8	Chinook Salmon
2011	795*Lm*	0.020	0.041	0.065	11.0	Chinook Salmon
2012	M800	0.022	0.039	0.054	5.3	Chinook Salmon
2012	795*Lm*	0.020	0.039	0.124	6.6	Chinook Salmon
2012	795*LD*	0.004	0.006	0.008	0.0	Steelhead
Source: Data compiled by AECOM and Turnpenny Horsfield Associates in 2013.						

5.1.3 Surgical, Handling, and Release Methods

The barrier effectiveness evaluations described in this report were conducted as part of a coordinated suite of studies in the south Delta, which included the VAMP (SJRGA 1999) and the 6YSS (NMFS 2009; SJRGA 2013). The coordinated studies relied on one husbandry team (VAMP/6YSS) to conduct the surgical implantation, transport of the fish to the release site (i.e., Durham Ferry for all years, 2009 through 2012), handling of the fish to minimize effects on behavior and health, and release of the tagged juveniles according to the agreed schedule.

Concept guidelines important to the tag implantation procedures for HTI and VEMCO tags are described by Adams et al. (1998) and Martinelli et al. (1998). These guidelines were used to develop the methodologies employed in these coordinated studies (this study, VAMP [SJRGA 1999; SJRGA 2010, 2011, and 2013], and 6YSS [NMFS 2009; SJRGA 2013]); the south Delta applications for surgery, handling, and release were described in general by Liedtke et al. (2012) and specifically for each year: 2009 (SJRGA 2010), 2010 (SJRGA 2011), 2011 (SJRGA 2013), and 2012 (J. Israel, pers. comm., 2013). For 2011, the methodology describing the specifics of surgical implantation, handling, and release can be evaluated in SJRGA (2013). For the 2012 methodology, Israel (pers. comm., 2013) reported that methods varied in only minor details from SJRGA (2013).

For tagged juvenile Chinook salmon, the 2009 releases were executed earlier than any other year, with an initial release of April 22, 2009, and initial arrival at the HOR study area on April 23, 2009 (an arrival onset 4 to 11 days earlier than other years) (Table 5-4). In contrast, the 2011 tagged juvenile releases were executed later than any other year, with the initial release of May 17, 2011, later by 22 to 26 days.

Table 5-4
Release and Detection Dates for Tagged Juvenile Salmonid Releases Used in the Studies

Year	Species	First Release[1]	First Fish[2]	Last Release[3]	Last Fish[4]
2009	Chinook Salmon	4/22/2009, 17:05	4/23/2009, 8:24	5/13/2009, 21:38	5/18/2009, 13:48
2010	Chinook Salmon	4/27/2010, 14:02	4/27/2010, 22:25	5/19/2010, 08:00	5/20/10, 5:54
2011	Chinook Salmon	5/17/2011, 15:00	5/17/2011, 21:24:47	6/19/2011, 12:00	6/22/2011, 4:24
2011	Steelhead	3/22/2011, 15:00[5]	5/4/2011, 02:51:51	6/18/2011, 0:00	6/22/2011, 04:24:00
2012	Chinook Salmon	4/26/2012, 13:00	4/28/2012, 4:13	5/27/2012, 05:00	5/29/2012, 16:35
2012	Steelhead	5/22/2012, 23:00	5/23/2012, 23:38:44	5/22/2012, 23:00	5/28/2012, 15:56:39

Notes: BAFF = bio-acoustic fish fence.
1 First Release is the date/time the first fish went in the water at Durham Ferry.
2 First Fish is the date/time when the first tagged fish was nearest the 2009 (2009 data) or 2010 (2010–2012 data) BAFF line and detected by the HOR study area hydrophone array.
3 Last Release is the date/time the last fish went in the water at Durham Ferry.
4 Last Fish is the date/time the last tagged fish was nearest the 2009 (2009 data) or 2010 (2010–2012 data) BAFF line.
5 The hydrophone array at the HOR study area was not operational between 3/22/11 and 4/5/11.
Sources: Johnston, pers. comm., 2013; SJRGA 2010, 2011, and 2013

5.1.4 Acoustic Telemetry Assessments

HTI Hydrophone Deployment

Hydrophone arrays allowing 2D tracking of tagged fish were installed at the HOR study area from 2009 through 2012. A hand-held global positioning system (GPS) (precision level 2 to 3 m) was used to deploy each hydrophone at the appropriate location and to measure the Universal Transverse Mercator (UTM) coordinates for each hydrophone in the array. Once all hydrophones were in place, a procedure was performed to fine-tune the measured locations. This procedure used the transmitting capability of each hydrophone to produce a signal that all other hydrophones received. By measuring the time delay between the signal of the transmitting hydrophone and the signal arriving at each receiving hydrophone, the location of each hydrophone could be adjusted to fit all other time delays from all other hydrophones. In addition, the water temperature at each hydrophone was measured at the time of signal transmission to calculate the speed of sound during the procedure. For stationary hydrophones, this process results in hydrophone position estimates that allow sub-meter accuracy for acoustic tags located within the bounds of the array. During 2009, this procedure was performed once at the start of the monitoring period. During 2010, 2011, and 2012, the procedure was performed seven, four, and three times throughout the monitoring period, respectively.

In 2009, four hydrophones were installed around the BAFF (Figure 5-1). In 2010, eight hydrophones were installed: four located upstream and four downstream of the BAFF (Figure 5-2). In 2011, nine hydrophones were installed in approximately the same configuration as 2010, with the addition of one hydrophone deployed deep in the scour hole (Figure 5-3). For 2012, 13 hydrophones were installed around the rock barrier. Four hydrophones were located in the San Joaquin River upstream of the Old River divergence, three downstream of the divergence in the San Joaquin River, two upstream of the rock barrier in the Old River, and four downstream of the rock barrier in the Old River (Figure 5-4).

Source: Hydroacoustic Technology, Inc. 2013

Figure 5-1 HOR Study Area—2009 Hydrophone Array with BAFF (red line)

Source: Hydroacoustic Technology, Inc. 2013

Figure 5-2 **HOR Study Area—2010 Hydrophone Array with BAFF (red line)**

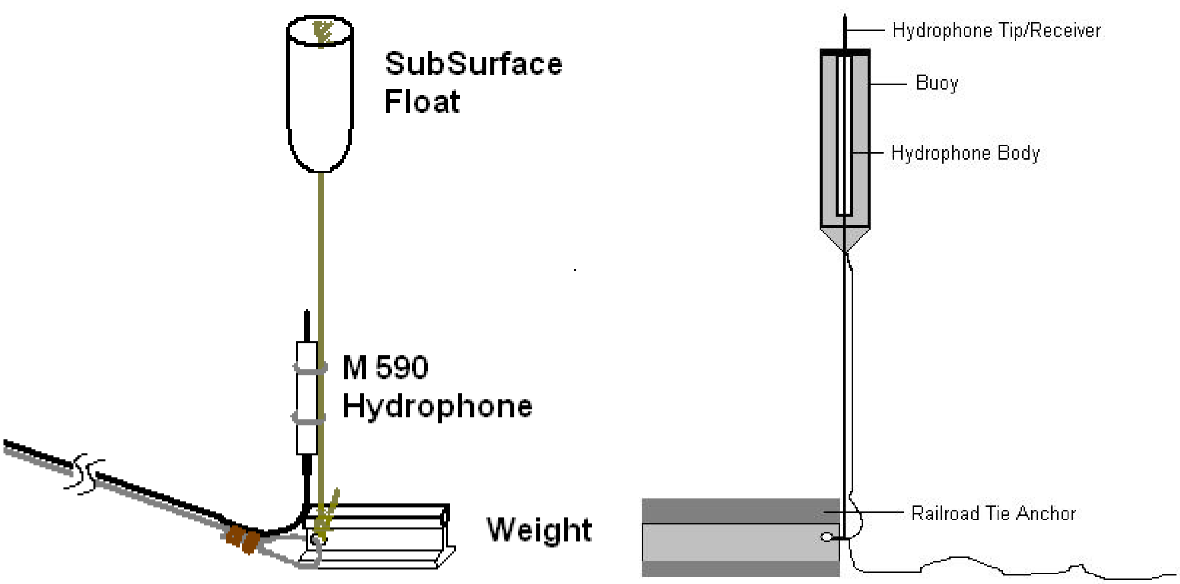
Source: Hydroacoustic Technology, Inc. 2013

Figure 5-3 **HOR Study Area—2011 Hydrophone Array, No Barrier Treatment**

Source: Hydroacoustic Technology, Inc. 2013

Figure 5-4 HOR Study Area—2012 Hydrophone Array with Rock Barrier

All hydrophones near the San Joaquin-Old River divergence were deployed using bottom mounts fabricated from a section of railroad tie as an anchor. The hydrophones were installed using tensioned aircraft cable or rope lines extending to subsurface floats (Figure 5-5).



Source: Hydroacoustic Technology, Inc. 2013

Figure 5-5 Conceptual Depiction of the Two Types of Hydrophone Bottom Mounts with Tensioned Lines

HTI ACOUSTIC TAG SPECIFICATIONS

HTI Model 795 and 800 acoustic tags were used for the telemetry studies conducted 2009 through 2012 at the HOR study area (Table 5-2). The tags operate at a frequency of 307 kilohertz (kHz), and were encapsulated with a nonreactive, inert, low-toxicity resin compound.

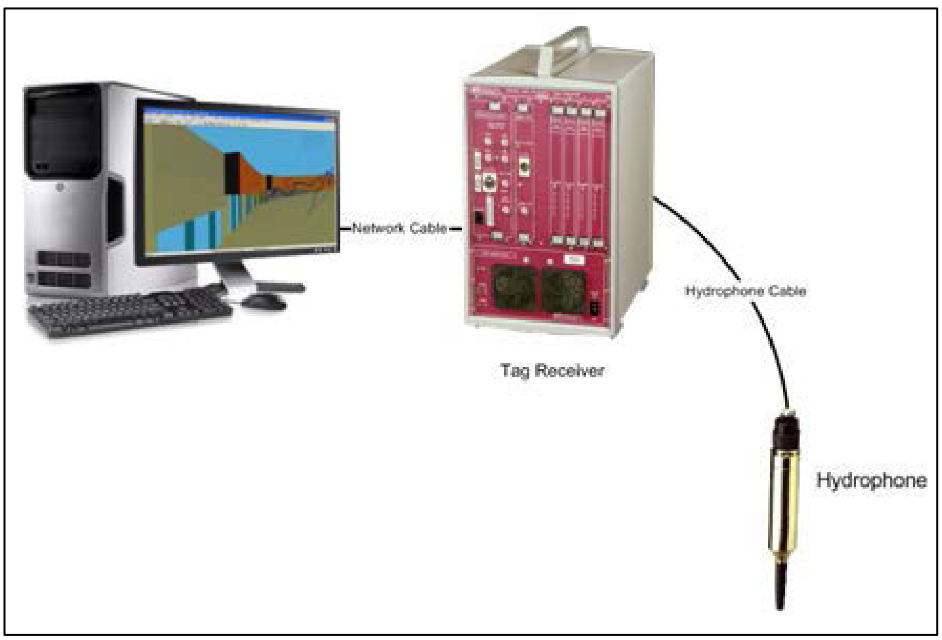
During the 2009 through 2012 study period, three different sizes of acoustic tags were used to tag juvenile Chinook salmon and steelhead, and two different sizes were used for the predator fish. Table 5-2 lists the quantity of each tag type used, with basic tag specifications, for each year of the study period.

TWO-DIMENSIONAL TRACK DEVELOPMENT

Data Collection

The acoustic tag tracking system consisted of acoustic tags implanted in fish, hydrophones deployed underwater, and an on-shore receiver and data storage computer. Each acoustic tag transmitted an underwater sound signal or acoustic "ping" that sent identification information about the tagged fish to the hydrophones. The hydrophones were deployed at known locations within the array to maximize spacing of the hydrophones in a 2D or 3D format. For 3D tracking, tags must be received on at least four hydrophones; for 2D tracking, tags must be received on at least three hydrophones. By comparing the time of arrival of the sound signal at multiple hydrophones, the 2D (or if the hydrophones are arranged appropriately, the 3D) position of the tagged fish can be calculated.

2D acoustic tag tracking was conducted using an HTI Model 290 Acoustic Tag Tracking System (ATTS). The primary components of the ATTS included the acoustic tag receiver, hydrophones, and a user interface/data storage computer (Figure 5-6). The system used a fixed array of underwater hydrophones to track movements of fish implanted with HTI acoustic tags.



Source: Hydroacoustic Technology, Inc. 2013

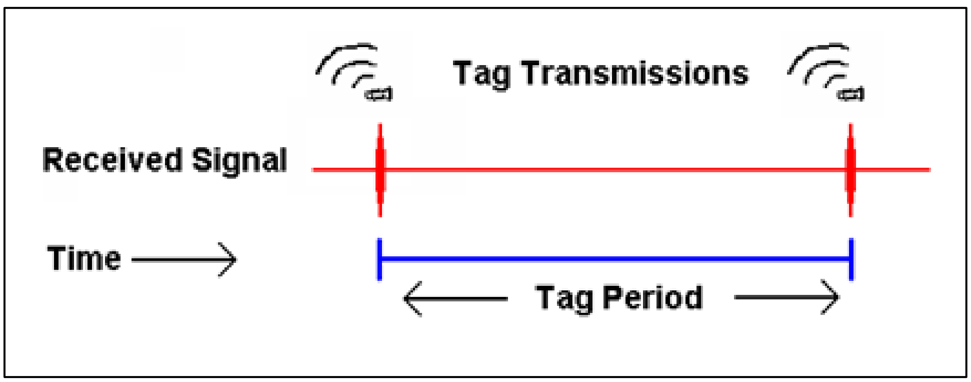
Figure 5-6 **Basic Components of the HTI Model 290 Acoustic Tag Tracking System Used to Track Movements of Fish Implanted with HTI Acoustic Tags**

As tagged fish approached the study area, the ping or signal was detected and the arrival time recorded at several hydrophones. The differences in tag signal arrival time at each hydrophone were used to calculate the 2D position of each tagged fish. The ATTS includes the following hardware and software components:

- A tag programmer that activates and programs the tag;
- Acoustic tags each transmitting a pulse of sound at regular intervals;
- Hydrophones that function like underwater microphones, listening within a defined volume of water;
- Cables connecting hydrophones to tag receivers; and
- Tag receiver that receives the tag signal from the hydrophones; conditions the signal; and, using specialized software, outputs the data into a format that is stored in computer data files.

Acoustic Tags

The HTI Model 795 acoustic tags use “pulse-rate encoding,” which provides increased detection range, improves the signal-to-noise ratio and pulse-arrival resolution, and decreases position variability when compared to other types of acoustic tags (Ehrenberg and Steig 2003). Pulse-rate encoding used the interval between each transmission to detect and identify the tag (Figure 5-7). Each tag was programmed with a unique pulse-rate encoding to detect and track the behavior of individual tagged fish moving within the array.

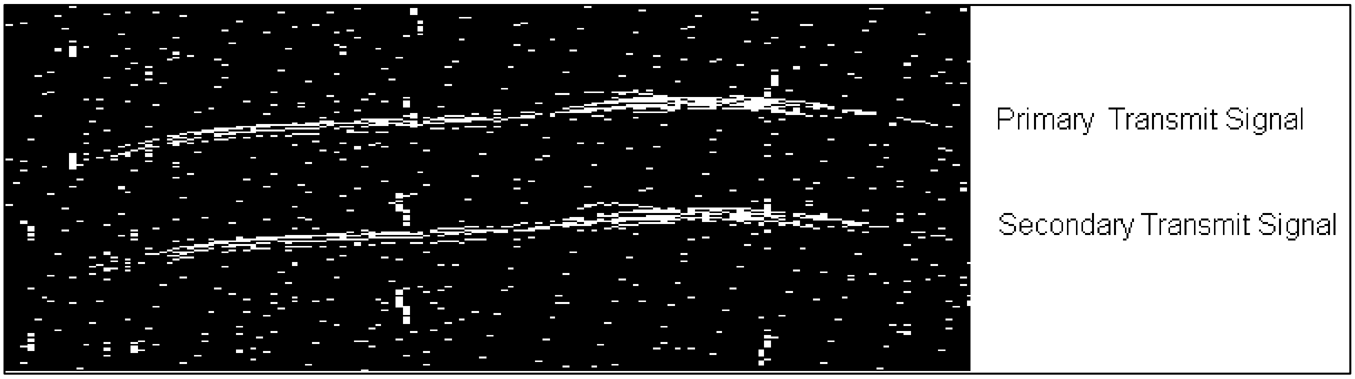


Source: Hydroacoustic Technology, Inc. 2013

Figure 5-7 Pulse-Rate Interval Describing the Amount of Elapsed Time Between Each Primary Tag Transmission

The pulse rate was measured from the leading edge of one pulse to the leading edge of the next pulse in sequence. By using slightly different pulse rates, tags can be uniquely identified. The timing of the start of each transmission was precisely controlled by a microprocessor within the tag. Each tag was programmed to have its own tag period to uniquely identify each tag.

In addition to the tag period, the HTI tag double-pulse mode or “subcode” option was used to increase the number of unique tag identification (ID) codes available. Using this tag coding option, each tag was programmed with a defined primary tag period and with a defined secondary transmit signal, called the subcode. This subcode defined a precise elapsed time period between the primary and secondary tag transmissions (Figure 5-8). There were 31 different subcodes possible for each tag period, resulting in more than 100,000 total unique tag ID codes.



Source: Hydroacoustic Technology, Inc. 2013

Figure 5-8 Example Graphic from the Data Collection Program Showing the Primary (tag period) and Secondary (subcode) Transmit Signal Returns from a Model 795 Acoustic Tag

Hydrophones

The Model 590 hydrophones operate at 307 kHz and include a low-noise preamplifier and temperature sensor. Hydrophone directional coverage is approximately 330°, with equivalent sensitivity in all directions, except for a 30° limited-sensitivity cone directly behind the hydrophone where the cable is attached. The hydrophone sensor element tip is encapsulated in specially treated rubber with acoustic impedance close to that of water to ensure maximum sensitivity. The hydrophone and connector housing are made of a corrosion-resistant aluminum/bronze alloy. Specially designed cables incorporating twisted pair wire and double shields for noise reduction were used to connect each deployed hydrophone to the acoustic tag receiver.

The hydrophone preamplifier circuit provides signal conditioning and background noise filtering for transmission over long cable lengths and in acoustically noisy environments. A calibration circuit in the preamplifier provides a method for field testing hydrophone operation and was used to measure the signal time delays between hydrophones in the array. Measurement of the signal delays was used to verify the absolute position of each hydrophone within the sampling array, which is a critical part of monitoring equipment deployment. This process of measuring the hydrophone positions via the signal travel times between each hydrophone is typically referred to as the “ping-around.” The Model 590 hydrophones include temperature sensors to measure water temperature at each location within the array, which was used to precisely estimate the sound velocity in water and referenced during the “ping-around” procedure.

Acoustic Tag Receiver

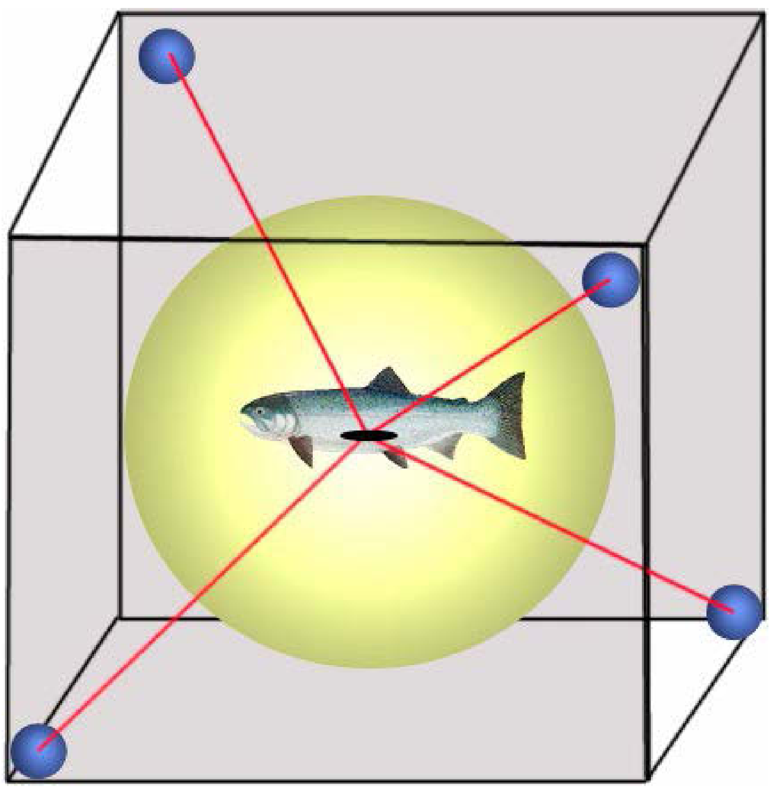
An HTI Model 290 acoustic tag receiver (ATR) can receive acoustic tag information simultaneously on up to 16 separate channels. Each ATR channel was assigned to a single hydrophone. The ATR was connected to the data collection computer, which analyzed and stored the acoustic data. An individual raw data file was automatically created for each sample hour and contained the complete set of information describing detection of each tag for all hydrophones. Data acquisition filters in the ATR were configured to identify the acoustic tag sound pulse and discriminate tag transmissions from background noise that may have been present.

The ATR pulse measurements were automatically reported for each tag signal from each hydrophone and were written to Raw Acoustic Tag (*.RAT suffix) files by the HTI acoustic tag data collection software program. Each

*.RAT file contains header information describing all data acquisition parameters, followed by the raw tag signal data. Each raw tag signal data file contains all acoustic signals detected during the time period, including signals from tagged fish and some amount of unfiltered acoustic noise, which is removed during the data analysis processes.

Mathematical Derivation of Position Calculations

Detection of a tagged fish by a single hydrophone is sufficient to confirm the presence and identity of the target, but a tag must be simultaneously detected by at least four hydrophones to be positioned in three dimensions (Figure 5-9). To be accurately positioned in two dimensions, a tag must be simultaneously detected on at least three hydrophones. 2D and 3D acoustic tag coordinates with sub-meter accuracy require accurate knowledge of the individual hydrophone positions. In addition, the hydrophones detecting the tag signal must have a direct "line of sight" path to the tag, and must be located in different vertical planes (for 3D only). As an acoustic tag is detected by three or four hydrophones that are all cabled to a single receiver, the difference in the arrival time of the transmission to each sensor was used to triangulate the exact location of the tag. HTI receivers have a built-in GPS receiver that updates to Universal Coordinated Time (UTC), so there is no clock drift. HTI receiver clock times are within 20 to 50 nanoseconds of UTC. Typically, many sequential tag positions are derived for each fish, providing a time series of locations. These positions are tracked and associated to define a swimming path for each tagged fish, which is mapped and presented in a 2D or 3D display. The underlying data are all stored for additional analyses.



Source: Hydroacoustic Technology, Inc. 2013

Figure 5-9 Positioning of an Acoustic Tag in Three Dimensions with a Four-Hydrophone Array

The method that is used to determine acoustic tag positions by the HTI systems follows the same basic principles employed by GPS technology. The acoustic tag transmits a signal that is received by at least four hydrophones. By knowing the positions of the four hydrophones and measuring the relative signal arrival times at the hydrophones, the locations of the tagged fish can be estimated.

This process is described mathematically in the following equation. Assuming that h_{ix}, h_{iy}, h_{iz} define the x, y, z coordinate locations of the ith hydrophone, and F_x, F_y, F_z represent the unknown x, y, z locations of the tagged fish, the signal travel time from the tagged fish to the ith hydrophone, t_i, is given by:

$$t_i = \frac{1}{c}\sqrt{(h_{ix} - F_x)^2 + (h_{iy} - F_y)^2 + (h_{iz} - F_z)^2}$$

The constant "c" in the above equation defines the underwater sound velocity. This equation cannot be solved for a single hydrophone detection; however, given the three unknown fish coordinates, a solution can be determined based on the convergence of multiple hydrophone measurements. The differences between the arrival times of the signal at the multiple hydrophones ($t_i - t_j$) is described as follows:

$$t_i - t_j = \frac{1}{c}\left[\sqrt{(h_{ix} - F_x)^2 + (h_{iy} - F_y)^2 + (h_{iz} - F_z)^2} - \sqrt{(h_{jx} - F_x)^2 + (h_{jy} - F_y)^2 + (h_{jz} - F_z)^2}\right]$$

For four hydrophones, there are three such distinct signal arrival-time difference equations. The system of nonlinear equations is determined by solving the tagged fish coordinates, such that the mean squared difference between the measured (left side of the equation above) and calculated time differences (right side of the equation above) are minimized.

Individual tag positions were then assembled in chronological order to form a 2D trace representing the movement of the fish as it passed through the array. This process was done from stored arrival time data (from *.RAT files) and in real time through the acoustic tracking system.

The relatively shallow water depths present in the vicinity of the HOR study area dictated the use of a 2D tracking approach. The 2D HTI tracking algorithm requires time delays from just three hydrophones, modifying the above equation to address only the x and y dimensions. Although 3D tracking is possible in shallow water, it requires close hydrophone spacing and a large increase in the total number of hydrophones to accurately derive the depth component. 2D tracking provided the necessary fish passage and behavioral information required for the HOR study area evaluation at a lower cost than a 3D array. The HTI data collection and analysis software programs incorporated both 2D and 3D tag tracking algorithms and automatically selected the best available solutions from multiple hydrophone detections.

Data Analysis

Two separate programs were used to process acoustic tag data: AcousticTag (Version 5.00.04) and MarkTags software (HTI, Seattle, Washington). AcousticTag was used initially to acquire data from the ATR and store it in raw acoustic echoes files. MarkTags was used to read the raw acoustic echo files, identify tag signals, and create acoustic tag files. These processed acoustic tag files were used again in AcousticTag to position the tags in 2D space.

As described previously, AcousticTag acquires data and stores it in *.RAT files. These raw echoes are not associated with any specific tag ID or spatial positioning. Depending on the project site and environmental conditions, many echoes found within these files are not tag data, but originate from secondary sources such as ambient noise or reflections from the surface or nearby structure (called multipath). Thus, the first phase of post-processing was to identify and select the acoustic echoes that were received directly from tags, and to assign the unique tag ID to these echoes.

The echo selection process was completed in the MarkTags program. The procedure for isolating the signals from a given tag follows from the method used for displaying the signals themselves. Each vertical scan in the time-scaled window shows the detected arrivals that are equal to the pulse-rate encoding of a particular tag (Ehrenberg and Steig 2003). Only signals from the tag programmed with the same period will fall along the straight line. The results of the tag selection process completed in MarkTags was written to track acoustic tag files (*.TAT file). These files contain the individual raw acoustic echoes with assigned tag ID codes, but without spatial positioning assignments.

AcousticTag was used for the triangulation calculations and to output a database of 2D coordinate locations for each fish. This program provided information describing date and time; the x, y, and z coordinates; and hydrophones used in creating the 2D track. It then recorded this information to a Microsoft® Access database file.

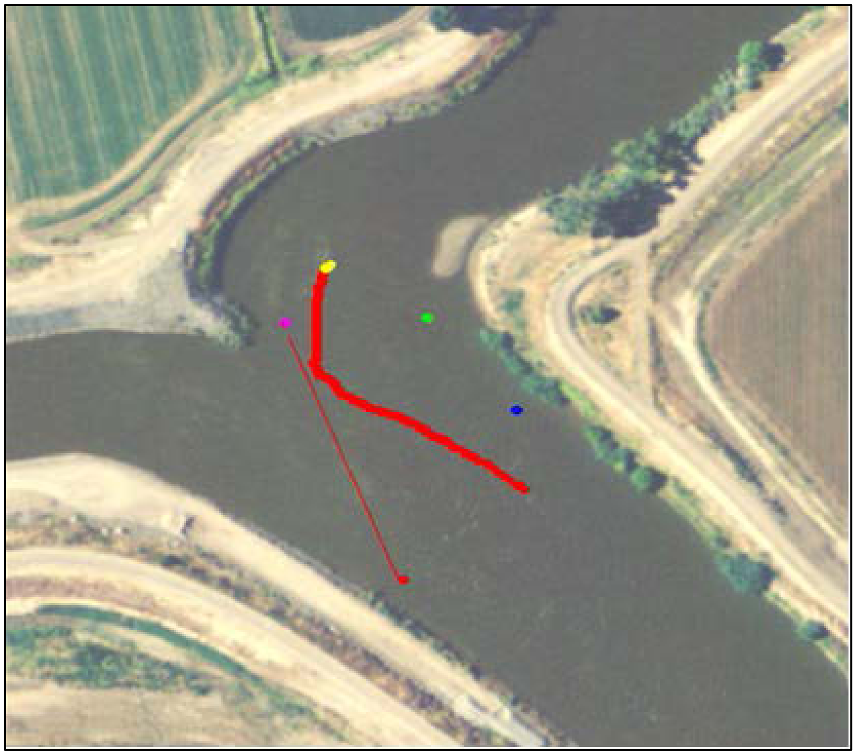
Deterrence and Fate Determination Guidelines

Deterrence Determination from Two-Dimensional Track

For all years of the study, a hydrophone array was deployed that allowed tracks of individual fish to be developed from tag transmission data. Each individual position calculated from a single tag transmission was developed in a geo-referenced UTM coordinate system, so it could be overlaid onto a geo-referenced map of the HOR study area. The time-stamped positions for each tagged fish were assembled into a time-ordered track which could be viewed in the context of the HOR study area and the barrier treatment, barrier status (Off/On), or no barrier, present for that time period.

Each tagged fish track was evaluated to determine if the tagged fish encountered the barrier (if present), if the tagged fish was deterred by the barrier (if BAFF was present and status was On), if the tagged fish exhibited predator-like behavior, and finally the ultimate fate of the tagged fish.

The guidelines for categorizing each tagged fish track into deterred (BAFF years 2009 and 2010), non-deterred (BAFF years 2009 and 2010), predation, route selected (San Joaquin River or Old River), or unknown, are listed in Appendix E. There were small differences in the guidelines for each study year based on the presence of a BAFF, the presence of a physical rock barrier (which caused large scale hydraulic effects unlike a non-physical barrier), or the absence of any barrier. Example tracks for tagged fish that were categorized as deterred, non-deterred, and predation are shown in Figures 5-10, 5-11, and 5-12, respectively. More examples of tracks for each deterrence category for each year are presented in Appendix E.

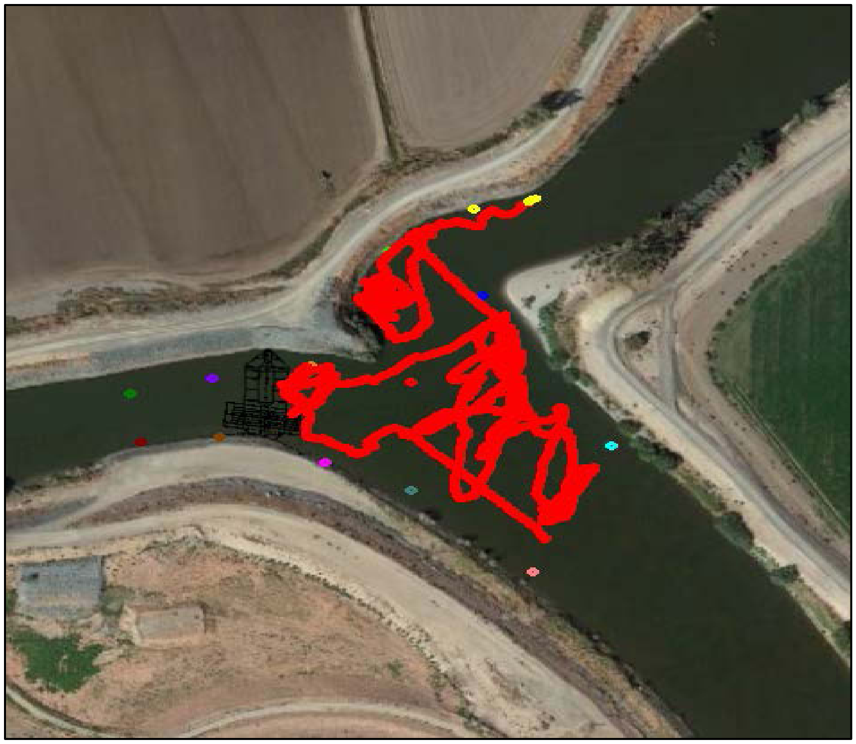


Source: Hydroacoustic Technology, Inc. 2013

Figure 5-10 Tagged Chinook Number 5674.21 Deterred by the BAFF (On) at 03:38 PDT on May 15, 2009 and Exiting the Array down the San Joaquin River

Source: Hydroacoustic Technology, Inc. 2013

Figure 5-11 Tagged Chinook Number 5437.14 Passing through the BAFF (On) at 0:27 PDT on April 28, 2010 and Exiting the Array down the Old River



Source: Hydroacoustic Technology, Inc. 2013

Figure 5-12 Tagged Chinook Number 2203.03 (designated as having been eaten by a predator) Showing Directed Movement Downstream at the Beginning of the Track, then Becoming "Predator-Like," Exhibiting Both Upstream and Looping Movement between 19:16 and 21:24 PDT on May 20, 2012 at the HOR Study Area

Tag Drags and Ping-Arounds

In each year, after the hydrophones were set up, several tag drags were conducted. The tag drags ensured that a tag could be heard by three or more hydrophones at all locations within the hydrophone array.

The tagged fish-release periods are defined in Table 5-4. During the periods when the tagged fish were in the water, ping-arounds were done periodically using AcousticTag software. The ping-around information was used to improve the precision of the tag positions. These tag positions were used to build the 2D tracks. Tag positioning precision was estimated by HTI personnel at ≤1 m (Johnston, pers. comm., 2009).

5.2 EVALUATION OF JUVENILE SALMONID ROUTING INCLUDING BARRIER EFFECTS

5.2.1 GROUPING JUVENILE SALMONIDS INTO SAMPLES

The data analyses described were reanalyses of the data published in Bowen et al. (2012) and Bowen and Bark (2012), combined with analyses of new data collected in 2011 and 2012. An essential element of this reanalysis was assigning tags to samples depending on the time they were at the HOR study area, rather than the date and time at which they were released.

The first sample was assigned when the first fish arrived at the HOR study area. As long as the barrier state did not change, ambient light did not cross a critical threshold, and average water velocity did not cross a critical threshold, each fish that arrived was placed in this sample. When barrier state, or light, or velocity changed, a new sample was assigned. In this manner, all tagged fish were placed in samples. Samples with only one fish were removed from the analysis.

Barrier state was defined by the type and its status. For example, in 2009 and 2010, the barrier was a BAFF and the status was determined by whether the BAFF was turned on or off. In 2011, no barrier was installed. Thus, this treatment was referred to as "No Barrier" and the barrier status was always off. In 2012, a physical rock barrier was installed, thus the barrier was always on.

The critical threshold used for determining low- and high-light conditions was 5.4 lux. This critical threshold was chosen with regard to the operation of the BAFF. Based on the work of Anderson et al. (1988) on juvenile Chinook salmon strobe-light avoidance reactions, it was assumed that if the ambient light was ≥ 5.4 lux, then ambient light may influence the ability of the high-intensity modulated lights to produce a reaction in juvenile Chinook salmon encountering the BAFF. This critical light threshold (5.4 lux) was also used in analysis of the effects of a non-physical barrier at Georgiana Slough (DWR 2012).

The critical velocity threshold used to determine low- and high-velocity conditions was 0.61 m/s average channel velocity. This critical velocity threshold was selected based on a conservative estimate of the sustained swimming speed of juvenile Chinook salmon of 4.37 body lengths per second (BL/s) (Appendix B: Table B-1). This threshold was designed to protect juvenile Chinook salmon measuring 57 mm FL, which was the minimum size observed for a fall-run individual at the Tracy Fish Collection Facility and Skinner Delta Fish Protective Facility from August 1, 2011, through July 31, 2012 (NMFS 2013). Therefore, at a sustained swimming speed of 4.37 BL/s, a 57-mm FL juvenile Chinook salmon could swim 0.25 m/s. Thus, it was assumed that a fall-run juvenile had the capacity to swim away from the BAFF when the approach velocity was ≤ 0.25 m/s. An approach velocity of 0.25 m/s occurred when the average channel velocity was 0.61 m/s for the angle incident to the flow for the 2009 BAFF (24°) (Figure 5-1).

5.2.2 Calculation of Overall Efficiency

Overall efficiency (O_E) for the BAFF and the rock barrier were determined for each sample using Equation 5-1, in relation to start and finish lines similar to those depicted in Figure 5-13 (exact locations differed depending on hydrophone coverage in each year).

Equation 5-1:

$$O_E = S_A/L_A$$

Where:

O_E = overall efficiency,
S_A = the number of tags that left the HOR study area downstream via the San Joaquin River, passing the San Joaquin River finish line, and
L_A = the number of tags that entered the HOR study area from the upstream San Joaquin River, passing the San Joaquin River start line.

Source: Data compiled by AECOM in 2013

Figure 5-13 **Head of Old River Study Area: Start and Finish Lines and 2012 VEMCO Hydrophone Placements**

The calculation of O_E for 2011 (the "No Barrier" year) was the same mathematically as the calculation of O_E in Equation 5-1; therefore, it was possible to compare this parameter statistically across years. The hypotheses used for these comparisons are discussed under "Primary Objectives and Hypotheses Related to Juvenile Salmonid Routing, Including Barrier Effects" in Section 1.2.2, "Juvenile Salmonid Routing Including Barrier Effects," in Chapter 1.

5.2.3 CALCULATION OF PROTECTION EFFICIENCY

Protection efficiency (P_E) for the BAFF and the rock barrier were determined for each sample using Equation 5-2, in relation to start and finish lines similar to those depicted in Figure 5-13 (exact locations differed depending on hydrophone coverage in each year).

Equation 5-2:

$$P_E = S_N/(S_N+L_N)$$

Where:

P_E = protection efficiency,
S_N = the number of juvenile salmonids that left the HOR study area via the downstream San Joaquin River, passing the San Joaquin River finish line that were not eaten, and
L_N = the number of juvenile salmonids that left the HOR study area via Old River, passing the Old River finish line that were not eaten.

This calculation for P_E in relation to the BAFF and rock barriers (Equation 5-2) was also used to calculate P_E for 2011 (the "No Barrier" year), noting that there was no actual "protection" afforded by the lack of a barrier. Because the same equation was used for all years, it was possible to compare these two parameters statistically across years. The hypotheses used for these comparisons are discussed under "Primary Objectives and Hypotheses Related to Juvenile Salmonid Routing Including Barrier Effects" in Section 1.2.2, "Juvenile Salmonid Routing Including Barrier Effects," in Chapter 1.

5.2.4 CALCULATION OF BARRIER DETERRENCE EFFICIENCY

Deterrence efficiency (D_E) for the BAFF when it was on and off was evaluated using 2009 and 2010 data. A juvenile salmonid was determined to have experienced the BAFF if it came within 10 m of the BAFF in low-light conditions and if it came within 3 m of the BAFF in high-light conditions. D_E was determined for each sample according to Equation 5-3.

Equation 5-3:

$$D_E = R/E$$

Where:

D_E = barrier deterrence efficiency,
R = the number of tags that were deterred, and
E = the number of tags that experienced the BAFF.

D_E was calculated only for the years in which the BAFF was used: 2009 and 2010. The hypotheses used for these comparisons are discussed under "Primary Objectives and Hypotheses Related to Juvenile Salmonid Routing Including Barrier Effects," in Section 1.2.2, "Juvenile Salmonid Routing Including Barrier Effects," of Chapter 1.

5.2.5 CALCULATION OF BAFF EFFECT

It was possible to calculate the BAFF's effect when two samples occurred immediately adjacent in time, and therefore had the same light and velocity conditions, but where the BAFF was changed as part of an tagged manipulation. Thus, there was a directly comparable BAFF "on" to "off" condition. The BAFF effect was calculated according to a simple calculation (Equation 5-4).

Equation 5-4:

$$F = E_N - E_O$$

Where:

F = BAFF effect,
E_N = efficiency with the BAFF on, and
E_O = efficiency with the BAFF off.

The results for BAFF effect are reported in Chapter 6, "Results." The results are uncommon because it was unusual for the conditions to occur to acquire a BAFF effect sample.

5.2.6 STATISTICAL COMPARISONS

Using the samples assigned as described in Section 5.2.1, each of the null hypotheses described in Section 1.2, "Study Design, Objectives, and Hypotheses," was tested statistically. Additionally, when appropriate, the null hypotheses were also tested at each combination of light and velocity.

Four dependent variables of interest were compared. The first dependent variable was O_E, which provided an estimate of the proportion of tags that left the HOR study area via the San Joaquin River. The second dependent variable was P_E, which provided an estimate of the proportion of juvenile salmonids that left the HOR study area via the San Joaquin River that were not eaten. The third variable of interest was D_E, which provided an estimate of the proportion of juvenile salmonids that turned away from or were guided by the BAFF. The fourth variable of interest was BAFF effect, calculated when possible, which was the difference in an efficiency metric (O_E, P_E, or D_E) between the BAFF on and off.

An independent variable of interest was BAFF status, specific to the years when the BAFF was operated. In 2009 and 2010, it was possible to obtain a set of samples with the BAFF on and off for comparison. The comparison between BAFF on and off showed whether or not operation of the BAFF deterred juvenile Chinook salmon from entering Old River. If BAFF operation could not be shown to be better with the BAFF on compared to off, then the BAFF would have no utility as a fish deterrent.

The independent variable of primary interest was treatment, which had four states: (1) BAFF-2009; (2) BAFF-2010; (3) No Barrier-2011; and (4) Rock Barrier-2012. Each of these treatments occurred in a particular year because it was not logistically feasible to change the barriers during a single study season. Thus, each treatment was also a function of a particular combination of physical attributes described in Chapter 3, "Physical Parameters." Because the physical attributes might have significant impact on barrier function, the treatment/year was depicted as the independent variable.

The independent variables of secondary interest were light intensity and water velocity. These were developed because of published literature accounts (Perry et al. 2012; Welton et al. 2002) of their effects on the operation of a BAFF. Thus, when appropriate, O_E, P_E, and D_E were evaluated at two light and velocity levels. The critical light and velocity thresholds are described in Section 5.2.1.

For each comparison, a one-way analysis of variance (ANOVA) was conducted for an independent variable and a dependent variable. For example, the first comparison was made in 2009: O_E was evaluated for the BAFF on versus off. Then, after the ANOVA was completed, the data were evaluated to determine whether they met the assumptions of the ANOVA procedure (Sokal and Rohlf 1995). With only one exception in the entire study, the data did not meet the assumptions of the ANOVA, and it was necessary to rely on a nonparametric equivalent: the Kruskal-Wallis Test (Hollander and Wolfe 1973).

The test statistic and P-value were reported. If the null hypothesis was rejected and there were more than two sets of samples, the sets of samples were then subjected to pair-wise comparisons to determine which populations were different. When more than one two-sample comparison was made, a Bonferroni adjustment in the critical alpha was made to control the experiment-wise error rate (Sokal and Rohlf 1995).

5.3 EVALUATION OF PREDATION ON JUVENILE SALMONIDS INCLUDING BARRIER EFFECTS

5.3.1 PROPORTION EATEN (UNIVARIATE ANALYSES)

The proportion of tagged fish in a sample that were eaten was determined for each sample according to Equation 5-5.

Equation 5-5:

$$C = C_P/L_A$$

Where:

C = sample proportion eaten;
C_P = the number of tags that were identified as having been eaten; and
L_A = the number of tags that entered the HOR study area from the upstream San Joaquin River, passing the San Joaquin River start line.

The procedure for grouping juvenile salmonids into samples is described in Section 5.2.1, "Grouping Juvenile Salmonids into Samples." The sample proportion eaten was used for testing hypotheses $H8_0$, $H9_0$, and $H10_0$, which were described under "Objectives and Hypotheses Related to Proportion Eaten" in Section 1.2.3, "Predation on Juvenile Salmonids, Including Barrier Effects." The sample proportion eaten is reported with the results of the statistical comparisons used for the hypothesis testing. In addition, when mean sample proportion eaten was reported, population proportion eaten was also reported. The population proportion eaten for a given year is the grand proportion eaten determined by the total number of tagged juveniles eaten divided by the total number of tagged juveniles passing by the HOR study area in that year. The population proportion eaten summarizes the proportion eaten across all barrier states and light and velocity levels, and is comparable to the probability of predation described in Section 5.3.2, "Probability of Predation (Generalized Linear Modeling)," and in San Joaquin River Group Authority reports (SJRGA 2010, 2011, and 2013).

Statistical comparisons to test hypotheses $H8_0$, $H9_0$, and $H10_0$ were made with univariate tests in an analogous manner to that described for O_E, P_E, and D_E in Section 5.2.6, "Statistical Comparisons." In addition, interpretation was conducted in the same way using a comparison of the P-value and critical alpha (0.05), to determine if the null hypothesis should be rejected.

5.3.2 PROBABILITY OF PREDATION (GENERALIZED LINEAR MODELING)

The probability of tagged juvenile salmonids being preyed upon at the HOR study area was assessed in relation to several predictor variables that were hypothesized *a priori* to have potential influence on predation (see "Objectives and Hypotheses Related to Proportion Eaten" in Section 1.2.3, "Predation on Juvenile Salmonids Including Barrier Effects)": discharge, water temperature, turbidity, light level, juvenile size, small-fish density, and large-fish density. Discharge is highly correlated with velocity, and thus chosen for inclusion in modeling, as it is the more commonly used variable for planning and operations purposes. Discharge has been positively associated with salmonid survival probability through the Delta in several studies (Cavallo et al. 2013; Newman 2003; Perry 2010; but see also Zeug and Cavallo 2013). This may be because greater discharge results in shorter travel time or more direct migration routing, and therefore, less exposure to predators (Anderson et al. 2005). It was hypothesized that this predictor would be negatively related to predation probability at the HOR study area. Salmonid survival in the Delta has been demonstrated to be negatively associated with water temperature (Newman 2003; Zeug and Cavallo 2013), perhaps because predatory fish energy requirements increase at higher temperatures, and so food requirements are greater (Hanson et al. 1997). It was hypothesized that water temperature would be positively related to predation probability at the HOR study area.

Studies have found a positive relationship between turbidity and survival of Delta native fishes, both in the field (Chinook salmon: Newman 2003) and in the laboratory (delta smelt: Ferrari et al. 2013), presumably because the visual range of predators is less under more turbid conditions (Aksnes and Giske 1993). Similarly, light level affects the visual range of predators (Aksnes and Giske 1993), and some predatory species, such as largemouth bass, predominantly feed during the day (Moyle 2002). Accordingly, it was hypothesized that predation probability in the HOR study area would be negatively related to turbidity and positively related to light level.

The size of juvenile Chinook salmon migrating through the Delta was found to be positively associated with subsequent ocean recovery rate by Zeug and Cavallo (2013), possibly because of greater escape ability and reduced probability of being eaten by gape-limited predators. Predation probability at the HOR study area, therefore, was hypothesized to be negatively related to juvenile size. Small-fish density at the HOR study area (see predictor definition and description that follows; Table 5-5) was hypothesized to be negatively related to predation probability, reflecting the potential that greater density of alternative prey would reduce the predation risk to any individual juvenile. Large-fish density at the HOR study area was hypothesized to be positively related to predation probability because there is evidence that predator abundance is negatively related to juvenile Chinook salmon survival in the Delta (Cavallo et al. 2013). Barrier status also was included as a predictor (see further discussion that follows), with the null hypothesis that there was no difference between barrier states in predation probability at the HOR study area. Survival in relation to barrier status at the HOR study area previously had been evaluated at a broader scale. For example, recent analysis by Zeug and Cavallo (2013) found no well-supported effect on ocean recovery rate of Chinook salmon in relation to installation of the physical rock barrier during the juvenile migration period through the Delta, whereas previous analysis by Newman (2008) suggested that survival was higher in the San Joaquin River than in Old River, and therefore, effective installation of the rock barrier would increase survival through the Delta.

Table 5-5
Summary of Predictor Variables Used in Generalized Linear Modeling of Juvenile Salmonid Probability of Predation at the Head of Old River Study Area

Variable (Unit)	Location	Source	Transformation	Notes
Water temperature (°C)	SJL	CDEC (Baldwin, pers. comm., 2013)	None	15-minute average data
Discharge (m^3/s)	SJL	CDEC (Baldwin, pers. comm., 2013)	None	15-minute average data
Turbidity (NTU)	MSD	CDEC (Dempsey, pers. comm., 2013)	None	15-minute average data
Ambient light (lux)	Manteca (CIMIS site #70)	CIMIS (State of California 2009)	Natural logarithm + 1	Original CIMIS data (Langley/day) were first converted into PAR per Clark et al. (2009: PAR, µmol/m^2/s = 1.1076*Langley/day), and subsequently PAR was converted into lux per Apogee Instruments, Inc. (2013:Lux = 54*PAR). Original hourly data were linearly interpolated to 15-minute increments for consistency with water quality data.
Small fish density (<15 cm FL/10,000 m^3)	Mossdale (trawling)	USFWS survey data (Speegle, pers. comm., 2011 and 2013)	Natural logarithm + 1	
Large fish density (> 30 cm TL/10,000 m^3)	HOR study area	Mobile hydroacoustic data (this study)	Natural logarithm + 1	

Notes: °C = degrees Celsius; CDEC = California Data Exchange Center; CIMIS = California Irrigation Management Information System; cm = centimeters; m^3 = cubic meters; m^3/s = cubic meters per second; MSD = San Joaquin River at Mossdale; NTU = nephelometric turbidity units; PAR = photosynthetically active radiation; SJL = San Joaquin River at Lathrop; USFWS = U.S. Fish and Wildlife Service
Source: Present study

Each tagged juvenile entering the HOR study area was assigned a fate according to Bowen et al. (2012) and Bowen and Bark (2012) (i.e., visual examination of juvenile tracks using Eonfusion software (Myriax Software, Hobart, Tasmania, Australia); see Appendix E, “Fish Fate Determination Guidelines”). Tracks that initially entered the HOR study area with well-directed downstream movement but subsequently displayed evidence of predation (e.g., looping movements through the study area without clear downstream movement) were assigned the fate of “predation.” It was not possible to assign a fate to every fish that entered the HOR study area, because it was not always clear when fish may have been preyed upon or may have survived; only fish that were successfully classified as preyed upon or survived were included in the analysis. Complex hydrodynamics within the HOR study area caused by the physical rock barrier during 2012 made fate assignment particularly challenging for data from this year, and hydrodynamic modeling (see Section 3.2, "Velocity Field") was used to aid these classifications. The qualitative procedure used to assign fates is being compared to quantitative mixture model analyses for data generated at Georgiana Slough in 2012 (DWR in review; Romine et al. 2014).

The predictor variables included in the predation-probability analyses generally were the same as those used for analyses of greater than 30-cm fish abundance from mobile hydroacoustics (Table 5-5) (see also "Statistical Methods" in Section 5.4.2, "Hydroacoustic Surveys"). Abiotic variables (discharge, water temperature, turbidity, and ambient light) were based on the closest 15-minute observation to the time that the juveniles were at their minimum distance from common reference points: the 2009 or 2010 non-physical barrier alignments. Two estimates of the density of large fish (> 30 cm TL), taken to be indicators of potential predatory fish abundance at the HOR study area, were included in the analysis based on side-looking and down-looking mobile surveys conducted in 2011 and 2012 (see Section 5.4.2, "Hydroacoustic Surveys"). Consistent with small-fish density estimates, the large-fish density estimates associated with each juvenile's fate were averaged over the 3-day period, ending the day a juvenile entered the HOR study area. A 3-day period was used to increase the number of juveniles that could be retained in the analysis by avoiding missing values for this predictor variable. In addition, juvenile length was included per the hypothesis that larger fish may have a greater probability of survival.

Three analyses of predation probability were conducted based on species, barrier/discharge conditions, and the availability of > 30-cm fish density data from mobile hydroacoustic surveys. The first analysis tested hypothesis H11 (see Table 1-2 in Section 1.2.3, "Predation on Juvenile Salmonids Including Barrier Effects") and was based on tagged juvenile Chinook salmon predation data from 2009, 2010, and 2012 (n = 1,169); it included all previously mentioned predictor variables except large fish density from mobile hydroacoustics, which was not undertaken in 2009 and 2010. Barrier status was included as a predictor variable with three levels: BAFF on, BAFF off, and physical rock barrier. Data from 2011 were not included in this analysis because it would have been difficult to ascertain whether any differences in predation probability resulted from the absence of the barrier or from the very high discharge; these variables were confounded. The second analysis tested hypothesis H12 and was based on Chinook salmon predation data from 2011 and 2012 (n = 876); it included all predictor variables except barrier status. The third analysis tested hypothesis H13 and was based on steelhead predation data from 2011 (n = 163); it included all predictor variables except barrier status. There were insufficient data (n = 5) from 2012 for inclusion in the steelhead predation probability analysis.

The probability-of-predation analyses were undertaken using a GLM within a model averaging/information theoretic framework (Burnham and Anderson 2002) based on the R software (Version 3.0.0; R Core Team 2013) package "glmulti" (Calcagno and de Mazancourt 2010). This modeling technique has been applied on a number of recent occasions for fish research in the San Francisco Bay–Delta and Central Valley (e.g., Beakes et al. 2012; Perry et al. 2012; Zeug and Cavallo 2013). In addition to the standard reference text (Burnham and Anderson 2002) for this modeling technique, a useful summary is provided by Mazerolle (2006).

The glmulti package was used to provide all possible first-order GLMs for probability of predation (response = 1) versus survival (response = 0), with the response modeled with a binomial distribution and logit link function. The relative level of support for each possible model was estimated in glmulti with Akaike's Information Criterion (AIC), corrected for small sample sizes (AIC_c) (Mazerolle 2006). The difference in AIC_c, Δ_i, between each model and the best model (i.e., the model with the lowest AIC_c) was calculated, and Akaike weights (w_i) were calculated based on the Δ_i. Model averaging of the predictor variable coefficients was undertaken based on the Akaike weights for each model, and unconditional confidence intervals were calculated for each coefficient (Mazarolle 2006). The importance of each predictor variable was assessed by summing the w_i of all models in which the variable appeared; following Calcagno and de Mazancourt (2010), importance of 0.8 or greater was used to infer support for a variable's potential influence on predation probability, in addition to unconditional 95% confidence intervals for variable coefficients not overlapping zero (per Zeug and Cavallo 2013).

GLMs including predictors were assessed to provide a better fit to the data than intercept-only models if the AIC_c of the full model (with all predictors included) was three or more units greater than the AIC_c of the intercept-only model (Zeug and Cavallo 2013). Model fit to observed data was assessed using similar methods to those of Beakes et al. (2012) and Perry et al. (2012). Model-fit assessment was conducted with the PresenceAbsence package of the R software (Freeman and Moisen 2008). As described by Beakes et al. (2012), an optimized threshold based on Kappa was calculated for each GLM. The threshold value was set where Kappa was maximized for each GLM, and this threshold value was used to estimate Kappa and several additional threshold-dependent model performance statistics: Cohen's Kappa statistic, percent correctly classified (PCC), sensitivity, and specificity. Each statistic is a measure of the capacity to accurately discriminate the correct outcome of predation of tagged juvenile salmonids observed in the data, where probabilities that exceed the threshold were classified as predation (positive) and probabilities below the threshold were classified as survival (negative). Beakes et al. (2012) described these statistics as follows:

> The Kappa statistic is a measure of all possible outcomes of presence or absence that are predicted correctly, after accounting for chance predictions; it is generally accepted as a conservative and standardized metric for comparing the predictive accuracy of binary models regardless of their statistical algorithm (Manel et al. 2001). PCC compares the proportion of outcomes correctly classified. In this application, sensitivity represents the proportion of true positives correctly identified, and specificity is the proportion of true negatives correctly identified, where 1-specificity is the proportion of false positives.

In addition to the threshold-dependent model performance statistics, a threshold-independent measure of model performance was also used: the area under the receiver operating characteristic (ROC). This measure indicates the probability of detecting a true signal (sensitivity) versus a false signal (1–specificity) (Hosmer and Lemeshow 2000). The area under the ROC is interpreted based on the following general rule (Hosmer and Lemeshow 2000: 162):

- If ROC = 0.5, this suggests no discrimination (i.e., the net result is the same).
- If 0.7 ≤ ROC less than 0.8, this is considered acceptable discrimination.
- If 0.8 ≤ ROC less than 0.9, this is considered excellent discrimination.
- If ROC ≥ 0.9, this is considered outstanding discrimination.

Similar to Perry et al. (2012), the fit of the GLM of juvenile Chinook salmon predation in 2009/2010/2012 was assessed by plotting the observed response in relation to model predictions. This involved plotting predation proportions in light (≥ 5.4 lux) and dark (< 5.4 lux) conditions across all three levels of the barrier status predictor (non-physical barrier on, non-physical barrier off, and physical rock barrier) versus the predicted predation probabilities, using the average continuous covariate values for each of these levels.

5.4 EVALUATION OF BEHAVIOR AND DENSITY CHANGES IN PREDATORY FISHES

5.4.1 PREDATORY FISH ACOUSTIC TAGGING

FIELD METHODS

Predatory fish (striped bass, largemouth bass, channel catfish, and white catfish) at the HOR study area were captured by hook-and-line fishing using bait and artificial lures, primarily in 2011 and 2012. Three additional fish were captured and tagged in 2009 and 2010; two fish (both striped bass) tagged outside the study area that moved into the HOR study area were also included in the analysis. Barbed circle hooks were used during bait fishing to minimize hooking injuries. Captured predatory fish having hooking or other injuries and/or displaying obvious abnormal behavior were released immediately and not included in the study. Predatory fish capture occurred primarily from fishing boats, but also from shoreline locations such as the sandy point on the right bank of the San Joaquin River across from the divergence with Old River. Hooks were removed carefully immediately after capture, and fish were placed in aerated live wells (1,500 gallons per hour pumping capacity) filled with water of temperature nearly identical to river temperature. To increase tagging efficiency, tagging generally was undertaken after several fish had been captured (holding duration generally was no more than 1 to 2 hours, and sometimes less than 1 hour). Tagging took place either on board the fishing boat or on the sandy point mentioned previously.

Predatory fish retained for tagging were identified to species and had length (FL in 2011, TL in 2012) and weight (2012) recorded. Tagged predatory fish generally were 30 cm or longer to allow a focus on the individuals most likely to prey on primarily juvenile Chinook salmon. Predatory fish typically consume prey that is 20% to 30% of their length (Uphoff 2003), and thus, would have greater potential to consume juvenile Chinook salmon of approximately 80 to 100 mm when 30 cm or larger. It is acknowledged that predatory fish occur at smaller sizes than 30 cm. Fish were fitted with HTI 795*LX* or 795*LG* tags (see Table 5-2) that were attached externally in the same manner described by Vogel (2011). External tag attachment consisted of two plastic-coated stainless steel wires attached to the transmitter, inserted through the musculature under the dorsal fin using hypodermic needles, and held in place with two plastic plates crimped on the opposite side of the fish.

Each tag had a unique four-digit identifier that was used to cross-reference detections with the identity and characteristics of tagged fish as recorded in field datasheets. The life span of the tags used in this study is several hundred days, depending on pulse width and pulse rate interval.

Fish generally were released where they were tagged. In 2011, fish releases typically occurred near capture locations. In 2012, fish were released near capture locations (which included the San Joaquin River upstream of the HOR study area and Old River downstream of the HOR study area, to allow an examination of how predatory fish behaved in relation to each of the barriers), from the sandy point referenced previously, or from other locations chosen to ensure that the fish remained within the range of the acoustic array. Fish tagging lasted from May 6 through June 15 in 2011 and from April 22 through May 24 in 2012.

DATA ANALYSIS

A total of 102 predatory fish were captured and tagged (including two individuals captured and tagged elsewhere in the south Delta), but only 84 were detected within the acoustic array at the HOR study area and were included in this analysis. The acoustic tags used for predatory fish in this study emitted double pulses every few seconds. Only the first of the double pulses was used in the present analysis.

Residence Time

Residence time at the HOR study area is an important factor because it has implications for the feasibility of predatory fish control (Gingras and McGee 1997). The length of time that each tagged predatory fish spent at the HOR study area was estimated based on detections by the HTI array and summarized as the number of days detected. Examination of the data indicated that several fish were not detected continuously for long periods, but were frequently detected over many days, suggesting that they occupied areas on the periphery of the array's detection ability. In addition, the potential length of time that each tagged fish could spend at the HOR study area depended on when each fish was tagged relative to the deactivation and removal of the acoustic array at the end of the study period. Deactivation/removal dates were May 20, 2009, May 25, 2010, June 22, 2011, and May 31, 2012.

To account for these factors, the percentage of possible dates that a tagged predator spent at the HOR study area between tagging/release and array deactivation/removal was calculated. For example, largemouth bass tag code 3324 was captured, tagged, and released on May 24, 2011, and subsequently detected from June 9 through 11, June 13, June 15 through June 18, and June 20 through June 22, 2011, for a total of 11 dates detected out of 29 dates between the day of tagging and the day of array deactivation/removal (i.e., 38%). Data calculated in this manner for all individual fish were then summarized for several groups defined by species, year, and—for 2012 data only—location of release (referred to as "San Joaquin River" for fish released upstream of the physical rock barrier and "Old River" for fish released downstream of the rock barrier).

Few fish (one largemouth bass and four striped bass, including two individuals captured outside the HOR study area) were tagged in 2009 and 2010. The striped bass were grouped together for analysis because BAFF was installed in both years. A resampling method ("bootstrapping") (Brown et al. 2012) was used to produce statistical summaries of the data to account for the small sample sizes (i.e., relatively few [generally less than 10] fish in each species/year/release location group). For each species/year/release location group, the percentage-of-dates-detected data for fish within the group were resampled with replacement until each resample contained the same number of observations (fish) as the original sample. This procedure was repeated 10,000 times, and the arithmetic mean was calculated for each of the 10,000 resamples. The 10,000 resamples were then used to generate statistical summaries for the percentage of dates detected within each species/year/release location group. The quantities estimated included the mean (50th percentile of the 10,000 resamples), interquartile range (25th and 75th percentiles of the 10,000 resamples), and 95% confidence interval (2.5th and 97.5th percentiles of the 10,000 resamples).

