APPENDIX A

Additional Background on the Study Area and Nearby Areas

A.1 HISTORIC DELTA

The Sacramento–San Joaquin Delta (Delta) was considered a barrier by the first explorers of the region in the late 1700s. Crossing the myriad of sloughs, wetlands, and flooded lands discouraged exploration and development (Thompson 1957). Further exploration effort was suppressed by the hostile reception by native residents. From the late 1700s through the early 1840s, most exploration of the region centered around disrupting native presence, forming missions, and hunting for fur (Thompson 1957).

Modern development of the Delta began with the discovery of gold resources in 1848 (Lund et al. 2007; Thompson 1957). In the ensuing months, many coastal settlements were deserted as the masses migrated inland. Settlement was kept in check because of the limitations and challenges of sailing, the primary mode of transportation at that time in the area (Lund et al. 2007). However, steam-powered railroads became available after the 1850s, and the rate of settlement and development increased substantially (Thompson 1957). Many individuals soon discovered that agricultural opportunities surpassed those of mining, and the early 1850s marked the beginning of Delta wetland conversion and levee construction.

The federal Swamp Lands Act of 1850 was a major legislative enactment that intensified and facilitated reclamation of Delta lands (Lund et al. 2007; Thompson 1957). This law ceded federal swamplands to the states to encourage land reclamation, and California received nearly 202,343 hectares within the Delta (Lund et al. 2007). Creation of the Board of Reclamation in 1861 further facilitated reduction of floodplain and wetland habitat by creating reclamation districts from collectives of smaller parcel owners, the objectives of which were to enclose large areas defined by natural levees for agricultural development and to provide flood management (Lund et al. 2007). Ninety-three of these local entities still operate within the Delta today, with primary responsibility for providing levee maintenance (Lund et al. 2007).

Technological advances played a major role in reclamation. The first mechanized equipment for levee construction was developed in 1865 (Thompson 1957). Large-scale reclamation escalated as mechanized power was applied to levee construction, land clearing, ditch building, dredging, and pump-powered draining (Lund et al. 2007). The influence of these institutional and technological innovations on the reclamation of Delta lands is shown in Table A-1. Reclamation of the McCormack-Williamson Tract in 1934 marked the end of those activities that formed the primary physical features characterizing the present-day Delta.

Table A-1
Magnitude of Reclamation in the Sacramento–San Joaquin Delta, 1860–1930

Decade	Hectares Reclaimed	Cumulative Reclaimed Hectares
1860–1870	6,070	6,070
1870–1880	37,231	43,301
1880–1890	28,328	71,629
1890–1900	23,472	95,101
1900–1910	35,612	130,713
1910–1920	38,040	168,753
1920–1930	9,712	178,465

Source: Thompson 1957

A.2 SAN JOAQUIN RIVER

The San Joaquin River is the second longest river in California, measuring approximately 530 kilometers (km). The watershed originates high on the western slopes of the Sierra Nevada and drains most of the area from the southern border of Yosemite National Park south to Kings Canyon National Park.

The region's climate is characterized by long, hot summers and mild winters, with an approximate average annual precipitation of 15 centimeters (USACE 1993). Precipitation occurs primarily between November and April, and very little rainfall occurs during the summer months. Pulse flows occur in the basin from intense rainfall during the late fall and winter, and from snowmelt during the spring and early summer (USACE 2000). Higher peak-discharges occur from rainfall events, but the duration of these events typically is not as lengthy as those occurring from snowmelt (USACE 2000). Annual flow characteristics are affected substantially by water resources development that has occurred over the past approximately 130 years, including large multipurpose reservoirs, levee and channel improvements, bypasses, and local diversions (USACE 1993).

Surrounding land use is primarily agricultural, accounting for approximately 85% of the region's water use allocations (DWR 1994). The pattern of channel networks in the Delta is distributary (branches off from the main channel), with the division of the channel network into numerous individual channels producing a distinctive anastomosing channel network (Mount 1995). The distributary drainage pattern is characterized by high gradient tributaries discharging into low-gradient areas, delivering high sediment loads (Mount 1995). The major tributaries to the San Joaquin River, all of which are located upstream from the Head of Old River (HOR) at the divergence of the San Joaquin River and Old River (HOR study area), include the Stanislaus, Tuolumne, and the Merced rivers (Figure A-1). Currently, all salmonid production occurs in the San Joaquin River tributaries; the mainstem serves as a migratory corridor. Each of these rivers has been greatly affected by dredge mining, and the bulk of the finer sediments that made up the historical alluvial valley fill of these three tributaries has been transported downstream into the San Joaquin River (USACE 2000). This process continues to transport and deposit large quantities of fine sediments into the San Joaquin River (USACE 2000).

A.3 STANISLAUS RIVER

The Stanislaus River is approximately 154 km long, originates on the western slope of the Sierra Nevada, and flows southwest to the confluence with the San Joaquin River on the floor of the Central Valley. Several reservoirs and dams control flows in the Stanislaus River for flood management, power generation, and water supply. Water uses include irrigation and municipal needs, recreational activities, and water quality control. Goodwin Dam is approximately 94 km upstream from the San Joaquin-Sacramento River confluence and blocks the upstream migration of anadromous fish (S. P. Cramer and Associates 2001).

The Stanislaus River is designated critical habitat for California Central Valley steelhead distinct population segment (DPS). The California Central Valley steelhead is present in small numbers in the Stanislaus River, and smolts have been captured in rotary screw traps at Caswell State Park and Oakdale annually since 1995. The California Central Valley spring-run Chinook salmon evolutionarily significant unit (ESU) has been extirpated from the Stanislaus River, primarily due to dam construction causing elimination of spawning habitat. California Central Valley fall-run Chinook salmon ESU is present in the Stanislaus River, although populations are depressed below historical levels (FISHBIO Environmental 2007; NMFS 2011).

A.4 TUOLUMNE RIVER

The Tuolumne River is approximately 240 km long, originates on the western slope of the central Sierra Nevada, and flows west to the confluence with the San Joaquin River on the floor of the Central Valley. La Grange Dam, completed in 1883, is located approximately 84 km upstream from the San Joaquin River confluence, and constitutes a the migration barrier to anadromous fishes (Turlock Irrigation District and Modesto Irrigation District 2010).

The Tuolumne River is designated critical habitat for California Central Valley steelhead DPS, and populations are currently present (Ford and Kirihara 2010; NMFS 2011). The California Central Valley spring-run Chinook salmon ESU has been extirpated from the Tuolumne River (NMFS 2011) due to dam construction causing elimination of spawning habitat. The California Central Valley fall-run Chinook salmon ESU is present in the Tuolumne River. Population estimates have shown a decline through the last decade (Turlock Irrigation District and Modesto Irrigation District 2010).

A.5 MERCED RIVER

The Merced River is approximately 233 km long, originates on the western slope of the central Sierra Nevada, and flows west to the confluence with the San Joaquin River on the floor of the Central Valley. The Crocker-Huffman Dam, completed in 1910, is located approximately 84 km upstream from the San Joaquin River confluence and constitutes a the migration barrier to anadromous fishes (USFWS 2007).

An annual steelhead run in the Merced River has not been documented (USFWS 2007). However, the National Marine Fisheries Service (NMFS) states that incidental catches of juvenile steelhead during monitoring efforts have occurred on the Merced River (NMFS 2007), and that the species' presence in the Merced River is assumed because of proximity, similar habitats, and historical presence when compared to the Stanislaus and Tuolumne rivers (NMFS 2011). The California Central Valley spring-run Chinook salmon ESU has been extirpated from the Merced River (NMFS 2011) due to dam building causing elimination of spawning habitat. A California Central Valley fall-run Chinook salmon ESU is present in the Merced River, although population estimates have been very low for many years (California HSRG 2012). The Merced River Fish Hatchery, located just downstream from Crocker-Huffman Dam, historically has supplemented naturally produced Chinook salmon populations.

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APPENDIX B

Focal Fish Species Information

B.1 FOCAL SALMONID SPECIES FOR PROTECTION AT HEAD OF OLD RIVER

B.1.1 CHINOOK SALMON—LIFE HISTORY AND JUVENILE SWIMMING CAPACITY

This appendix provides a synopsis of what is known about the life history and behavior of Chinook salmon (*Oncorhynchus tshawytscha*) with emphasis on the Sacramento–San Joaquin Delta (Delta).

Chinook salmon is in long-term decline in California, although the species is not in immediate danger of extinction. The Sacramento River has spring, fall, late-fall, and winter-runs of Chinook salmon (Kjelson et al. 1982; Williams 2006). By contrast, the San Joaquin River has supported only three runs: fall, late-fall, and spring with the latter two runs extirpated in the 1940s (Fisher 1994). At present, only fall-run Chinook salmon inhabit the San Joaquin River. Fall-run fish have been the most studied (Kjelson et al. 1982).

This section discusses the various life stages of salmonids. The terminology follows that of Allan and Ritter (1977). In chronological order, these terms are “egg,” “alevin,” “fry,” “parr,” “smolt,” “adult,” and “kelt.” One additional term is used because authors in Central Valley studies use it with some frequency: “pre-smolt,” defined as an anadromous salmonid undergoing the smoltification process that exhibits some characteristics of smolts but has not completed all the physiological, morphological, and behavioral changes of smolts. The term “juveniles” refers to the sexually immature stages of pre-smolts and smolts.

Chinook salmon are semelparous and show a wide array of life-history pattern adaptations that have allowed it to take advantage of diverse and highly variable lotic environments. Within two basic types of life-history strategies, stream-type and ocean-type, the variations are recognized as runs. Stream-type Chinook salmon juveniles overwinter in freshwater before entering the ocean, and spend usually more than 1 year in freshwater. Ocean-type adults become sexually mature while during the ocean phase and spawn soon after entering freshwater, in late summer and fall. Juveniles migrate to the ocean early in their first year of life. Both types are present in California (Moyle 2002), but San Joaquin River fall-run Chinook salmon exhibit an ocean-type life history (SJRRP 2008).

ADULT AND SPAWNING MIGRATION

Adult Chinook salmon are the largest of any Pacific salmon, typically measuring 75 to 80 centimeters (cm) in standard length and weighing 9 to 10 kilograms (kg). Adults can grow to 140 cm long and weigh up to 45 kg (Healey 1991; Moyle 2002). Males vary more in size than females at maturity, and for most populations, average males are smaller than average females (Quinn 2005). Growth is variable but often rapid in the ocean; thus, ocean-type Chinook adults are often larger than stream-type individuals.

To spawn, Chinook salmon leave the Pacific Ocean and return to their natal rivers over great distances. Upstream migration takes place mainly during the day, with fish apparently tracking stream odors on which they imprinted as juveniles (Healey 1991). Although most fish home to their natal stream, some stray and spawn in a different streams. Straying presumably is an adaptive mechanism that allows salmon to (re)colonize newly opened areas and mix genetically with other runs, especially those in streams close to their natal streams (Moyle 2002). During spawning migration, adult Chinook salmon mistakenly enter intake structures or unscreened diversions (Yoshiyama et al. 1998). Upstream-migrating adults may pass through the San Joaquin River or Old River, moving upstream through the Head of Old River (HOR) study area. The adult migration of Chinook salmon is heavily concentrated from August through November, reflecting the numerical dominance of the fall-run salmon in the Sacramento-San Joaquin rivers (Williams 2006).

Despite the large variation in run timing in most rivers, spawning times tend to be similar among runs. Once the natal streams are reached, salmon select areas for holding, although fall-run Chinook salmon may spawn without any delay. Chinook salmon use a variety of freshwater habitats, but they more commonly spawn in larger mainstem rivers than other salmonids. Female salmon excavate redds in gravel deposits. When each redd is dug, the female essentially cleans an area measuring 2 to 10 square meters (m^2), loosening gravel and mobilizing fine sediments (particles less than 2 millimeters [mm] in diameter), so that the future embryos will have access to a steady flow of oxygen-containing water (Healey 1991). Females deposit eggs and males fertilize the eggs, and both cover the eggs with substrate immediately after fertilization. Chinook salmon have been observed digging redds and spawning at a variety of depths from a few centimeters to several meters (m), and at water velocities of 15 to 190 centimeters per second (cm/s), but most seem to spawn at depths between 25 and 100 cm and velocities of 30 to 80 cm/s (Healey 1991). Regardless of depth, the key to successful spawning is having an adequate flow of water around developing embryos, which means they have to be buried in coarse substrate with low silt content.

EGG

Generally, female Chinook salmon produce 2,000 to 17,000 eggs in their one-time only spawning event. Although the number of eggs increases with body size, this relationship is not as strong in Chinook as in other salmonids and varies among populations and runs (Moyle 2002). Survival of eggs in the Central Valley is highly variable between runs and years, but overall is considered generally low (Williams 2006). For maximum embryo survival, water temperatures must be between 5 and 13 degrees Celsius (°C), and oxygen levels must be close to saturation (Healey 1991; Moyle 2002). Under such conditions, embryos hatch in 40 to 60 days and remain in gravel as alevins for another 4 to 6 weeks until the yolk sac is fully absorbed when they emerge as fry.

ALEVIN AND PARR

Size at hatching and emergence depends on water temperature, with optimal water temperatures ranging between 5° and 8°C (Williams 2006). Fry generally are 30 to 40 mm long (Williams 2006).

After emerging from gravel, fry typically are washed downstream into back or edge-water areas, where velocities are slower than the channel thalweg, cover is dense, and prey items are abundant. Many disperse downstream, especially if high-flow events correspond with emergence (Healey 1991; Moyle 2002). Dispersal behavior shows variations among fry that emerge from a single redd, with larger individuals most likely to disperse (Bradford and Taylor 1997). Movement occurs mostly at night; for stream-type individuals, this movement tends to cease after a couple of weeks, when fry settle down into rearing habitat in streams or estuaries. Because ocean-type Chinook salmon juveniles may begin movement immediately, they may move through the Sacramento-San Joaquin Delta (Delta) and pass by the HOR study area. Therefore, it is important to understand the effect of any barrier installed at the HOR study area on the Chinook salmon juvenile life stage.

A major limiting factor for juvenile Chinook salmon is water temperature, which strongly affects growth and survival. For Central Valley fall-run Chinook fry, optimal water temperatures for growth and survival are 13° to 18°C (Marine 1997), although throughout the range of Chinook salmon, positive growth is experienced at water temperatures of 5° to 19°C (McCullough 1999). At 22° to 23°C, mortality is experienced in wild populations, and very few individuals can survive water temperatures greater than 24°C for even short periods of time (Moyle 2002). At sub-lethal water temperatures, growth is reduced and predation rates increased as a consequence. Water temperature in the Delta in June is inversely proportional to survival of Chinook salmon juveniles as they pass through and out of the Delta (Baker et al. 1995; Kjelson et al. 1982).

Optimal juvenile rearing habitat contains instream structure (e.g., undercut banks, large woody debris) and canopy cover, an adequate food supply (aquatic and terrestrial invertebrates), suitable water velocities and depth, and low turbidity (SWRI 2003). In general, microhabitat use by juvenile Chinook salmon occurs in deeper and faster water as they grow larger. Microhabitat use and foraging behavior can be influenced, however, by the presence of predators (i.e., other fish, bullfrogs, piscivorous birds, river otters, harbor seals, and sea lions), which may force Chinook salmon to select areas of heavy cover and suppress foraging in more open areas. During the night, juvenile Chinook salmon may abandon their foraging areas in swift-moving water and retreat to quiet edge-waters or pools (Moyle 2002) as an energy-conserving measure or as a way to avoid nocturnal predators (e.g., Sacramento pikeminnow [*Ptychocheilus grandis*] in the Central Valley) (Moyle 2002).

While in freshwater, juvenile Chinook salmon are opportunistic drift feeders and eat a wide variety of terrestrial and aquatic insects. Juveniles feed mostly during the day, with peaks at dawn and during the afternoon. In the Delta, terrestrial insects are the most important food, but crustaceans also are eaten (Moyle 2002).

Smoltification and Seaward Migration

Juvenile salmonids undergo a set of physiological and behavioral changes before they migrate to the sea. These changes are associated with their downstream migration and the transition from freshwater to marine habitats, and with the transformation from parr into smolts, a physiological process known as smoltification (Williams 2006). Smoltification typically occurs in the spring; if the fish do not migrate, most of these changes reverse and they remain parr, but often they smolt again the next spring (Williams 2006).

In general, stream-type juveniles move downstream and out to sea as smolts, at lengths of 80 to 150 mm fork length (FL), but wild ocean-type (fall-run) juveniles move downstream at smaller sizes (30 to 50 mm FL) to rear in the San Francisco Bay estuary. Movement into the estuary varies with year (Moyle 2002). Migrating juvenile salmon are susceptible to mortality from unscreened water diversions (Yoshiyama et al. 1998).

Hatchery contributions of juveniles and smolts, and their sizes, for this study were described in Chapter 5, “Methods.” The swimming capacity of the hatchery Chinook salmon juveniles in this study was evaluated through a literature review of critical swimming speed (U-crit), a measure of maximum sustained swimming capacity, and sustained swimming speed (Brett 1964; Peake 2008). The lowest U-crit value reported in the literature for Chinook salmon juveniles from Central Valley stock origin is 4.37 body lengths per second (BL/s) at a water temperature of 12°C (Katzman 2001; Swanson et al. 2004) (Table B-1). The HOR study area experienced temperatures greater than 12°C for all 3 years of data collection while a barrier was in place (Figures 3-21, 3-22, 3-23, and 3-24 in Chapter 3, “Physical Parameters”). Presumably, the sustained swimming speed for the hatchery Chinook juveniles in this study due to warmer water is greater than or equal to 4.37 body lengths per second (BL/s) when the barriers are in place. Swanson et al. (2004) used a 120-minute time interval; thus, it was assumed that the hatchery fish in this study could swim 4.37 BL/s for up to, but not more than, 120 minutes.

Table B-1 Swimming-Speed Capacity of Juvenile Chinook Salmon from Central Valley Stock Origin					
Chinook Salmon Size	**Water Temperature (°C)**	**Source**	**Swimming Metric**	**Swimming Speed (body lengths per second)**	**Swimming Speed Time Interval (minutes)**
87–96 mm SL[1]	17	Wild	U-crit	5.91 to 6.26	20
62–79 mm SL[2]	12	Hatchery	Sustained	4.37 to 5.56	120
56–77 mm SL[2]	19	Hatchery	Sustained	4.91 to 6.75	120

Notes: mm = millimeters; SL = standard length; U-crit = critical swimming speed; °C = degrees Celsius
[1] For Katzman (2001), swimming speed reported is the range.
[2] For Swanson et al. (2004), the swimming speed is the mean, in body lengths per second, for the reported size range.
Sources: Katzman 2001; Swanson et al. 2004

As the juveniles and/or smolts move downstream in the San Joaquin River from their natal streams they pass the HOR study area at the divergence of the San Joaquin and Old rivers. Some smolts remain in the San Joaquin River and pass through the Delta, primarily through the eastern and central Delta, on their way to the Pacific Ocean. This route is >89.0 kilometers (km) from the HOR study area to Chipps Island via Stockton (Google Earth 2013).

Another possible route is for the juveniles and/or smolts to enter Old River and migrate through the southern Delta, passing by the entrance of the Tracy Fish Collection Facility (TFCF); this route is >86.2 kilometers (km) from the HOR study area to Chipps Island via the TFCF entrance (Google Earth 2013). In addition, some juveniles that pass the HOR study area and entered Old River could enter the Central Valley Project (CVP) or State Water Project (SWP) pumping plant intakes, subject to salvage, and transported by truck downstream to be released in the western Delta.

Pacific Ocean

Once reaching the Pacific Ocean, juvenile Chinook salmon from California rivers tend to stay along the California coast, although a general northward movement of fish may occur, causing a few to be found off Washington state. Concentration of California salmon in nearby marine waters is not surprising, considering their high productivity. This productivity is caused by upwelling that is generated by the California Current, a southward-moving current originating in the Gulf of Alaska. In these food-rich waters, juvenile Chinook salmon swim at depths that vary with the season (0 to 100 m), but they typically swim deeper than most other salmon. Ocean survival of salmon declines during years when the California Current does not flow as strongly and upwelling decreases (Moyle 2002). Chinook salmon spend a few months to seven years at sea (Williams 2006).

B.1.2 Chinook Salmon—Fall-Run

Status

The Central Valley fall-run evolutionarily significant unit (ESU) covers fall-run and late fall-run salmon in the Sacramento and San Joaquin rivers and tributaries (Lindley et al. 2004; Moyle 2002). This ESU always has been the most abundant run in the Sacramento River watershed, historically numbering over 1 million spawners in some years (Yoshiyama et al. 1998). Although California Central Valley fall-run Chinook salmon is not listed as threatened or endangered under the federal Endangered Species Act (ESA), it was classified in 2004 as a Species of Concern by the National Marine Fisheries Service (NMFS). These are the most common Chinook salmon in the southern Central Valley and make up most of the juvenile Chinook salmon that pass the HOR study area each year.

ADULT AND SPAWNING MIGRATION

Fall-run Chinook salmon are ocean-type Chinook salmon, adapted for spawning in lowland reaches of large rivers and their tributaries.

Fall-run Chinook salmon adults enter Central Valley rivers to spawn between late summer and fall (Williams 2006). Historical spawning habitat of the fall-run Chinook salmon remains available below existing dams. These fish spawn shortly after entering their natal river. The strategy allows fall-run salmon to take advantage of extensive high-quality spawning and rearing areas in valley reaches of rivers that are often too warm to support salmon in summer. Because of the timing of the fall-run, adults pass by the HOR study area before the spring barriers are placed.

Most fall-run Chinook spawn in gravel and cobble areas, primarily at the head of riffles of the main rivers and tributaries in the Central Valley and foothills. Gravel and cobble sizes can range from 0.2 to 15 cm (SWRI 2003). Preferred water velocity for spawning is 0.4 to 1.2 m/s. Spawning typically begins when the water temperature cools to approximately 14° or 15°C, lasting from late September to December, peaking in late October (Fisher 1994; Williams 2006).

EGG

Sacramento fall-run Chinook salmon appear to have exceptionally high fecundity for their size (Healey 1991). The average fecundity of females in the Sacramento River has been estimated to be about 5,500 eggs (Fisher 1994).

ALEVIN, PARR, AND JUVENILE

Fall-run fry emerge from December into April, depending on the date of spawning and water temperature during incubation. They exhibit two main patterns within their ocean-type life-history strategy. Most begin migrating as fry, shortly after emergence (Hatton 1940), and most of these apparently rear for 1 to 3 months in the Delta before moving into the bays. However, some continue directly through Carquinez Strait into San Pablo Bay (Hatton 1940). Analogous groups in Puget Sound, Washington, have been described as “delta users” and “fry migrants” (Greene and Beechie 2004). Of the Chinook salmon that do not leave the spawning reaches as fry, most do so as juveniles by May or early June, before the lower river water temperature become lethal or near lethal, and they pass fairly quickly through the Delta. These larger migrants are sometimes called “fingerlings” or “90-day Chinook,” and are undergoing smoltification. The relative contributions of fry and juveniles migrants to adult escapement are not known, but Williams (2006) has suggested that fry do not survive as well as juvenile migrants.

SMOLT AND SEAWARD MIGRATION

Downstream migration of fall-run Chinook smolts occurs from March through July (Fisher 1994). Reservoirs increase overwinter water temperatures of rivers than was the case historically, so that embryos and alevins develop more rapidly since the development of dams. Monitoring (Snider and Titus 2000a, 2000b, 2000c) indicates that Chinook fall-run fry migrants in the Sacramento River downstream of Shasta Dam begin their migration approximately 1 month earlier than indicated by pre-dam installation monitoring, as reported by Rutter (1904) and Hatton and Clark (1942). The consequences of the change in timing are unknown, but it could be significant (Williams 2006). It should be noted that historic juvenile migration timing should not be directly compared to current juvenile migration timing without considering the genetic influences from hatchery stock and climate change.

The peak exit period for juveniles and smolts out of the Delta and into the estuary is from April through June (Kjelson et al. 1982). Presumably, a peak exists in emigration to the ocean by Chinook salmon, as they pass by the HOR study area during that same period (Table B-2). Kjelson et al. (1982) have suggested that the migration is driven by water temperature. For this reason, it is speculated that the exit of smolts from the San Joaquin River may be earlier than the exit from the Sacramento River because of the more southerly position of the San Joaquin River in the Central Valley.

Table B-2
Dates of Chinook Salmon Salvages from January 1 through June 30
for 10 Years of Data Collected at the Skinner Delta Fish Protective Facility (Byron, California)

Year	First Salvage	Beginning Peak	End Peak	Last Salvage
2003	January 1	January 13	April 24	June 27
2004	January 1	January 14	May 11	June 17
2005	January 1	January 28	June 9	July 3
2006	January 1	February 21	June 22	July 5
2007	January 5	February 23	May 3	June 12
2008	January 13	January 31	May 29	June 7
2009	February 4	April 19	May 16	June 11
2010	January 23	January 26	June 2	July 6
2011	January 1	February 18	June 22	July 21
2012	January 5	–	–	–

Source: Compiled by Turnpenny Horsfield Associates and AECOM from data from CDFG 2012

PACIFIC OCEAN

Once reaching the Pacific Ocean, juveniles switch to a fish diet, and growth is rapid. At age 2, Sacramento River fall-run Chinook salmon average approximately 55 cm FL; at age 3, approximately 70 cm FL; at age 4, approximately 90 cm FL; and at age 5, approximately 100 cm FL (Moyle 2002). Considerable variation exists in length at different ages. Fall-run Chinook salmon spend 1 to 4 years at sea, although fall-run from the San Joaquin River spend the least amount of time, and late fall-run Chinook spend the most time (Myers et al. 1998). Fall-run

Chinook salmon spend most of their oceanic life nearshore. It is speculated that the juveniles and young adults remain close to their natal river.

B.1.3 CHINOOK SALMON—SPRING-RUN

STATUS

The Central Valley spring-run Chinook salmon ESU has been reduced from an estimated 17 historical populations to only four extant populations with consistent spawning runs: Mill, Deer, and Butte creeks, and the Feather River (DWR 2003; NMFS 2008). The reintroduction of an experimental population of spring-run Chinook salmon began in 2014, and any barrier at the HOR study area needs to consider the potential impacts on the reintroduction of these fish.