Spatial Analysis

A GIS map of the HOR study area was divided into zones to facilitate spatial analysis (Figure 5-14). A total of 83 zones were delineated on the basis of bathymetric features such as the scour hole, proximity to shoreline, and the locations of the 2012 rock barrier and the 2009/2010 BAFF alignments. Three major groupings of zones encompassed the San Joaquin River upstream of the divergence with Old River (zones 1–33), San Joaquin River downstream of the divergence with the Old River (zones 34–59), and the HOR (zones 60–83). Within each of these major zonal groupings, nearshore ("buffer") zones were within 5 m of shore, and offshore zones were greater than 5 m from shore. The scour hole in the San Joaquin River downstream of the Old River divergence was divided longitudinally (upstream/downstream) approximately in two, and several depth zones were defined on the basis of four major elevation ranges from 2012 bathymetric data:

- -12 to -17 feet [-3.66 to -5.18 m] NAVD of 1988 (zones 44, 45, 52, and 59)
- -17 to -27 feet [-5.18 to -8.23 m] (zones 46, 47, 53, 58)
- -27 to -32 feet [-8.23 to -9.75 m] (zones 48, 49, 54, and 57)
- deeper than -32 feet [-9.75 m] (zones 50, 51, 55, 56)

The 2012 rock barrier was represented by several zones encompassing the base of the barrier (zones 70–73) and the culverts (zones 67 and 75), in addition to near-field areas within 5 m of the barrier and its culverts (zones 65, 66, 68, and 69 upstream; zones 74, 76, 77, and 78 downstream). The extent of the barrier base that was accessible by fish in 2012 was variable based on water level; the trapezoidal shape of the barrier (relatively narrow top tapering to a wider base) is evident in the aerial image underlying Figure 5-14 (the top of the barrier is the white area in zones 70–73). The immediate (within 5 m) vicinity of the BAFFs was delineated for the 2009 (zones 27–33) and 2010 (zones 20–26) alignments.

Geo-referenced datasets (easting and northings, UTM Zone 10 N) of confirmed positive detections (i.e., "positive echoes") were output for each tagged predatory fish. To facilitate manipulation of the very large datasets generated during the study for spatial analysis, eastings and northings were rounded to the nearest meter for each detection. A grid of 1-m by 1-m points was generated that included the area of the HOR study area spatial zones (Figure 5-14), so that each grid point was assigned to a single spatial zone. Each predatory fish detection was merged with the database of grid points and spatial zones. The number and percentage of detections occurring within each spatial zone was calculated for each predatory fish. Similar to the analysis of residence time (described previously), the percentage of detections was summarized statistically for each species/year/release location group using 10,000 resamples of grouped spatial zones. Only predatory fish with at least 1,000 detections were included in the analysis to exclude information on fish that rapidly left the study area. The threshold of 1,000 detections was chosen on the basis of this value generally representing at least several hours of continuous detections, as opposed to rapid exit from the study area. In addition, only species, year, and release location groups with at least three tagged fish were included in the analysis.[1] A total of 14 spatial zone groupings were used for the analysis:

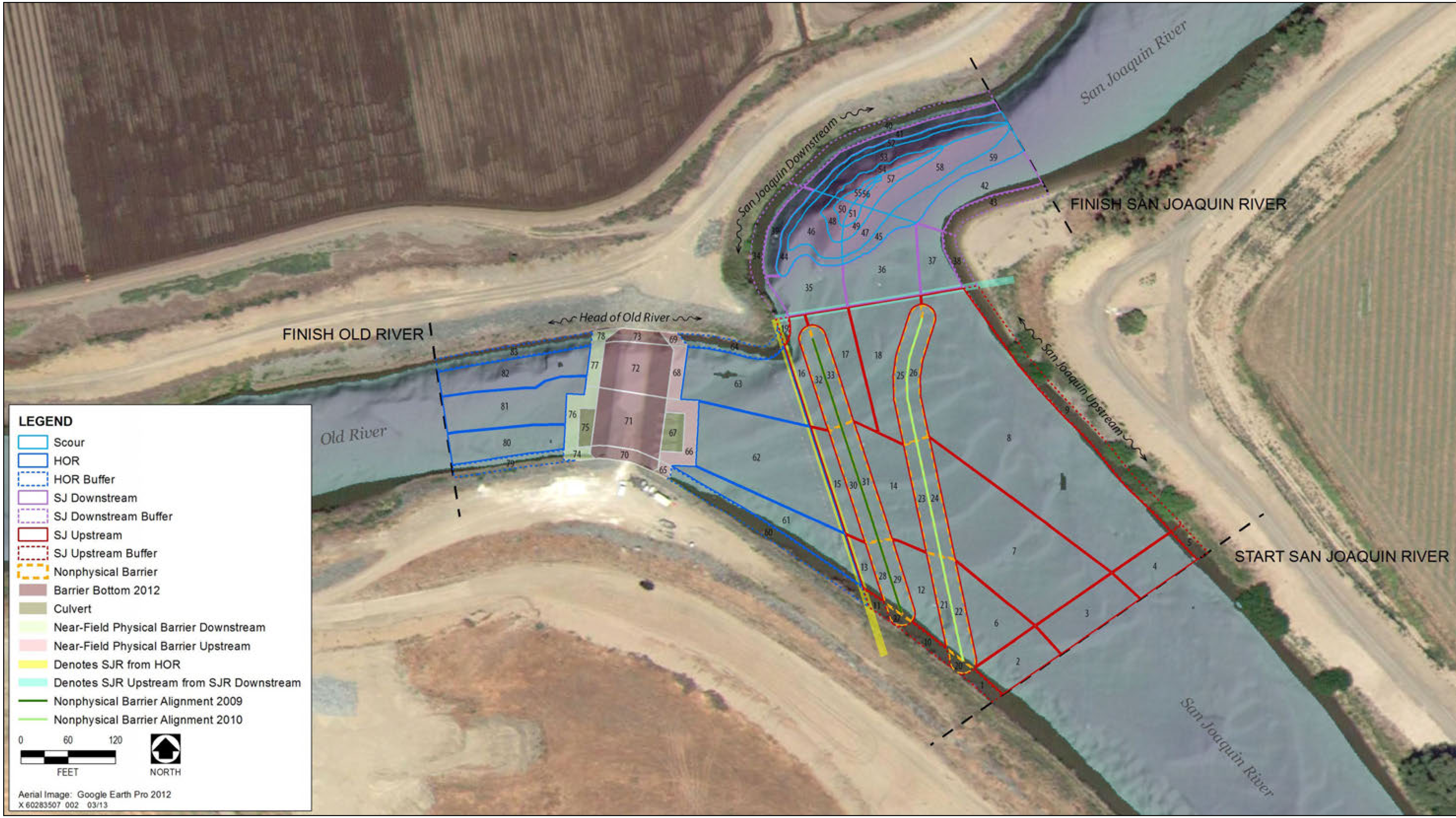
- San Joaquin River upstream of the Old River divergence, offshore (zones 2–4, 6–8, 12–18)
- San Joaquin River upstream of the Old River divergence, nearshore (zones 1, 5, 9–11, 19)

[1] Two striped bass (tag codes 2024 and 2472) that were tagged and released in 2010 met the criterion of 1,000 detections, but no other striped bass met this criterion in 2010. The results of these fish are discussed separately because their association with the 2010 BAFF is of management interest. For the same reason, the results for largemouth bass tag code 4306 are discussed in relation to the 2009 BAFF.

- Less than 5 m from the 2010 non-physical barrier (zones 20–26)
- Less than 5 m from the 2009 non-physical barrier (zones 27–33)
- San Joaquin River downstream of the Old River divergence, offshore (zones 35–37, 39, 41–42)
- San Joaquin River downstream of the Old River divergence, nearshore (zones 34, 38, 40, 43)
- Scour hole (zones 44–59)
- Head of Old River upstream of the 2012 rock barrier, offshore (zones 61–63)
- Head of Old River upstream of the 2012 rock barrier, nearshore (zones 60, 64)
- Near-field (less than 5 m) upstream of the 2012 rock barrier (zones 65–69)
- 2012 rock barrier (zones 70–73)
- Near-field (less than 5 m) downstream of the 2012 rock barrier (zones 74–78)
- Head of Old River downstream of the 2012 rock barrier, offshore (zones 80–82)
- Head of Old River downstream of the 2012 rock barrier, nearshore (zones 79, 83)

The spatial zones differ in size, and therefore, also differ in the number of 1-m by 1-m grid points that they possessed. To provide an indication of the extent of use of each zone relative to its size, a simple index was calculated for each group of spatial zones: percentage of detections within the grouped zone divided by percentage of grid points within the grouped zone. Values greater than 1 for this index indicated that the zone was used more frequently than would be expected based on its relative size. Predatory fish tagged in 2012 were released into either Old River downstream of the 2012 rock barrier or the San Joaquin River upstream of the 2012 rock barrier; therefore, the number of grid points used as the denominator in the calculation was adjusted to exclude the zones to which the fish would not have had access. This included the apparently unwetted portions of the 2012 rock barrier (i.e., zones 70–73 in Figure 5-14) that formed the bottom of the barrier. This adjustment removed approximately 79% of the area of zones 70–73 from consideration for fish released into the Old River downstream of the rock barrier in 2012, and approximately 71% of the area of zones 70–73 for fish released upstream of the rock barrier in 2012. In addition, the 2011 acoustic array was not able to detect fish beyond the zones downstream of the 2012 rock barrier bottom, so these zones were excluded from the calculations for fish released in 2011.

Near-surface water velocity within the areas occupied by tagged predatory fish in 2012 was estimated using velocity fields estimated from data collected with the SL-ADCP (see Section 3.2, "Velocity Field"). Tag detection data for each tagged predatory fish released upstream of the 2012 rock barrier that had more than 1,000 detections was merged with the 15-minute estimated velocity data. This was done by assigning each tag detection to the nearest 5-m by 5-m velocity grid point for the same 15-minute period in which the tag detection had occurred. Only tag detections within the grid of velocity estimates were included. The velocities at which each tagged fish had occurred were compared to all of the velocities that had occurred within the HOR study area at the time the fish had been detected. This was accomplished by comparing medians and by examining graphically the percentage of observations in velocity increments rounded to the nearest 0.05 m/s. Only velocity magnitude was considered (i.e., direction was not included in the analysis). Similar to the index of spatial use described above, an index of velocity occupied in relation to available velocity was calculated for each individual of each species; values greater than 1 suggested that fish occupied a particular velocity in greater proportion than its availability. As with the residence time and spatial analyses, statistical summaries of the data for each species were generated from 10,000 resamples of the velocity index results. Higher velocities that occurred only for some individuals within a given species were excluded from the analysis.



Sources: DWR 2012; Bianchini and Cane pers. comms., 2013; Present study; Data compiled by Turnpenny Horsfield Associates and AECOM in 2013

Figure 5-14 **Spatial Zones Used in the Analysis of Predatory Fish and Predation at the Head of Old River**

Emigration from the area of the HOR study area was determined for fish that left the study area before the deactivation of the acoustic array. Each fish was classified as having emigrated upstream (in the San Joaquin River) or downstream (into Old River or San Joaquin River) based on the final zone of detection. In addition to fish evaluated from 2009 through 2011, only the fish tagged and released to the upstream side of the 2012 rock barrier were included in this analysis.

Stationary Tag Locations

Information on spatial distribution of predatory fish at the HOR study area was provided by acoustic tagging (as described previously) and hydroacoustic surveys (as described under "Data Analysis" in Section 5.4.2, "Hydroacoustic Surveys"). Additional information on predator locations was obtained by examining the locations of stationary tags from juvenile salmonids. Stationary tags may represent juveniles that were preyed upon and subsequently defecated by predatory fish (or other predators) (Vogel 2011). Areas of high predation—or at least areas of high tag defecation—have been inferred from relatively high numbers of stationary tags, and include locations such as the trash racks leading to the Tracy Fish Facilities, Grant Line Canal, San Joaquin River near Stockton, and in some years, the HOR (SJRGA 2013).

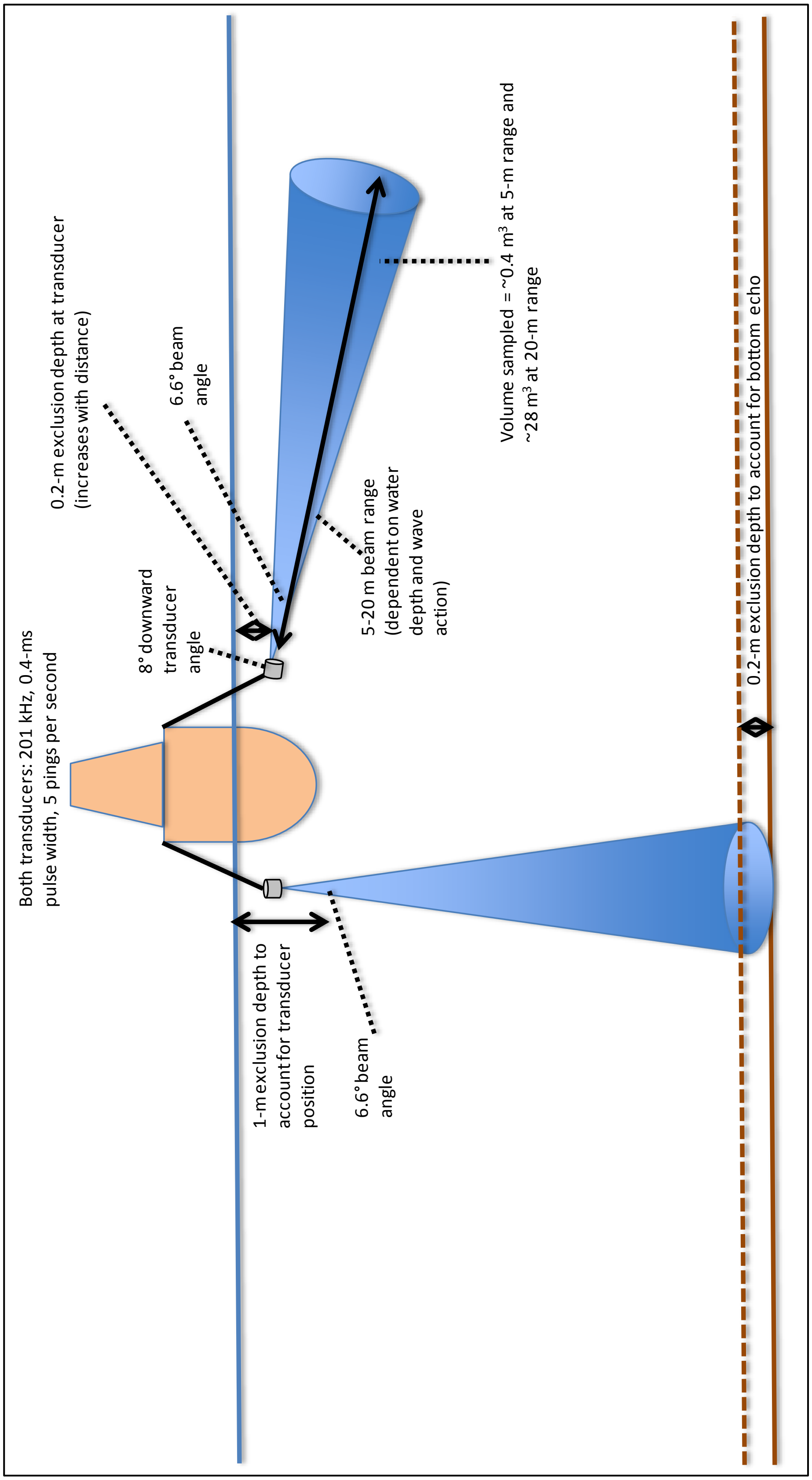
The locations of stationary salmonid tags at the HOR study area from 2009 through 2012 were plotted with GIS and enumerated by spatial zone, separating tags by salmonid species (Chinook salmon or steelhead) and year.

5.4.2 HYDROACOUSTIC SURVEYS

SURVEY METHODS

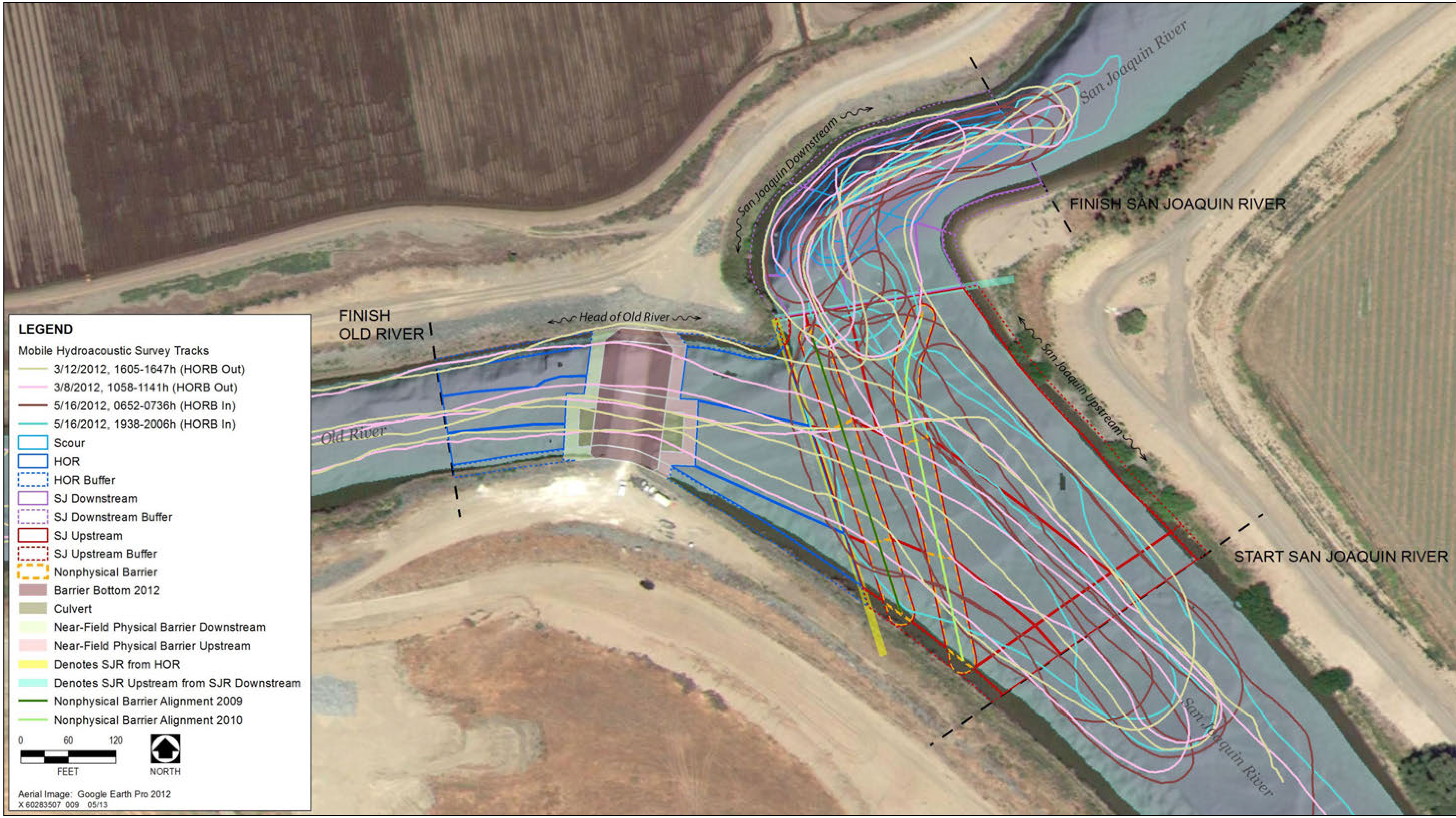
Mobile hydroacoustic surveys were conducted at the HOR study area to provide information on fish distribution and fluxes in fish density; surveys also were conducted at three reference sites. Mobile survey methods were similar to those used by Miranda et al. (2010) during the fish salvage facilities' Release Site Predation Study. Much of their description of the methods they used is provided herein. The acoustics unit employed for the mobile hydroacoustics survey was a BioSonics DT6000 split-beam system (BioSonics, Seattle, Washington). The unit employed two 201-kHz transducers, with one transducer mounted to point vertically down into the water column and the other mounted to point laterally off to the port side of the survey vessel (Figure 5-15). The acoustics unit used a -70-decibel (dB) threshold. A Wide Area Augmentation System-enabled E-Trex Vista (Garmin International, Olathe, Kansas) GPS unit was connected to the surface unit, and a location was recorded for each target detected.

Mobile hydroacoustic surveys consisted of driving the boat through the area of the HOR study area at a speed of approximately 7.2 km per hour (4.5 miles per hour). Surveys at the HOR study area typically lasted 30 to 40 minutes, and each individual survey covering all four sites generally lasted approximately 2 hours (Table 5-6). Nearly all surveys included sampling at all four sites. In 2011, sampling that yielded usable data was undertaken at the HOR study area during all 23 surveys (compared to 21 surveys for site 1 and 22 surveys for sites 2 and 4). In 2012, sampling that yielded usable data was undertaken on 26 of 29 surveys at the HOR study area (compared to 29 surveys for site 2, 27 surveys for site 1, and 28 surveys for site 4). Example survey paths from March and May 2012 are illustrated in Figure 5-16, with the physical rock barrier out and in, respectively.



Source: Present study.

Figure 5-15 **Schematic Diagram of Mobile Hydroacoustic Survey Equipment**



Sources: DWR 2012; ICF International 2013; AECOM 2013

Figure 5-16 **Examples of Mobile Hydroacoustic Survey Tracks with Head of Old River Barrier In and Out**

Table 5-6
Start and End Times of Mobile Hydroacoustics Surveys, 2011 and 2012

Survey Number	2011		2012	
	Start	End	Start	End
1	5/16/11, 16:30	5/16/11, 19:02	3/8/12, 9:14	3/8/12, 12:19
2	5/16/11, 20:03	5/16/11, 22:36	3/12/12, 13:40	3/12/12, 16:14
3	5/16/11, 23:25	5/17/11, 1:00	3/14/12, 13:56	3/14/12, 16:25
4	5/18/11, 7:46	5/18/11, 10:47	3/15/12, 6:44	3/15/12, 9:33
5	5/18/11, 11:52	5/18/11, 14:42	5/2/12, 6:48	5/2/12, 9:04
6	5/18/11, 17:36	5/18/11, 20:25	5/2/12, 9:18	5/2/12, 11:29
7	5/18/11, 21:16	5/18/11, 23:55	5/3/12, 8:55	5/3/12, 11:18
8	5/23/11, 7:56	5/23/11, 10:50	5/3/12, 12:17	5/3/12, 14:10
9	5/23/11, 11:49	5/23/11, 14:40	5/15/12, 6:43	5/15/12, 8:57
10	5/23/11, 18:34	5/23/11, 21:13	5/15/12, 10:22	5/15/12, 12:29
11	5/23/11, 21:57	5/24/11, 0:30	5/15/12, 16:50	5/15/12, 18:56
12	5/25/11, 7:49	5/25/11, 10:20	5/16/12, 4:41	5/16/12, 7:01
13	5/25/11, 11:09	5/25/11, 13:49	5/16/12, 9:55	5/16/12, 11:50
14	5/25/11, 18:30	5/25/11, 21:07	5/16/12, 17:35	5/16/12, 19:28
15	5/25/11, 21:56	5/26/11, 0:37	5/17/12, 4:42	5/17/12, 6:37
16	6/6/11, 14:26	6/6/11, 17:43	5/17/12, 10:28	5/17/12, 11:11
17	6/6/11, 18:28	6/6/11, 21:17	5/22/12, 4:55	5/22/12, 7:03
18	6/6/11, 21:53	6/7/11, 0:37	5/22/12, 8:36	5/22/12, 11:03
19	6/7/11, 9:02	6/7/11, 12:01	5/23/12, 4:28	5/23/12, 6:24
20	6/8/11, 9:19	6/8/11, 12:05	5/23/12, 6:41	5/23/12, 8:07
21	6/8/11, 12:23	6/8/11, 15:11	5/23/12, 17:42	5/23/12, 19:19
22	6/8/11, 18:59	6/8/11, 21:14	5/24/12, 4:42	5/24/12, 6:34
23	6/8/11, 21:35	6/9/11, 0:13	5/24/12, 6:49	5/24/12, 8:50
24			5/24/12, 11:28	5/24/12, 13:11
25			5/29/12, 15:34	5/29/12, 17:11
26			5/30/12, 4:18	5/30/12, 6:03
27			5/30/12, 13:30	5/30/12, 15:39
28			5/31/12, 4:41	5/31/12, 5:56
29			5/31/12, 6:50	5/31/12, 8:28

Source: Present study

Mobile hydroacoustic surveys also were conducted at three reference sites to provide comparisons to fish density at the HOR study area. The reference sites were on river bends and possessed deep holes somewhat similar to the HOR study area (Figure 5-17). A summary of water depths encountered by down-looking mobile hydroacoustic surveys in 2012 is provided in Table 5-7.

Table 5-7 Summary of Water Depths during Mobile Hydroacoustic Surveys in 2012								
Statistic	Site 1		Site 2		HOR		Site 4	
	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
Minimum	0.7	2.4	0.9	2.8	0.9	3.0	0.8	2.7
5th Percentile	1.6	5.3	2.5	8.1	1.5	5.0	1.6	5.3
25th Percentile	2.5	8.1	4.1	13.3	2.3	7.4	2.3	7.5
Median	3.4	11.1	5.5	17.9	2.8	9.3	3.3	10.8
75th Percentile	5.6	18.5	6.7	21.9	4.3	14.0	4.5	14.9
95th Percentile	8.3	27.3	8.2	27.0	9.1	29.9	7.4	24.3
Maximum	10.0	32.7	10.5	34.5	11.6	38.2	8.2	26.8

Note: HOR = Head of Old River
Source: Present study

DATA ANALYSIS

Echo Counting/Processing

Echo counting methods following those described by Miranda et al. (2010) were used to measure acoustic target strength (fish size). The account herein was adapted from that of Miranda et al. (2010), and a useful introduction to fisheries acoustics is provided by Rudstam et al. (2012). Target strengths were measured using split-beam techniques for all sample locations. The target strength of a fish generally is related to the size of the fish, and is a measure of the capacity of a fish to reflect sound energy. Target strength, measured in units of decibels, is calculated from the energy reflected from the target, and is a function of the cross-sectional area of the target and the density difference between water and the component parts of the target (e.g., bones, scales, flesh, gas bladder).

Fish orientation, and to an extent species, can play a significant role in estimation of target size. The dB scale used to measure fish size is logarithmic and referenced in negative numbers (i.e., where the larger the negative number, the smaller the fish). Fish size was estimated from echo target strength using the following equation (Horn, pers. comm., 2013):

$$\text{Fish TL (cm)} = 1{,}529 * e^{(-0.1142*|\text{Target Strength (dB)}|)}$$

Thus, for example, an echo intensity of -30 dB is estimated to be a fish of nearly 50 cm, whereas an echo intensity of -40 dB is estimated to be a fish just less than 16 cm. These sizes assume a transducer is looking down on a perfectly oriented fish from above. This is typically the case when looking down on a fish. When looking from the side, however, fish may not be perfectly oriented parallel to the transducer. When this occurs, a fish target will appear smaller than it actually is due to the reduced cross-sectional area of the target. Little can be done to rectify this problem.

Source: Present study

Figure 5-17 **Locations of Head of Old River and Reference Mobile Hydroacoustic Survey Sites**

The SonarData software package, Echoview v4.x (Myriax Software, Hobart, Tasmania, Australia) was used to analyze all data. The echogram was reviewed to locate individual fish targets, which were acquired and logged to data files. An amplitude threshold was used to reject echoes smaller than a predetermined voltage, and areas of high acoustic noise were manually removed from the raw echogram data prior to analysis by defining a line or region below which any data are ignored during the analysis phase (see Figure 38 in Miranda et al. 2010:87). Analyses of acoustic data consisted of a series of post-processing steps that are described in Appendix J of Miranda et al. (2010): observation, calibration and thresholding, regions for exclusion (noise), echo extraction, and output formatting/quality assurance. Considerable debris and acoustic noise within the system, as well as the study's emphasis on larger, potential predatory fish, led to the use of a target strength threshold of approximately 15 cm TL (i.e., approximately -40 dB), with fish less than this size being excluded from the data outputs.

The number of targets (assumed to be fish) detected, mean target strength, and beam volume sum were output into a number of "bins" of information from each survey at each site. Data from 2011 were output into bins of 200 pings, whereas data from 2012 were output into bins of 100 pings. Potential predator-sized targets were assessed to be those estimated to be greater than 30 cm TL for consistency with sizes of predatory fish studied with acoustic tagging (see "Field Methods" in Section 5.4.1, "Predatory Fish Acoustic Tagging"). Analyses focused on the targets that measured greater than 30 cm TL, with other fish being binned into a 15- to 30-cm TL size class. In addition to binned outputs, data on each individual target were output, and included target strength (fish size), location (latitude/longitude), target water depth, and total water column depth (for down-looking hydroacoustic data).

Statistical Methods

Areas Occupied

Data derived from mobile hydroacoustic surveys in 2011 and 2012 were used to address several of the study objectives. GIS plots of individual targets (estimated to be greater than 30 cm TL) were made to illustrate fish distribution within the study area, particularly with respect to habitat features such as the scour hole. The number of targets from down- and side-looking transducers were summed for each spatial zone.

Density Changes

Changes of greater than 30 cm TL fish density (abundance per unit volume) at the HOR study area in 2011 and 2012 were examined in relation to several environmental variables that could influence density and that were included in the analysis of probability of predation of juvenile salmonids: water temperature, discharge, turbidity, light level, and small fish density. Features of the environmental data are summarized in Table 5-8. Abiotic habitat variables such as water temperature have been shown to correlate with movements and behavior of predatory fish such as striped bass (e.g., upstream movement in spring for spawning purposes; Moyle 2002). Biotic variables such as prey fish density have also been hypothesized to influence striped bass distribution (e.g., predators moving to areas where prey are relatively abundant; LeDoux-Bloom 2012). For some predatory fish species such as largemouth bass, habitat suitability may be inversely related to river discharge and channel velocity (Stuber et al. 1982).

Table 5-8
Summary of Predictor Variables Used in GLM of Abundance of Fish Greater than 30 cm TL at the Head of Old River Study Area

Variable (Unit)	Location	Source	Transformation	Notes
Water Temperature (°C)	SJL	CDEC (Baldwin, pers. comm., 2013)	None	15-minute average data
River Discharge (m^3/s)	SJL	CDEC (Baldwin, pers. comm., 2013)	None	15-minute average data
Turbidity (NTU)	MSD	CDEC (Dempsey, pers. comm., 2013)	None	15-minute average data
Ambient light (lux)	Manteca (CIMIS site #70)	CIMIS (State of California 2009)	Natural logarithm + 1	Original CIMIS data (Langley/day) were first converted into PAR per Clark et al. (2009: PAR, µmol/m^2/s = 1.1076*Langley/day), and subsequently PAR was converted into lux per Apogee Instruments, Inc. (2013: Lux = 54*PAR). Original hourly data were linearly interpolated to 15-minute increments for consistency with water quality data.
Small-fish density (fish < 15 cm FL/10,000 m^3)	Mossdale (trawling)	USFWS survey data (Speegle, pers. comm., 2011 and 2013)	Natural logarithm + 1	

Notes: °C = degrees Celsius; CDEC = California Data Exchange Center; CIMIS = California Irrigation Management Information System; cm = centimeters; m^3 = cubic meters; m^3/s = cubic meters per second; MSD = San Joaquin River at Mossdale; NTU = nephelometric turbidity units; PAR = photosynthetically active radiation; SJL = San Joaquin River at Lathrop; USFWS = U.S. Fish and Wildlife Service
Source: Present study

In contrast to the analysis of predation probability, however, the analysis of changes in predatory fish density (as represented by density of echoes greater than 30 cm TL) in relation to environmental variables was more of an exploratory analysis that relied on a model-averaging approach to examine support for the influence of the different variables on predatory fish density. Accordingly, the analysis was conducted to test the null hypothesis $H14_0$ (see "Objectives and Hypotheses Related to Changes in Density of Predatory Fishes" in Section 1.2.4, "Behavior and Density Changes in Predatory Fishes").

The analysis of changes in density in relation to environmental variables was conducted with GLM within a model averaging/information theoretic framework similar to that used for modeling predation probability of juvenile salmonids (see Section 5.3.2, "Probability of Predation [Generalized Linear Modeling]"). The number of fish targets greater than 30 cm TL in each survey at the HOR study area was modeled in the GLM as a count response variable with a negative binomial error structure and logarithmic link function, incorporating the beam volume sum as an offset to account for differences in the volume of water ensonified with the acoustic equipment during each survey.

The glmulti package was used to provide all possible first-order GLMs for fish targets greater than 30 cm TL as a function of water temperature, discharge, turbidity, light, and small-fish density (i.e., a measure of potential prey for predatory fish). The relative level of support for each possible model was estimated in glmulti with the quasi-likelihood equivalent of AIC corrected for small sample sizes ($QAIC_c$) (Mazerolle 2006). The variance inflation factor, $\hat{c}$, required to compute $QAIC_c$ was estimated by initially running a single GLM with all predictor variables included, and then providing $\hat{c}$ to the glmulti package for the automated model averaging procedure. The difference in $QAIC_c$, Δ_i, between each model and the best model (i.e., the model with the lowest $QAIC_c$) was calculated, and Akaike weights (w_i) were calculated based on the Δ_i. Model averaging of the predictor variable coefficients was undertaken based on the Akaike weights for each model, and unconditional confidence intervals were calculated for each coefficient (Mazarolle 2006). The importance of each predictor variable was assessed by summing the w_i of all models in which the variable appeared. Following Calcagno and de Mazancourt (2010), importance of 0.8 or greater was used to infer support for a variable's potential influence on greater than 30-cm fish density, in addition to unconditional 95% confidence intervals for variable coefficients not overlapping zero (per Zeug and Cavallo 2013). GLMs, including predictors, were assessed to provide a better fit to the data than intercept-only models if the $QAIC_c$ of the full models (with all predictors included) was 3 or more units greater than the $QAIC_c$ of the intercept-only models (Zeug and Cavallo 2013).

Four sets of GLM analyses were included, with two each for the down-looking and side-looking greater than 30-cm fish density data. "Same-day" GLM analyses used water quality and light variables that were averaged based on the time that the survey had occurred at the HOR study area (e.g., if a survey took place between 0500 and 0545 hours, the water quality data and light data were the average values for this time period).

The small-fish density data variable from Mossdale trawling was based on the mean daily densities from the day of the mobile hydroacoustic survey and the previous 2 days (see description of calculation of abundance index in Section 2.2.3, "River Channel Mossdale Trawl"), because trawling did not necessarily occur daily and it was desirable to retain all mobile hydroacoustic survey data points. (The 3-day-average small-fish density avoided censoring of mobile hydroacoustic data because of missing data.) It was felt that this was a reasonable approach to provide a general indication of small-fish (potential prey) density in the area at the time of the mobile hydroacoustic surveys, given that the Mossdale trawl site is upstream of the HOR study area, and there would be some delay in fish reaching the HOR study area, coupled with natural variability in these data.

The "7-day" GLM analyses used water-quality and small-fish-density data averaged over the time of the mobile hydroacoustic survey and the 6 days. These analyses were included to account for potential longer-term environmental influences on greater than 30-cm fish density at the HOR study area. Light data for the GLM analyses were identical to those for the "same-day" analyses because light level was hypothesized only to be a short-term potential influence on density.

Comparisons to Reference Sites

The HOR study area was compared to the three reference sites to assess whether changes in greater than 30-cm fish density were correlated and to assess the evidence for common environmental influences on fish density (e.g., migration). Density (number of targets per 10,000 cubic meters) of greater than 30-cm fish from each survey at the HOR study area were paired with corresponding densities from the same survey at each reference site. Density data were incremented by 1 to account for 0 values and natural-log-transformed to accommodate the assumptions of the parameter statistical tests. Pearson correlation analyses were used to test the null hypothesis $H15_0$ (see "Objectives and Hypotheses Related to Density of Predatory Fishes" in Section 1.2.4, "Behavior and Density Changes in Predatory Fishes") of no significant correlation between density at the HOR study area with density at each reference site. A Bonferroni-adjusted statistical significance of $P < 0.017$ was used to correct for the three comparisons. The null hypothesis $H16_0$ of no significant difference in density between the HOR study area and the reference sites was tested using paired t-tests. Statistical analyses comparing the HOR study area to the reference sites were undertaken with SAS/STAT software, Version 9.3, of the SAS System for Windows.[2]

Diel Changes in Depth

Fish depth is of management interest because it influences capture methods that can be used for predatory fish. Fish are often found deeper in the water column by day (Hrabik et al. 2006; Miranda et al. 2010). In addition, large densities of common carp were visually observed in the vicinity of the physical rock barrier in 2012, suggesting that many large-fish targets detected with mobile hydroacoustics may not be predatory fish. Common carp are omnivorous bottom feeders (Moyle 2002) that would be expected to be associated with the bottom at all times of day. Depth of greater than 30-cm TL targets from down-looking mobile hydroacoustic surveys was examined in relation to total water column depth for evidence of changes in distribution with diel period. Following Hrabik et al. (2006), plots of individual target depth against distance from the bottom (based on water column depth) were made to assess differences between day, night, dawn, and dusk. Day was defined as greater than 1 hour after sunrise and before sunset, dawn was the 2-hour period centered around sunrise, dusk was the 2-hour period centered around sunset, and night was greater than 1 hour after sunset and before sunrise. Sunrise and sunset times were estimated for SJL using the National Oceanic and Atmospheric Administration's sunrise/sunset spreadsheet calculator (NOAA 2013).

[2] Copyright 2002–2010, SAS Institute (SAS). SAS and all other SAS Institute product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, North Carolina.

6 RESULTS

6.1 JUVENILE SALMONID ROUTING INCLUDING BARRIER EFFECTS

6.1.1 2009 RESULTS

SALMONID SIZE DISTRIBUTION

The juvenile Chinook salmon tagged and released in 2009 were smaller overall than those from any other year (Table 5-1). In addition, the tagged 2009 juvenile Chinook salmon were Feather River Fish Hatchery fall-spring–run hybrids; 2009 was the only year when this hatchery and these hybrids were used as a source of juvenile Chinook salmon.

OVERALL EFFICIENCY

Chinook Salmon

The data were evaluated to determine whether they satisfied the assumptions of ANOVA. In every case, except as noted in the following discussion, the data were not distributed normally and/or did not meet the assumption of homogeneity of variances. In general, the lack of normally distributed data stemmed from the common occurrence of 0.0 and 1.0 values in the samples. These categories tended to be among the most common values observed which resulted in many variables exhibiting a bimodal distribution.

The overall efficiency (O_E) was only 2.5 percentage points better with the BAFF on than off (Table 6-1). Only 20.9% of tags in juvenile Chinook salmon continued down the San Joaquin River with the BAFF on, compared with 18.4% with the BAFF off. These results suggested that the BAFF did not significantly change the proportion of fish remaining in the San Joaquin River in 2009 (i.e., hypothesis $H1_0$ was accepted).

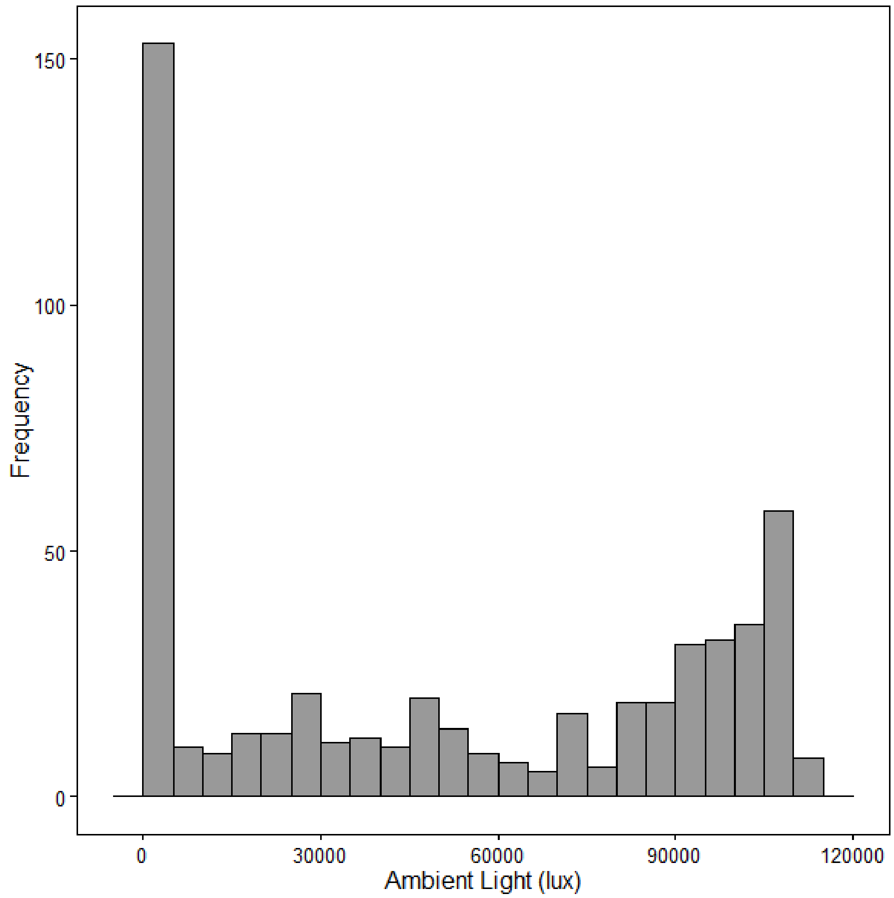
Table 6-1
Statistics for Overall Efficiency during BAFF Operations in 2009

Statistic	BAFF On	BAFF Off	Percentage Point Change	Kruskal-Wallis X^2	P-value
Mean	0.209	0.184	2.5	0.030	0.8635
Standard Deviation	0.218	0.185			
Minimum	0.000	0.000			
Maximum	0.750	0.500			
Samples (n)	21	27			

Notes: BAFF = bio-acoustic fish fence; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Effect of Ambient Light Level on Overall Efficiency

Tagged juvenile Chinook salmon approached the 2009 BAFF line at various light levels (Figure 6-1). When the 2009 fish were placed into samples, and the juvenile Chinook salmon O_E samples were partitioned by ambient light level, eight to 17 samples were distributed throughout the experimental matrix (Table 6-2). For high-ambient-light conditions, it was noted that O_E with the BAFF on was 9.9 percentage points higher than with the BAFF off (Table 6-3). However, there was no significant improvement in O_E with the BAFF on compared to off at either ambient light level. In 2009, it appeared that there was insufficient statistical power to resolve any effect or ambient light did not influence the BAFF's O_E.



Source: Data compiled by AECOM and Turnpenny Horsfield Associates

Figure 6-1 Frequency Histogram of 2009 Light-Level Observations (collected at CIMIS, Station #70–Manteca, 37.834822, -121.223194) Obtained for Each Tagged Juvenile Chinook Salmon when the Individual was Nearest the 2009 BAFF Line

Table 6-2
Summary of Overall Efficiency Samples for Tagged Juvenile Chinook Salmon Encountering the BAFF during On/Off Operations at Low and High Ambient Light Levels in 2009

Ambient Light Level	BAFF On (n)	BAFF Off (n)
Low Light (<5.4 lux)	8	10
High Light (≥5.4 lux)	13	17
Total	21	27

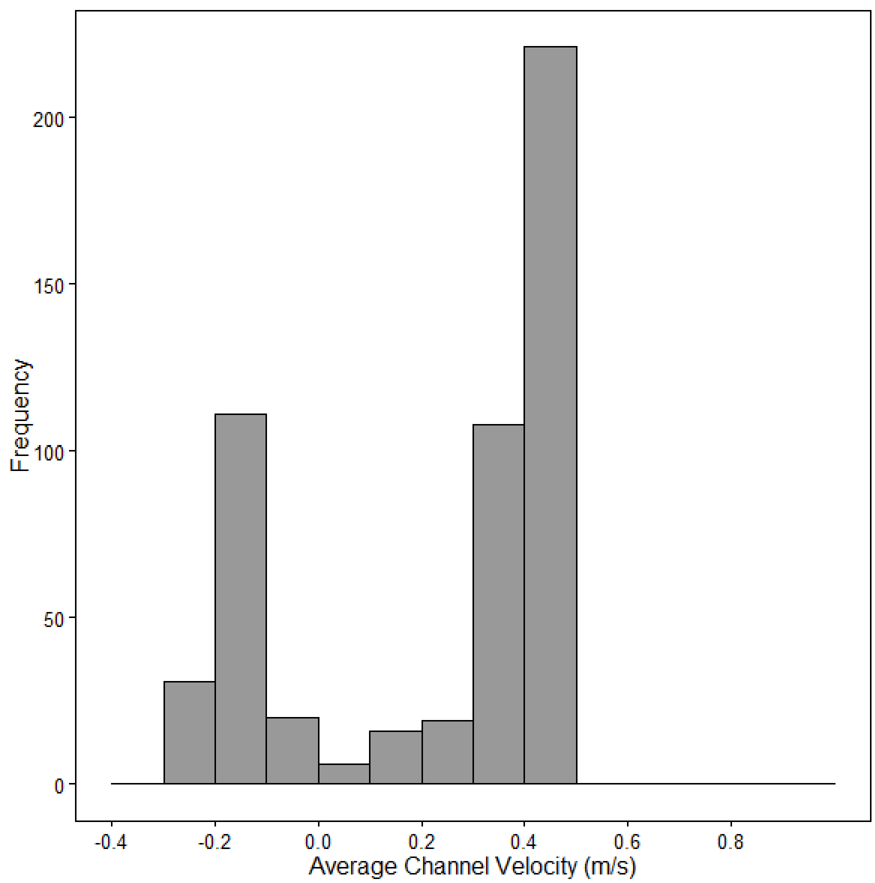
Notes: BAFF = bio-acoustic fish fence; n = number of overall efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-3 Mean Overall Efficiency of the BAFF for Tagged Juvenile Chinook Salmon at Low and High Ambient Light Levels in 2009					
Overall Efficiency—Ambient Light Level	BAFF On Mean	BAFF Off Mean	Percentage Point Change	Kruskal-Wallis X^2	P-value
Low Light (<5.4 lux)	0.068	0.159	-9.1	0.772	0.3797
High Light (≥5.4 lux)	0.297	0.198	9.9	1.131	0.2876

Notes: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Effect of Average Channel Velocity on Overall Efficiency

Tagged juvenile Chinook salmon approached the 2009 BAFF line at various average channel velocities (ACV) (Figure 6-2). When the 2009 fish were placed into samples and the O_E samples for juvenile Chinook salmon were partitioned by ACV value (low = less than 0.61 m/s ACV; high = greater than or equal to 0.61 m/s ACV), no samples existed at high ACV values (Figure 6-2). This result was expected because in 2009 the water year had the lowest discharge range and mean among the years studied. The maximum ACV recorded during the tagged juvenile Chinook salmon release period was 0.48 m/s.



Source: Data compiled by AECOM and Turnpenny Horsfield Associates

Figure 6-2 Frequency Histogram of 2009 Average Channel Velocity Observations (SJL Gauge) Obtained for Each Tagged Juvenile Chinook Salmon when the Individual was Nearest the 2009 BAFF Line

PROTECTION EFFICIENCY

BAFF protection efficiency (P_E) (efficiency after the removal from the data set of juvenile Chinook salmon that were eaten) was 0.234 with the BAFF off. The proportion of flow into the San Joaquin River during the study period was 0.35 (Table 3-1). Thus, in the present study, without the BAFF in operation, the fraction of juvenile Chinook salmon was smaller than the fraction of water entering the San Joaquin River. In contrast, in Table I-1 in Appendix I, "Route Entrainment Analysis at Head of Old River, 2009 and 2010," the proportion of flow entering the San Joaquin River was correlated with the probability that an individual juvenile Chinook salmon would continue down the San Joaquin River route. The model that included flow at the San Joaquin River at Lathrop (SJL) gauge fit the data better than did the proportion of flow into the San Joaquin River (Table I-2 in Appendix I).

P_E was 10.4 percentage points better with the BAFF on than with the BAFF off, but this result was not significant (Table 6-4) (i.e., hypothesis $H1_0$ was accepted). However, a comparison of Tables 6-1 and 6-4 showed that with "tagged juvenile Chinook determined to have been eaten" removed, the BAFF-on performance improved from an O_E of 20.9% to a P_E of 33.8%. These results showed that the BAFF maintained juvenile Chinook salmon in the San Joaquin River at a proportion (0.338) similar to the fraction of water entering the San Joaquin River (0.35) at the HOR study area. The GLM presented in Appendix I showed that with the BAFF on, there was a greater probability (P = 0.0010) that a juvenile Chinook salmon would enter the San Joaquin River route (Table 7-1 in Appendix I).

Table 6-4
Statistics for Protection Efficiency during BAFF Operations in 2009

Statistic	BAFF On	BAFF Off	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Mean	0.338	0.234	10.4	0.669	0.4133
Standard Deviation	0.330	0.220			
Minimum	0.000	0.000			
Maximum	1.000	0.667			
Samples (n)	18	25			

Notes: BAFF = bio-acoustic fish fence; n = number of protection efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Effect of Ambient Light Level on Protection Efficiency

When the samples for 2009 BAFF P_E were partitioned by ambient light level (Table 6-5), seven to 16 samples were found for various combinations of BAFF operations with ambient light levels. For high-ambient-light levels, it was noted that BAFF P_E with the BAFF on was 21.9 percentage points higher than with the BAFF off (Table 6-6); the statistical power of the test was only 0.435. In addition, there was no improvement in P_E with the BAFF on compared to the BAFF off at either ambient light level. In 2009, it appeared that there was insufficient power to resolve any effect, or ambient light did not influence BAFF P_E.

Table 6-5 Summary of Protection Efficiency Samples for Tagged Chinook Salmon Encountering BAFF during On/Off Operations at Low and High Light Levels in 2009		
Ambient Light Level	BAFF On (n)	BAFF Off (n)
Low Light (<5.4 lux)	7	9
High Light (≥5.4 lux)	11	16
Total	18	25

Notes: BAFF = bio-acoustic fish fence; n = number of protection efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-6
2009 BAFF Operations—Mean Protection Efficiency for Chinook Salmon at Low and High Light Levels

Ambient Light Level	BAFF On Mean	BAFF Off Mean	Percentage Point Change	Kruskal-Wallis X^2	P-value
Low Light (<5.4 lux)	0.108	0.178	-7.0	0.720	0.3960
High Light (≥5.4 lux)	0.484	0.265	21.9	3.126	0.0771

Notes: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Effect of Average Channel Velocity on Protection Efficiency

No samples were acquired under high-ACV conditions in 2009. Thus, sample sizes and means under low-velocity conditions were the same as those shown in Table 6-4.

DETERRENCE EFFICIENCY

For deterrence efficiency (D_E), some tags were removed for the calculation. If a tag was determined to have been eaten before it experienced the BAFF, then it was not included. D_E with the BAFF on showed a significant improvement (Kruskal-Wallis $X^2 = 11.398$, $P = 0.007$), 2.35 times greater, than D_E with the BAFF off (Table 6-7). Hypothesis $H1_0$ was rejected for D_E. It appeared that the BAFF was effective at deterring juvenile Chinook salmon when individuals approached the BAFF.

Table 6-7
Deterrence Efficiency Statistics for BAFF Operations in 2009

Statistic	BAFF On	BAFF Off	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Mean	0.732	0.311	42.1	11.398	0.0007
Standard Deviation	0.335	0.322			
Minimum	0.000	0.000			
Maximum	1.000	1.000			
Samples (n)	18	23			

Notes: BAFF = bio-acoustic fish fence; n = number of deterrence efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

The D_E with the BAFF off was 31.1%. This is the percentage of fish that exhibited movements that appeared to be movements away from the BAFF and toward the San Joaquin River, or movements of a fish guided along the line of, and past the end of, the BAFF. These movements may have occurred because the BAFF infrastructure took up some proportion of the water column, which may create turbulence or reflect ambient light. It is possible that a proportion of the fish would sense the turbulence created by the BAFF infrastructure or see ambient light reflected from barrier components and would move away from it or be guided along it.

The mean D_E with the BAFF on was 73.2% in the 2009 analysis reported. This is slightly less than the grand D_E reported in Bowen et al. (2012) of 81.4%. This difference arose from the reanalysis of the deterrence data in the present study because fish were placed into samples from the same time period with similar ambient light and ACV values when the fish arrived at the HOR study area (see definition of samples in Chapter 5, "Methods") instead of being placed in groups that were associated with the release date/time.

Effect of Ambient Light Level on BAFF Deterrence Efficiency

When the samples for 2009 BAFF D_E were partitioned by ambient light level (Table 6-8), seven to 15 samples were found for various combinations of BAFF operations and ambient light levels. For high-ambient-light conditions, it was noted that D_E with the BAFF on was 52.7 percentage points higher than with the BAFF off (Table 6-9), and this difference was significant. This result was consistent with the laboratory study of a BAFF by Bowen et al. (2009), which found the highest D_E for juvenile Chinook salmon occurred during the day and at the lower turbidity condition studied: 10 NTU. The lowest mean turbidity in the HOR study area of all the years studied, 19.9 NTU (Table 3-4), occurred in 2009.

Table 6-8
Summary of Deterrence Efficiency Samples for Tagged Juvenile Chinook Salmon Encountering BAFF during On/Off Operations at Low and High Light Levels in 2009

Ambient Light Level	BAFF On (n)	BAFF Off (n)
Low Light (<5.4 lux)	7	8
High Light (≥5.4 lux)	11	15
Total	18	23

Notes: BAFF = bio-acoustic fish fence; n = number of deterrence efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-9
2009 BAFF Operations—Mean Deterrence Efficiency for Tagged Juvenile Chinook Salmon at Low and High Light Levels

Ambient Light Level	BAFF On Mean	BAFF Off Mean	Percentage Point Change	Kruskal-Wallis X^2	P-value
Low Light (<5.4 lux)	0.474	0.202	27.2	2.330	0.1269
High Light (≥5.4 lux)	0.897	0.370	52.7	12.448	0.0004

Notes: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

There was an improvement of 27.2% in D_E with the BAFF on compared to operations with the BAFF off at low ambient light levels (Table 6-9). However, this result was not significant. In 2009, it was concluded that the BAFF delivered juvenile Chinook salmon deterrence (Table 6-9), and that the performance of the BAFF was the best at high ambient light magnitudes, in contrast to the findings of Welton et al. (2002), who found the highest proportion deflected at night.

Effect of Average Channel Velocity on Barrier Deterrence Efficiency

In 2009, all samples were categorized as "low velocity," where ACV is less than 0.61 m/s (= Approach Velocity <0.25 m/s). Thus, no comparisons of D_E at various ACV ranges were possible.

6.1.2 2010 RESULTS

SIZE AND SOURCE OF JUVENILE CHINOOK SALMON USED

The juvenile Chinook salmon tagged and released in 2010 were similar in size to those from 2011 and 2012, and larger than those from 2009 (Table 5-1). In 2010, and in all subsequent years of the research reported herein, the Merced River Hatchery was the source of juvenile Chinook salmon.

OVERALL EFFICIENCY

Chinook Salmon

The O_E for the BAFF was only 11.0 percentage points higher with the BAFF on than with the BAFF off, which was not statistically significant (Table 6-10); hypothesis $H2_0$ was accepted.

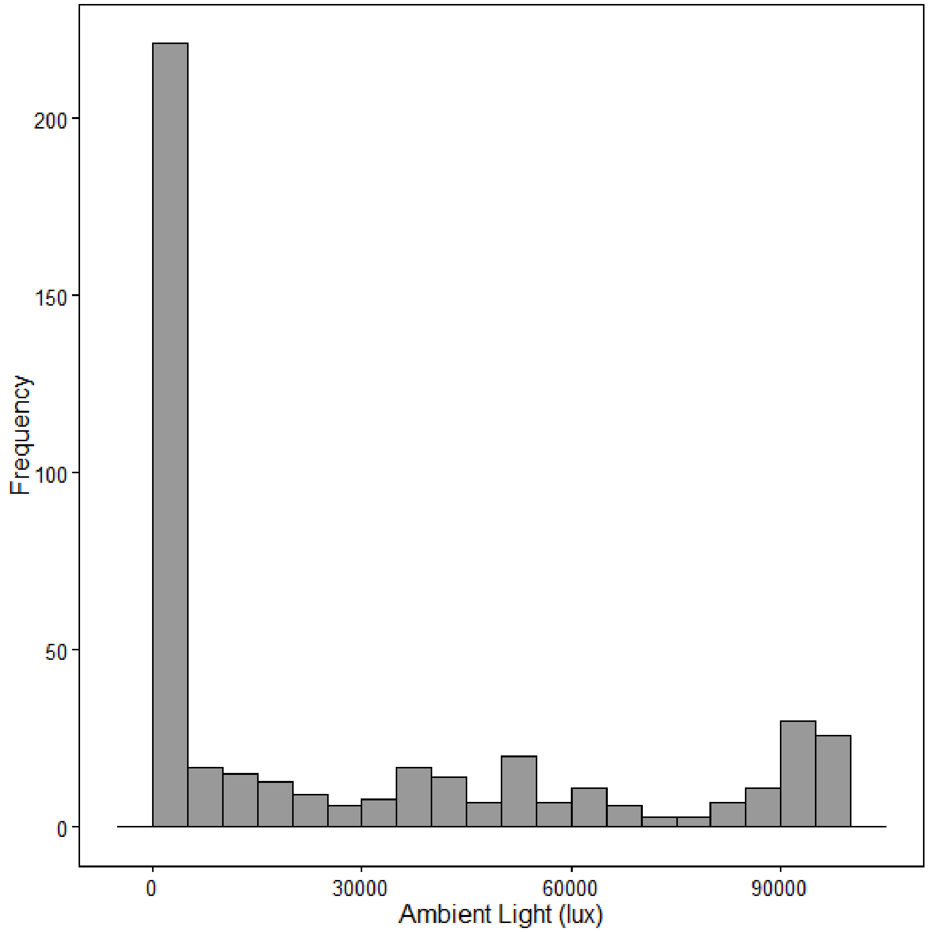
Table 6-10
Statistics for Overall Efficiency during BAFF Operations in 2010

Statistic	BAFF On	BAFF Off	Percentage Point Change	Kruskal-Wallis X^2	P-value
Mean	0.355	0.245	11.0	1.392	0.2380
Standard Deviation	0.243	0.183			
Minimum	0.000	0.000			
Maximum	1.000	0.500			
Samples (n)	19	22			

Notes: BAFF = bio-acoustic fish fence; n = number of overall efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Effect of Ambient Light Level on Overall Efficiency

Tagged juvenile Chinook salmon approached the 2010 BAFF line at various light levels (Figure 6-3). When the 2010 juvenile Chinook salmon were placed into samples, and the O_E samples were partitioned by light level, nine to 12 samples were acquired in the BAFF status and light level combinations (Table 6-11). For low-light levels, mean O_E with the BAFF on was 19.1 percentage points higher than with the BAFF off (Table 6-12), but there was no improvement in O_E with the BAFF on compared to off at either light level. In 2010, it appeared that there was insufficient statistical power to resolve any effect, or light level did not influence the BAFF's O_E.



Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Figure 6-3 Frequency Histogram of 2010 Light-Level Observations (collected at CIMIS, Station #70–Manteca, 37.834822, -121.223194) Obtained for Each Tagged Juvenile Chinook Salmon when the Individual was Nearest the 2010 BAFF Line

Table 6-11
Summary of Overall Efficiency Samples for Tagged Juvenile Chinook Salmon Encountering BAFF during On/Off Operations at Low and High Ambient Light Levels in 2010

Ambient Light Level	BAFF On (n)	BAFF Off (n)
Low Light (<5.4 lux)	9	12
High Light (≥5.4 lux)	10	10
Total	19	22

Notes: BAFF = bio-acoustic fish fence; n = number of overall efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-12 2010 BAFF Operations—Mean Overall Efficiency for Tagged Juvenile Chinook Salmon at Low and High Light Levels					
Ambient Light Level	BAFF On Mean	BAFF Off Mean	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Light (<5.4 lux)	0.506	0.315	19.1	2.155	0.1421
High Light (≥5.4 lux)	0.219	0.161	5.8	1.379	0.2403

Note: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Effect of Average Channel Velocity on Overall Efficiency

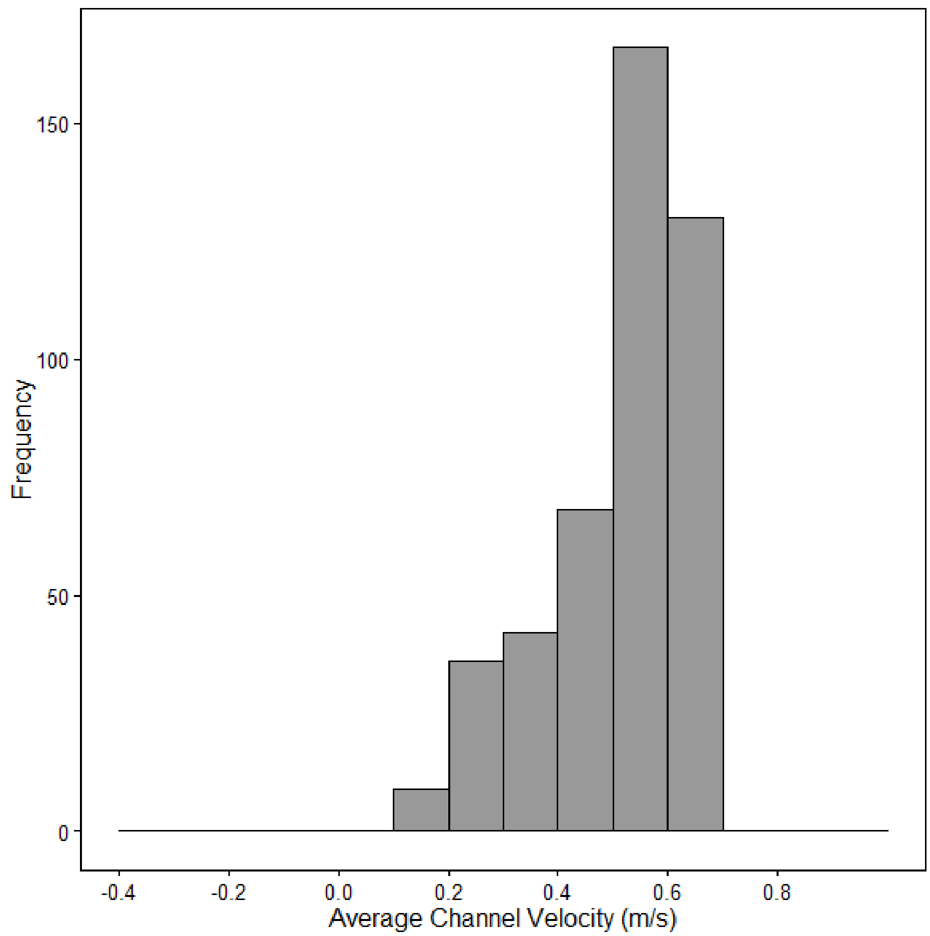
Tagged juvenile Chinook salmon approached the 2010 BAFF line at various light levels (Figure 6-4). When the 2010 fish were placed into samples and the O_E samples for juvenile Chinook salmon were partitioned by ACV level, only four samples were acquired for high-velocity conditions for both the BAFF on and off (Table 6-13). For low-velocity conditions, mean O_E with the BAFF on was 11.9 percentage points higher than with the BAFF off (Table 6-14), but there was no significant improvement in O_E with the BAFF on compared to off at either ACV level. In 2010, it appeared that there was insufficient statistical power to resolve any effect or ACV did not influence the BAFF's O_E.

Table 6-13 Summary of Overall Efficiency Samples for Tagged Juvenile Chinook Salmon Encountering BAFF during On/Off Operations at Low and High Average Channel Velocity Levels in 2010		
Average Channel Velocity Level	BAFF On (n)	BAFF Off (n)
Low Velocity (<0.61 m/s)	15	18
High Velocity (≥0.61 m/s)	4	4
Total	19	22

Notes: BAFF = bio-acoustic fish fence; n = number of overall efficiency samples; m/s = meters per second; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-14 2010 BAFF Operations—Mean Overall Efficiency for Tagged Juvenile Chinook Salmon at Low and High Average Channel Velocity Levels					
Average Channel Velocity Level	BAFF On Mean	BAFF Off Mean	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Velocity (<0.61 m/s)	0.352	0.233	11.9	1.479	0.2240
High Velocity (≥0.61 m/s)	0.367	0.298	6.9	0.021	0.8845

Notes: BAFF = bio-acoustic fish fence; m/s = meters per second
Source: Data compiled by Turnpenny Horsfield Associates and AECOM



Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Figure 6-4 Frequency Histogram of 2010 Average Channel Velocity Observations (SJL Gauge) Obtained for Each Tagged Juvenile Chinook Salmon when the Individual was Nearest the 2010 BAFF Line

PROTECTION EFFICIENCY

BAFF P_E was 0.286 with the BAFF off, and the proportion of flow into the San Joaquin River during the study period was 0.56 (Table 3-1). Similar to 2009, the proportion of juvenile Chinook salmon entering the San Joaquin River in 2010 was not the same as the proportion of flow. The fraction was lower. In contrast, in Table 7-3 in Appendix I, the proportion of flow entering the San Joaquin River was correlated ($P = 0.0003$) with the probability that an individual juvenile Chinook salmon would continue down the San Joaquin River route. The multivariate analysis showed that the proportion of flow into the San Joaquin River (SJL gauge), and ACV models fit the data equally well (Table 7-2 in Appendix I). All analyses showed correlation with the probability that a juvenile Chinook salmon would be entrained into the San Joaquin River route.

P_E was 15.5 percentage points higher with the BAFF on than with the BAFF off and, in contrast to 2009, this result was statistically significant (Table 6-15). Hypothesis $H2_0$ was rejected. It was found that 44.1% of tagged juvenile Chinook salmon continued down the San Joaquin River with the BAFF on. These results showed that the BAFF improved the proportion of juvenile Chinook salmon remaining in the San Joaquin River in 2010, but it is unknown whether this improvement was biologically significant at the population level. These results were consistent with the GLM presented in Appendix I. It showed that with the BAFF on a greater probability ($P = 0.0002$) existed that a juvenile Chinook salmon would enter the San Joaquin River route (Table 7-3 in Appendix I).

Table 6-15
Statistics for Protection Efficiency during BAFF Operations in 2010

Statistic	BAFF On	BAFF Off	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Mean	0.441	0.286	15.5	3.943	0.0471
Standard Deviation	0.239	0.206			
Minimum	0.000	0.000			
Maximum	1.000	0.667			
Samples (n)	19	20			

Notes: BAFF = bio-acoustic fish fence; n = number of protection efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Effect of Ambient Light Level on Protection Efficiency

When the samples for 2010 P_E were partitioned by ambient light level (Table 6-16), nine to 10 samples were found for various combinations of BAFF operations with ambient light levels. For low-ambient-light levels, mean P_E with the BAFF on was 16.7 percentage points higher than off (Table 6-17). For high-ambient-light levels, mean P_E with the BAFF on was 15.3 percentage points higher than with the BAFF off, the P_E test provided a P value of 0.0812 and a statistical power of just 0.417. It appeared that it may not have been possible to reject a false null hypothesis because of the low power of the test. As in 2009, at both low and high light levels, there was no statistically significant improvement in P_E with the BAFF on compared to off. In 2010, it appeared that there was insufficient power to resolve any effect, or light level did not influence the BAFF's P_E.

Table 6-16
Summary of Protection Efficiency Samples for Tagged Juvenile Chinook Salmon Encountering BAFF during On/Off Operations at Low and High Light Levels in 2010

Ambient Light Level	BAFF On (n)	BAFF Off (n)
Low Light (<5.4 lux)	9	10
High Light (≥5.4 lux)	10	10
Total	19	20

Notes: BAFF = bio-acoustic fish fence; n = number of protection efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-17 2010 BAFF Operations—Mean Protection Efficiency for Juvenile Chinook Salmon at Low and High Light Levels					
Ambient Light Level	BAFF On Mean	BAFF Off Mean	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Light (<5.4 lux)	0.526	0.359	16.7	1.513	0.2186
High Light (≥5.4 lux)	0.365	0.212	15.3	3.041	0.0812

Notes: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Effect of Average Channel Velocity on Protection Efficiency

When the samples for 2010 P_E were partitioned by ACV level only, four samples were acquired for high-ACV conditions for both BAFF on and off (Table 6-18) status. For low-ACV conditions, P_E with the BAFF on was 16.9 percentage points higher than off (Table 6-19), but there was no statistically significant improvement in P_E with the BAFF on compared to off at either velocity level. These results suggested that there may have been insufficient power to resolve any effect, or ACV did not influence the BAFF's P_E. However, the P-value for low ACV was 0.0544 but the statistical power of this test was only 0.544. It appears that more research in this area would be useful.

Table 6-18 Summary of Protection Efficiency Samples for Tagged Juvenile Chinook Salmon Encountering BAFF during On/Off Operations at Low and High Average Channel Velocity Levels in 2010		
Average Channel Velocity Level	BAFF On (n)	BAFF Off (n)
Low Velocity (<0.61 m/s)	15	16
High Velocity (≥0.61 m/s)	4	4
Total	19	20

Notes: BAFF = bio-acoustic fish fence; n = number of protection efficiency samples; m/s = meters per second
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-19 2010 BAFF Operations—Mean Protection Efficiency for Tagged Juvenile Chinook Salmon at Low and High Average Channel Velocity Levels					
Average Channel Velocity Level	BAFF On Mean	BAFF Off Mean	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Velocity (<0.61 meter per second)	0.435	0.266	16.9	3.699	0.0544
High Velocity (≥0.61 meter per second)	0.465	0.365	10.0	0.527	0.4678

Notes: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

DETERRENCE EFFICIENCY

The BAFF-on treatment showed an improvement (Kruskal-Wallis $X^2 = 13.095$, $P = 0.0003$) in D_E: 13.8 percentage points greater than with the BAFF off (Table 6-20). Thus, hypothesis $H2_0$ was rejected. The analysis showed that the BAFF provided a statistically significant deterrent for diverting juvenile Chinook salmon when an individual approached the BAFF. It is unknown whether this level of improved deterrence is biologically significant at the population level.

Table 6-20
Deterrence Efficiency Statistics for BAFF Operations in 2010

Statistic	BAFF On	BAFF Off	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Mean	0.150	0.012	13.8	13.095	0.0003
Standard Deviation	0.193	0.044			
Minimum	0.000	0.000			
Maximum	0.680	0.200			
Samples (n)	19	22			

Notes: BAFF = bio-acoustic fish fence; n = number of deterrence efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

The apparent D_E with the BAFF off was 1.2%. This is the percentage of juvenile Chinook salmon that exhibited movements that appeared to be movements away from the BAFF or guided along the line of the BAFF even though the BAFF was off.

The 2010 mean D_E with the BAFF on was 15.0% in the analysis reported in Table 6-20. This is slightly less than the grand D_E reported in Bowen et al. (2012), which was 23.0%. Similar to 2009, this difference arose from the reanalysis of the deterrence data in the present study, because fish were placed into samples from the same time period with similar values for ambient light and ACV when the fish arrived at the HOR study area (see definition of samples in Chapter 5, “Methods”), instead of being placed in groups that were associated with the release date/ time.

Effect of Ambient Light Level on BAFF Deterrence Efficiency

When the samples for 2010 BAFF D_E were partitioned by ambient light level (Table 6-21), 9 to 12 samples were found for various combinations of BAFF operations and light levels. For high-light levels, D_E with the BAFF on was 26.0 percentage points higher than with the BAFF off (Table 6-22), and this difference was statistically significant. However, there was no improvement in D_E with the BAFF on compared to off at low light levels. In 2010, similar to 2009, it appeared that light did influence the BAFF’s D_E at light levels greater than or equal to 5.4 lux.

Table 6-21 Summary of Deterrence Efficiency Samples for Tagged Juvenile Chinook Salmon Encountering BAFF during On/Off Operations at Low and High Light Levels in 2010		
Ambient Light Level	BAFF On (n)	BAFF Off (n)
Low Light (<5.4 lux)	9	12
High Light (≥5.4 lux)	10	10
Total	19	22

Notes: BAFF = bio-acoustic fish fence; n = number of deterrence efficiency samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-22 2010 BAFF Operations—Mean Deterrence Efficiency for Tagged Juvenile Chinook Salmon at Low and High Light Levels					
Ambient Light Level	BAFF On Mean	BAFF Off Mean	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Light (<5.4 lux)	0.019	0.017	0.2	0.575	0.4481
High Light (≥5.4 lux)	0.267	0.007	26.0	15.093	0.0001

Note: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Effect of Average Channel Velocity on Barrier Deterrence Efficiency

When the samples for 2010 D_E were partitioned by ACV level, only four samples were acquired for high-ACV conditions for both the BAFF on and BAFF off (Table 6-23). For low-ACV conditions, D_E with the BAFF on was 11.1 percentage points higher than off (Table 6-24). In addition, D_E with the BAFF on was 23.6 percentage points higher than off for high-ACV conditions (Table 6-24). In 2010, the BAFF improved D_E under both low- and high-ACV conditions.

Table 6-23 Summary of Deterrence Efficiency Samples for Tagged Juvenile Salmon Encountering BAFF during On/Off Operations at Low and High Average Channel Velocity Levels in 2010		
Average Channel Velocity Level	BAFF On (n)	BAFF Off (n)
Low Velocity (<0.61 m/s)	15	18
High Velocity (≥0.61 m/s)	4	4
Total	19	22

Notes: BAFF = bio-acoustic fish fence; n = number of deterrence efficiency samples; m/s = meters per second
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-24 2010 BAFF Operations—Mean Deterrence Efficiency for Tagged Juvenile Chinook Salmon at Low and High Average Channel Velocity Levels					
Average Channel Velocity Level	BAFF On Mean	BAFF Off Mean	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Velocity (<0.61 m/s)	0.122	0.011	11.1	8.562	0.0034
High Velocity (≥0.61 m/s)	0.254	0.018	23.6	5.600	0.0180

Note: BAFF = bio-acoustic fish fence; m/s = meters per second
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

6.1.3 2009 COMPARED TO 2010

STUDY FISH

There were three important differences in the juvenile Chinook salmon used in 2009 and 2010. The juvenile Chinook salmon used in 2009 were from the Feather River Hatchery and were fall-spring–run hybrids. Juvenile Chinook salmon used in 2010 were from the Merced River Hatchery and were fall-run (Table 5-1). Also, the range of sizes was different between the two years. The Feather River Hatchery fall-spring hybrid individuals were 80 to 110 mm TL while the Merced River Hatchery fall-run individuals were 99 to 121 mm TL. Finally, the tag burden was higher than 5.4% for a large proportion of juvenile Chinook salmon in 2009 over 2010 (Table 5-3).

In addition to differences in the juvenile Chinook salmon, there were differences in the BAFF location, orientation, length, and shape (Figure 4-3). The principal objective in comparing 2009 and 2010 was to determine which of these two shapes seemed to best improve P_E. However, the analysis was confounded by the three important differences between the juvenile Chinook salmon between the two years.

OVERALL EFFICIENCY

The number of samples ranged from 19 to 27 for BAFF operations in 2009 and 2010 (Table 6-25). There was not a statistical difference between 2009 and 2010 in any measured variable (Table 6-26); hypotheses $H3_0$ and $H4_0$ were accepted. With the BAFF on, O_E was never higher than 35.5%. Thus, it appeared the BAFF was not effective at maintaining juvenile Chinook salmon in the San Joaquin River. The 2010 O_E with the BAFF on showed a 14.6-percentage-point improvement over 2009; the P-value was 0.0563, but the statistical power was only 0.489. These results suggested that there could be differences between 2009 and 2010 BAFF alignments, but low power meant it was not possible to reject a false null hypothesis (Table 1-1: $H3_0$).

Table 6-25 Overall Efficiency Samples with BAFF Operations—2009 vs. 2010			
Treatment	2009 (n)	2010 (n)	Total
BAFF On	21	19	40
BAFF Off	27	22	49
BAFF Effect	15	11	26

Notes: BAFF = bio-acoustic fish fence; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-26 Overall Efficiency Statistics with BAFF Operations—2009 vs. 2010					
Treatment	2009 Mean	2010 Mean	Percentage Point Change	Kruskal-Wallis X^2	P-Value
BAFF On	0.209	0.355	-14.6	3.645	0.0563
BAFF Off	0.184	0.245	-6.1	1.958	0.1617
BAFF Effect	0.047	0.080	-3.3	0.017	0.8967

Note: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

PROTECTION EFFICIENCY

The number of P_E samples ranged from 18 to 25 in 2009 and 2010 (Table 6-27). There were fewer BAFF effect samples, 11 to 12. Calculation of BAFF effect required a switch in BAFF status while ACV and light level were consistent. That did not happen on every BAFF switch occasion. No statistical difference was observed between 2009 and 2010 in any measured variable (Table 6-28); P_E with the BAFF on was never higher than 44.1%. Hypotheses $H3_0$ and $H4_0$ were accepted. Thus, it appeared the BAFF was not effective under any conditions studied, thus it did not facilitate maintaining juvenile Chinook salmon in the San Joaquin River.

Table 6-27 Protection Efficiency Samples with BAFF Operations—2009 vs. 2010			
Treatment	2009 (n)	2010 (n)	Total
BAFF On	18	25	43
BAFF Off	19	20	39
BAFF Effect	12	11	33

Notes: BAFF = bio-acoustic fish fence; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-28 Protection Efficiency Statistics with BAFF Operations—2009 vs. 2010					
Treatment	2009 Mean	2010 Mean	Percentage Point Change	Kruskal-Wallis X^2	P-Value
BAFF On	0.338	0.441	-10.4	1.567	0.2106
BAFF Off	0.234	0.286	-5.2	0.635	0.4256
BAFF Effect	0.108	0.145	-3.7	0.077	0.7817

Note: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

DETERRENCE EFFICIENCY

The number of D_E samples ranged from 18 to 23 in 2009 and 2010 (Table 6-29). In 2009, operation of the BAFF produced much greater D_E than in 2010 (a 58.2-percentage-point improvement). However, with the BAFF off, there was also a 29.9-percentage-point greater D_E in 2009 than in 2010 (Table 6-30). The percentage of juvenile Chinook salmon that appeared deterred with the BAFF off was 31.1% in 2009 and 1.2% in 2010, and were different (see Table 6-30). Hypotheses $H3_0$ and $H4_0$ were rejected.

Table 6-29
Deterrence Efficiency Samples with BAFF Operations—2009 vs. 2010

Treatment	2009 (n)	2010 (n)	Total
BAFF On	18	19	37
BAFF Off	23	22	45
BAFF Effect	10	11	21

Notes: BAFF = bio-acoustic fish fence; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-30
Deterrence Efficiency Statistics with BAFF Operations—2009 vs. 2010

Treatment	2009 Mean	2010 Mean	Percentage Point Change	Kruskal-Wallis X^2	P-Value
BAFF On	0.732	0.150	58.2	16.997	<0.0001
BAFF Off	0.311	0.012	29.9	18.351	<0.0001
BAFF Effect	0.432	0.166	26.6	3.248	0.0715

Notes: BAFF = bio-acoustic fish fence
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

In 2009, the calculated BAFF effect on D_E was 26.6 percentage points greater than in 2010. Thus, the difference in calculated D_E due to the BAFF effect from 2009 to 2010 accurately approximated the difference in D_E from 2009 to 2010, due only to BAFF operation rather than other factors. Although it appeared that BAFF operation resulted in much greater deterrence in 2009, the deterrence due to the BAFF effect was not different from 2009 to 2010, possibly due to sample sizes of 10 and 11 (Table 6-29), and relatively low statistical power (0.444).

6.1.4 2011 RESULTS

SIZE AND SOURCE OF JUVENILE CHINOOK SALMON AND STEELHEAD USED

The juvenile Chinook salmon tagged and released in 2011 were similar in size to those in 2010 and 2012 and larger than 2009 (Table 5-1).

The juvenile steelhead implanted with tags and released in 2011 were larger than the tagged juvenile Chinook salmon (Table 5-1). In 2011, the Mokelumne River Fish Hatchery provided the juvenile steelhead used in the studies; the production of the juvenile steelhead is described in Section B.1 of Appendix B.

CHINOOK SALMON OVERALL AND PROTECTION EFFICIENCY STATISTICS

In 2011, there were 53 samples of tagged juvenile Chinook salmon for which O_E and P_E could be calculated (Table 6-31). With no barrier installed, 51.9% of tags in juvenile Chinook salmon continued down the San Joaquin River. However, when the juvenile Chinook salmon that had been determined to be eaten were removed, the P_E improved. With no barrier installed, 57.4% of the juvenile Chinook salmon determined to have not been consumed went down the San Joaquin River. The mean proportion of flow into the San Joaquin River during the period of fish release was 48% (Table 3-1). In 2009 and 2010 the proportion of juvenile Chinook salmon entering the San Joaquin River was lower than the proportion of flow. In contrast in 2011, the proportion of juvenile Chinook salmon entering the San Joaquin River was similar to the proportion of flow.

Table 6-31
Chinook Salmon Statistics for the No-Barrier Treatment in 2011

	Mean	Standard Deviation	Minimum	Maximum	Number of Samples (n)
Overall Efficiency	0.519	0.160	0.000	1.000	53
Protection Efficiency	0.574	0.178	0.000	1.000	53

Notes: n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

6.1.5 2009 BAFF OFF COMPARED TO 2010 BAFF OFF COMPARED TO 2011

OVERALL EFFICIENCY— JUVENILE CHINOOK SALMON

O_E was significantly different between treatments at the HOR study area with the BAFF off in 2009 and 2010, and with no barrier in 2011 (Kruskal-Wallis $X^2 = 49.008$, P-value <0.0001). Hypothesis $H5_0$ was rejected. There was no significant difference in O_E in 2009 with the BAFF off compared to 2010 with the BAFF off (Table 6-26). Thus, 2009 with the BAFF off was grouped with 2010 with the BAFF off (Table 6-32). Because the data did not meet the assumptions of ANOVA, one nonparametric two-sample comparison was made between treatments (i.e., 2010 vs. 2011). The O_E in 2011 was significantly greater than O_E in 2010 with the BAFF off (Kruskal-Wallis $X^2 = 26.577$, P-value <0.0001).

Table 6-32
Statistics for Overall Efficiency for 2009–2011

Treatment—Year	Mean	Standard Deviation	Number of Samples (n)	Statistical Grouping
BAFF Off—2009	0.184	0.185	27	a
BAFF Off—2010	0.245	0.183	22	a
No Barrier—2011	0.519	0.160	53	b

Note: BAFF = bio-acoustic fish fence; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

PROTECTION EFFICIENCY—JUVENILE CHINOOK SALMON

P_E was significantly different for the BAFF-off and "no barrier" years at the HOR study area (Kruskal-Wallis $X^2 = 39.650$, P-value <0.0001). Hypothesis $H5_0$ was rejected. There was no significant difference in P_E with the BAFF off in 2009 compared to 2010 (Table 6-28); so, the "BAFF Off—2009" statistics were grouped with the "BAFF Off—2010" statistics (Table 6-33). Because the data did not meet the assumptions of ANOVA, one nonparametric two-sample comparison was made between treatments (i.e., 2010 vs. 2011). The P_E in 2011 was greater than the P_E with the BAFF off for 2009 and 2010 (Kruskal-Wallis $X^2 = 21.378$, P-value <0.0001).

Table 6-33
Statistics for Protection Efficiency for 2009–2011

Treatment—Year	Mean	Standard Deviation	Number of Samples (n)	Statistical Grouping
BAFF Off—2009	0.234	0.220	25	a
BAFF Off—2010	0.286	0.206	20	a
No Barrier—2011	0.574	0.178	53	b

Note: BAFF = bio-acoustic fish fence; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM.

6.1.6 2011 JUVENILE CHINOOK SALMON COMPARED TO JUVENILE STEELHEAD

OVERALL EFFICIENCY

The number of O_E samples ranged from 53 to 93 for juvenile Chinook salmon and juvenile steelhead (Table 6-34). The O_E for tagged juvenile Chinook salmon that passed the San Joaquin River finish line was 51.9% (Table 6-34).

Table 6-34
Statistics for Overall Efficiency for Tagged Juvenile Chinook Salmon and Steelhead in 2011

Statistic	Chinook Salmon	Steelhead	Percentage Point Change	Kruskal-Wallis X^2	P-value
Mean of Samples	0.519	0.368	15.1	12.717	0.0004
Standard Deviation	0.160	0.287			
Minimum	0.000	0.000			
Maximum	1.000	1.000			
Samples (n)	53	93			

Note: n = number of samples
Overall Efficiency reported in this table is the mean of samples. The grand overall efficiency (see text) was 38.3%.
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

For juvenile steelhead, the O_E was significantly lower (Kruskal-Wallis $X^2 = 12.717$, P = 0.0004) than for juvenile Chinook salmon (Table 6-34). Hypothesis $H6_0$ was rejected. However, in 2011, 37.7% of steelhead selected the Old River route and this was similar to the usage of the Old River route by Chinook (38.6%). Recall that O_E includes all tags (even those originally in juvenile salmonids that were eaten and now in predators) that pass by the finish lines. This largely appeared to reflect greater predation on juvenile steelhead (see section 6.2.1, “Proportion Eaten (Univariate Analyses)”).

The mean of overall efficiency samples was 36.8% (Table 6-34). This mean was calculated as the mean of all the samples derived by the method described in Methods (Section 5.2.1 “Grouping Juvenile Salmonids Iinto Samples”). The grand overall efficiency was 38.3%. The grand mean overall efficiency was calculated as the total number of tags, originally inserted into steelhead, that remained in the San Joaquin River (199) divided by the total number tags (520) that moved past the Head of Old River study site. This difference between these values arose from how the tags were allocated into samples but the difference was very small between the two measures.

Tagged juvenile Chinook salmon and steelhead passed through the HOR study area at various light levels (Figure 6-5). When the 2011 juvenile salmonids were placed into samples, and the O_E samples were partitioned by light level, 25 to 61 samples were distributed throughout the experimental matrix (Table 6-35). Also, tagged juvenile Chinook salmon and steelhead passed through the HOR study area at various ACV levels (Figure 6-6). When the 2011 juvenile salmonids were placed into samples and the O_E samples were partitioned by ACV level, sample sizes ranged from 24 to 48 (Table 6-37). The relationships (discussed in Section 6.1.6, “Overall Efficiency”) for juvenile Chinook salmon and steelhead O_E were similar for all light and ACV levels. That is, juvenile Chinook salmon had an approximate 15-percentage-point greater O_E than did steelhead for all light levels and ACV levels (Tables 6-34, 6-36, and 6-38), and this difference was significant. It was concluded that, at both light levels and at both ACV levels studied, tagged juvenile Chinook salmon had an approximately 15% greater chance of following the San Joaquin River route compared to tagged steelhead.

Table 6-35
Summary of Overall Efficiency Samples for Tagged Chinook Salmon and Steelhead at Low and High Ambient Light Levels in 2011

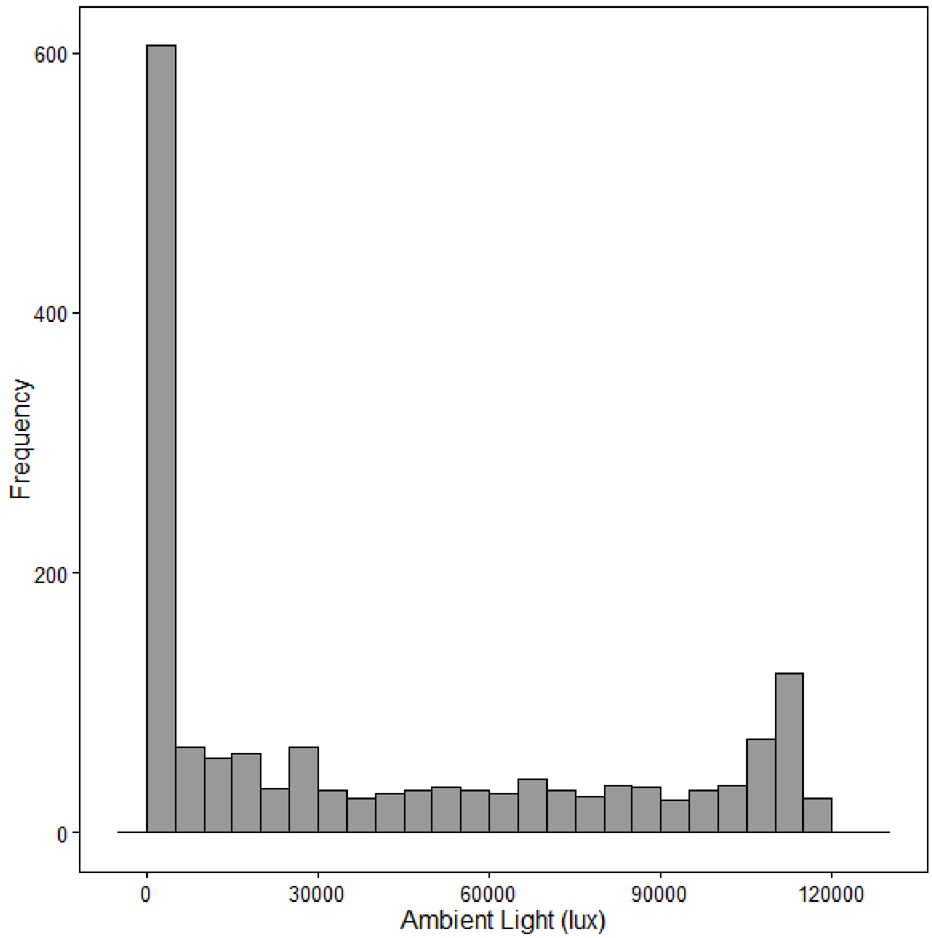
Ambient Light Level	Chinook Salmon (n)	Steelhead (n)	Total (n)
Low Light (<5.4 lux)	25	32	57
High Light (≥5.4 lux)	28	61	89

Note: n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-36
Mean Overall Efficiency for Tagged Juvenile Chinook Salmon and Steelhead at Low and High Light Levels in 2011

Ambient Light Level	Chinook Salmon	Steelhead	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Light (<5.4 lux)	0.540	0.367	17.3	5.426	0.0198
High Light (≥5.4 lux)	0.501	0.368	13.3	6.854	0.0088

Source: Data compiled by Turnpenny Horsfield Associates and AECOM



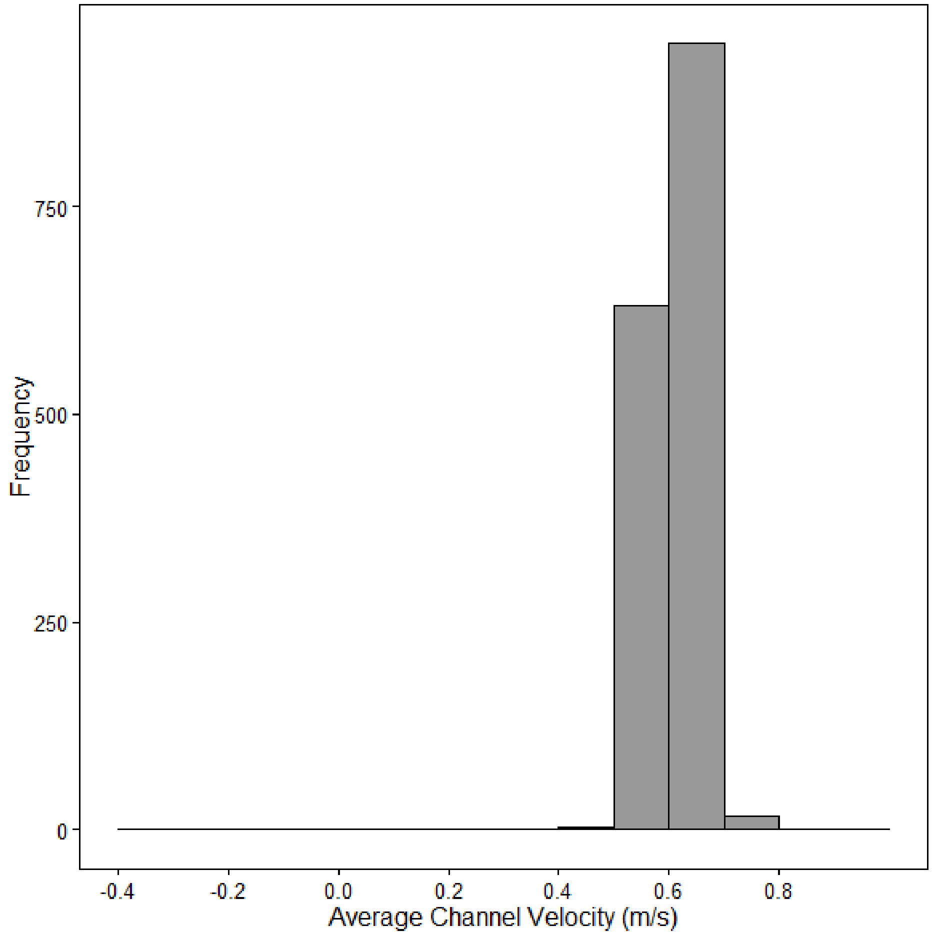
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Figure 6-5 Frequency Histogram of 2011 Light-Level Observations (collected at CIMIS, Station #70–Manteca, 37.834822, -121.223194) Obtained for Each Tagged Juvenile Salmonid when the Individual was Nearest the 2010 BAFF Line

Table 6-37
Summary of Overall Efficiency Samples for Tagged Juvenile Chinook Salmon and Steelhead at Low and High Average Channel Velocity Levels in 2011

Average Channel Velocity Level	Chinook Salmon (n)	Steelhead (n)	Total (n)
Low Velocity (<0.61 m/s)	29	48	77
High Velocity (≥0.61 m/s)	24	45	69
Total	53	93	146

Note: n = number of samples; m/s = meters per second
Source: Data compiled by Turnpenny Horsfield Associates and AECOM



Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Figure 6-6 **Frequency Histogram of 2011 Average Channel Velocity Observations (SJL Gauge) Obtained for Each Tagged Juvenile Salmonid when the Individual was Nearest the 2010 BAFF Line**

Table 6-38
Mean Overall Efficiency for Tagged Juvenile Chinook Salmon and Steelhead at Low and High Average Channel Velocity Levels in 2011

Average Channel Velocity Level	Chinook Salmon	Steelhead	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Velocity (<0.61 m/s)	0.489	0.341	14.8	6.793	0.0092
High Velocity (≥0.61 m/s)	0.555	0.396	15.9	7.063	0.0079

Note: m/s = meters per second
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

PROTECTION EFFICIENCY

The difference observed in O_E for juvenile Chinook salmon compared to steelhead was not observed in P_E (Table 6-39). It was notable that the P_E for steelhead, 49.0%, was consistent with the proportion of flow into the San Joaquin River, 48% (Table 3-1), but the P_E for juvenile Chinook salmon, 57.4%, was higher; the difference was not significant. Hypothesis $H6_0$ was accepted.

Table 6-39
Statistics for Protection Efficiency for Tagged Juvenile Chinook Salmon and Steelhead in 2011

Statistic	Chinook Salmon	Steelhead	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Mean	0.574	0.490	8.4	2.511	0.1131
Standard Deviation	0.178	0.296			
Minimum	0.000	0.000			
Maximum	1.000	1.000			
Samples (n)	53	77			

Note: n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

The sample-size tables for ambient light level and ACV (Tables 6-40 and 6-42) show greater than 20 samples for every combination of species, light level, and ACV. There were no differences in P_E between juvenile Chinook salmon and steelhead for any light level or ACV level (Tables 6-41 and 6-43).

Table 6-40
Summary of Protection Efficiency Samples for Tagged Juvenile Chinook Salmon and Steelhead at Low and High Ambient Light Levels in 2011

Ambient Light Level	Chinook Salmon (n)	Steelhead (n)	Total (n)
Low Light (<5.4 lux)	25	26	51
High Light (≥5.4 lux)	28	51	79

Note: n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-41
Mean Protection Efficiency for Tagged Juvenile Chinook Salmon and Steelhead at Low and High Ambient Light Levels in 2011

Ambient Light Level	Chinook Salmon	Steelhead	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Light (<5.4 lux)	0.565	0.440	12.5	1.786	0.1814
High Light (≥5.4 lux)	0.581	0.516	6.5	1.112	0.2916

Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Table 6-42 Summary of Protection Efficiency Samples for Tagged Juvenile Chinook Salmon and Steelhead at Low and High Average Channel Velocity Levels in 2011			
Average Channel Velocity Level	Chinook Salmon (n)	Steelhead (n)	Total (n)
Low Velocity (<0.61 m/s)	29	38	67
High Velocity (≥0.61 m/s)	24	39	63
Note: n = number of samples; m/s = meters per second Source: Data compiled by Turnpenny Horsfield Associates and AECOM			

Table 6-43 Mean Protection Efficiency for Tagged Juvenile Chinook Salmon and Steelhead at Low and High Average Channel Velocity Levels in 2011					
Average Channel Velocity Level	Chinook Salmon	Steelhead	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Low Velocity (<0.61 meter per second)	0.545	0.473	7.2	1.384	0.2395
High Velocity (≥0.61 meter per second)	0.608	0.508	10.0	1.459	0.2271
Source: Data compiled by Turnpenny Horsfield Associates and AECOM					

6.1.7 2012 Results

Size and Source of Juvenile Chinook Salmon and Steelhead Used

The juvenile Chinook salmon tagged and released in 2012 were similar in size to those released in 2010 and 2011 and came from the Merced River Hatchery (Table 5-1). Similar to 2011, the tagged juvenile steelhead released in 2012 were larger than the tagged juvenile Chinook salmon (Table 5-1). In 2012, the Mokelumne River Hatchery was the source of juvenile steelhead.

Physical Barrier Overall and Protection Efficiency—Chinook Salmon

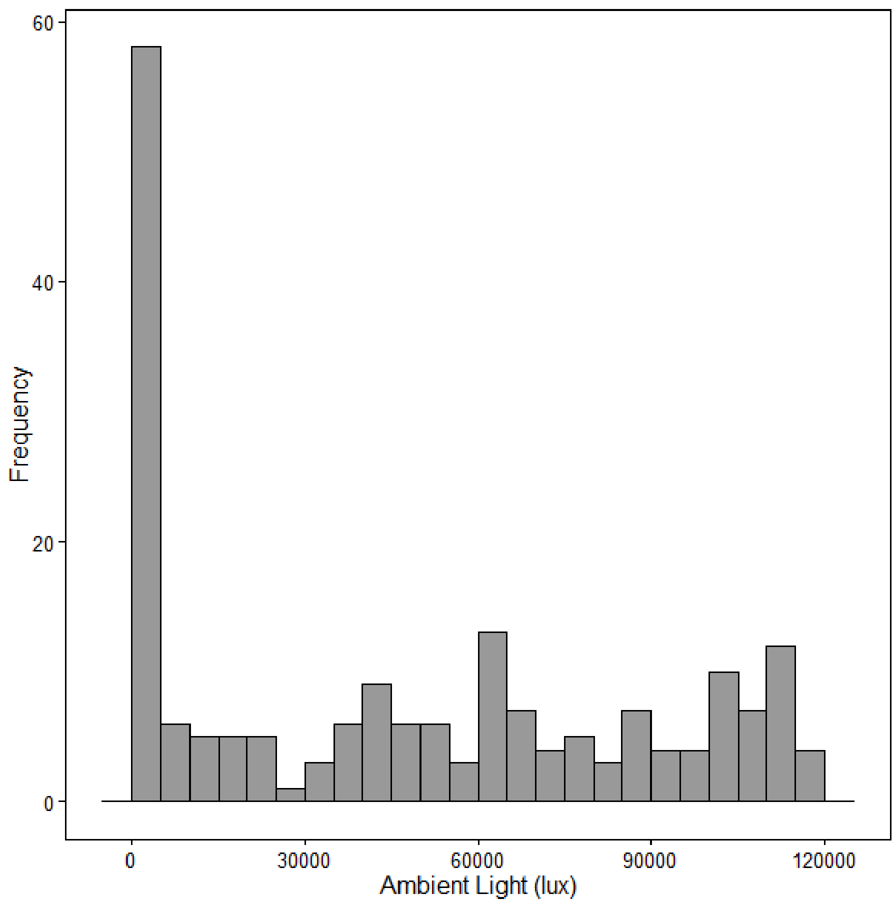
In 2012, there were 21 to 27 samples of tagged juvenile Chinook salmon for which O_E and P_E could be calculated (Table 6-44).[1] The number of samples available for P_E was always less than or equal to the number of samples of O_E because, for some samples, enough juvenile Chinook salmon were eaten to remove the samples from P_E consideration due to insufficient sample size (n <2). With a physical rock barrier installed, 61.8% of tagged juvenile Chinook salmon continued down the San Joaquin River. In contrast, 100% of tagged juvenile Chinook salmon that were not eaten continued down the San Joaquin River. In addition, the mean proportion of flow into the San Joaquin River during the study period was 82% (Table 3-1). Thus, the proportion of juvenile Chinook salmon remaining in the San Joaquin River was higher than the proportion of flow.

[1] Note: The BAFF 2010 line was used in 2010, 2011, and 2012 for a consistent reference line across years.

Table 6-44 Physical Rock Barrier Statistics for Tagged Juvenile Chinook Salmon in 2012					
Efficiency Type	Mean	Standard Deviation	Minimum	Maximum	Number of Samples (n)
O_E	0.618	0.321	0.000	1.000	27
P_E	1.000	0.000	1.000	1.000	21

Note: n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Tagged juvenile Chinook salmon passed through the HOR study area at various ambient light levels (Figure 6-7). When the 2012 juvenile Chinook salmon were placed into samples and the O_E samples were partitioned by light level, 11 to 16 samples were found (Table 6-45). Tagged juvenile Chinook salmon passed through the HOR study area at various ACV levels (Figure 6-8). When the 2012 juvenile Chinook salmon were placed into samples, no samples were obtained at ACVs greater than 0.61 m/s.

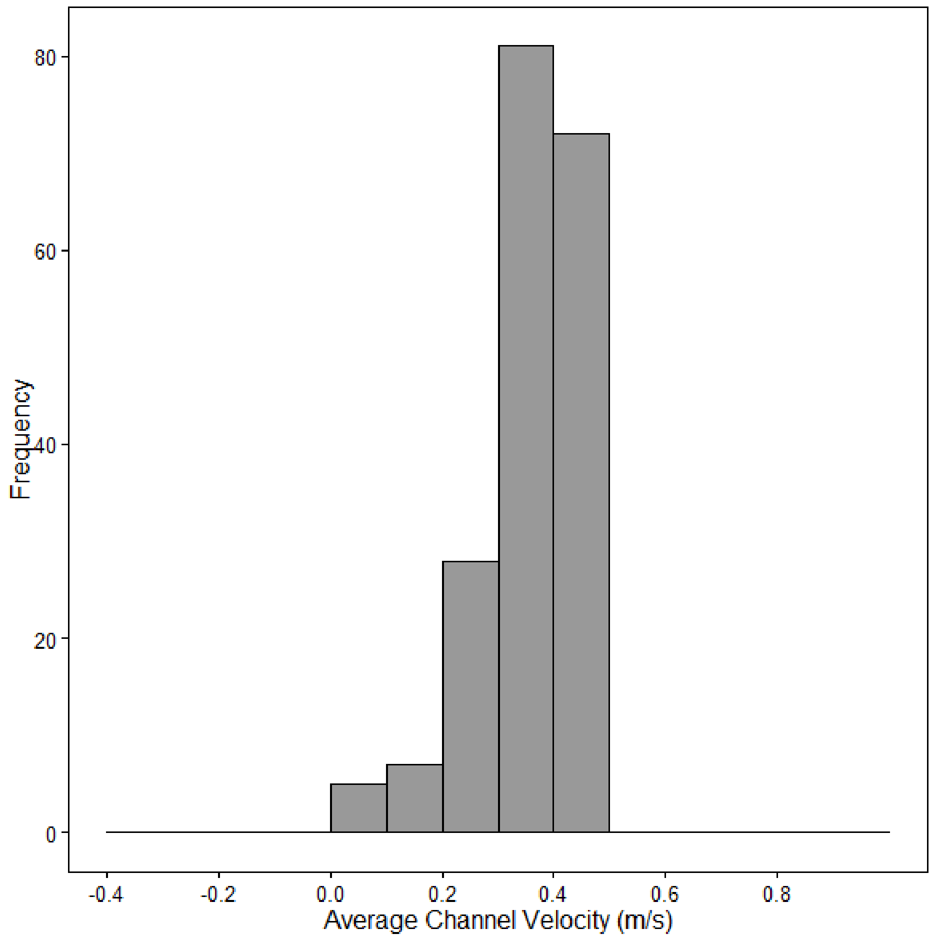


Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Figure 6-7 Frequency Histogram of 2012 Light-Level Observations (collected at CIMIS, Station #70–Manteca, 37.834822, -121.223194) Obtained for Each Tagged Juvenile Chinook Salmon when the Individual was Nearest the 2010 BAFF Line

Table 6-45 Statistics for Overall Efficiency for Tagged Juvenile Chinook Salmon at Low and High Ambient Light Levels in 2012					
Statistic	Low Ambient Light (<5.4 lux)	High Ambient Light (≥5.4 lux)	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Mean	0.868	0.446	42.2	12.204	0.0005
Standard Deviation	0.203	0.271			
Minimum	0.500	0.000			
Maximum	1.000	0.842			
Samples (n)	11	16			

Note: n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM



Source: Data compiled by Turnpenny Horsfield Associates and AECOM

Figure 6-8 **Frequency Histogram of 2012 Average Channel Velocity Observations (SJL Gauge) Obtained for Each Tagged Juvenile Chinook Salmon when the Individual was Nearest the 2010 BAFF Line**

In 2012, the mean O_E for tagged juvenile Chinook salmon was 42.2 percentage points greater for tagged juvenile Chinook salmon encountering the rock barrier in low-light levels than for tagged juvenile Chinook salmon encountering the barrier in high-light levels (Table 6-45). This difference was statistically significant, and may have been a result of higher predation rates at high-light levels, a feature that was apparent from GLM of juvenile Chinook salmon for 2009 through 2012 data (see Section 6.2.2). This is explored further under in Section 6.2.1, "Proportion Eaten (Univariate Analyses)."

When tags implanted in juvenile Chinook salmon and subsequently determined to have been eaten by predators were removed from consideration, the physical rock barrier's P_E was 100% efficient for both low- and high-light levels. In addition, P_E was not different for juvenile Chinook salmon that encountered the rock barrier at different light levels (Table 6-46). This result supports the hypothesis that the large difference in O_E under varying light levels (Table 6-45) was due to greater predation on juvenile Chinook salmon during the day. As noted previously, this topic is explored further under in Section 6.2.1, "Proportion Eaten (Univariate Analyses)."

Table 6-46
Statistics for Protection Efficiency for Tagged Juvenile Chinook Salmon at Low and High Ambient Light Levels in 2012

Statistic	Low Ambient Light (<5.4 lux)	High Ambient Light (≥5.4 lux)	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Mean	1.000	1.000	0.0	NA	NA
Standard Deviation	0.000	0.000			
Minimum	1.000	1.000			
Maximum	1.000	1.000			
Samples (n)	10	11			

Note: n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

OVERALL AND PROTECTION EFFICIENCY—STEELHEAD

Of the five tagged steelhead that arrived at the HOR study area in 2012, one was eaten in the study area and four went down the San Joaquin River. Thus, the grand O_E for steelhead in 2012 was 0.800, and the grand P_E was 1.000.

6.1.8 COMPARISON AMONG CONDITIONS FROM 2009 (BAFF ON), 2010 (BAFF ON), 2011 (NO BARRIER), AND 2012 (PHYSICAL ROCK BARRIER)

OVERALL EFFICIENCY—CHINOOK SALMON

O_E was significantly different between barrier treatments at the HOR study area (Kruskal-Wallis X^2 = 34.311, P-value <0.0001). Hypothesis $H7_0$ was rejected. The BAFF showed no difference in O_E in 2009 compared to 2010 (Table 6-26); therefore, the 2009 "BAFF On" statistics were grouped with the 2010 "BAFF On" statistics (Table 6-47). Because the data did not meet the assumptions of ANOVA, three nonparametric two-sample comparisons were made between treatments: 2010 compared to 2011; 2010 compared to 2012; and 2011 compared to 2012.

To make multiple two-sample comparisons, a Bonferroni-method reduction of the critical alpha was employed to control the experiment-wise error rate: 0.05/3 = 0.0167 (Sokal and Rohlf 1995). The only two-sample comparison that was not among these three tests was 2011 compared to 2012 (Kruskal-Wallis $X^2 = 2.759$, P-value = 0.0967). The statistical power of this last test was 0.885, which exceeds the conventional value of 0.80 (Cohen 1988). Thus, it was concluded that there is likely no true difference between O_E of 2011 compared to 2012.

It was concluded that the BAFF produced the lowest O_E among the three treatment types. There was no difference in "no barrier" O_E and "physical rock barrier" O_E.

Table 6-47
Statistics for Overall Efficiency from 2009–2012

Treatment—Year	Mean	Standard Deviation	Number of Samples (n)	Statistical Grouping
BAFF On—2009	0.209	0.218	21	a
BAFF On—2010	0.355	0.243	19	a
No Barrier—2011	0.519	0.160	53	b
Rock Barrier—2012	0.618	0.321	27	b

Note: BAFF = bio-acoustic fish fence; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

PROTECTION EFFICIENCY—CHINOOK SALMON

P_E was significantly different between barrier treatments at the HOR study area (Kruskal-Wallis $X^2 = 49.630$, P-value <0.0001). Hypothesis $H7_0$ was rejected. The BAFF showed no significant difference in P_E in 2009 compared to 2010 (Table 6-28); therefore, the 2009 "BAFF On" statistics were grouped with the 2010 "BAFF On" statistics (Table 6-48). Because the data did not meet the assumptions of ANOVA, three nonparametric two-sample comparisons were made between treatments (i.e., 2010 compared to 2011; 2010 compared to 2012; and 2011 compared to 2012). As noted above, the critical alpha for these comparisons was 0.0167. The 2010 and 2011 data met the assumptions of ANOVA, and the pairwise comparison used this traditional parametric statistical approach (F = 6.413, P-value = 0.0136).

Table 6-48
Statistics for Protection Efficiency from 2009–2012

Treatment—Year	Mean	Standard Deviation	Number of Samples (n)	Statistical Grouping
BAFF On—2009	0.338	0.330	18	a
BAFF On—2010	0.441	0.239	19	a
No Barrier—2011	0.574	0.178	53	b
Rock Barrier—2012	1.000	0.000	21	c

Note: BAFF = bio-acoustic fish fence; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM

It was concluded that the BAFFs in 2009 and 2010 grouped together had the lowest P_E among the three treatment types (Table 6-48). However, once eaten tags were removed, leaving only surviving tags-in-Chinook-salmon, there was considerable improvement in P_E compared to O_E (compare Tables 6-47 and 6-48). In contrast to the O_E results, there was a difference in “no barrier” P_E and “physical rock barrier” P_E. The rock barrier P_E for surviving tags-in-Chinook-salmon was 100%. The mean proportion of flow passing through the culverts was 18% (Table 3-1), which was higher than the percentage of juvenile Chinook salmon passing down Old River. Note that two juvenile Chinook salmon were actually detected passing through the culverts, but these were subsequently preyed upon in the HOR study area downstream of the rock barrier, so their fate was not recorded as “Old River” but as “Predation.”

6.2 PREDATION ON JUVENILE SALMONIDS INCLUDING BARRIER EFFECTS

6.2.1 PROPORTION EATEN (UNIVARIATE ANALYSES)

2009 RESULTS

In 2009, the proportion of juvenile Chinook salmon determined to have been eaten with the BAFF on and off combined was 22.9% in the HOR study area. Thus, the percentage uneaten was 77.1%; this value was similar to that reported for 2009 survival in the Mossdale-to-HOR reach, 83.0%, by SJRGA (2010). The proportion eaten was 15.2% higher with the BAFF on than with the BAFF off, and this difference was significant (Table 6-49). Hypothesis $H8_0$ was rejected. These results suggested that the BAFF caused an increase in predation when it was operated in 2009.

Table 6-49
Proportion of Juvenile Chinook Eaten Statistics for BAFF Operations in 2009

Statistic	BAFF On	BAFF Off	Percentage Point Change	Kruskal-Wallis X^{2a}	P-Value[a]
Mean Sample Proportion Eaten[a]	0.290	0.138	15.2	5.391	0.0202
Standard Deviation[a]	0.216	0.167			
Samples (n)[a]	21	27			
Population Proportion Eaten[b]	0.309	0.164	14.5		
Standard Error[b]	0.030	0.022			

Notes: BAFF = bio-acoustic fish fence; n = number of samples
[a] Sample proportion eaten parameters
[b] Population proportion eaten parameters
Source: Present study

2010 RESULTS

The proportion of juvenile Chinook salmon eaten with the BAFF on and off combined was 25.9% in the HOR study area. Because the proportion eaten reported in 2009 was 22.9%, it appeared that in both years the BAFF was studied (2009 and 2010), the predation rate was consistent. In contrast to 2009, in 2010, the proportion eaten was 0.5 percentage point higher with the BAFF on than off; this difference was not statistically significant (Table 6-50). Hypothesis $H8_0$ was accepted. It is not known why this difference occurred in 2009 but not in 2010.

Table 6-50 **Proportion of Juvenile Chinook Eaten Statistics for BAFF Operations in 2010**					
Statistic	BAFF On	BAFF Off	Percentage Point Change	Kruskal-Wallis X^{2b}	P-Value[b]
Mean Sample Proportion Eaten[a]	0.217	0.212	0.5	0.051	0.8218
Standard Deviation[a]	0.217	0.167			
Samples (n)[a]	19	22			
Population Proportion Eaten[b]	0.310	0.205			
Standard Error[b]	0.030	0.027			

Notes: BAFF = bio-acoustic fish fence; n = number of samples
[a] Sample proportion eaten parameters
[b] Population proportion eaten parameters
Source: Present study

The major differences between the two years were the lower mean turbidities and lower discharge magnitudes in 2009. These results suggest an area of interesting future inquiry. It was notable that, for 2010, the sample proportion eaten with the BAFF on, 0.217, was lower than the population proportion eaten, 0.310. This difference was a result of how the tags were sorted into samples: Of the 19 samples in question, seven samples, each containing two to 11 tags, had a proportion eaten of zero. In contrast, the remaining 12 samples ranged in size from six to 28 tags, with an average proportion eaten of 0.344, which was consistent with the population proportion eaten.

2009 COMPARED TO 2010

The number of proportion eaten samples ranged from 19 to 27 in 2009 and 2010 (Table 6-51). In 2009, the ratio of proportion eaten with the BAFF on compared to the BAFF off was 1.88, and that was similar to the ratio in 2010 (1.51), suggesting similar predation pressure between years. In 2009, the proportion of tags eaten was not statistically different from the proportion eaten in 2010 (Table 6-52) for the BAFF on or off. However, the statistical power of the test for the BAFF off was only 0.426, and the P-value for the comparison between 2009 and 2010 with the BAFF off was 0.0749. Thus, it is possible that there was a difference in the “BAFF off” proportion eaten in 2009 compared to 2010, and low power made it difficult to resolve.

Table 6-51 **Proportion of Juvenile Chinook Eaten Samples with BAFF Operations—2009 vs. 2010**			
Treatment	2009 (n)	2010 (n)	Total (n)
BAFF On	21	19	40
BAFF Off	27	22	49

Notes: BAFF = bio-acoustic fish fence; n = number of samples
Source: Present study

Table 6-52 **Proportion of Juvenile Chinook Eaten Statistics with BAFF Operations—2009 vs. 2010**					
Sample Proportion Eaten					
Treatment	2009 Mean Proportion Eaten[a]	2010, Mean Proportion Eaten[a]	Percentage Point Change	Kruskal-Wallis X^{2}[a]	P-value[a]
BAFF On	0.290	0.217	7.3	1.530	0.2161
BAFF Off	0.138	0.212	-7.4	3.173	0.0749
Population Proportion Eaten					
Treatment	2009 Proportion Eaten[b]	2010 Proportion Eaten[b]	Percentage Point Change		
BAFF On	0.309	0.310	-0.1		
BAFF Off	0.164	0.205	-4.1		
Ratio On/Off	1.88	1.51			

Notes: BAFF = bio-acoustic fish fence

[a] Sample proportion eaten parameters are those derived from the proportion eaten of each group of fish that arrived at the HOR study area forming a single sample (see Section 5.2.1 in Chapter 5, "Methods," for the definition of a sample).

[b] Population proportion eaten parameters are those derived from the grand total eaten divided by the total number of tags in juvenile Chinook salmon (see definition in Section 5.3.1 in Chapter 5, "Methods").

Source: Present study

Another method to evaluate predation on juvenile Chinook salmon was to pool the proportion eaten with the BAFF on for 2009 and 2010. Then, the proportion eaten observations for the BAFF off were pooled for 2009 and 2010. There was no difference between the BAFF on proportion eaten (mean = 0.256) and the BAFF-off proportion eaten (mean = 0.171) when the years were pooled (Kruskal Wallis X^2 = 3.043, P = 0.0811); however, the statistical power of the test was low (0.427). It was concluded that it might not have been possible to resolve a true difference, given the sample size and power achieved.

COMPARISON OF 2009 BAFF OFF, 2010 BAFF OFF, AND 2011 CONDITIONS

In Table 6-53, the proportion of tags eaten was not significantly different between "BAFF Off—2009" and "No Barrier—2011" at the HOR study area (Kruskal-Wallis X^2 =0.523, P-value = 0.4694). Additionally, the proportion of tags eaten was not significantly different between "BAFF Off—2009" and "BAFF Off—2010" (Table 6-52). The proportion of tags eaten was significantly different between "BAFF Off—2010" and "No Barrier—2011" at the HOR study area (Kruskal-Wallis X^2 =10.989, P-value = 0.0009). The "No Barrier—2011" treatment produced the lowest predation level among all years studied at 0.101.

This may have been related to high discharge in 2011, resulting in several potential changes in the environment: (1) higher channel velocities that increased the salmonid juvenile transit rates (see Appendix D, "Transit Speed Analyses," Table D-13); (2) increased stage height that caused the predators to search a larger volume of water; (3) greater energetic cost for predators to swim in the thalweg than in other years, potentially reducing searched volume; (4) lower habitat suitability and fewer predators inhabiting the area; and/or (5) greater turbidity and, therefore, less ability for predators to see prey. Factors influencing predation rate are analyzed further in Section 6.2.2, "Probability of Predation (Generalized Linear Modeling)."

Table 6-53
Statistics for Proportion of Juvenile Chinook Eaten, 2009, 2010, and 2011

Treatment—Year	Proportion Eaten[1]	Standard Deviation[1]	Number of Samples (n)[1]	Statistical Grouping[2]
Sample Proportion Eaten				
BAFF Off—2009	0.138	0.167	27	ab
BAFF Off—2010	0.212	0.167	22	a
No Barrier—2011	0.087	0.091	53	b
Population Proportion Eaten				
Treatment—Year	Proportion Eaten[2]	Standard Error[2]		
BAFF Off—2009	0.164	0.022		
BAFF Off—2010	0.205	0.027		
No Barrier—2011	0.101	0.009		

Notes: BAFF = bio-acoustic fish fence

1 Sample proportion eaten parameters are those derived from the proportion eaten of each group of fish that arrived at the HOR study area forming a single sample (see Section 5.2.1 in Chapter 5, "Methods," for the definition of a sample).

2 Population proportion eaten parameters are those derived from the grand total eaten divided by the total number of tags in juvenile Chinook salmon (see definition in Section 5.3.1 in Chapter 5, "Methods").

Source: Present study

2011 Chinook Salmon Compared to Steelhead

For 2011, the proportion of juvenile Chinook salmon determined to have been eaten was 0.087, and the proportion of juvenile steelhead determined to have been eaten was 0.243; this difference was significant (Table 6-54). Hypothesis $H9_0$ was rejected. However, there were two important related concepts: (1) there was a greater likelihood of steelhead being incorrectly assigned a fate of "eaten" compared to juvenile Chinook salmon (see the subsection entitled "Chinook Salmon Compared to Steelhead" in Section 7.1.4, "2011 No Barrier", of Chapter 7, "Discussion"); and (2) the juvenile steelhead used in this study were much larger than juvenile Chinook salmon (see Table 5-1 in Chapter 5, "Methods") and, therefore, probably had better swimming capabilities.

There were major differences in the behavior pattern of juvenile Chinook salmon and steelhead determined to have not been eaten at the HOR study area. Juvenile Chinook salmon had a consistent downstream migratory pattern, but steelhead swam upstream on occasion and even had some looping patterns. The similarity between steelhead behavior and predator behavior was at times difficult to distinguish. Thus, many steelhead may have been inappropriately classified as eaten. It is hypothesized that the statistical difference between juvenile Chinook salmon and steelhead proportion eaten was not because of "real" differences between the species, but because of misclassification errors in assigning predation to steelhead two-dimensional tracks. This hypothesis was supported by the observation that, after "eaten" tags were removed, juvenile Chinook salmon and steelhead P_E was not different (Table 6-39).

Table 6-54 Statistics for Proportion Eaten for Chinook Salmon and Steelhead in 2011					
Statistic	Chinook Salmon	Steelhead	Percentage Point Change	Kruskal-Wallis X^{2a}	P-Value[a]
Mean Sample Proportion Eaten[a]	0.087	0.243	-15.6	13.463	0.0002
Standard Deviation[a]	0.091	0.238			
Samples (n)[a]	53	93			
Proportion Eaten[b]	0.101	0.240			
Standard Error[b]	0.009	0.019			

Notes: n = number of samples.

[a] Sample proportion eaten parameters are those derived from the proportion eaten of each group of fish that arrived at the HOR study area forming a single sample (see Section 5.2.1 in Chapter 5, "Methods," for the definition of a sample).

[b] Population proportion eaten parameters are those derived from the grand total eaten divided by the total number of tags in juvenile Chinook salmon (see definition in Section 5.3.1 in Chapter 5, "Methods").

Source: Present study

2012 RESULTS

Chinook Salmon

In 2012, 39.3% of the tagged juvenile Chinook salmon were identified as having been eaten (Table 6-55). This was the highest proportion eaten observed in this study for any treatment/year combination, and was examined further in relation to the barrier treatments (see "Comparison of 2009 [BAFF On], 2010 [BAFF On], 2011[No Barrier], and 2012 [Rock Barrier] Conditions," below).

Table 6-55 Statistics for Proportion Eaten, 2009–2012				
Sample Proportion Eaten				
Treatment—Year	Proportion Eaten[1]	Standard Deviation[1]	Number of Samples (n)[1]	Statistical Grouping[1]
BAFF On—2009	0.290	0.216	21	ab
BAFF On—2010	0.217	0.217	19	ab
No Barrier—2011	0.087	0.091	53	a
Rock Barrier—2012	0.382	0.321	27	b
Population Proportion Eaten				
Treatment—Year	Proportion Eaten[2]	Standard Error (SE)[2]		
BAFF On—2009	0.309	0.030		
BAFF On—2010	0.310	0.030		
No Barrier—2011	0.101	0.009		
Rock Barrier—2012	0.394	0.035		

Notes: BAFF = bio-acoustic fish fence; n = number of samples

[1] Sample proportion eaten parameters are those derived from the proportion eaten of each group of fish that arrived at the HOR study area forming a single sample (see Section 5.2.1 in Chapter 5, "Methods," for the definition of a sample).

[2] Population proportion eaten parameters are those derived from the grand total eaten divided by the total number of tags in juvenile Chinook salmon (see definition in Section 5.3.1 in Chapter 5, "Methods").

Source: Present study

The proportion of tagged juvenile Chinook salmon classified as having been eaten at the HOR study area under different ambient light levels supported the hypothesis that the large difference in O_E, between low-light and high-light conditions, was due to greater predation on juvenile Chinook salmon during the day (see Section 6.1.7). In high-light conditions, the mean proportion of tagged juvenile Chinook salmon that were determined to have been eaten at the HOR study area was 42.3 percentage points greater than the proportion determined to have been eaten in low light (Table 6-56). A large difference in predation rates between low and high light was expected because the predators were primarily visual, and was one of the main hypotheses examined with GLM analysis (see Section 6.2.2, "Probability of Predation [Generalized Linear Modeling]"). This also is discussed in Section 7.2, "Predation on Juvenile Salmonids Including Barrier Effects," in Section 7, "Discussion".

Table 6-56
Statistics for Sample Proportion of Chinook Salmon Tags Eaten at Low and High Ambient Light Levels in 2012

Statistic	Low Ambient Light (<5.4 lux)	High Ambient Light (≥5.4 lux)	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Mean	0.131	0.554	-42.3	12.204	0.0005
Standard Deviation	0.203	0.271			
Minimum	0.000	0.158			
Maximum	0.500	1.000			
Samples (n)	11	16			

Note: n = number of samples
Source: Present study

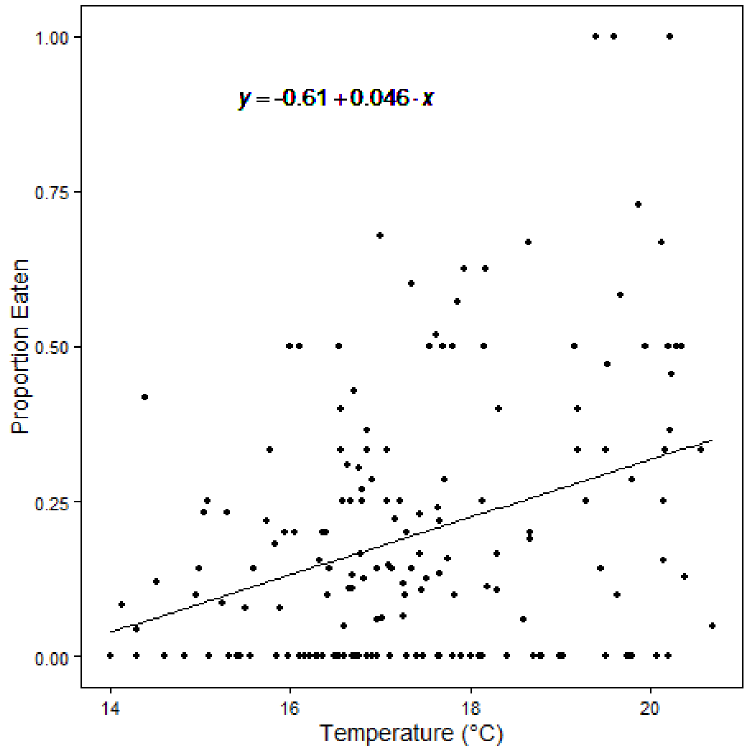
Steelhead

Of the five tagged steelhead that arrived at the HOR study area in 2012, one was eaten in the study area, so the proportion eaten was 0.200.