Historically, spring-run Chinook salmon were likely the most abundant species in the San Joaquin River watershed (Williams 2006; Yoshiyama et al. 1998). However, they have undergone the most dramatic decline among the four Chinook salmon runs in the Central Valley, mainly as a result of intensive in-river harvest pressure and massive losses (70% to 90%) of spawning and rearing habitat in the upper watersheds from construction of hydropower and irrigation diversion projects (NMFS 2008; Yoshiyama et al. 1998).

In the mainstems of the Sacramento and the Feather rivers, spring-run Chinook salmon have undergone significant hybridization with fall-run. Because of the small number of non-hybridized populations remaining and low population sizes, the Central Valley spring-run Chinook ESU was listed as threatened by the State of California in 1998 and by NMFS in 1999 (64 FR 50393, September 16, 1999; Title 50, Part 223 of the Code of Federal Regulations [50 CFR 223]). Critical habitat was designated in 2005 by NMFS (70 FR 52488, September 2, 2005; 50 CFR 226).

ADULT AND SPAWNING MIGRATION

Adult spring-run Chinook salmon enter freshwater in the spring, over-summer in pools while their gametes mature, and spawn in late August to early October (Fisher 1994). Adults pass upstream into their holding areas from February into early July, with migration peaking in mid-April in Butte Creek, mid- to late May in Mill and Deer creeks, and May and June on the Feather River (Williams 2006). If the restored spring-run Chinook salmon run in the San Joaquin River is similar to those in the Sacramento River tributaries, then the adults would pass any barrier in place at the HOR study area.

In rivers, adult spring-run Chinook salmon select large, deep (usually greater than 2 m) pools before spawning. These pools typically have bedrock bottoms and moderate velocities. In California, spring-run Chinook salmon usually hold where mean water column velocities are 0.15 to 0.8 m/s, often under ledges, in deep pockets, or under the “bubble curtain” formed by water plunging into pools (Moyle et al. 1995). The fish do not necessarily stay in the same pool all summer long, but move between pools, usually with a net upstream movement. Holding areas often are near spawning areas. Spawning areas may occur at the tailouts of holding pools.

Spring-run Chinook salmon spawn in late August through early October, with peak spawning in mid-September (Fisher 1994). During the spawning period, water temperatures are decreasing. The species’ spawning areas are in the upper reaches of the Sacramento River mainstem and its principal tributaries (Healey 1991).

Typically, spring-run Chinook salmon spawn farther upstream and at higher elevations than fall-run. In these areas, water cools to suitable temperatures earlier than in the fall-run spawning areas.

Historically, spatiotemporal segregation helped to maintain reproductive isolation on the McCloud River (DFG 1998) and Sacramento River below Shasta Dam (Moffett 1949). However, Slater (1963) reported that the spawning periods of the two runs overlapped, resulting in hybridization. Hybridization between spring- and fall-run Chinook also has occurred in the Feather River (Lindley et al. 2004).

EGG

The average fecundity of females in the Sacramento River has been estimated to be approximately 4,900 eggs (Fisher 1994). Spring-run Chinook salmon spawn when water temperatures are decreasing; evidence exists that their eggs are more tolerant of warm water shortly after fertilization than they are later.

ALEVIN, PARR, AND JUVENILES

The juvenile emergence period occurs from November through March for spring-run Chinook salmon (Fisher 1994). Juveniles may rear in the Delta for 3 to 15 months, depending on flow conditions (Fisher 1994). Spring-run Chinook salmon require cool water while they grow in freshwater over the summer. Since most cool-water habitat is now located upstream of impassable dams, water temperature is a limiting factor to the spring-run.

SMOLT AND SEAWARD MIGRATION

Spring-run Chinook salmon in the Sacramento River exhibit an ocean-type life history, emigrating as fry, sub-yearlings, and yearlings. Most spring-run emigrate from December through March, primarily as newly emerged fry, especially in Butte Creek, but some migrate as larger parr from March through June. Fall-run Chinook salmon produced by the hatcheries are regarded as surrogates for these larger spring-run parr migrants. In the future, after spring-run Chinook salmon are restored to the San Joaquin River, spring-run juveniles and smolts are likely to encounter any barrier type installed at the HOR study area if it is in place from April through June.

Another group of spring-run Chinook salmon parr and juveniles hold over through the summer and migrate in the fall or winter. Only a few hold over until the following spring and migrate as 1-year-old or older juveniles (Williams 2006).

PACIFIC OCEAN

Spring-run Chinook salmon have a wider ocean distribution than fall-run, often leaving nearshore waters in their first year of life and seeking more northerly high-sea areas (Healey 1991). Recent observations show that while the vast majority of spring-run Chinook salmon leave Butte Creek as young-of-the-year, yearling outmigrants account for approximately 25% of the ocean catch of Butte Creek spring-run Chinook (Ward et al. 2002).

B.1.4 STEELHEAD

The iteroparous steelhead trout (*Oncorhynchus mykiss gairdneri*) (Page et al. 2013) includes stream-resident rainbow trout and anadromous steelhead (Moyle 2002) in the Sacramento and San Joaquin rivers below all impassable dams. In this report, *O. mykiss* is used to refer to rainbow trout and steelhead collectively. Resident rainbow trout can have offspring that are anadromous. This rare characteristic is strongly related to parental genetic composition (Stillwater Sciences 2006). Also, anadromous *O. mykiss* can become residents under optimal rearing conditions in freshwater (Cramer and Beamesderfer 2006). For example, streams with water temperatures consistently averaging 11° to 15°C during summer and rarely exceeding 18°C would provide *O. mykiss* with suitable habitat to complete all life stages. A resident strategy would be one possible outcome.

Historically, the greatest steelhead production in the Central Valley came from Sacramento River populations (Lindley et al. 2006). Most observations reported herein derive from this population because no studies of San Joaquin steelhead were completed until 2001 (McEwan 2001).

Historically, steelhead were widely distributed throughout the Sacramento and San Joaquin River watersheds, and were composed of summer- and winter-runs. Presently, only the winter-run persists in the Sacramento–San Joaquin River system (Williams 2006). Because of the construction of dams, summer steelhead were prevented from reaching tributaries in the upper reaches of the watersheds where they previously over-summered in deep, cool pools. As a consequence, summer steelhead in the Central Valley are now extirpated (McEwan 2001).

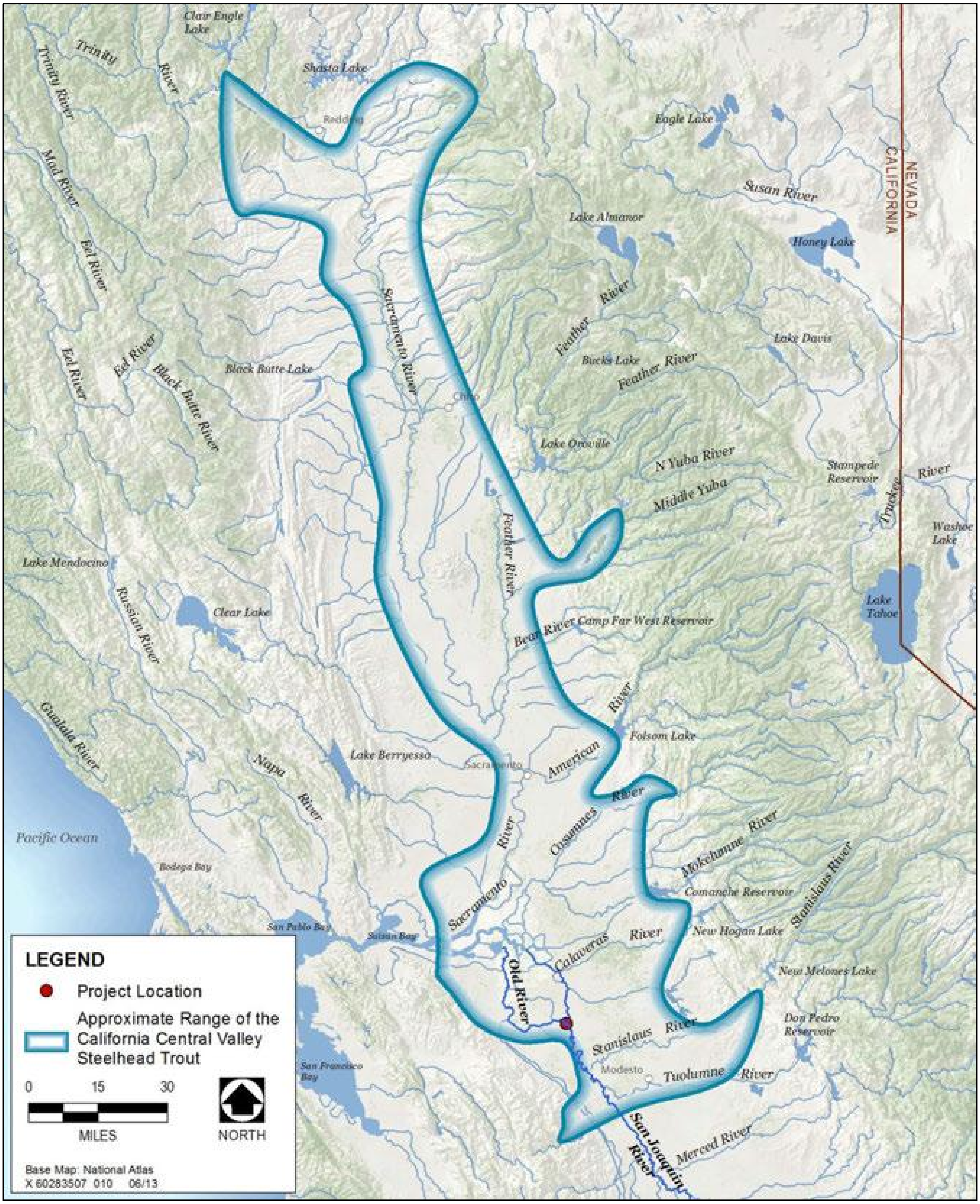
STATUS AND HISTORICAL DISTRIBUTION

The California Central Valley steelhead distinct population segment (DPS)[1] was listed as threatened in 1998 (63 Federal Register [FR] 13347–13371) under the federal ESA. The listing of Central Valley steelhead trout DPS was affirmed in 2006 (50 FR 834–862) (Good et al. 2005). The term "evolutionarily significant unit (ESU)" also is found in literature. In this case, ESU and DPS are equivalent terms, meaning "species" under the ESA (71 FR 834–862). The Central Valley steelhead trout DPS (Figure B-1) includes all naturally spawned populations of steelhead in the Sacramento and San Joaquin rivers and their tributaries below major dams. The populations in the two artificial propagation programs at the Coleman National Fish and Feather River Steelhead hatcheries, are also part of the DPS, but steelhead from the two other hatchery programs (Nimbus Fish Hatchery on the American River and the Mokelumne River Fish Hatchery) are not.

An estimated 95% of the historically available spawning habitat is inaccessible to steelhead because of dam construction and water projects (McEwan 2001; Lindley et al. 2006). The lost habitat resulted in a significant decrease in the population from an estimated 1 to 2 million adult steelhead in the Sacramento–San Joaquin River watershed to as little as 40,000 individuals in the 1960s, and to less than 10,000 in the early 1990s (McEwan 2001).

Some factors contributing to the decline of Central Valley steelhead include habitat alteration, such as bank protection (rip-rap and armoring), dredging, and gravel mining. Some biological stressors also have been identified as contributing to the decline of steelhead: predation, invasive species, and disease (McEwan 2001). However, the two most important factors in the decline of steelhead are the development of water export related resources and management of that water in the Central Valley (McEwan and Jackson 1996). Furthermore, NMFS (1997) has suggested that the decline in the steelhead population has curtailed the species' resiliency to natural factors such as predation, drought, and poor ocean conditions. Lindley et al. (2006) concluded that insufficient information existed to adequately assess the risk of population extinction for Central Valley winter run steelhead.

[1] West Coast steelhead (*O. mykiss*) includes 10 DPS (NOAA 2006). DPS policy is found at 61 FR 4722, February 7, 1996.



Source: 71 *Federal Register* 834–862

Figure B-1 **California Central Valley Steelhead Range**

ADULT

After spending 1 to 4 years at sea, adult Central Valley steelhead return to the Sacramento River weighing between 1.4 and 5.4 kg (Moyle 2002) and measure 35 to 65 cm TL. Steelhead rely on olfactory cues to find their natal stream during the spawning migration. Most steelhead make their way into freshwater beginning in August, with a peak in September and October (McEwan 2001). However, in nearly every month of the year, steelhead migrate up the Sacramento River (Moyle 2002). A barrier in place at the HOR study area may influence the behavior of adults or change the passage difficulty of migrating upstream. During the upstream spawning migration, many adults travel through the area of the HOR study area. Changes in flow patterns by the construction of any barriers may have impacts on upstream migrating adults. No such effects have been quantified to date.

Williams (2006) and McEwan (2001) have suggested that some Central Valley steelhead may hold for months in spawning streams while gamete maturation is completed, but now this life history pattern is rare because of the loss of suitable habitat. Thus, most steelhead become sexually mature in the ocean and spawn soon after reaching their spawning sites (Williams 2006). Spawning in the upper Sacramento River generally occurs between November and late April with a peak from early January through late March (Reclamation 2004). The spawning peak occurs when water temperatures throughout much of the Sacramento River are suitable to support egg incubation and emergence. It is suspected that these conditions would be similar in the San Joaquin River.

In the Sacramento River watershed, steelhead spawn in Butte, Deer, and Mill creeks; the American, Feather, Stanislaus, and Yuba rivers; and the Sacramento River below Keswick Dam (Figure B-1) (CALFED 2010; Moyle 2002). Under historical conditions, steelhead spawned in much higher gradient reaches in the Sacramento River and its tributaries than any other steelhead DPS in western North America (McEwan 2001).

Spawning occurs where well-oxygenated water exists, good hyporheic flow is found, and water temperatures are appropriate (McEwan and Jackson 1996). The female digs a redd in a riffle, successively digging, spawning, and resting as she moves upstream. Water velocity varies between 0.2 and 1.5 m/s, and depth varies from 0.1 to 1.5 m. Typically, one dominant male will spawn with one female, but other males also can participate (Moyle 2002). Larger steelhead spawn in the higher range of water velocity (McEwan 2001). Steelhead redds generally are found in substrates ranging from 0.6 to 10 cm in diameter (Bjornn and Reiser 1991).

Steelhead is iteroparous: surviving post spawners can return to the ocean. After a year or more, gamete rematuration occurs and steelhead migrate back to their natal streamto spawn again. Although some kelts (post-spawned adults) have been documented in the Sacramento River, probably few repeat spawners exist in this population (Reclamation 2004). Repeat spawners are observed returning every other year (Moyle 2002). Photoperiod, stream flow, and water temperature appear to influence emigration timing (Holubetz and Leth 1997).

Adult post-spawning outmigration occurs from March through July. The steelhead kelts moving from the southern Central Valley tributaries from April to June will travel through the HOR study area while a barrier is in place.

EGGS

Female steelhead lay approximately 2,000 eggs per kg of body weight and leave the spawning ground soon after laying their eggs, while males remain to have a chance to spawn with more than one female (Moyle 2002). Egg hatching is temperature-dependent, but generally requires 4 weeks.

No Central Valley–specific information exists about water temperature requirements for successful spawning and incubation, but values derived from other steelhead stocks in more northerly locations suggest that optimal spawning water temperatures are between 4° and 11°C, with egg mortality occurring at water temperatures above 13°C (Bell 1986; Bovee 1978; Hooper 1973; McEwan and Jackson 1996; Reiser and Bjornn 1979).

FRY

After hatching, sac-fry will remain in the gravel 4 to 6 weeks before emerging (McEwan and Jackson 1996; Shapovalov and Taft 1954). Once the yolk sac is fully digested, fry emerge from the gravel and become free-swimming (Quinn 2005). The timing of emergence by fry (less than or equal to 50 mm total length [TL]) is strongly influenced by water temperature (Shapovalov and Taft 1954). Fry congregate along the bank in shallow water (Barnhart 1986), where velocity is low. During spring rearing, fry may be vulnerable to entrainment at unscreened diversions.

JUVENILE: PARR AND SMOLT

In rivers, juvenile steelhead search for energetically advantageous positions (Bowen 1996). They tend to select velocity shelters adjacent to swift velocities that provide abundant drifting invertebrates. These shelters allow maximize energy intake while minimizing the cost of swimming to maintain position (Everest and Chapman 1972; Fausch 1984). Steelhead may remain in these velocity shelters for a long time if the position is of sufficient quality, affording low focal velocity and high-velocity shear. These energetically advantageous positions can increase growth and survival, and individual fish may display aggressive behavior to defend them (Bowen 1996). In more open habitat (e.g., large pools), juveniles are not as territorial and are more prone to school with similar-size congeners (Moyle 2002). While in the river, they feed primarily on drifting invertebrates (Moyle 2002).

The preferred water temperature range for juveniles is between 7 and 14°C (Bell 1986). At water temperatures greater than 21°C, steelhead have trouble extracting oxygen from the water (Hooper 1973). The upper, lethal thermal limit is between 23.9°C (Bell 1986) and 24.0°C (Nielsen et al. 1994).

The triggers that influence whether or not juvenile *O. mykiss* migrate to the sea are complex (Quinn 2005). *O. mykiss* may become resident and spend their entire life in freshwater. Thus, *O. mykiss* released at Durham Ferry could conceivably swim upstream and survive to reproduce. However, for those individuals that choose anadromy, they spend 1 to 3 years in freshwater before outmigrating; a tiny proportion in California, perhaps 0.3%, emigrate when older than 4 years (Quinn 2005). Hatcheries in the Central Valley produce *O. mykiss* that emigrate to the ocean when older than 1 year.

The Mokelumne River Fish Hatchery in Clements, California, provided the juvenile steelhead used to evaluate fish barriers in this report (Table 5-1 in Chapter 5, "Methods"). Brood stock for steelhead are collected and spawned in November and December (Smith, pers. comm., 2013). The hatchery maintains the juveniles for more than 1 year to mimic the winter-run steelhead life history.

The Mokelumne River Fish Hatchery uses the following four process stages of development (Smith, pers. comm., 2013):

(1) Eggs are incubated at 11.1 to 12.2°C until they hatch.

(2) Once the sac-fry fully absorb their yolk sacs, the fry are fed at a high rate with a target of an 18% to 20% weight increase per week.

(3) The parr then are moved to outdoor "raceway ponds" at 60 to 80 mm TL, and are fed 2% of their total body weight per day.

(4) In the autumn, the juveniles are starved on alternating weeks to keep the growth rate slow and meet the stocking target of 180 mm TL in February, when the fish are approximately 15 months old.

The parr may undergo the behavioral and physiological changes of smoltification. For this study, the fish were held past the stocking target and used in the period of experimental releases from April through June.The juveniles were parr or smolts, depending on the degree of smoltification of each individual, and ranged in size from 110 to 320 mm TL (Table 5-1 in Chapter 5, "Methods"). The juveniles produced in the hatchery were used in this research as surrogates for naturally produced (wild) steelhead, and surgically implanted with acoustic transmitters and released in the San Joaquin River 24.4 km upstream of the HOR study area (see Chapter 5, "Methods").

The U-crit (Brett 1964; Peake 2008) was evaluated via literature review. The reported U-crit for hatchery steelhead ranged from 3.02 to 5.76 BL/s (Table B-3). Steelhead on the small end of the size range of the species was used in the experimental releases (Table B-3). To be conservative, the lowest U-crit, 3.02 BL/s, was selected as the minimum U-crit that the experimentally released steelhead would exhibit. Thus, it was assumed that the hatchery steelhead in this study could swim 3.02 BL/s for up to, but not more than, 2 minutes. The water temperatures that occurred at the HOR study area were impossible to determine definitively, but they generally were closer to 19°C than to 10.5 to 11.5°C. As a result, it seems plausible, that a U-crit for steelhead juveniles in this study may have been closer to 4.72 BL/s. (This value is similar to the sustained swimming speed used for Chinook salmon; see Table B-1.)

Table B-3
Steelhead Critical Swimming Speed, U-crit, for Juveniles

Fish Size (mm; length ± SE)	Water Temperature (°C)	Source	U-crit Body Lengths per Second (-2SE to +2SE)	U-crit Time Period (minutes)
109 ± 6.1 (TL ± SE) [1]	19	Hatchery	4.72 to 5.76	10
126 ± 0.5 (FL ± SE) [2]	10.5 to 11.5	Hatchery	3.02 to 4.34	2
148.6 ± 1.9 (FL ± SE) [3]	10.5 to 12	Hatchery	3.90 to 5.52	5

Notes: FL = fork length; SE = standard error of the mean; TL = total length; U-crit = critical swimming speed; mm = millimeters; °C = degrees Celsius
Values reported are Mean - 2 SE to Mean + 2 SE. The actual range of values was not available for all studies, and only SE could be determined for all three references to provide a directly comparable statistic.
Sources: [1] Myrick and Cech 2000; [2] Anderson et al. 1997; [3] Murchie et al. 2004

Juvenile steelhead emigrate to the Pacific Ocean from the Central Valley between November and late June, with a peak from early January through late March (Reclamation 2004) (Table B-4). Therefore, juvenile steelhead pass by the HOR study area mostly from November through June; These juveniles would be affected by any barrier at the HOR study area during this period.

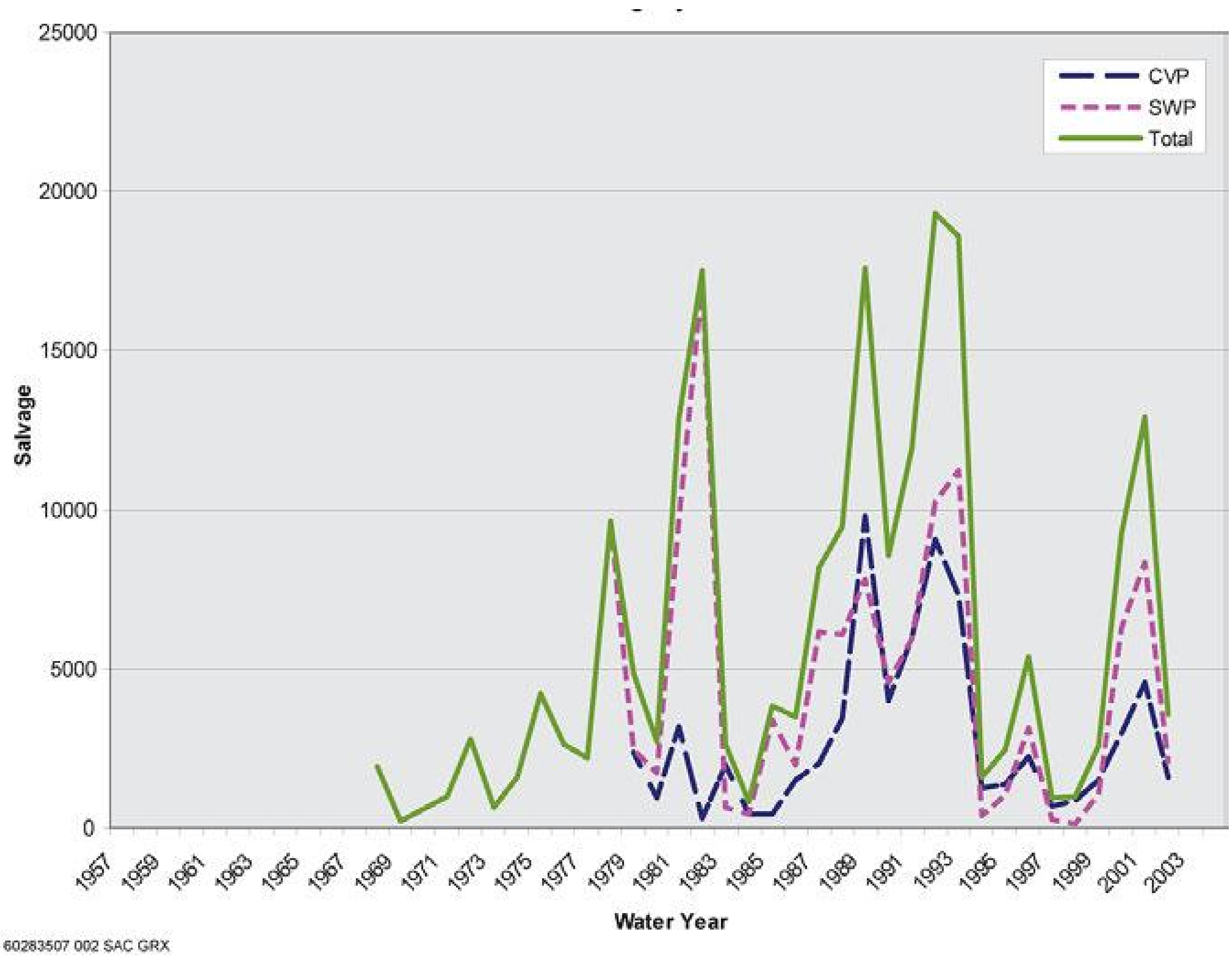
Table B-4
Dates of Steelhead Salvage January 1 through June 30 for 10 Years of Data Collected at the Skinner Delta Fish Protective Facility (Byron, California)

Year	First Salvage	Beginning Peak	End Peak	Last Salvage
2003	January 1	January 11	February 10	June 24
2004	January 6	February 15	March 2	May 19
2005	January 8	January 26	March 2	June 27
2006	January 4	February 18	April 11	June 28
2007	January 14	February 26	April 25	May 30
2008	January 25	February 15	March 1	June 10
2009	January 18	February 25	March 26	May 23
2010	January 19	February 7	March 10	June 27
2011	January 18	February 18	March 13	June 29
2012	January 5	March 29	April 18	June 3

Source: Present Study

Juvenile steelhead measuring 100 to 250 mm FL that are between 1 and 3 years old emigrate to the ocean (Moyle 2002; Reynolds et al. 1993). In coastal populations, juvenile steelhead migrate downstream at older than 1 year old and rear in the estuary for an additional 1 year before the onset smoltification. Some steelhead older than 1 year old moving down the Sacramento River are captured in rotary screw traps at Red Bluff Diversion Dam (RBDD), Glenn Colusa Irrigation District, and Knights Landing. These captures represent a large group of outmigrating juveniles that are experiencing the parr–smolt transition, and could theoretically spend some time rearing in the Delta. However, little information is available about use of the Delta by steelhead as rearing habitat (Stillwater Sciences 2006).