WATER TEMPERATURE AND TURBIDITY EFFECTS ON PROPORTION EATEN

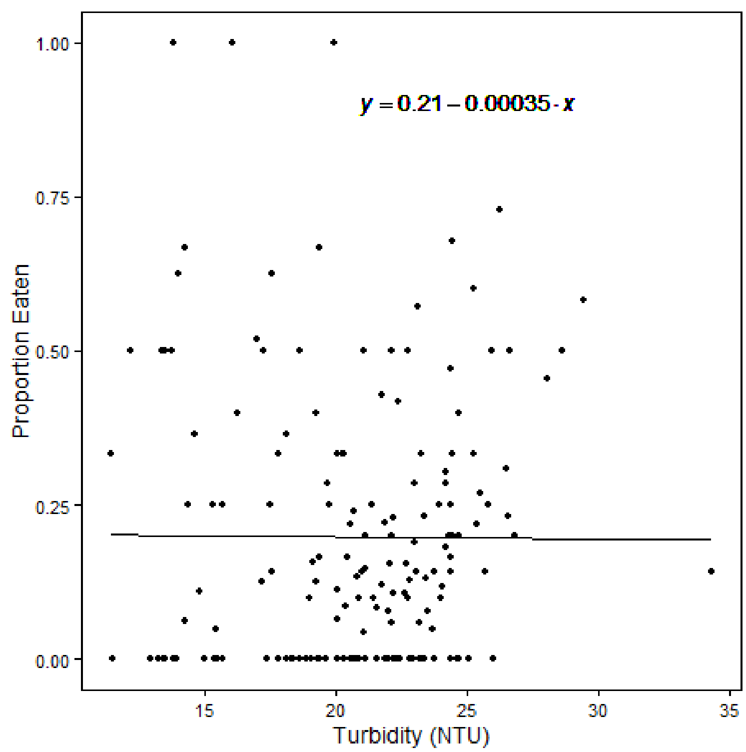
Samples from all years were considered together, and mean sample water temperature was positively correlated with proportion of juvenile Chinook salmon eaten (Spearman's $\rho = 0.264$, $P = 0.0005$, Figure 6-9). It was hypothesized that as water temperatures moved toward critically warmer temperatures for juvenile Chinook salmon (Table 3-4 in Section 3.3.1 of Section 3, "Physical Parameters"), predators gained an advantage over the juvenile salmonids in swimming performance and survival. It is also possible that increased water temperatures led to greater bioenergetic demands for prey consumption, thus increasing predation pressure at the warmer temperatures.

Similar to water temperature, turbidity samples from all years were considered together. In contrast to the effect of water temperature, turbidity was not correlated with proportion eaten for juvenile Chinook salmon (Spearman's $\rho = 0.098$, $P = 0.2034$, Figure 6-10). Further examination of water temperature and turbidity effects is provided with the GLM of predation probability (see Section 6.2.2, "Probability of Predation [Generalized Linear Modeling]").



Source: Present study

Figure 6-9 Sample Mean Temperatures and Proportion of Tagged Juvenile Chinook Salmon Eaten During Fish Release Periods from 2009–2012 with Equation of Fitted Line Shown



Source: Present study

Figure 6-10 Sample Mean Turbidities and Proportion of Tagged Juvenile Chinook Salmon Eaten During Fish Release Periods from 2009–2012 with Equation of Fitted Line Shown

COMPARISON OF 2009 (BAFF ON), 2010 (BAFF ON), 2011(NO BARRIER), AND 2012 (ROCK BARRIER) CONDITIONS

Proportion eaten was different between barrier treatments at the HOR study area (Kruskal-Wallis $X^2 = 20.505$, P-value = 0.0001). Hypothesis H_{10} was rejected. The BAFF showed no significant difference in proportion eaten in 2009 compared to 2010 (Table 6-52); therefore, the "BAFF On—2009" statistics were grouped with the "BAFF On—2010" statistics (Table 6-55). Because the data did not meet the assumptions of ANOVA, three nonparametric two-sample comparisons were made between treatments: 2010 compared to 2011; 2010 compared to 2012; and 2011 compared to 2012. As noted previously, the critical alpha for these comparisons was 0.0167. Only the two-sample comparison of 2011 vs. 2012 was significant (Kruskal-Wallis $X^2 = 77.938$, P-value <0.0001) (Table 6-55).

Among the three treatment/year types, "No Barrier—2011" produced a smaller proportion of tagged juveniles eaten (Table 6-55) compared to 2012. However, in 2011 the highest discharges were exhibited of all years studied (Appendix D, "Transit Speed Analyses," Table D-13). It was hypothesized that high discharges led to high ACVs, and these high ACVs reduced the proportion eaten by reducing predator/prey encounters. Other potential mechanisms are discussed in Section 7.1, "Predation on Juvenile Salmonids Including Barrier Effects," and Section 7.2, "Predation on Juvenile Salmonids Including Barrier Effects," in Section 7, "Discussion".

The proportion of tagged juvenile Chinook salmon that did not arrive at the HOR study area after release provided additional information about survival and predation for each year (Table 6-57). In 2009, 44.6% of the tagged juvenile Chinook salmon did not arrive at the study area, which indicated that the tags may have experienced a high predation rate prior to encountering the BAFF, and/or were more vulnerable to predation due to tag burden. In contrast, in 2010, just 11.2% of the tagged juvenile Chinook salmon did not arrive. In 2011, the high-discharge year, only a subset of tags was analyzed and so it is not possible to make inferences regarding the proportion of fish that never arrived at the HOR study area. The 2012 statistics included the highest proportion of tags eaten (39.3%), and also the highest percentage of tags released that never arrived (53.9%). Thus, it was hypothesized that the high rate of 2012 predation was not due solely to the presence of the physical rock barrier, but also was influenced by other factors contributing to greater predator numbers or better predator capture success in 2012 than in 2011 (see Sections 6.3.2, "Hydroacoustic Data," and 7.3.3, "Changes in Density of Predatory Fishes").

Table 6-57
Statistics for Chinook Salmon Tags Released and Arrived, 2009–2012

Treatment—Year	Released (n)	Arrived (n)	Never Arrived (n)	Proportion Never Arrived
BAFF—2009	960	532	428	0.446
BAFF—2010	508	451	57	0.112
No Barrier—2011[1]	—	—	—	—
Rock Barrier—2012	419	193	226	0.539

Notes: BAFF = bio-acoustic fish fence; n = number of samples
[1] Only a subset of data were processed in 2011 and so the proportion not arriving in the study area is unknown.
Source: Present study

6.2.2 PROBABILITY OF PREDATION (GENERALIZED LINEAR MODELING)

CHINOOK SALMON

Of the 2,244 tagged juvenile Chinook salmon entering the HOR study area from 2009 through 2012, it was estimated that 422 were preyed upon (0.188, or approximately 19%) (Table 6-58). A lower proportion of juvenile Chinook salmon were preyed upon with the non-physical barrier (BAFF) turned off in 2009 and 2010 (0.182), compared to a noticeably higher proportion of juveniles that were preyed upon with the non-physical barrier turned on (0.310) and with the 2012 physical rock barrier (0.394). Approximately 0.10 of juveniles were preyed upon with no barrier (2011), which coincided with appreciably higher SJL discharge (mean of approximately 5,000 cfs) than in other years (mean of approximately 1,600 to 1,900 cfs). The proportion of juvenile Chinook salmon that were preyed upon was lower in the dark (<5.4 lux) than in the light (≥5.4 lux), and this pattern was consistent across all barrier treatments (Table 6-58). The magnitude of difference between predation proportion in the light and dark light levels ranged from double with the non-physical barrier turned off to approximately three times greater with the physical rock barrier.

GLM and modeling averaging of the 2009, 2010, and 2012 data for juvenile Chinook salmon found good support for the ambient light level, barrier status, and small-fish density predictors of predation probability, as indicated by coefficient 95% confidence intervals excluding zero and importance greater than 0.8 (Table 6-59).

The positive coefficient for the ambient light level predictor indicates a greater predation probability with increasing light level, which allowed acceptance of hypothesis H11 for this predictor (see "Objectives and Hypotheses Related to Probability of Predation" in Section 1.2.3, "Predation on Juvenile Salmonids Including Barrier Effects"). In contrast, the positive coefficient for the small-fish density predictor was contrary to the hypothesis that predation probability would be lower with greater density of small fish (i.e., greater safety in numbers for an individual juvenile entering the HOR study area).

The coefficients for the barrier status predictor indicated that there was greater predation probability with the physical rock barrier and with the non-physical barrier turned on (for which the 95% coefficient confidence intervals excluded zero) than with the non-physical barrier turned off (which was the baseline barrier treatment in the model [i.e., a value of zero]). This led to the rejection of the null hypothesis of no difference between barrier treatment included in H11. None of the other predictors of predation probability were well supported by the GLMs, and H11 was rejected for these predictors.

The GLMs with predictors included provided a better fit to the data than the intercept-only model. The full model with all predictors was the second-ranked model (out of 128 total models) and had AIC_c of 1,258.2, in comparison to AIC_c of 1,360.4 for the intercept-only model (rank 128) (Table F-1 in Appendix F, "Model Fit and Weight Tables from Results of Predation Probability Generalized Linear Modeling").

Table 6-58
Number and Proportion of Tagged Juvenile Chinook Salmon Preyed Upon at the Head of Old River in 2009, 2010, 2011, and 2012, with Means and Standard Deviations of Environmental Variables

Barrier/ Light Level	No. of Juveniles		Predation		Juvenile Length (mm)		Small-Fish Density (No./10,000 m³)		Discharge (cfs)		Turbidity (NTU)		Temperature (°C)	
	Total	Predation	Proportion	SE	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1. Non-physical Barrier Off	511	93	0.182	0.017	101.8	8.6	2.7	2.6	1,642.5	1,240.7	21.1	5.1	17.6	1.8
a. Dark	136	14	0.103	0.026	103.3	8.8	2.6	2.3	1,723.5	1,283.9	21.0	4.4	17.1	1.4
b. Light	375	79	0.211	0.021	101.3	8.5	2.8	2.8	1,613.1	1,225.1	21.1	5.4	17.8	1.9
2.Non-physical Barrier On	465	144	0.310	0.021	102.6	8.9	2.7	2.4	1,740.4	1,270.4	23.0	4.6	17.5	1.6
a. Dark	105	10	0.095	0.029	103.6	8.4	2.6	2.6	1,342.2	1,547.9	21.4	4.2	17.1	1.5
b. Light	360	134	0.372	0.025	102.3	9.0	2.8	2.4	1,856.5	1,154.2	23.5	4.6	17.6	1.6
3.No Barrier	1,075	109	0.101	0.009	110.1	6.2	140.8	145.2	5,117.4	268.3	21.7	1.5	16.5	1.2
a. Dark	306	9	0.029	0.010	109.5	5.8	136.1	144.6	5,042.9	266.6	21.1	1.4	16.2	1.2
b. Light	769	100	0.130	0.012	110.4	6.3	142.6	145.5	5,147.1	263.3	22.0	1.4	16.7	1.2
4.Rock Barrier	193	76	0.394	0.035	110.0	7.4	4.1	2.3	1,855.4	465.1	17.2	3.1	18.6	0.9
a. Dark	38	6	0.158	0.059	106.4	6.2	3.2	1.9	1,880.2	382.7	18.0	3.5	19.0	0.9
b. Light	155	70	0.452	0.040	110.9	7.4	4.4	2.3	1,849.3	484.0	17.0	2.9	18.5	0.9
Total	2,244	422	0.188	0.008	106.7	8.4	69.0	121.8	3,345.8	1,904.6	21.5	3.8	17.2	1.6

Notes: Shaded rows indicate data used in GLM of predation probability for juvenile Chinook salmon in 2009, 2010, and 2012.
°C = degrees Celsius; cfs = cubic feet per second; m^3 = cubic meters; mm = millimeters; No. = number; NTU = nephelometric turbidity units; SD = standard deviation; SE = standard error; Dark <5.4 lux; Light ≥5.4 lux
Source: Present study

Table 6-59
Model-Averaged Coefficients, 95% Confidence Limits, and Variable Importance for Generalized Linear Modeling of Predation Probability of Tagged Juvenile Chinook Salmon at Head of Old River in 2009, 2010, and 2012

Variable	Estimate	95% Confidence Limits		Importance
		Lower	Upper	
Ambient Light	0.108	0.072	0.144	1.00
Barrier (Non-physical Barrier On)	0.605	0.285	0.924	1.00
Barrier (Physical Rock)	0.853	0.310	1.396	1.00
Small-Fish Density	0.222	0.049	0.394	0.96
Turbidity	0.035	-0.005	0.076	0.86
Juvenile Length	0.015	-0.011	0.041	0.72
Water Temperature	0.078	-0.059	0.215	0.71
Discharge	0.002	-0.003	0.007	0.44

Note: Barrier status coefficients are in relation to baseline estimates with the non-physical barrier turned off (Non-physical Barrier Off).
Source: Present study

The optimum threshold for the model-averaged predictor coefficients was 0.36 based on the maximum Kappa method. The Kappa statistic indicated that approximately 33% of all possible predation and survival fates were correctly predicted by the model-averaged coefficients, adjusting for correct predictions by chance. The percent of outcomes correctly classified was 73.5%. The model-averaged coefficients correctly predicted 51.4% of true positives (juveniles that had been preyed upon [i.e., sensitivity]) and 81.5% of true negatives (juveniles that had survived [i.e., specificity]), indicating a false positive classification of 19.5%. The area under ROC was 0.70, indicating that the model-averaged coefficients were at the lower end of the “acceptable discrimination” range (Hosmer and Lemeshow 2000: 162). Overall, the model-averaged predictors provided a reasonable representation of the predation probability in relation to the observed predation proportion, although the model somewhat underestimated the higher predation proportion that occurred in light conditions (Figure 6-11).

A second set of GLMs was used to assess the probability of predation on juvenile Chinook salmon for 2011 and 2012. As described in Section 5.3.2, “Probability of Predation (Generalized Linear Modeling),” this analysis included estimates of the density of large fish (greater than 30 cm TL) from mobile hydroacoustics as a potential indicator of predatory fish abundance at the HOR study area. Such estimates were not available for 2009 and 2010. These GLMs did not include barrier status as a predictor because discharge was considerably different between 2011 and 2012 and so confounded the barrier predictor. Table 6-60 summarizes the data used in this analysis. These data are a subset of the data from Table 6-58 because many juveniles had missing values for the large-fish density predictor (i.e., their entry into the study area did not coincide suitably with mobile hydroacoustic surveys).

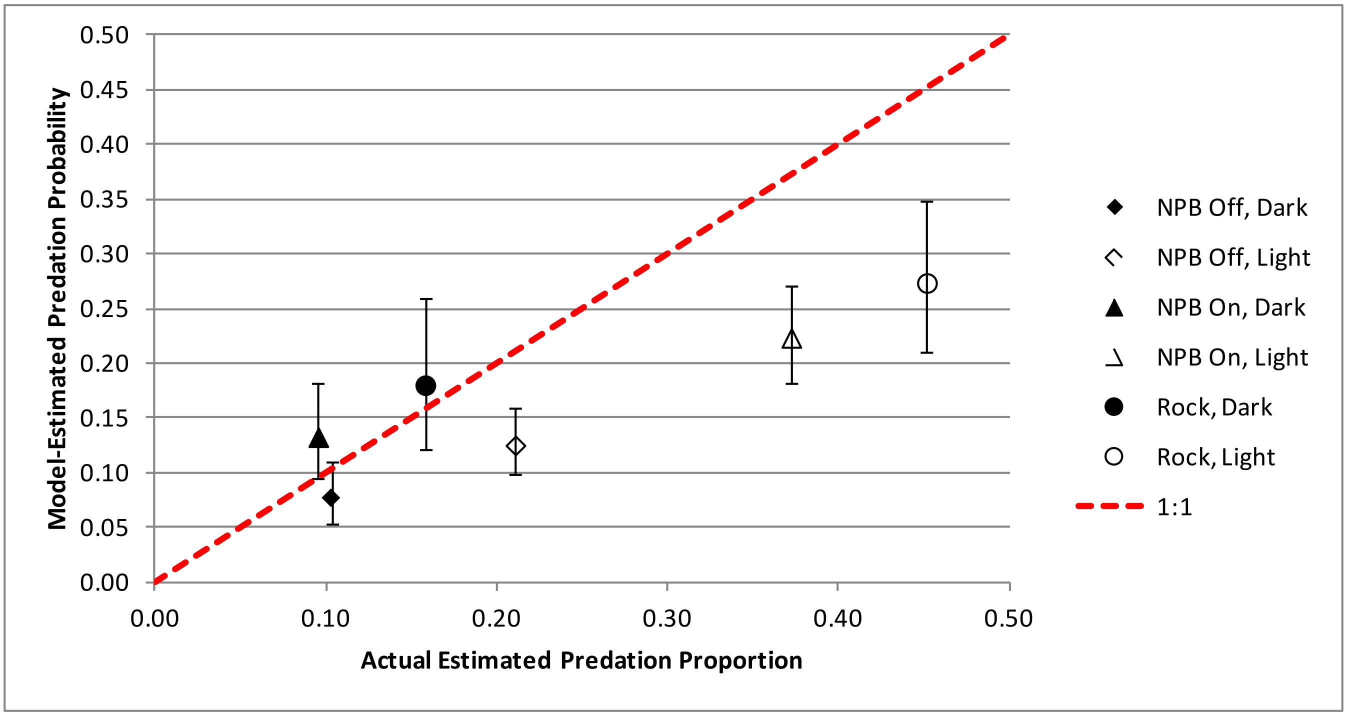
Table 6-60
Number and Proportion of Tagged Juvenile Chinook Salmon Preyed Upon at the Head of Old River in 2011 and 2012, with Means and Standard Deviations of Environmental Variables

Barrier/ Light Level	No. of Juveniles		Predation		Juvenile Length (mm)		Large-Fish Density, Down (No./10,000 m³)		Large-Fish Density, Side (No./10,000 m³)		Small-Fish Density (No./10,000 m³)		Discharge (cfs)		Turbidity (NTU)		Temperature (°C)	
	Total	Predation	Proportion	SE	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1.No Barrier	797	80	0.100	0.011	109.1	5.3	4.3	2.0	1.6	0.4	157.7	151.5	5,165.5	248.2	21.7	1.3	16.1	1.1
a. Dark	240	8	0.033	0.012	108.9	5.2	3.9	2.2	1.6	0.5	142.2	150.3	5,071.5	259.1	21.0	1.2	15.9	1.1
b. Light	557	72	0.129	0.014	109.2	5.3	4.4	1.9	1.6	0.4	164.4	151.7	5,206.0	232.1	22.0	1.3	16.2	1.1
2.Rock Barrier	79	30	0.380	0.055	110.5	7.6	144.3	143.7	6.1	2.1	3.7	1.1	1,850.0	478.1	16.7	2.9	18.7	1.0
a. Dark	15	3	0.200	0.103	105.5	5.2	136.2	149.4	6.0	2.1	4.1	1.4	1,976.0	328.7	17.4	2.6	18.8	1.0
b. Light	64	27	0.422	0.062	111.7	7.6	146.2	143.4	6.1	2.1	3.6	0.9	1,820.4	504.3	16.5	3.0	18.7	1.1
Total	876	110	0.126	0.011	109.3	5.5	16.9	58.8	2.0	1.5	143.8	151.1	4,866.5	989.7	21.2	2.1	16.4	1.3

Notes: °C = degrees Celsius; cfs = cubic feet per second; m^3 = cubic meters; mm = millimeters; No. = number; NTU = nephelometric turbidity units; SD = standard deviation; SE = standard error; Dark <5.4 lux; Light ≥5.4 lux.

Shaded rows indicate data used in GLM of predation probability for juvenile Chinook salmon in 2011 and 2012.

Source: Present study



Note: NPB = non-physical barrier
Source: Present study

Figure 6-11 **Probability of Predation (with 95% Confidence Interval) of Tagged Juvenile Chinook Salmon at Head of Old River, Estimated from GLM in Relation to Observed Predation Proportion, for Various Combinations of Barrier Status and Light/Dark Conditions in 2009, 2010, and 2012**

Model-averaging indicated that only ambient light level and turbidity were well-supported predictors of the probability of predation on juvenile Chinook salmon in 2011 and 2012 (Table 6-61). The signs of the coefficients indicated support for hypothesis H12 that predation probability would be greater under higher visibility conditions (lower turbidity, higher light levels). None of the other predictors were well-supported from model-averaging (coefficient 95% confidence intervals included zero and importances were less than 0.8); hypothesis H12 was rejected for these predictors.

The GLMs including predictors provided a better fit to the data than the intercept-only model, with the full model having AIC_c = 593.3 (model rank = 17 out of 256 models) and the intercept-only model having AIC_c = 664.0 (ranked last out of all models) (Table F-2 in Appendix F, "Model Fit and Weight Tables from Results of Predation Probability Generalized Linear Modeling"). The optimum threshold for the model-averaged predictor coefficients was 0.18 based on the maximum Kappa method. The Kappa statistic indicated that approximately 29% of all possible predation and survival fates were correctly predicted by the model-averaged coefficients, adjusting for correct predictions by chance. The percent correctly classified was 82.8%. The model-averaged coefficients correctly predicted 43.6% of true positives (i.e., sensitivity) and 88.4% of true negatives (i.e., specificity), for a false positive classification of 11.6%. The area under the ROC was 0.73, which was slightly greater than the GLMs of predation probability in 2009, 2010, and 2012, and indicated that the model-averaged coefficients were within the "acceptable discrimination" range (Hosmer and Lemeshow 2000:162).

Table 6-61 Model-Averaged Coefficients, 95% Confidence Limits, and Variable Importance for the Generalized Linear Modeling of Predation Probability of Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012				
Variable	Estimate	95% Confidence Limits		Importance
		Lower	Upper	
Ambient Light	0.127	0.071	0.182	1.00
Turbidity	-0.270	-0.412	-0.129	1.00
Water Temperature	0.171	-0.105	0.448	0.74
Large-Fish Density (Down)	-0.126	-0.467	0.215	0.49
Juvenile Length	0.012	-0.024	0.047	0.44
Small-Fish Density	0.038	-0.109	0.184	0.39
Large-Fish Density (Side)	0.164	-0.580	0.908	0.35
Discharge	0.000	-0.005	0.005	0.31
Source: Present study				

STEELHEAD

A total of 525 tagged juvenile steelhead entered the HOR study area in 2011 and 2012, and 126 (0.24, or 24%) were estimated to have been preyed upon (Table 6-62). Only five juveniles entered the area in 2012 when the physical rock barrier was present, and one was preyed upon. For 2011 (no barrier), the predation proportion was higher in light (0.261) than dark (0.182) conditions.

Only 2011 data were included in the GLM analysis for steelhead predation probability at the HOR study area. The desire to include large-fish density data from mobile hydroacoustics as an indication of predator abundance reduced sample size because steelhead entry did not always coincide with mobile hydroacoustics. Table 6-63 summarizes the data included in the steelhead GLM of predation probability for 163 steelhead entering the study area in 2011. GLMs with predictors included did not produce a better fit to the data than the intercept-only model. The full model with all predictors included ranked 250 out of 256 models, with an AIC_c of 199.0, which was higher than the intercept-only model (AIC_c = 192.1, rank = 16) (Table F-3 in Appendix F, "Model Fit and Weight Tables from Results of Predation Probability Generalized Linear Modeling"). The lack of support for all predictors of steelhead predation probability included in the GLM was also evident from model-averaged coefficients, for which all 95% confidence intervals included zero and importances were all less than 0.8.

Table 6-62
Number and Proportion of Tagged Juvenile Steelhead Preyed Upon at the Head of Old River in 2011 and 2012, with Means and Standard Deviations of Environmental Variables

	No. of Juveniles		Predation		Juvenile Length (mm)		Small-Fish Density (No./10,000 m³)		Discharge (cfs)		Turbidity (NTU)		Temperature (°C)	
Barrier/Light	Total	Predation	Proportion	SE	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2011 No Barrier	520	125	0.240	0.019	282.2	23.3	69.3	119.7	5,424.4	857.7	21.8	2.3	16.4	1.1
a. Dark	137	25	0.182	0.033	279.5	20.4	80.5	131.9	5,603.4	947.8	20.9	1.8	16.6	1.2
b. Light	383	100	0.261	0.022	283.1	24.2	65.3	115.0	5,360.4	814.9	22.2	2.4	16.3	1.0
2012 Rock Barrier	5	1	0.200	0.179	242.8	14.0	3.6	0.6	1,320.8	635.2	15.0	3.2	19.2	0.3
a. Dark	2	0	0.000	0.000	232.0	2.8	3.7	0.3	1,223.0	589.7	13.2	1.0	19.2	0.6
b. Light	3	1	0.333	0.272	250.0	14.0	3.5	0.8	1,386.0	785.6	16.2	3.9	19.3	0.2
Total	525	126	0.240	0.019	281.8	23.6	68.7	119.3	5,385.4	943.9	21.8	2.4	16.4	1.1

Notes: °C = degrees Celsius; cfs = cubic feet per second; m^3 = cubic meters; mm = millimeters; No. = number; NTU = nephelometric turbidity units; SD = standard deviation; SE = standard error; Dark <5.4 lux; Light ≥5.4 lux

Source: Present study

Table 6-63
Number and Proportion of Tagged Juvenile Steelhead Preyed Upon at the Head of Old River in 2011 and 2012, with Means and Standard Deviations of Environmental Variables

	No. of Juveniles		Predation		Juvenile Length (mm)		Large-Fish Density, Down (No./10,000 m³)		Large-Fish Density, Side (No./10,000 m³)		Small-Fish Density (No./10,000 m³)		Discharge (cfs)		Turbidity (NTU)		Temperature (°C)	
Barrier/Light	Total	Predation	Proportion	SE	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2011 No Barrier	163	44	0.270	0.035	284.9	24.3	4.6	2.0	1.8	0.6	132.8	143.8	5,116.3	239.4	22.1	1.3	16.2	0.9
a. Dark	44	8	0.182	0.058	282.3	22.3	4.9	1.9	1.7	0.5	156.6	157.0	5,036.4	278.2	21.2	1.0	16.0	0.9
b. Light	119	36	0.303	0.042	285.9	25.0	4.6	2.1	1.8	0.6	124.0	138.3	5,145.8	217.4	22.4	1.3	16.2	0.9
2012 Rock Barrier	4	0	0.000	0.000	238.5	11.8	311.2	19.5	8.3	0.1	3.8	0.2	1,133.5	551.5	13.7	1.8	19.2	0.3
a. Dark	2	0	0.000	0.000	232.0	2.8	320.9	27.5	8.3	0.1	3.7	0.3	1,223.0	589.7	13.2	1.0	19.2	0.6
b. Light	2	0	0.000	0.000	245.0	15.6	301.4	0.0	8.3	0.0	3.9	0.0	1,044.0	729.7	14.3	2.8	19.2	0.1
Total	167	44	0.263	0.034	283.8	25.1	12.0	47.1	1.9	1.2	129.7	143.5	5,020.9	659.2	21.9	1.8	16.2	1.0

Notes: °C = degrees Celsius; cfs = cubic feet per second; m^3 = cubic meters; mm = millimeters; No. = number; NTU = nephelometric turbidity units; SD = standard deviation; SE = standard error; Dark <5.4 lux; Light ≥5.4 lux

Shaded rows indicate data used in GLM of predation probability for juvenile steelhead in 2011.

Source: Present study

6.3 BEHAVIOR AND DENSITY CHANGES IN PREDATORY FISH

6.3.1 DATA FROM TAGGED PREDATORY FISH

OVERVIEW OF TAGGED PREDATORY FISH

One hundred predatory fish were captured, acoustically tagged, and released at the HOR study area from 2009 through 2012 (Table 6-64). However, only 82 were detected post-tagging within the acoustic arrays, which, when combined with an additional two fish tagged elsewhere in the system (both striped bass in 2010), provided an overall total of 84 fish for analysis. Only two fish were tagged in 2009 (largemouth bass tag code 4306 and striped bass tag code 4222), and only one fish was tagged in 2010 (striped bass tag code 2472). In 2011, 37 fish were tagged, of which three were largemouth bass (290 to 300 mm FL), 30 were striped bass (340 to 686 mm FL), and four were white catfish (255 to 375 mm FL). In 2012, 42 fish were tagged, of which six were channel catfish (305 to 625 mm TL; one released into Old River below the HOR physical rock barrier, the remainder San Joaquin River side of the physical rock barrier), 13 were largemouth bass (307 to 440 mm TL; six released into Old River below the physical rock barrier, the remainder into the San Joaquin River), 22 were striped bass (310 to 667 mm TL; 15 released into Old River below the physical rock barrier, the remainder upstream of the physical rock barrier), and one was a white catfish (320 mm TL, released into the San Joaquin River) (Table 6-64).

In the following sections describing the detailed results related to tagged predatory fish, fish tagged in 2012 are referred to either as being released into the HOR if they were released downstream of the physical rock barrier, or released into the San Joaquin River if they were released upstream of the physical rock barrier (either into the San Joaquin River or into Old River upstream).

RESIDENCE TIME

The approximate duration that tagged predatory fish spent within the detectable distance of the acoustic arrays at the HOR study area ranged from 0.01 hour (striped bass tag code 3366 in 2011) to 622 hours (white catfish tag code 3408 in 2011) (Table 6-64). There were considerable ranges in the length of time spent at the HOR study area by each species: channel catfish (0.08 to 71.5 hours), largemouth bass (0.11 to 242.6 hours), striped bass (0.01 to 282.6 hours), and white catfish (1.0 to 621.9 hours).

The percentage of dates between tagging/release and deactivation of the acoustic array was assessed to account for two factors: capture and tagging events occurring over a number of weeks (which affected the potential maximum duration that a fish could spend at the HOR study area), and the observation that some fish were detected on many dates but had relatively few positive detections by the array. Striped bass generally were detected on the smallest percentage of possible dates between tagging/release and acoustic array deactivation of the four predatory fish species. Striped bass had bootstrapped mean percentages of dates detected in all years of 10% to 20%, with bootstrapped 95% confidence intervals ranging from around 8% to 14% for 2011, and 2012 Old River releases from 4% to 38% for 2012 San Joaquin River releases (Figure 6-12).

The 95% confidence intervals of the percentage of dates when striped bass were detected in 2009 and 2010 (4.5 to 26%), 2011, and 2012 (Old River releases) did not overlap the 95% confidence intervals for largemouth bass in 2012 (San Joaquin River releases: 33 to 90%) or white catfish in 2011 (35 to 100%). They also had very little overlap with the 95% confidence interval for channel catfish released into Old River in 2012 (22 to 61%) (Figure 6-12).

Table 6-64
Tagged Predatory Fish at the Head of Old River, 2009-2012

Species	Length (mm FL unless noted in "Comments")	Tag Code	Tagging/ Release Date	Dates Detected in Study Area	Approx. Duration in Study Area (Hours)	Release Area	Comments
Channel Catfish	515	2511	4/22/2012	NA	Undetected	SJ River	Total Length
Channel Catfish	460	2847	5/9/2012	5/9/2012, 5/14/2012, 5/20/2012 to 5/24/2012, 5/26/2012, 5/27/2012	6.57	SJ River	Total Length
Channel Catfish	305	2490	5/20/2012	5/20/2012	4.76	SJ River	Total Length
Channel Catfish	625	2112	5/22/2012	5/22/2012	0.08	Old River	Total Length
Channel Catfish	473	2952	5/22/2012	5/22/2012, 5/23/2012, 5/27/2012, 5/29/2012	10.69	SJ River	Total Length
Channel Catfish	545	2763	5/23/2012	5/23/2012 to 5/28/2102	71.54	SJ River	Total Length
Channel Catfish	535	2994	5/23/2012	5/23/2012, 5/24/2012, 5/31/2012	3.54	SJ River	Total Length
Largemouth Bass	315	4306	5/6/2009	5/06/2009 to 5/16/2009	88.17		
Largemouth Bass	300	3324	5/24/2011	6/9/2011 to 6/11/2011, 6/13/2011, 6/15/2011 to 6/18/2011, 6/20/2011 to 6/22/2011	17.09		
Largemouth Bass	290	3436	5/24/2011	5/24/2011	0.11		
Largemouth Bass	320	3464	5/24/2011	NA	Undetected		
Largemouth Bass	290	3492	5/24/2011	5/25/2011 to 5/28/2011, 5/30/2011 to 6/1/2011, 6/7/2011, 6/9/2011, 6/13/2011, 6/15/2011, 6/16/2011, 6/21/2011, 6/22/2011	20.86		
Largemouth Bass	350	2049	4/22/2012	NA	Undetected	SJ River	Total Length
Largemouth Bass	440	2280	4/22/2012	4/23/2012, 4/27/2012, 5/17/2012, 5/18/2012	3.09	SJ River	Total Length
Largemouth Bass	440	2091	4/29/2012	4/29/2012, 5/10/2012, 5/12/2012 to 5/20/2012	96.61	Old River	Total Length
Largemouth Bass	360	2742	4/29/2012	4/29/2012, 5/5/2012	3.61	Old River	Total Length
Largemouth Bass	323	2322	5/6/2012	5/6/2012 to 5/9/2012, 5/11/2012 to 5/31/2012	242.57	Old River	Total Length
Largemouth Bass	350	2133	5/15/2012	5/15/2012	0.70	Old River	Total Length
Largemouth Bass	316	3078	5/18/2012	5/18/2012 to 5/27/2012	95.27	SJ River	Total Length
Largemouth Bass	420	2826	5/19/2012	NA	Undetected	Old River	Total Length
Largemouth Bass	335	3057	5/19/2012	5/19/2012	1.68	Old River	Total Length

Table 6-64
Tagged Predatory Fish at the Head of Old River, 2009-2012

Species	Length (mm FL unless noted in "Comments")	Tag Code	Tagging/ Release Date	Dates Detected in Study Area	Approx. Duration in Study Area (Hours)	Release Area	Comments
Largemouth Bass	323	2028	5/20/2012	5/20/2012 to 5/31/2012	182.51	SJ River	Total Length
Largemouth Bass	380	2196	5/20/2012	5/20/2012	0.45	Old River	Total Length
Largemouth Bass	395	2259	5/20/2012	5/20/2012 to 5/22/2012	39.13	SJ River	Total Length
Largemouth Bass	374	2070	5/22/2012	5/22/2012, 5/25/2012	3.07	SJ River	Total Length
Largemouth Bass	316	2301	5/22/2012	NA	Undetected	SJ River	Total Length
Largemouth Bass	307	2721	5/22/2012	5/22/2012 to 5/31/2012	192.89	SJ River	Total Length
Largemouth Bass	345	2532	5/23/2012	5/23/2012 to 5/31/2012	48.18	SJ River	Total Length
Largemouth Bass	332	3141	5/24/2012	NA	Undetected	SJ River	Total Length
Striped Bass	370	4222	5/12/2009	5/12/2009	0.26		
Striped Bass	406	2024	4/4/2010	4/28/2010, 5/7/2010	0.61		Tagged downstream of the HOR study area in San Joaquin River near Weston Ranch
Striped Bass	480	2976	5/5/2010	5/22/2010	0.54		Tagged downstream of the HOR study area at Tracy Fish Facility
Striped Bass	508	2472	5/16/2010	5/16/2010 to 5/18/2010	3.04		
Striped Bass	425	2136	5/14/2011	NA	Undetected		
Striped Bass	570	2234	5/14/2011	5/14/2011, 5/15/2011	7.14		
Striped Bass	405	2206	5/19/2011	5/19/2011	0.13		
Striped Bass	565	2262	5/19/2011	5/19/2011 to 5/28/2011	38.77		
Striped Bass	340	3422	5/19/2011	5/19/2011	0.20		
Striped Bass	405	2556	5/20/2011	5/20/2011, 5/28/2011	0.60		
Striped Bass	360	3338	5/20/2011	5/20/2011	0.07		
Striped Bass	330	3478	5/20/2011	NA	Undetected		
Striped Bass	415	2290	5/21/2011	5/21/2011, 5/23/2011 to 5/25/2011, 6/9/2011	5.90		

Table 6-64
Tagged Predatory Fish at the Head of Old River, 2009-2012

Species	Length (mm FL unless noted in "Comments")	Tag Code	Tagging/ Release Date	Dates Detected in Study Area	Approx. Duration in Study Area (Hours)	Release Area	Comments
Striped Bass	540	3060	5/21/2011	5/21/2011	0.66		
Striped Bass	405	3366	5/21/2011	5/21/2011	0.01		
Striped Bass	381	3380	5/22/2011	5/22/2011, 5/24/2011	0.19		
Striped Bass	390	3450	5/24/2011	5/24/2011, 5/27/2011, 6/22/2011	0.60		
Striped Bass	490	3074	5/26/2011	5/26/2011	0.07		
Striped Bass	350	2122	6/1/2011	6/1/2011	0.07		
Striped Bass	399	3172	6/2/2011	NA	Undetected		
Striped Bass	686	3382	6/2/2011	6/2/2011	0.09		
Striped Bass	360	3200	6/6/2011	NA	Undetected		
Striped Bass	385	3270	6/6/2011	6/6/2011	0.30		
Striped Bass	461	3298	6/6/2011	6/6/2011	7.40		
Striped Bass	544	2094	6/7/2011	NA	Undetected		
Striped Bass	445	2486	6/7/2011	6/7/2011, 6/8/2011	6.35		
Striped Bass	440	3340	6/7/2011	6/7/2011	12.99		
Striped Bass	374	3088	6/8/2011	6/8/2011, 6/9/2011	24.50		
Striped Bass	433	3144	6/8/2011	6/8/2011	0.06		
Striped Bass	455	3186	6/8/2011	6/8/2011	0.03		
Striped Bass	400	3242	6/8/2011	6/8/2011	0.05		
Striped Bass	410	3158	6/9/2011	6/9/2011	0.04		
Striped Bass	370	3284	6/9/2011	6/9/2011, 6/10/2011	0.81		
Striped Bass	395	2178	6/13/2011	6/13/2011	0.09		
Striped Bass	430	2248	6/13/2011	6/13/2011, 6/14/2011	2.44		
Striped Bass	420	2332	6/13/2011	NA	Undetected		
Striped Bass	390	3102	6/13/2011	NA	Undetected		

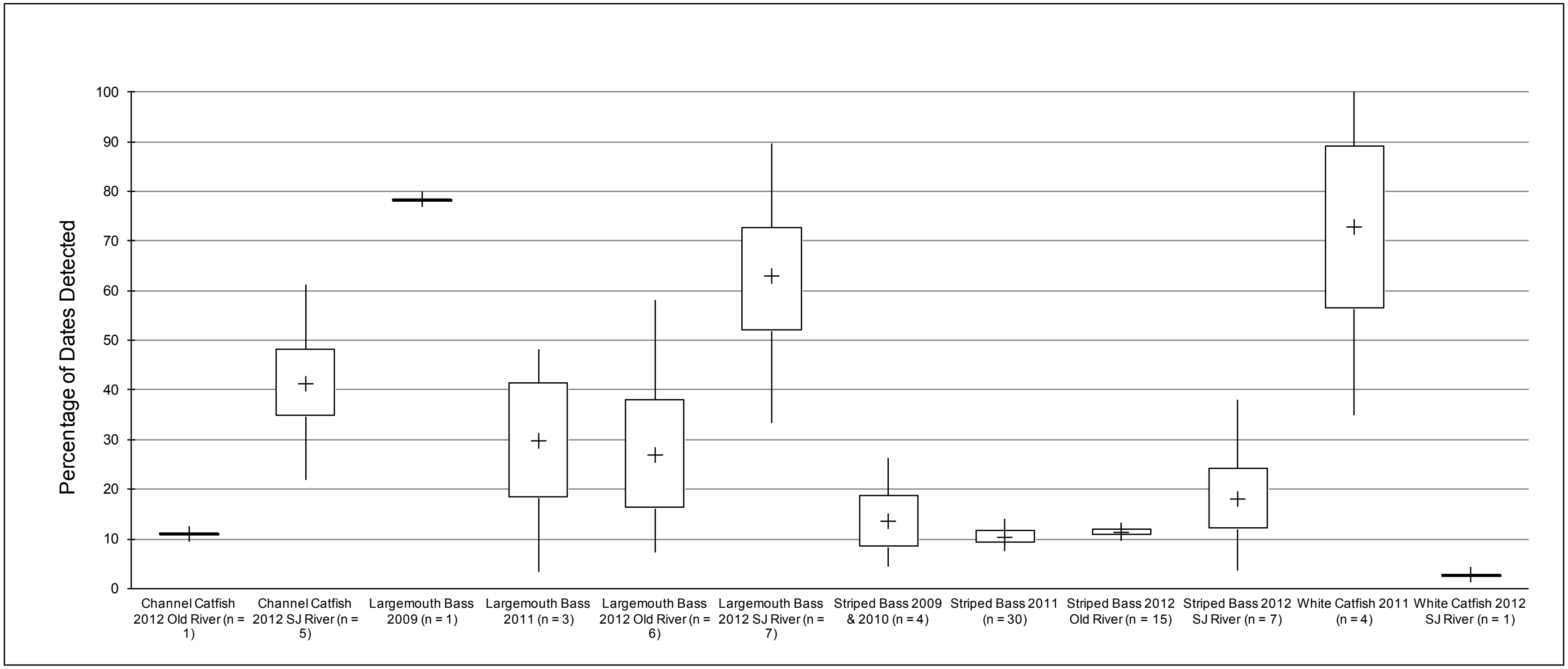
Table 6-64
Tagged Predatory Fish at the Head of Old River, 2009-2012

Species	Length (mm FL unless noted in "Comments")	Tag Code	Tagging/ Release Date	Dates Detected in Study Area	Approx. Duration in Study Area (Hours)	Release Area	Comments
Striped Bass	385	3130	6/13/2011	NA	Undetected		
Striped Bass	390	3312	6/13/2011	6/13/2011	0.07		
Striped Bass	580	3354	6/13/2011	6/13/2011	0.03		
Striped Bass	410	3368	6/13/2011	NA	Undetected		
Striped Bass	450	3228	6/14/2011	6/14/2011, 6/16/2011	7.57		
Striped Bass	620	3256	6/15/2011	6/15/2011, 6/16/2011, 6/18/2011	11.95		
Striped Bass	400	2007	4/24/2012	4/24/2012, 4/25/2012	0.66	SJ River	Total Length
Striped Bass	450	2238	4/24/2012	NA	Undetected	SJ River	Total Length
Striped Bass	405	2469	4/24/2012	4/24/2012	0.04	SJ River	Total Length
Striped Bass	411	2700	4/27/2012	4/27/2012	0.99	SJ River	Total Length
Striped Bass	398	2973	4/29/2012	4/29/2012, 5/1/2012, 5/2/2012, 5/25/2012	12.39	Old River	Total Length
Striped Bass	504	2154	5/6/2012	5/6/2012, 5/15/2012 to 5/26/2012, 5/29/2012 to 5/31/2012	282.60	SJ River	Total Length
Striped Bass	405	2385	5/6/2012	5/6/2012	0.05	SJ River	Total Length
Striped Bass	415	2553	5/6/2012	5/6/2012, 5/7/2012	8.53	Old River	Total Length
Striped Bass	420	2616	5/6/2012	5/6/2012	0.02	SJ River	Total Length
Striped Bass	450	2784	5/15/2012	5/15/2012	0.13	Old River	Total Length
Striped Bass	425	3015	5/15/2012	5/15/2012	8.73	Old River	Total Length
Striped Bass	433	2364	5/16/2012	5/16/2012	0.42	Old River	Total Length
Striped Bass	410	2595	5/16/2012	5/16/2012, 5/17/2012	12.14	Old River	Total Length
Striped Bass	310	2427	5/20/2012	5/20/2012, 5/21/2012	20.09	Old River	Total Length
Striped Bass	400	2658	5/21/2012	5/21/2012	1.61	Old River	Total Length
Striped Bass	355	2217	5/22/2012	5/22/2012	0.18	Old River	Total Length
Striped Bass	667	2343	5/22/2012	5/22/2012 to 5/25/2012	43.02	SJ River	Total Length

Table 6-64
Tagged Predatory Fish at the Head of Old River, 2009-2012

Species	Length (mm FL unless noted in "Comments")	Tag Code	Tagging/ Release Date	Dates Detected in Study Area	Approx. Duration in Study Area (Hours)	Release Area	Comments
Striped Bass	409	2889	5/22/2012	5/22/2012	0.23	Old River	Total Length
Striped Bass	401	3120	5/22/2012	5/22/2012	0.35	Old River	Total Length
Striped Bass	330	2448	5/24/2012	5/24/2012	0.20	Old River	Total Length
Striped Bass	440	2574	5/24/2012	5/24/2012	7.40	Old River	Total Length
Striped Bass	330	2679	5/24/2012	5/24/2012	0.11	Old River	Total Length
Striped Bass	325	2910	5/24/2012	5/24/2012	0.23	Old River	Total Length
White Catfish	255	3352	5/25/2011	5/25/2011 to 6/22/2011	572.04		
White Catfish	286	3394	5/25/2011	5/25/2011, 5/26/2011, 6/1/2011 to 6/22/2011	412.51		
White Catfish	280	3408	5/25/2011	5/25/2011 to 6/22/2011	621.88		
White Catfish	325	2598	6/6/2011	NA	Undetected		
White Catfish	375	2346	6/7/2011	6/7/2011, 6/9/2011	1.04		
White Catfish	405	3116	6/8/2011	NA	Undetected		
White Catfish	320	2931	4/27/2012	4/27/2012	1.54	SJ River	Total Length

Notes: HOR = Head of Old River; mm = millimeters; SJ = San Joaquin
Source: Present study



Source: Present study

Figure 6-12 **Percentage of Dates when Tagged Predatory Fish Were Detected within the HOR Study Area: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**

The 95% confidence intervals of the percentage of dates detected generally overlapped for the other species/year/release location groups, probably as a result of relatively small sample size (i.e., few fish per group). Individual channel catfish (San Joaquin River release) and white catfish (Old River release) in 2012 were detected on a much lower percentage of dates than the 95% confidence intervals of dates detected for the other species/year/release location group of each of these species. The single largemouth bass tagged in 2009 was detected on nearly 80% of dates; this was within the 95% confidence interval for the 2012 San Joaquin River releases and greater than the 95% confidence intervals for 2011 (3.4 to 48%) and 2012 Old River (7 to 58%) releases of this species (Figure 6-12).

AREAS OCCUPIED AND EMIGRATION

Areas Occupied

A full summary of the percentage of total detections by zone for each of the 84 individual tagged predatory fish at the HOR study area is provided in Table 6-65. Zone location was presented in Figure 5-14 in the "Spatial Analysis" subsection of the "Data Analysis" subsection of Section 5.4.1, "Predatory Fish Acoustic Tagging." More detailed analyses were conducted only for fish with at least 1,000 detections in the study area. The following seven species/year/release location groups with more than one fish per group were evaluated:

- Channel catfish released in the San Joaquin River in 2012
- Largemouth bass released into the San Joaquin River in 2012 (i.e., upstream of the physical rock barrier)
- Largemouth bass released into the HOR in 2012 (i.e., downstream of the physical rock barrier)
- Striped bass released in 2011
- Striped bass released into the San Joaquin River in 2012 (i.e., upstream of the physical rock barrier)
- Striped bass released into the HOR in 2012 (i.e., downstream of the physical rock barrier)
- White catfish released in 2011

In addition, a summary of detections from a single largemouth bass tagged and released in 2009, as well as observations from several striped bass tagged and released in 2009 and 2010, were made in relation to the non-physical barrier (BAFF) installed in those years.

Channel Catfish

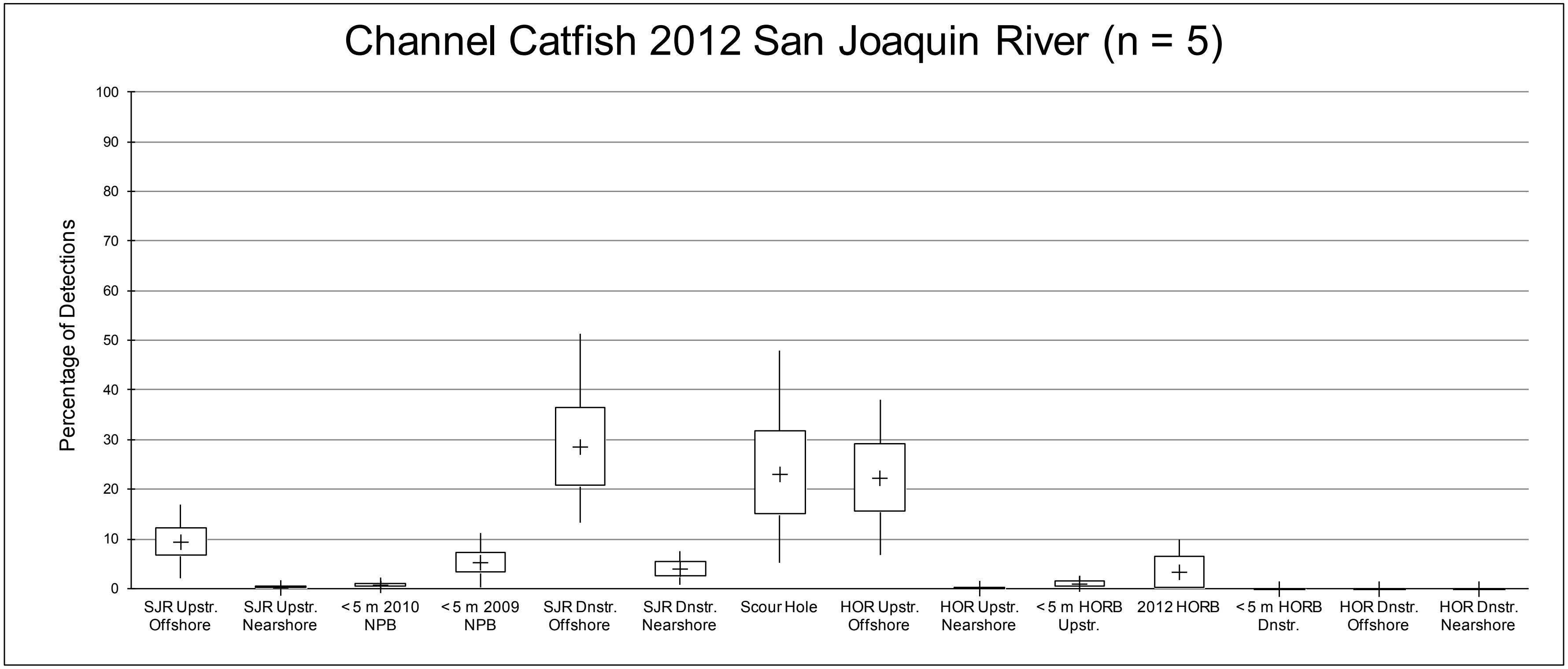
Channel catfish released on the San Joaquin River side of the physical rock barrier in 2012 (n = 5 fish) were detected most frequently at two locations (Figure 6-13):

- In the San Joaquin River downstream of the Old River divergence (San Joaquin River downstream offshore: bootstrapped mean = 29%, 95% confidence interval = 13–52%; the scour hole: bootstrapped mean = 23%, 95% confidence interval = 5–48%)

- At the HOR upstream (HOR study area upstream offshore: bootstrapped mean = 22%, 95% confidence interval = 7–38%)

Table 6-65
Percentage of Tag Detections by Zone for Predatory Fish at the Head of Old River, 2009–2012

Species/Year/Release Site	Tag Code	Total Detections	Dates in Area		Zones		San Joaquin River Upstream																																	San Joaquin River Downstream																										Head of Old River																							
							N				N				N	N	N								N	<5 m 2010 NPB							<5 m 2009 NPB							N				N		N			N	Scour Hole																N				N	<5 m HORB ustr.					2012 HORB				<5 m HORB dstr.					N				N
			First	Last	First	Last	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83
Channel Catfish 2012 Old River	2112	153	22 May	22 May	71	81																																																																							1				2	10				10	41	21	16
Channel Catfish 2012 SJ River	2490	9,732	20 May	20 May	43	58																																		10	9				60	0	3	1	0	8		4		1		0		1	1	0	0	0	0	0	0																								
Channel Catfish 2012 SJ River	2763	102,050	23 May	28 May	67	2		0	0	0		0	0					0	0	0	0	1	0	0	0		0	0	0					0	0	0	0	1	0	1	2	0			3	0	1	0		6	2	6	3	1	0	0	0	4	4	0	0	0	0	0	0	0	0	1	40	0		1	0	3	0		0	16	0				0						
Channel Catfish 2012 SJ River	2847	6,347	9 May	22 May	42	2		1		1				4										1							0	0								1	2	1	0		6	0	11	1		6	0	5	0	6	0	3	0	10	20	12	3	0	1	2	1																								
Channel Catfish 2012 SJ River	2952	17,274	22 May	29 May	33	4		0	0	1		0	1	4				2	1	1	1	3	3	0	0		1	0	0	0	0	0		3	1	0	1	4	0	1	30				1					0																		2	36	0																			
Channel Catfish 2012 SJ River	2994	5,907	23 May	31 May	58	52		0	0			1	1					1	0	0	0	6	9	0	1		0	0	0	0				0	0			8	7	3	8	0			0	5	6			0		0						2	1					0	1		1	3	29			0		1	0			1											
Largemouth Bass 2009	4306	80,179	6 May	16 May	21	62											39	0	11								0						8	37	1																																	1	4	0																					
Largemouth Bass 2011	3324	834	9 Jun	18 Jun	52	9				15	4			5	75																																											0																															
Largemouth Bass 2011	3436	32	24 May	24 May	36	59																																				31									34														34																								
Largemouth Bass 2011	3492	1,284	27 May	21 Jun	9	5				1	1			1	97																																																																																									
Largemouth Bass 2012 Old River	2091	63,523	29 Apr	20 May	77	71																																																																						6	48	16	2	1	4	4	2	1	1	0	0	8	8
Largemouth Bass 2012 Old River	2133	219	15 May	15 May	71	82																																																																							1				3	3					26	42	25
Largemouth Bass 2012 Old River	2196	747	20 May	20 May	76	82																																																																							0	40	2			3	13	2			0	33	6
Largemouth Bass 2012 Old River	2322	150,067	6 May	31 May	72	71																																																																		0	0			1	13	0		16	9	33	0	0	13	12	2	1	0
Largemouth Bass 2012 Old River	2742	4,341	29 Apr	5 May	80	82																																																																						0	9	1	0	0	1	8	1	0	1	0	0	47	31
Largemouth Bass 2012 Old River	3057	811	19 May	19 May	75	82																																																																							11	15			10	7	5			0	0	19	32
Largemouth Bass 2012 SJ River	2028	137,170	20 May	31 May	69	63																0			1													0	0	23	17				32	5	1			3		0																0	11	5		0	0	1	0	0	0	0	0										
Largemouth Bass 2012 SJ River	2070	4,849	22 May	25 May	60	6		2				2				1		4	2			2	0		1	1	1	1					0	1	1			0	0	8	2				8	16	9											5	0							0	14	2	4	3	0	2	3	0	0		0	1										
Largemouth Bass 2012 SJ River	2259	77,211	20 May	22 May	68	41		0				2	0			0		32	0		0	3	0	0	0	0	1	1		0	0	0		1	11			0	0	17	1	0			1	0	0			0																0	3	1	3	22		0		0	0		0	0	0										
Largemouth Bass 2012 SJ River	2280	5,401	23 Apr	18 May	4	52				0	1			5	7																											0	2	0		17	51	1	1		0							14	1	0				0	0																								
Largemouth Bass 2012 SJ River	2532	74,498	23 May	31 May	66	66	0	2				1				13	0	2	4		0	1	0	0	1	0	0	0					9	1	5	0		0	0	1	0	0			0	2	0				0		0		0		0	0	0	0		0				14	37	1	0	0	2	1	0	0	0	0	1	1	0										
Largemouth Bass 2012 SJ River	2721	310,489	22 May	31 May	33	9	0	0		1	3			54	42	0	0	0	0			0	0	0	0	0	0				0	0	0	0	0			0	0	0	0				0																					0	0	0	0	0	0	0	0	0	0	0	0	0											
Largemouth Bass 2012 SJ River	3078	121,293	18 May	27 May	63	41																4			0													0	0	13	1		0		5	44	25	0										6	1	0			0	0	0				1	0				0															
Striped Bass 2009 & 2010	2024	1,153	28 Apr	7 May	37	37				3	1			30	1								3	7							0	0							4		1	10	5	3				5	17		5		2											0	2																								
Striped Bass 2009 & 2010	2472	4,883	16 May	18 May	62	67		10	3	1		8	8	16	1							0	1	2							0	1						0	1		3	18	1	0			0	1	0	0	1	0	3		1	1	1	0	2	1	1	1	2	3	1		0	2	2			0	0																	
Striped Bass 2009 & 2010	2976	688	22 May	22 May	62	2		3				5	2							12	3						2	4	3	12				2	4	8	17																																	24				1	0				1												
Striped Bass 2009 & 2010	4222	301	12 May	12 May	8	8								77																	4	19																																																									
Striped Bass 2011	2122	101	1 Jun	1 Jun	25	53																		3							8	12										36									3		3		2		5		9	14	2	2	2																											
Striped Bass 2011	2178	159	13 Jun	13 Jun	35	63																16	21															9	8		21																											6	19																				
Striped Bass 2011	2206	249	19 May	19 May	9	9								9	82	8																																																																																									
Striped Bass 2011	2234	6,042	14 May	15 May	3	58				0				0	1									1	8							3	0							0		13				1	0	2			42		23		0				1	1		0	0	0	0																									
Striped Bass 2011	2248	4,983	13 Jun	14 Jun	36	18																0	18	44														0	12		15	1								2	1	4	0	1		0		0	1	1	0			0																									
Striped Bass 2011	2262	31,753	19 May	28 May	42	58	1	7	0	0		3	0	4	20	1	0	6	1	1	1	8	2	0	0	0	5	4	0	0	0	0	1	1	1	0	0	11	1	0	5	1	0	1	0	0	1	0	0	2	0	1	0	0	0	0	0	1	2	0	0	0	0	0	0	0	2	3	1	0				0															
Striped Bass 2011	2290	7,536	21 May	8 Jun	8	64	0	0	0			0	1	1	1	0		1	0		0	34	2	0	1	0	0	0	0	0	0			0	0			13	1	0	16	1	0	0	2	0	3	0	0	2	0	2	0	0	0	0	0	3	3	0	0	0	1	1	0		4	1	0	1																			
Striped Bass 2011	2486	10,357	7 Jun	8 Jun	16	61										0	0	0	1		0	1	1		0								0	1	1			1	1	0	17	0			1	0	1			10	0	50	0	5		0		0	3	1	0					0	4	1	0	0																			
Striped Bass 2011	2556	934	20 May	28 May	9	52								1	0																									0	27	3	4	1	1		0		2	15	1	22	2	5	2	4	1	1	3	3	0	2	0	0																									
Striped Bass 2011	3060	321	21 May	21 May	9	59								39	30																	1										6									3		3		2		2					4	7	1	4																								
Striped Bass 2011	3074	72	26 May	26 May	9	42								29	4									1																		17						6			3		3		3		1					3	14	11	6																								
Striped Bass 2011	3088	30,021	8 Jun	9 Jun	62	59										0	0	3	6		7	1	0										1	9	8	3	1	2	0		0									0		0		0		0			0	0	0	0		0	0	4	17	37	0																				
Striped Bass 2011	3144	80	8 Jun	8 Jun	45	58																																														4								3	8			28	54	5																								
Striped Bass 2011	3158	55	9 Jun	9 Jun	46	42																																		2					7			2		5		9								9	7		13	22	24																								
Striped Bass 2011	3186	38	8 Jun	8 Jun	46	59																																										16					18		16		5	5		13	3		13		8	3																								
Striped Bass 2011	3228	7,215	14 Jun	16 Jun	9	2	1	1						0	0	0		2	0			0	0			0	0	0					0	0	2			0	0		0	0	0							0	0	0	0	0					0	0	0	0	0	0		12	43	36	0																				
Striped Bass 2011	3242	30	8 Jun	8 Jun	48	42																																											7						13	3	3	10						10	30	23																								
Striped Bass 2011	3256	12,865	15 Jun	18 Jun	58	63		1	0			0	0					1	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0		2	0				7	1	33			6		5		0		0		33	4	0				0			2	1	0																				
Striped Bass 2011	3270	111	6 Jun	6 Jun	9	40								1	2																											11	14	3		3	5	3	14		6		9		2			1	5	4	4	4	2		10																								
Striped Bass 2011	3284	607	9 Jun	10 Jun	46	53				1	2			2	29	36																												1	8				4	3			1	0	0	0	0	0		0					8	1																								
Striped Bass 2011	3298	7,072	6 Jun	6 Jun	64	62	4	12				5				3	2	5	2	0	0	11	0	0	1	3	5	11	0	0			5	2	3	0	0	3	0	1	10	0			0					1		0														1	5	1	0	0																			
Striped Bass 2011	3312	103	13 Jun	13 Jun	39	63																3	17															2	6		31				2					10		9																2	18																				
Striped Bass 2011	3338	84	20 May	20 May	9	71								25	8							4	6	11							5	8						4	4																													6	18			1					1												
Striped Bass 2011	3340	14,090	7 Jun	7 Jun	9	62	0	0						0	0	0	0	0	0		0	0	0	0		0	0	0			0	0	1	0	0	0		0	0																													29	47	21																					
Striped Bass 2011	3354	47	13 Jun	13 Jun	46	54																																			2									2		23		9		2	15			2		6	38																											
Striped Bass 2011	3366	13	21 May	21 May	57	57																																																									##																											
Striped Bass 2011	3380	221	22 May	24 May	9	64		2		5		5		40	29					4	1	1						2	1							2	1																																		5	4																			
Striped Bass 2011	3382	114	2 Jun	2 Jun	7	40							6	37																													1	15	9		1	5													6	2	3	2		4	5	5																								
Striped Bass 2011	3422	75	19 May	19 May	2	66	9	8				13						1		7	5							4	9							4	4																															31				3	1																
Striped Bass 2011	3450	718	24 May	22 Jun	36	16								2							1	1	6	11							0	1						1	2		12	6	0							1	5	5	2	0					13	4			10	3	3			8	2																				
Striped Bass 2012 Old River	2217	360	22 May	22 May	75	82																																																																							0				3	2				11	26	34	23
Striped Bass 2012 Old River	2364	486	16 May	16 May	71	82																																																																							6	21				4	19				30	21	
Striped Bass 2012 Old River	2427	31,613	20 May	21 May	75	82																																																																								0			0	0	0				0	90	9
Striped Bass 2012 Old River	2448	128	24 May	24 May	75	80																																																																											15	2				63	20		
Striped Bass 2012 Old River	2553	252	6 May	6 May	76	81																																																																								1				5	2			0	73	19	
Striped Bass 2012 Old River	2574	12,424	24 May	24 May	76	82																																																																						0	16	7	0	0	36	20	4	0	0	0	8	7	0
Striped Bass 2012 Old River	2595	5,550	16 May	16 May	76	79																																																																							2	8				2	7		20	26	35	0	
Striped Bass 2012 Old River	2658	1,780	21 May	21 May	76	80																																																																										5	1	18			13	61	2		
Striped Bass 2012 Old River	2679	160	24 May	24 May	80	82																																																																											9	4				1	46	41	
Striped Bass 2012 Old River	2784	30	15 May	15 May	76	81																																																																												83					17		
Striped Bass 2012 Old River	2889	288	22 May	22 May	76	82																																																																							1	17	3			20	9	7			1	25	17
Striped Bass 2012 Old River	2910	270	24 May	24 May	76	82																																																																							4	17	1		2	5	24				0	33	12
Striped Bass 2012 Old River	2973	5,995	29 Apr	25 May	82	80																																																																															1	20	74	5	0
Striped Bass 2012 Old River	3015	338	15 May	15 May	81	82																																																																													7				2	88	3
Striped Bass 2012 Old River	3120	348	22 May	22 May	71	82																																																																							5	28	4			1	10	4				33	14
Striped Bass 2012 SJ River	2007	1,527	24 Apr	25 Apr	68	59		5		5	0	1		40	2			3	1					1			2	2				1		1	2							4				0	3				1		1		0	0	0	2	3	0	0			0	0		4	8	1			2		2				2												
Striped Bass 2012 SJ River	2154	666,469	6 May	31 May	43	37			0	0			0	0	0					0	0	1	1	0	0				0	0	0	0				0	0	0	0	0	23	4	17	5	0	0	0	2	0	5	2	11	6	7	6	3	3	0	0	0	0	0	0	0	0		0	0	0	0		0		0			0	0											
Striped Bass 2012 SJ River	2343	85,049	22 May	25 May	62	4		0		0		1	0	13	0	0		2	1		1	5	4	1	0	0	1	1			0	0		1	1	0	0	3	2	1	9	2	12	0	1	0	0	1	0	1	0	0	0		0		0	0	0				0	0	0	0	4	14	11	2	0	2	0	2	0		0	2	0										
Striped Bass 2012 SJ River	2385	7	6 May	6 May	43	42																																										71	29																																									
Striped Bass 2012 SJ River	2469	88	24 Apr	24 Apr	42	59																																										53																15	32																								
Striped Bass 2012 SJ River	2616	33	6 May	6 May	43	59																																										39	15																45																								
Striped Bass 2012 SJ River	2700	1,488	27 Apr	27 Apr	42	41																																				11	46	3		0	2	26	2		0							0	1					1	7																								
White Catfish 2011	2346	1,712	7 Jun	9 Jun	4	62		0		7		1		26	16			1			0						0	0						0	0	1	0					17	16	1				2	3		1		0											0	1			5																					
White Catfish 2011	3352	473,942	25 May	22 Jun	35	47							0	0	0					0			0						0	0									0	0	0	0	0		0	0	0			1	0	11	37	11	28	1	1	0	6	1	0	1	1	0	0																								
White Catfish 2011	3394	185,620	25 May	22 Jun	39	44																0	1	0							0							0	0	0	17	0	0		3	0	1			36	0	31	0	0	0	0	0	1	8	2	0	0	0	0	0			0	0																				
White Catfish 2011	3408	490,453	25 May	22 Jun	49	51								0	0									0							0	0								0	0	0	0		1	0	0			2	0	9	6	14	63	2	3	0	0	0	0	0	0	0																									
White Catfish 2012 SJ River	2931	2,504	27 Apr	27 Apr	47	40																																		83	1				6	6	1			0			0		0	0	0	0	1	1	1																													



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

Figure 6-13 **Percentage of Tag Detections for Channel Catfish within Different Zones of the HOR Study Area for 2012 San Joaquin River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**

The index of zone use relative to zone size was computed as the percentage of detections divided by the percentage of grid points in each zone; values of 1 indicated that the use of the zone was exactly proportional to its size. This index indicated that use of the San Joaquin River's downstream offshore zone was proportionally greater than the zone's size (95% confidence interval = 1.4 to 5.3) (Figure 6-14). By contrast, several zones in the upstream San Joaquin River and the HOR's upstream nearshore zone were used considerably less than proportional to their size (95% confidence intervals <1).