All species of fish using the Delta are affected by CVP and SWP operations (71 FR 834–862). The potential effects of water diversions on steelhead have not been comprehensively evaluated (McEwan 2001). However, pre-screen loss at Clifton Court Forebay is 82 to 87% (Clark et al. 2009). Steelhead are salvaged at the CVP and SWP, and the number salvaged varies depending on the year (Figure B-2).



Source: Dan B. Odenweller, California Department of Fish and Wildlife

Figure B-2 Combined Number of Steelhead Salvaged from Tracy Fish Collection Facility (CVP) and Skinner Delta Fish Protective Facility (SWP)

B.2 OTHER SPECIES FOR PROTECTION AT HEAD OF OLD RIVER

B.2.1 DELTA SMELT

STATUS

The delta smelt (*Hypomesus transpacificus*) is endemic to the Sacramento-San Joaquin River Delta. Before 1970, it was undifferentiated from pond smelt, *Hypomesus olidus* (Moyle 2002). Until the early 20th century, delta smelt were common enough to be harvested commercially in the Delta (Bennett 2005). Delta smelt were listed as threatened under the federal and state ESAs in 1993. Between 1993 and 1999, some years saw a small rebound in delta smelt numbers. By 2002, populations of delta smelt, longfin smelt (*Spirinchus thaleichthys*), threadfin shad (*Dorosoma petenense*), and young striped bass (*Morone saxatilis*) were declining in the monitoring surveys. Sommer et al. (2007) hypothesized that poor stock size, habitat deterioration, increased winter entrainment, and zooplankton declines in rearing areas contributed to the decrease in the delta smelt population. Baxter et al. (2008) specified these factors in the decline of delta smelt: fewer adults lead to reduced larval production, reduced food in the low-salinity zone, reduced size because of prey species changes, and increased winter entrainment. Bennett (2005) reported reduced food availability as one of the main causes for the decline of delta smelt. Various detailed analyses in recent years have supported some of the above factors as being of importance to delta smelt survival and abundance, and have also highlighted other factors such as increasing water clarity as being important (Mac Nally et al. 2010; Thomson et al. 2010; Miller et al. 2012; Rose et al. 2013a,b).

ADULT

Delta smelt are small translucent fish with large eyes. Adults typically have a fork length between 60 and 70 mm, but can reach lengths exceeding 120 mm FL (Moyle 2002). Most delta smelt complete their life cycle in 1 year, but some live for 2 years.

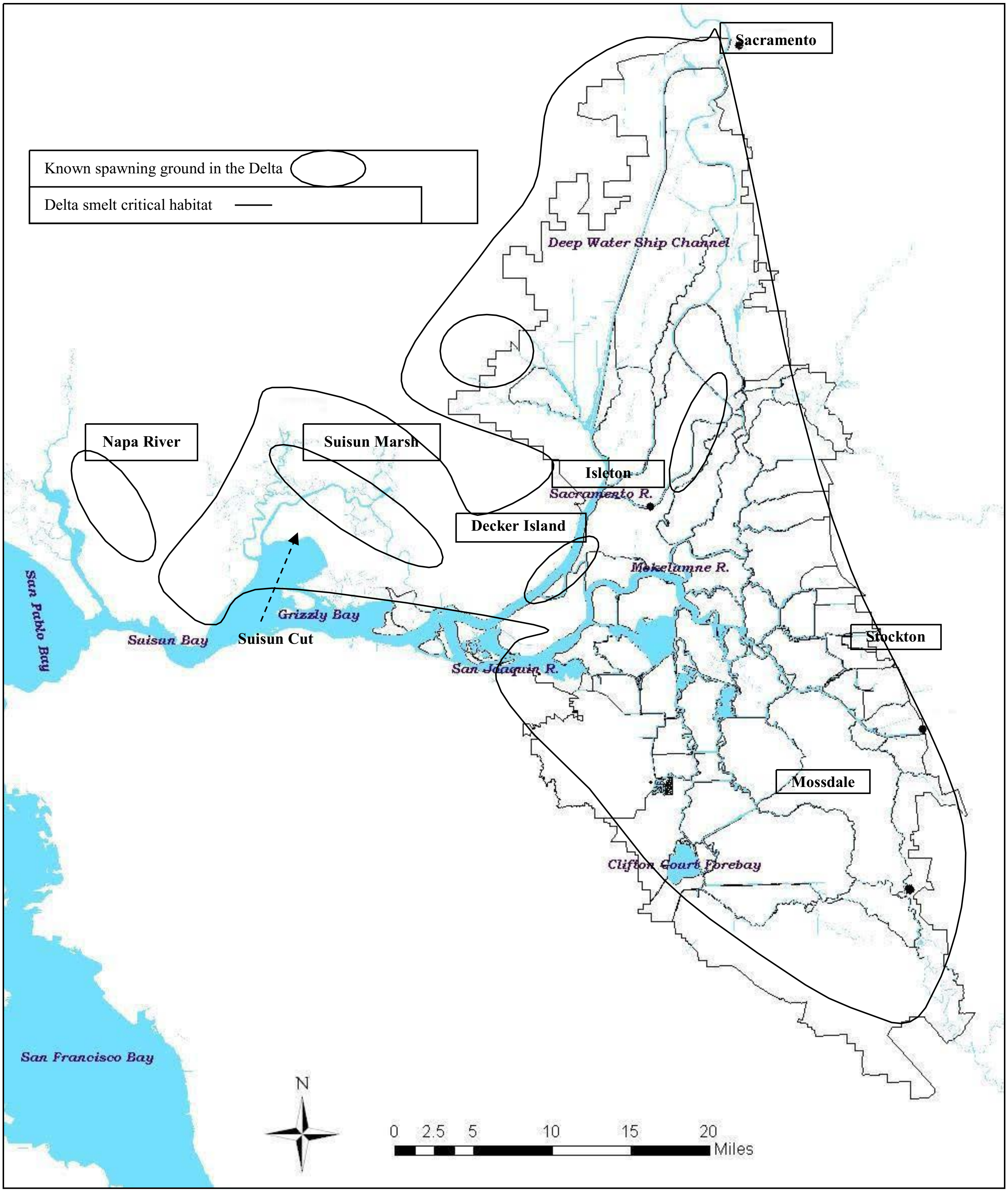
Delta smelt are found principally in Suisun Marsh and the Delta (Figure B-3) (Moyle et al. 1992). Most of the year, delta smelt are found around Suisun Marsh and Decker Island (Bennett 2005). Delta smelt have recently been recorded in the Sacramento Deep Water Ship Channel and may be using this area for spawning.Their distribution in the Delta is seasonal but does not appear to be determined by water temperature. Delta smelt can be found in water throughout a broad temperature range, but less than 25.4°C, their critical thermal maxima (Swanson et al. 2000).

Delta smelt inhabit a broad range of salinities, from 0 to 18 practical salinity units (PSU). Delta smelt typically inhabits shallow waters (less than 3 m) with salinity of 18 PSU or lower (fresh to mesohaline). A salinity of 19 PSU (polyhaline) is lethal to delta smelt (Swanson et al. 2000). Most delta smelt are caught in water with salinity ranging from 0.2 to 2.0 PSU (fresh to oligohaline). These shallow areas are rich in zooplankton with hydraulic conditions that delta smelt seek to maintain position to improve feeding (Bennett 2005). This zone also is referred to as the Low Salinity Zone (LSZ). During high tide conditions, the LSZ can be found as far inland as 161 km (100 miles) upstream near the City of Sacramento on the Sacramento River. The LSZ also can be found as far west as the Carquinez Strait under high-flow conditions (Hobbs et al. 2006). Delta smelt abundance usually is centered a little upstream of the 2.0 PSU mark (Bennett 2005).These conditions are favorable for the prey of delta smelt, and thus, delta smelt remain near the LSZ. Delta smelt are poor swimmers, with a maximum burst speed of approximately 0.35 m/s (Cech, pers. comm., 2013). They usually swim in a short burst with a period of glide. This stroke-and-glide behavior may allow delta smelt to avoid predators.

The main prey for delta smelt historically was calanoid copepod (*Eurytemora affinis*) (Moyle et al. 1992). However, *E. affinis* has declined precipitously in the Delta attributed to the introduction of the clam (*Corbula amurensis*) by 1986[2] (Kimmerer et al. 1994). As *E. affinis* became rare, it was replaced in the delta smelt's diet by the copepod (*Pseudodiamptomus forbesi*). *P. forbesi* was observed for the first time in the San Francisco Bay estuary in 1987 (Carlton et al. 1990). However, *P. forbesi* also has experienced a precipitous decline, beginning at approximately the time of the arrival of the introduced copepod (*Limnoithona tetraspina*).

Since its introduction to the San Francisco Bay estuary in 1993 (Orsi and Ohtsuka 1999), *Limnoithona tetraspina* has become increasingly numerous (Bouley and Kimmerer 2006). This increase has occurred at the expense of *P. forbesi*. Furthermore, *L. tetraspina* is less susceptible to predation by delta smelt. Thus, Bennett (2005) has concluded that this has reduced food availability and is one of the main causes for the decline of delta smelt.

[2] First record from Suisun Bay in October 1986.



Source: Data provided by California Department of Water Resources in 2013

Figure B-3 **Map of the Sacramento–San Joaquin Delta Showing Hypothesized Spawning Areas of Delta Smelt**

Delta smelt seldom were found in the stomach of predators, even when delta smelt were more abundant (Moyle 2002). The turbidity of the Delta, the transparency of delta smelt, and their burst-and-glide swimming behavior seem to be a good strategy to avoid predation (Moyle 2002).

Adults

Delta smelt migrate from the LSZ in the western Delta upstream to spawn from late February through May. The actual migration starts after the first winter flush of water due to rain in December, when the LSZ is farther downstream and turbidity is more than 12 Nephelometric turbidity units (NTU) (Grimaldo, pers. comm., 2013). Depending on the water quality conditions, both delta smelt spawning grounds and migration routes vary from year to year. For undetermined reasons, delta smelt migrate preferentially to the Sacramento River or the San Joaquin River in different years. Their selection of spawning location could be influenced by water quality (Moyle 2002). In those years when delta smelt migrate to the San Joaquin River to spawn, any movements from the south Delta upstream may change after construction of a barrier or delta smelt may be inhibited by the presence of a barrier at the divergence of the San Joaquin and Old rivers.

Many channels have been connected in the Delta to accommodate water distribution to irrigate agricultural lands. One of the major structural changes is that the Delta once had a dendritic structure, but many waterways are now linked (J. Burau, pers. comm., 2012). The Delta's current structure may allow increased numbers of delta smelt to become entrained at the CVP and SWP water export facilities from greater distances than would have occurred with the historic Delta dendritic structure.

The state managed Harvey O. Banks Pumping Plant and the federally managed Jones Pumping Plant, both located in the south Delta (Figure B-3), draw a large amount of water from the north Delta toward the south Delta for export. At times of high export, the net flow of rivers in the Delta can be negative, toward the diversion facilities, rather than positive, toward the ocean. The combinationof levee construction, interconnection of all Delta channels, and pumping plant export operations can lead delta smelt to be entrained at the pumps, increasing the probability of their mortality (Kimmerer 2008).

Delta smelt spawn February through June, with a peak around April (Moyle 2002). The spawning behavior of delta smelt is suspected to be triggered by a water temperature ranging from 14 to 18°C (Bennett 2005). Lunar cycles also are thought to be an important cue for spawning season (Moyle and Cech 1996). According to Hobbs et al. (2006), the suitable salinity for spawning is from 0 to 0.5 PSU (freshwater). At salinities exceeding 0.5 PSU, the suitability for spawning drops sharply. According to Bennett (2005), larger delta smelt may migrate earlier, and therefore, may spawn earlier and spawn more than once. No spawning area for delta smelt is known to exist upstream of the HOR study area (Figure B-3).

The preferred spawning habitat is not known, but based on the preferences of other smelt species, it may be sandy shoals (Sommer and Mejia 2013) like those located in the Sacramento Deep Water Ship Channel. Delta smelt release their eggs close to the substrate and rarely on vertical substrate (Bennett et al. 2002).

Eggs and Larvae

Females usually have approximately 1,200 to 2,600 eggs (Moyle et al. 1992). Fecundity increases with body length (Mager 1996), with a second-year smelt having three to six times as many eggs as a first-year smelt (Wang 2007).

Fertilized eggs are approximately 1 mm in diameter and likely adhere to the sandy substrate. Yolk-sac larvae hatch at 5.5 to 6.0 mm TL, 10 to 14 days after spawning. Early-hatching larvae can be from bigger delta smelt that can spawn early (Bennett 2005). These early-hatching larvae may be more likely to be entrained at the Banks and Jones pumping plants. This entrainment of early-spawned larvae may result in negative selection against the offspring of the larger, early-spawning females. Larvae are particularly vulnerable to pesticides. Furthermore, depending on the spawning location, larvae can rear in areas receiving agricultural or urban wastewater. The amount of pesticides in the water can be low, below a lethal dose, but the mixture of multiple pesticides and lengthy exposure can have sublethal effects (Kuivila and Moon 2004).

In the spring, water diversion is substantially reduced under the Vernalis Adaptive Management Program (VAMP). This reduction is executed to accommodate migrations by juvenile Chinook salmon. VAMP was created to reduce entrainment at the export facilities by helping migratory fish reach areas less influenced by the export pumping activities.

Ultimately, juvenile delta smelt need to reach the LSZ, where they can find advantageous feeding areas, although a portion of the population remains in productive upstream areas such as the Cache Slough complex year-round (Sommer et al. 2011a). Many delta smelt are carried to Suisun Bay by the first floods of spring. During this downstream migration period, they are vulnerable to entrainment at agricultural diversions or the pumps located in the south Delta. They also can be flushed into San Pablo Bay if the freshwater flow is very high, resulting in salinity related mortality. The larvae are attracted by light and swim close to the surface. The yolk sac is absorbed when the larvae reach a size of 6 to 7 mm TL, 4 to 5 days after hatching. Subsequently, the larvae become external feeders (Bennett 2005). At this early stage, delta smelt consume subadult cyclopoid and calanoid copepods (Nobriga 2002). At this stage, the growth rate of delta smelt is unknown in the wild (Bennett 2005). The high turbidity in which the first life stages exist suggests that feeding success is prey-density dependent. When they reach 10 to 15 mm TL, larvae feed on adult copepods (Nobriga 2002).

JUVENILES

The post-larval stage (15 to 20 mm TL) is reached 20 to 40 days after hatching, which typically is in June. The swim bladder usually is fully developed. This is when the fins are just starting to unfold (Bennett 2005).

Post-larval juveniles often are concentrated in Suisun Marsh close to the shore (Bennett 2005). In June, large schools of delta smelt can be found in Suisun Cut (Figure B-3), thought to be a critical nursery habitat (Hobbs et al. 2006).

Juveniles (20 to 50 mm FL) have a growth rate averaging 0.35 mm per day. Adult morphological characteristics appear when the fish reach 25 to 30 mm FL (Bennett 2005).

Delta smelt can be widely dispersed in the Delta, but usually are associated with the LSZ. Their swim bladder allows them to go up and down within the water column and stay in the LSZ. In Suisun Cut, delta smelt have a reverse diel vertical migration. They are close to the surface during the day and more widely distributed in the water column at night. This behavior may lead to increased feeding success (Bennett et al. 2002).

By early September, delta smelt reach 55 to 70 mm standard length (SL) (Moyle 2002). By fall, they are fully grown. Between fall and February, most of the energy is allocated for gamete production.

Nobriga et al. (2013) found that there was no correlation between the abundance of juvenile striped bass and delta smelt survival, which could be attributed to relatively low spatial overlap of the two species or predation by striped bass always being sufficiently high to suppress the delta smelt population growth rate. According to Matica and Nobriga (2005), 27% of June and July inflows to the Delta are diverted for agricultural uses in the Delta. Most of these diversions pass through unscreened siphons, 20 to 46 cm in diameter, that draw water 60 to 90 cm above the channel bottom. These diversions may significantly affect the survival rate of delta smelt; however, analyses on the cumulative impact of these diversions on delta smelt remain unstudied, although Nobriga et al. (2004) noted that the low spatial overlap of delta smelt (generally occurring away from shore) with these diversions and the small hydrodynamic influence of these diversions led to low density of juvenile delta smelt in the entrainment samples they examined.

POTENTIAL BARRIER EFFECTS

Delta smelt are an indicator species for the health of the Sacramento-San Joaquin River-Delta. Delta smelt is a short-lived species of low fecundity. The species' life strategy is unusual and requires specific water quality and biotic conditions at certain times of the year to be successful. Delta smelt are highly adapted to the Delta's conditions; however, the Delta has changed considerably over the past 100 years. Delta waters are more consistently fresh and less similar to estuarine conditions and accommodate invasive species that are adapted to similar conditions in other systems. Two principal life stages are most vulnerable to direct influences by the operation of a fish barrier at the HOR study area. First, adult delta smelt must be able to migrate upstream from the area of the LSZ to spawning areas from winter through spring (generally December through March/April). Second, post-larvae and juveniles must be able to move from spawning areas back to the LSZ (generally March through June).

Delta smelt could be in the area of the HOR study area during their adult spawning migration and juvenile migration downstream to the LSZ. These life stages are most likely to be affected by the installation of a barrier at the HOR. As discussed previously, delta smelt are not known to spawn upstream of the HOR study area; thus, the potential impacts of a barrier are only hypothetical at this time.

B.2.2 GREEN STURGEON

STATUS

Few or no green sturgeon (*Acipenser medirostris*) have ever been recorded in the San Joaquin River (Adams et al. 2007), although white sturgeon (*A. transmontanus*) have been recently been documented to spawn in the lower San Joaquin River (Jackson and Van Eenennaam 2013). Because fish in the San Joaquin River have unimpeded access from the Sacramento River through the Delta, it is possible that green sturgeon may use the San Joaquin River, like white sturgeon. Therefore, the life history of green sturgeon and the potential effects of a barrier at the HOR on this species are discussed.

The population of green sturgeon that spawns in the Sacramento River is a member of the southern DPS[3] and was listed as threatened under the federal ESA in 2006[4] (Adams et al. 2007). In 2007, the California Fish and Game Commission adopted new regulations that made harvesting green sturgeon illegal. Although green sturgeon has little commercial value, it is a valuable species for traditional tribal fisheries and for the biodiversity of Pacific Northwest ecosystems. This anadromous fish is rare within the Delta, and population densities are sensitive to harvest (Heppell 2007). Little is known regarding green sturgeon's life history in and out of the Delta.

Adults

Green sturgeon is a long-lived species which exhibits bimaturation. Male smature earlier than females (Moyle 2002) at 13 to 18 years (152 to 185 cm TL), and females at 16 to 27 years (165 to 202 cm TL) (Beamesderfer et al. 2007). The maximum age is unknown, but Moyle (2002) hypothesizes that a maximum age of 60 to 70 years is possible. The maximum recorded ages for males and females, respectively, are 32 and 40 years at the Klamath River according to Beamesderfer et al. (2007).

Green sturgeon is the most marine-oriented sturgeon species, spending more time in the ocean than other members of the family Acipenseridae. Adults (greater than 150 cm TL) primarily are oceanic. NOAA (2005) postulated that green sturgeon may come into contact with polluted waters less often than white sturgeon because green sturgeon spends more time at sea. Adults can be found in inlets and bays along the West Coast, from Baja California to Alaska (Moyle 2002). However, the only adult tagged in San Pablo Bay proceeded out the Golden Gate immediately after tagging, strengthening the argument that adults are primarily ocean-going (Kelly et al. 2007).

In the ocean, green sturgeon disperses widely after outmigration from freshwater (Moyle et al. 1992). NOAA (2005) summarized results from acoustic tags, Oregon trawl books, and archival tags, showing that some green sturgeon make migrations as far north as Vancouver Island, Canada. During these saltwater migrations, green sturgeon commonly were found in water 40 to 70 m, and were never observed in water greater than 100 m in depth.

The adult green sturgeon diet includes small fish and benthic invertebrates such as shrimps, clams, and amphipods (Houston 1988; Moyle et al. 1992). Although no comprehensive assessment of the green sturgeon diet has been completed since that time, this diet could have changed; green sturgeon's common foods may have been replaced by the nonnative clam *Corbula amurensis*, established in the Delta by 1986. *C. amurensis* has become the most common food of white sturgeon, and also has been found in green sturgeon (DFG 2002).

Moser and Lindley (2007) suggested that adults may use the entire west coast of North America, but green sturgeon do not appear to reenter freshwater for any significant amount of time unless ready to spawn. In the San Francisco Bay-Delta, adults begin migrating into freshwater in late February. The spawning migrating southern DPS adults may encounter significant barriers. This DPS is suffering the loss of habitat in the Sacramento River, and some of this loss is caused by passage problems. During irrigation operations May 15 through September 15, Red Bluff Diversion Dam (RBDD) historically was a partial barrier and reduced upward migration of adult green

[3] A fish population is considered a DPS if it represents an ESU of a biological species. The fish stock must satisfy two criteria to be considered an ESU: (1) it must be substantially isolated reproductively from other population units and (2) it must represent an important component in the evolutionary legacy of the species (61 FR 61 4722, February 7, 1996).

[4] 71 FR 17757, April 7, 2006.

sturgeon (Brown 2007). Observations of spent adult green sturgeon have been made at RBDD (Brown 2007). Heublein (2006) reported that early green sturgeon migrants successfully passed RBDD and spawned. During the warmer months and when the Sacramento River is at low flow, water temperature increases and dissolved oxygen decreases. However, the swimming capacity of green sturgeon is not altered by water temperature up to 24°C (Allen et al. 2006) or by moderate hypoxia (Kaufman et al. 2006).

The Feather River is thought to be the most likely lost historical spawning habitat for green sturgeon (DFG 2002). Green sturgeon have been recorded in the Feather River as larvae caught in screw traps (Beamesderfer et al. 2004). Spawning has recently been recorded with eggs from three different sturgeon females (Van Eenenaam 2011). In spring 2011, many sturgeon adults were spotted while DIDSON surveys were being conducted (Seesholtz 2011). No juvenile green sturgeon have been documented in the San Joaquin River.

Green sturgeon are iteroparous, spawning every 2 to 5 years (Moyle 2002). The oldest females are estimated to spawn only eight times in their lifetime (Klimley et al. 2007). Spawning occurs from March through July, with peak activity April through June (Moyle 2002). Green sturgeon spawn in deep areas, or “holes,” that are large, with turbulent and swift waters (0.8 to 2.8 m/s) (Moyle 2002; Parsley et al. 1993). Green sturgeon require specific spawning habitat, such as rocky substrates with crevices (Deng et al. 2002).

The Sacramento River has the only known spawning habitat for the southern DPS of green sturgeon (Moyle 2002). The main spawning area is thought to be between Hamilton City (river kilometer 320) and Keswick Dam (river kilometer 486) (DFG 2002) (Figure B-3). Heublein (2006) reports that Battle Creek is good spawning habitat for green sturgeon. The decline in green sturgeon abundance occurred after Keswick Dam was built, primarily because of the loss of spawning habitat located upstream (Moyle 2002).

Moyle (2002) suggests that green sturgeon may have reproduced in the San Joaquin River, because adult green sturgeon were captured at Santa Clara Shoal and Brannan Island State Recreation Area in the Delta. However, green sturgeon have not been documented in the San Joaquin River upstream of the Delta, and have not been observed in the river’s tributaries (Beamesderfer et al. 2007; DFG 2002). The earliest available records noted green sturgeon as being “abundant in the [San Francisco] Bay and the rivers and creeks flowing into it” (Beamesderfer et al. 2007; Lockington 1879), but these reports do not specify green sturgeon locations. An impassible barrier (Friant Dam), high water temperatures, low discharges, possible entrainment, introduced species, poaching, pesticides, heavy metals, and poor water quality reduce the chance that green sturgeon could colonize the San Joaquin River (NOAA 2005).

Individual green sturgeon may emigrate after spawning, but many individuals aggregate in freshwater during summer before returning to the ocean in the fall (Belchik 2005). The largest known aggregation of green sturgeon in the Sacramento River is found near the Glenn Colusa Irrigation District’s diversion intake (Heublein 2006). Green sturgeon appear to emigrate when temperatures fall below 10°C, generally after the first fall rainstorm (Erickson et al. 2002).

Green sturgeon tagged in spawning areas of the Klamath, Rogue, and Columbia rivers and Willapa Bay, Washington, with acoustic transmitters in 2002, 2003, and 2004 sustained migrations of 100 km per day. Rogue River fish tagged in 2002 returned in 2004, suggesting a minimal spawning periodicity of 2 years in the Rogue River watershed (NOAA 2005).

Eggs

Green sturgeon eggs require cold, well-oxygenated water. They spawn the largest eggs (with a mean diameter of 0.434 cm) of any sturgeon species (Cech et al. 2000). Females generate 60,000 to 140,000 eggs (Moyle 2002). The high degree of adhesiveness of its eggs allows green sturgeon to spawn in fast-moving water (Heublein 2006). The eggs incubate for approximately 6 days.

Larvae and Juveniles

After spawning and egg incubation, most larvae hatch at sizes between 0.8 and 1.9 cm TL (Emmett et al. 1991). Optimum temperatures for larval development are between 15° and 19°C (Mayfield and Cech 2004), but development can still occur at temperatures as low as 11°C (Van Eenennaam et al. 2005).

Juvenile green sturgeon (i.e., those less than 1.5 years of age, 75 cm TL, and 1.5 kg) are not physiologically ready for estuarine or oceanic emigration (Allen 2005; Allen and Cech 2007). In experiments with seawater treatments, 23% of juveniles less than 100 days post-hatch died because of starvation in the 33% salinity treatments (Allen and Cech 2007). Ten percent of the juveniles died in a second treatment with salinity of less than 3%. Allen and Cech's (2007) experiment showed that juveniles are more likely to survive if they spend some time in freshwater or the LSZ (e.g., the river or the Delta) before continuing to the ocean. Freshwater residence time is uncertain, but in the Klamath River, juvenile green sturgeon could spend between 1 and 4 years in freshwater and the estuary before entering the ocean (Nakamoto et al. 1995).