Largemouth Bass

Largemouth bass released into the San Joaquin River in 2012 (n = 7 fish) were detected most frequently in the San Joaquin River downstream of the Old River divergence (San Joaquin River downstream offshore: bootstrapped mean = 22%, 95% confidence interval = 7 to 39%; San Joaquin River downstream nearshore: bootstrapped mean = 21%, 95% confidence interval = 9 to 35%) (Figure 6-15). This result was notable because five of these seven fish were released at the HOR just upstream of the physical rock barrier (Table 6-65).

Relative to zone size, the San Joaquin River downstream nearshore zone was used to a considerable extent by largemouth bass (95% confidence interval: 2.3 to 8.6) (Figure 6-16). Two other nearshore zones (San Joaquin River upstream nearshore and HOR upstream nearshore), as well as the San Joaquin River downstream offshore zone, also were used appreciably relative to their size.

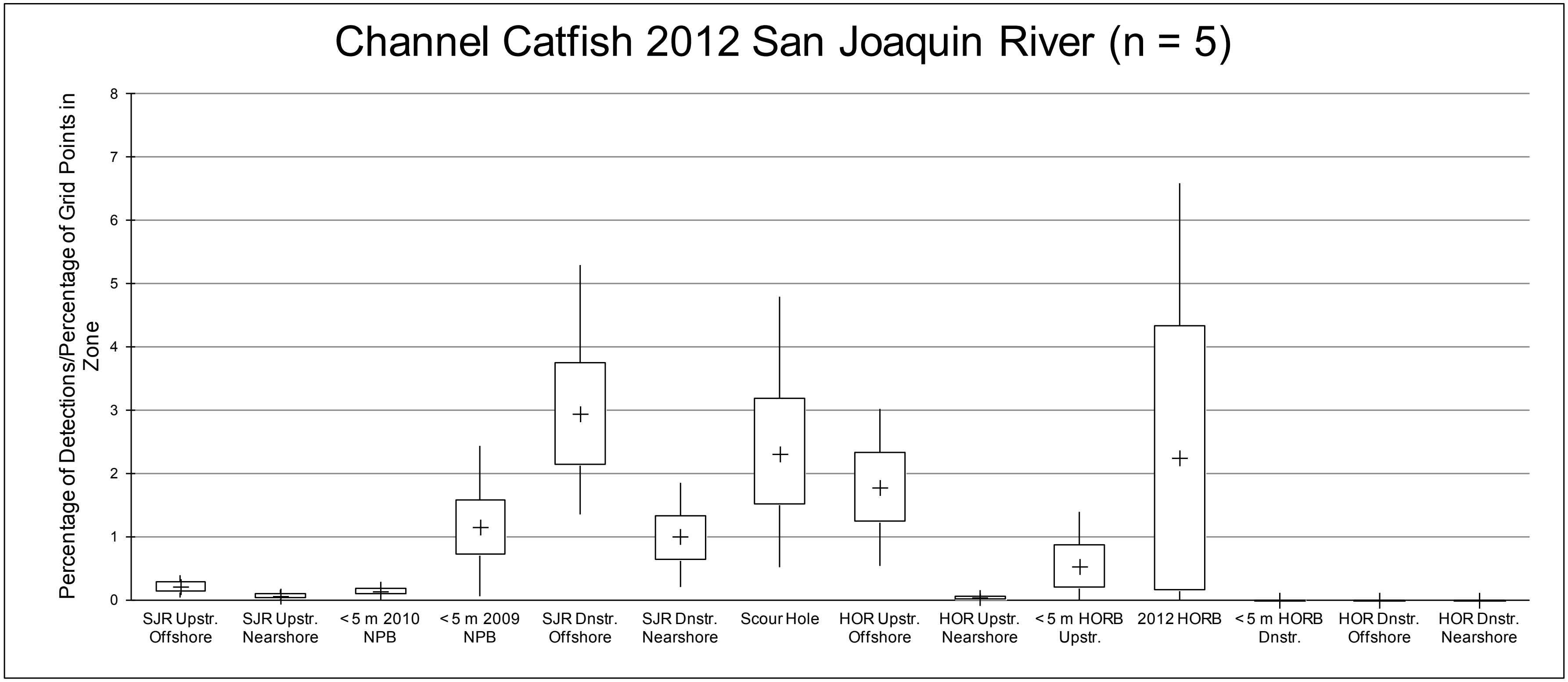
Three largemouth bass released into HOR downstream of the 2012 physical rock barrier were detected most frequently within the footprint of the physical rock barrier bottom (bootstrapped mean: 32%, 95% confidence interval: 13 to 72%) or within 5 m of the barrier (bootstrapped mean: 27%, 95% confidence interval: 10 to 58%) (Figure 6-17). The small surface area of the wetted portion of the barrier bottom zone, coupled with the relatively large percentage of detections within this zone, led to a high use index (95% confidence interval: 1.2 to 8.0); the HOR study area downstream offshore zone was used infrequently relative to its size (95% confidence interval: 0.13 to 0.77) (Figure 6-18).

The largemouth bass with tag code 4306 was tagged and released in 2009. Approximately 40% of its detections were nearshore in a quite restricted area (zone 11), whereas 46% of its detections were within 5 m of the 2009 non-physical barrier (either nearshore in zone 8, or offshore in zones 28 and 29) (Table 6-65).

Striped Bass

Striped bass tagged and released in 2011 (n = 10) were detected most frequently in offshore areas (San Joaquin River upstream offshore and HOR upstream offshore), as well as the scour hole; there was a bootstrapped mean of approximately 20% of detections in these zones (Figure 6-19). Note that the acoustic array's detection ability was somewhat limited in the HOR study area zones in 2011. As a result, the HOR zones downstream of the 2012 physical rock barrier bottom zones would not have registered detections (and were excluded from the calculations of use relative to zone size).

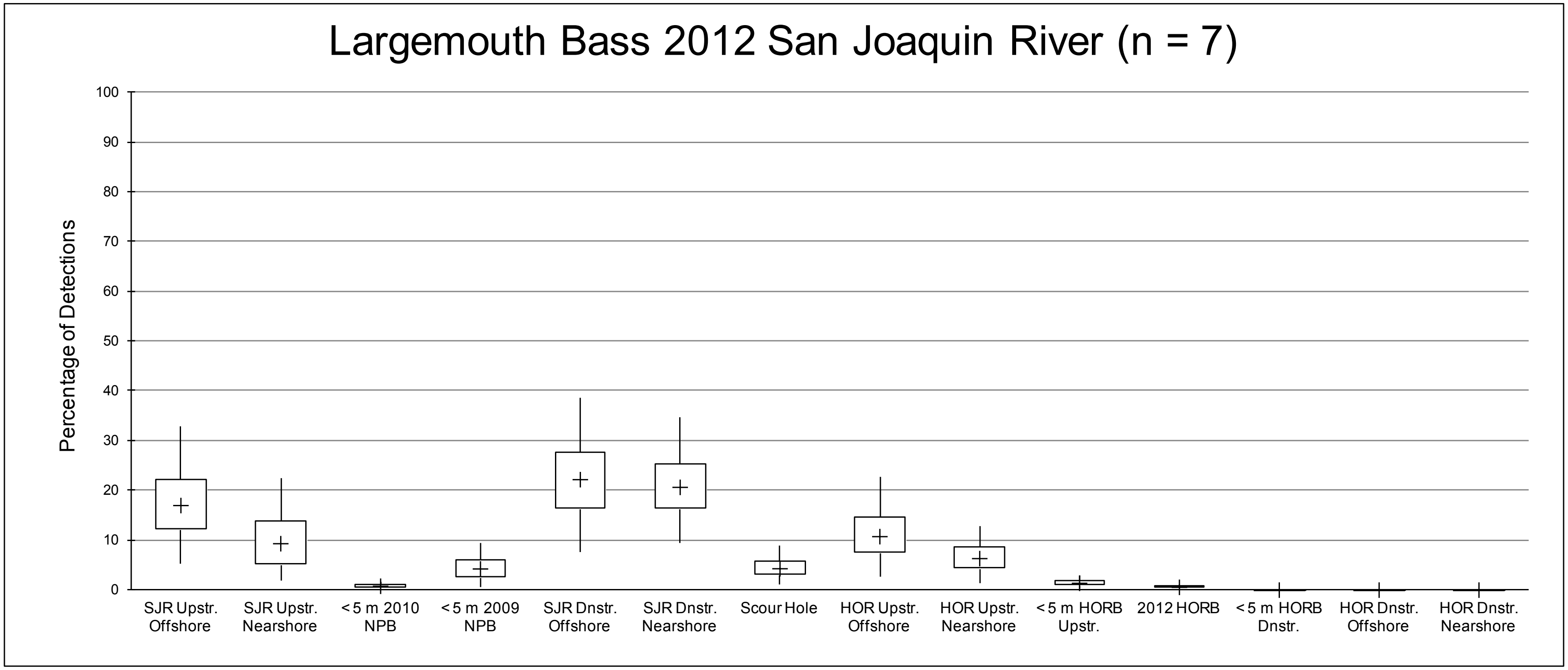
There was considerable variability in the percentage of detections in each zone relative to zone size. Detections within 5 m of the 2009 non-physical barrier alignment were relatively frequent relative to the small size of this zone (95% confidence interval: 0.9 to 3.1); this was also the case for the scour hole (95% confidence interval: 0.7 to 4.1) (Figure 6-20). Relative to zone size, there was low use of the San Joaquin River upstream offshore and San Joaquin River downstream nearshore zones by striped bass in 2011.



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

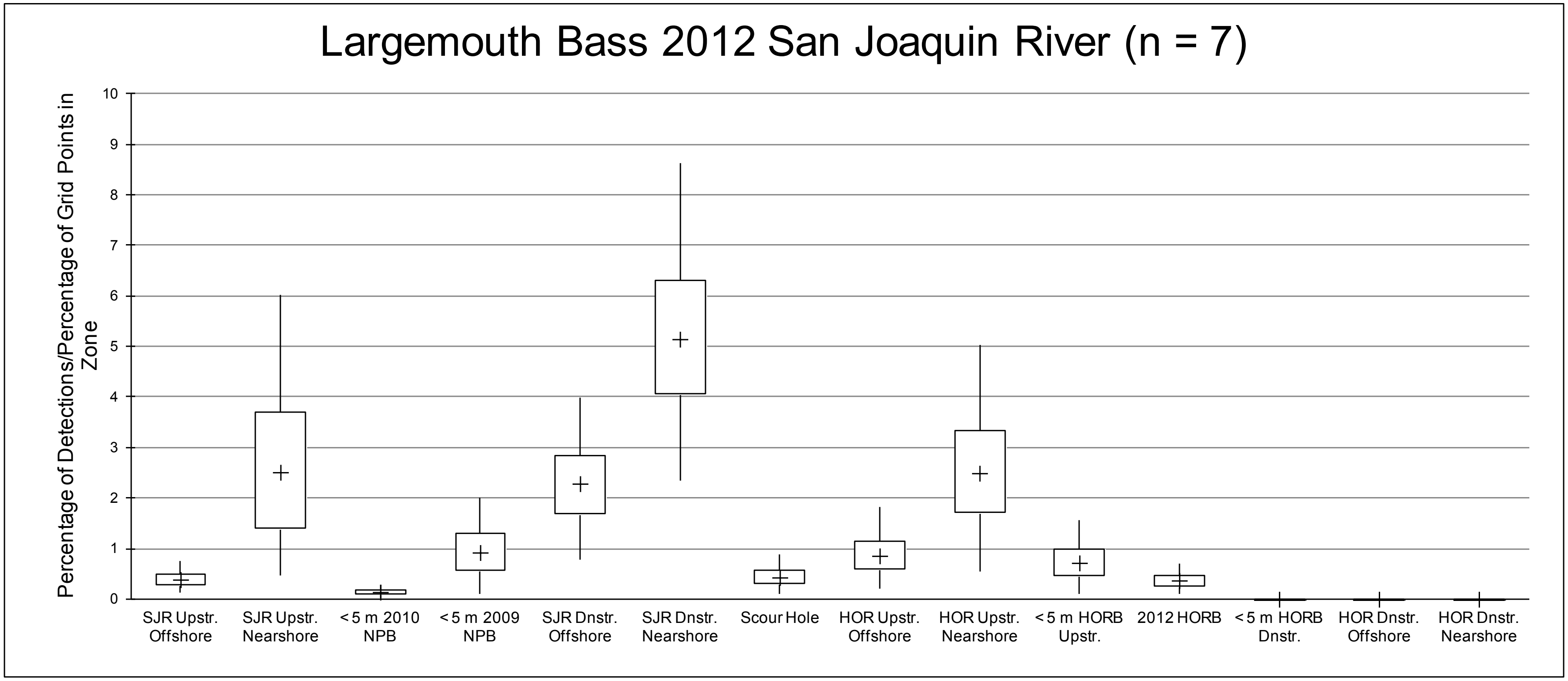
Figure 6-14 **Percentage of Tag Detections for Channel Catfish within Different Zones of the HOR Study Area, Divided by Percentage of Grid Points in Each Zone for 2012 San Joaquin River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

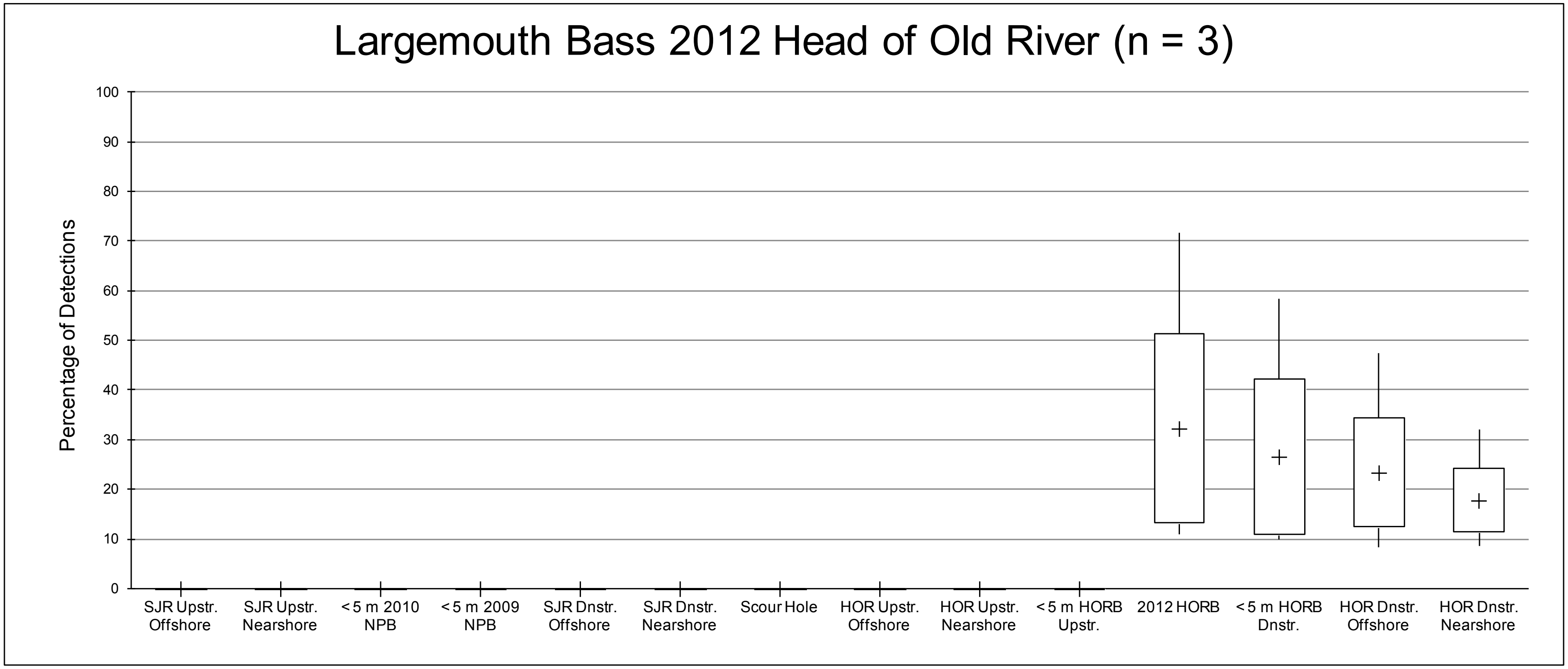
Figure 6-15 **Percentage of Tag Detections for Largemouth Bass within Different Zones of the HOR Study Area for 2012 San Joaquin River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

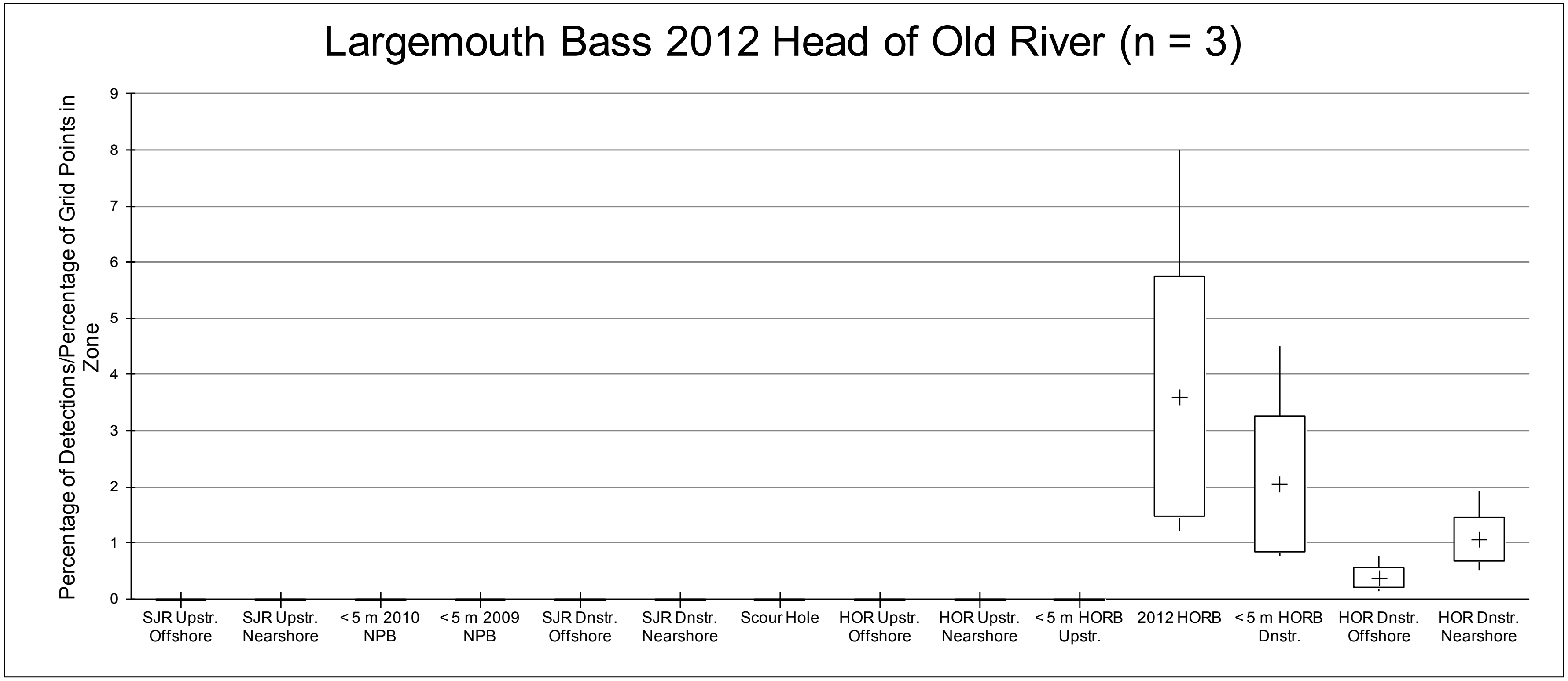
Figure 6-16 **Percentage of Tag Detections for Largemouth Bass within Different Zones of the HOR Study Area, Divided by Percentage of Grid Points in Each Zone for 2012 San Joaquin River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

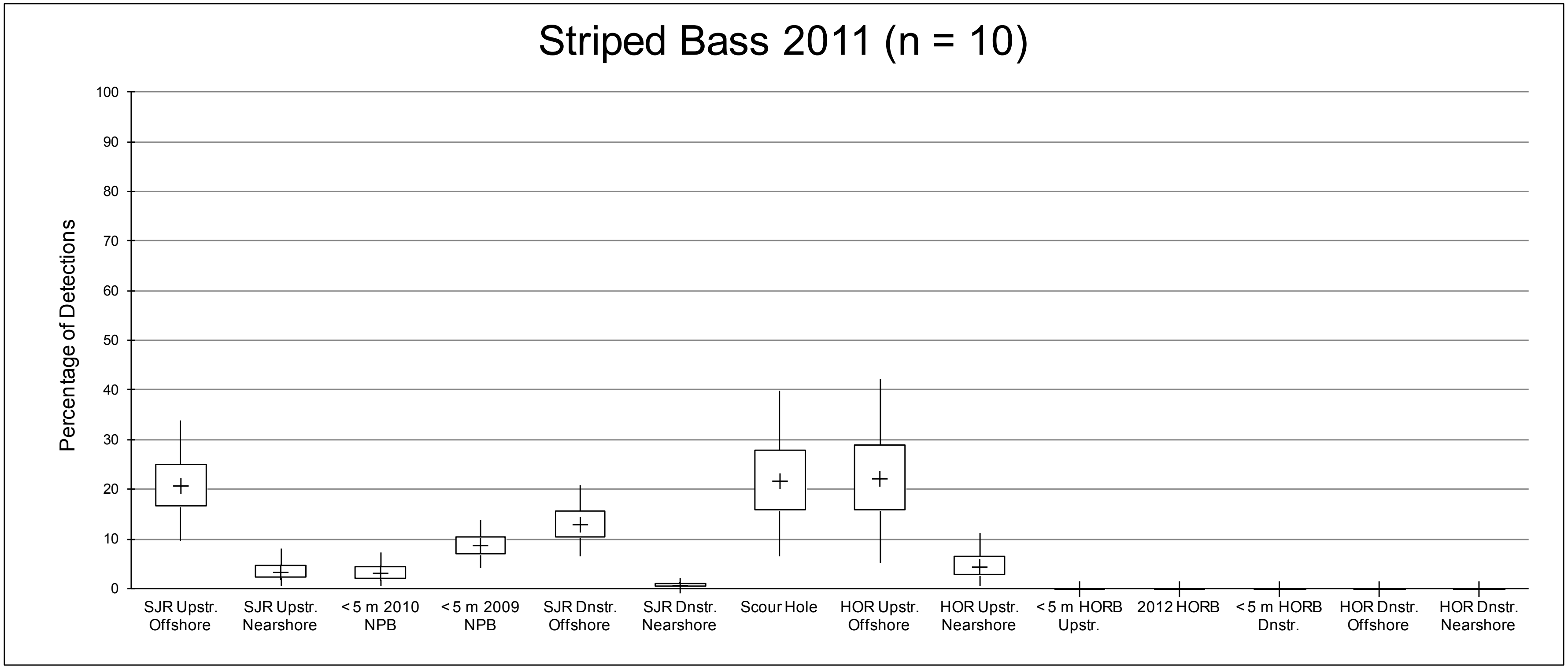
Figure 6-17 **Percentage of Tag Detections for Largemouth Bass within Different Zones of the HOR Study Area for 2012 Head of Old River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

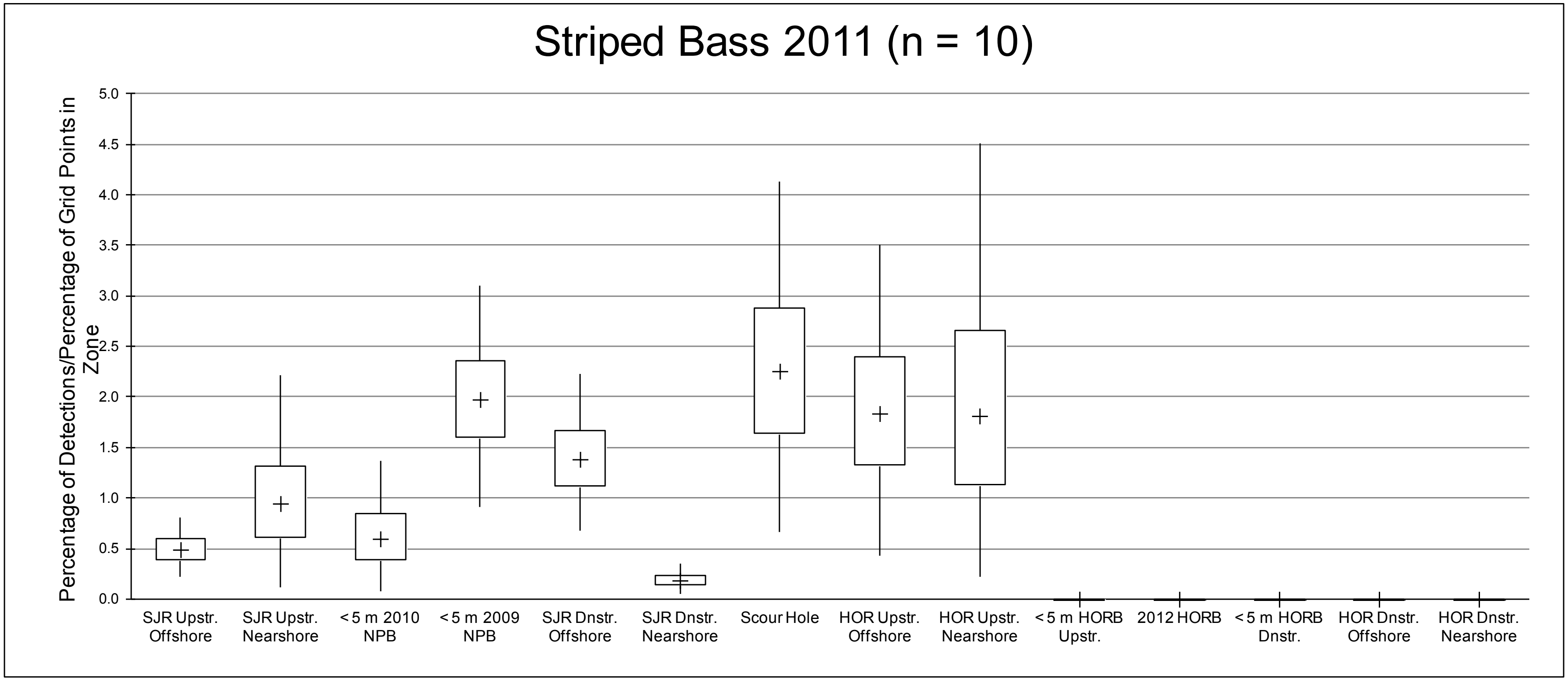
Figure 6-18 **Percentage of Tag Detections for Largemouth Bass within Different Zones of the HOR Study Area, Divided by Percentage of Grid Points in Each Zone for 2012 Head of Old River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

Figure 6-19 **Percentage of Tag Detections for Striped Bass within Different Zones of the HOR Study Area for 2011 Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

Figure 6-20 Percentage of Acoustic Tag Detections for Striped Bass within Different Zones of the HOR Study Area, Divided by Percentage of Grid Points in Each Zone for 2011 Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)

Striped bass released in the San Joaquin River in 2012 (n = 4) had the highest frequency of detection in the San Joaquin River downstream offshore zone (bootstrapped mean: 41%, 95% confidence interval: 16 to 70%) (Figure 6-21). The percentage of detections relative to zone size also was high for this zone (95% confidence interval: 4.2 to 7.2) (Figure 6-22). Most of the other zones upstream of the divergence and in the upstream HOR study area were used considerably less, both relative to their size and in absolute terms.

Five striped bass released into HOR downstream of the physical rock barrier in 2012 were most frequently detected offshore in the HOR study area downstream of the physical rock barrier (HOR study area downstream offshore; bootstrapped mean: 66%, 95% confidence interval: 40 to 90%) and less frequently near the physical rock barrier or nearshore (Figure 6-23). Relative to zone size, there was less difference in use of the zones than when comparing the percentage of detections alone (Figure 6-24).

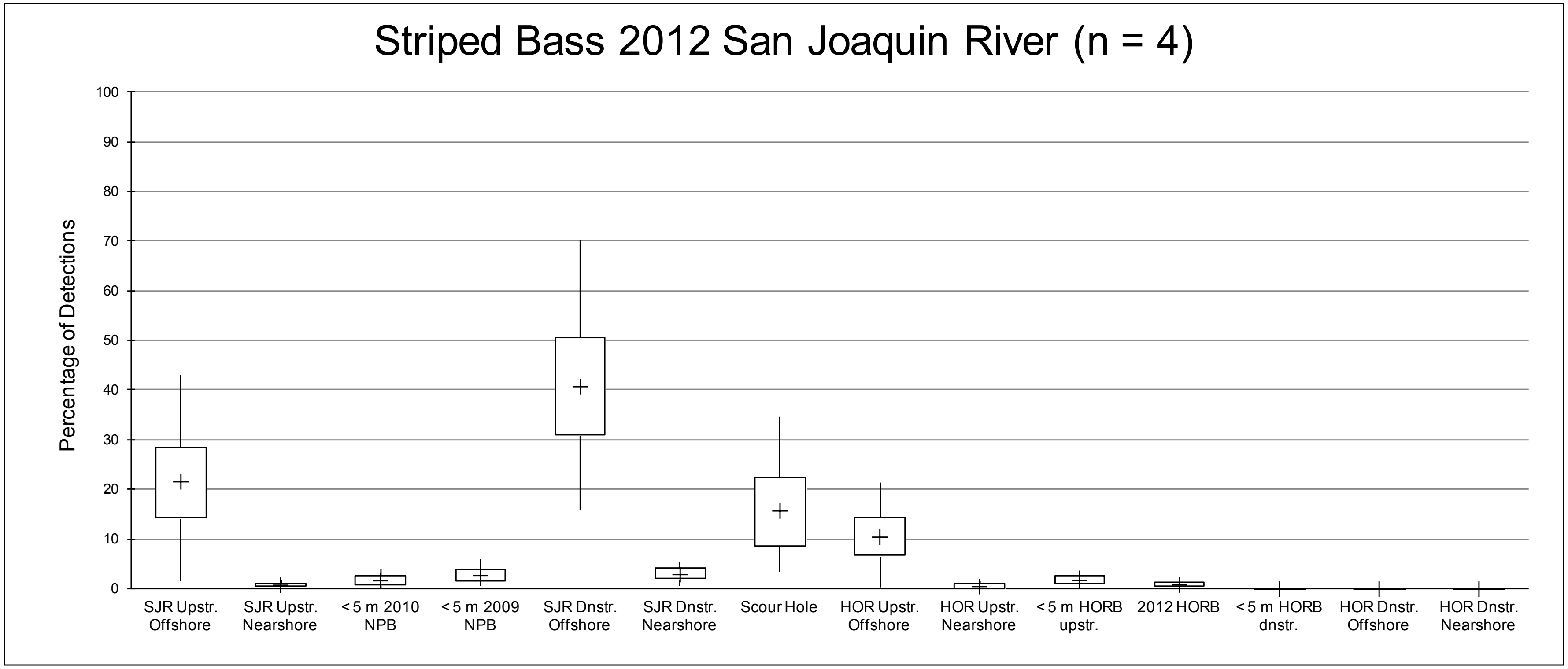
In addition to the striped bass included in the foregoing analyses, two striped bass (tag codes 2024 and 2472) were tagged and released in 2010. These fish each had more than 1,000 detections (Table 6-65) and were detected at the HOR study area for 0.6 to 3 hours (Table 6-64). Of interest is the extent to which they were found near the 2010 non-physical barrier. The acoustic tag detection data suggest that they spent a small proportion (1% or less) of their time within 5 m of the non-physical barrier (Table 6-65). Other striped bass tagged and released in 2009 and 2010 (tag codes 2976 and 4222) were present in the study area for short durations (0.3 to 0.5 hours). Striped bass 2976 spent approximately 20% of its time within 5 m of the 2010 non-physical barrier, whereas striped bass 4222 was not detected within 5 m of the 2009 non-physical barrier (Table 6-65).

White Catfish

White catfish tagged and released in 2011 spent a considerable percentage of their time at the scour hole (bootstrapped mean: 69%, 95% confidence interval: 26–99%) (Figure 6-25). Three individuals (tag codes 3352, 3394, and 3408) that were captured, tagged, and released at the scour hole subsequently remained almost entirely within that area; one individual (tag code 2346) was caught and released in the San Joaquin River upstream of the divergence, and only 2% of its detections were at the scour hole, with the final detection suggesting emigration down Old River. The percentage of detections for white catfish at the scour hole was high relative to the size of this zone (Figure 6-26).

Velocity

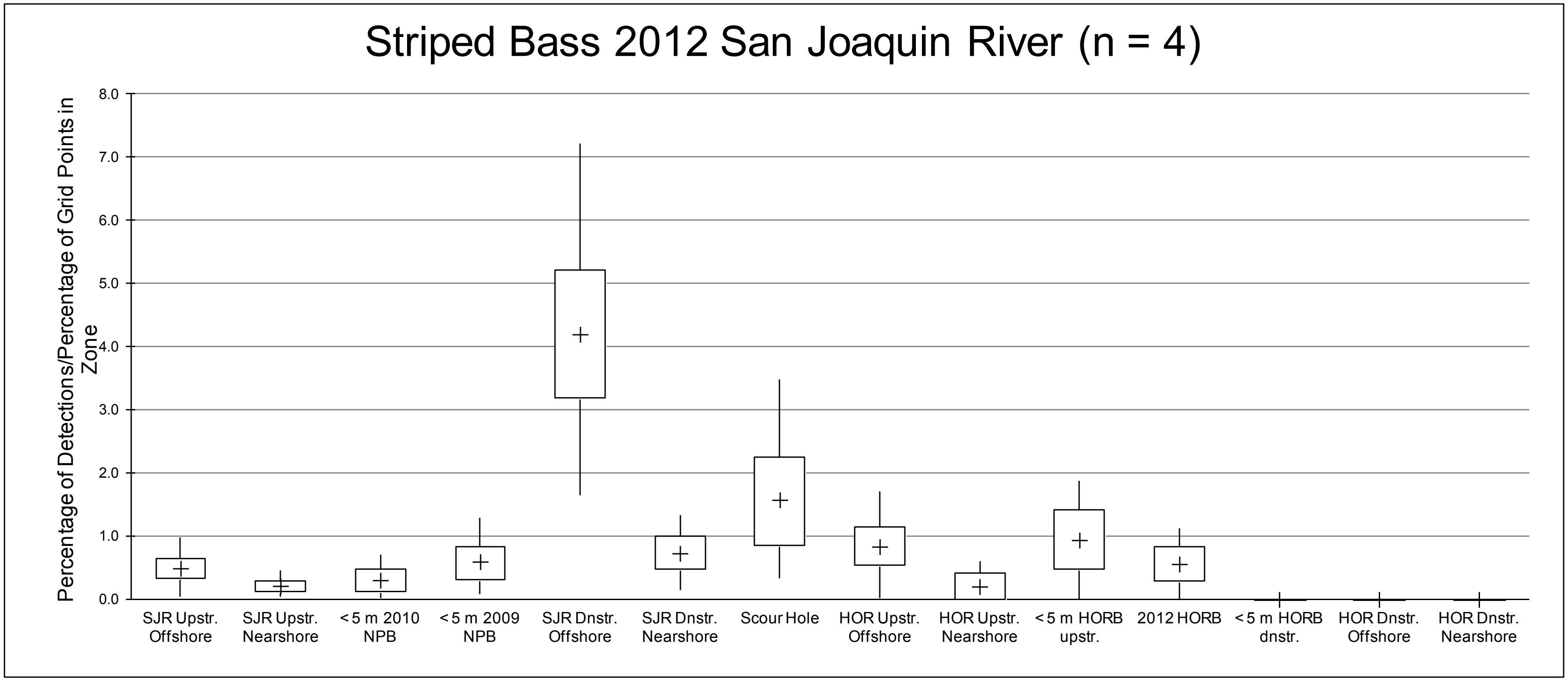
The estimated near-surface velocities at the portions of the HOR study area occupied by tagged predatory fish generally were quite different from all of the available velocities at the overall HOR study area upstream of the physical rock barrier (Table 6-66). Channel catfish, largemouth bass, and white catfish all had median detection velocities that were considerably lower than the overall median velocities present in the study area. Striped bass detection velocity was variable in relation to all available velocities.



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

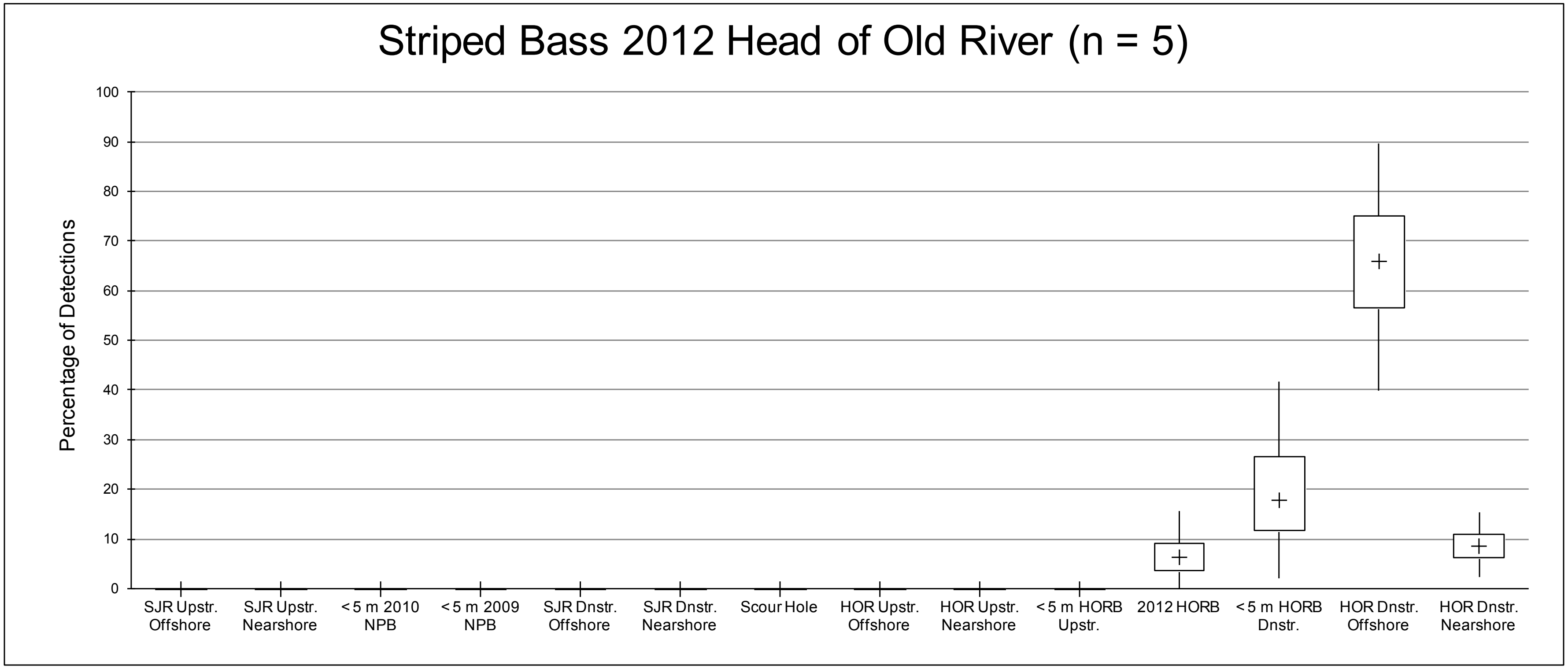
Figure 6-21 **Percentage of Tag Detections for Striped Bass within Different Zones of the HOR Study Area, for 2012 San Joaquin River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

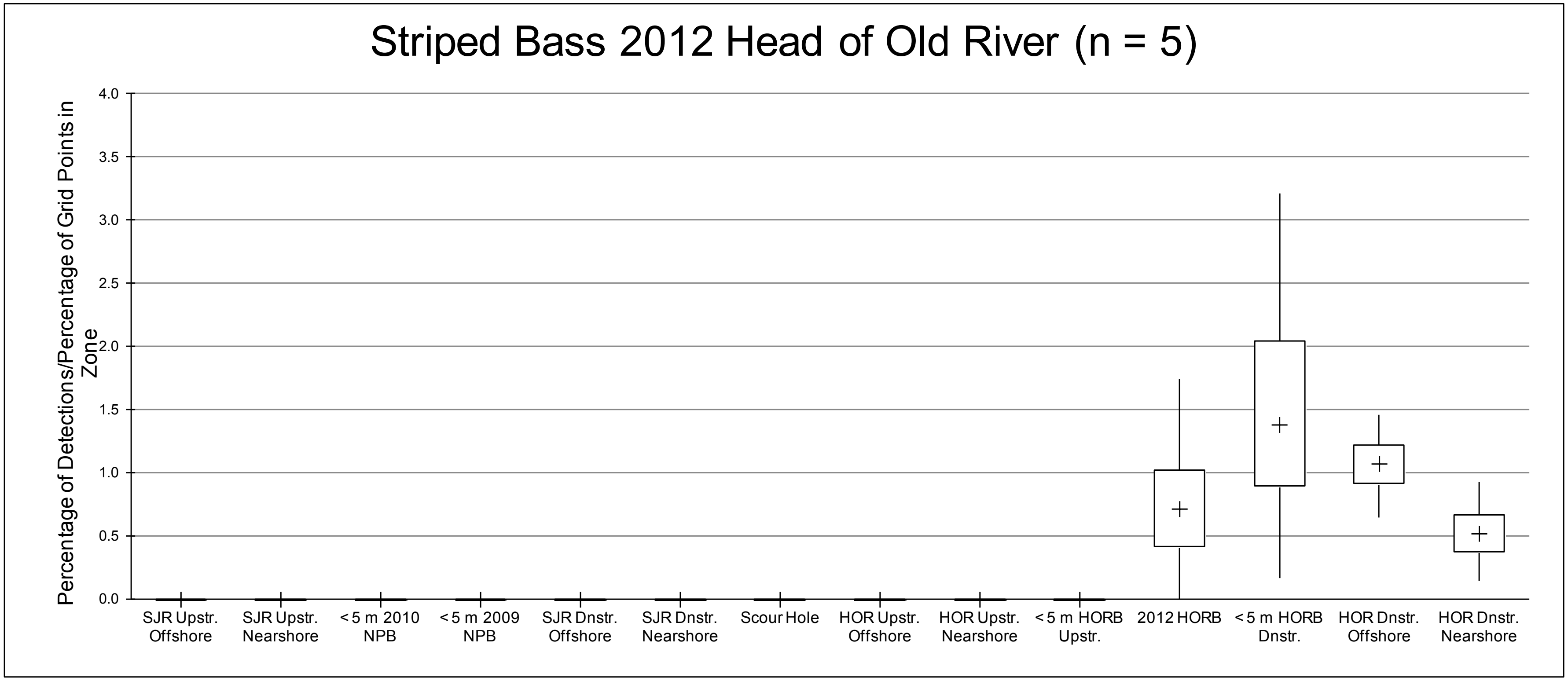
Figure 6-22 **Percentage of Tag Detections for Striped Bass within Different Zones of the HOR Study Area, Divided by Percentage of Grid Points in Each Zone for 2012 San Joaquin River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

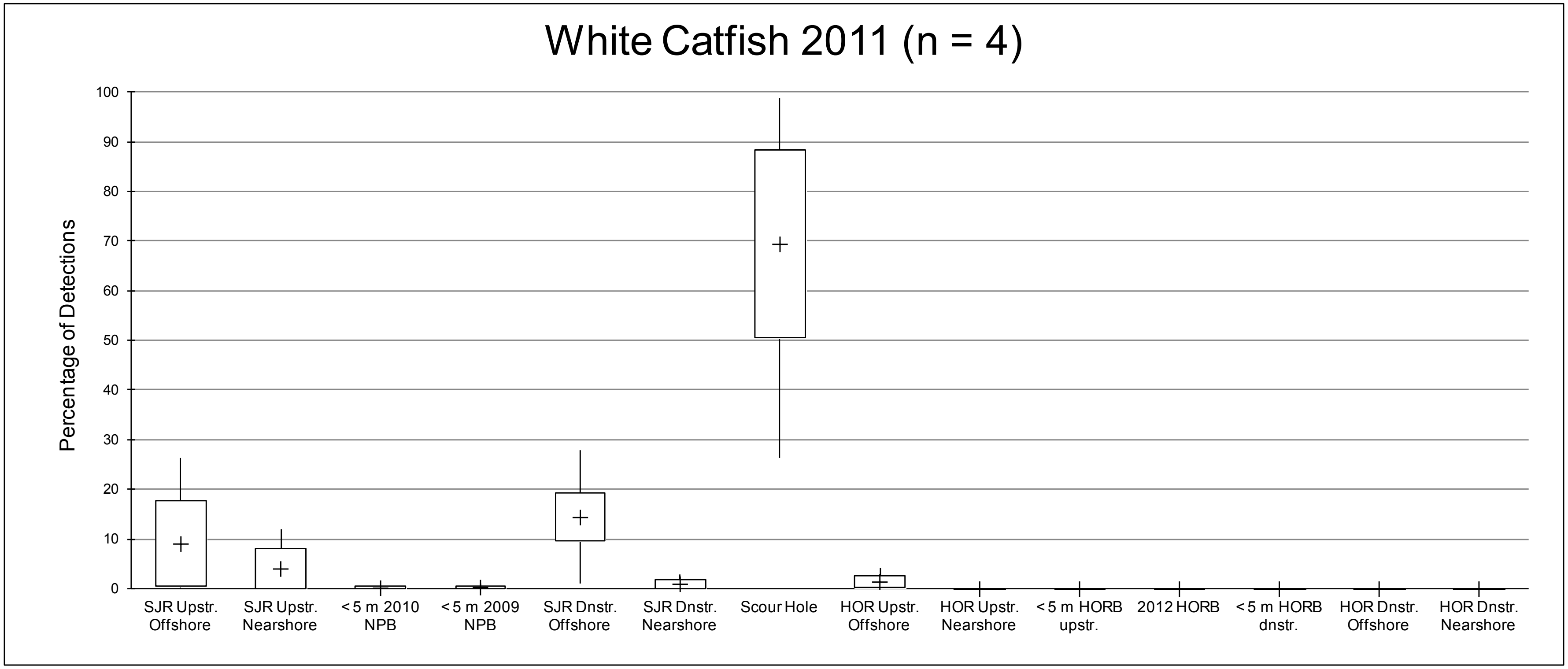
Figure 6-23 **Percentage of Tag Detections for Striped Bass within Different Zones of the HOR Study Area for 2012 Head of Old River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

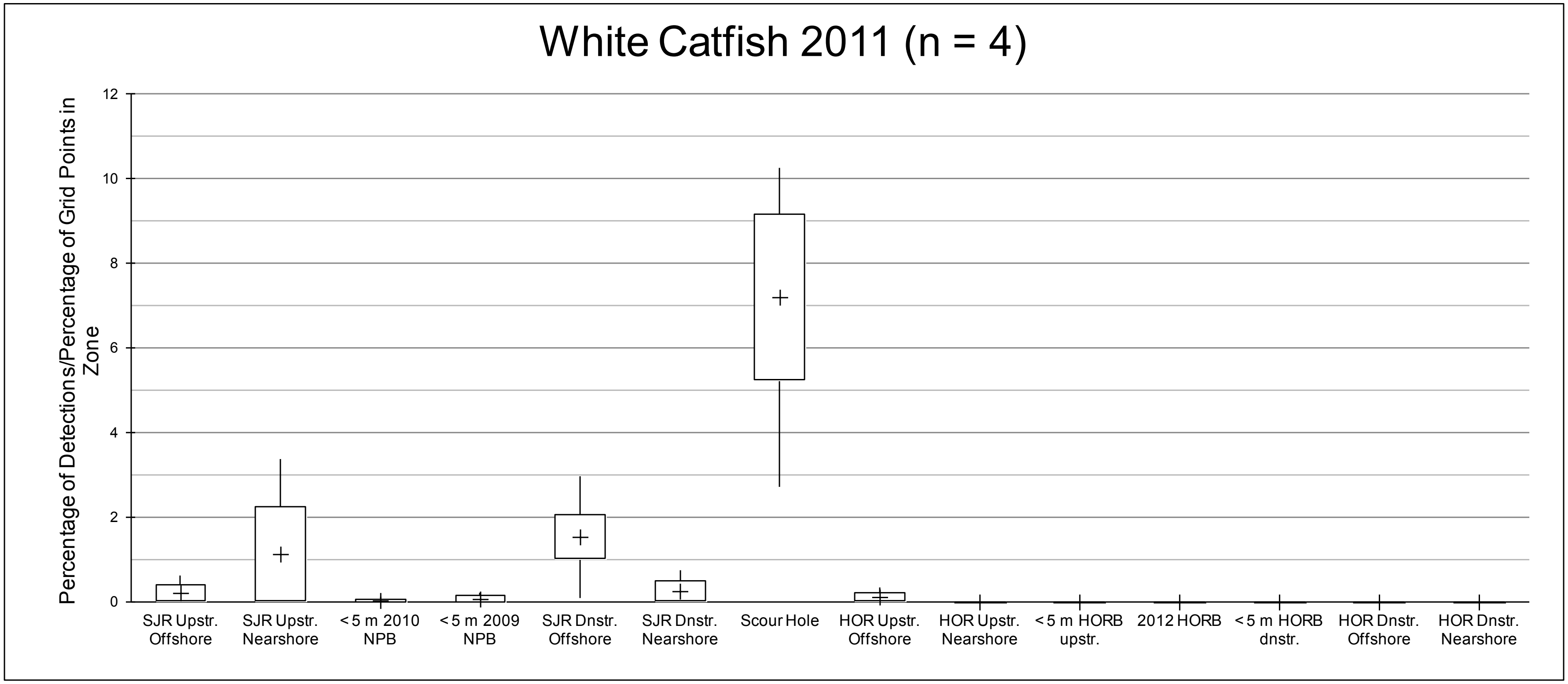
Source: Present study

Figure 6-24 **Percentage of Tag Detections for Striped Bass within Different Zones of the HOR Study Area, Divided by Percentage of Grid Points in Each Zone for 2012 Head of Old River Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream
Source: Present study

Figure 6-25 **Percentage of Tag Detections for White Catfish within Different Zones of the HOR Study Area for 2011 Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Physical Rock Barrier; NPB = non-physical barrier (BAFF); SJR = San Joaquin River; Upstr. = upstream

Source: Present study

Figure 6-26 **Percentage of Tag Detections for White Catfish within Different Zones of the HOR Study Area, Divided by Percentage of Grid Points in Each Zone for 2011 Releases: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**

Table 6-66
Summary of Estimated Median Near-Surface Velocity and Percentage of Observations in Areas in which Tagged Predatory Fish Were Detected, Relative to All Available Velocities at the Head of Old River Study Area, Upstream of the 2012 Physical Rock Barrier

Species	Tag Code	Available Velocities (All) or at which Fish Detected	No. of Observations	Median Velocity (m/s)	Percentage of Observations by Velocity (roundest to nearest 0.05 m/s)												
					0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
Channel Catfish	2490	All	7,425,516	0.15	16	19	9	10	14	15	9	7	0	0	0	0	0
	2490	Detected	9,120	0.03	31	61	5	2	1	0	0	0	0	0	0	0	0
Channel Catfish	2763	All	77,864,150	0.11	18	22	15	15	13	11	5	2	0	0	0	0	0
	2763	Detected	66,018	0.05	35	42	16	7	1	0	0	0	0	0	0	0	0
Channel Catfish	2847	All	4,842,761	0.23	13	18	8	6	5	6	9	14	18	2	0	0	0
	2847	Detected	3,969	0.11	4	27	23	19	10	12	2	2	0	0	0	0	0
Channel Catfish	2952	All	13,180,062	0.11	17	21	15	18	15	8	4	1	0	0	0	0	0
	2952	Detected	16,417	0.03	28	57	5	4	5	1	0	0	0	0	0	0	0
Channel Catfish	2994	All	4,273,563	0.12	18	20	13	17	17	12	1	0	0	0	0	0	0
	2994	Detected	3,761	0.03	49	28	12	11	1	0	0	0	0	0	0	0	0
Largemouth Bass	2028	All	98,542,213	0.10	17	23	16	12	12	11	7	2	0	0	0	0	0
	2028	Detected	114,293	0.02	61	39	0	0	0	0	0	0	0	0	0	0	0
Largemouth Bass	2070	All	3,699,787	0.09	18	25	18	7	8	12	10	2	0	0	0	0	0
	2070	Detected	2,997	0.01	72	25	3	0	0	0	0	0	0	0	0	0	0
Largemouth Bass	2259	All	58,911,993	0.11	17	23	15	12	12	11	8	3	0	0	0	0	0
	2259	Detected	68,472	0.03	47	51	1	0	0	0	0	0	0	0	0	0	0
Largemouth Bass	2280	All	3,782,191	0.15	16	19	10	13	18	15	5	4	0	0	0	0	0
	2280	Detected	398	0.03	38	31	5	2	6	0	0	12	6	0	0	0	0
Largemouth Bass	2532	All	49,136,437	0.11	17	22	15	16	15	11	4	0	0	0	0	0	0
	2532	Detected	39,305	0.02	81	19	1	0	0	0	0	0	0	0	0	0	0
Largemouth Bass	2721	All	207,541,341	0.11	17	21	15	14	13	11	6	2	0	0	0	0	0
	2721	Detected	207,818	0.02	50	46	3	0	0	0	0	0	0	0	0	0	0
Largemouth Bass	3078	All	92,546,559	0.12	17	21	14	10	11	12	10	4	0	0	0	0	0
	3078	Detected	32,571	0.03	48	48	3	0	0	0	0	0	0	0	0	0	0

Table 6-66
Summary of Estimated Median Near-Surface Velocity and Percentage of Observations in Areas in which Tagged Predatory Fish Were Detected, Relative to All Available Velocities at the Head of Old River Study Area, Upstream of the 2012 Physical Rock Barrier

Species	Tag Code	Available Velocities (All) or at which Fish Detected	No. of Observations	Median Velocity (m/s)	Percentage of Observations by Velocity (roundest to nearest 0.05 m/s)												
					0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
Striped Bass	2007	All	1,165,101	0.21	10	16	11	7	6	9	16	12	11	0	0	0	0
	2007	Detected	1,058	0.16	5	23	20	15	6	17	8	5	1	0	0	0	0
Striped Bass	2154	All	470,252,923	0.12	16	21	14	12	12	11	8	4	2	0	0	0	0
	2154	Detected	566,232	0.16	1	9	20	27	21	12	6	3	2	1	0	0	0
Striped Bass	2343	All	64,892,387	0.10	17	24	18	13	11	9	5	2	0	0	0	0	0
	2343	Detected	75,883	0.04	28	41	17	9	5	1	0	0	0	0	0	0	0
Striped Bass	2700	All	1,135,344	0.20	14	18	8	6	7	13	21	11	1	0	0	0	0
	2700	Detected	780	0.36	0	0	0	0	0	0	22	29	47	2	0	0	0
White Catfish	2931	All	1,910,552	0.20	11	17	10	7	7	11	16	19	2	0	0	0	0
	2931	Detected	2,192	0.00	85	13	1	0	1	0	0	0	0	0	0	0	0

Notes: m/s = meters per second; No. = number
Source: Present study

Channel Catfish

The median detection velocity for channel catfish ranged from 0.03 m/s (tag codes 2490, 2952, and 2994) to 0.11 m/s (tag code 2847), compared with median available velocities of 0.11 to 0.23 m/s (Table 6-66). A generally large percentage (approximately 75% or more) of tag detections was estimated to occur in areas with near-surface velocity less than 0.075 m/s (the exception was tag code 2847); by contrast, only 35 to 40% of available velocities were in this range. This was reflected in the index of detection velocity to available velocity, which generally was well above 1 (Figure 6-27), while the 95% confidence intervals for velocity of 0.075 to 0.275 m/s overlapped 1, indicating that this range of velocity was used more in proportion to its availability; higher velocity (>0.275 m/s) was rarely used (Table 6-66; Figure 6-27).

Largemouth Bass

The median detection velocity for largemouth bass ranged from 0.01 m/s (tag code 2070) to 0.03 m/s (tag codes 2259, 2280, and 3078), compared with median available velocities of 0.09 to 0.15 m/s (Table 6-66). For most tagged largemouth bass, nearly all (96% to 100%) of tag detections were estimated to be in areas with near-surface velocity less than 0.075 m/s. The exception was tag code 2280 (70% of detections in this range), and this individual was detected relatively rarely during the period for which velocity was modeled. By contrast, approximately 38–44% of all available velocities were less than 0.075 m/s.

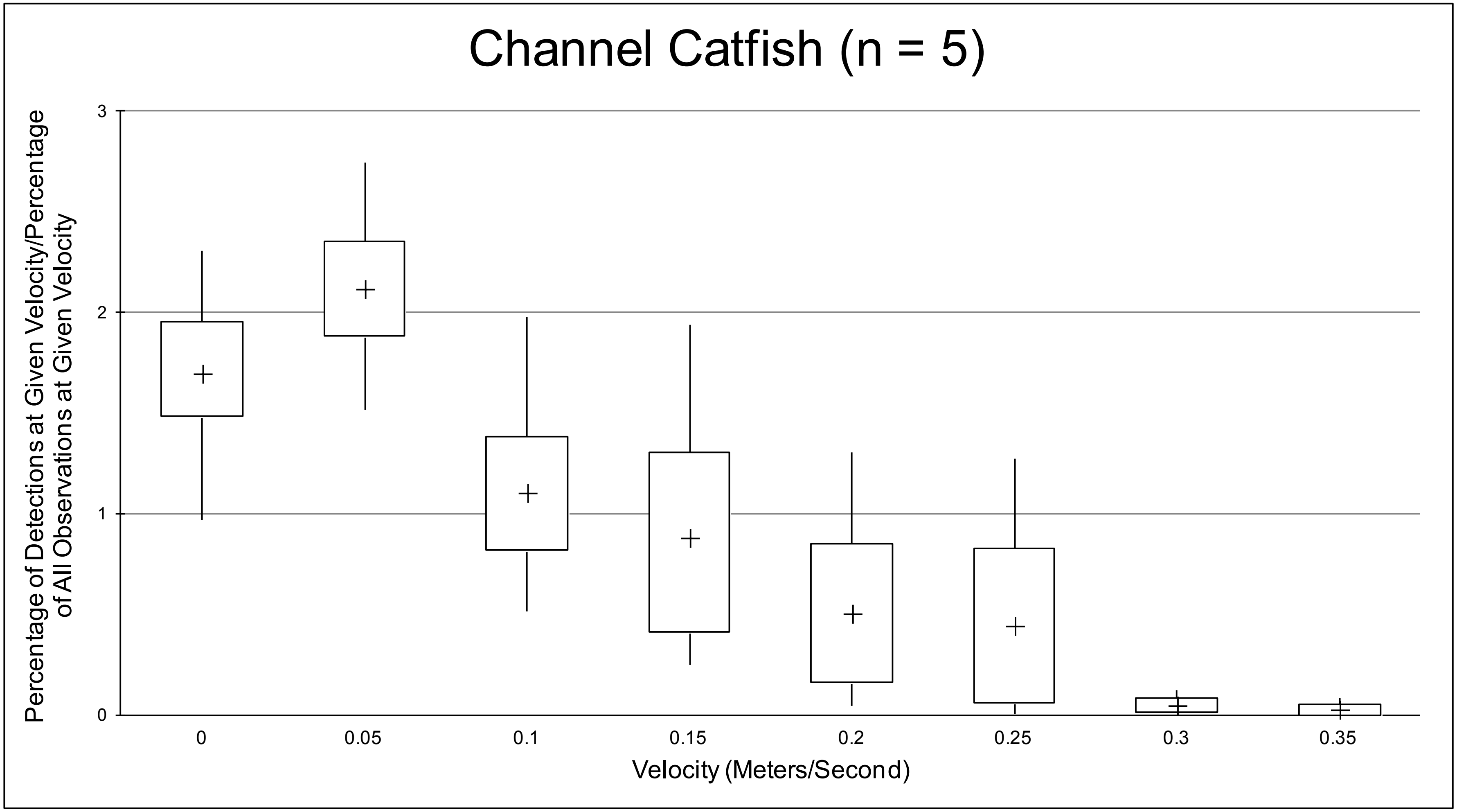
Occupation of lower-velocity areas was reflected in the index of detection velocity to available velocity, for which the 95% confidence intervals were considerably above 1, indicating greater use than proportionally available (Figure 6-28). By contrast, the 95% confidence intervals for velocity indices over the range of 0.075 to 0.325 m/s were below 1, indicating that this range of velocity was used considerably less than its proportional availability. Overlap of the 95% confidence intervals of velocity from 0.325 to 0.425 m/s with a velocity use index of 1 reflects the single individual (tag code 2280) that was detected relatively rarely.