Exogenous feeding is correlated with the initiation of downstream migration (Moyle 2002). Based on trap samples at RBDD, downstream movements of juvenile green sturgeon occur from May through August at sizes between 2 and 6 cm (Gaines and Martin 2002). In riverine environments, juvenile green sturgeon are substrate-oriented and active at night (Kynard et al. 2005). In the Sacramento River watershed, juvenile green sturgeon swim down the Sacramento River and enter the Delta. The Delta is both a migratory route and a rearing ground. In the Sacramento–San Joaquin watershed, green sturgeon reach the ocean at approximately 1.5 years of age (Moyle 2002). They enter the ocean primarily during summer and fall (Emmett et al. 1991). Potentially, green sturgeon juveniles that use the Delta as a rearing area could come into contact with a barrier at the HOR study area.

Exogenous feeding begins 10 to 15 days after hatching when fish are 2.3 to 2.5 cm in length (Deng et al. 2002). Little is known about the diet of juvenile green sturgeon. The diet of green sturgeon changes as it grows; this is evident in the diet summary presented by the California Department of Water Resources (DWR 2003). In the Delta, small juveniles eat opossum shrimp (*Neomysis mercedis*) and amphipods (Radtke 1966). Then, as they grow, green sturgeon eat invertebrates such as clams, shrimps, and crabs associated with the demersal habitats that they frequent. As adults, green sturgeon eat the previously described demersal invertebrates and demersal fish (Kohlhorst 2001).

During downstream migration by juvenile green sturgeon they can be entrained at the SWP and CVP water diversion facilities and their associated fish salvage facilities, the Skinner Delta Fish Protective Facility (SFPF) and Tracy Fish Collection Facility (TFCF). Before 1986, SFPF caught an average of 732 green sturgeon per year. After 1986, the annual average fell to 47. At TFCF, 889 green sturgeon were salvaged per year before 1986, and 32 per year after 1986. Green and white sturgeon may not have been differentiated before 1986. However, large decreases apparently occurred at SFPF between the mid-1970s and 1986, and at TFCF during the mid-1980s (NOAA 2005). The decline in green sturgeon continues with fewer fish entrained each year (fewer than 10 individuals annually) at state and federal fish facilities (DFG 2002). For example, between 1993 and 1997, seven green sturgeon were caught at SFPF and TFCF.

In freshwater, juvenile green sturgeon are subject to predation from invasive species. For example, in July 2000, two juvenile green sturgeon (each approximately 10 cm long) were regurgitated from two smallmouth bass (*Micropterus dolomieu*) that were caught on the Umpqua River in Oregon (NOAA 2005).

Substrate composition has a significant effect on larval green sturgeon growth, according to Nguyen and Crocker (2007). Green sturgeon larvae prefer flat and smooth surfaces, such as slate rock. Nguyen and Crocker (2007) also noticed that green sturgeon larvae typically are photosensitive. In their native environment, slate rock-like surfaces can provide cover from light and predators. Sand and cobble substrates seem to be lethal for these exogenous feeders. The green sturgeon feeds by suctioning river substrate (Nguyen and Crocker 2007). Sand can affect their digestive system. Also, the larvae can become trapped between cobbles.

Subadult

Subadult (sexually immature) green sturgeon are more than 1.5 years old and 75 cm TL, but less than 15 years old and 150 cm TL. At this age, subadult green sturgeon enter the ocean or remain in the estuary to feed and grow. Kelly et al. (2007) indirectly showed that subadult green sturgeon may use the San Francisco Bay estuary as a feeding ground. Kelly et al. (2007) tagged four subadult green sturgeon in San Pablo Bay and tracked them for 12 months. These four sturgeon remained in San Pablo Bay for the entire tracking study. Kelly et al. (2007) recorded movements characteristic of foraging behavior. Summer concentrations in coastal estuaries may indicate feeding aggregations or thermal refugia (Beamesderfer et al. 2007; Moser and Lindley 2007). Moser and Lindley (2007) hypothesized that green sturgeon improve their growth rates in summer by foraging in the relatively warm, saline waters of Willapa Bay, Washington. Green sturgeon may use San Pablo Bay, where they are found in unusual numbers, because San Pablo Bay's warm water is similar to that of Willapa Bay (Beamesderfer et al. 2007).

The data from salvaged fish at SFPF and TFCF are the only data available on green sturgeon, and cannot be used to examine population size (Beamesderfer et al. 2007) because of limitations in how these data were collected. However, Beamesderfer et al. (2007) described a hypothetical population structure for green sturgeon, with the majority of the population (63%) represented by subadults from age 1.5 to 15 years old. If true, the main threat to their continued existence could reside in the estuaries in the summer where these subadult fish spend substantial time.

Potential Barrier Effects

Long lifespan, delayed maturation, large body size, high fecundity, iteroparity, and anadromy are life-history traits of the green sturgeon. These traits do not lend themselves toward overcoming the challenges (predation, entrainment, and introduced species) at the HOR study area. Juveniles may spend an appreciable duration of time in the Delta, but are difficult to study because they do not seem to school. Therefore, identifying local threats and vulnerabilities in the Delta and estuary can be difficult. The principal threats to green sturgeon in the Delta are thought to be pollution, loss of habitat, and entrainment at water diversion systems. Subadults may use the warm summer waters in San Pablo Bay to achieve higher growth rates than in cooler habitats. Because of the lack of data, a complete and accurate picture of the life history of green sturgeon is not possible. Specifically, more information is needed to get a complete picture of the green sturgeon's life history should it be determined that green sturgeon do occur in the San Joaquin River. Until then, the potential impact of a barrier at the HOR study area on green sturgeon is hypothetical.

B.3 FOCAL PREDATORY FISH SPECIES

B.3.1 STRIPED BASS

Striped bass is an anadromous, iteroparous fish native to the eastern United States (St. Lawrence River to Louisiana) and introduced into the San Francisco Bay estuary in 1879 (Dill and Cordone 1997). A commercial fishery for striped bass was established within 10 years of introduction and continued until the fishery was closed in 1935 due to an observed severe population decline in the San Francisco Bay estuary. The commercial fishery maintained annual catches averaging 660,000 pounds in the fishery's final decade (Skinner 1962, as cited by Dill and Cordone 1997). The sport fishery developed more slowly than the commercial fishery. By the late 1960s, it became extremely popular, and constituted approximately 60% of the angling dependent on the San Francisco Bay estuary, including the ocean and river Pacific salmon fisheries (Chadwick 1968, as cited by Dill and Cordone 1997). Population estimates for striped bass are problematic as the portion of the population inhabiting the ocean remains unstudied and current estimates are based upon fish counted in the rivers and estuary only. Adult striped bass are commonly caught off beaches from Monterey Bay to San Francisco. Recent studies have shown that subadult striped bass also emigrate to the ocean (LeDoux-Bloom 2012).

The adult striped bass population (males age 2 and older and females age 4 and older) was estimated at between 2.3 and 3 million fish in the early 1960s (Dill and Cordone 1997). Adult abundance declined from the 1960s to the late 1980s/early 1990s, at which point female abundance was estimated by modeling at 500,000 fish and male abundance was 300,000 to 400,000 fish (Loboschefsky et al. 2012). Subsequent abundance from the mid-1990s to mid-2000s was higher. The abundance of subadult striped bass (males younger than age 2 and females younger than age 4) was estimated to be highly variable (4 to 15 million fish) between 1981 and 2003; age 2 abundance doubled in the mid- to late 1990s (Loboschefsky et al. 2012).

Striped bass are epipelagic, opportunistic feeders, and prey changes with life stage and season. Juvenile and older striped bass prey upon fish and invertebrates. Striped bass prey selection has not been studied in the Pacific Ocean. Modeling has estimated the total annual consumption of prey fish by striped bass (age 3 and older) between 1969 and 2004 in the San Francisco Bay-Delta watershed ranged between approximately 8,200 metric tons in 1994 and approximately 30,500 metric tons in 1972 (Loboschefsky et al. 2012). Annual total consumption of prey fish by subadult striped bass (those ages 1 and 2) between 1981 and 2003 was estimated to have varied between approximately 2,000 metric tons in 1988 and approximately 19,000 metric tons in 1999/2000 (Loboschefsky et al. 2012).This estimate may be high as subadults are known to consume mainly benthic invertebrates during this life stage.

The abundance of young-of-the-year striped bass collected in the Fall Midwater Trawl survey conducted by the CDFW has declined considerably over time. It is unknown why this has occurred based on the lack of a similar decline in adult abundance (Baxter et al. 2010). Factors related to the decline in young-of-the-year abundance may include changes in summer food availability, fall Delta outflow, water clarity, and low adult abundance (MacNally et al. 2010; Thomson et al. 2010).

A long-term shift of smaller striped bass distribution into shallower areas may have occurred, which decreased the number of the species available for capture in survey trawls (Sommer et al. 2011). Telemetry studies of subadult striped bass have shown seasonal shifts in habitat use in winter and spring associated with changing water temperature and schooling behavior based on salinity and possibly the onset of sexual maturity (LeDoux-Bloom 2012). Seasonal habitat preference may influence predation rates and create seasonal predation hotspots. Of particular relevance at the HOR study area is the overlap of adult upstream migration periods with the downstream migration period of juvenile salmonids when water temperature exceed 15°C.

Based on catch composition from angling studies (e.g., DWR 2012), striped bass appear to be the main transitory predatory fish species at the HOR study area and elsewhere in the Delta, at least during the main months of interest for outmigrating juvenile salmonids (late winter through late spring). The effects on trends in the populations of native fish species from striped bass predation have received some study. Using a modeling approach, Lindley and Mohr (2003) suggested that increases in the abundance of adult striped bass could appreciably increase the probability of extinction of winter-run Chinook salmon. No support exists for abundance of adult striped bass (combined with water clarity) as a factor influencing trends in delta smelt abundance (Maunder and Deriso 2011; Miller et al. 2012). The main biological and ecological characteristics of striped bass are summarized in Table B-5.

B.3.2 Largemouth Bass

Largemouth bass is a freshwater native from the eastern United States. Largemouth bass was introduced into California's Central Valley in the 1890s (Dill and Cordone 1997) and was present in the Delta shortly thereafter (Baxter et al. 2010). Abundance in the Delta has increased considerably over the past several decades, at the same time as an increase in coverage of the naturalized and invasive submerged aquatic plant species *Egeria densa*,[5] with which largemouth bass are associated (Baxter et al. 2010; Brown 2003). The Delta now is rated as one of the top ten fishing locations in the United States for the centrarchid basses, including largemouth bass (Hall 2013)

Largemouth bass switch to piscivory at smaller sizes than do striped bass and other predatory fish species such as Sacramento pikeminnow and catfishes. Largemouth bass consume a larger number of native fish species than striped bass (Nobriga and Feyrer 2007). Studies about the potential effect of largemouth bass on the native fish population are ongoing. Some early analyses show evidence of negative effects of largemouth bass on native fishes (e.g., MacNally et al. 2010; Maunder and Deriso 2011) while others do not (Miller et al. 2012). The main biological and ecological characteristics of largemouth bass are presented in Table B-6.

B.3.3 Channel Catfish

Channel catfish (*Ictalurus punctatus*) is a freshwater native to central U.S. drainages and northern Mexico. The population in California's Sacramento River area is likely the result of planting that occurred in the American River in the 1920s (Dill and Cordone 1997). Channel catfish are omnivorous, scavengers and consume fish prey

[5] Commonly referred to as Brazillion waterweed, large-flowered waterweed, or *Elodea.*

as part of their diet (Moyle 2002). A summary of channel catfish biological and ecological characteristics is presented in Table B-7.

B.3.4 WHITE CATFISH

White catfish (*Ameiurus catus*) is a freshwater native to the U.S. Atlantic coastal states and was introduced into the San Joaquin River at Stockton in 1874 (Dill and Cordone 1997). White catfish spread rapidly following introduction, and provided a significant portion of the 200,000- to 700,000-pound-per-year commercial catfish fishery that developed in the Delta before the fishery was closed in 1953 as a result of overfishing concerns (Dill and Cordone 1997).

Catfish constitute one of the most popular inland sport fisheries in California (Dill and Cordone 1997). The population in the south Delta is relatively slow growing, possibly the result of high density and low prey availability (Schaffter 1997). White catfish are omnivorous scavengers and their diet includes fish (O'Rear 2012). O'Rear (2012) studied the dietary habits of white catfish in Suisun Marsh and the relative potential effects on native fishes. He concluded that white catfish do not eat fishes targeted for conservation and much of the food they eat is either not utilized by at-risk or commercially important fishes or is unlikely to be limiting. Consequently, white catfish appear to be relatively harmless to populations of other fishes in Suisun Marsh. Predation on fish by white catfish appeared to occur only when water management of wetlands made such predation feasible. O'Rear (2012) suggested that high production of fish and invertebrates in managed wetlands could contribute to a larger population of white catfish in Suisun Marsh in the future, and that such a population increase could pose more of a threat to fish species of conservation concern. A summary of the main biological and ecological characteristics of white catfish are provided in Table B-8.

Table B-5
Main Biological and Ecological Characteristics of Striped Bass

Maximum Size and Age	Size By Age	Diet and Other Feeding Characteristics	Primary Habitat and Environmental Conditions	Migratory Behavior	Intraspecific Associations	Reproduction
125 cm FL (41 kg), >30 years (Moyle 2002)	First year: 9–11 cm FL Second year: 23–30 cm FL Third year: 28–40 cm FL Fourth year: 44–54 cm FL Growth of 5–10 cm/year thereafter (Moyle 2002) Assumed sizes at age in bioenergetics modeling by Loboschefsky et al. (2012): 1: 172 mm FL 2: 254 mm FL 3: 448 mm FL 4: 537 mm FL 5: 611 mm FL 6: 680 mm FL (Loboschefsky, pers. comm., 2013)	Age 1: 12% fish, 88% other (by volume) Age 2: 82% fish, 18% other (by volume) Age 3+: 99% fish, 1% other (by volume) (values assumed by Loboschefsky et al. 2012) Epipelagic opportunistic feeders that consume most possible prey types, including fish such as American and threadfin shad, juvenile striped bass, and juvenile salmonids (Moyle 2002; Tucker et al. 1998)	Pelagic (Moyle 2002); temperature tolerance 7.2° to 27°C, salinity 0–33.7 ppt, current velocity tolerance 0–500 cm/s and optimum 0–100 cm/s (Hassler 1988); intolerant of poor water quality conditions and low oxygen; inhabit water temperatures above 16°C when available (LeDoux-Bloom 2012).	Subadults (~23–42 cm FL) in the Bay-Delta watershed have three main residency patterns: riverine (freshwater), low-salinity zone (0.5 to 10 ppt), and bay (10–30 ppt) (LeDoux-Bloom 2012). Riverine residents from the Sacramento/American Rivers move to the south Delta (Clifton Court Forebay) in fall, and then return upstream to the rivers in spring. Subadults emigrate to the ocean in winter and return to the bays and rivers in late spring (LeDoux-Bloom 2012). Adults generally move into freshwater from San Pablo and San Francisco Bays in fall, and many overwinter in the Delta before a spring upstream spawning migration and return to the bays thereafter (Moyle 2002; LeDoux-Bloom 2012).	Gregarious (Moyle 2002)	Spawn in freshwater mostly from mid-April to mid-June (Hassler 1988). No spawning occurs below 14°C, optimum temperature is 15° to 20°C, and spawning ceases at >21°C (Moyle 2002). Most San Joaquin River spawning occurs from Venice Island to Antioch, and farther upstream in high-flow years (Moyle 2002). Females typically first spawn at 4–6 years (45 cm FL), and males mostly first spawn at 2–3 years (25 cm FL) (Moyle 2002).

Notes: °C = degrees Celsius; Bay-Delta = San Francisco Bay/Sacramento–San Joaquin Delta; cm = centimeters; FL = fork length; kg = kilograms; cm/s = centimeters per second; mm = millimeters; ppt = parts per thousand

Table B-6
Main Biological and Ecological Characteristics of Largemouth Bass

Maximum Size and Age	Size By Age	Diet and Other Feeding Characteristics	Primary Habitat and Environmental Conditions	Migratory Behavior	Intraspecific Associations	Reproduction
76 cm TL (10.5 kg), 16 years (Moyle 2002)	First year: 5–20 cm Second year: 7–32 cm Third year: 15–37 cm Fourth year: 20–41 cm (Moyle 2002)	Generally subsist on fish when greater than 100–125 mm SL (Moyle 2002). Fish greater than 150 mm FL have high probability of having fish in stomachs (Nobriga and Feyrer 2007). Fish consumed in older studies included threadfin shad, Chinook salmon, bluegill (*Lepomis macrochirus*), and black crappie (*Pomoxis nigromaculatus*) (Turner 1966a). Bullfrogs (*Lithobates catesbeiana*) formed more than 50% of diet in specimens examined by Turner (1966a). Fish consumed in San Joaquin River downstream of Old River in 2008–2010 included juvenile largemouth bass; threadfin shad; shimofuri gobies (*Tridentiger bifasciatus*); western mosquitofish (*Gambusia affinis*); and unidentified gobies, sunfish, and catfish (Conrad, pers. comm., 2013). Active during most of day and moonlit nights, intense foraging at dusk, most efficient foraging in low to moderate light (Moyle 2002). Feeding rate decreases with increasing turbidity (Ferrari et al. 2013; Huenemann et al. 2012).	Tolerate poor water quality conditions: can survive water of 36°–37°C and dissolved oxygen down to 1 milligram per liter (Moyle 2002). Optimal growth at 25°–30°C, with adults preferring 27°C (Moyle 2002). Usually found in waters with salinity <3 ppt and avoid salinities >5 ppt in California (Moyle 2002). Generally found close to shore in areas with lower flows (optimally <6 cm/s, unsuitable at >20 cm/s) (Stuber et al. 1982); individual adults may remain in restricted areas close to structures (submerged rocks or woody debris) or wander widely (Moyle 2002).	Spring migrations to areas with suitable spawning habitat may occur within river systems (e.g., movements in excess of 5 km) (Goclowski et al. 2013).	Solitary as adults, school as juveniles (Moyle 2002).	Spawn into nests created and guarded by males in sand, gravel, or debris-littered bottoms, often next to submerged objects (e.g., logs and boulders) in shallow waters (0.5 to 2 m) (Moyle 2002). Nest-building begins at 15°–16°C (March/April), and spawning continues up to 24°C (June). First spawning at 18–21 cm TL (males) and 20–25 cm TL (females) in second/third year (Moyle 2002).

Notes: °C = degrees Celsius; cm = centimeters; FL = fork length; kg = kilograms; cm/s = centimeters per second; mm = millimeters; ppt = parts per thousand; TL = total length; SL = standard length

Table B-7
Main Biological and Ecological Characteristics of Channel Catfish

Maximum Size and Age	Size By Age	Diet and Other Feeding Characteristics	Primary Habitat and Environmental Conditions	Migratory Behavior	Intraspecific Associations	Reproduction
>100 cm TL (>26 kg), nearly 40 years; in California fish more than 53 cm TL (2.5 kg), 10 years are unusual (Moyle 2002).	In good habitat: First year: 7–10 cm TL Second year: 12–20 cm TL Third year: 20–35 cm TL Fourth year: 30–40 cm TL Fifth year: 35–45 cm TL (Moyle 2002)	Omnivorous, including mostly invertebrates and fish (Moyle 2002). Piscivory begins at larger size (30–38 cm TL) (Moyle 2002), with fish in diet of larger catfish found to be 11% of stomach volume in Clifton Court Forebay (Edwards 1995) and 25% in the Delta as a whole (Turner 1966b). Fish species consumed in Clifton Court Forebay included striped bass and threadfin shad (Edwards 1995). Feed at night in faster water (Moyle 2002).	Main channels of large streams, with adults spending daytime in pools or beneath logjams/undercuts, then moving into faster water to feed at night (Moyle 2002). Optimal midsummer water temperatures in pools/backwaters/littoral areas for adults are 26°–29°C; maximum salinity in summer is optimal at approximately 1 ppt or lower, and suitability is zero at around 12 ppt (McMahon and Terrell 1982). Tolerant of a wide variety of environmental conditions, such as low dissolved oxygen (Moyle 2002).	Studies in other systems have demonstrated both migration and homing of channel catfish (e.g., occupation of relatively small home ranges in summer followed by migration downstream in fall, then return upstream to spawn in spring in the lower Wisconsin River) (Pellett et al. 1998).	Schooling has been observed for a number of weeks in stocked hatchery-reared channel catfish, with schools breaking up following a period of high flow/turbidity (Siegwarth and Johnson 1998).	Variable size/age at maturity, but typically at least 30 cm TL (>3 years) (Moyle 2002). Spawning at 21°–29°C (26°–28°C is optimal) (Moyle 2002). Cave-like sites used for nesting (e.g., old muskrat burrows, undercut banks, logjams, riprap) (Moyle 2002). Males aerate their nests (Moyle 2002).

Notes: °C = degrees Celsius; cm = centimeters; kg = kilograms; ppt = parts per thousand; TL = total length

Table B-8
Main Biological and Ecological Characteristics of White Catfish

Maximum Size and Age	Size By Age	Diet and Other Feeding Characteristics	Primary Habitat and Environmental Conditions	Migratory Behavior	Intraspecific Associations	Reproduction
>60 cm TL (>3 kg), but fish >2 kg are unusual (Moyle 2002).	Average for first 8 years of life in south Delta: First year: 125 mm FL Second year: 163 mm FL Third year: 192 mm FL Fourth year: 214 mm FL Fifth year: 229 mm FL Sixth year: 243 mm FL Seventh year: 258 mm FL Eighth year: 272 mm FL (Schaffter 1997)	Carnivorous bottom feeders, occasionally at surface to feed on planktivorous fishes (Moyle 2002). Wide variety of bottom-oriented food items, including invertebrates (amphipods and opossum shrimp). Percentage of diet made up by fish is variable: 40% (Turner 1966b), 4% (Edwards 1995), 20% (O'Rear 2012). Fish species consumed included sculpin *Cottus* spp.) in Clifton Court Forebay (Edwards 1995), and threespine stickleback (*Gasterosteus aculeatus*), prickly sculpin (*Cottus asper*), shimofuri goby, yellowfin goby (*Acanthogobius flavimanus*), western mosquitofish, and rainwater killifish (*Lucania parva*) in Suisun Marsh (O'Rear 2012).	Most abundant in slow-current areas; avoid shallow areas (<2 m) by day but move into them by night; tolerate salinity of 11–14.5 ppt, but not present in Suisun Marsh at >8 ppt (Moyle 2002). Usually found in water that is >20°C in summer, and tolerate 29°–31°C (Moyle 2002).	No regular seasonal migrations; aggregate in deepest parts of channels in winter, and disperse more widely in warmer months (Moyle 2002).	Aggregate in deeper parts of channels (Moyle 2002).	Mature at 20–21 cm FL, with spawning at >21°C (mostly June–July) (Moyle 2002). Nests built by males on sand, gravel, near cover, or caves made by rocks (Moyle 2002). Males care for the young (Moyle 2002).

Notes: °C = degrees Celsius; cm = centimeters; FL = fork length; kg = kilograms; mm = millimeters; ppt = parts per thousand; TL = total length

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APPENDIX C

Comparisons Using HTI- and VEMCO-Derived Data

C.1 INTRODUCTION

Two primary acoustic telemetry manufacturers design equipment that was used or evaluated in the current study: Hydroacoustic Technology, Inc. (HTI) (Seattle, Washington) and VEMCO (Bedford, Nova Scotia, Canada). For this report, HTI acoustic transmitters, receivers, and software were used to collect behavioral information in the form of two-dimensional (2D) data (position information obtained using two or more hydrophones at a time). In contrast, VEMCO acoustic transmitters and receivers were used by the Six-Year Steelhead Study (6YSS) team to collect survival information in the form of one-dimensional data (position information obtained using one hydrophone at a time). The fact that juvenile salmonids with VEMCO transmitters were passing through the Head of Old River (HOR) study area in 2012 during the experimental period provided an opportunity to compare the utility of these two technologies for our study purposes.

The HTI gear used in 2012 was used for hydrophone deployment, which is described in Section 5.1.3, "Acoustic Telemetry Assessments." Thirteen hydrophones were used to provide 2D tracks upstream and downstream of the physical rock barrier (Figure 5-4).

The VEMCO gear used in 2012 consisted of four sets of hydrophones deployed around the HOR study area:

- one hydrophone, VEMCO-HOR-U (Figure 5-13), was approximately 650 meters (m) upstream of the HTI San Joaquin River (SJR) start line;
- one hydrophone, VEMCO-HOR-W (Figure 5-13), was approximately 64 m upstream of the HTI SJR start line;
- four hydrophones were deployed downstream of the HTI SJR finish line, the furthest of which was 554 m downstream and defined the VEMCO SJR finish line; and
- four hydrophones were deployed downstream from the HTI Old River finish line, the furthest of which was 860 m downstream and defined the VEMCO Old River finish line.

Decisions about further monitoring and research in the south Delta would benefit from knowing whether data collected using these two types of equipment were comparable and which type of equipment would be an appropriate fit for a planned study. Thus, the primary objective in collecting and analyzing data with VEMCO equipment was to determine whether there was any observed difference between VEMCO- and HTI-derived data.

The one measure of barrier efficiency that was determined using both HTI and VEMCO gear was overall efficiency (O_E) for juvenile Chinook salmon in 2012 (See Table C-1, hypothesis $HC1_0$). Juvenile Chinook salmon O_E (see Equation 5-1 in Chapter 5, "Methods") was the number of tags inserted into juvenile Chinook salmon and released at Durham Ferry that were 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 upstream HOR study area hydrophones (Figure 5-13). A similar calculation was made with juvenile steelhead using tags inserted into juvenile steelhead and released at Durham Ferry.