Striped Bass

Four acoustically tagged striped bass met the criterion for inclusion in the velocity analysis, 1,000 or more detections before merging with velocity modeling estimates. (Note that the number of detections remaining after the merge with velocity data was lower than 1,000 for some fish [e.g., striped bass tag code 2700] because not all detections were within the grid of velocity estimates or occurred outside the period of velocity data availability.)

The median detection velocity was appreciably greater for striped bass than for the other species (0.16 to 0.34 m/s) for three individuals (tag codes 2007, 2154, and 2700), and similar (0.04 m/s) for the other individual (tag code 2343) (Table 6-66). The median detection velocity for striped bass tag code 2007 (0.16 m/s) was similar to the median of all available velocities (0.21 m/s); the median detection velocities for striped bass tag codes 2154 and 2700 were greater than the median of all available velocities; and the median detection velocity of striped bass 2343 was considerably less than the median of all available velocities (0.04 vs. 0.20 m/s).

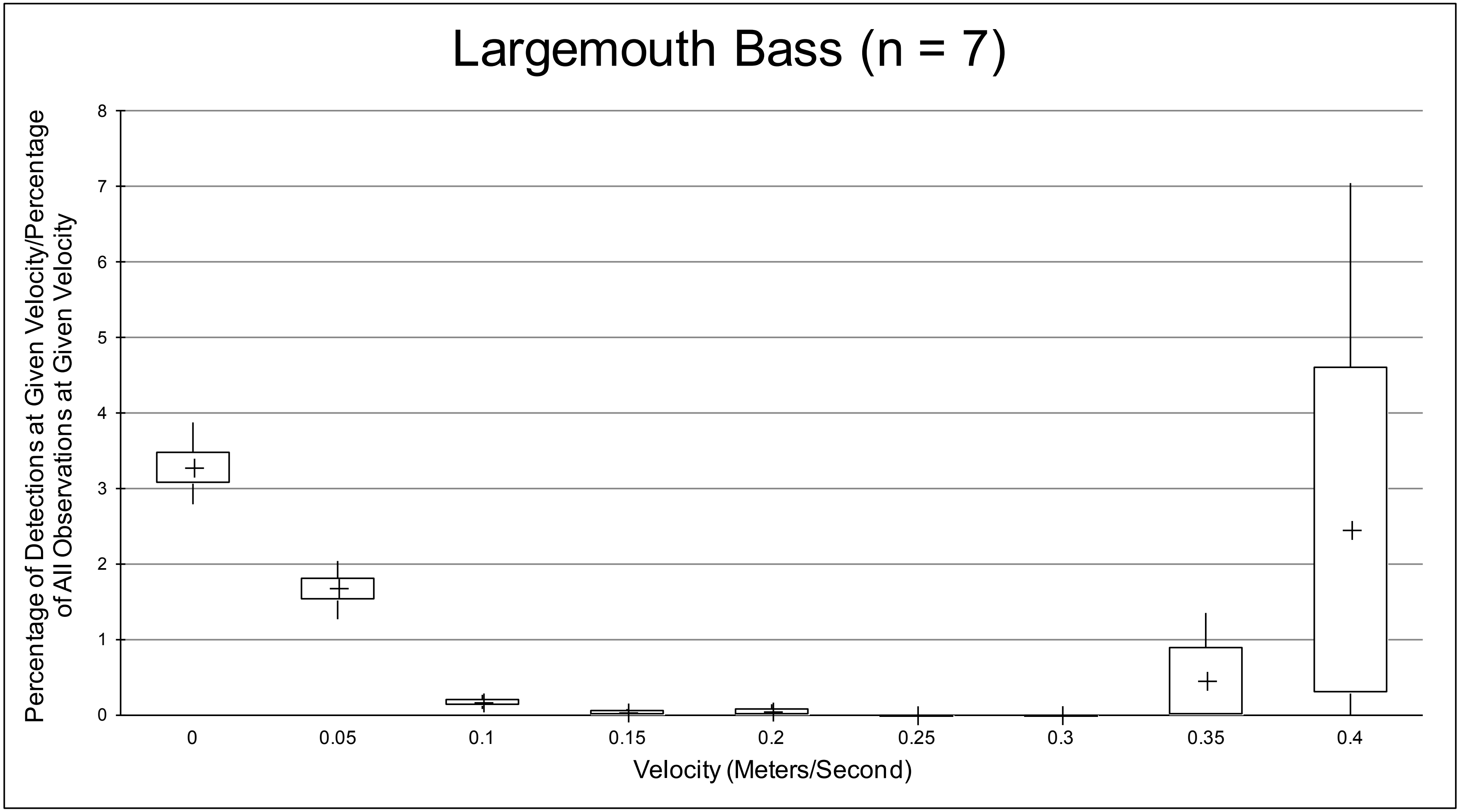
The approximate velocity ranges in which tag detections occurred most frequently differed by fish: 0.025 to 0.275 m/s (tag code 2007), 0.075 to 0.275 m/s (tag code 2154), 0 to 0.125 m/s (tag code 2343), and 0.275 to 0.425 m/s (tag code 2700). This led to little evidence of occupation by fish of any particular velocity in greater or less proportion than it was available in the study area, as judged by the 95% confidence intervals of the velocity index across most velocity increments overlapping an index value of 1 (Figure 6-29).



Note: Velocity is rounded to the nearest 0.05 meter per second.

Source: Present study

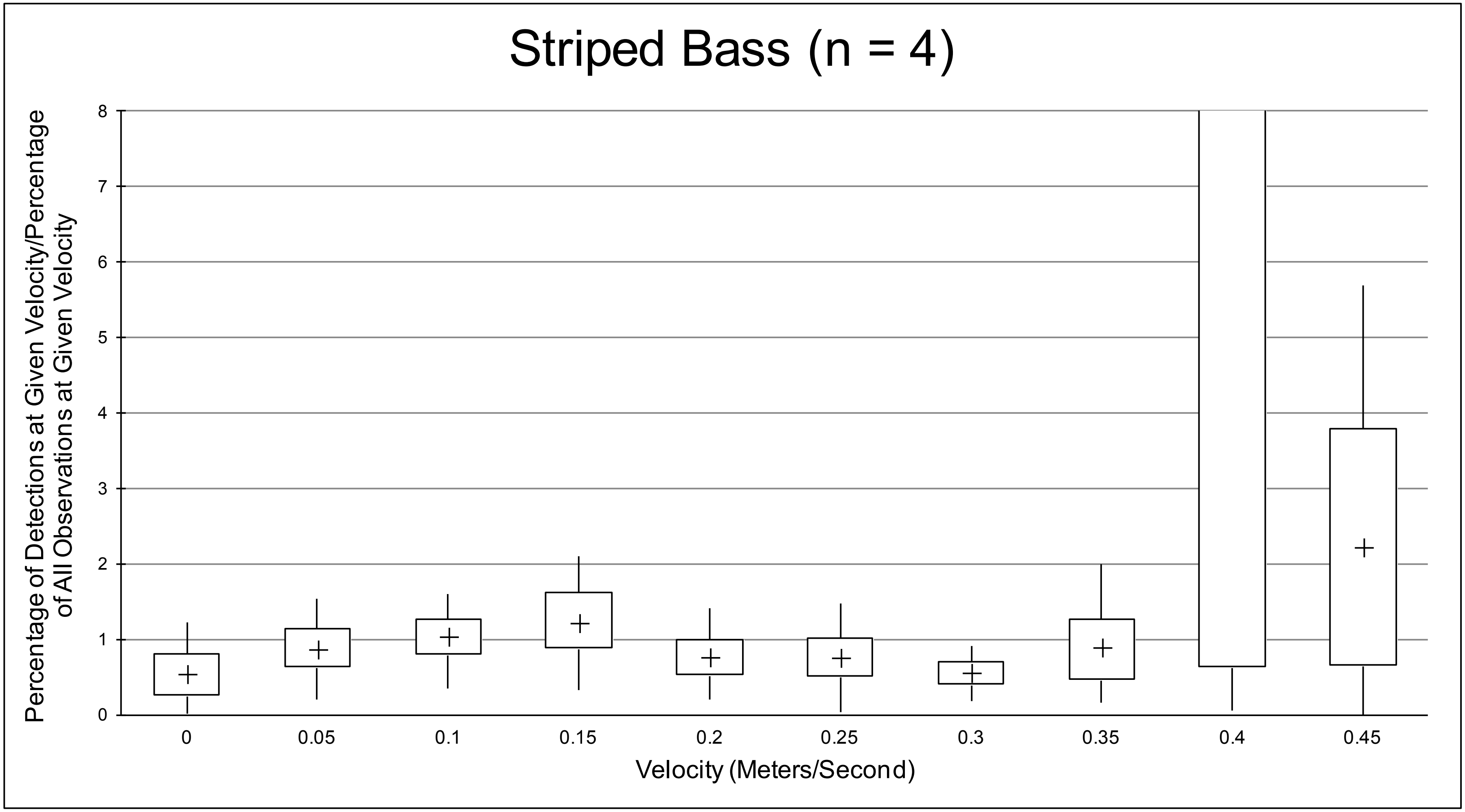
Figure 6-27 Percentage of Tag Detections for Channel Catfish at Different Near-Surface Velocities at the HOR Study Area, Divided by Percentage of All Near-Surface Velocities in the HOR Study Area, Upstream of the 2012 Physical Rock Barrier: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)



Note: Velocity is rounded to the nearest 0.05 meter per second.

Source: Present study

Figure 6-28 **Percentage of Tag Detections for Largemouth Bass at Different Near-Surface Velocities at the HOR Study Area, Divided by Percentage of All Near-Surface Velocities in the HOR Study Area, Upstream of the 2012 Physical Rock Barrier: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**



Notes: Velocity is rounded to the nearest 0.05 meter per second. The y-axis of plot is truncated at 8; 95th percentile at 0.4 meters per second was 46.5.

Source: Present study

Figure 6-29 **Percentage of Tag Detections for Striped Bass at Different Near-Surface Velocities at the HOR Study Area, Divided by Percentage of All Near-Surface Velocities in the HOR Study Area, Upstream of the 2012 Physical Rock Barrier: Bootstrapped Mean (+), Interquartile Range (Box), and 95% Confidence Interval (Whiskers)**

White Catfish

The single white catfish (tag code 2931) included in the velocity analysis had a median near-surface detection velocity of 0.00 m/s (Table 6-66), and 97% of its tag detections occurred in areas with velocity of 0.075 m/s or less. This was considerably less than the available velocities at the times of detection (median = 0.20 m/s, 28% of observations less than 0.075 m/s).

Emigration from Study Area

Four of five channel catfish tagged and released into the San Joaquin River in 2012 were last detected within the spatially defined zones of the study area before deactivation of the acoustic array; the last detections suggested that three of the four moved upstream and one moved downstream (Table 6-65). Five of six largemouth bass that were released into and moved out of the study area during the 2009 through 2012 physical rock barrier studies moved downstream. The single largemouth bass tagged and released in 2009 (tag code 4306) was last detected moving downstream into Old River; the single largemouth bass tagged and released in 2011 that appeared to leave the study area (tag code 3436) moved downstream in the San Joaquin River. Three of four largemouth bass tagged and released in the San Joaquin River that left the study area in 2012 moved downstream and one moved upstream.

Of the four striped bass detected in the study area in 2009 and 2010, two appeared to move upstream in the San Joaquin River, one moved downstream in the San Joaquin River, and one moved downstream in Old River, as indicated by the last zones of detections (Table 6-65). There were 29 tagged striped bass for which movement out of the study area could be deduced by the zone of last detection in 2011. Of these, 16 moved downstream in the San Joaquin River, 11 moved downstream in Old River, and two moved upstream in the San Joaquin River. One of six tagged striped bass released into the San Joaquin River in 2012 moved upstream out of the study area, and the remainder moved downstream.

The single white catfish tagged and released in 2011 (tag code 2346) that moved out of the range of detection of the acoustic array was last detected in Old River (i.e., downstream movement) (Table 6-65). The single white catfish tagged and released in the San Joaquin River in 2012 (tag code 2931) moved downstream out of the study area.

STATIONARY TAG LOCATIONS

A total of 24 stationary (i.e., no longer moving, as judged by consistent positions from signals received by hydrophones) salmonid tags were detected at the HOR study area from 2009 through 2012. This finding may indicate predation following these salmonids' entry into the study area as juveniles, and subsequent defecation. In both 2009 and 2010, only a single stationary tag was detected; 16 stationary tags were detected in 2011 (juvenile Chinook salmon, 10; steelhead, 6) and 6 in 2012 (all juvenile Chinook salmon).

The majority of stationary tags (20 of 24; 83%) was detected in the San Joaquin River downstream of the divergence with Old River; of these, a greater percentage was found at the scour hole (12 of 20; 60%) than offshore (8 of 20; 40%) (Figure 6-30). One stationary juvenile Chinook salmon tag was detected immediately adjacent to the downstream side of the physical rock barrier, with another tag approximately 91 m downstream in Old River. The stationary steelhead tag immediately adjacent to the upstream culvert zone of the physical rock barrier was detected in 2011, and therefore, was not associated with the physical rock barrier. No stationary tags were detected within 5 m of shore (Figure 6-30).

To some extent, the differences in the number of stationary tags detected in each year are related to hydrophone placement, as well as to the number of tagged juveniles entering the study area. In 2011, a hydrophone was placed deep within the scour hole, and therefore, allowed better detection of stationary tags in that year, even though tags classified as having been preyed upon were less frequent in that year than other years (see Section 6.2, "Predation on Juvenile Salmonids Including Barrier Effects"). However, the number of tagged juveniles entering the study area in 2011 (approximately 1,200) was considerably greater than in the other years (approximately 270 to 650 per year). These two factors combined resulted in relatively more stationary tags being detected in 2011 than other years.

6.3.2 Hydroacoustic Data

Areas Occupied and Diel Changes in Depth

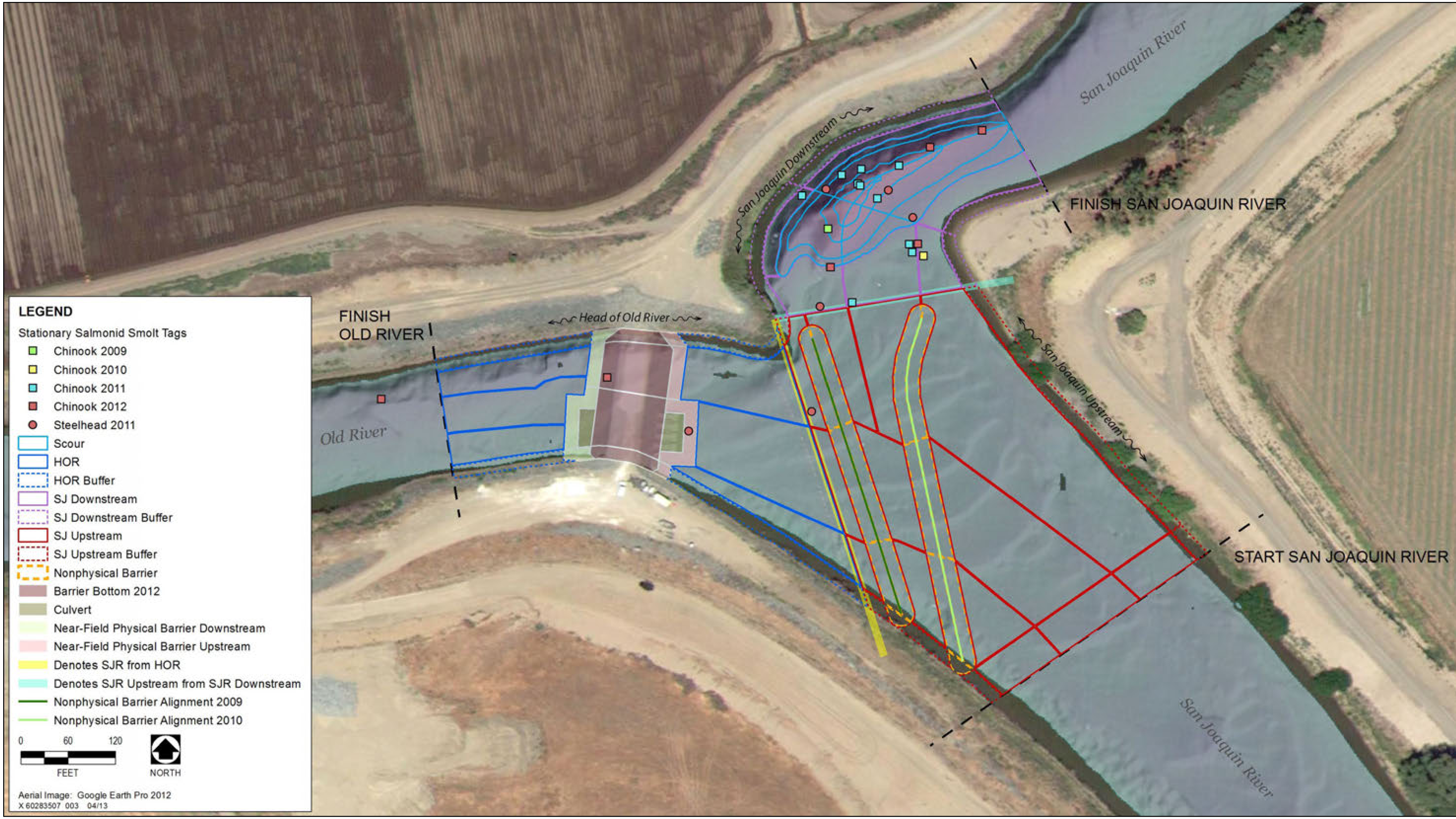
Areas Occupied

A total of 600 fish greater than 30 cm TL were detected within the spatially defined zones of the HOR study area during 49 mobile hydroacoustic surveys in 2011 and 2012. The number of fish detected by down-looking surveys was 20 in 2011 and 279 in 2012, which compared with 57 fish in 2011 and 244 fish in 2012 from side-looking surveys. The greatest proportions of fish detected by down-looking surveys were found in the San Joaquin River downstream of the divergence with Old River (75% of fish in 2011, 99% of fish in 2012) (Figure 6-31; Table 6-67). In particular, many fish were detected at the scour hole (35% of fish in 2011, 95% of fish in 2012). (Note that the ability of mobile hydroacoustic surveys to detect fish in the HOR study area zones was limited following installation of the physical rock barrier in 2012.)

Fish distribution as assessed by side-looking mobile hydroacoustic surveys was more equitable at the HOR study area than the distribution assessed by down-looking surveys, with approximately half of the fish detected in the San Joaquin River downstream of Old River in both 2011 and 2012 (Figure 6-32; Table 6-67). Approximately 23% of fish were detected at the scour hole in both years. An appreciable percentage of fish was detected in the offshore portion of the San Joaquin River upstream of the Old River divergence: 14% in 2011 and 32% in 2012.

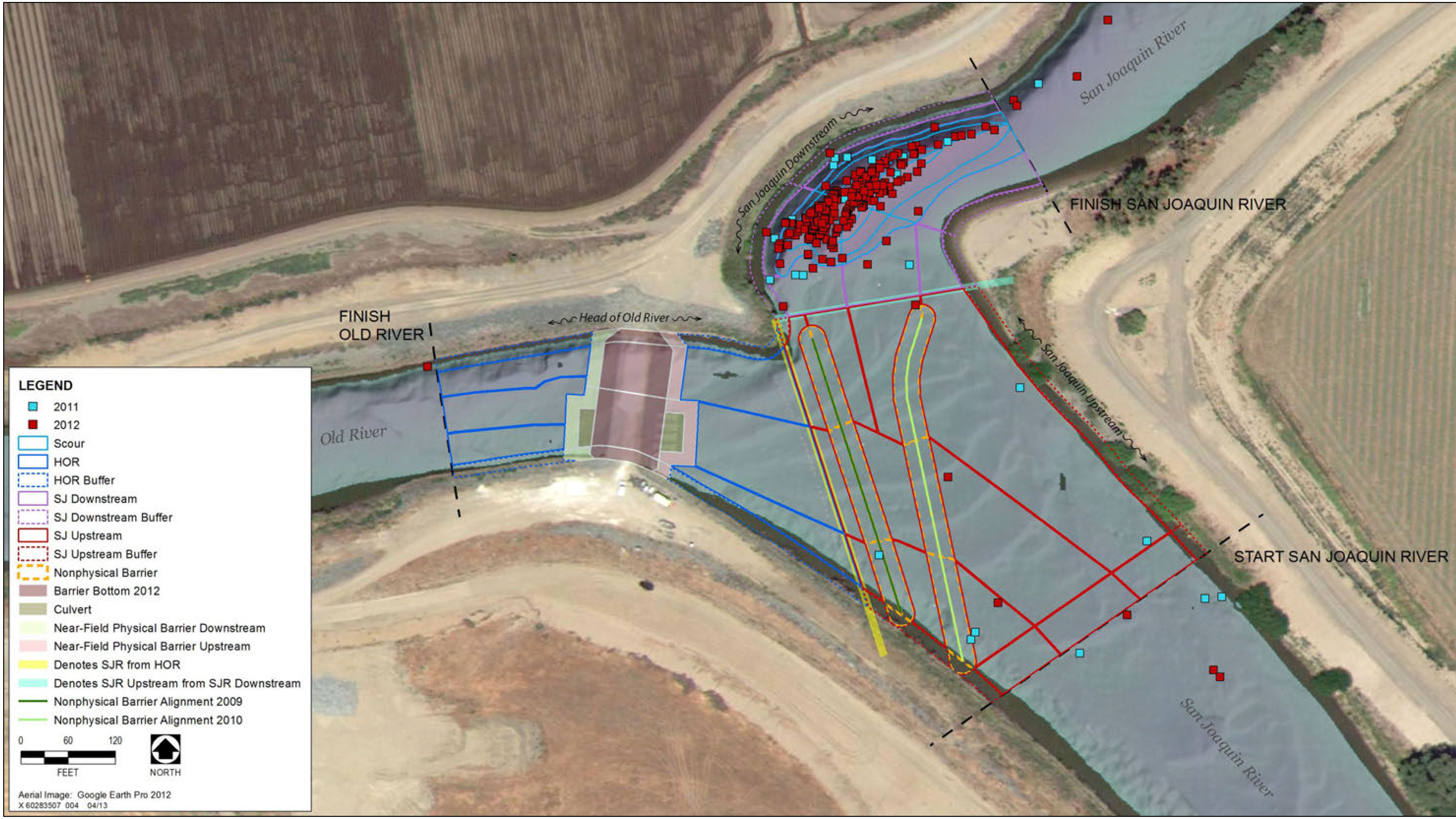
Diel Changes in Depth

There was little evidence that the depth distribution of fish detected by down-looking mobile hydroacoustic surveys changed in relation to diel period. Figure 6-33 shows the vertical distance from the river bottom, where 23 individual fish were detected (12 during the day, 11 at night), in relation to the total water column (bottom) depth in 2011. Evidence of movement higher into the water column at night would be provided by the black symbols being relatively closer to the dashed water-surface line than the yellow circles for a given bottom depth. No such relationship was apparent. No nighttime were data available from the 2012 sampling, and there was no apparent relationship between diel period (day, dawn, or dusk) and position in the water column for 287 fish (Figure 6-34).



Sources: Google Earth Pro 2012; DWR 2012; Present study

Figure 6-30 **Locations of Stationary Juvenile Salmonid Tags, 2009-2012**



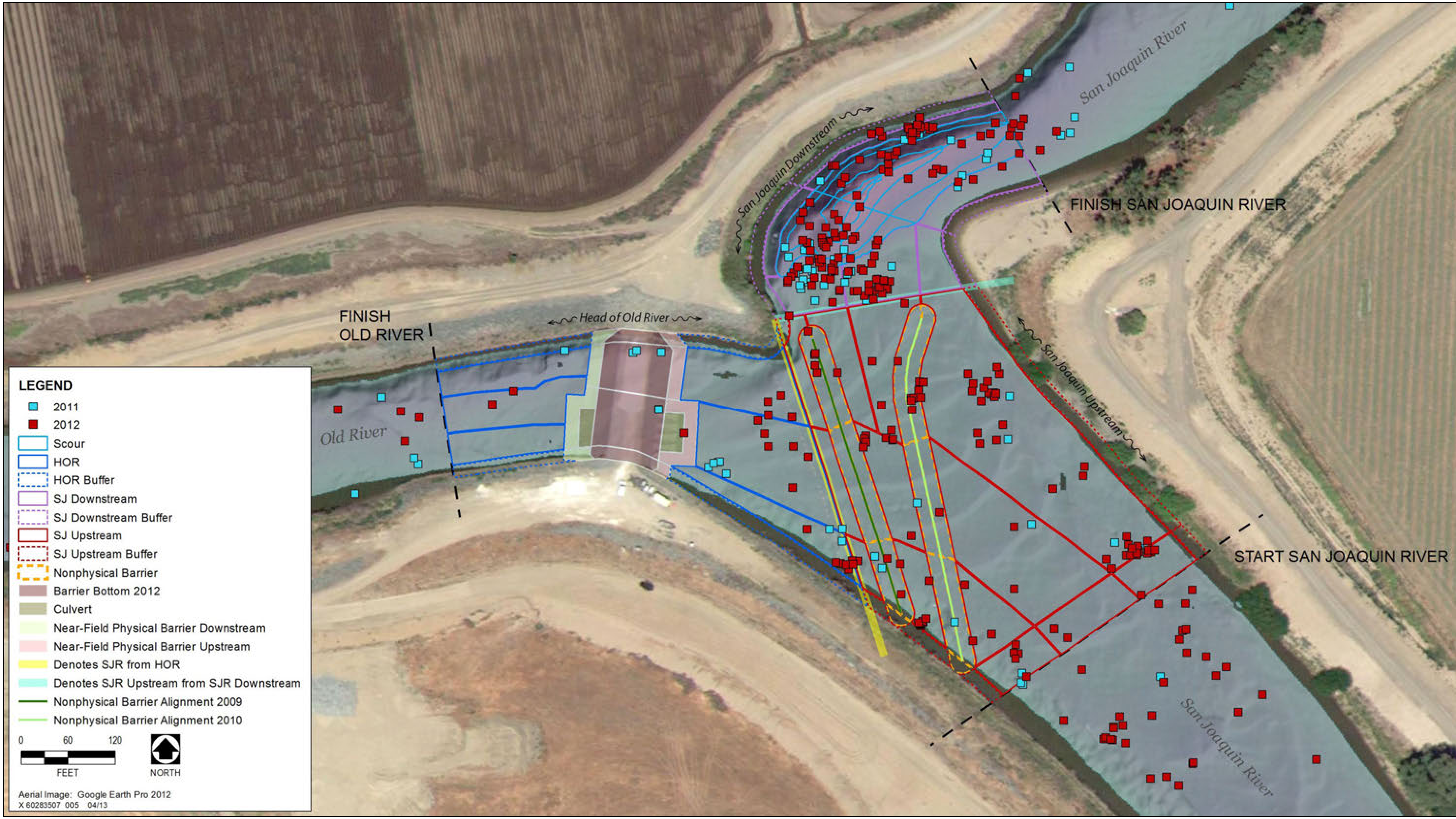
Sources: Google Earth Pro 2012; DWR 2012; Present study

Figure 6-31 **Locations of Fish Estimated to be >30 Centimeters Total Length from Down-Looking Mobile Hydroacoustic Surveys, 2011 and 2012**

Table 6-67
Number and Percentage of Large Fish >30 Centimeters Total Length Detected by Down- and Side-Looking Mobile Hydroacoustic Surveys in Different Zones at the Head of Old River, 2011 and 2012

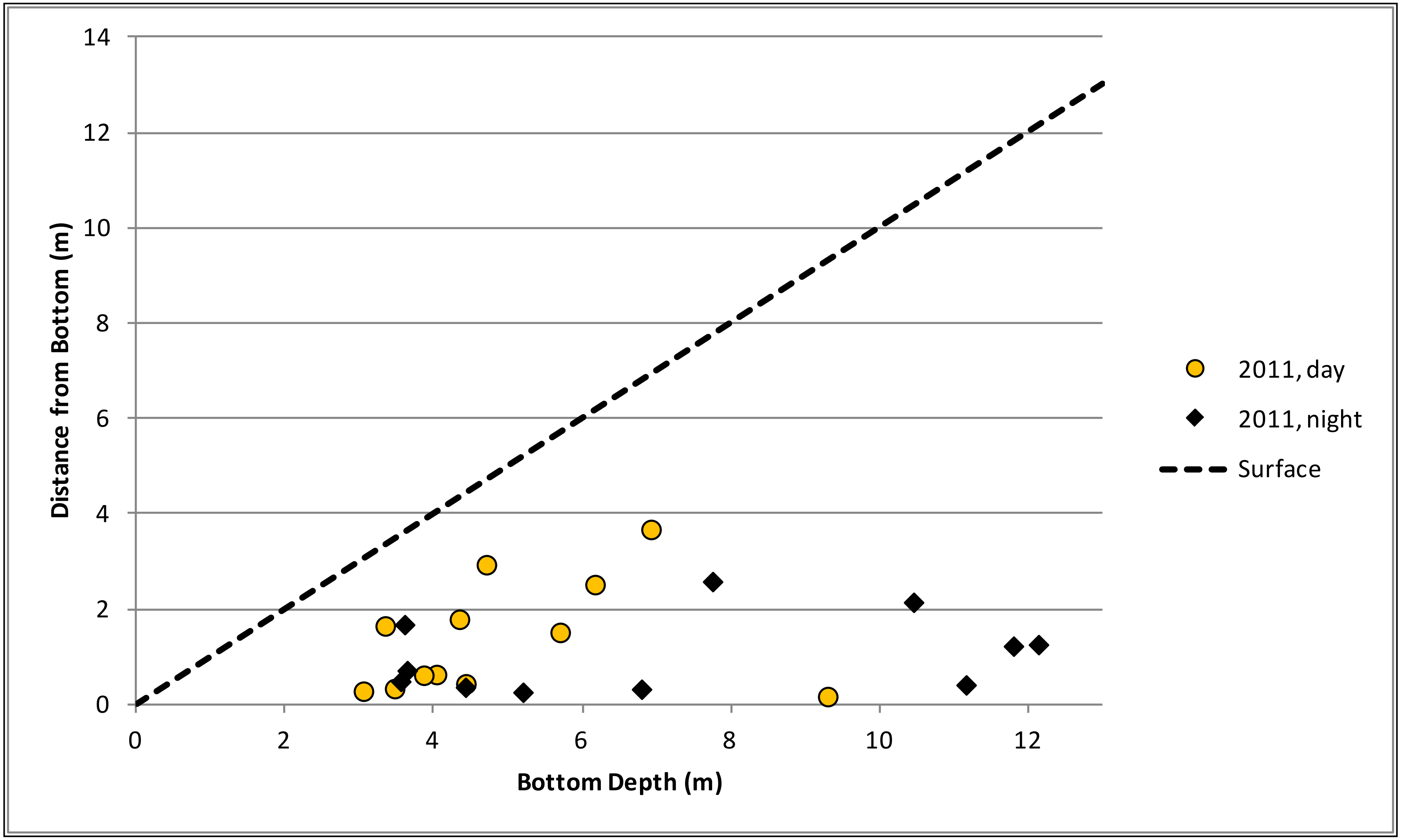
Year/Survey Type	SJR Upstr. Offshore	SJR Upstr. Nearshore	<5 m 2010 Nonphysical Barrier	<5 m 2009 Nonphysical Barrier	SJR Dnstr. Offshore	SJR Dnstr. Nearshore	Scour Hole	HOR Upstr. Offshore	HOR Upstr. Nearshore	<5 m HORB Upstr.	2012 HORB	<5 m HORB Dnstr.	HOR Dnstr. Offshore	HOR Dnstr. Nearshore
2011/down	3 (15%)	0 (%)	1 (5%)	1 (5%)	8 (40%)	0 (%)	7 (35%)	0 (%)	0 (%)	0 (%)	0 (%)	0 (%)	0 (%)	0 (%)
2011/side	8 (14%)	0 (%)	2 (4%)	2 (4%)	18 (32%)	0 (%)	13 (23%)	8 (14%)	0 (%)	0 (%)	5 (9%)	0 (%)	1 (2%)	0 (%)
2012/down	3 (1%)	0 (%)	0 (%)	0 (%)	9 (3%)	3 (1%)	264 (95%)	0 (%)	0 (%)	0 (%)	0 (%)	0 (%)	0 (%)	0 (%)
2012/side	79 (32%)	0 (%)	8 (3%)	7 (3%)	69 (28%)	4 (2%)	57 (23%)	17 (7%)	0 (%)	1 (%)	0 (%)	0 (%)	2 (1%)	0 (%)

Notes: Dnstr. = downstream; HOR = Head of Old River; HORB = Head of Old River Barrier; m = meters; SJR = San Joaquin River; Upstr. = upstream
Source: Present study



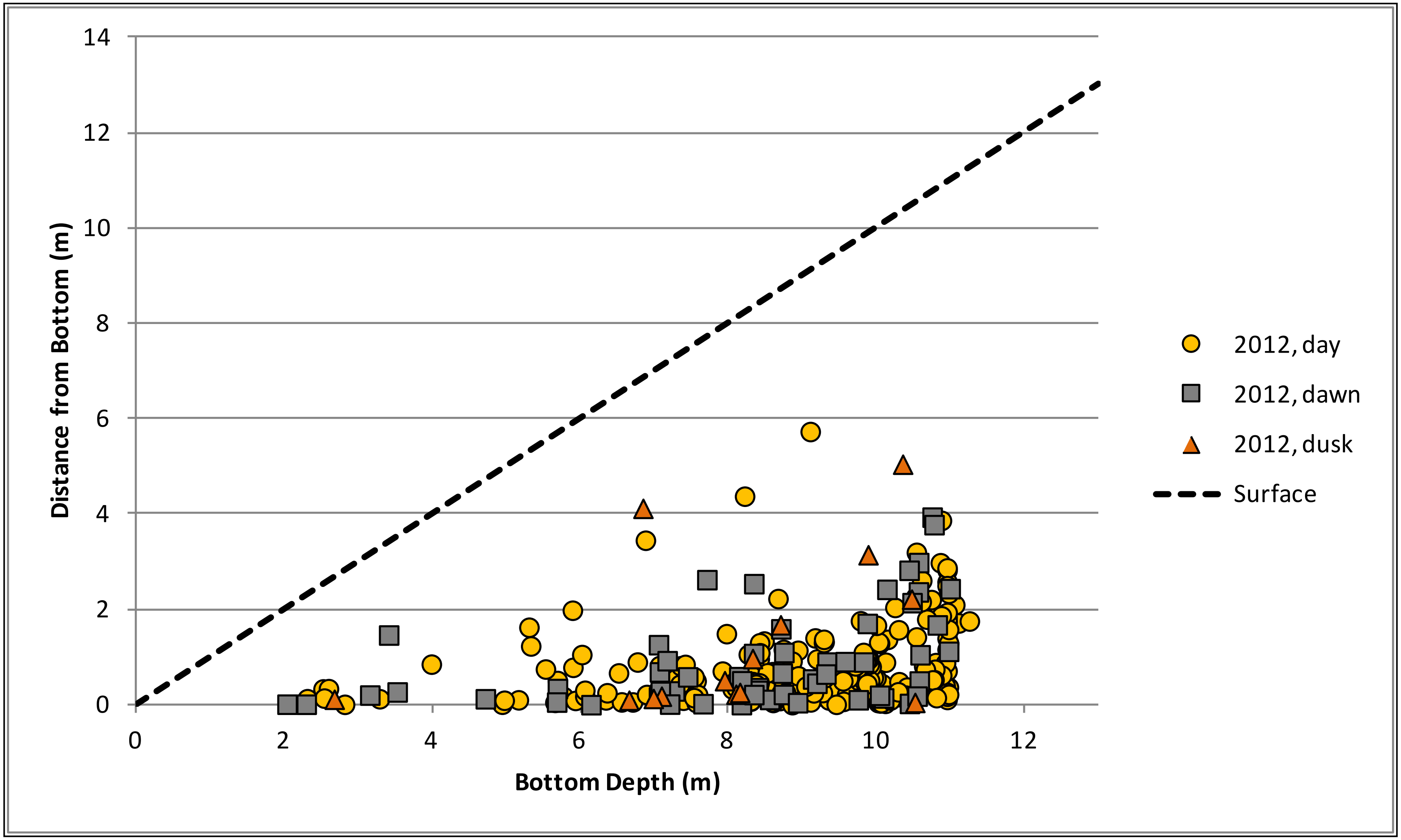
Sources: Google Earth Pro 2012; DWR 2012; Present study

Figure 6-32 **Locations of Fish Estimated to be >30 Centimeters Total Length from Side-Looking Mobile Hydroacoustic Surveys, 2011 and 2012**



Source: Present study

Figure 6-33 Distance from River Bottom of Individual Fish Echoes Estimated to be >30 Centimeters Total Length as a Function of Bottom Depth, as Detected during the Day and Night in Down-Looking Mobile Hydroacoustic Surveys in 2011



Source: Present study

Figure 6-34 Distance from River Bottom of Individual Fish Echoes Estimated to be >30 Centimeters Total Length as a Function of Bottom Depth, as Detected during the Day, Dawn, and Dusk in Down-Looking Mobile Hydroacoustic Surveys in 2012

DENSITY CHANGES AND COMPARISONS TO REFERENCE SITES

Density Changes

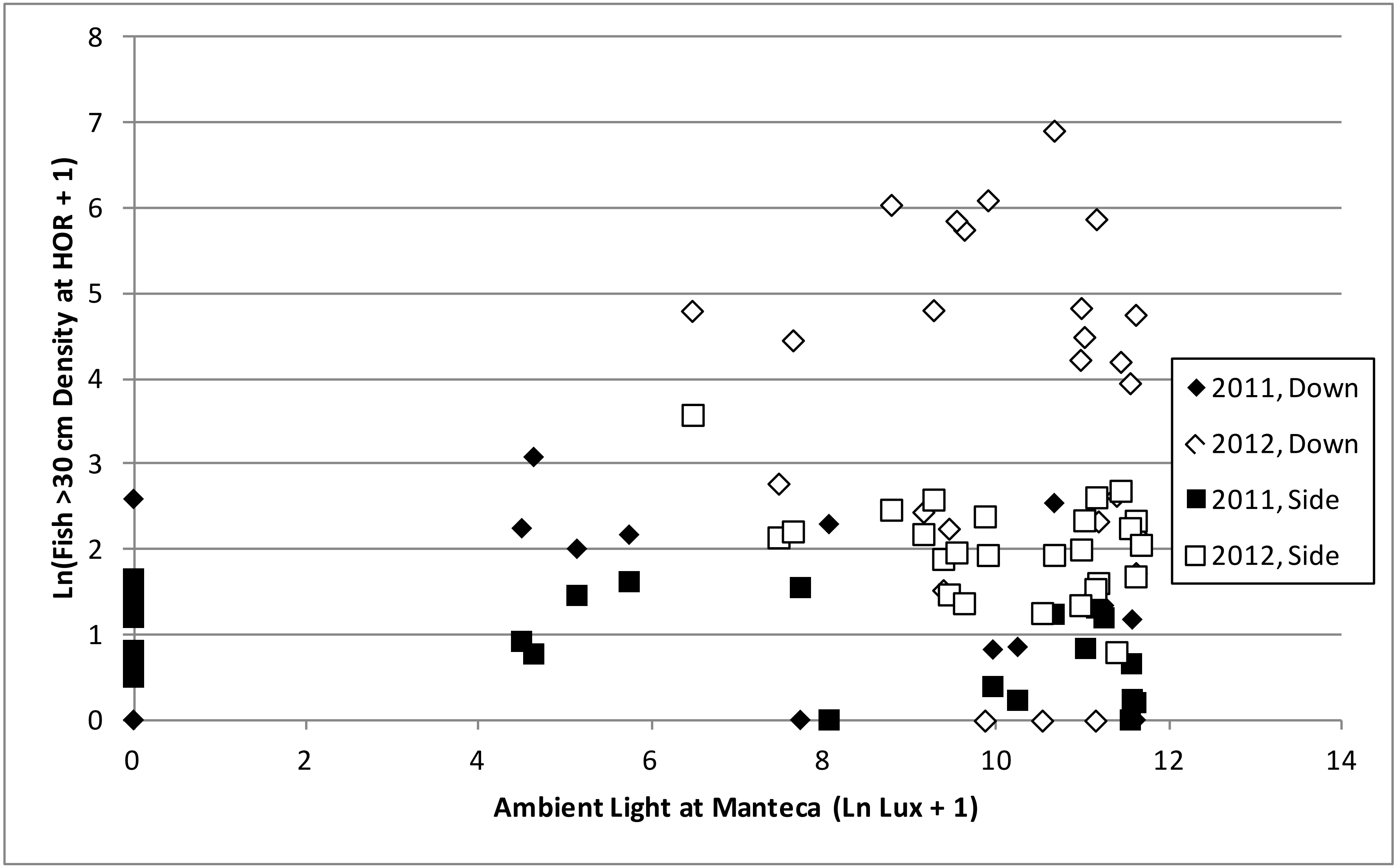
The density of large fish (greater than 30 cm TL) estimated from down-looking mobile hydroacoustic surveys generally was considerably greater in 2012 (mean = 146 fish per 10,000 m^3, median = 66.6 fish per 10,000 m^3) than 2011 (mean = 3.9 fish per 10,000 m^3, median = 1.4 fish per 10,000 m^3). Figures of down-looking density from each survey are presented in relation to environmental variables (discharge, water temperature, turbidity, and small-fish density) for 2011 (Figures G-1, G-2, G-3, and G-4 in Appendix G, "Plots of Environmental Variables and Large-Fish Density from Mobile Hydroacoustic Surveys") and 2012 (Figures G-5, G-6, G-7, and G-8 in Appendix G). The 2011 surveys occurred between May 16 and June 8, and density ranged from zero (10 of 23 surveys) to more than 20 fish per 10,000 m^3 on May 23 (night). In 2012, surveys occurred between March 8 and May 31 (no surveys occurred in April during rock barrier construction), with density ranging from zero (3 of 26 surveys) to more than 1,000 fish per 10,000 m^3 at dusk on May 23. Density in 2012 generally was greater after the physical rock barrier was installed, during higher water temperatures (Figure G-6 in Appendix G).

The density of large fish (greater than 30 cm TL) estimated from side-looking mobile hydroacoustic surveys generally was considerably greater in 2012 (mean = 8.0 fish per 10,000 m^3, median = 6.6 fish per 10,000 m^3) than in 2011 (mean = 1.7 fish per 10,000 m^3, median = 1.4 fish per 10,000 m^3). Figures of side-looking density from each survey are presented in relation to environmental variables in 2011 (Figures G-9, G-10, G-11, and G-12 in Appendix G) and 2012 (Figures G-13, G-14, G-15, and G-16 in Appendix G). Density in 2011 surveys ranged from zero (2 of 23 surveys) to more than 4.2 fish per 10,000 m^3 on May 25 (night). Density in 2012 surveys ranged from just more than 1.2 fish per 10,000 m^3 on March 8 (day) to nearly 35 fish per 10,000 m^3 at dawn on May 23. As with the down-looking data, density in 2012 generally was greater after the physical rock barrier was installed, during higher water temperatures (Figure G-14 in Appendix G).

Plots of the hydroacoustic data included in the GLM analyses (Figures 6-35, 6-36, 6-37, 6-38, and 6-39) showed evidence for greater density of large fish with higher water temperature and lower discharge.

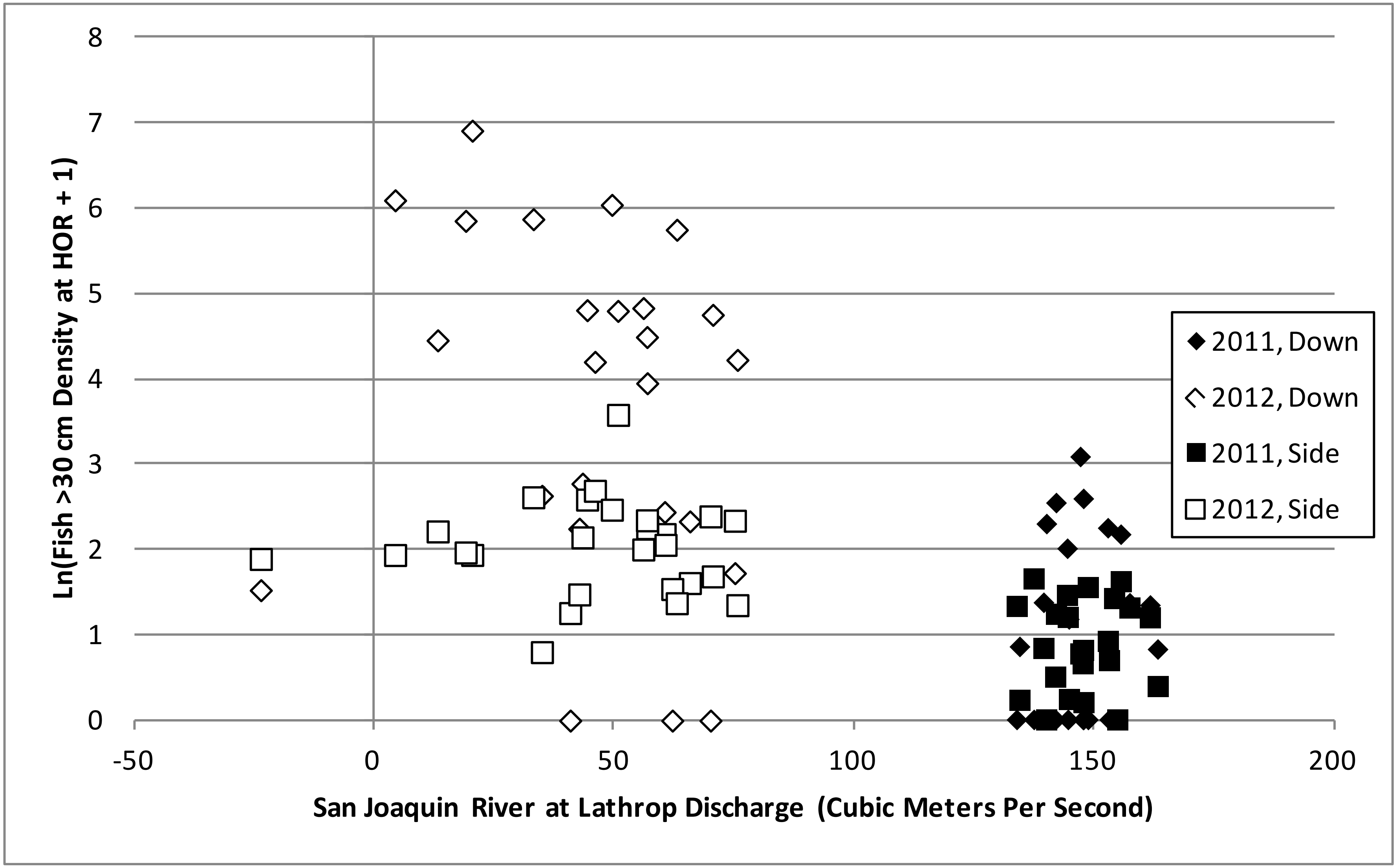
GLM and model-averaging suggested support for same-day discharge and water temperature as predictors of large-fish density from down-looking surveys at the HOR study area, as indicated by predictor coefficients with 95% confidence intervals excluding zero and importance greater than 0.8 (Tables 6-68 and 6-69). Therefore, the null hypothesis $H14_0$ was rejected for these predictors (see "Objectives and Hypotheses Related to Changes in Density of Predatory Fishes" in Section 1.2.4, "Behavior and Density Changes in Predatory Fishes").

Consistent with the observations from the original data described previously, density was negatively related to discharge and positively related to water temperature. There was little support for any other predictors, so null hypothesis $H14_0$ was accepted for these predictors. The GLMs with predictors included provided a better fit to the data than the intercept-only model: the full model with all predictors was ranked eighth out of 32 total models and had the quasi-likelihood equivalent of AIC corrected for small sample sizes ($QAIC_c$) of 255.8, in comparison to $QAIC_c$ of 282.1 for the intercept-only model (ranked last of all models) (Table 6-70). The GLMs using 7-day-mean predictors also suggested support for water temperature as a predictor of large-fish density (Table 6-68). However, the full model had a higher $QAIC_c$ (266.1; 26th-ranked model) (Table 6-71) than the full model for same-day predictors (255.8), suggesting that the model-averaged coefficients based on same-day predictors provided a better fit to the data.



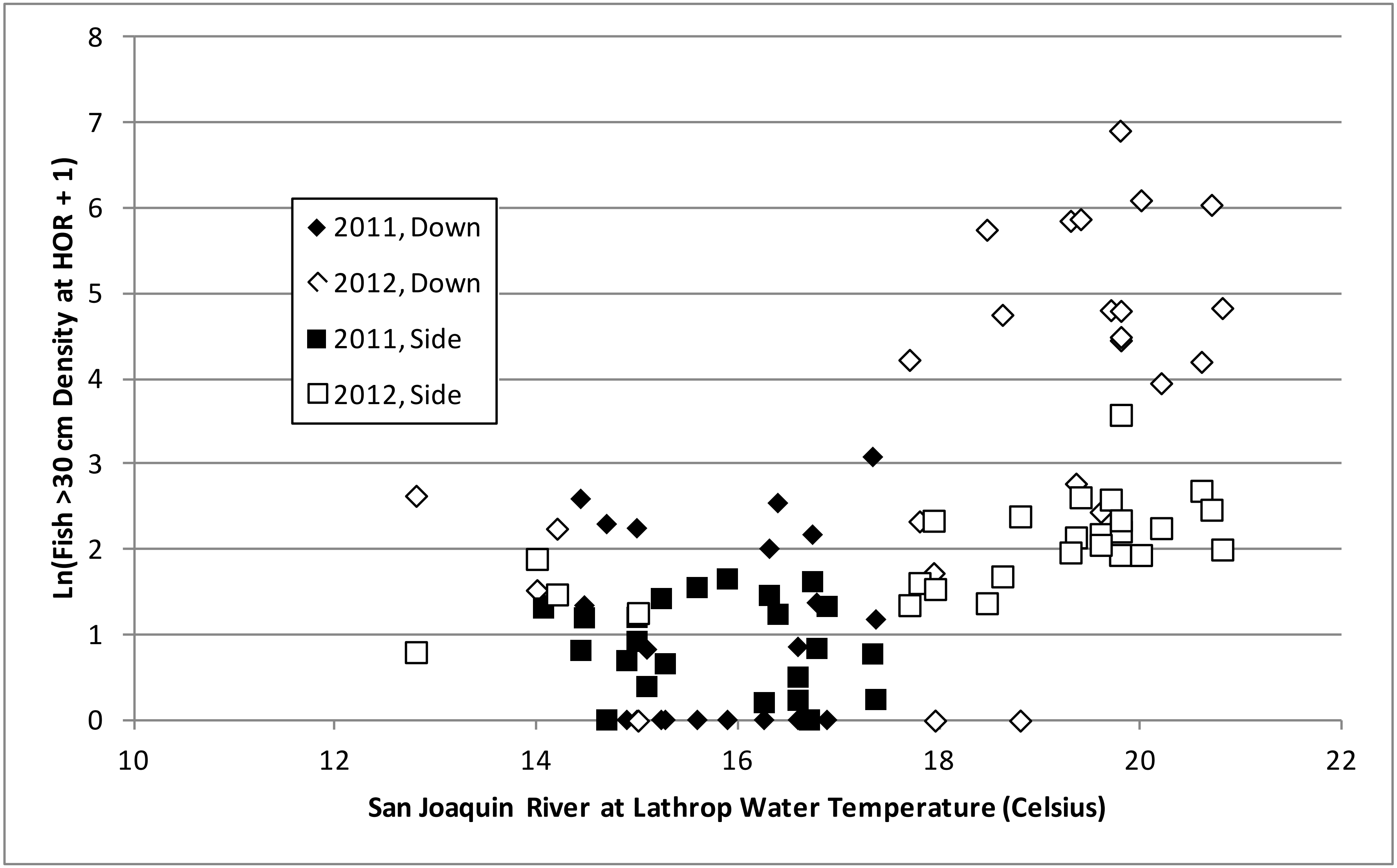
Source: Present study

Figure 6-35 **Estimated Density of Fish >30 Centimeters Total Length in Relation to Ambient Light for 2011 and 2012 Down- and Side-Looking Mobile Hydroacoustic Surveys**



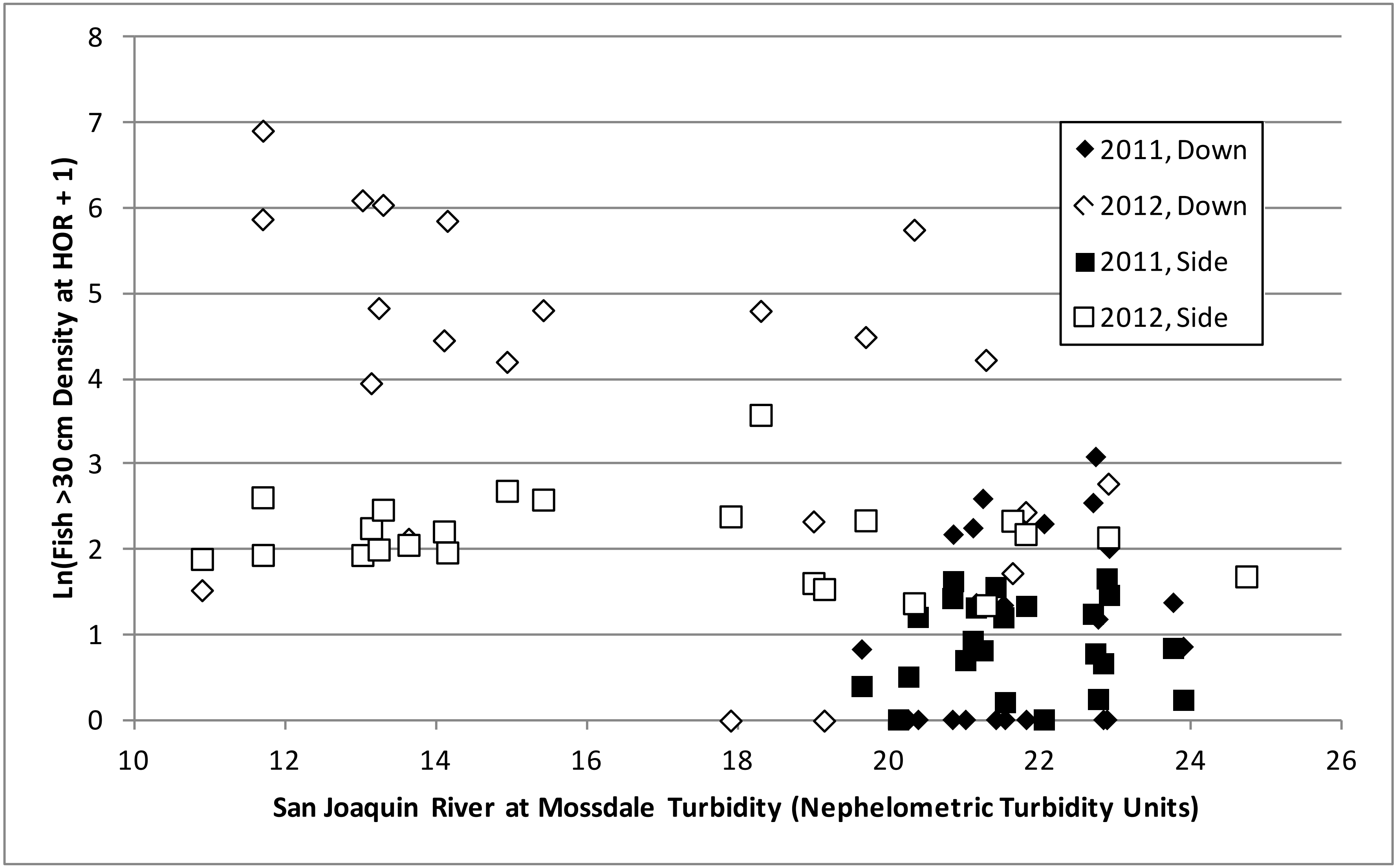
Source: Present study

Figure 6-36 **Estimated Density of Fish >30 Centimeters Total Length in Relation to River Discharge for 2011 and 2012 Down- and Side-Looking Mobile Hydroacoustic Surveys**



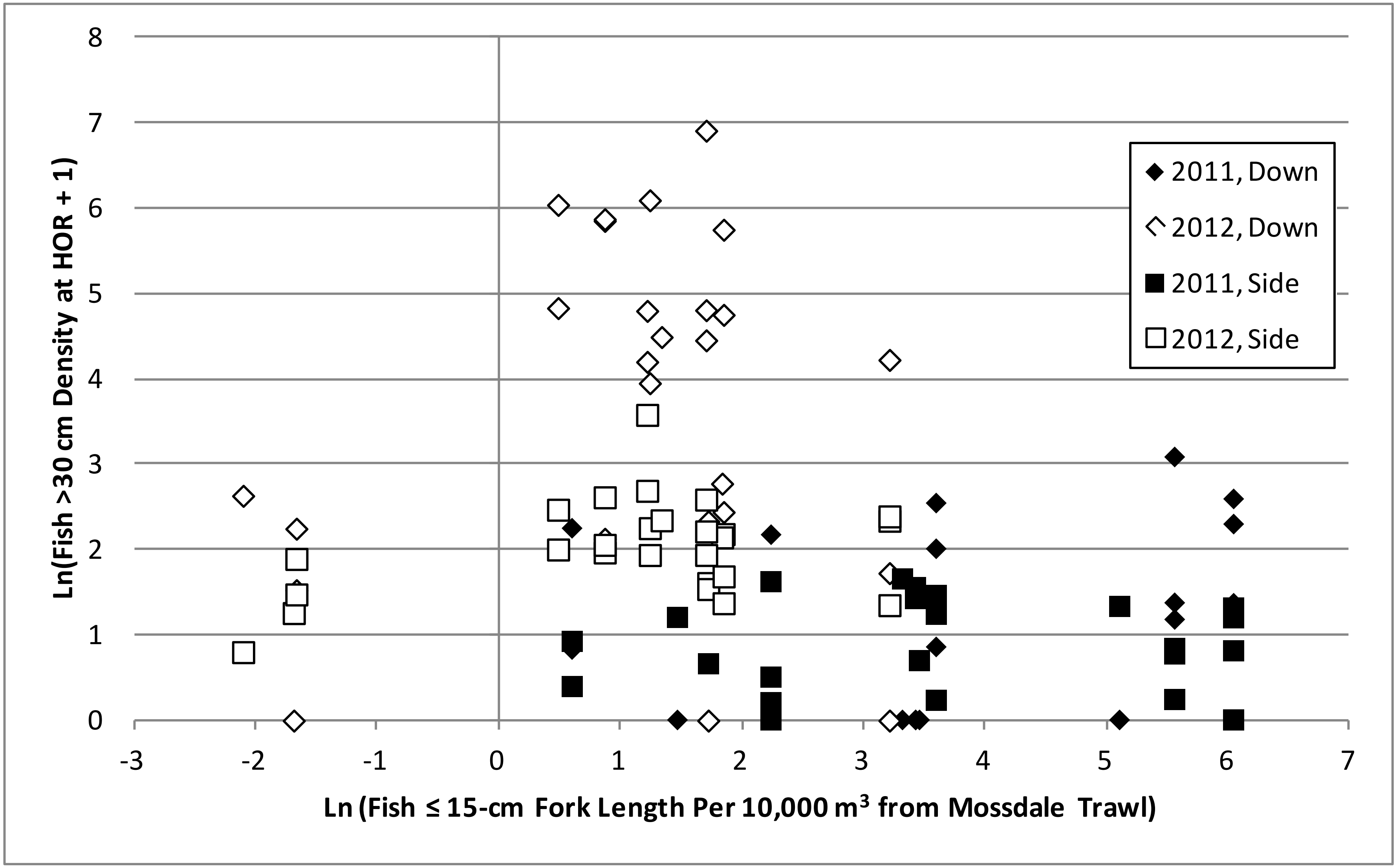
Source: Present study

Figure 6-37 **Estimated Density of Fish >30 Centimeters Total Length in Relation to Water Temperature for 2011 and 2012 Down- and Side-Looking Mobile Hydroacoustic Surveys**



Source: Present study

Figure 6-38 **Estimated Density of Fish >30 Centimeters Total Length in Relation to Turbidity for 2011 and 2012 Down- and Side-Looking Mobile Hydroacoustic Surveys**



Source: Present study

Figure 6-39 **Estimated Density of Fish >30 Centimeters Total Length in Relation to Density of Fish ≤ 15 Centimeters Fork Length from Mossdale Trawling for 2011 and 2012 Down- and Side-Looking Mobile Hydroacoustic Surveys**

Table 6-68
Model-Averaged Coefficients, 95% Confidence Limits, and Variable Importance for the Generalized Linear Modeling of Changes in Density of Large Fish (>30 Centimeters Total Length) from Down-Looking Mobile Hydroacoustic Surveys as a Function of 7-Day Environmental Variables

Variable	Estimate	95% Confidence Limits		Importance
		Lower	Upper	
Water Temperature	0.693	0.354	1.032	0.97
Discharge	-0.013	-0.035	0.009	0.69
Small-Fish Density	0.064	-0.220	0.349	0.35
Turbidity	-0.031	-0.169	0.107	0.32
Ambient Light Level	-0.005	-0.042	0.032	0.22

Source: Present study

Table 6-69
Model-Averaged Coefficients, 95% Confidence Limits, and Variable Importance for the Generalized Linear Modeling of Changes in Density of Large Fish (>30 Centimeters Total Length) from Down-Looking Mobile Hydroacoustic Surveys as a Function of Same-Day Environmental Variables

Variable	Estimate	95% Confidence Limits		Importance
		Lower	Upper	
Discharge	-0.024	-0.040	-0.007	0.95
Water Temperature	0.357	0.022	0.692	0.86
Small-Fish Density	0.101	-0.179	0.381	0.51
Ambient Light Level	-0.004	-0.038	0.030	0.23
Turbidity	-0.003	-0.035	0.029	0.15

Source: Present study

Table 6-70
Model Fit and Weight for Generalized Linear Modeling of Changes in Density of Large Fish (>30 Centimeters Total Length) from Down-Looking Mobile Hydroacoustic Surveys as a Function of Same-Day Environmental Variables

Model Rank	Variables	$QAIC_c$	w_i
1	Intercept + Discharge + Temperature	252.760	0.218
2	Intercept + Small-Fish Density + Discharge + Temperature	253.237	0.172
3	Intercept + Small-Fish Density + Discharge + Temperature + Turbidity	253.237	0.172
4	Intercept + Ambient Light + Discharge + Temperature	255.138	0.066
5	Intercept + Discharge + Temperature + Turbidity	255.238	0.063
6	Intercept + Discharge	255.728	0.049
7	Intercept + Ambient Light + Small-Fish Density + Discharge + Temperature	255.774	0.048
8	Intercept + Ambient Light + Small-Fish Density + Discharge + Temperature + Turbidity	255.774	0.048
9	Intercept + Small-Fish Density + Discharge	256.476	0.034
10	Intercept + Temperature + Turbidity	257.222	0.023
11	Intercept + Ambient Light + Discharge + Temperature + Turbidity	257.724	0.018
12	Intercept + Discharge + Turbidity	257.932	0.016
13	Intercept + Ambient Light + Discharge	258.080	0.015
14	Intercept + Ambient Light + Small-Fish Density + Discharge	258.947	0.010
15	Intercept + Small-Fish Density + Discharge + Turbidity	258.953	0.010
16	Intercept + Small-Fish Density + Temperature + Turbidity	259.484	0.008
17	Intercept + Ambient Light + Temperature + Turbidity	259.500	0.007
18	Intercept + Temperature	260.013	0.006
19	Intercept + Ambient Light + Discharge + Turbidity	260.369	0.005
20	Intercept + Small-Fish Density + Temperature	261.245	0.003
21	Intercept + Ambient Light + Temperature	261.455	0.003
22	Intercept + Ambient Light + Small-Fish Density + Discharge + Turbidity	261.538	0.003
23	Intercept + Ambient Light + Small-Fish Density + Temperature	263.388	0.001
24	Intercept + Ambient Light + Small-Fish Density + Temperature + Turbidity	263.388	0.001
25	Intercept + Ambient Light + Turbidity	272.783	0.000
26	Intercept + Turbidity	274.698	0.000
27	Intercept + Ambient Light + Small-Fish Density + Turbidity	275.166	0.000
28	Intercept + Small-Fish Density + Turbidity	275.333	0.000
29	Intercept + Small-Fish Density	277.677	0.000
30	Intercept + Ambient Light	277.763	0.000
31	Intercept + Ambient Light + Small-Fish Density	278.070	0.000
32	*Intercept Only*	*282.148*	*0.000*

Notes: $QAIC_c$ = Akaike's Information Criterion adjusted for small sample sizes, accounting for overdispersion; w_i = weight
Source: Present study

Table 6-71
Model Fit and Weight for Generalized Linear Modeling of Changes in Density of Large Fish (>30 Centimeters Total Length) from Down-Looking Mobile Hydroacoustic Surveys as a Function of 7-Day Environmental Variables

Model Rank	Variables	$QAIC_c$	w_i
1	Intercept + Discharge + Temperature	255.029	0.219
2	Intercept + Temperature + Turbidity	255.832	0.147
3	Intercept + Small-Fish Density + Discharge + Temperature	256.241	0.120
4	Intercept + Small-Fish Density + Discharge + Temperature + Turbidity	256.241	0.120
5	Intercept + Ambient Light + Discharge + Temperature	257.309	0.070
6	Intercept + Ambient Light + Discharge + Temperature + Turbidity	257.309	0.070
7	Intercept + Discharge + Temperature + Turbidity	257.509	0.063
8	Intercept + Small-Fish Density + Temperature + Turbidity	258.254	0.044
9	Intercept + Ambient Light + Temperature + Turbidity	258.272	0.043
10	Intercept + Small-Fish Density + Temperature	259.008	0.030
11	Intercept + Temperature	259.714	0.021
12	Intercept + Small-Fish Density + Discharge + Turbidity	260.883	0.012
13	Intercept + Ambient Light + Temperature	261.349	0.009
14	Intercept + Ambient Light + Small-Fish Density + Temperature	261.440	0.009
15	Intercept + Ambient Light + Small-Fish Density + Temperature + Turbidity	261.440	0.009
16	Intercept + Discharge + Turbidity	262.761	0.005
17	Intercept + Small-Fish Density + Discharge	263.796	0.003
18	Intercept + Ambient Light + Discharge + Turbidity	265.089	0.001
19	Intercept + Discharge	265.627	0.001
20	Intercept + Ambient Light + Small-Fish Density + Discharge	266.056	0.001
21	Intercept + Ambient Light + Small-Fish Density + Discharge + Temperature	266.056	0.001
22	Intercept + Ambient Light + Small-Fish Density + Discharge + Turbidity	266.056	0.001
23	Intercept + Ambient Light + Small-Fish Density + Discharge + Temperature + Turbidity	266.056	0.001
24	Intercept + Ambient Light + Discharge	267.995	0.000
25	Intercept + Small-Fish Density	279.895	0.000
26	Intercept + Ambient Light + Small-Fish Density	280.513	0.000
27	Intercept + Ambient Light	281.994	0.000
28	Intercept + Small-Fish Density + Turbidity	282.225	0.000
29	Intercept + Ambient Light + Turbidity	282.508	0.000
30	Intercept + Ambient Light + Small-Fish Density + Turbidity	282.999	0.000
31	Intercept + Turbidity	284.671	0.000
32	*Intercept Only*	*286.484*	*0.000*

Notes: $QAIC_c$ = Akaike's Information Criterion adjusted for small sample sizes, accounting for overdispersion; w_i = weight
Source: Present study

Similar to the down-looking density results, GLM and model-averaging suggested support for same-day discharge (negative relationship) and water temperature (positive relationship) as predictors of the density of large fish from side-looking surveys at the HOR study area (Table 6-72). Null hypothesis $H14_0$ was therefore rejected for these predictors. Note that the upper 95% confidence interval for discharge is 0.000. No other predictors were supported through model-averaging; $H14_0$ was accepted for these predictors. Inclusion of predictors improved the fit of the model to the data (full model $QAIC_c$ = 300.5, intercept-only model $QAIC_c$ = 320.5) (Table 6-73). Water temperature was also supported as a predictor of side-looking density for 7-day-mean predictor data (Table 6-74), although the full model had a $QAIC_c$ (303.9) (Table 6-75) that was more than three units greater than the $QAIC_c$ for the full model based on same-day predictors (300.5). As with down-looking density data, this suggests that the model-averaged coefficients based on same-day predictors provided a better fit to the data.

Table 6-72
Model-Averaged Coefficients, 95% Confidence Limits, and Variable Importance for Generalized Linear Modeling of Density Changes of Large Fish (>30 Centimeters Total Length) from Side-Looking Mobile Hydroacoustic Surveys as a Function of Same-Day Environmental Variables

Variable	Estimate	95% Confidence Limits		Importance
		Lower	Upper	
Water Temperature	0.205	0.057	0.354	0.93
Discharge	-0.008	-0.016	0.000	0.87
Ambient Light Level	-0.025	-0.090	0.041	0.47
Small-Fish Density	0.009	-0.069	0.087	0.35
Turbidity	-0.001	-0.022	0.020	0.20

Source: Present study

Table 6-73
Model Fit and Weight for Generalized Linear Modeling of Density Changes of Large Fish (>30 Centimeters Total Length) from Side-Looking Mobile Hydroacoustic Surveys as a Function of Same-Day Environmental Variables

Model Rank	Variables	$QAIC_c$	w_i
1	Intercept + Discharge + Temperature	298.333	0.211
2	Intercept + Ambient Light + Discharge + Temperature	298.432	0.201
3	Intercept + Ambient Light + Small-Fish Density + Discharge + Temperature	300.508	0.071
4	Intercept + Ambient Light + Small-Fish Density + Discharge + Temperature + Turbidity	300.508	0.071
5	Intercept + Small-Fish Density + Discharge + Temperature	300.681	0.065
6	Intercept + Small-Fish Density + Discharge + Temperature + Turbidity	300.681	0.065
7	Intercept + Discharge + Temperature + Turbidity	300.730	0.064
8	Intercept + Ambient Light + Discharge + Temperature + Turbidity	300.966	0.057
9	Intercept + Temperature + Turbidity	301.971	0.034
10	Intercept + Small-Fish Density + Temperature	302.442	0.027
11	Intercept + Temperature	303.361	0.017
12	Intercept + Discharge	303.392	0.017
13	Intercept + Ambient Light + Temperature + Turbidity	303.445	0.016
14	Intercept + Ambient Light + Discharge	303.998	0.012
15	Intercept + Small-Fish Density + Temperature + Turbidity	304.167	0.011
16	Intercept + Ambient Light + Small-Fish Density + Temperature	304.480	0.010
17	Intercept + Ambient Light + Small-Fish Density + Temperature + Turbidity	304.480	0.010
18	Intercept + Discharge + Turbidity	304.543	0.009
19	Intercept + Small-Fish Density + Discharge	305.016	0.007
20	Intercept + Ambient Light + Small-Fish Density + Discharge	305.105	0.007
21	Intercept + Ambient Light + Discharge + Turbidity	305.304	0.006
22	Intercept + Ambient Light + Temperature	305.658	0.005
23	Intercept + Small-Fish Density + Discharge + Turbidity	306.807	0.003
24	Intercept + Ambient Light + Small-Fish Density + Discharge + Turbidity	307.255	0.002
25	Intercept + Small-Fish Density	317.184	0.000
26	Intercept + Turbidity	318.391	0.000
27	Intercept + Small-Fish Density + Turbidity	318.972	0.000
28	Intercept + Ambient Light + Small-Fish Density	319.461	0.000
29	*Intercept Only*	*320.544*	*0.000*
30	Intercept + Ambient Light + Turbidity	320.728	0.000
31	Intercept + Ambient Light + Small-Fish Density + Turbidity	321.437	0.000
32	Intercept + Ambient Light	322.063	0.000

Notes: $QAIC_c$ = Akaike's Information Criterion adjusted for small sample sizes, accounting for overdispersion; w_i = weight
Source: Present study

Table 6-74
Model-averaged Coefficients, 95% Confidence Limits, and Variable Importance for Generalized Linear Modeling of Density Changes for Large Fish (>30 Centimeters Total Length) from Side-Looking Mobile Hydroacoustic Surveys as a Function of 7-Day Environmental Variables

Variable	Estimate	95% Confidence Limits		Importance
		Lower	Upper	
Water Temperature	0.362	0.204	0.521	1.00
Ambient Light Level	-0.059	-0.136	0.019	0.77
Turbidity	-0.076	-0.196	0.044	0.65
Discharge	-0.003	-0.012	0.006	0.35
Small-Fish Density	-0.007	-0.044	0.030	0.09

Source: Present study

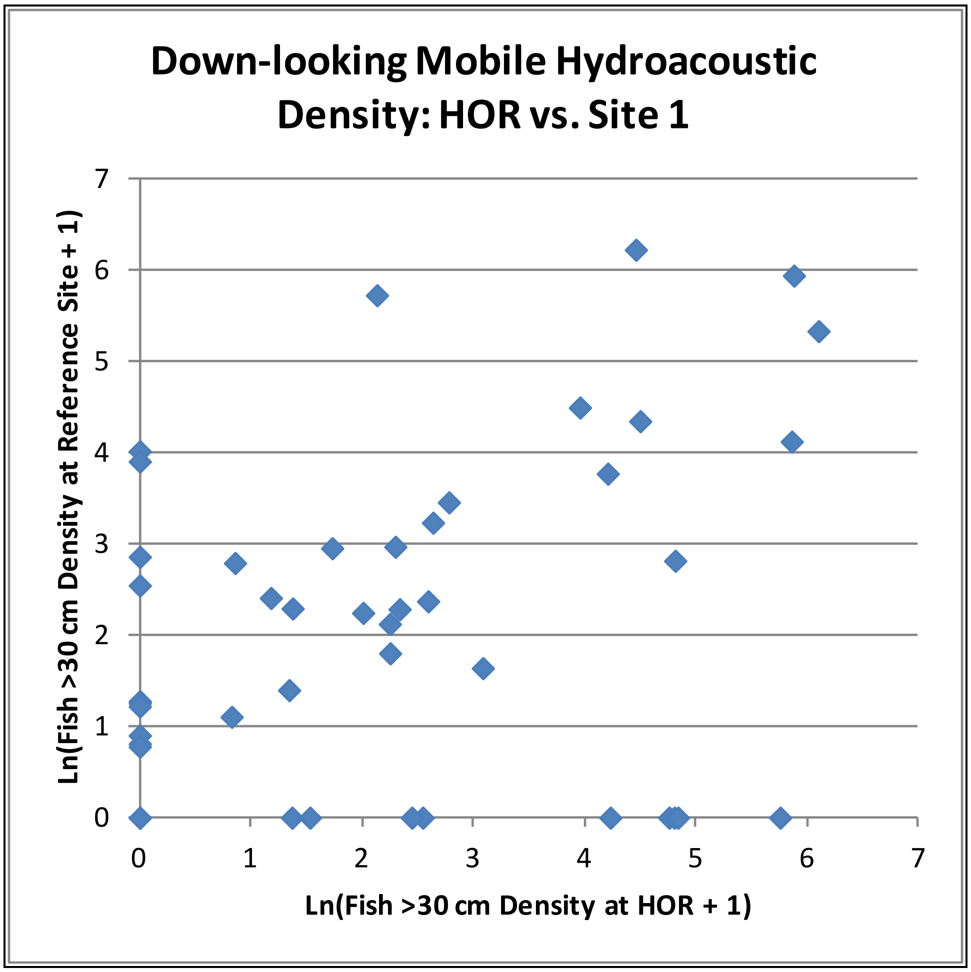
Table 6-75
Model Fit and Weight for Generalized Linear Modeling of Density Changes for Large Fish (>30 Centimeters Total Length) from Side-Looking Mobile Hydroacoustic Surveys as a Function of 7-Day Environmental Variables

Model Rank	Variables	$QAIC_c$	w_i
1	Intercept + Ambient Light + Temperature + Turbidity	289.010	0.485
2	Intercept + Ambient Light + Discharge + Temperature	291.663	0.129
3	Intercept + Ambient Light + Discharge + Temperature + Turbidity	291.663	0.129
4	Intercept + Temperature + Turbidity	292.120	0.102
5	Intercept + Discharge + Temperature	294.228	0.036
6	Intercept + Small-Fish Density + Temperature + Turbidity	294.589	0.030
7	Intercept + Discharge + Temperature + Turbidity	294.605	0.030
8	Intercept + Ambient Light + Small-Fish Density + Temperature	296.426	0.012
9	Intercept + Ambient Light + Small-Fish Density + Temperature + Turbidity	296.426	0.012
10	Intercept + Small-Fish Density + Temperature	296.487	0.012
11	Intercept + Small-Fish Density + Discharge + Temperature	296.707	0.010
12	Intercept + Small-Fish Density + Discharge + Temperature + Turbidity	296.707	0.010
13	Intercept + Temperature	301.578	0.001
14	Intercept + Ambient Light + Discharge	302.974	0.000
15	Intercept + Discharge	303.067	0.000
16	Intercept + Ambient Light + Discharge + Turbidity	303.818	0.000
17	Intercept + Ambient Light + Temperature	303.829	0.000
18	Intercept + Ambient Light + Small-Fish Density + Discharge	303.860	0.000
19	Intercept + Ambient Light + Small-Fish Density + Discharge + Temperature	303.860	0.000
20	Intercept + Ambient Light + Small-Fish Density + Discharge + Turbidity	303.860	0.000
21	Intercept + Ambient Light + Small-Fish Density + Discharge + Temperature + Turbidity	303.860	0.000
22	Intercept + Discharge + Turbidity	304.119	0.000
23	Intercept + Small-Fish Density + Discharge	304.531	0.000
24	Intercept + Small-Fish Density + Discharge + Turbidity	306.075	0.000
25	Intercept + Small-Fish Density	312.476	0.000
26	Intercept + Ambient Light + Small-Fish Density	314.740	0.000
27	Intercept + Small-Fish Density + Turbidity	314.755	0.000
28	Intercept + Turbidity	315.641	0.000
29	Intercept + Ambient Light + Small-Fish Density + Turbidity	317.117	0.000
30	Intercept + Ambient Light + Turbidity	318.010	0.000
31	*Intercept only*	*318.914*	*0.000*
32	Intercept + Ambient Light	320.436	0.000

Notes: $QAIC_c$ = Akaike's Information Criterion adjusted for small sample sizes, accounting for overdispersion; w_i = weight
Source: Present study

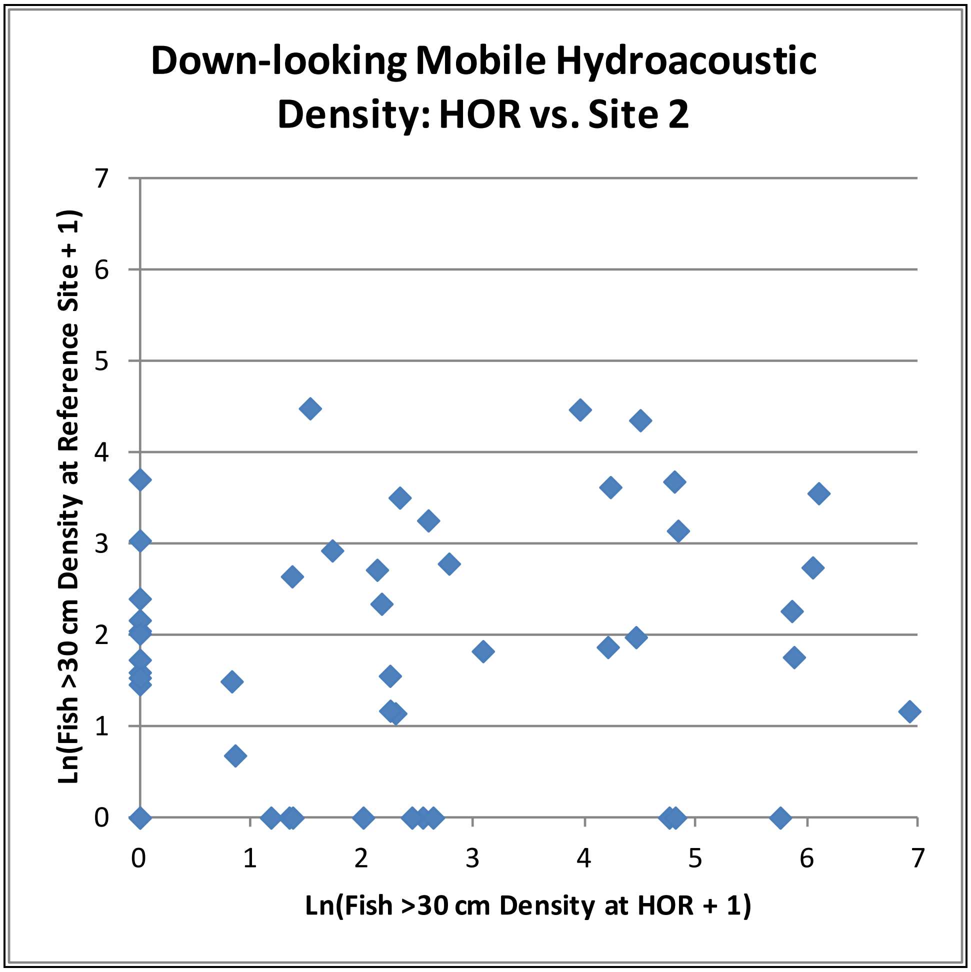
Comparisons to Reference Sites

There was considerable variability in the density of large fish (>30 cm TL) as estimated from down-looking mobile hydroacoustic surveys at the HOR study area and at the reference sites (Figures 6-40, 6-41, and 6-42). There was a statistically significant (P = 0.01) positive correlation between density at the HOR study area and density at Site 4 (San Joaquin River downstream of the HOR study area) (Figure 6-42), which led to rejection of null hypothesis $H15_0$ (See "Objectives and Hypotheses Related to Changes in Density of Predatory Fishes" in Section 1.2.4, "Behavior and Density Changes in Predatory Fishes,"). However, there was no significant correlation between density at the HOR study area and density at the other two sites (allowing acceptance of $H15_0$) (Table 6-76). The density of large fish from down-looking surveys at the HOR site was significantly greater than at Site 4 (P <0.0001), leading to rejection of hypothesis $H16_0$, and not significantly different from density at Sites 1 and 2 (hypothesis $H16_0$ was accepted for these comparisons).



Source: Present study

Figure 6-40 **Estimated Density of Fish >30 Centimeters Total Length at the HOR Study Area in Relation to Density of Fish at Reference Site 1, 2011 and 2012 Down-Looking Mobile Hydroacoustic Surveys**



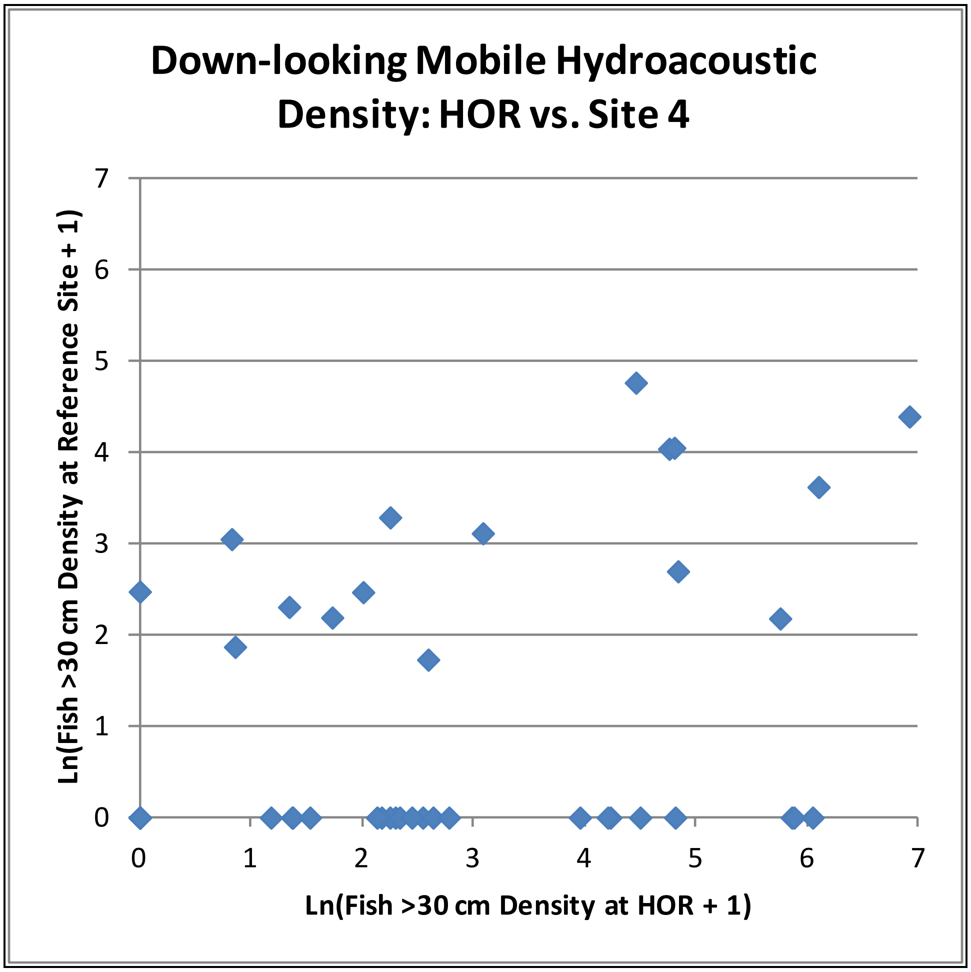
Source: Present study

Figure 6-41 Estimated Density of Fish >30 Centimeters Total Length at the HOR Study Area in Relation to Density of Fish at Reference Site 2, 2011 and 2012 Down-Looking Mobile Hydroacoustic Surveys

Table 6-76
Summary of Statistical Tests Comparing Density of Large Fish (>30 Centimeters Total Length) at the Head of Old River Study Area to Reference Sites in the San Joaquin River from Down-Looking Mobile Hydroacoustic Surveys in 2011 and 2012

Comparisons	Correlations		Paired Differences		
	Pearson R	*P* (no. of observations)	Mean Difference (HOR—Reference Site)	Paired T-test t (degrees of freedom)	*P*
HOR vs. Site 1	0.29	0.06 (n = 45)	0.14	0.41 (44 d.f.)	0.68
HOR vs. Site 2	0.14	0.34 (n = 48)	0.62	1.85 (47 d.f.)	0.07
HOR vs. Site 4	**0.37**	**0.01 (n = 48)**	**1.47**	**4.91 (47 d.f.)**	**<0.0001**

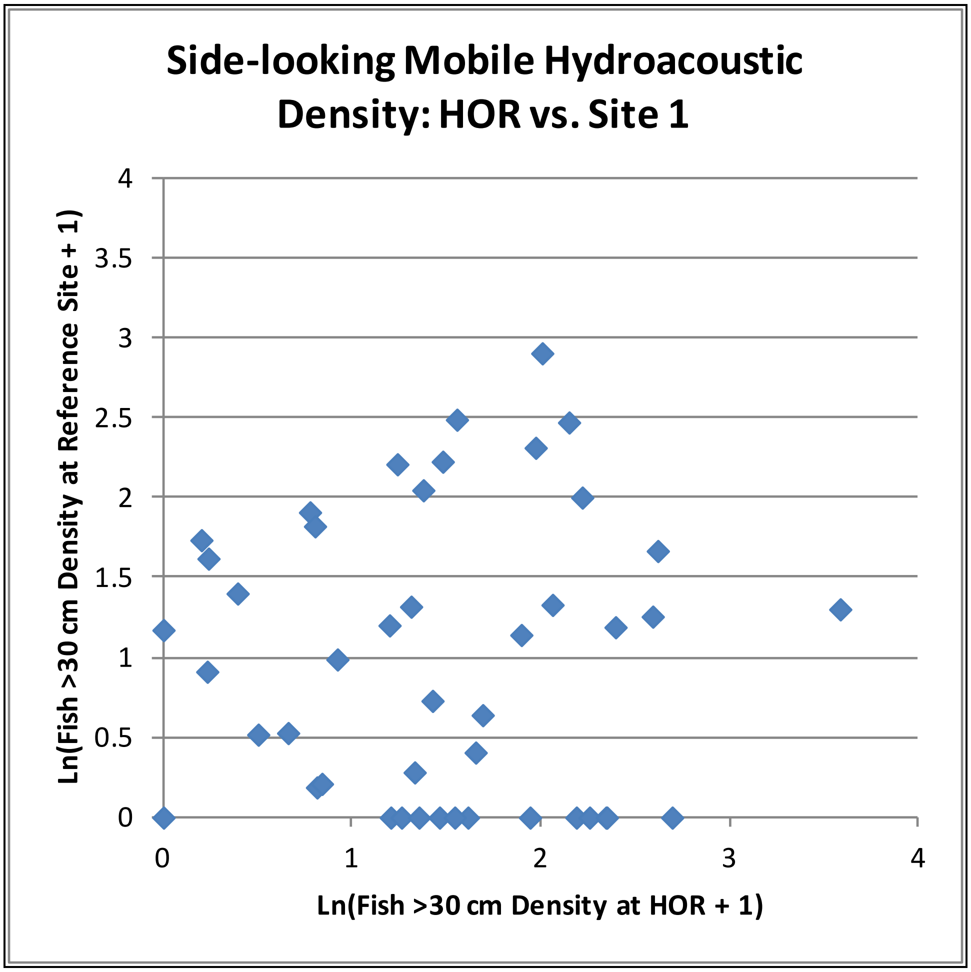
Notes: HOR = Head of Old River study area; n = number of observations; n = number; d.f. = degrees of freedom
Comparisons were based on natural-logarithm-transformed data.
Bold Indicates statistical significance at Bonferroni-adjusted *P* < 0.017.
Source: Present study



Source: Present study

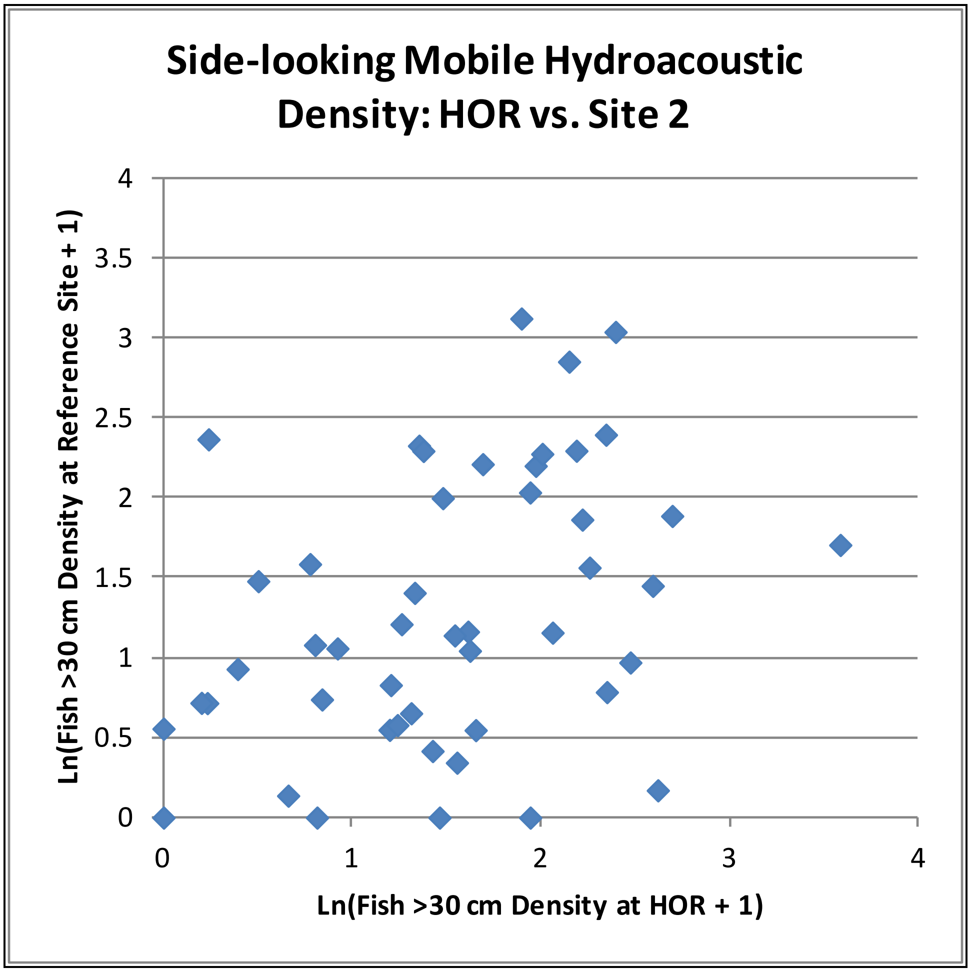
Figure 6-42 Estimated Density of Fish >30 Centimeters Total Length at the HOR Study Area in Relation to Density of Fish at Reference Site 4, 2011 and 2012 Down-Looking Mobile Hydroacoustic Surveys

As noted for down-looking density data, appreciable variability in large-fish density was estimated from side-looking mobile hydroacoustic surveys at the HOR study area and at the reference sites (Figures 6-43, 6-44, and 6-45). Statistically significant positive correlations existed between density at the HOR study area and density at Sites 2 and 4 ($P \leq 0.01$) (Table 6-77), so that $H15_0$ was rejected for these comparisons. There was no correlation between density at the HOR study area and density at Site 1 ($H15_0$ was accepted). Density of large fish from side-looking surveys at the HOR study area was significantly greater than at Sites 1 ($P = 0.01$) and 4 ($P < 0.001$), leading to rejection of hypothesis $H16_0$, and not significantly different from density at Site 2 (hypothesis $H16_0$ was accepted) (Table 6-77).



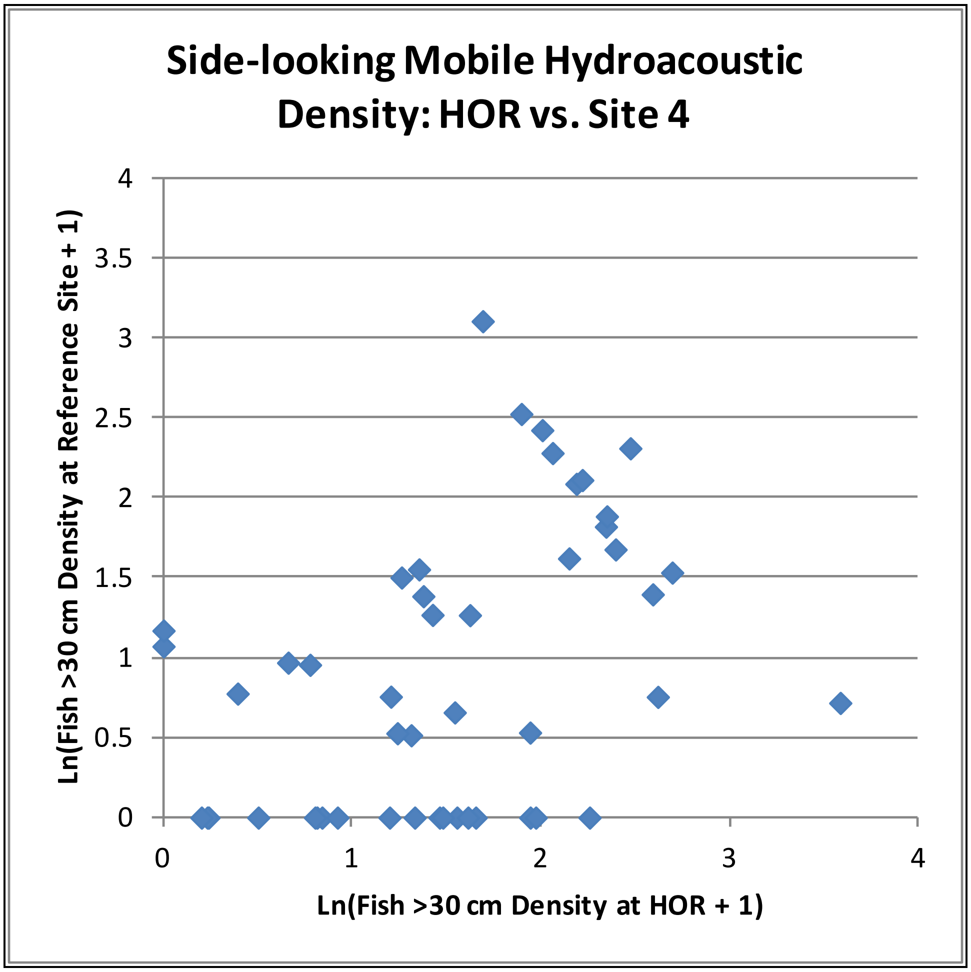
Source: Present study

Figure 6-43 **Estimated Density of Fish >30 Centimeters Total Length at the HOR Study Area in Relation to Density of Fish at Reference Site 1, 2011 and 2012 Side-Looking Mobile Hydroacoustic Surveys**



Source: Present study

Figure 6-44 **Estimated Density of Fish >30 Centimeters Total Length at the HOR Study Area in Relation to Density of Fish at Reference Site 2, 2011 and 2012 Side-Looking Mobile Hydroacoustic Surveys**



Source: Present study

Figure 6-45 **Estimated Density of Fish >30 Centimeters Total Length at the HOR Study Area in Relation to Density of Fish at Reference Site 4, 2011 and 2012 Side-Looking Mobile Hydroacoustic Surveys**

Table 6-77
Summary of Statistical Tests Comparing Density of Large Fish (>30 Centimeters Total Length) at the Head of Old River Study Area to Reference Sites in the San Joaquin River from Side-Looking Mobile Hydroacoustic Surveys in 2011 and 2012

Comparisons	Correlations		Paired Differences		
	Pearson R	*P* (no. of observations)	Mean difference (HOR—Reference Site)	Paired T-test t (degrees of freedom)	*P*
HOR vs. Site 1	0.01	0.92 (n = 45)	**0.49**	**2.78 (44 d.f.)**	**0.01**
HOR vs. Site 2	**0.37**	**0.01 (n = 48)**	0.22	1.63 (47 d.f.)	0.11
HOR vs. Site 4	**0.41**	**<0.01 (n = 48)**	**0.61**	**4.61 (47 d.f.)**	**<0.0001**

Notes: HOR = Head of Old River study area; No. = number; n = number of observations; d.f. = degrees of freedom
Comparisons were based on natural-logarithm-transformed data.
Bold Indicates statistical significance at Bonferroni-adjusted *P* < 0.017.
Source: Present study

7 DISCUSSION

7.1 JUVENILE SALMONID ROUTING INCLUDING BARRIER EFFECTS

Considerable differences existed between barrier treatments for all dependent variables measured: barrier efficiency, predation rates measured as proportion eaten, and transit speed. In this chapter, the differences between barrier treatments and years are described and compared in tandem, because the associations between barrier treatment and year cannot be separated due to study design. The results of the univariate analyses and proportion eaten are discussed in this chapter because they are closely related. Section 7.2, "Predation on Juvenile Salmonids Including Barrier Effects," focuses on explaining the results from the probability of predation as investigated with generalized linear modeling (GLM). Results related to transit speed are addressed in Appendix D, "Transit Speed Analyses."

7.1.1 2009 BAFF

In 2009, with the BAFF on, overall efficiency ($O_{E)}$ for tagged juvenile Chinook salmon was 20.9% and protection efficiency (P_E) was 33.8% (Tables 6-1 and 6-4). These results were difficult to reconcile with the observed BAFF deterrence efficiency (D_E) of 73.2% (Table 6-7). Two explanations were explored: predation and other factors.

The first explanation for the large gap between O_E and P_E was that a large proportion of the deterred tagged juvenile Chinook salmon subsequently were eaten which decreased O_E. When proportion eaten and the 2D tracks were evaluated for the 2009 data, many tagged juvenile Chinook salmon were determined to have been deterred and then eaten. Therefore, it seems that some of the benefit obtained by the BAFF's deterrence of tagged juvenile Chinook salmon could have been nullified by predation before they successfully migrated past the San Joaquin River finish line.

The difference between D_E and P_E for tagged juvenile Chinook salmon in 2009 was consistent with the striped bass tracking performed in 2011 and 2012. The tracking showed that the scour hole, the San Joaquin River's downstream and upstream offshore areas, and the HOR's upstream offshore areas were the most commonly used places at the HOR study area (Figures 6-19 and 6-21). The data from the mobile hydroacoustic survey also suggested that, in 2011 and 2012, the distribution of the majority of fish greater than 30 cm TL were downstream of the BAFF area (Figures 6-31 and 6-32). Although these data were collected in 2011 and 2012, they support the conclusion that the predator/prey encounter rates may be highest downstream of the 2009 BAFF line. Thus, the 2011 and 2012 data on predators support the conclusion that the difference in D_E and P_E in 2009 may have been caused by predation. Further discussion of areas occupied by predatory fish is provided in Section 7.3.2, "Areas Occupied by Predatory Fishes."

The predation explanation for the 2009 difference between D_E and P_E was consistent with other data collected from 2009 to 2012. Eighty-three percent of stationary/defecated tags were detected in the San Joaquin River downstream of the divergence and of these, 60% were found in the scour hole and 40% were found in the downstream San Joaquin River offshore areas (Figure 6-30). Although the number of stationary tags was small in 2009 and 2010, the pattern was similar through all years studied.

The ability to determine which tags were eaten was imperfect. In 2009, 532 tagged juvenile Chinook salmon released at Durham Ferry passed the San Joaquin River start line (Table 6-57). The total number of tags that passed the finish lines (San Joaquin River and Old River combined) was 410. Therefore, at least 122 perished at the HOR study area. In addition, the proportion of those that were eaten was not definitively determined. It was possible only to estimate the proportion eaten with the data that existed: the 2D tracks. The process by which this was done for tagged juvenile Chinook salmon was expert assessment without validation. No validation was possible because no tagged juvenile Chinook salmon were recaptured to determine the rate of incorrect "eaten" determinations. This error rate for tagged juvenile Chinook salmon therefore, must be estimated. If that error rate is high, many incorrect determinations were made, and the explanation for the discrepancy between 2009 O_E and D_E may not be acceptable. If it is accepted that the error rate is intermediate or small, then it may be concluded that the predation of tagged juvenile Chinook salmon explains some proportion of the difference between O_E and D_E.

The proportion of the difference between O_E and D_E that may be explained by predation was calculated. In 2009, the number of deterred tagged juvenile Chinook salmon was 103 and the number subsequently eaten, after they were deterred, was 36. If those 36 are added in, then the O_E in 2009 under "BAFF On" conditions increases to 36.5%, recall D_E was 73.2%. Thus, predation alone, even if it is accepted that the eaten determination error rate is not high, cannot explain the difference in O_E and D_E.

The second explanation for the large difference between O_E and D_E was the discharge regime in 2009 (Figure 3-2). Many tagged juvenile Chinook salmon were deterred by the BAFF, but may have ultimately exited the HOR study area via Old River because they were transported back on reverse flows. These fish passed between the BAFF and the north shore on reverse flows or passed through the BAFF.

Therefore, predation may account for some of the difference between BAFF deterrence and O_E in 2009. The calculations presented suggest that reverse flows may also have been responsible for some of this difference. Thus, it is concluded that predation on tagged juvenile Chinook salmon that were deterred but exited via Old River, contributed to the difference.

Other researchers working in the south Delta in 2009, including at the HOR study area, found a P_E of 47.4% (SJRGA 2013:155; reproduced in Appendix I, "Route Entrainment Analysis at Head of Old River, 2009 and 2010"). A total of 173 tagged juvenile salmonids passed the San Joaquin River finish line, compared to a total of 365 that passed the Old River or San Joaquin River finish line. This was much higher than the combined (BAFF on and off) P_E of 27.7% reported in this study. At least three reasons explain this difference: (1) the way in which predation was assigned by the two groups; (2) the distance between the San Joaquin River start and finish lines for the two studies; and (3) the fact that in 2009, the San Joaquin River Group Authority (SJRGA) (2013) used one-dimensional detection data (i.e., used one hydrophone's detections at a time), while 2D positions with track visualization were used for this study.

In 2009, the predator classification was based on the acoustic signal pattern through time within the detection of the tag at each individual hydrophone, using the method of Vogel (2010). This method used limited comparison to detections on other Vernalis Adaptive Management Program (VAMP) hydrophones. In this study, predation was assigned using behavior patterns that could be observed with the 2D track visualizations (see Appendix E, "Fish Fate Determination Guidelines"). The method used in the SJRGA (2010) study apparently was less likely to determine that a tag from a salmonid juvenile had been consumed by a predator compared to the method used in the present study.

The finish line used in this study (Figure 5-13) was approximately 303 m upstream of the finish line used by SJRGA (2010). Within this distance, an unknown amount of predation took place. Those salmonids eaten between the two finish lines would count as protected in this study, and SJRGA (2013) would have determined that those juveniles never arrived at the finish line.

The third difference between these two methodologies was that SJRGA (2013) used one-dimensional detection data. By contrast, in this study, 2D positions with track visualization were used for predation determinations. Which of these techniques is more conservative for predation determinations is unknown. Compared to this study, SJRGA (2013) apparently assigned fewer tags a fate of predation.

The effect of light level was evaluated relative to all three measures of barrier efficiency. The only measure that showed a significant influence from light level was D_E; when compared to the BAFF off, D_E was significantly higher when the BAFF was on (Table 6-9). D_E with the BAFF on during high light conditions was 89.7%. This may reflect a greater ability of tagged juvenile Chinook salmon to orient away from the BAFF's main noxious stimulus (the acoustic deterrent) in high light because of the increased visibility of the BAFF. An analogous situation occurs when fish are able to better avoid water intakes by day than by night in low-turbidity water (Helvey and Dorn 1981). However, a previous BAFF trial in England found greater efficiency by night than by day because the increased daytime visibility possibly allowed Atlantic salmon smolts to pass through gaps in the bubble curtain (Welton et al. 2002). However, in this study, the visual predators at the HOR study area were more likely to prey on juvenile Chinook salmon under daylight conditions. Thus, this exceptionally high deterrence delivered with the BAFF only provided a P_E of 48.4%. The benefit gained by BAFF deterrence appears reduced by predation.

No high-velocity samples were acquired in 2009 because of the low magnitude and negative discharges in the San Joaquin River (Figure 3-2). Thus, evaluating the effect of velocity on BAFF efficiency was not possible.

7.1.2 2010 BAFF

In 2010, "BAFF on" O_E was 35.5% (i.e., including tags preyed on at the HOR study area). When the tags that were determined to have been eaten were removed, the P_E improved substantially by operation of the BAFF (44.1%) (Table 6-15). The combined (BAFF on and BAFF off) P_E for 2010 was 36.1%. In 2010, SJRGA (2011) found that the P_E for "tags-in-juveniles" was 47.0%. As with 2009, the value reported in this study was lower than that of SJRGA (2013).

In Section 7.1.1 three reasons were given to explain this difference: (1) the way in which predation was assigned; (2) the distance between the San Joaquin River start and finish lines for the two studies; and (3) the fact that SJRGA (2011) used one-dimensional detection data, while 2D positions with track visualization were used in this study. The one major difference in methodology between 2009 and 2010 was that SJRGA (2011) used a different method for determining predation. In 2010, predation was assigned by SJRGA (2013:Table 5-8) to tag detections using residence time, migration rate, number of return visits to a hydrophone, discharge, and water velocity. In addition, some special conditions were applied to tag detection patterns regarding tide and pumping by the CVP or SWP. Also, the spatial/temporal pattern of detections throughout the VAMP hydrophone array was considered as a whole to determine predation, rather than limiting analysis to a single spatial area. Still, the result was the same: SJRGA (2011, 2013) was less likely to assign a fate of predation in 2010 than this study. These factors probably played a role in the difference between the estimate reported in this study and the SJRGA estimate; the relative importance of each factor is unknown.

The difference in D_E with the BAFF on compared to the BAFF off was 13.8%. This was very similar in magnitude to the difference between P_E with the BAFF on and off (15.5%). These results suggest that the BAFF operation was deterring about 14% of the tagged juvenile Chinook salmon that approached the BAFF, and that translated to a similar improvement in P_E. In addition, in 2010, a very low percentage of tagged juvenile Chinook salmon exhibited deterrence with the BAFF off (1.2%).

No difference existed in sample proportion eaten between the BAFF on and off, suggesting that, in 2010, BAFF operation did not increase predation rate over the BAFF infrastructure's effect (Table 6-50). This was in contrast to 2009, when the BAFF on proportion eaten was significantly higher than the BAFF off proportion eaten (Table 6-49).

In 2010, light level was not shown to have a substantial effect on O_E (Table 6-12). As in 2009, it was possible that this lack of significance occurred because of small sample sizes and low statistical power. At high light levels, P_E with the BAFF on was higher than with the BAFF off (P-value = 0.0812; Table 6-17); however, the statistical power of this test was only 0.417. The lack of significance (using a critical α of 0.05) could have been a function of low power; thus, it appeared that at high light levels, there could have been significantly higher P_E with the BAFF on than off. This could have been driven by substantial improvement in D_E at high light levels with the BAFF on relative to off conditions (Table 6-22). These results were similar to those of Bowen et al. (2010), at low turbidities (10 NTU), the highest deterrence was observed at high light levels. These results suggest that for the 2010 juvenile Chinook salmon at the HOR study area, additional visual cues to avoid the BAFF were available to the tagged juvenile Chinook salmon during high light, as noted previously for 2009 data.

Velocity did not affect O_E. However, at low velocity, P_E was 16.9 percentage points higher with the BAFF on than off (Kruskal-Wallis $X^2 = 3.699$; P-value = 0.0544) (Table 6-19). This result may have been a consequence of the tagged juvenile Chinook salmon having had more time to evaluate the BAFF and move away before being swept through. The average channel velocity (ACV) did not affect deterrence; deterrence with the BAFF on was significantly better than BAFF off at both velocity levels evaluated (Table 6-24).

For 2010, D_E was significantly improved with the BAFF on, by about 14 percentage points (Table 6-20). This was reflected in an improvement in P_E with the BAFF on by approximately this same amount. These improvements in D_E and P_E were the largest during high-light conditions. Thus, the BAFF's operation did significantly improve the tagged juvenile Chinook salmon proportion selecting the San Joaquin River route (Table 6-15) (Table I-3 in Appendix I), but BAFF-on conditions also exhibited a population proportion eaten of 31.0% (Table 6-50).

7.1.3 BAFF Operations: 2009 vs. 2010

No significant difference in O_E occurred with the BAFF on in 2009 versus in 2010; however, the P-value (0.0563) (Table 6-26) and the low statistical power observed for the test, 0.489, suggest that a difference could exist between these years with different BAFF alignments. It was concluded that the low statistical power made it impossible to determine if O_E was higher in 2010 than in 2009.

The difference in O_E and P_E between BAFF on and off status was greater in 2010 than in 2009. At least three phenomena contributed to explaining these differences: (1) the discharge regimes differed; (2) tagged juvenile Chinook salmon differed between the two years; and (3) in 2010, the BAFF alignment was longer and curved more than in 2009 (Figure 4-3).

First, in 2009, BAFF efficiencies (Tables 6-1 and 6-4) and the discharge magnitudes (Figure 3-2; see also Appendix D, "Transit Speed Analyses") were the lowest, and the percentage of flow into the San Joaquin River during the study period was the lowest observed across all years (35%). In 2010, BAFF efficiencies were higher (Tables 6-10 and 6-15), discharge magnitude was intermediate (Figure 3-4), and the percentage of flow into the San Joaquin River was 56% (Table 3-1).

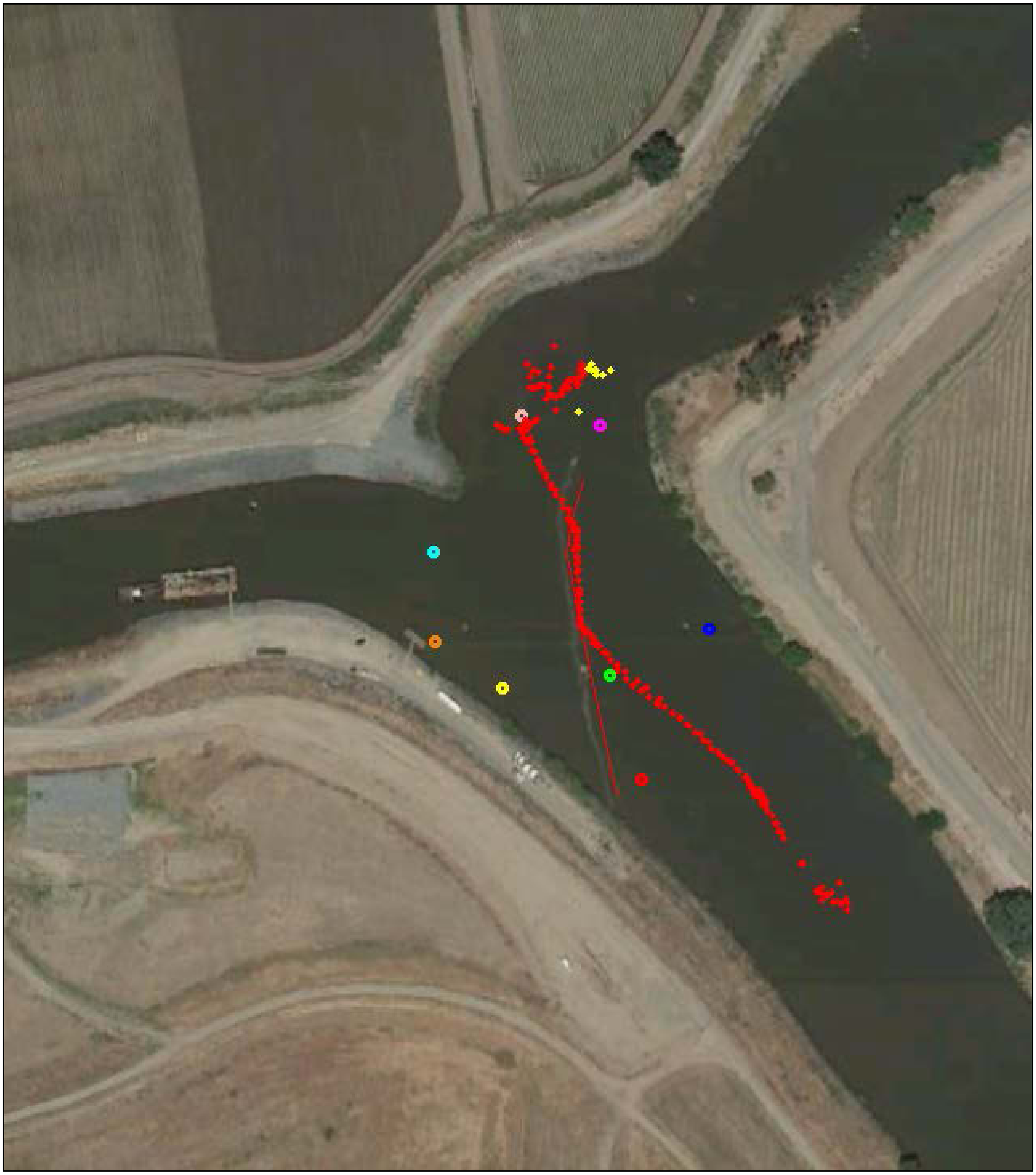
Second, the tagged juvenile Chinook salmon were smaller in 2009, and the tag burden was higher in 2009 than in 2010 (described in Tables 5-1 and 5-3 in Chapter 5, "Methods," and in Section 6.3 in Chapter 6, "Results").

Third, the longer-curved 2010 BAFF alignment could have improved O_E and P_E relative to the 2009 alignment without improving D_E. A number of tagged fish in 2010 were not deterred (by the strict definition of deterrence used in the study), but their route was changed from the Old River to the San Joaquin River (Figure 7-1). This would add to the O_E and P_E values, but not to the D_E value (see discussion by Bowen and Bark [2012]).

Like O_E, P_E was 10.4 percentage points higher in 2010 than 2009, but this difference was not significant. In addition, D_E was significantly higher with the BAFF on than off in both years. This study concluded that a statistically significant but small increase in D_E always occurred during BAFF operation (13.8% to 42.1%), and this deterrence increased P_E in both years. However, the increases in P_E were not significant.

A significantly higher proportion of tagged juvenile Chinook salmon were deterred when the BAFF was off in 2009 than in 2010 (Table 6-30). One possible explanation for this was the difference in discharge patterns between the two years, with negative discharges common in 2009 (Figure 3-2) and no negative discharges during the experimental fish releases occurring in 2010, only positive discharges (see Figure 3-4). A second possible explanation was that higher discharges and concomitant higher stage heights in 2010 meant that the BAFF infrastructure took up a smaller proportion of the water column than in 2009; perhaps a smaller proportion of the fish could sense the turbulence created by the BAFF infrastructure or its visual presence, and they did not move away from it or did not follow the alignment in as great a proportion. Alternatively, the higher deterrence rate with the BAFF off in 2009 compared to 2010 could have been due to the different BAFF alignments in the two years. In 2009, the BAFF alignment was straight, and in 2010 the alignment was curved at the end like a hockey stick (Figure 4-3). Thus, a tagged juvenile Chinook salmon turning once guiding along the BAFF would appear to be deterred in 2009. However, the same path in 2010 might cross the BAFF line, and it would be determined to have been undeterred.

In 2010, no substantial difference occurred between the proportions eaten with the BAFF on and off (Table 6-50). However, in 2009, the proportion eaten was significantly higher with the BAFF on than off (Table 6-49). There were no differences in the proportions eaten between 2009 and 2010 for both the BAFF on and off (Table 6-52), suggesting somewhat similar levels of predation in both years.



Note: This tagged juvenile Chinook salmon was determined to have been “not deterred,” was guided along the BAFF, passed into the San Joaquin River where it was determined to have not been eaten, and successfully passed the San Joaquin River finish line.

Source: Data compiled by Hydroacoustic Technology Inc. this study

Figure 7-1 **Tagged Juvenile Chinook Salmon Number 5353.14 2D Track through the Head of Old River Study Area in 2010**

The 2011 and 2012 GLM modeling of changes in predator density from downward- and sideward-looking hydroacoustics suggests another possible mechanism besides tag burden and turbidity. The GLM modeling showed a negative relationship between same-day discharge and the density of large fish greater than 30 cm TL (Section 6.3.2, "Hydroacoustic Data"). The same-day discharges in 2009 (Figure 3-2) were smaller than those in 2010 (Figure 3-4).

The GLM modeling also found a positive relationship between large-fish density and water temperature. The temperature averaged 2°C warmer in 2009 than in 2010 (Table 3-3). Thus, it was hypothesized that 2009 also supported a greater predator density than 2010. In theory, when the BAFF was turned on in 2009, more predators were at the HOR study area to use the BAFF to improve prey encounter rate or capture probability. Furthermore, because it was, on average, 2°C warmer in 2009, there would have been increased energetic demand per predator and greater total energetic demand (see also Appendix H, "Illustrative Example of Striped Bass Predation Using Bioenergetics Modeling"). These results suggest an area of interesting future inquiry. In addition, tagged juvenile Chinook salmon were smaller in 2009 (Table 5-1); thus, the gape size of a predator needed to eat these fish would be smaller. This would tend to increase the size of the effective predator pool.

For both 2009 and 2010, a portion of the benefit from deterrence was removed by predation. With the BAFF on a range of 30.9 to 31.0% of the tagged juvenile Chinook salmon passing through the HOR study area was eaten. Most of this predation may have taken place after the fish had passed the BAFF in the scour hole and the San Joaquin River downstream offshore areas. However, in 2009, some of this predation could have been caused by BAFF operation itself; the proportion eaten was significantly greater with the BAFF on (0.290) than off (0.138).

7.1.4 2011 No Barrier

In 2011, the discharge magnitudes ranged from 5,000 to 7,500 cfs, far greater than in 2009 or 2010. The 2011 results were also very different, with a mean O_E for tagged juvenile Chinook salmon (0.519) that was similar to the proportion of flow remaining in the San Joaquin River (0.48: Table 3-1). It was concluded that, in a high-discharge year with no barrier, tagged juvenile Chinook salmon entered the San Joaquin River in approximately the same proportion as the fraction of flow.

2009 BAFF Off Compared To 2010 BAFF Off Compared To 2011 No Barrier

In 2009 with the BAFF off, many flow reversals in the San Joaquin River (Figure 3-2) led to flow lines routinely moving toward Old River (Figure 3-9), and the population proportion eaten at the HOR study area with the BAFF off was estimated to be 16.4% that year (Table 6-49). In 2010 with the BAFF off, positive discharges always occurred, but the ACVs were intermediate compared to 2011 ACVs, and the population proportion eaten was estimated to be 20.5% (Table 6-50). In contrast, in 2011, high discharges led to the highest ACVs measured during the entire study, with flow lines more toward the San Joaquin River (Figure 3-11); the measured population proportion eaten was 10.1% (Table 6-53).

These discharge and predation patterns resulted in the pattern of O_E (Table 6-32). It was concluded that the effect of the BAFF infrastructure during BAFF off conditions could not be discerned from these data because of the confounding effects of differing environmental conditions, principally discharge, between years.

CHINOOK SALMON COMPARED TO STEELHEAD

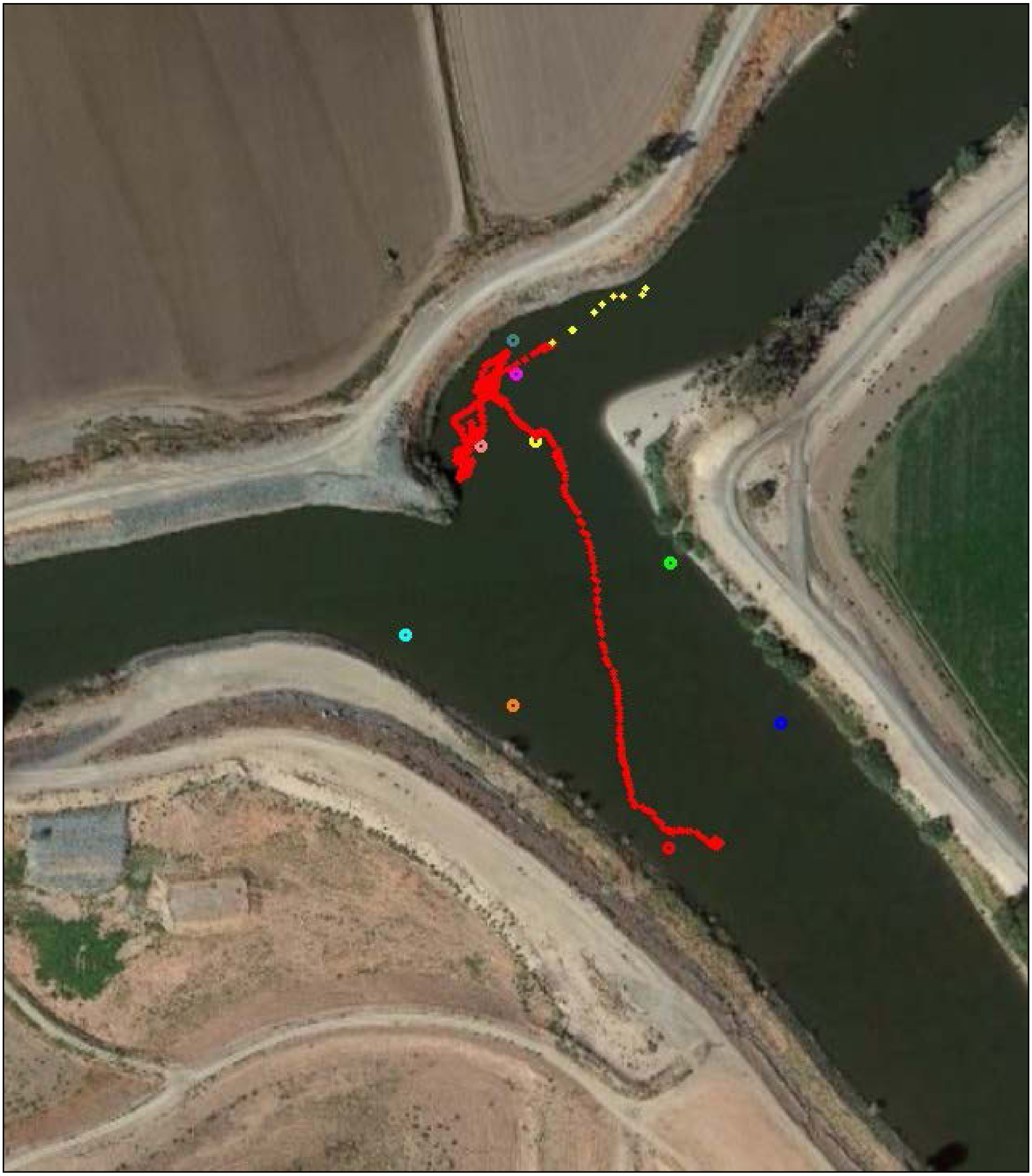
In 2011, tagged juvenile Chinook salmon seemed to enter the San Joaquin River in approximately the same proportion as the fraction of flow. By contrast, steelhead appeared to be less likely than juvenile Chinook salmon to enter the San Joaquin River. However, when tags that were determined to have been eaten were removed, the P_E was not different between tagged juvenile Chinook salmon and steelhead. This suggests that steelhead, like tagged juvenile Chinook salmon, remained in the San Joaquin River in a proportion that was approximately the same as the fraction of the flow.