Table C-1 Objectives and Hypotheses Related to Juvenile Salmonid Routing Including Barrier Effects, as Derived from VEMCO and HTI Equipment			
Year and Treatment	**Objective**	**Hypothesis Number**	**Hypotheses**
2012 Physical Rock Barrier	Determine whether, for 2012, the overall efficiency derived from tagged juvenile Chinook salmon with HTI acoustic transmitters was the same as the overall efficiency derived from tagged juvenile Chinook salmon with VEMCO transmitters.	$HC1_0$	Rock barrier overall efficiency estimated from VEMCO gear was equal to the overall efficiency estimated from HTI gear for juvenile Chinook salmon.
	Determine barrier efficiency in 2012 using VEMCO gear.	$HC2_0$	Overall efficiency was the same for juvenile Chinook salmon and juvenile steelhead.
Source: Data compiled by Turnpenny Horsfield Associates and AECOM 2013			

Comparisons of treatments (barrier/years) for juvenile Chinook salmon O_E using HTI-derived gear are presented in Section 6.1.8, “Comparison Among Barrier Treatments from 2009 (BAFF On), 2010 (BAFF On), 2011 (No Barrier), and 2012 (Rock Barrier),” in Chapter 6, “Results.” In this appendix, these HTI-derived O_E observations are compared with VEMCO-derived O_E observations.

In 2012, juvenile Chinook salmon and steelhead were surgically implanted with VEMCO transmitters. This allowed a direct comparison of the physical rock barrier effectiveness between species (Table C-1, hypothesis $HC2_0$). However, for HTI-derived data in 2012, no comparison between species could be made because only five juvenile steelhead were detected through the HTI hydrophone array. The sample size was too small to allow valid hypothesis testing or analysis.

Transit speed was the other measure of behavior efficiency determined with both HTI and VEMCO gear for juvenile Chinook salmon in 2012. Transit speed for a tagged juvenile salmonid was the distance traveled from an upstream detection point to a detection point downstream from the divergence in either the San Joaquin or Old rivers, divided by the amount of time the tag took to travel that distance. See Appendix D, “Transit Speed Analysis,” for a discussion on transit speed.

C.2 METHODS

C.2.1 VEMCO EQUIPMENT SPECIFICATIONS

Two hatchery sources were used to provide the juvenile Chinook salmon and steelhead in 2012 (Table C-2). The juvenile Chinook salmon that received VEMCO tags had a different size range but were from the same hatchery (Merced River Fish Hatchery) as the fish that received HTI tags (Tables 5-1 and C-2). The juvenile steelhead that received VEMCO tags had a different size range than the fish that received HTI tags (Tables 5-1 and C-2). The hatchery production methods for the juvenile Chinook salmon and steelhead used in the study were the same for both VEMCO and HTI and described in Appendix B, “Focal Fish Species Information.” In 2012, the target tag burden was seldom exceeded (Table C-3).

Table C-2 Juvenile Salmonids Used for Head of Old River Barrier Evaluations with VEMCO Gear						
Study Year	Species	Hatchery	Run	Total Number Released	Minimum size (mm TL)	Maximum size (mm TL)
2012	Chinook Salmon	Merced River Fish Hatchery	Fall	961	100	199
2012	Steelhead	Mokelumne River Fish Hatchery	Winter	1,435	115	316

Notes: mm = millimeter; TL = total length.
Source: Israel, pers. comm., 2013

Table C-3 Range of VEMCO Tag Burdens Experienced by Juvenile Salmonids						
		Percent Tag Burden				
Study Year	Model Number	Minimum	Mean	Maximum	Percentage of Tags Exceeding 5% of Body Mass	Species
2012	V5	0.020	0.038	0.054	3.5	Chinook Salmon
2012	V6	0.003	0.009	0.030	0.0	Steelhead

Source: Data compiled by Turnpenny Horsfield Associates 2013

In 2012, Model V5 tags inserted into juvenile Chinook salmon and Model V6 tags inserted into the juvenile steelhead (Table C-4) had newly available coding from VEMCO. The first type of coding was typical VEMCO coding with Pulse Period Modulation (PPM), which allowed each tag to produce a unique series of pulses in a transmission sequence that lasted 3–5 seconds. A 30-second nominal delay occurred (although the exact amount of time ranged randomly from 20 to 40 seconds) before subsequent transmissions. This first type of coding was detected at all locations except at the Tracy Fish Collection Facility (TFCF) and Skinner Delta Fish Protective Facility (SFPF) in the southwest Delta. The second type of coding, which was used at the TFCF and SFPF, was a newly available High Residency/PPM (HR/PPM) transmission alternated with the PPM transmission. This HR/PPM transmission was similar to the PPM. Thus, there were two codes for each tag in the dataset. The HR/PPM transmission capability was designed to lower the rate of transmission collisions when a large number (greater than 10 tags) were resident for long periods near a VEMCO hydrophone.

Table C-4 VEMCO Acoustic Tag Model and Specifications Used in the HOR Studies						
Study Year	Model Number	Quantity Used	Diameter (mm)[1]	Length (mm)[1]	Mass Range (g)[2]	Used for sampling
2012	V5	961	5.0	12.0	0.62 to 0.71	Juvenile Chinook Salmon
2012	V6	1,435	6.0	16.5	1.01 to 1.08	Juvenile Steelhead

Notes: g = grams; HOR = Head of Old River; mm = millimeter.
Sources: [1] VEMCO 2012; [2] U.S. Fish and Wildlife Service 2012

All VEMCO hydrophones near the San Joaquin River–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 buoys on the surface (Figure 5-5 in Chapter 5, "Methods.").

C.2.2 ACOUSTIC TELEMETRY ASSESSMENT—VEMCO GEAR

The description of the methodologies will point primarily to publications of cooperative entities (i.e., the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, and San Joaquin River Group Authority) in the south Delta research programs. These entities were responsible for the VEMCO gear's deployment, maintenance, and removal in 2011 (SJRGA 2013) and 2012 (discussed herein). Furthermore, these entities were responsible for the data downloads, processing, and transferal of these data to AECOM for analysis.

The VEMCO hydrophone/receiver network deployed in 2012 was similar to that in 2011 (J. Israel, pers. comm., 2013; SJRGA 2013). The locations of the hydrophones are shown in Table C-5. The HOR-W hydrophone defined the VEMCO Start Line used to determine O_E (Figure C-1). The SJLD.1 hydrophone defined the VEMCO-San Joaquin River-Finish Line used to determine O_E. The ORED.1 hydrophone defined the VEMCO-Old River-Finish Line used to determine O_E. VEMCO start and finish lines and the HTI start and finish lines may be viewed in Figure C-1. It should be noted that the VEMCO-SJR-Finish Line defined by hydrophone SJLD.1 is downriver from that SJR-Finish-Line used by VAMP in 2009 (defined in "Discussion," page 7-3).

Table C-5
UTM Coordinates Defining Entering and Exiting Positions and Transit Path for VEMCO-Derived Transit Speed Calculation

Hydrophone Station	UTM Coordinate	
	Easting	Northing
HORU	647893.49	4185567.59
HORD	647779.60	4185506.96
HOR-W	647368.00	4185705.00
HOR-E	647387.00	4185751.00
OREU.1	646538.88	4186218.57
OREU.2	646497.15	4186227.07
ORED.1	646528.08	4186286.86
SJLU.1	647772.77	4186159.86
SJLU.2	647662.99	4186143.09
SJLD.1	647771.19	4186172.21
SJLD.2	647771.67	4186130.53

Note: UTM = Universal Transverse Mercator
Sources: J. Israel, pers. Comm., 2013; Reclamation 2013; Turnpenny Horsfield Associates 2013

Juvenile salmonids implanted with VEMCO transmitters were grouped into samples for statistical analysis according to the sample creation methods described in Section 5.2.1. The calculation of O_E for VEMCO-derived data was the same as that for HTI-derived data, described in Section 5.2.2, "Calculation of Barrier Overall Efficiency and Overall Passage Efficiency."

Figure C-1 **2012 VEMCO Hydrophone Placements, VEMCO Start and Finish Lines, and HTI Start and Finish Lines near the Head of Old River Study Area**

C.3 RESULTS

C.3.1 OVERALL EFFICIENCY—CHINOOK SALMON COMPARED TO STEELHEAD

In 2012, the number of O_E samples ranged from 26 to 45 for juvenile Chinook salmon and steelhead (Table C-6). The O_E, the proportion of tags inserted into juvenile Chinook that passed the VEMCO SJR finish line (Figure C-1), was 94.0%.

Table C-6
Statistics for Overall Efficiency for Juvenile Salmonids Derived from VEMCO Data in 2012

Statistic	Chinook Salmon	Steelhead	Percentage Point Change	Kruskal-Wallis X^2	P-Value
Mean	0.940	0.974	-3.4	1.600	0.2059
Standard deviation	0.128	0.062	—	—	—
Minimum	0.500	0.667	—	—	—
Maximum	1.000	1.000	—	—	—
Samples (n)	26	45	—	—	—

Note: n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM 2013

For juvenile steelhead, O_E was 97.4%, which was 3.4 percentage points higher than for juvenile Chinook salmon, but the O_E was not significantly different between the two. As described for 2011 results (Section 6.1.6, subsection on “Overall Efficiency,” in Chapter 6, “Results”), it is possible that fewer juvenile steelhead were eaten because they were larger (Table C-2) and better swimmers compared to the juvenile Chinook salmon.

C.3.2 2012 OVERALL EFFICIENCY—CHINOOK SALMON, HTI COMPARED TO VEMCO

The O_E derived from VEMCO tag detections of juvenile Chinook salmon was 32.2 percentage points higher than the O_E derived from HTI tag detections (Table C-7). However, it was hypothesized that this difference was attributable to the fact that most of the tagged juvenile Chinook salmon were eaten by predators before they passed the VEMCO SJR finish line (Figure C-1), but detected at the HTI SJR finish line were counted as passing down into the San Joaquin River. This was not the case with the HTI-derived estimate: Tags with a determined fate of predation before the HTI SJR finish line were removed from the numerator of the O_E calculation even if they were detected at the HTI SJR finish line.

The hypothesis that the higher value for VEMCO (32.2%) was attributable to the presence of eaten tags in the dataset was supported by comparing this difference to the mean of sample proportion eaten. The mean of HTI-derived sample proportion eaten was 38.2% (Section 6.2.1, “Proportion Eaten [Univariate Analyses],” in Chapter 6, “Results”: Table 6-55), which is similar to the difference between VEMCO and HTI O_E.

Table C-7 Statistics for Overall Efficiency for Juvenile Chinook Salmon Derived from HTI and VEMCO Equipment in 2012					
Statistic	**HTI**	**VEMCO**	**Percentage Point Change**	**Kruskal-Wallis X^2**	**P-Value**
Mean	0.618	0.940	-32.2	14.502	0.0001
Standard deviation	0.321	0.127	—	—	—
Minimum	0.000	0.500	—	—	—
Maximum	1.000	1.000	—	—	—
Samples (n)	27	26	—	—	—

Note: n = number of samples
Source: Data compiled by AECOM 2013

C.4 DISCUSSION

C.4.1 2012 Chinook Salmon Compared to Steelhead (VEMCO-Derived Data)

Overall Efficiency

Of 460 VEMCO-tagged juvenile steelhead that arrived at the HOR study area, 16 were estimated to have been eaten during the cursory review performed by HTI (S. Johnston, pers. comm., 2013). This proportion eaten (3.5%), is probably underestimated given the higher HTI-derived proportion of steelhead eaten (24%) in 2011 (Table 6-54).

In 2012, juvenile steelhead O_E was 97.4%, which was 3.4% higher than that for juvenile Chinook salmon, but the O_E was not substantially different between the two (Table C-7). It seems highly likely that both steelhead and Chinook salmon O_E were overestimated in the VEMCO dataset because most of the eaten tags were not removed. This may be an avenue of future research, but this comparison should be done after the 6YSS team removes likely predation from the dataset.

C.4.2 2012 HTI-Derived Data Compared to VEMCO-Derived Data

Chinook Salmon Overall Efficiency

The juvenile Chinook salmon O_E derived from VEMCO tag detections was 32.2 percentage points higher than the O_E derived from HTI tag detections (94.0 % and 61.8%, respectively) (Table C-7). In Section C.3.2, "2012 Overall Efficiency—Chinook Salmon, HTI Compared to VEMCO," it was hypothesized that this difference resulted from most of the tagged juvenile Chinook salmon being eaten by predators not having been removed from the VEMCO-derived dataset.

Of 471 VEMCO tagged juvenile Chinook salmon and detected at the HOR study area, no tags were identified as having been eaten based on the cursory review provided by HTI in 2012–2013 (S. Johnston, pers. comm., 2013). The HTI-derived results estimated that sample proportion eaten was 38.2% of juvenile Chinook salmon in the HOR study area in 2012 (Table 6-55).

An unknown proportion (perhaps as much as 38.2%) of VEMCO tags in the 2012 dataset may have been eaten by predatory fishes and were not removed in the analysis reported here. Thus, positive bias existed in the O_E calculated from VEMCO-derived data, making a valid comparison of VEMCO tags to HTI tags impossible at this point. To make the data derived from these two sets of equipment directly comparable, additional study and development of criteria for identifying tags subject to predation are necessary.

C.5 RECOMMENDATIONS

After the 6YSS is completed, it is recommended that the predator classification methodology used by the 6YSS team be applied to the 2012 VEMCO data used in this evaluation of the HOR study area. Then, a valid comparison of O_E with the HTI-derived data from 2012 may be made to the 2012 VEMCO-derived and HTI-derived data. Further, after the tags have been determined to have been eaten can be removed from the VEMCO data with a greater degree of confidence, a comparison of protection efficiency (P_E) and proportion eaten derived from HTI data and from VEMCO data will be possible because these metrics rely heavily on predation determinations.

APPENDIX D

Transit Speed Analyses

D.1 INTRODUCTION

Transit speed was defined as the rate at which a tag passed through the hydrophone array. Transit speed was analyzed to determine whether it changed with different barrier treatments/years. In all years of study, the guidelines for determining the fate of a tag originally inserted into a juvenile salmonid provided a basis for comparing transit speed of those tags determined to have been eaten and those tags determined to have remained in juvenile salmonids through the Head of Old River (HOR) study area. Because looping behavior and movement against the current were pieces of evidence pointing toward a predation event, these tag behaviors were used to identify which tags had been eaten. Then transit speeds for tags that had been identified as having been eaten and not eaten were determined, and their mean transit speeds were examined. It was expected that mean transit speed through the HOR study area would be slower for tags determined to have been eaten than for tags determined not to have been eaten (Table D-1).

Table D-1
Objectives and Hypotheses Related to Transit Speed

Year	Objectives	Hypothesis Number	Hypotheses
2009–2012	Examine the juvenile Chinook salmon transit speed for each year of study as a basis for understanding barrier effectiveness and the influence of factors such as predation.	—	No hypothesis test possible.
2011	Examine juvenile steelhead transit speed for the only year these data were available, 2011, as a basis for understanding barrier effectiveness and the influence of factors such as predation.	—	No hypothesis test possible.
2011	Examine juvenile Chinook salmon and steelhead transit speed for the only year these data were available as a basis for understanding barrier effectiveness.	$HD1_0$	Transit speed for juvenile Chinook salmon was equal to transit speed for juvenile steelhead.
2012	Provide a comparison of transit speeds for juvenile Chinook salmon and steelhead determined using HTI and VEMCO gear.	$HD2_0$	For juvenile Chinook salmon and steelhead, VEMCO*-derived transit speed was equal to HTI**-derived transit speed.

Notes:
* = VEMCO (Bedford, Nova Scotia, Canada).
** = Hydroacoustic Technology, Inc. (Seattle, WA).
Source: Turnpenny Horsfield Associates and AECOM 2013

At the HOR study area from 2009 through 2012 barrier efficiency was the primary response metric of interest. However, analysis of the transit speed of each acoustically tagged juvenile salmonid provided information about behavior and water velocity that could be used to improve understanding of the behavioral responses to the barrier treatment at the HOR study area.

D.2 METHODS

D.2.1 TRANSIT SPEED CALCULATION—HTI EQUIPMENT

DETERMINATION OF START AND FINISH LINES

Start and finish line positions were derived from the furthest upstream and downstream hydrophone positions using all hydrophone positions from 2009 through 2012. A line perpendicular to the shoreline was drawn starting with these hydrophone positions. The Hydroacoustic Technology, Inc. (HTI; Seattle, Washington) San Joaquin River (SJR) start line (Figure C-1) used the position of Hydrophone (HD) 4 from the 2011 study. The HTI SJR finish line and the HTI Old River finish line were derived from the positions of HD 1 and HD 13, respectively, during the 2012 barrier study (Figures C-1 and D-1). Start and finish line Universal Transverse Mercator (UTM) coordinates are presented in Table D-2.

Table D-2
UTM Coordinates Defining Start and Finish Lines for HTI-Derived Transit Speed Calculations at the Head of Older River Study Area

	UTM Coordinate for End Position of Line			
	Right Bank (Easting)	Right Bank (Northing)	Left Bank (Easting)	Left Bank (Northing)
San Joaquin River start line	647379	4185796	647298	4185735
San Joaquin River finish line	647312	4185932	647284	4185974
Old River finish line	647081	4185864	647093	4185819

Notes: UTM = Universal Transverse Mercator
Right and left bank are determined by looking downstream
Source: S. Johnston, pers. comm., 2013

CALCULATION OF TRANSIT SPEED

A cross-product method was used to determine whether a tagged juvenile salmonid track position was on one side or the other of any given start/finish line. The cross-product value is negative on one side of the line, positive on the other, and 0 when exactly on the line. These values determined when a tagged juvenile salmonid track crossed the start and finish lines.

The following equation was used to determine whether a position is on one side of a line or another:

$$\text{Test Value} = (Bx - Ax) * (Cy - Ay) - (By - Ay) * (Cx - Ax)$$

Where:

Point A = Left bank of start or finish line, or (Ax,Ay)
Point B = Right bank of start or finish line, or (Bx,By)
Point C = Tag position test point, or (Cx,Cy)
Test Value = Positive on downstream side of line AB, negative on upstream side of line AB

Figure D-1 shows the HOR study area with start, finish, and path lines. Straight line segments were drawn between the start and finish lines, approximately mid-channel for each route. A standardized distance through the

Note: Upstream start line derived from 2011 HD 4 position and downstream finish lines derived from 2012 HD 1 and HD 13 positions.
Source: Hydroacoustic Technology, Inc.2013

Figure D-1 **Start and Finish Lines Used to Determine Transit Speed at the Head of Old River Study Area**

HOR study area array to be used for all fish in all years was calculated using these lines by adding all line segments for each route between the start and finish lines for each route. Thus, the standardized transit distance for the Old River route was 276.88 meters (m) and for the San Joaquin River route was 265.88 m.

To find the transit distance for "short" tracks (i.e. tracks that do not cross the start and/or finish lines), the point along the mid-channel line that is on the line perpendicular to the endpoint was found, and then the distance from that point to the next segment endpoint (perpendicular to the mid-channel line) was calculated. All segments traversed by the tagged juvenile salmonid were then summed to find the total distance made through the array area. This distance was then divided by the end time minus the start time for that fish to find transit speed in meters per second (m/s). To calculate a standardized "transit time," times were normalized by the proportion of the total transit distance that was actually travelled by each tagged juvenile salmonid.

The following equation was used to determine a point on a line segment perpendicular to the given point:

> Calculate the slope (m) and y-intercept (b) of the line segment from the center of the start line to the diversion point. These values were then used to find the point on the line segment that was perpendicular to tag position F:
>
> $Gx = [(m * Fy) + Fx - (m * b)] / (m^2 + 1)$
> $Gy = m * Gx + b$
>
> Where:
>
> Point D = Start of first San Joaquin River line segment also center of HTI SJR start line, or (Dx,Dy)
> Point E = End of first San Joaquin River line segment at diversion point, or (Ex,Ey)
> Point F = Tag position to find perpendicular or first position inside start line, or (Fx,Fy)
> Point G = Point on segment DE perpendicular to point F, or (Gx,Gy)

An example of a tagged juvenile salmonid track from the HOR study area 2012 physical rock barrier study with the line segments overlaid is provided in Figure D-2.

D.2.2 TRANSIT SPEED CALCULATIONS—VEMCO EQUIPMENT

FATE DETERMINATION GUIDELINES

The fates of juvenile salmonids tracked with VEMCO (Bedford, Nova Scotia, Canada) equipment were determined based on a limited review by HTI. VEMCO tags that were determined during the analysis to be in predators or to be false positive detections were those that: (1) left the area of the HOR study area and returned days later; (2) made numerous, extremely quick movements between the San Joaquin and Old rivers; (3) made many crossings through culverts both downstream and upstream; or (4) made multiple upstream movements from downstream San Joaquin River hydrophones to upstream San Joaquin River hydrophones and/or Old River hydrophones. This coarse technique identified no juvenile Chinook salmon that were eaten out of the 961 tagged individuals released (0.0%) and 16 steelhead that were eaten out of the 1,435 tagged juvenile steelhead released (0.6% of total). In general, it is expected that the limited review left most of the eaten juvenile Chinook salmon and steelhead in the VEMCO dataset that was analyzed for barrier Operation Efficiency (O_E) and transit speed.

Note: Tagged fish number 2028.03 exits the array and continues down the San Joaquin River. Calculated transit speed for 2028.03 was 0.42 meter per second.

Source: Hydroacoustic Technology, Inc. 2013

Figure D-2 2012 HOR Study Area HTI Hydrophone Array with Start and Finish Lines Displayed

VEMCO Data Preparation for Transit Speed Calculation

Determination of Time Entering and Exiting the HOR Study Area

The time a tag (tagged juvenile salmonid) entered the HOR study area was determined to be the earliest time the tag was detected simultaneously at HOR-W (Head of Old River - West) and HOR-E (Head of Old River - East) (Figure C-1) (Table D-3). If a tag was never detected simultaneously at both of these receivers but was detected at only one receiver, the earliest detection time at that receiver was used.

Table D-3
UTM Coordinates Defining Entering and Exiting Positions and Transit Path for VEMCO-Derived Transit Speed Calculation

Hydrophone Station	UTM Coordinate	
	Easting	Northing
HORU	647893.49	4185567.59
HORD	647779.60	4185506.96
HOR-W	647368.00	4185705.00
HOR-E	647387.00	4185751.00
OREU.1	646538.88	4186218.57
OREU.2	646497.15	4186227.07
ORED.1	646528.08	4186286.86
SJLU.1	647772.77	4186159.86
SJLU.2	647662.99	4186143.09
SJLD.1	647771.19	4186172.21
SJLD.2	647771.67	4186130.53
Departure point	647269.00	4185823.00
San Joaquin P1	647239.00	4185932.00
Old River P1	647140.00	4185853.00
ORPt1	646825.00	4185804.00
ORPt2	646534.00	4186030.00
SJRPt1	647402.00	4186041.00
SJRPt2	647579.00	4186138.00

Note: UTM = Universal Transverse Mercator
Sources: J. Israel, pers. comm., 2013; Reclamation 2013; Turnpenny Horsfield Associates and AECOM 2013

The time a tag exited the HOR study area was determined to be the latest time the tag was detected simultaneously at the maximum number of VEMCO receivers at one of the downstream exit zones (San Joaquin River or Old River). For example, tagged juvenile Chinook salmon 1136865 was detected simultaneously at HOR-W and HOR-E at 20:10:17 on May 3, 2012. The tag then passed through the HOR study area and was detected downstream in the San Joaquin River. However, the tag was detected at only three of the downstream hydrophones (SJLU.1, SJLU.2, and SJLD.1) simultaneously, at 20:47:16 on May 3, 2012. Therefore, tag 1136865 had a transit time of 0:36:59 hours.

Determination of Entering and Exiting Positions in the HOR Study Area

The "position on entering" for each tag was determined as follows:

1. If the tag was detected simultaneously at both upstream hydrophones, then "position on entering" was defined as the midpoint between the two hydrophones.

2. If the tag was detected only on one upstream hydrophone, then "position on entering" was defined as the mid-channel point on the cross-channel line perpendicular to the flow and passing through the hydrophone location.

The "position on exiting" for each tag was determined as follows:

1. If the tag was detected simultaneously at all four downstream hydrophones (either in San Joaquin River or Old River), then "position on exiting" was calculated to be the point equidistant from all four hydrophones.

2. If the tag was detected simultaneously at only three downstream hydrophones, then "position on exiting" was calculated to be the point equidistant from these three hydrophones.

3. If the tag was detected simultaneously at only two downstream hydrophones, then "position on exiting" was calculated to be the midpoint between these two hydrophones.

4. If the tag was detected at only one downstream hydrophone, then "position on exiting" was calculated to be the mid-channel point on the cross-channel line passing through this hydrophone.

Calculation of Transit Distance

The transit distance for each tag was then calculated as follows:

If the tag passed through the HOR study area and went to the Old River exit, then the transit distance was calculated as follows:

$X_T = X_{ED} + X_{DO} + X_{OX}$

Where:

X_T = transit distance
X_{ED} = distance from "position on entering" to divergence point
X_{DO} = distance from divergence point down Old River to ORPt2 (Table D-3), via Old River P1 and ORPt1
X_{OX} = distance from ORPt2 to "position on exiting"

If the tag passed through the HOR study area and went to the San Joaquin River exit, then the transit distance was calculated as follows:

$X_T = X_{ED} + X_{DS} + X_{SX}$

Where:

X_T = transit distance
X_{ED} = distance from "position on entering" to divergence point
X_{DS} = distance from divergence point down San Joaquin River to SJRPt2, via San Joaquin P1 and SJRPt1
X_{SX} = distance from SJRPt2 to "position on exiting"

Calculation of Transit Speed

For each tag that was detected with VEMCO gear both entering and exiting the HOR study area, it was possible to calculate a transit speed. After transit distance and transit time had been calculated, the transit distance was then divided by the exit time minus the entering time for that fish to find transit speed.