In 2011, tagged juvenile steelhead appeared to be subject to predation at a higher rate than tagged juvenile Chinook salmon (Table 6-54). However, some of the tags originally inserted into steelhead that were deemed eaten possibly were not eaten. The possibility that steelhead were more likely to receive an incorrect eaten determination than were tagged juvenile Chinook salmon evolved from the steelhead released at Durham Ferry by the Six-Year Steelhead Study/VAMP team and detected at the CVP and SWP holding tanks (see Appendix E, "Fish Fate Determination Guidelines," for discussion). From these steelhead juveniles it was learned that steelhead at the HOR study area sometimes exhibited looping behavior or swam against the flow (Figure 7-2), behavior that also was used as a criterion for determining predation on tagged juvenile Chinook salmon.

For a more accurate understanding of the effects of predation on outmigrating juvenile steelhead in the HOR study area, further research may be required, and alternative methods may need to be developed to distinguish eaten tags. The issue of determining whether a juvenile salmonid has been eaten, for both tagged juvenile Chinook salmon and steelhead, is of prime importance, and is discussed further in Section 8.2.1, "Further Examine Predation Classification."

There did not appear to be any effect on tagged juvenile Chinook salmon or steelhead O_E at different light or velocity levels. However, small sample sizes and low statistical power could have caused an inability to detect any influence. O_E was always higher for tagged juvenile Chinook salmon (13.3 to 17.3 percentage points) than for steelhead, and it was hypothesized in Section 6.1.6, "2011 Chinook Salmon Compared to Steelhead," that steelhead might prefer the Old River route compared to tagged juvenile Chinook salmon.

When tags that had been eaten were removed, no statistical difference was shown between P_E for tagged juvenile Chinook salmon and for steelhead at any light or velocity levels. Thus, the pattern seen in P_E was consistent across all examined light and velocity conditions. However, small sample sizes and low statistical power could have made it impossible to resolve a true difference caused by light or velocity.



Note: Steelhead 5171.04 entered the HOR study area on June 1, 2011, at 11:17 a.m., departed the same day at 11:43 a.m., and was determined to have not been eaten; this determination was confirmed because 5171.04 was later detected at an export facility's holding tank.

Source: Data compiled by Hydroacoustic Technology Inc. this study.

Figure 7-2 Tagged Juvenile Steelhead Number 5171.04 2D Track in the Vicinity of the Head of Old River Study Area

7.1.5 2012 PHYSICAL ROCK BARRIER

For tagged juvenile Chinook salmon, the physical rock barrier's O_E was 61.8%. When tags eaten were removed, the rock barrier's P_E was 100%.

The proportion of flow that went down the San Joaquin River in 2012 was 0.82. Eight culverts were installed for the first time in a rock barrier at the HOR study area. Even with eight culverts, however, the proportion of flow entering Old River was relatively low because the rock barrier physically blocked much of the flow.

Of the tagged juvenile Chinook salmon in 2012, a mean of 38.2% were classified as having been eaten in the sample proportion eaten determination (Table 6-55). This was the highest proportion eaten in all four years of study, although no statistically significant difference existed between 2012 and 2009 and 2010 with the BAFF on (2009: 29.0%; 2010: 21.7%), whereas the 2012 proportion eaten was significantly higher than the 2011 proportion eaten (8.7%).

Tagged juvenile Chinook salmon may have been more vulnerable to predation in 2012 than in other years because of eddies that formed near the rock barrier (Figure 3-18). Additionally, a higher density of large fish (greater than 30 cm TL) occurred in 2012 than in 2011. Large-fish density in 2012 increased after the physical rock barrier was installed, during higher water temperatures (see Appendix G, "Plots of Environmental Variables and Large-Fish Density from Mobile Hydroacoustic Surveys," Figure G-6). Thus, the high density of large fish in 2012 may have been caused, in part, by the rock barrier's role in creating more favorable habitat for predation, coupled with more predatory fish moving into the area as water temperatures increased. Additional discussion is provided in Section 7.2, "Predation on Juvenile Salmonids Including Barrier Effects."

7.2 PREDATION ON JUVENILE SALMONIDS INCLUDING BARRIER EFFECTS

This section focuses on the results of the probability of predation analyses as investigated using GLM. The results of the univariate analyses related to proportion eaten are discussed in Section 7.1, "Juvenile Salmonid Routing Including Barrier Effects," because they are closely related to calculations and analysis of O_E and P_E.

Based on the GLM, the present study found the best support for light level, barrier status, and turbidity as predictors of predation probability on tagged juvenile Chinook salmon in the HOR study area. Light level was important in the GLM for 2009/2010/2012 and 2011/2012; because light level was positively related to predation probability, this supported the hypothesis that visual-feeding predators (such as striped bass and largemouth bass) would have lower predation rates in darkness. Examination of the raw data shows that the proportion of tagged juvenile Chinook salmon entering the HOR study area that were preyed upon by day was two to four times greater than the proportion preyed upon at night (Tables 6-58 and 7-1).

The negative relationship between turbidity and predation probability for the 2011/2012 GLM also agrees with greater predation rate with better visibility, as hypothesized based on observed relationships in the Delta (Ferrari et al. 2013). Turbidity is not as highly correlated with discharge (e.g., to the extent that velocity is). Nevertheless, turbidity is higher with greater discharge, and thus, it reflects to some degree the importance of discharge as a master variable that may influence predation.

Table 7-1
Number and Population Proportion Eaten of Tagged Juvenile Chinook Salmon Preyed Upon at the HOR Study Area, 2009–2012

	Number of Juveniles		Predation	
Year/Barrier/Light	Total	Predation	Proportion	Standard Error
2009	525	120	0.229	0.018
a. NPB Off	292	48	0.164	0.022
i. dark	59	3	0.051	0.029
ii. light	233	45	0.193	0.026
b. NPB On	233	72	0.309	0.030
i. dark	45	6	0.133	0.051
ii. light	188	66	0.351	0.035
2010	451	117	0.259	0.021
a. NPB Off	219	45	0.205	0.027
i. dark	77	11	0.143	0.040
ii. light	142	34	0.239	0.036
b. NPB On	232	72	0.310	0.030
i. dark	60	4	0.067	0.032
ii. light	172	68	0.395	0.037
No Barrier (2011)	1,075	109	0.101	0.009
a. dark	306	9	0.029	0.010
b. light	769	100	0.130	0.012
Rock Barrier (2012)	193	76	0.394	0.035
a. dark	38	6	0.158	0.059
b. light	155	70	0.452	0.040
Total	**2,244**	**422**	**0.188**	**0.008**

Notes: NPB = non-physical barrier (bio-acoustic fish fence); Dark <5.4 lux, light ≥5.4 lux
Source: Present study

Turbidity was not found to be a well-supported predictor of predation probability for the 2009/2010/2012 data, which was in agreement with the absence of a statistically important univariate relationship between proportion eaten and turbidity when using groups of juveniles combined across all years (See "Temperature and Turbidity Effects on Proportion Eaten" in Section 6.2.1, "Proportion Eaten [Univariate Analyses].") The years 2011 and 2012 may have offered sufficient contrast in turbidity to detect the relationship of this variable to predation, and this may have been masked when including the other years.

Discharge alone was not supported as an important predictor of predation probability at the HOR study area. This finding is consistent with a recent study that related discharge to the survival of tagged juvenile Chinook salmon in the Delta (Zeug and Cavallo 2013), but not consistent with the results of other studies (Newman 2010; Perry 2010). To some extent, this may reflect difficulties in assigning a particular discharge to each juvenile for the GLM analysis; the present study used the nearest 15-minute discharge reading from the San Joaquin River at

Lathrop (SJL) gauge at the time when the juvenile track was nearest the 2009 or 2010 BAFF alignments. For variables such as discharge, which may change more rapidly in tidal situations, this means of assigning a discharge value to each juvenile's fate may cause the conditions relevant to predation to differ from those included in the analysis.

Other predictors that change less rapidly (e.g., light level, turbidity) may be more reflective of the conditions experienced by juveniles at the time of predation. However, although water temperature changes would be less rapid, this predictor was not found to be an important predictor of predation probability. The univariate analysis using data from all years did give a statistically significant positive correlation between water temperature and proportion of juveniles eaten. (See "Temperature and Turbidity Effects on Proportion Eaten" in Section 6.2.1, "Proportion Eaten [Univariate Analyses].") This could be explained by the increased bioenergetics requirements of predators and possibly the greater ability of predatory fish to swim faster in warmer waters compared to tagged juvenile Chinook salmon.

At the broader, annual scale, the predation rate of tagged juvenile Chinook salmon at the HOR study area was appreciably less in 2011 (0.10) than in the other years (0.23 to 0.39). To some degree, this finding likely was related to discharge and its effect on other abiotic and biotic factors (e.g., density of predatory fishes). (See Section 7.3.3, "Changes in Density of Predatory Fishes." Also see the comments in "Comparison of 2009 BAFF Off, 2010 BAFF Off, and 2011 Conditions" in Section 6.2.1, "Proportion Eaten [Univariate Analyses]," about potential mechanisms for differences between years in the proportion of juveniles eaten.) However, despite considerably higher discharge in 2011 than 2010, the overall through-Delta survival of tagged juvenile Chinook salmon released in the San Joaquin River in 2011 (0.02, i.e., 2%) (SJRGA 2013) was not greater than survival in 2010 (0.05, i.e., 5%) (SJRGA 2011). This latter finding could suggest that in 2011, the relatively intense rates of predation observed in 2010 occurred in areas farther downstream where tidal influence was greater (Cavallo et al. 2013). This topic is revisited in Section 8.2.4, "Study Effects of Physical Barriers on Location of Predation Hotspots", in Section 8, "Recommendations."

Barrier status was found to be a well-supported predictor of predation probability for tagged juvenile Chinook salmon in the analysis comparing the non-physical BAFF on/off from 2009/2010 and the physical rock barrier in 2012. Predation probability was appreciably higher with the non-physical barrier turned on or with the rock barrier than with the non-physical barrier off. The analysis did not aim to differentiate between the 2009 and 2010 barrier configurations; still, a reexamination of the basic proportional predation data subdivided by year gives confidence to the conclusion that the results were reasonably consistent for both years of the BAFF deployment (Table 7-1).

In both 2009 and 2010, approximately 0.31 (i.e., 31%) of tagged juvenile Chinook salmon were preyed on with the non-physical BAFF barrier on, compared to 0.16 (2009) and 0.21 (2010) off. Pairwise, statistical comparisons of the proportion eaten using groups of juvenile Chinook salmon found differences between BAFF on and off conditions in 2009, but not in 2010; no substantial difference existed between years in the proportion eaten when the BAFF was on or off. (See "2009 Results," "2010 Results," and "2009 Compared to 2010" in Section 6.2.1, "Proportion Eaten [Univariate Analyses].")

The higher proportion of predation in light conditions than in the dark also was consistent between years (Table 7-1). Operation of the BAFF has been shown to have some efficacy in deterring juveniles from entering Old River (see "Deterrence Efficiency" in Section 6.1.1, "2009 Results," and Section 6.1.2, "2010 Results"). The results of the present study suggest, however, that a tagged juvenile Chinook salmon has as high a probability of being preyed upon when the BAFF is operational compared to when the physical rock barrier is installed. This may be the case because juveniles have longer travel distances through the HOR study area as they avoid the noxious stimuli of the BAFF and may be disoriented by the stimuli, or because they are entrained into the eddies that are created by the rock barrier (Johnston, pers. comm., 2013) (see Section 3.2, "Velocity Field"). The transit speed of tagged juvenile Chinook salmon through the HOR study area was greater with the BAFF on than off in 2009 (but not in 2010; see Appendix D, "Transit Speed Analyses," Tables D-4 and D-6). This finding would support the hypothesis that longer travel distance and speed influence predation rate. Anderson et al. (2005) concluded that survival of juvenile salmon in the Snake River depends more on travel distance than travel time or migration velocity. Deterrence away from Old River to the scour hole also may increase predation probability at the HOR study area with the BAFF turned on or with the physical rock barrier installed. The scour hole was one area where the density and occurrence of predatory fish were relatively high, based on the 2011/2012 mobile hydroacoustic surveys and the occurrence of tagged predatory fish (see discussion in Section 7.3.2, "Areas Occupied by Predatory Fishes").

The fit of the binomial GLMs of predation probability (area under receiver operating characteristic [ROC] = 0.70, 0.73) in the present study was within the range of acceptability based on the criteria of Hosmer and Lemeshow (2000). The fit was somewhat better than the fit from a study predicting the presence of Chinook salmon fry in the American River as a function of velocity, depth, substrate, and cover (Beakes et al. 2012); those authors described their model fit (area under ROC = 0.65) as fair predictive ability. By contrast, the GLMs from the present study fit the data considerably less well than the GLMs used to predict the probability of tagged juvenile Chinook salmon entering Georgiana Slough from the Sacramento River, as a function of the operation of the BAFF and other factors (area under ROC = 0.93, "excellent ability to predict fates" [Perry et al. 2012]). The response data (predation) from the present study include some uncertainty because it is not known whether predation actually occurred. Classifying predation was challenging in 2012. Discharge conditions and the physical rock barrier produced juvenile movement patterns that were unlike those seen in previous years (Johnston, pers. comm., 2013).

As noted previously, some difficulty existed in temporally matching the most relevant periods for abiotic predictor variables to juveniles entering the HOR study area. The closest 15-minute readings were used in the present study. Longer averaging periods also would be possible, which may reduce variability (e.g., averages of readings 30 to 60 minutes before and after). The biotic predictor variables representing the potential abundance of predators and abundance of alternative prey—large-fish density from mobile hydroacoustics and small-fish density from Mossdale trawling, respectively—had longer averaging periods than would have been ideal to avoid reducing the sample size of juvenile-response data because of missing values. A better situation would have been to include data specific to the HOR study area that co-occurred more directly in time and space with each juvenile's arrival.

Despite these shortcomings, the statistical analyses of predation probability for tagged juvenile Chinook salmon provided some insights that supported the initial hypotheses. This was not the case for the tagged juvenile steelhead, for which model fits were poor and no better than intercept-only models. Assigning fates to juvenile steelhead was very difficult because their movement patterns were quite different from those of juvenile Chinook salmon (e.g., steelhead holding behavior and upstream movement was reminiscent of movements by tagged predatory fish [Johnston, pers. comm., 2013]). Further research into means of determining predation is warranted, and this topic is discussed further in Section 8.2.1, "Further Examine Predation Classification."

Bioenergetics modeling conducted as an ancillary part of this study illustrated the relative differences in prey-fish consumption rates between striped bass of different sizes at water temperatures observed at the HOR study area in 2011 and 2012 (Appendix H, "Illustrative Example of Striped Bass Predation Using Bioenergetics Modeling"). The illustrative example of potential consumption rate for prey fish entering the HOR study area produced estimates of predation that were of similar magnitude to the predation estimates for tagged juvenile Chinook salmon in 2012. However, the bioenergetics-derived estimates for 2011 were appreciably lower than the estimates for tagged fish. The relative difference between years (i.e., higher predation in 2012 than in 2011) from bioenergetics modeling was consistent with estimates from the studies of tagged juvenile salmonids, and reflected higher predator density, higher water temperature, and lower prey-fish biomass in 2012. Although illustrative and subject to appreciable uncertainty, the results of the bioenergetics modeling suggested that the rates of predation estimated at the HOR study area from the studies of juvenile salmonid survival may be plausible.

The findings of this study regarding barrier status and its association with predation have clear management implications, particularly when compared to recent studies of the relative survival of tagged juvenile Chinook salmon through the Old River and San Joaquin River routes (Buchanan et al. 2013). This topic is discussed further in Chapter 8, "Recommendations." (In particular, see Section 8.1.1, "Study the Cost-Benefit of Barriers in Relation to Alternative [Non-engineering] Management Strategies," and Section 8.1.3, "Investigate Physical Barrier Alternatives to the Rock Barrier and BAFF.")

7.3 BEHAVIOR AND DENSITY CHANGES IN PREDATORY FISHES

In the following discussion of the results of the evaluation of behavior and density changes in predatory fish at the HOR study area, the results from the study's main elements (tagged predators and mobile hydroacoustics) are considered together. This discussion emphasizes these elements' main findings with respect to several topics of management importance regarding predatory fish at the HOR study area: residence time, areas occupied, and changes in density.

7.3.1 RESIDENCE TIME OF PREDATORY FISHES

The time spent at the HOR study area by tagged predatory fish varied. Generally, however, channel catfish, white catfish, and largemouth bass spent appreciably longer amounts of time overall than striped bass. Variability existed both within and among species.

In other Delta studies, tagged white catfish mostly have been recaptured close to the original site of capture (Moyle 2002). Largemouth bass adults may remain or may wander more widely (Moyle 2002). Nearly all of the largemouth bass that left the HOR study area moved downstream. Studies of channel catfish in the lower Wisconsin River found that they occupied small home ranges in summer, migrated downstream in fall, and migrated upstream to spawn in spring (Pellett et al. 1998). Consistent with these studies, three of the four tagged channel catfish moving from the HOR study area moved upstream in the San Joaquin River.

The residence time of striped bass at discrete areas in the Delta has been the subject of several studies. One study for which the basic data can be summarized in a similar manner to the present study is the 2011 Georgiana Slough Non-physical Barrier Study (DWR 2012). In that study, which also included spotted bass and Sacramento pikeminnow (not discussed here), 35 acoustically tagged striped bass were detected by the acoustic array near the divergence of Georgiana Slough from the Sacramento River on one to five dates after tagging. The mean percentage of dates when the fish were detected between tagging and deactivation of the acoustic array was 8% (in a range of 2% to 27%), which is comparable to the rates observed in the present study. Miranda et al. (2010) described little fidelity of six tagged adult striped bass within the State Water Project's Horseshoe Bend fish-salvage release site, as fish were detected on one to three dates after tagging. Gingras and McGee (1997) found that the flux of striped bass into or out of Clifton Court Forebay was appreciable; 0 to 100% (mean 17%) of weekly fish movements at the forebay were through the radial gates, as opposed to other parts of the forebay.

The length of time that striped bass spent at the HOR study area before capture and tagging is unknown, although the two striped bass (tag codes 2024 and 2976) that were captured and tagged outside of the study area in 2010 spent short durations (0.5 to 0.6 hour) at the site. These short durations were similar for many of the fish captured and tagged at the HOR study area.

Most movement of striped bass out of the HOR study area (indicated by zone of last detection) was downstream in the San Joaquin or Old rivers. Vogel (2011) described the movements of 24 striped bass tagged and released at the Tracy Fish Facility in spring 2010 that were detected elsewhere in the Delta. Of these, 13 moved downstream to Chipps Island, four moved into various south Delta locations and were last detected in Clifton Court Forebay, four moved north in Old River, two moved upstream to Mossdale via the HOR study area, and one moved to the San Joaquin Deep Water Ship Channel via Old River. This is consistent with a predominantly downstream migration from the south Delta.

Tagged sub-adult striped bass (n = 99) studied by LeDoux-Bloom (2012) showed three main migratory strategies: (1) bay residency; (2) residency in the low-salinity zone; and (3) riverine residency. The riverine resident fish spent summer in the Sacramento and American rivers before migrating downstream to the south Delta (Clifton Court Forebay) in fall, then returned back upstream to the Sacramento and American rivers in the spring to again spend the summer before the fall downstream migration. Adult striped bass generally migrate upstream in spring to spawn, with optimum water temperatures being 15 to 20°C, with no spawning occurring outside the range of 14° to 21°C (Moyle 2002). In 2011, the optimum water temperature range occurred during most of April, May, and June based on water temperatures recorded at the SJL gauge. Most striped bass spawning in the San Joaquin River are found downstream of the HOR study area because of water quality issues (Moyle 2002), but the range extends farther upstream in wetter years, and some striped bass migrating downstream in 2011 possibly had spawned upstream of the HOR study area.

The present study's results indicate that the turnover of striped bass generally is appreciable, with most fish spending a limited amount of time within the HOR study area. Although the residence time of the other predatory fish species is longer, turnover is apparently considerable. Cavallo et al. (2013) conducted a predator removal effort on a 1.6-km reach of the North Fork Mokelumne River on May 19, 2010, and collected an estimated 91% (i.e., 144 of 158) of predatory fish that were vulnerable to electrofishing; 6 days later, a similar effort yielded 83% (i.e., 497 of 601) of predatory fish. The most abundant of these fish were redear sunfish (*Lepomis microlphus*), largemouth bass, bluegill, redeye bass (*Micropterus coosae*), and spotted bass (*Micropterus punctulatus*), with only 10 striped bass collected on both dates. This shows that turnover may be substantial in species other than striped bass. Cavallo et al. (2013) noted:

> While mechanisms are unclear, removal of a stable predator community accomplished in the first treatment was apparently undone within one week by an influx of new predators. If site-specific predator removals are to benefit juvenile salmon survival, sustained effort over time (with daily rather than weekly removals) may be necessary.

The issue of the intensity of predator relocation efforts is discussed further in Section 8.2.3, "Conduct a Pilot Predatory Fish Relocation Study," in Section 8, "Recommendations."

7.3.2 AREAS OCCUPIED BY PREDATORY FISHES

The present study confirms the importance of the scour hole at the HOR study area as an important area for occupancy by predatory fish, as previously suggested on a regional scale from many detections of stationary tags at that location (Vogel 2007, 2010; as cited by SJRGA 2011). One of the reference sites used for comparison to the fish-salvage release sites at Horseshoe Bend (Sacramento River) included a deep hole that harbored high densities of fish (Miranda et al. 2010), as observed in the present study at the HOR study area.

Tagged predatory fish often were found occupying portions of the HOR study area in the San Joaquin River downstream of the Old River divergence, both at the scour hole and in the immediately adjacent areas. To some extent, the areas occupied by tagged predatory fish during the present study reflect the location of release. In this regard, the three white catfish that spent almost all of their time at the scour hole in 2011 were captured, tagged, and released at the scour hole. They remained very close to where they were released, which is not uncommon for the species (see previous comments; Moyle 2002). Capture and tagging crews often found the scour hole to be a profitable place for fishing, although standardized fishing was not undertaken to compare capture rates at the scour hole with other areas. Standardized hook-and-line fishing was conducted at the HOR study area in spring 2013 (Kennedy, pers. comm., 2013). The results, currently being evaluated, will provide data to compare capture rates of predatory fish at the scour hole and vicinity.

Some differences existed in the areas occupied by the different species of tagged predatory fish. For example, striped bass generally were found more often in areas away from shore, although they also occurred nearshore; by contrast, largemouth bass tended to occur more in the nearshore zones. (The index of zone use relative to zone size emphasized the relatively frequent use of nearshore zones.) Such findings reflect differences in the biology of the species, with largemouth bass tending to be more structure-oriented inhabitants of lower-velocity areas (Stuber et al. 1982), and striped bass being pelagic (Moyle 2002). Channel catfish were found more in offshore areas, which may indicate their movement into somewhat faster water to feed, although areas with cover also were important (Moyle 2002). The aforementioned occurrence of white catfish in the scour hole for much of the time was in keeping with aggregation in deeper parts of the channel for this species (Moyle 2002).

The analysis of velocities occupied by tagged predatory fish confirmed the main patterns shown by the spatial analysis of the areas occupied. Catfish and largemouth bass occupied areas with estimated near-surface velocities that were very low in comparison to all velocities available at the HOR study area. Largemouth bass is the only focal predatory fish species from the present study with a published habitat suitability index for velocity. That suitability index is expressed as average summer-current velocity at 0.6 of water depth and ranges from optimal (index = 1) at zero to 0.06 m/s, before a steep decline to zero at 0.2 m/s (Stuber et al. 1982). The results of the present study were in agreement with this index; largemouth bass rarely were found in waters with estimated near-surface velocity of 0.1 m/s or more. Near-surface velocity is not truly representative of velocity in the demersal habitats occupied by catfishes or largemouth bass, but it may still provide an index of velocity differences at greater depths.

Striped bass was different from the other predatory fish in that it occupied a wide range of velocities. Some individuals had median occupation velocities greater than the median velocities available at the HOR study area. As noted previously, this reflects the species' pelagic nature and occupation of a variety of habitats.

Down-looking mobile hydroacoustic surveys showed an extremely high concentration of fish in the scour hole, whereas side-looking hydroacoustic surveys showed many fish at that location, but also appreciable numbers in other areas. This probably reflects a combination of fish distribution and sampling efficiency. The spread of the down-looking beam is less in shallow areas than in deeper areas, so a greater likelihood to detect fish in deeper areas such as the scour hole may be possible. By contrast, the side-looking beam does not have this issue, and generally samples over a greater range. It was nevertheless apparent from side-looking mobile hydroacoustics that the scour hole and the area just upstream were areas of high fish density.

This study assumed that mobile hydroacoustic surveys reasonably indicate changes in the abundance of large-bodied predatory fish at the HOR study area, although the proportion of predatory fish versus non-predatory fish was unknown. Considerable aggregations of common carp were observed visually near the 2012 HOR physical rock barrier. Many of the large-bodied fish observed with down-looking mobile hydroacoustics also may have been common carp; the analysis of fish depth relative to water column depth found that many fish remained close to the substrate at all times of the day. Such a pattern would be consistent with a primarily demersal, benthic-feeding fish such as common carp (Moyle 2002). Catfish, one of the focal predatory fish from the present study, also are primarily demersal (Moyle 2002).

Stationary tags (thought to be from juvenile salmonids that had been preyed upon) provided a third source of information about areas occupied by predators. These tags also indicated the considerable importance of the scour hole and vicinity, because most stationary tags were found there, with very few stationary tags found elsewhere. The acoustic arrays at the HOR in the present study allowed the locations of stationary tags to be determined more precisely than the mobile surveys undertaken as part of the VAMP studies (SJRGA 2010, 2011, 2013). In the present study, one stationary tag from a tagged juvenile Chinook salmon was found immediately adjacent to the downstream side of the 2012 physical rock barrier (another was found farther downstream in Old River), suggesting that the near-barrier area was occupied by predatory fish. These two stationary tags suggest that the only two juveniles entering Old River through the culverts of the 2012 physical rock barrier were preyed upon, based on the detection data. Previous studies have found stationary tags close to other barriers, as with those that were installed as part of the Temporary Barriers Project (Vogel 2010, as cited by SJRGA 2010).

In the present study, tagged largemouth bass that were released downstream of the 2012 physical rock barrier were detected at the barrier bottom or within 5 m of the barrier much of the time. Detection of these largemouth bass indicated a tendency by these fish to remain at or close to the barrier, and therefore, to potentially pose a predation threat to any fish passing through the barrier's culverts. The single largemouth bass tagged in 2009 spent an appreciable amount of time (nearly 50% of all detections) within 5 m of the 2009 BAFF at the upstream end, closest to shore. Little evidence existed of striped bass spending much time close to the 2009/2010 BAFF, although the number of tagged fish during these years was very low (n = 4).

The main importance of the present study's results is that the scour hole was confirmed as an area of high predator occupation. Areas adjacent to the scour hole also were found to be important for predatory fish, and species-specific differences existed in habitat use (e.g., nearshore/offshore). Also, the barrier treatments (particularly the 2012 physical rock barrier) were apparently somewhat important as a location for predatory fish. These findings have important implications for limiting predator abundance at the HOR study area, whether through direct means (capture/relocation) or through indirect means (habitat manipulation, such as scour hole filling). This is discussed further in Section 8.2.2, "Study Feasibility of Physical Habitat Reconfiguration," and Section 8.2.3, "Conduct a Pilot Predatory Fish Relocation Study," in Section 8, "Recommendations."

7.3.3 CHANGES IN DENSITY OF PREDATORY FISHES

The main environmental predictors associated with changes in the density of large fish (greater than 30 cm TL) from both down-looking and side-looking mobile hydroacoustic surveys were same-day discharge and water temperature. Large-fish density increased as discharge decreased and water temperature increased. To some extent, this reflected differences both between and within years. The density of large fish was considerably less in 2011 than in 2012; discharge was considerably higher in 2011 than in 2012. The lower density of large fish in 2011, presumably including many predatory fish, may reflect lower habitat suitability with higher velocity, as has been described for largemouth bass (Stuber et al. 1982). The 2012 surveys provided a contrast between very low abundance during March, which had low water temperatures (approximately 12° to 15°C), and higher abundance in May (18° to 22°C). This suggests seasonal migration to and through the HOR study area by large fish, such as striped bass that spawn during spring.

The results found little evidence for much importance of other predictors of large-fish density. However, in relation to the predictor of small-fish abundance (from Mossdale trawling), which was taken to be a measure of potential prey abundance in the general area, the extent to which upstream trawling would provide an indication of small-fish abundance at the HOR study area is unknown. Nevertheless, pulses of fish in Mossdale trawls generally were followed by pulses of fish at the south Delta's salvage facilities (Jones & Stokes 2007). Therefore, the issue may be more of a temporal mismatch (i.e., 3-day mean small-fish density is not necessarily representative of the density of small fish at the time of the mobile hydroacoustic surveys).

Considerable noise in the water column (e.g., from suspended, non-fish materials being washed downstream) precluded using the hydroacoustic surveys to estimate the density of small fish at the HOR study area. In addition, and as discussed briefly in Section 7.3.2, "Areas Occupied by Predatory Fishes," a difficulty in interpreting data from mobile hydroacoustic surveys existed because the proportion of large fish actually consisting of predatory fish was unknown.

The density of large fish at the HOR study area was either greater than or not substantially different from the density of large fish at the reference sites. In addition, although density estimates were quite variable at all sites, important correlations existed between the HOR study area and the reference sites in approximately half of the comparisons. Taken together, these results suggest that wide-ranging factors (e.g., discharge and water temperature) affect fish density over much of the San Joaquin River, and that the HOR study area has a relatively high density of large fish compared to other sites. As noted previously, the scour hole at the HOR study area was found to be a hotspot of predation in some years, based on stationary tag detections (Vogel 2007, 2010; as cited by SJRGA 2010).

In more recent years, other locations farther downstream in the San Joaquin River and Grant Line Canal have had greater concentrations of stationary tags (SJRGA 2011, 2013), suggesting that more intense predation occurs at those locations. Indeed, SJRGA (2011 2013) noted that “predation did not appear to be a problem near the Head of Old River” in 2010 and 2011 based on the relative density of stationary tags. As described in Section 7.2, “Predation on Juvenile Salmonids, Including Barrier Effects,” predation at the HOR study area was lower in 2011 than in the other years, but predation in 2009 and 2010 during BAFF operations was comparable to predation in 2012 (and overall appeared somewhat high, with predation of more than 30% of juveniles entering the area). This study’s findings of discharge- and water temperature-related differences in the density of large fish and relatively high large-fish density compared to other areas of the San Joaquin River have implications in terms of prioritizing predator management efforts at the HOR study area, both temporally (within and between years) and spatially (at which location). These implications are discussed further in Appendix J, “Recommended Aspects of a Pilot Predatory Fish Relocation Study,” and Appendix K, “Relevant Aspects of the Proposed Bay Delta Conservation Plan” (see Section K.2, “Predation Reduction”).

8 RECOMMENDATIONS

8.1 JUVENILE SALMONID ROUTING INCLUDING BARRIER EFFECTS

8.1.1 STUDY THE COST-BENEFIT OF BARRIERS IN RELATION TO ALTERNATIVE (NONENGINEERING) MANAGEMENT STRATEGIES

The present study showed that non-physical (BAFF) and physical (rock) barriers had varying levels of effectiveness in influencing juvenile salmonid routing at the HOR study area. No option that was studied provided overall efficiency (O_E) greater than 62% and a population proportion eaten less than 30 % (Table 8-1). The O_E result provided herein does not depend upon classification of salmonid juvenile fate from 2D tracks. (Note that there is some uncertainty about classification of salmonid juvenile fate, and this is recommended for further study; see Section 8.2.1, "Further Examine Predation Classification").

Table 8-1
Summary of Statistics for Tagged Juvenile Chinook Salmon Released, 2009–2012

Year/Treatment	Overall Efficiency	Protection Efficiency	Proportion Eaten at Study Area	Proportion Never Arrived at Study Area	Mean Water Temperature (°C)[1]	Mean Discharge (cfs)[1]
2009 BAFF on	0.209	0.338	0.309	0.446[2]	18.6	864
2010 BAFF on	0.355	0.441	0.310	0.112[2]	16.4	2,646
2011 no barrier	0.519	0.574	0.101	*	16.6	5,117
2012 rock barrier	0.618	1.000	0.393	0.539	18.9	1,855

Notes: °C = degrees Celsius; BAFF = bio-acoustic fish fence; cfs = cubic feet per second

1 Water temperature and discharge mean values were calculated from measurements when fish were detected in the Head of Old River study area, and refer to the San Joaquin River at Lathrop gauge.

2 Proportion Never Arrived was calculated with all tags, rather than only tags that later encountered the BAFF when it was on.

* Unknown because only a subset of tags were processed in this year, with the focus on the Head of Old River study area.

Sources: Present study; Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013

Since 2010, the rate of juvenile salmonid survival through the Delta along the San Joaquin River route has been similar to or lower than the survival rate along the Old River route (SJRGA 2011, 2013); previous studies showed that survival was higher along the San Joaquin River route than along the Old River route (see review by Hankin et al. 2010). Lower survival along the San Joaquin River route is contrary to the management goal that a HOR barrier is intending to achieve—less use of the Old River route. However, survival rates are very low along either route, generally less than 10% (SJRGA 2011, 2013; Buchanan et al. 2013). This suggests that conditions in the south Delta are generally poor, particularly compared to through-Delta survival rates for Sacramento River–origin salmonids, 35.1 to 54.3% (Perry et al. 2010). Perry et al. (2013:389) noted that:

> …while shifting the distribution of fish among routes influences overall survival, the magnitude of absolute change in [through-Delta survival] is constrained by the maximum survival observed in any given route. Further increases in [through-Delta survival] require management actions that affect not only migration routing, but also survival within migration routes.

In this light, it is recommended that the cost and benefit of barriers at the HOR study area be studied in relation to the costs and benefits of alternative management strategies, particularly nonengineering solutions such as habitat restoration.

Existing planning efforts are considering the potential for habitat restoration in the south Delta, which could improve the quality of different migration routes. The proposed BDCP contemplates a suite of conservation measures that would restore floodplain habitat, tidally influenced habitat, and channel margin habitat, while enhancing flood control benefits for surrounding areas (see Section K.3, "South Delta Habitat Restoration," in Appendix K, "Relevant Aspects of the Proposed Bay Delta Conservation Plan," of this report). It is recommended that the potential benefits of barrier installation at the HOR study area be considered in light of such efforts. Note that this recommendation is consistent with a recommendation to study physical barriers further (see Section 8.1.3, "Investigate Physical Barrier Alternatives to the Rock Barrier and BAFF"), because the potential benefits of a physical barrier involves both near-field effects (preventing fish from entering an undesirable route, e.g., Old River) and potential far-field effects (retaining flow in the San Joaquin River; see also Section 8.2.4, "Study Effects of Physical Barriers on Location of Predation Hotspots"). The far-field effects may contribute to a potential change in survival along a given route (Perry et al. 2013). The potential to change habitat and directly affect numbers of predatory fish is discussed in Section 8.2.2, "Study Feasibility of Physical Habitat Reconfiguration," and Section 8.2.3, "Conduct a Pilot Predatory Fish Relocation Study."

The potential synergy between nonengineering and engineering strategies therefore is recommended for further study. Barrier installation at the HOR study area may have more value if habitat is improved along the south Delta migration routes.

8.1.2 Conduct Additional Analysis of Existing Data Using Supplementary Techniques

The assessment of juvenile salmonid routing, including barrier effects, was based on a number of univariate analyses that generally tested null hypotheses specified *a priori*. This approach was adopted largely to maintain consistency with previous evaluations at the HOR study area (Bowen et al. 2012; Bowen and Bark 2012). It is recommended that additional analysis of these data be considered using supplementary techniques, such as GLM. The GLM approach was used in the present study's analysis of probability of predation (see Section 7.2, "Predation on Juvenile Salmonids Including Barrier Effects"). Recently this approach was applied to an analysis of the probability of route entrainment at the HOR study area (SJRGA 2013; reproduced in this report as Appendix I, "Route Entrainment Analysis at Head of Old River, 2009 and 2010").

The GLM approach supplements the univariate approach by allowing simultaneous consideration of many environmental variables. In addition, the GLM approach allows consideration of the continuous nature of environmental variables, as opposed to grouping variables (e.g., velocity) by predefined thresholds (as was undertaken with the univariate analyses in the present study). This allows consideration of barrier effects across the range of a given environmental variable. Thus, for example, SJRGA (2013) found that in 2009, below approximately 1,000 cfs (San Joaquin River at Lathrop discharge), there was little difference between BAFF-on and BAFF-off treatments in the probability that juvenile Chinook salmon would remain in the San Joaquin River. In contrast, above a discharge of 1,000 cfs, the probability was appreciably greater with the BAFF on (see Figure 7-1 in Appendix I, "Route Entrainment Analysis at Head of Old River, 2009 and 2010").

The analysis of route entrainment conducted by SJRGA (2013) is analogous to the univariate analysis of protection efficiency (P_E) (i.e., only surviving juvenile Chinook salmon are considered). It is recommended that a GLM analysis be undertaken that is more analogous to the univariate analysis of O_E, i.e., including juveniles that were preyed upon at the HOR study area. This could be done with a GLM based on a trinomial response distribution, for example, with three juvenile Chinook salmon fates ("remained in San Joaquin River," "entered Old River," or "preyed upon").

It is also recommended that additional analyses be undertaken of data collected in 2013 (i.e., from the study similar to the Vernalis Adaptive Management Program's release of tagged juvenile Chinook salmon and from tagged juvenile steelhead released as part of the Six Year Steelhead Study mandated by the NMFS [2009] OCAP BO). Such analyses would allow comparison of juvenile salmonid routing and survival with a low-discharge, no-barrier treatment (i.e., 2013) with the other years (2009–2012) included in the present study.

8.1.3 Investigate Physical Barrier Alternatives to the Rock Barrier and BAFF

Deploying a BAFF at the HOR study area is not recommended at this time, for two main reasons. First, estimated population proportion eaten of juvenile Chinook salmon during BAFF operation in 2009/2010 was very high, at 31%, and predation was not significantly different from predation when the physical rock barrier was installed in 2012, as discussed in Section 7.2, "Predation on Juvenile Salmonids Including Barrier Effects." Second, in 2009, predation was significantly greater with the BAFF on than off.

As described in Section 8.2.1, "Further Examine Predation Classification," there is a need to develop further the methods to classify the fate of tagged juvenile salmonids. Irrespective of this need, even if predation had been overestimated considerably with the BAFF on, the BAFF's influence on routing of juvenile salmonids produced only a modest gain in the proportion of juvenile salmonids remaining in the San Joaquin River (e.g., in 2010, mean P_E of 0.441 with BAFF on versus 0.286 with BAFF off; see also Figures 7-3 and 7-4 of Appendix I, "Route Entrainment Analysis at Head of Old River, 2009 and 2010"). Sample proportion eaten was relatively high with the physical rock barrier (and not significantly different than with the BAFF on); however, the rock barrier eliminated entry into Old River of tagged juvenile Chinook salmon determined to have not been eaten, the primary management goal of the barrier installation (see Protection Efficiency in Table 8-1).

The second reason for not recommending deployment of a BAFF is that recent studies have not found through-Delta survival to be lower for juvenile Chinook salmon entering Old River instead of remaining in the San Joaquin River, in contrast to the situation generally observed historically (Hankin et al. 2010). Indeed, survival along the Old River route has been comparable to or greater than survival along the San Joaquin River route in recent years (SJRGA 2010, 2013; Buchanan et al. 2013). The reasons for this recent change are unknown, although Buchanan et al. (2013: 228) have suggested that "it is possible that the non-physical barrier deprived smolts routed to the San Joaquin River of the increased flows necessary for improved survival." It is recommended that juvenile Chinook salmon survival through the Delta be studied further to assess if evidence persists into the future for the Old River route having higher survival than the San Joaquin River route. Because no long-term route survival data series exists for steelhead, juvenile Chinook salmon survival is the only metric currently available for assessment of the through-Delta success of the Old River route compared to the mainstem San Joaquin River route.

Hankin et al. (2010:27) considered the installation of a physical barrier at the HOR study area to be potentially beneficial because, in addition to the more desirable mainstem San Joaquin River fish routing, it would "ensure that essentially all San Joaquin flow proceeds down the main channel, thereby presumably enhancing (juvenile) smolt survival via a mainstem flow effect." Furthermore, they made the following recommendation (Hankin et al. 2010: 28):

> If an Obermeyer Gate is considered, it should be located near the edge of the hydraulic flow line of the main channel of the San Joaquin River. Data support that in-river structures such as a fill dam, but also bridge abutments, scour holes, piers and pump stations, provide habitat for predators in this reach of the river (Vogel, pers. comm., 2010). The position of the original HORB [Head of Old River Barrier] was set back into the entrance of the channel leading into Old River. This site was chosen most likely for ease and cost to construct and remove. Unfortunately, it also set up hydraulic conditions ideally suited for predators: slack water and cover. If a future barrier at the HOR is constructed, alignment along the San Joaquin embankment would create a higher sweeping velocity down the main channel, would move smolts more swiftly past this location, and should reduce predator habitat.

The results of the present study tend to support the foregoing recommendation of Hankin et al. (2010). Predation at the HOR study area with a physical rock barrier installed may have been relatively high. Population proportion eaten was 39% of tagged juveniles entering the study area, if the estimates of juvenile Chinook salmon eaten are reasonably accurate. This appeared to be at least partly attributable to unfavorable hydraulic conditions, such as eddies generated by the position of the rock barrier. Therefore, it is recommended that the feasibility of physical barrier alternatives be considered for the HOR study area, following the recommendations of Hankin et al. (2010).

Important considerations for the feasibility of a physical barrier include the need to consider water use in Old River (i.e., maintaining adequate water levels for agricultural diversions) and the Old and Middle River flows necessary to limit the potential for delta smelt (and other species of concern) to move toward the south Delta export facilities from the central or west Delta. In addition, locating a physical barrier closer to the San Joaquin River's hydraulic flow line would increase construction and operations/maintenance costs (J. McQuirk, pers. comm., 2013).

Further investigation of the feasibility of a physical barrier at the HOR site would inform the proposal to construct an HOR operable gate under the Bay Delta Conservation Plan (DWR 2013). This is discussed further in Section K.1, "Operable HOR Gate," in Appendix K, "Relevant Aspects of the Proposed Bay Delta Conservation Plan," of this report. Such a gate would obviate the need for a non-physical barrier and may facilitate the types of mainstem San Joaquin River discharge–related benefits suggested by Hankin et al. (2010).

Study of a physical barrier should consider any effects on the potential for changes in delta smelt entrainment at the south Delta export facilities because of changes in Old and Middle river discharges. This could be done at a planning level, for example, by modeling Old and Middle river discharges under different physical barrier configurations. The modeling then could be applied to established relationships between proportional entrainment of larval/juvenile delta smelt and spring (March–June) Old/Middle River discharge and the location of the low-salinity zone (see USFWS 2008:220).

Any study of physical barrier alternatives to the rock barrier and BAFF should consider the timing of barrier installation relative to juvenile salmonids' outmigration periods. Historic installation of the HOR barrier has been tailored to coincide with the spring (April–June) outmigration period of juvenile Chinook salmon in the San Joaquin River watershed, whereas juvenile steelhead outmigration may warrant earlier installation. (For example, the migration period noted for the Stanislaus River at Caswell is January to July, with a peak in March, and moderate abundance from February to June [NMFS 2009:Table 4-6].)

The recommendation to investigate physical barrier alternatives includes a recommendation to consider possible effects of the San Joaquin River Restoration Program (SJRRP). The SJRRP aims to implement the restoration goal of the San Joaquin River Restoration Settlement: "To restore and maintain fish populations in 'good condition' in the main stem of the San Joaquin River below Friant Dam to the confluence of the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish" (SJRRP 2011).

The SJRRP's actions occur well upstream of the HOR study area. The migration route of spring-run and fall-run Chinook salmon emigrating to or from the restoration area includes the HOR study area. Therefore, management actions at the HOR study area would affect these fish. The timing of fall-run Chinook salmon migration presumably would be similar to that observed elsewhere in the San Joaquin River basin (i.e., primarily juvenile spring outmigration and fall adult immigration). However, the timing of spring-run Chinook salmon may result in new considerations (e.g., with respect to adult spring upstream migration). In addition, depending on the juvenile phenotypes expressed, a broader variety of outmigration timing may exist, with differences between young-of-the-year, fry migrants, and older juveniles that may have reared in-river for over a year. These are considerations for the timing of any barrier operation at the HOR study area, as well as any other associated activities that may be planned (e.g., predator relocation; see Section 8.2.3, "Conduct a Pilot Predatory Fish Relocation Study").

Clearly, the potential exists for any future management activities at the HOR study area to affect migrating salmonids from a restored San Joaquin River above the Merced River confluence. Based on the SJRRP's use of tagging studies to assess juvenile Chinook salmon survival in the watershed above the Merced River confluence (SJRRP 2012), it is recommended that study efforts specific to the HOR study area and the SJRRP be coordinated, to track the same tagged study fish as they pass through the HOR study area. This would be of value because these study fish would have had considerably longer to acclimate to the natural environment by the time they reached the HOR study area, compared to fish released at more typical locations, such as Durham Ferry (e.g., Bowen et al. 2012). Sample sizes may be low, however, because of the losses that may occur between the release sites and the HOR study area. Coordinated efforts may have to significantly increase the number of study fish.

8.2 PREDATION ON JUVENILE SALMONIDS INCLUDING BARRIER EFFECTS

8.2.1 FURTHER EXAMINE PREDATION CLASSIFICATION

With respect to predation, a key uncertainty that warrants further research is the actual fate of tagged juvenile salmonids that have been classified as having been preyed upon or having survived at the HOR study area. The GLM statistical analysis of juvenile Chinook salmon at the HOR study area was successful in supporting some of the *a priori* hypotheses regarding factors affecting juvenile predation (i.e., light level and turbidity), as well as highlighting the fact that predation was greater with the physical rock barrier and BAFF operations than with the BAFF not operating.

However, the GLM analysis for steelhead provided no insight into mechanisms affecting predation. This may be attributable to the difficulty in assigning predation fate. Predation studies of both juvenile Chinook salmon and steelhead would benefit from some means of verifying predation fate, or of developing objective, quantitative criteria to classify predation. An example of this was provided in the 2012 Georgiana Slough Non-physical Barrier Study (DWR in review), which used mixture models to estimate the probability of a track being a predator based on the tortuosity of the track in the study area (Romine et al. 2014). It is recommended that the 2009–2012 data from the HOR study area be examined to determine how fate classification corresponds with classifications from mixture models based on data either from tagged predatory fishes at Georgiana Slough or, preferably, from the tagged predatory fishes from the HOR study area presented in this study.

It is also recommended that predation classification in future studies at the HOR study area (by mixture models, qualitative fate classification, or other means) incorporate the use of the new predation tag. Predation tags are proprietary technology that has been developed by Hydroacoustic Technology, Inc., and for which a patent application is in process. The acoustic signal emitted by predation tags changes sometime after a tagged juvenile salmonid has been preyed upon, thus indicating the fate of the juvenile salmonid. Classification by mixture models or other means can then be compared to the known fate of the predation tag. Therefore predation rules described in Appendix E could be tested as follows: (1) develop 2D tracks for juvenile Chinook salmon before and after known predation events from the predation tag; (2) experts apply human rules described in Appendix E to assign fate; and (3) statistically compare the groups of uneaten, eaten, and unknown from predation-tag known to those for expert human assessments.

The primary limitation to using predation tags is the lag time between the predation event and the change in signal from the predation tag, which may preclude assigning predation by predatory fishes at the HOR study area if these predatory fishes have a relatively short residence time (striped bass). Nevertheless, predation tags appear to hold promise for informing broader-scale survival estimates through the south Delta as a whole. Thus, they would tie in to studies that consider the broader circumstances along the migration route rather than just the HOR study area (see Section 8.1.1, “Study the Cost-Benefit of Barriers in Relation to Alternative [Nonengineering] Management Strategies”).

Transit speed was identified as a quantitative attribute that can assist in classifying predation on juvenile salmonids (see Appendix D, “Transit Speed Analyses”). It is recommended that this attribute be used to aid predation classification in future studies. Tagged juvenile Chinook salmon that were classified as having been preyed upon passed through the HOR study area at a much slower rate than tagged fish that were not eaten.

It is further recommended that the use of transit speed as one criterion for classifying predation also take into account the relationship between discharge, average channel velocity, and transit speed. Individual transit speed should be evaluated as an indicator of predation probability. The individual transit speed should be compared to the mean transit speed for all tags experiencing the same conditions in a specific year. However, because the behavior of steelhead juveniles can appear similar to the behavior of predators, it is recommended that transit speed evaluation be species-specific.

8.2.2 Study Feasibility of Physical Habitat Reconfiguration

The preponderance of stationary acoustic tags for juvenile salmonids in the scour hole and the association of predatory fish with the scour hole and adjacent areas at the HOR study area (see Section 7.3.2, “Areas Occupied by Predatory Fishes”) leads to the recommendation that a study be undertaken regarding modification of the scour hole’s bathymetry. Modification could involve filling the scour hole with suitable substrate. Such actions are under consideration in other planning efforts for the Delta, e.g., the Bay Delta Conservation Plan (Section K.2, “Predation Reduction,” in Appendix K, “Relevant Aspects of the Proposed Bay Delta Conservation Plan,” of this report). Clearly, such action would require a detailed modeling effort to ascertain the potential effects on both the river near the HOR study area and upstream and downstream of the site. Particular consideration would be needed for effects on river banks and levees that could occur as a result of any modification to the scour hole.

8.2.3 Conduct a Pilot Predatory Fish Relocation Study

Regardless of the presence or absence of a barrier at the HOR, sufficient evidence is apparent to conclude that predation is considerable at the study area. The present study suggests that the population proportion eaten of juvenile Chinook salmon entering the site has been high in most years (0.23 in 2009, 0.26 in 2010, 0.10 in 2011, and 0.39 in 2012; see Table 7-1 of Section 7.2, “Predation on Juvenile Salmonids Including Barrier Effects”, in Section 7, “Discussion”). As noted previously in Section 8.2.1, “Further Examine Predation Classification,” there is the need to investigate further the uncertainty about the fates of juvenile salmonids.

Mobile surveys of stationary acoustic tags from dead salmonids have not always shown that the HOR study area and vicinity to be a regional hotspot of predation (SJRGA 2010, 2011, 2013); however, the foregoing rates of predation, assuming that they are reasonably accurate, are of concern. Consideration of relocating predators from the HOR study area and vicinity may be warranted; as described further in Section 8.2.4, “Study Effects of Physical Barriers on Location of Predation Hotspots,” identifying the locations of predation hotspots and how they shift seasonally in relation to environmental conditions is valuable, so that efforts to relocate predatory fish could focus on problem areas. Given the scarcity of predator control studies in the Delta (see Grossman et al. 2013) and the proposed use of such actions in planning efforts (see Section K.2, “Predation Reduction,” in Appendix K, “Relevant Aspects of the Proposed Bay Delta Conservation Plan”), it is recommended that a pilot predatory fish relocation study be undertaken at the HOR study area.

The feasibility of relocating predators is highly uncertain and problematic, particularly with respect to an open area such as the HOR study area. Gingras and McGee (1997:13) discussed the feasibility of predator control in Clifton Court Forebay, another open system in the Delta, and concluded:

> Because removal efforts at Clifton Court Forebay would not affect reproduction in the striped bass (predator) population or recruitment to Clifton Court Forebay, logic dictates that the level of exploitation to substantially reduce predation at Clifton Court Forebay would need to be very high.
>
> Notwithstanding the extraordinary effort that predator removal would pose as a means to improve prescreen survival of fish entrained at Clifton Court Forebay, a coordinated program to reduce predation should be expected to yield some degree of positive effect. In this respect, initiating a predator control program may seem attractive; however, in a review of 250 fish control projects, Meronek et al. (1996) classified most of them as failures. They documented many proximate causes for failure (e.g., insufficient reduction in numbers) but suggested that unreported “seminal reasons” were more often the cause. Suggested seminal causes of failure were insufficient pre- and post-treatment study and lack of criteria for success. Proposed predator removal activities at Clifton Court Forebay have been delayed in substantial part due to the inability to reach a

consensus on the criteria to quantify success. Because fundamental assumptions of mark/recapture methods for abundance estimation are not valid when Clifton Court Forebay is operated normally, predator control activities would need to be evaluated without accurate predator abundance estimates. Quantifying any improvement in prescreen survival attributable to predator removal efforts would be difficult.

In the only available published Delta study of predator control efforts, a study on the North Fork Mokelumne River, Cavallo et al. (2013) demonstrated that predator removal may be feasible[1]. Electrofishing was used to catch predatory fishes in a 1.6-km impact reach; the survival rates of tagged juvenile Chinook salmon were compared before and after the removal in the impact reach and in an upstream 2-km control reach. Survival was greater than 99% in the reach after the removal, compared to less than 80% before the removal. Survival in the control reach was variable and did not differ before and after the removal. However, survival in the impact reach declined to initial levels after a second predator removal effort, before increasing to very high levels (again greater than 99%) after a considerable increase in discharge caused by the opening of the Delta Cross Channel gates.

Although the results of Cavallo et al. (2013) show predator removal may be challenging, their study serves as a useful template for the type of study that could be considered as a pilot predator relocation effort at the HOR study area. Indeed, the National Marine Fisheries Service's Southwest Fisheries Science Center has commenced study to manipulate predatory fish density at the HOR study area in 2014-2016. This study and any other similar studies would have direct relevance for the proposed BDCP (see Section K.2, "Predation Reduction," in Appendix K, "Relevant Aspects of the Proposed Bay Delta Conservation Plan," of this report).

The results of the present study also have the potential to guide any pilot predator relocation efforts that may be considered, such as by illustrating the areas of greatest predatory fish density (see "Areas Occupied" in Section 6.3.2, "Hydroacoustic Data" of Section 6, "Results"). Features of a pilot predator relocation study are summarized in Appendix J, "Recommended Aspects of a Pilot Predatory Fish Relocation Study." That appendix, as well as Section K.2, "Predation Reduction", of Appendix K, "Relevant Aspects of the Proposed Bay Delta Conservation Plan," also discuss how the results of the present study have the power to inform future studies and planning efforts.

8.2.4 Study Effects of Physical Barriers on Location of Predation Hotspots

With respect to the influence of a physical barrier on flow, Cavallo et al. (2013) illustrated that river inflow to the Delta has an important effect on the extent of the channel under appreciable tidal influence (i.e., with bi-directional flows much of the time). They suggested, "If the tidal transition zone occurs where habitat conditions are poor, or where predator densities are high, juvenile salmon are likely to experience greater predation mortality, and perhaps impaired growth. This should be studied more fully."

In relation to the situation at the HOR study area, and to the broader San Joaquin River and south Delta, examining the locations where predation hotspots occur (SJRGA 2010, 2011, 2013) is recommended, to see how they relate to the tidal transition zone. Clearly, deploying a physical barrier would have the potential to influence

[1] Note that Sabal (2014), in her master's thesis work, found that juvenile Chinook salmon survival below Woodbridge Irrigation District Dam on the lower Mokelumne River increased by approximately 25-30% following removal of predatory fishes by electrofishing.

the position of the tidal transition zone and may guide future management efforts, such as predator relocation (see Section 8.2.3, “Conduct a Pilot Predatory Fish Relocation Study,” and Section 8.3.2, “Assess Predatory Fish Density in Relation to Predation Hotspots”) and the proposal for a physical barrier in the Bay Delta Conservation Plan (Section K.1, “Operable HOR Gate,” in Appendix K, “Relevant Aspects of the Proposed Bay Delta Conservation Plan”).

In addition, understanding the factors influencing predation hotspots would improve planning of complementary management strategies such as habitat restoration and habitat reconfiguration. (See Section K.2, “Predation Reduction,” and Section K.3, “South Delta Restoration,” in Appendix K, “Relevant Aspects of the Proposed Bay Delta Conservation Plan.”) Therefore it is recommended that the influence of a physical barrier on the location of predation hotspots and the tidal transition zone be studied further to elucidate potential far-field effects of physical barrier installation.

8.2.5 Study Potential Effects of Changing Recreational Fishing Regulations

The results of the present study suggested that predation on juvenile salmonids is considerable at the HOR study area. In addition to studying localized effects of predatory fish manipulation (see Section 8.2.3, “Conduct a Pilot Predatory Fish Relocation Study”), it is recommended that additional study be pursued into the potential effects of changing recreational fishing regulations for striped bass and other predatory fish species. The goal of such study would be to assess the prospects for an increase in the survival of juvenile salmonids, including those emigrating from the San Joaquin River region through the HOR study area.

The California Department of Fish and Game (now California Department of Fish and Wildlife) recently proposed changes to fishing regulations for striped bass (DFG 2011). The changes included generally increased bag limits and decreased size limits, with very large bag limits and no size limit in a “South Delta Hot Spot” region (including Clifton Court Forebay and portions of nearby channels such as Old River and West Canal). The California Fish and Game Commission (2012) rejected this proposal amid concerns from the recreational fishing community about potential adverse effects on the fishery which is currently in decline. In addition, leading fish biologists have expressed concerns about potential adverse effects on the Delta ecosystem, such as compensatory increases in predation by other predatory fishes and increases in the abundance of fishes that may compete with threatened fishes (Moyle and Bennett 2010). Therefore, it is recommended that additional studies be conducted into the potential effects of changes in fishing regulations. It is important to note that DWR cannot implement any changes to fishing regulations; these are the purview of the California Fish and Game Commission.

Under this recommendation, DWR would facilitate studies that would inform future decision making, with the recognition that a broader California Resources Agency effort probably would be needed to engage stakeholders from the recreational fishing and other communities (e.g., scientific and environmental organizations) in order to explore fully all considerations related to the feasibility and utility of changes in fishing regulations. Any studies undertaken as part of this recommendation should adhere to the guidelines of Grossman et al. (2013) for studies of predation in the Delta, and should include consideration of:

- changes in survival of listed species (e.g., juvenile Central Valley steelhead, including those from the San Joaquin River basin, and delta smelt) and other species of concern (e.g., juvenile San Joaquin River fall-run Chinook salmon);

- age-specific changes in abundance of striped bass; and
- changes in fishing opportunities (e.g., catch rates of recreational fishers).

8.3 BEHAVIOR AND DENSITY CHANGES IN PREDATORY FISHES

8.3.1 ASSESS PREDATORY FISH MOVEMENTS AS PART OF A PILOT PREDATORY FISH RELOCATION STUDY

It is recommended that predatory fish movements be studied as part of a pilot predatory fish relocation study (see Section 8.2.3, "Conduct a Pilot Predatory Fish Relocation Study"), if the study includes relocation of predators to other parts of the Delta. As described in Appendix J, "Recommended Aspects of a Pilot Predatory Fish Relocation Study," it may be desirable to hold captured predatory fishes in net pens during assessments of changes in survival of tagged salmonids in reaches that have had predatory fishes removed; after completion of the study, the captured predatory fishes could be released (Cavallo et al. 2013). In this case, an assessment of predatory fish movement would not be required. If, on the other hand, predatory fish are relocated elsewhere in the system, then it is recommended that their movements be tracked with acoustic tagging to assess the locations to which they disperse and determine whether they return to the HOR study area (or to other areas from which they were relocated).

Important considerations for such a study include the locations to which releases of predatory fish should be made, particularly because of the potential to enhance predation on listed fishes in other parts of the Delta. Bowen and Bark (2012) suggested that relocating predatory fish from the HOR study area could involve moving captured fish to San Luis Reservoir; however, this may not be desirable because it would remove predatory fish from the Delta system and therefore could provide less opportunity for recreational fishing. Additionally, relocating fish raises concerns about spread of disease between populations. As noted in Section K.2, "Predation Reduction," of Appendix K, "Relevant Aspects of the Proposed Bay Delta Conservation Plan," the Bay Delta Conservation Plan proposes only localized reduction of predatory fishes to relieve predation pressure at hotspots, rather than achieving a system-wide reduction in predatory fishes.

8.3.2 ASSESS PREDATORY FISH DENSITY IN RELATION TO PREDATION HOTSPOTS

In association with a study of predation hotspots (see Section 8.2.4, "Study Effects of Physical Barriers on Location of Predation Hotspots"), it is recommended that predatory fish density be assessed by species and seasonally to determine whether there is evidence of a concentration of predatory fishes at predation hotspots compared to other areas where predation is not so intense. It is of interest to determine whether physical and environmental conditions as well as predatory fish density contribute to predation hotspots. For example, do hotspots have modest densities of predatory fishes that are not significantly different from densities in other areas, but these fishes are more efficient in feeding because of physical and/or environmental conditions? (Examples of such hotspots include areas of flow reversals at the intersection of riverine conditions with tidally influenced areas; see Section 8.2.4, "Study Effects of Physical Barriers on Location of Predation Hotspots.")

Predation hotspots are not solely attributable to predatory fishes; thus, the potential for predation by other piscivorous taxa (bullfrogs, birds, river otters, harbor seals, and sea lions) at hotspots is also recommended for investigation. Clark et al. (2009) and Miranda et al. (2010) examined the abundance of piscivorous birds at

Clifton Court Forebay and at the south Delta export facility's salvage release sites. Similar methods could be applied to evaluate the evidence of high densities of piscivorous birds relative to predation hotspots at the HOR study area and along the main migration routes through the south Delta. In addition, avian scat and river otter latrine sites could be sampled for Chinook salmon and steelhead otoliths/scales and scanned for acoustic tags.

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