For example, tag 1136865 entered the HOR study area and was detected at both HOR-W and HOR-E. The tag passed through the study area and exited downstream in the San Joaquin River, detected at the SJLU.1, SJLU.2, and SJLD.1 hydrophones at the same time. So, the transit distance for this tag was calculated as follows:

X_T = 143.75 m + 510.97 m + 118.96 m = 773.68 m

Then the transit speed for tag 1136865 was 773.68 m/(0:36:59 hours) = 0.349 m/s

D.2.3 HYPOTHESIS TESTING

In Section D.2.1, "Transit Speed Calculation—HTI Equipment," and Section D.2.2, "Transit Speed Calculation—VEMCO Equipment," the estimation of an individual fish's transit speed is described. For each hypothesis tested, all transit speed observations for a given treatment were collected into a single population of observations, which was then compared statistically to the population of observations for the other treatment condition(s). Thus, population transit speed was used for hypothesis testing. This was possible because for transit speed, the sample unit was an individual fish. In contrast, O_E requires a number of individuals to calculate a proportion, and those individuals must all arrive (by definition of sample in Chapter 5, "Methods") during a period when there has been no significant change in barrier, light, or average channel velocity.

D.3 RESULTS

D.3.1 2009—JUVENILE CHINOOK SALMON TRANSIT SPEED

The mean population transit speed of all HTI tags that encountered the bio-acoustic fish fence (BAFF) in 2009 was 0.162 m/s. There was a difference in transit speed between tags in juvenile Chinook salmon that passed through the HOR study area when the BAFF was on versus when the BAFF was off (Table D-4). This result suggests that BAFF operations slowed down the migrating juvenile Chinook salmon compared to periods when the BAFF was off.

Table D-4 Statistics for Juvenile Chinook Salmon Population Transit Speed in 2009					
Statistic	**BAFF On (m/s)**	**BAFF Off (m/s)**	**Difference (m/s)**	**Kruskal-Wallis X^2**	**P-Value**
Mean	0.120	0.191	-0.071	16.808	<0.0001
Standard deviation	0.131	0.178	—	—	—
Minimum	0.001	0.001	—	—	—
Maximum	0.749	0.976	—	—	—

Notes: BAFF = bio-acoustic fish fence; m/s = meters per second
Sample size (n) is 161 with BAFF on and 244 with BAFF off
Source: Data compiled by Turnpenny Horsfield Associates and AECOM 2013

The mean population transit speed for juvenile Chinook salmon determined to have not been eaten was 0.162 m/s, whereas the mean population transit speed of eaten tags was 0.094 m/s (Table D-5). These results suggest that migrating juvenile salmonid may achieve a higher speed moving in a downstream direction (for example, see Figure 5-10) compared to predators. If these determinations of predation are largely correct, the predators in the HOR study area tended to remain resident for longer periods than juvenile Chinook salmonand moved more slowly as they searched for prey (for example, see Figure E-19).

Table D-5 Effect of Predation on Juvenile Chinook Salmon Population Transit Speed in 2009			
Statistic	**Not Eaten (m/s)**	**Eaten (m/s)**	**Difference (m/s)**
Mean	0.162	0.094	0.068
Standard deviation	0.164	0.110	
Minimum	0.001	0.000	
Maximum	0.976	0.613	

Notes: m/s = m per second
Sample size (n) is 410 for Not Eaten and 122 for Eaten
Source: Data compiled by Turnpenny Horsfield Associates 2013

D.3.2 2010—Chinook Salmon Transit Speed

The mean population transit speed of all HTI tags was 0.290 m/s. In contrast to 2009, there was no statistical difference between tags in juvenile Chinook salmon passing through the HOR study area when the BAFF was on versus when the BAFF was off (Table D-6). Thus, operation of the BAFF did not appear to slow down juvenile Chinook salmon in 2010.

Table D-6 Statistics for Chinook Salmon Population Transit Speed in 2010					
Statistic	**BAFF On (m/s)**	**BAFF Off (m/s)**	**Difference (m/s)**	**Kruskal-Wallis X^2**	**P-Value**
Mean	0.298	0.283	0.015	1.783	0.1818
Standard deviation	0.104	0.107			
Minimum	0.120	0.034			
Maximum	0.838	0.983			

Notes: BAFF = bio-acoustic fish fence; m/s = meters per second
Sample size (n) is 160 with BAFF on and 174 with BAFF off
Source: Data compiled by Turnpenny Horsfield Associates 2013

The mean population transit speed for juvenile Chinook salmon determined to not have been eaten was 0.290 m/s, and the mean population transit speed of eaten tags was 0.157 m/s (Table D-7). The 0.133 m/s change represents a 46% difference in speed between tags determined to have not been eaten and those determined to have been eaten. As in 2009, these results suggested that migrating juvenile salmonid tended to make purposeful speed moving in a downstream direction (Figure 5-10) compared to predators. As noted previously, for 2009, the predators that were tagged in the HOR study area commonly remained resident for longer periods and moved more slowly as they sought for prey (Figure E-19).

Table D-7 Effect of Predation on Juvenile Chinook Salmon Population Transit Speed in 2010			
Statistic	**Not Eaten (m/s)**	**Eaten (m/s)**	**Difference (m/s)**
Mean	0.290	0.157	0.133
Standard deviation	0.106	0.087	
Minimum	0.034	0.003	
Maximum	0.982	0.430	

Notes: m/s = meters per second
Sample size (n) is 334 for Not Eaten and 117 for Eaten
Source: Data compiled by Turnpenny Horsfield Associates 2013

D.3.3 2011—Juvenile Chinook Salmon and Steelhead Transit Speed

In 2011, the mean population transit speed for juvenile Chinook salmon was 0.068 m/s faster than for juvenile steelhead (Table D-8). Juvenile steelhead exhibited a broader range of transit speeds compared to juvenile Chinook salmon (Table D-8), especially on the lower end of the range. It appeared that some juvenile steelhead moved slowly compared to juvenile Chinook salmon (see “Minimum” row in Table D-8). These results supported the hypothesis that juvenile steelhead made more upstream movements, made more looping movements, and had more short holding periods in the study area than did juvenile Chinook salmon. All these types of movements would tend to reduce the overall juvenile steelhead population transit speed.

Table D-8
Statistics for Fish Determined to Have Not Been Eaten—Juvenile Chinook Salmon and Steelhead Population Transit Speed in 2011

Statistic	Chinook Salmon (m/s)	Steelhead (m/s)	Difference (m/s)	Kruskal-Wallis X^2	P-Value
Mean	0.535	0.467	0.068	54.425	<0.0001
Standard deviation	0.153	0.156			
Minimum	0.219	0.003			
Maximum	1.199	1.073			

Notes: m/s = meters per second
Sample size (n) is 966 for juvenile Chinook salmon and 395 for juvenile steelhead
Source: Data compiled by Turnpenny Horsfield Associates 2013

The mean population transit speed for juvenile Chinook salmon determined to have not been eaten was 0.535 m/s, and the mean population transit speed of eaten tags was 0.255 m/s (Table D-9). The 0.280 m/s change represents a 52% difference in speed between tags determined to have not been eaten and those determined to have been eaten.

Table D-9
Effect of Predation on Juvenile Chinook Salmon Population Transit Speed in 2011

Statistic	Not Eaten (m/s)	Eaten (m/s)	Difference (m/s)
Mean	0.535	0.255	0.280
Standard deviation	0.153	0.157	—
Minimum	0.219	0.002	—
Maximum	1.199	0.639	—

Notes: m/s = meters per second
Sample size (n) is 966 for Not Eaten and 109 for Eaten
Source: Data compiled by Turnpenny Horsfield Associates and AECOM 2013

The mean population transit speed for juvenile steelhead determined to have not been eaten was 0.467 m/s, and the mean population transit speed of tags determined to have been eaten was 0.160 m/s. The 0.307 m/s difference represents a 66% difference in speed between tags determined to have not been eaten and those determined to have been eaten (Table D-10). These results show that the higher population transit speeds of uneaten tags (i.e., juvenile salmonid) compared to eaten tags (i.e., predators) was consistent across both species studied. Because transit speeds were markedly higher for uneaten tags than for tags that were eaten for both juvenile Chinook salmon and steelhead, it may be useful to further develop transit speed as a component of criteria to identify predator-like behavior when conducting analysis of acoustic telemetry in future studies.

Table D-10 Effect of Predation on Juvenile Steelhead Population Transit Speed in 2011			
Statistic	**Not Eaten (m/s)**	**Eaten (m/s)**	**Difference (m/s)**
Mean	0.467	0.160	0.307
Standard deviation	0.156	0.125	
Minimum	0.003	0.001	
Maximum	1.073	0.544	

Notes: m/s = meters per second
Sample size (n) is 395 for Not Eaten and 125 for Eaten
Source: Data compiled by Turnpenny Horsfield Associates and AECOM 2013

D.3.4 2012—Juvenile Chinook Salmon Transit Speed

In 2012, the mean population transit speed for juvenile Chinook salmon was 0.261 m/s (Table D-11). The 2012 treatment produced a transit speed that was slower than in 2011 (0.535 m/s: Table D-8) and in 2010 (0.290 m/s), but faster than in 2009 (0.162 m/s).

The mean population transit speed for juvenile Chinook salmon determined to have not been eaten was 0.261 m/s, and the mean population transit speed of eaten tags was 0.193 m/s. The 0.068 m/s difference represents a 26% difference in speed between tags determined to have not been eaten and those determined to have been eaten (Table D-12). These results suggest that migrating juvenile salmonid tended to make purposeful movement patterns in a downstream direction in every year studied compared to predators.

Table D-11 Statistics for Juvenile Chinook Salmon Population Transit Speed in 2012					
Treatment – Year	**Mean (m/s)**	**Standard Deviation (m/s)**	**Minimum (m/s)**	**Maximum (m/s)**	**Sample Size (n)**
Rock Barrier – 2012	0.261	0.163	0.001	0.667	119

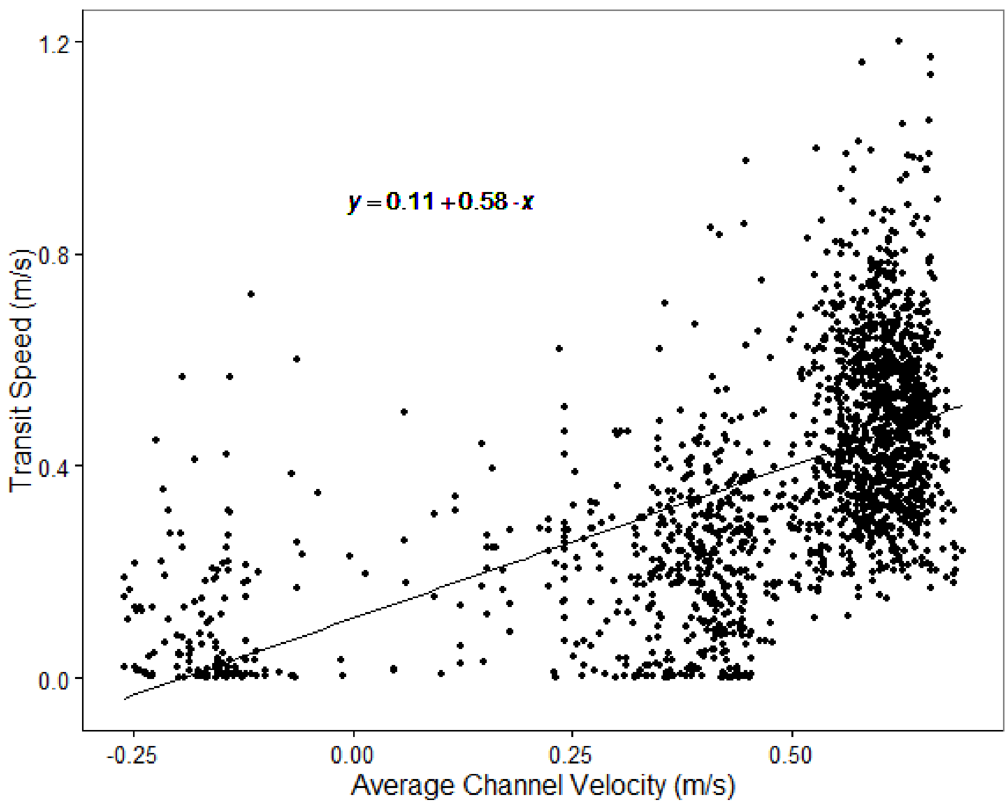
Note: m/s = meters per second; n = number of samples
Source: Data compiled by Turnpenny Horsfield Associates and AECOM 2013

Table D-12 Effect of Predation on Juvenile Chinook Salmon Population Transit Speed in 2012			
Statistic	**Not Eaten (m/s)**	**Eaten (m/s)**	**Difference (m/s)**
Mean	0.261	0.193	0.068
Standard deviation	0.163	0.156	
Minimum	0.001	0.001	
Maximum	0.667	0.657	

Notes: m/s = meters per second
Sample size (n) is 119 for Not Eaten and 74 for Eaten
Source: Data compiled by Turnpenny Horsfield Associates and AECOM 2013

D.3.5 TRANSIT SPEED—ALL YEARS COMPARED

For tags that were not eaten, there was a difference in mean transit speed of juvenile Chinook salmon among years (Kruskal-Wallis X^2 = 1067.446, P <0.0001) (Table D-13). It seemed that at least one variable, average channel velocity (ACV) influenced mean transit speed: ACV was positively correlated with transit speed (r = 0.583, P <0.0001) (Figure D-3). These results suggest that as the discharge increases and mean ACV increases, the mean transit speed increases, thereby supporting the hypothesis that juvenile Chinook salmon spent less time in the HOR study area at high discharges and ACVs. Those juvenile Chinook salmon that spent less time in the HOR study area may, in theory, have reduced the probability of encountering a predator. When 2010 and 2012 were grouped together statistically, they had a significantly faster transit speed than 2009. Transit speed was significantly higher in 2011 than in the other years, and 2011 showed the highest ACV observed among years. Statistical testing and grouping through pair-wise comparisons is described in Section 5.2.6 "STATISTICAL COMPARISONS." Note, however, that the Generalized Linear Model did not find substantial support for discharge as a predictor of predation probability (see Section 7.2, and Section 8.1.2, "Conduct Additional Analysis of Existing Data Using Supplementary Techniques").



Source: Turnpenny Horsfield Associates and AECOM 2013

Figure D-3 Average Channel Velocity Measured at the San Joaquin River at Lathrop Gauge and Juvenile Chinook Salmon Transit Speed Passing through the HOR Study Area Period (2009–2012)

Table D-13 Juvenile Chinook Salmon Transit Speed for Tags Determined to Have Not Been Eaten during Experimental Fish Release Periods					
Treatment – Year	**Discharge Minimum (cfs)**	**Discharge Maximum (cfs)**	**Mean ACV (m/s) (SD)**	**Mean Transit Speed (m/s) (SD) Tags Not Eaten**	**Statistical Grouping of Transit Speed**
BAFF – 2009	-1,300	2,070	0.186 (0.269)	0.162 (0.164)	a
BAFF – 2010	913	3660	0.510 (0.131)	0.290 (0.106)	b
No barrier – 2011	4,250	8,040	0.605 (0.034)	0.535 (0.153)	c
Rock barrier – 2012	210	2,620	0.371 (0.076)	0.261 (0.163)	b

Notes: ACV = average channel velocity; BAFF = bio-acoustic fish fence; cfs = cubic feet per second; m/s = meters per second; SD = standard deviation

Source: Data compiled by Turnpenny Horsfield Associates 2013

D.3.6 2012—HTI- AND VEMCO-DERIVED TRANSIT SPEED

In 2012, the difference in the mean juvenile Chinook salmon population transit speed derived from VEMCO data when compared to HTI data was 0.037 m/s, and this difference was significant (Table D-14). This result was unexpected, because it was hypothesized that VEMCO-derived data contained a number of tags that had been eaten but were not removed. Given the faster transit speeds for uneaten tags (Tables D-5, D-7, D-9, and D-12), it was expected that VEMCO-derived samples would have contained several tags with slower transit speeds. There may be a need to revisit the VEMCO data set in light of these initial findings.

Table D-14 Statistics for Juvenile Chinook Salmon Population Transit Speed in 2012					
Statistic	**HTI (m/s)**	**VEMCO (m/s)**	**Difference (m/s)**	**Kruskal-Wallis X^2**	**P-Value**
Mean	0.261	0.298	-0.037	4.749	0.0293
Standard deviation	0.163	0.176			
Minimum	0.001	0.003			
Maximum	0.667	0.880			

Notes: m/s = meters per second

Sample size (n) is 119 for HTI and 456 for VEMCO

Source: Data compiled by Turnpenny Horsfield Associates 2013

D.4 DISCUSSION

D.4.1 TRANSIT SPEED: BAFF ON COMPARED TO BAFF OFF

In 2009, transit speed with the BAFF on was substantially slower than with the BAFF off (Table D-4). In 2010, there was very little difference in juvenile Chinook salmon transit rates when the BAFF was on or off. In addition, the 2010 BAFF on transit speed was greater than the 2009 BAFF on transit speed (Kruskal-Wallis $X^2 = 154.124$, P-value < 0.0001). These results were consistent with the hypothesis that discharge determines ACV and, in turn, that ACV influences transit speed. This hypothesis also was supported by the transit speed comparison between years: The highest discharge magnitudes (Figure 3-1) produced the highest mean transit speed (Table D-13); the intermediate discharge magnitude years produced intermediate transit speeds; and the lowest discharge magnitude year, 2009 (Figure 3-2), produced the lowest mean transit speed (Table D-13). For all years combined, an important linear relationship exists between transit speed and ACV (Figure D-3).

D.4.2 Population Transit Speed: Not Eaten Compared to Eaten

The population transit speed for 2011 juvenile Chinook salmon that were not eaten (0.535 m/s) (Table D-8) was noted to be the highest observed during the 4 years of the study (Tables D-13). This is partially because of the relationship between discharge and transit speed, as described in the previous section. These results suggest that if individual transit speed is used as an indicator of predation probability, then it should be the difference between the mean transit speed for that year and that individual's transit speed that is considered when accounting for interannual differences in ACV and discharge.

In contrast to the high juvenile Chinook salmon transit rate in 2011, the low transit rate in 2009 appeared to be related to: (1) lower discharges and negative flows that led to lower ACV; (2) the smaller size of juvenile Chinook salmon individuals used in 2009 compared to other years (Table 5-1); and (3) the higher tag burden that the 2009 fish carried compared to the lower tag burden carried by fish in the other years (Table 5-3). All of these factors may interact to reduce transit speed. Additionally, low discharge, low ACV, and low transit speed could possibly interact to influence proportion eaten because slower transit speed could, at least theoretically, increase the probability of predator-prey encounters. However, size (fork length) of the juvenile was not found to be a well-supported predictor of predation probability from generalized linear modeling; other discharge-related factors (such as turbidity) also may play a role, and they are discussed further in Section 8.1.2, "Conduct Additional Analysis of Existing Data Using Supplementary Techniques."

In 2011, juvenile steelhead which were determined to have been uneaten also traveled through the HOR study area at a higher rate than tags determined to have been eaten (i.e., predators) (Table D-10). Transit rates for uneaten steelhead were slower than for uneaten juvenile Chinook salmon (Table D-8), probably because of the short holding periods, upstream movements, and looping behavior sometimes seen in steelhead.

D.4.3 2012—Transit Speed, HTI- Compared To VEMCO-Derived Data

The mean juvenile Chinook salmon transit speed for HTI tags passing through the HOR study area in 2012 was 0.261 m/s (Table D-14). The mean transit speed of juvenile Chinook salmon derived from VEMCO data, 0.298 m/s, was 0.037 m/s faster than the mean transit speed of juvenile Chinook salmon derived from HTI data.

This result was unexpected because the study hypothesized that the VEMCO-derived data contained a number of tags that were eaten but were not removed. Because of the slower transit speeds for eaten tags (Tables D-5, D-7, D-9, and D-12), the logical expectation was that VEMCO-derived observations should have contained several tags with slower transit speeds and should have produced slower transit speeds compared with HTI-derived data.

It was hypothesized that the difference in distance to the SJR finish lines, 554 m between the HTI and VEMCO SJR finish lines, may have caused this. The HTI SJR finish line was just downstream from the scour hole. Thus, juvenile salmonids that passed into the scour hole may have been slowed by the lower velocities that were often observed in that area (Figure 3-17). The VEMCO-tagged juvenile salmonids perhaps were slowed by the scour hole, but after they were out of the scour hole, they may have accelerated to a speed closer to the ACV (measured at San Joaquin River at Lathrop gauge). Another explanation is that the two methods routinely predict different transit speeds. This last possibility suggests that further study is needed.

D.5 RECOMMENDATIONS

Transit speed was identified as a quantitative attribute that can assist in classifying predation on juvenile salmonids. It is recommended that this attribute be used to aid predation classification in future studies. Tagged juvenile salmonids that were classified as having been preyed upon passed through the HOR study area at a slower rate than tagged juvenile salmonids 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, ACV, 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 juvenile steelhead can mimic the behavior of predators, it is recommended that transit speed evaluation be species-specific.

The fact that the VEMCO-derived transit speed was routinely faster than the HTI-derived estimate of transit speeds is important. It may be that the difference in distance between the finish lines between the two methods may have caused this difference. It is possible, however, that these two methods produced systematically different estimates of transit speed. Further work should be undertaken to determine whether these methods are producing systematically different results.

APPENDIX E

Fish Fate Determination Guidelines

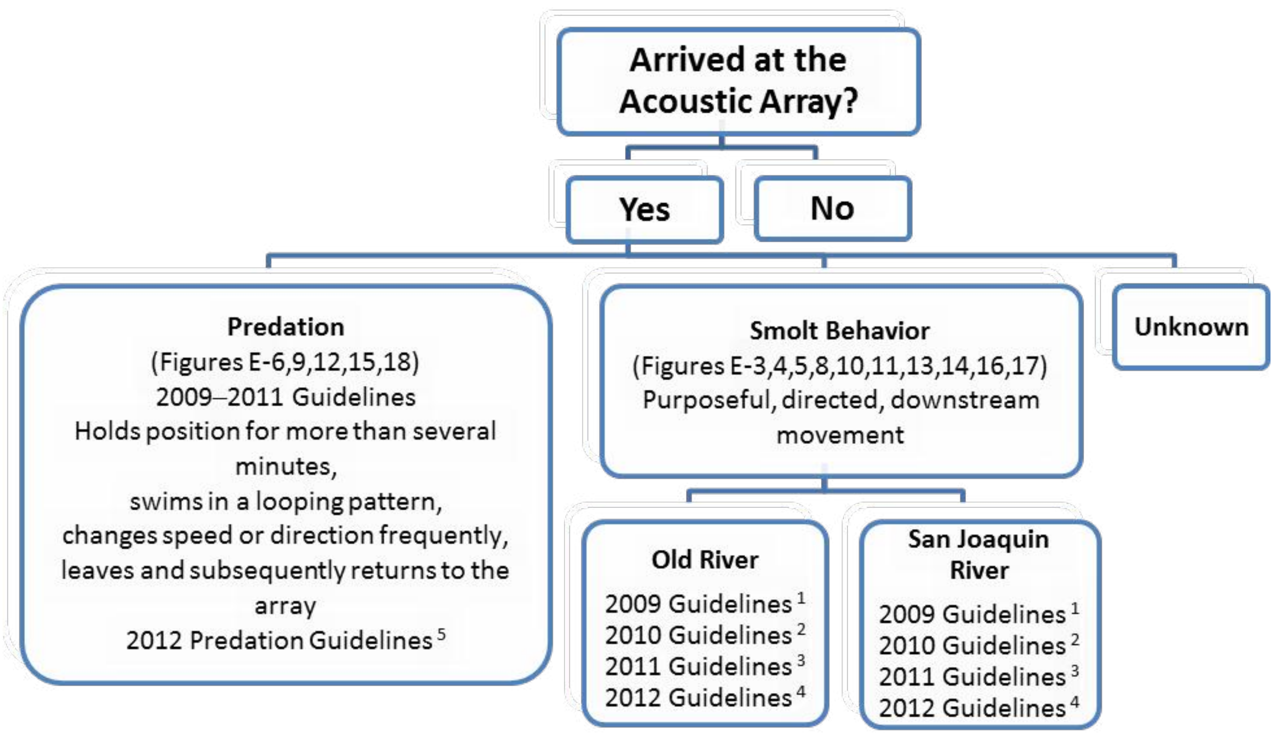
E FATE DETERMINATION GUIDELINES

During each of the Head of Old River (HOR) study years (2009 through 2012), a set of fish fate determination guidelines was applied to the observed juvenile salmonid tracks recorded at the HOR study area to classify whether the individual exhibited behaviors consistent with passing a juvenile salmonid or predatory fish species. In addition, standardized sets of rules were used to determine whether tagged fish exited the study area via Old River or the San Joaquin River. These fate classifications were necessary to test individual study hypotheses in the presence or absence of different barrier types. In 2009 and 2010, a non-physical barrier (referred to as BAFF throughout the report) was installed at the HOR study area and was evaluated. In 2011, no barrier was in place because of high river flows. However, deterrence fates were still determined for the 2011 data set, referenced to the position of the non-physical barrier installed in 2010. A physical barrier (referred to as rock barrier throughout the report) was installed at the HOR study area in 2012. A summary of the specific fate determination metrics developed during each study year is as follows:

(1) 2009–2012: Predation, juvenile salmonid behavior, or unknown (Figure E-1).

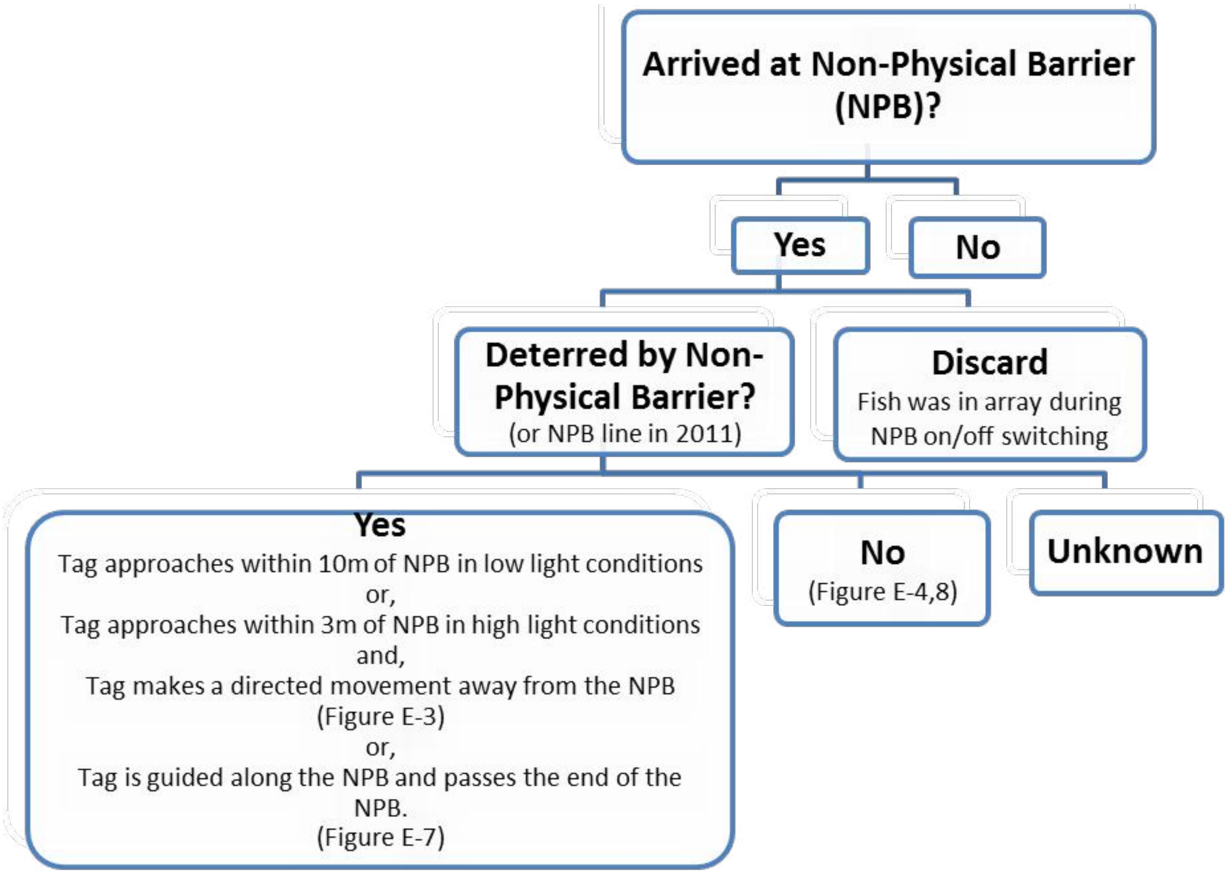
(2) 2009–2011: Deterred/undeterred by the non-physical barrier (or referenced to the 2010 non-physical barrier line for the 2011 no-barrier study), or unknown (Figure E-2). Fish deterrence fates were not determined for the 2012 physical barrier installation.

(3) 2009–2012: Final fate—Old River, San Joaquin River, predation, or unknown (Figure E-1).



Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-1 Flow Chart of Fish Fates Classification Categories Used to Establish Presumed Predation and Exit Route Selection for the HOR Study Area 2009–2012 Analyses



Note: NPB = non-physical barrier

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-2 Flow Chart of Data Analysis for Determining Whether a Tag Was Deterred by the Non-physical Barrier (or Non-physical Barrier Line) for the HOR Study Area 2009–2010 Analyses

E.1 2009 FATE DETERMINATION GUIDELINES

E.1.1 DETERMINING DETERRENCE OF A JUVENILE CHINOOK SALMON

(1) Learn what you can about the hydraulics at the site during the time of the individual's approach to the non-physical barrier (NPB): what is the discharge, Q (cubic feet per second [cfs]) at the San Joaquin River at Lathrop (SJL) gauge, and what is the average channel velocity (ACV)?

(2) Evaluate the tag for predator behavior (see "Determining Predation of a Juvenile Chinook Salmon," below) before evaluating for deterrence. If a juvenile Chinook salmon has been eaten before approach to the NPB, it cannot be deterred. A juvenile Chinook salmon is deterred if (a) it approaches within 10 meters (m) of the NPB under low-light conditions or within 3 m of the NPB during high-light conditions, (b) it makes some directed movement away from the NPB, or (c) it is guided along the NPB line and passed the end of the NPB.

E.1.2 DETERMINING PREDATION OF A JUVENILE CHINOOK SALMON

(1) Be aware of all the information acquired under "Determining Deterrence of a Juvenile Chinook Salmon," listed previously.

(2) Evaluate the two-dimensional (2D) track for juvenile Chinook salmon behavior. Juvenile Chinook salmon behavior is evident by purposeful, directed movement downstream, even if that directed movement is found only in the first portion of a 2D track. At the HOR study area in the scour hole, fish may follow a semicircular path because of an eddy current. This does not necessarily mean the tagged juvenile salmonid has been eaten by a predator.

(3) Evaluate the 2D track for predator behavior. The following behaviors were observed in predators at the HOR study area using dual-frequency identification sonar (DIDSON):

  (a) Predator behavior was evident when the tagged juvenile held position for time periods over several minutes, swam in loops in the area, swam upstream repeatedly, or changed speed or direction often.
  (b) A single 90-degree turn was not definitive proof that a tagged juvenile salmonid was in a predator.
  (c) If a tag left the hydrophone array and then came back into the array, it was assigned the fate of "predation."
  (d) If a track stopped in the center of the array or was otherwise incomplete, it sometimes was necessary to go back to the original raw acoustic tag file (.RAT file) using MarkTags (Hydroacoustic Technology, Inc., Seattle, Washington) to add additional data to get both longer tracks and longer trailing ends of tag detections. If a new database was to be created, the correct database was loaded into AcousticTag (Hydroacoustic Technology, Inc., Seattle, Washington) before creating the database.
  (e) In a track, 2D positions that were outside of the array had lower precision than those inside the array, and were not used solely to determine fate.

(4) If it was unclear which category a track belonged to using the above criteria, it was assigned the fate of "Unknown."

(5) Use weight of evidence of the data tracks to make the determination of the fate of predation or not.

E.1.3 DETERMINING THE FATE OF A JUVENILE CHINOOK SALMON IN 2009

(1) Be aware of all the information acquired under "Determining Deterrence of a Juvenile Chinook Salmon" and "Determining Predation of a Juvenile Chinook Salmon" listed previously.

(2) Evaluate the 2D track for juvenile Chinook salmon and predator behaviors. If the track is found to have not been eaten, then continue.

(3) Use the individual hydrophone display to find which hydrophone detected the tag last.

For NPB on: If the tag is last detected on hydrophone (HD) 1 (pink) and the signal slowly diminishes, indicating that the tag is steadily moving away from that hydrophone, then the fate of the San Joaquin River is assigned.

If the tag is last detected on HD 1 (pink), the signal strength is high, and the signal terminates quickly, indicating passage behind the divergence peninsula, then the fate of the Old River is assigned.

For NPB off: If the tag is last detected on HD 1 (pink) and the signal slowly diminishes, indicating that the tag is steadily moving away from that hydrophone, then the fate of the San Joaquin River is assigned.

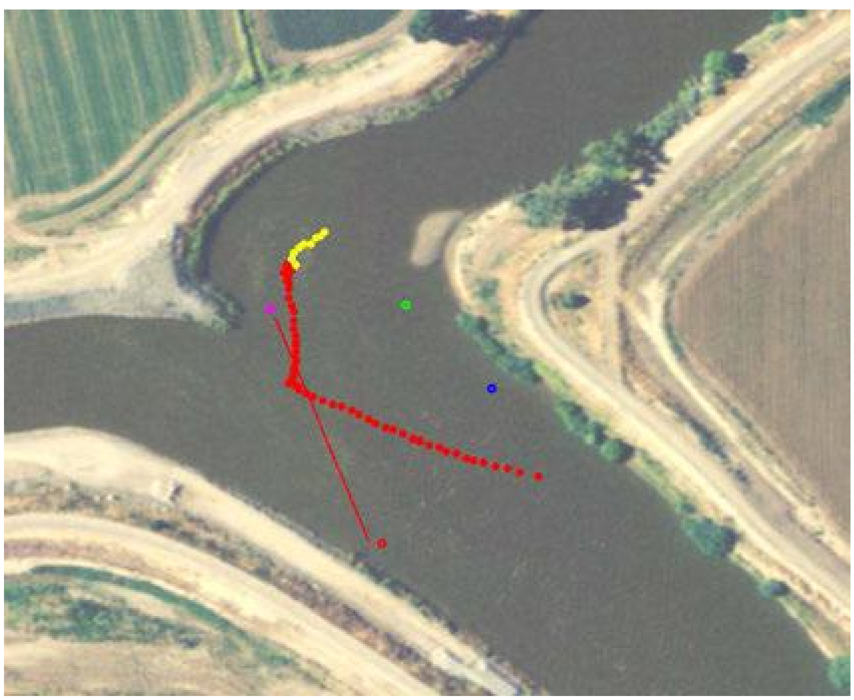
If the tag is last detected on HD 2 (green) or HD 3 (blue) and the signal slowly diminishes, or if the tag is last detected on HD 1 (pink), the signal strength is high, and the signal terminates quickly, indicating passage behind the divergence peninsula, then the fate of Old River is assigned.

(4) When using the foregoing rules, if it is not clear which category a track belongs, then the fate of “Unknown” is assigned.

(5) Use the preponderance of evidence to make the determination of predation or not.

E.2 2009 TAGGED JUVENILE CHINOOK SALMON FATE EXAMPLES

Examples of individual tagged juvenile Chinook salmon tracks from study year 2009 categorized as alive not eaten by a predator with fates of deterred, undeterred, and did not encounter the barrier are shown in Figures E-3, E-4, and E-5, respectively. Figure E-6 shows the track of a tagged juvenile Chinook salmon categorized as having been eaten by a predator. In all figures, the yellow dots at the end of each track represent the last 10 individual positions of the tagged juvenile Chinook salmon for that track.



Note: the bubble curtain was often swept downstream a few meters near the water surface, causing deterrence events to appear downstream of the BAFF line

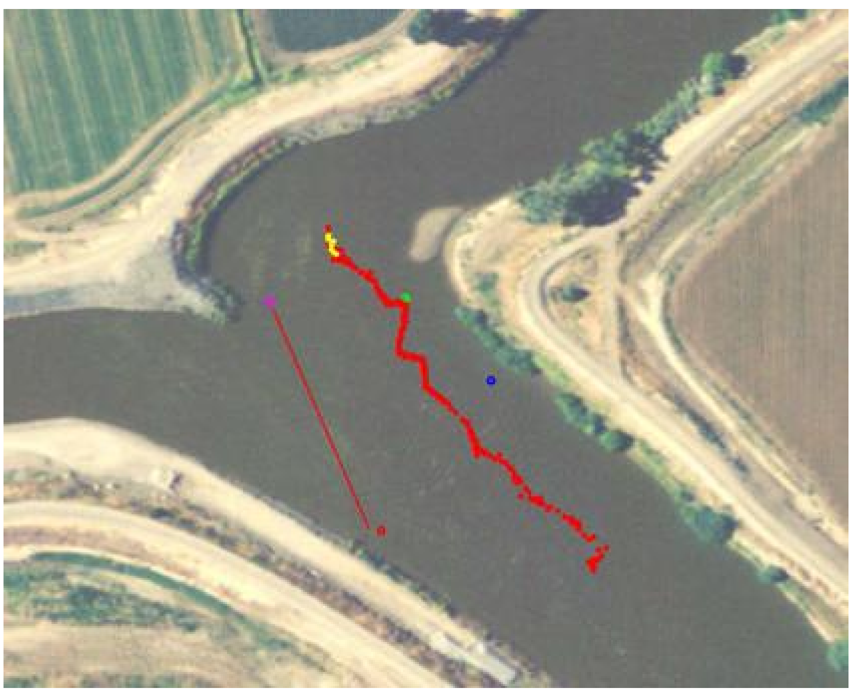
Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-3 **Tagged Juvenile Chinook Salmon Number 6214.15 Deterred by the BAFF (BAFF Operating) at 12:07 PDT on April 24, 2009, and Exiting the Array Down the San Joaquin River at the HOR Study Area**

Note: The 2D trace ends at the BAFF because hydrophones 2, 3, and 4 cannot detect tag transmissions through the bubble curtain.

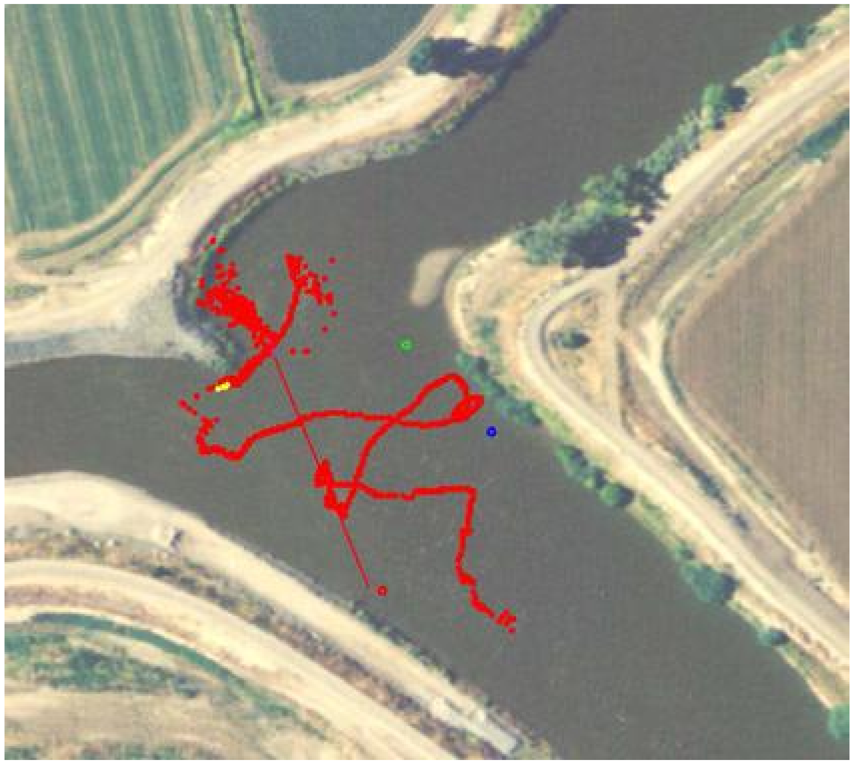
Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-4 Tagged Juvenile Chinook Salmon Number 6514.21 Passes through the BAFF (BAFF Operating) at 0:37 PDT on May 15, 2009 and Exits Array down the Old River at the HOR Study Area



Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-5 Tagged Juvenile Chinook Salmon Number 6828.11, Designated as Having Never Experienced the BAFF (Did Not Approach Within 10 meters) at 19:03 PDT on May 2, 2009, Exits Array Down the San Joaquin River



Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-6 Tagged Juvenile Chinook Salmon Number 6310.11, Designated as Having Been Eaten by a Predator, was Present in the Array Between 06:19 and 07:46 PDT, May 2, 2009, and Exited Down the Old River (Yellow Dots)

E.3 2010 FATE DETERMINATION GUIDELINES

(1) Be aware of all the information acquired under “Determining Deterrence of a Juvenile Chinook Salmon” and “Determining Predation of a Juvenile Chinook Salmon” noted previously.

(2) Evaluate the 2D track for tagged juvenile Chinook salmon and predator behaviors. If the track is found to have not been eaten, then continue.

(3) Use the individual hydrophone display to find which hydrophone detected the tag last and whether the detection’s signal strength slowly diminishes on that hydrophone, indicating that it was moving steadily away from that hydrophone.

If the tag is last detected on HD 1 (pink) or HD 8 (peach) and the signal slowly diminishes, then the fate of the San Joaquin River is assigned.

If the tag is last detected on HD 7 (light blue) and the signal slowly diminishes, then the fate of the Old River is assigned.

(4) When using the foregoing rules, if it is not clear in which category a track belongs, “Unknown” is assigned.

(5) Use the weight of evidence to make the determination of predation or not.

E.4 2010 TAGGED JUVENILE CHINOOK SALMON FATE EXAMPLES

Examples of individual tagged juvenile chinook salmon tracks from study year 2010 categorized as not eaten by a predator with fates of deterred and undeterred are shown in Figures E-7 and E-8, respectively. Figure E-9 shows the track of a tagged juvenile Chinook salmon categorized as having been eaten by a predator. In all figures, the yellow dots at the end of each track represent the last 10 individual positions of the tagged fish for that track.

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-7 Tagged Juvenile Chinook Salmon Number 5441.12 Deterred by the BAFF (BAFF Operating) at 13:00 PDT on May 19, 2010, and Exiting the Array Down the San Joaquin River at the HOR Study Area

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-8 Tagged Juvenile Chinook Salmon Number 5437.14 Passing through the BAFF (BAFF Operating) at 0:27 PDT on April 28, 2010, and Exiting the Array Down the Old River at the HOR Study Area

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-9 Tagged Juvenile Chinook Salmon Number 5680.02 Designated as Having Been Eaten by a Predator was Present in the Array Between 6:53 and 9:21 PDT on May 8, 2010, and Exited the Array Down the San Joaquin River at the HOR Study Area

E.5 2011 FATE DETERMINATION GUIDELINES

(1) Be aware of all the information acquired under “Determining Deterrence of a Juvenile Chinook Salmon” and “Determining Predation of a Juvenile Chinook Salmon” noted previously.

(2) Evaluate the 2D track for tagged juvenile Chinook salmon and predator behaviors. If the track is found to have not been eaten, then continue.

(3) Use the individual hydrophone display to find which hydrophone detected the tag last and whether the detection’s signal strength slowly diminishes on that hydrophone, indicating that it was moving steadily away from that hydrophone.

If the tag is last detected on HD 5 (light blue) or HD 9 (orange) and the signal slowly diminishes, then the fate of the Old River is assigned.

If the tag is last detected on HD 1 (yellow), HD 6 (peach), HD 7 (teal), or HD 8 (pink), and the signal slowly diminishes, then the fate of the San Joaquin River is assigned.

(4) When using the foregoing rules, if it is unclear in which category a track belongs, “Unknown” is assigned.

(5) Use the weight of evidence to make the determination of predation or not.

E.6 2011 TAGGED JUVENILE CHINOOK SALMON AND STEELHEAD FATE EXAMPLES

Examples of individual tagged juvenile Chinook salmon tracks from study year 2011 categorized as alive not eaten by a predator which took routes of the San Joaquin and Old rivers are shown in Figures E-10 and E-11, respectively. Figure E-12 shows the track of a tagged juvenile Chinook salmon categorized as having been eaten by a predator. In all figures, the yellow dots at the end of each track represent the last 10 individual positions of the tagged fish for that track.

Examples of individual tagged juvenile steelhead tracks from study year 2011 categorized as alive not eaten by a predator which took routes of San Joaquin and Old rivers are shown in Figures E-13 and E-14, respectively. Figure E-15 shows the track of a tagged juvenile steelhead categorized as having been eaten by a predator. In all figures, the yellow dots at the end of each track represent the last 10 individual positions of the tagged juvenile steelhead for that track.

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-10 Tagged Juvenile Chinook Salmon Number 5007.31 Passing through the Array at 16:51 PDT on May 18, 2011 and Exiting Down the San Joaquin River at the HOR Study Area

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-11 Tagged Juvenile Chinook Salmon Number 5113.16 Passing through the Array at 12:59 PDT on June 18, 2011 and Exiting Down the Old River at the HOR Study Area

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-12 Tagged Juvenile Chinook Salmon Number 5506.13 Designated as Having Been Eaten by a Predator was Present in the Array Between 1:43 and 20:38 PDT on June 10, 2011, and Exited the Array Down the San Joaquin River at the HOR Study Area

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-13 Tagged Juvenile Steelhead Number 6354.04 Passing through the Array at 00:41 PDT on May 7, 2011 and Exiting Down the San Joaquin River at the HOR Study Area

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-14 Tagged Juvenile Steelhead Number 5059.04 Passing through the Array at 03:27 PDT on May 7, 2011 and Exiting Down the Old River at the HOR Study Area

Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-15 Tagged Juvenile Steelhead Number 8965.04 Designated as Having Been Eaten by a Predator was Present in the Array Between 03:12 and 15:51 PDT on May 26, 2011, and Exited the Array Down the San Joaquin River at the HOR Study Area

E.7 2012 FATE DETERMINATION GUIDELINES

(1) Be aware of all the information acquired under 2012 Predation Guidelines.

(2) Evaluate the 2D track for tagged juvenile Chinook salmon and predator behaviors. If the track is found to have not been eaten, then continue.

If the tag is detected in the array of hydrophones located downstream from the physical barrier in Old River, then the fate of the Old River is assigned.

If the tag is last detected on HD 1 (yellow), HD 2 (green), or HD 3 (blue) and the signal slowly diminishes, indicating that the tagged fish is steadily moving away from that hydrophone, then the fate of the San Joaquin River is assigned.

(3) When using the foregoing rules, if it is unclear which category a track belongs, “Unknown” is assigned.

(4) Use the weight of evidence to make the determination of predation or not.

E.8 2012 PREDATION GUIDELINES

In 2012 at the HOR study area, tracks of juvenile salmonids were evaluated to determine the fate of each tagged fish. In addition to determining which route the fish took (either the Old River or the San Joaquin River), the tracks were examined and a determination was made regarding whether or not the track exhibited predator-like behavior, indicating that a predator had eaten the tagged juvenile salmonid.

In past years (2009, 2010, and 2011), rules were developed for determining whether a particular track appearance would lead to that tagged juvenile salmonid being classified as having been eaten by a predator. Flow data were not available for the periods of study during these years. Because of the presence of the physical rock barrier in 2012, the flow patterns at the HOR study area were expected to be very different than in previous years, possibly leading to differences in tagged juvenile salmonid tracks selection. This proved to be the case, and many more juveniles exhibited one or more loops in their tracks than had been seen in previous years.

During the initial fate determinations, many of these juvenile salmonid tracks (73) were temporarily classified as “Unknown” for the category “Predation1.” In 2012, acoustic Doppler current profiler (ADCP) data were collected at the HOR study area, allowing flow fields to be measured and a 5-m flow vector grid to be developed for 15-minute intervals during much of the study period. These data then were imported into EonFusion (Hobart, Tasmania, Australia) to visually show the magnitude (by varying color) and direction (by arrow direction) of flow on a geo-referenced image of the HOR study area, matched in time to the tagged juvenile salmonid track data.

A track reevaluation process was then performed for those 73 unknown tagged juvenile salmonid tracks to determine whether the loops or other potentially predator-like behavior was caused by the special flow conditions recorded by the ADCP created by the physical barrier in 2012.

The rules used in making predation determinations included the criteria developed for previous years, as well as the following additions:

(1) The rule about a closed loop being definitive of a predator was removed.

(2) A new looping rule was made, stating that loops are not definitive of predator behavior. The fate determination should be dependent on discharge; looping behavior that goes against medium to heavy flows suggests predator behavior.

(3) Upstream movement behavior was no longer definitive of predator behavior. A tagged juvenile salmonid that was in front of the physical barrier may swim upstream to get into the San Joaquin River. A tagged juvenile salmonid traveling sideways across medium to heavy flows suggests predator behavior.

(4) The overall behavior of the tagged juvenile salmonid and the different lines of evidence lead to a finding of predation, if such is the case.

(5) Velocity information (both speed and direction) was not available for review during initial fates assignments. Tagged salmonids that exhibited short-duration looping behavior, either in front of the physical barrier or in the scour hole, were assigned a fate based on their ultimate route, but a predation code of 1 ("unknown"). When velocity field information became available (May 2013), any fish with a "Predation = 1 ("unknown") code was reevaluated.

(6) A few tagged juvenile salmonids were examined with the velocity field to determine how their 2D tracks were influenced by the velocity field. All juvenile salmonids that exhibited purposeful downstream movements were assigned a predation of not eaten and assigned a fate based on their route selection. However, sudden direction changes associated with velocity direction and speed gradients became evident. For example, the juvenile Chinook salmon with tag 2987.03 made a directed downstream movement until it contacted an eddy in the scour hole that precipitated a strong turn to the right (Figure E-16).

(7) As opposed to earlier years, tagged juvenile salmonids that exhibited short-duration looping behavior, either in front of the physical barrier or in the scour hole, were assigned a fate based on their ultimate route unless specific predator-like behavior was observed (Figure E-17).

(8) After the velocity field information became available, all tagged juvenile salmonids that had predation with assigned fate "Unknown" were reevaluated. Some were checked to ensure the original fate that had been assigned was consistent with the velocity field. For example, the juvenile Chinook salmon with tag 2672.03 moved down in front of the physical barrier, traveled upstream, and made a complete loop, but was still assigned a fate of "San Joaquin River" (Figure E-17) because it did not exhibit predation behavior as defined in 2012.

(9) Predation behavior was defined in 2012 as clear, long upstream movements and/or looping behavior in areas where eddies would not have been expected to occur, or looping behavior for long periods of time (Figures E-18). If a tagged juvenile salmonid exited the HOR study area and returned later, this was considered evidence of predation, possibly outside the HOR study area; a longer period between exit and reentry gave stronger evidence of predation. Long residence time, greater than 8 hours, was considered strong evidence that a tagged juvenile salmonid was eaten and inside a predator.

(10) The duration of looping behavior and where it took place played a role in determining whether tagged juvenile salmonids were coded as "Unknown" or "eaten." If the looping was limited in space and to a time period substantially less than 1 hour, then "Unknown" was assigned. Thus, the tag behavior guidelines (2012 guidelines, numbers (6) and (7) for assigning predation were more restrictive in 2012 than in other years. These restrictions took place because of the changes in the velocity field.

(11) Special note on two tagged juvenile salmonids traveling very close together: By itself, two tags traveling together could indicate schooling behavior or incidence of predation. It was suggested that additional finer scale tracking be implemented such as manual marking (of the sets of two and three fish together), and time series consideration to determine whether the points were always within 1 m of each other at all times. If the tags (tagged juveniles) were more than 1 m apart (positioning precision within the array was 1 m) at any one point, they were schooling. If they always were within 1 m of each other, this could be used as evidence of predation. For example, because looping behavior occurs that is not always with an eddy current or when upstream movement occurs, evidence exists of predation. In conjunction, the two tags traveling together increased the chances for predation and exceeding the new standard of proof that suggested "weight of evidence" (or such relevant evidence as a reasonable mind may accept as adequate to support a conclusion).

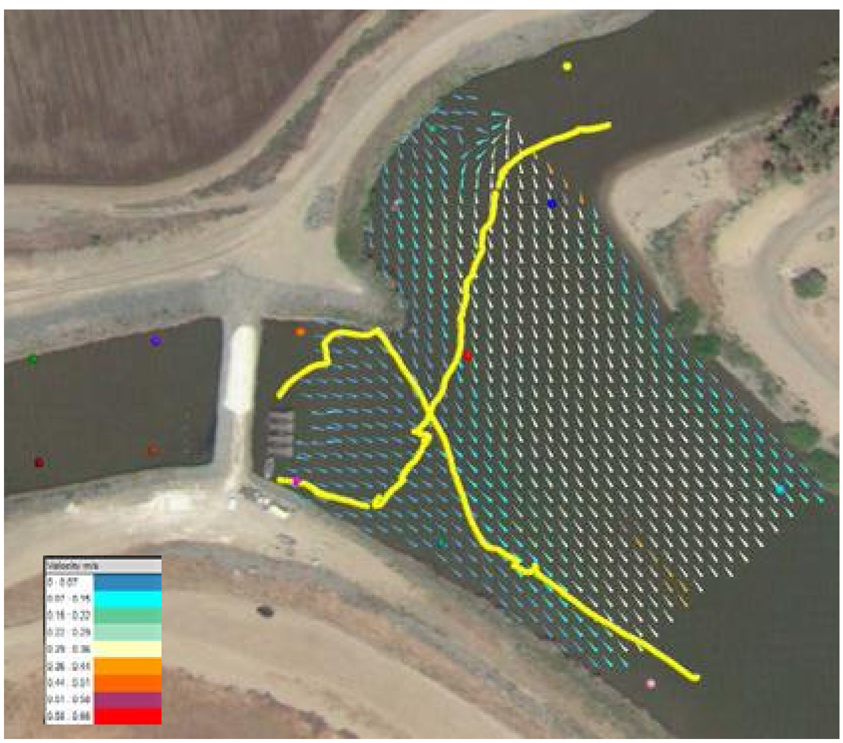
(12) If two or more tags (tagged juveniles) were traveling together (i.e., the positions of the two tracks were fully coincident), this was considered relevant evidence that predation of all tags had occurred. Alone, this was not sufficient to render a determination of predation, but this observation plus at least one more piece of evidence of predation (such as looping behavior in the absence of water eddies, upstream fish movement, or other) was convincing that this was predation (Bowen, pers. comm., 2013).

E.9 2012 TAGGED JUVENILE CHINOOK SALMON AND STEELHEAD FATE EXAMPLES

An example of an individual tagged juvenile Chinook salmon track from study year 2012 categorized not eaten by a predator which took the route of San Joaquin River is shown in Figure E-16, including flow field data for the time period that the tag was in the array. Figure E-17 shows a track of tagged juvenile Chinook salmon 2672.03 that makes a loop in front of the physical rock barrier, but does not move upstream, or cross areas of high velocity, so was categorized as having not been eaten by a predator. Figure E-18 shows a track of tagged juvenile Chinook salmon 4023.03, categorized as having been eaten by a predator, since it exhibits multiple loops and cross-flow behavior similar to a predator. Figure E-19 is the track of tagged predator (2154.14, striped bass of length 504 millimeters) showing looping behavior.

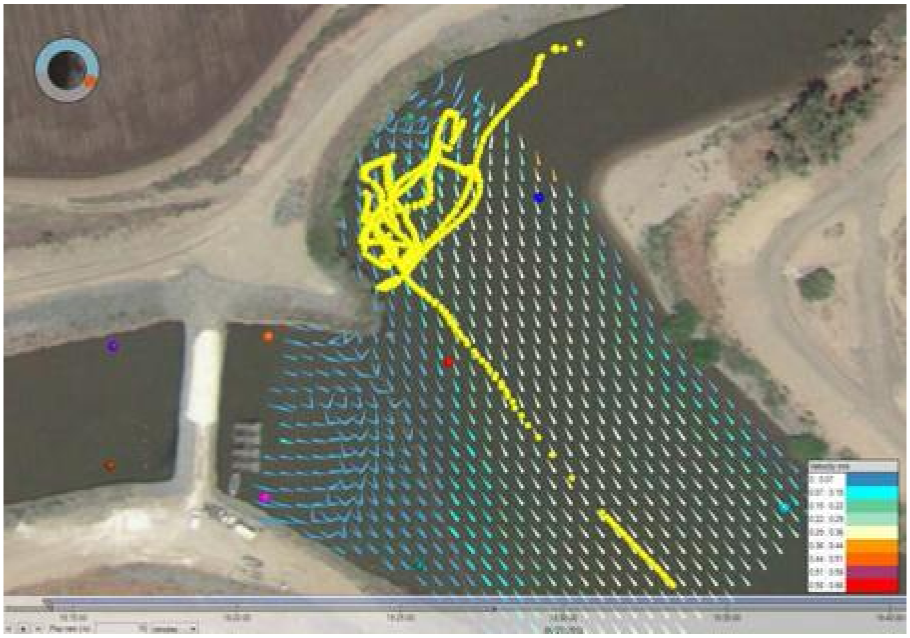
Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-16 **Juvenile Chinook Salmon Tag 2987.03 Moving Downstream in a Purposeful, Directed Way on 4/28/2012 with First Detection of 10:41:52 and Last Detection at 10:50:43 (residence time in area of HOR study area: 00:08:51 hours)**



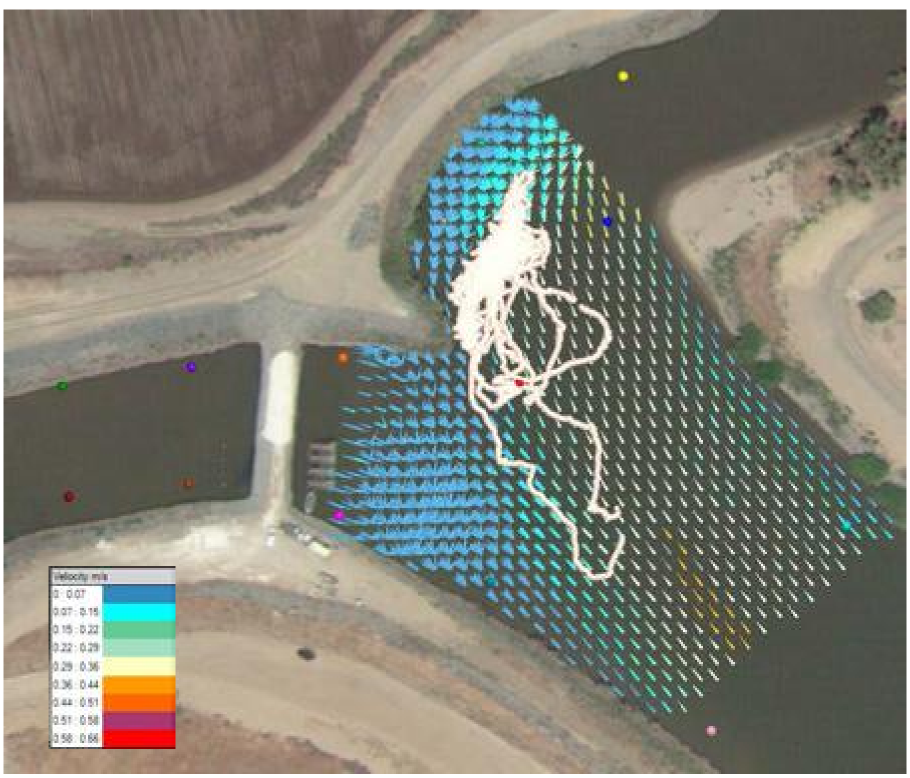
Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-17 **Juvenile Chinook Salmon Tag 2672.03 Designated as Not Having Been Eaten by a Predator, but Showing Loop in Front of Physical Barrier on 5/7/2012 at 21:58:00**



Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-18 Tagged Juvenile Chinook Salmon (4023.03) Designated as Having Been Eaten by a Predatory Fish, Showing Extensive Looping in the Scour Hole Between 19:14 and 19:41, on May 27, 2012



Source: Data compiled by Hydroacoustic Technology, Inc.

Figure E-19 Track of Tagged Predator 2154.14 (Striped Bass, 504 millimeters), Showing Extensive Looping and Upstream Movement Between 16:00, May 16 and 04:30, May 17, 2012

REFERENCES

Bowen, Mark D. Senior Fisheries Consultant. Turnpenny Horsfield Associates, Ashurst, UK. June 27, 2013—e-mail communication.

APPENDIX F

Model Fit and Weight Tables from Results of Predation Probability Generalized Linear Modeling

Table F-1
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2009, 2010, and 2012

Model Rank	Variables	AIC_c	w_i
1	Intercept + Barrier + Juvenile Length + Light + Small-Fish Density + Temperature + Turbidity	1257.088	0.280
2	Intercept + Barrier + Juvenile Length + Light + Small-Fish Density + Discharge + Temperature + Turbidity	1258.202	0.161
3	Intercept + Barrier + Juvenile Length + Light + Small-Fish Density + Turbidity	1259.186	0.098
4	Intercept + Barrier + Light + Small-Fish Density + Turbidity	1259.653	0.078
5	Intercept + Barrier + Light + Small-Fish Density + Discharge + Temperature + Turbidity	1259.862	0.070
6	Intercept + Barrier + Juvenile Length + Light + Small-Fish Density + Discharge + Temperature	1259.952	0.067
7	Intercept + Barrier + Light + Small-Fish Density + Discharge + Turbidity	1260.298	0.056
8	Intercept + Barrier + Light + Small-Fish Density + Temperature + Turbidity	1261.081	0.038
9	Intercept + Barrier + Juvenile Length + Light + Small-Fish Density + Discharge + Turbidity	1261.081	0.038
10	Intercept + Barrier + Juvenile Length + Light + Small-Fish Density + Temperature	1261.382	0.033
11	Intercept + Barrier + Light + Small-Fish Density + Discharge + Temperature	1262.019	0.024
12	Intercept + Barrier + Juvenile Length + Light + Temperature + Turbidity	1262.773	0.016
13	Intercept + Barrier + Juvenile Length + Light + Discharge + Temperature + Turbidity	1263.933	0.009
14	Intercept + Barrier + Light + Small-Fish Density + Discharge	1264.943	0.006
15	Intercept + Barrier + Juvenile Length + Light + Small-Fish Density	1265.857	0.003
16	Intercept + Barrier + Juvenile Length + Light + Turbidity	1265.939	0.003
17	Intercept + Barrier + Juvenile Length + Light + Discharge + Temperature	1265.963	0.003
18	Intercept + Barrier + Juvenile Length + Light + Small-Fish Density + Discharge	1266.034	0.003
19	Intercept + Barrier + Light + Discharge + Temperature + Turbidity	1266.713	0.002
20	Intercept + Barrier + Light + Turbidity	1267.043	0.002
21	Intercept + Barrier + Juvenile Length + Light + Temperature	1267.405	0.002
22	Intercept + Barrier + Light + Discharge + Turbidity	1267.606	0.001
23	Intercept + Barrier + Juvenile Length + Light + Discharge + Turbidity	1267.879	0.001
24	Intercept + Barrier + Light + Small-Fish Density	1268.148	0.001
25	Intercept + Barrier + Light + Temperature + Turbidity	1268.251	0.001
26	Intercept + Barrier + Light + Small-Fish Density + Temperature	1269.051	0.001
27	Intercept + Barrier + Light + Discharge + Temperature	1269.248	0.001
28	Intercept + Juvenile Length + Light + Small-Fish Density + Temperature + Turbidity	1272.785	0.000
29	Intercept + Barrier + Light + Discharge	1272.806	0.000
30	Intercept + Barrier + Juvenile Length + Light	1273.149	0.000

Table F-1
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2009, 2010, and 2012

Model Rank	Variables	AIC_c	w_i
31	Intercept + Barrier + Juvenile Length + Light + Discharge	1273.395	0.000
32	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge + Temperature + Turbidity	1273.890	0.000
33	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge + Temperature	1275.699	0.000
34	Intercept + Barrier + Light	1276.572	0.000
35	Intercept + Juvenile Length + Light + Small-Fish Density + Temperature	1277.160	0.000
36	Intercept + Barrier + Light + Temperature	1277.225	0.000
37	Intercept + Juvenile Length + Light + Temperature + Turbidity	1280.126	0.000
38	Intercept + Juvenile Length + Light + Small-Fish Density + Turbidity	1280.576	0.000
39	Intercept + Juvenile Length + Light + Discharge + Temperature + Turbidity	1281.204	0.000
40	Intercept + Light + Small-Fish Density + Discharge + Temperature	1282.272	0.000
41	Intercept + Light + Small-Fish Density + Discharge + Temperature + Turbidity	1282.407	0.000
42	Intercept + Juvenile Length + Light + Discharge + Temperature	1282.498	0.000
43	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge + Turbidity	1282.580	0.000
44	Intercept + Juvenile Length + Light + Temperature	1283.827	0.000
45	Intercept + Juvenile Length + Light + Small-Fish Density	1284.094	0.000
46	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge	1284.993	0.000
47	Intercept + Light + Small-Fish Density + Discharge + Turbidity	1286.429	0.000
48	Intercept + Light + Small-Fish Density + Discharge	1287.210	0.000
49	Intercept + Light + Small-Fish Density + Turbidity	1287.671	0.000
50	Intercept + Light + Small-Fish Density + Temperature + Turbidity	1287.699	0.000
51	Intercept + Light + Small-Fish Density	1291.649	0.000
52	Intercept + Juvenile Length + Light + Turbidity	1291.671	0.000
53	Intercept + Light + Small-Fish Density + Temperature	1291.835	0.000
54	Intercept + Light + Discharge + Temperature	1293.663	0.000
55	Intercept + Juvenile Length + Light + Discharge + Turbidity	1293.687	0.000
56	Intercept + Barrier + Small-Fish Density + Discharge + Temperature + Turbidity	1294.070	0.000
57	Intercept + Juvenile Length + Light	1294.172	0.000
58	Intercept + Barrier + Juvenile Length + Small-Fish Density + Discharge + Temperature + Turbidity	1294.306	0.000
59	Intercept + Light + Discharge + Temperature + Turbidity	1294.475	0.000
60	Intercept + Juvenile Length + Light + Discharge	1295.399	0.000

Table F-1
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2009, 2010, and 2012

Model Rank	Variables	AIC_c	w_i
61	Intercept + Barrier + Juvenile Length + Small-Fish Density + Discharge + Temperature	1295.821	0.000
62	Intercept + Barrier + Small-Fish Density + Discharge + Temperature	1295.870	0.000
63	Intercept + Barrier + Juvenile Length + Small-Fish Density + Temperature + Turbidity	1296.635	0.000
64	Intercept + Barrier + Small-Fish Density + Temperature + Turbidity	1299.841	0.000
65	Intercept + Light + Discharge	1300.753	0.000
66	Intercept + Light + Discharge + Turbidity	1300.801	0.000
67	Intercept + Barrier + Small-Fish Density + Discharge + Turbidity	1301.469	0.000
68	Intercept + Barrier + Small-Fish Density + Turbidity	1301.696	0.000
69	Intercept + Light + Temperature + Turbidity	1302.133	0.000
70	Intercept + Barrier + Juvenile Length + Discharge + Temperature + Turbidity	1302.537	0.000
71	Intercept + Barrier + Discharge + Temperature + Turbidity	1303.089	0.000
72	Intercept + Light + Turbidity	1303.117	0.000
73	Intercept + Barrier + Juvenile Length + Small-Fish Density + Temperature	1303.132	0.000
74	Intercept + Barrier + Juvenile Length + Small-Fish Density + Turbidity	1303.183	0.000
75	Intercept + Barrier + Juvenile Length + Small-Fish Density + Discharge + Turbidity	1303.481	0.000
76	Intercept + Barrier + Juvenile Length + Discharge + Temperature	1304.095	0.000
77	Intercept + Barrier + Discharge + Temperature	1305.001	0.000
78	Intercept + Barrier + Juvenile Length + Temperature + Turbidity	1305.041	0.000
79	Intercept + Light + Temperature	1305.717	0.000
80	Intercept + Light	1306.420	0.000
81	Intercept + Barrier + Small-Fish Density + Discharge	1307.509	0.000
82	Intercept + Barrier + Juvenile Length + Small-Fish Density + Discharge	1309.477	0.000
83	Intercept + Barrier + Temperature + Turbidity	1309.770	0.000
84	Intercept + Barrier + Small-Fish Density + Temperature	1310.445	0.000
85	Intercept + Barrier + Juvenile Length + Temperature	1311.701	0.000
86	Intercept + Barrier + Discharge + Turbidity	1312.177	0.000
87	Intercept + Barrier + Turbidity	1312.654	0.000
88	Intercept + Juvenile Length + Small-Fish Density + Discharge + Temperature + Turbidity	1313.184	0.000
89	Intercept + Barrier + Small-Fish Density	1313.483	0.000
90	Intercept + Barrier + Juvenile Length + Small-Fish Density	1313.561	0.000

Table F-1
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2009, 2010, and 2012

Model Rank	Variables	AIC_c	w_i
91	Intercept + Barrier + Juvenile Length + Turbidity	1313.880	0.000
92	Intercept + Barrier + Juvenile Length + Discharge + Turbidity	1314.196	0.000
93	Intercept + Juvenile Length + Small-Fish Density + Discharge + Temperature	1314.892	0.000
94	Intercept + Juvenile Length + Small-Fish Density + Temperature + Turbidity	1315.423	0.000
95	Intercept + Small-Fish Density + Discharge + Temperature + Turbidity	1318.014	0.000
96	Intercept + Small-Fish Density + Discharge + Temperature	1318.210	0.000
97	Intercept + Barrier + Discharge	1318.320	0.000
98	Intercept + Barrier + Juvenile Length + Discharge	1320.336	0.000
99	Intercept + Barrier + Temperature	1321.232	0.000
100	Intercept + Juvenile Length + Small-Fish Density + Temperature	1321.995	0.000
101	Intercept + Juvenile Length + Discharge + Temperature + Turbidity	1323.356	0.000
102	Intercept + Juvenile Length + Discharge + Temperature	1324.321	0.000
103	Intercept + Barrier + Juvenile Length	1324.510	0.000
104	Intercept + Barrier	1325.166	0.000
105	Intercept + Juvenile Length + Temperature + Turbidity	1325.961	0.000
106	Intercept + Small-Fish Density + Temperature + Turbidity	1329.178	0.000
107	Intercept + Discharge + Temperature	1331.317	0.000
108	Intercept + Juvenile Length + Temperature	1331.499	0.000
109	Intercept + Discharge + Temperature + Turbidity	1331.983	0.000
110	Intercept + Juvenile Length + Small-Fish Density + Turbidity	1332.335	0.000
111	Intercept + Small-Fish Density + Discharge + Turbidity	1332.643	0.000
112	Intercept + Juvenile Length + Small-Fish Density + Discharge + Turbidity	1333.200	0.000
113	Intercept + Small-Fish Density + Discharge	1334.051	0.000
114	Intercept + Small-Fish Density + Turbidity	1335.117	0.000
115	Intercept + Juvenile Length + Small-Fish Density + Discharge	1335.232	0.000
116	Intercept + Small-Fish Density + Temperature	1335.725	0.000
117	Intercept + Juvenile Length + Small-Fish Density	1337.312	0.000
118	Intercept + Small-Fish Density	1341.005	0.000
119	Intercept + Temperature + Turbidity	1346.870	0.000
120	Intercept + Juvenile Length + Turbidity	1349.629	0.000

Table F-1
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2009, 2010, and 2012

Model Rank	Variables	AIC_c	w_i
121	Intercept + Juvenile Length + Discharge + Turbidity	1350.490	0.000
122	Intercept + Juvenile Length + Discharge	1351.311	0.000
123	Intercept + Discharge + Turbidity	1351.552	0.000
124	Intercept + Discharge	1351.677	0.000
125	Intercept + Temperature	1352.604	0.000
126	Intercept + Juvenile Length	1352.909	0.000
127	Intercept + Turbidity	1355.678	0.000
128	Intercept Only	1360.401	0.000

Notes: AIC_c = Akaike's Information Criterion adjusted for small sample sizes; *wi* = model weight; temperature = water temperature
Source: Present study

Table F-2
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
1	Intercept + Light + Temperature + Turbidity	590.436	0.080
2	Intercept + Light + Large-Fish Density (Down) + Temperature + Turbidity	590.978	0.061
3	Intercept + Juvenile Length + Light + Temperature + Turbidity	591.406	0.049
4	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	591.553	0.046
5	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Temperature + Turbidity	591.981	0.037
6	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	592.046	0.036
7	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature + Turbidity	592.240	0.032
8	Intercept + Juvenile Length + Light + Turbidity	592.255	0.032
9	Intercept + Light + Large-Fish Density (Side) + Temperature + Turbidity	592.381	0.030
10	Intercept + Light + Discharge + Temperature + Turbidity	592.412	0.030
11	Intercept + Light + Small-Fish Density + Temperature + Turbidity	592.420	0.030
12	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Temperature + Turbidity	592.474	0.029
13	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Temperature + Turbidity	592.648	0.026
14	Intercept + Light + Turbidity	592.850	0.024
15	Intercept + Light + Large-Fish Density (Down) + Discharge + Temperature + Turbidity	592.879	0.023
16	Intercept + Juvenile Length + Light + Small-Fish Density + Temperature + Turbidity	592.923	0.023
17	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	593.284	0.019
18	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Temperature + Turbidity	593.433	0.018
19	Intercept + Juvenile Length + Light + Discharge + Temperature + Turbidity	593.433	0.018
20	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	593.574	0.017
21	Intercept + Juvenile Length + Light + Discharge + Turbidity	593.617	0.016
22	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature + Turbidity	593.619	0.016
23	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature + Turbidity	593.621	0.016
24	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature + Turbidity	593.763	0.015
25	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	593.977	0.014
26	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Turbidity	594.046	0.013
27	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Turbidity	594.164	0.012

Table F-2
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
28	Intercept + Light + Small-Fish Density + Turbidity	594.194	0.012
29	Intercept + Juvenile Length + Light + Small-Fish Density + Turbidity	594.278	0.012
30	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Discharge + Temperature + Turbidity	594.283	0.012
31	Intercept + Light + Large-Fish Density (Down) + Turbidity	594.292	0.012
32	Intercept + Light + Discharge + Turbidity	594.345	0.011
33	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	594.351	0.011
34	Intercept + Light + Small-Fish Density + Discharge + Temperature + Turbidity	594.397	0.011
35	Intercept + Light + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	594.409	0.011
36	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Discharge + Turbidity	594.684	0.010
37	Intercept + Light + Large-Fish Density (Side) + Turbidity	594.864	0.009
38	Intercept + Light + Large-Fish Density (Down) + Discharge + Turbidity	594.878	0.009
39	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	594.949	0.008
40	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge + Temperature + Turbidity	594.952	0.008
41	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Turbidity	595.106	0.008
42	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Discharge + Turbidity	595.409	0.007
43	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	595.457	0.006
44	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	595.466	0.006
45	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Turbidity	595.562	0.006
46	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge + Turbidity	595.602	0.006
47	Intercept + Light + Large-Fish Density (Side) + Discharge + Turbidity	595.766	0.006
48	Intercept + Light + Small-Fish Density + Discharge + Turbidity	595.881	0.005
49	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Turbidity	595.969	0.005
50	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Turbidity	596.040	0.005
51	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Turbidity	596.080	0.005
52	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Turbidity	596.192	0.004
53	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Turbidity	596.205	0.004
54	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	596.382	0.004
55	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Turbidity	596.679	0.004
56	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Turbidity	596.779	0.003

Table F-2
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
57	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Turbidity	596.894	0.003
58	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Turbidity	596.906	0.003
59	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	596.938	0.003
60	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	597.329	0.003
61	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Turbidity	597.470	0.002
62	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	597.554	0.002
63	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	598.039	0.002
64	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	598.926	0.001
65	Intercept + Juvenile Length + Light + Discharge + Temperature	603.689	0.000
66	Intercept + Light + Discharge + Temperature	604.298	0.000
67	Intercept + Juvenile Length + Light + Discharge	604.890	0.000
68	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Temperature	605.222	0.000
69	Intercept + Light + Small-Fish Density + Discharge + Temperature	605.629	0.000
70	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Discharge + Temperature	605.660	0.000
71	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Discharge + Temperature	605.662	0.000
72	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge + Temperature	605.704	0.000
73	Intercept + Light + Large-Fish Density (Side) + Temperature	605.757	0.000
74	Intercept + Light + Large-Fish Density (Down) + Discharge + Temperature	606.124	0.000
75	Intercept + Light + Large-Fish Density (Side) + Discharge + Temperature	606.294	0.000
76	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature	606.337	0.000
77	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature	606.450	0.000
78	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Temperature	606.544	0.000
79	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge	606.564	0.000
80	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Discharge	606.875	0.000
81	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Discharge	606.913	0.000
82	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Temperature	607.037	0.000
83	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature	607.366	0.000
84	Intercept + Light + Small-Fish Density + Discharge	607.490	0.000
85	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	607.582	0.000

Table F-2
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
86	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature	607.654	0.000
87	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	607.674	0.000
88	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature	607.693	0.000
89	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature	607.695	0.000
90	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature	608.174	0.000
91	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature	608.358	0.000
92	Intercept + Light + Discharge	608.408	0.000
93	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge	608.519	0.000
94	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge	608.583	0.000
95	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge	608.873	0.000
96	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Temperature	609.107	0.000
97	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge	609.225	0.000
98	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	609.365	0.000
99	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	609.464	0.000
100	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge	609.500	0.000
101	Intercept + Light + Small-Fish Density + Temperature	609.861	0.000
102	Intercept + Light + Temperature	609.905	0.000
103	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Temperature	609.990	0.000
104	Intercept + Light + Large-Fish Density (Side) + Discharge	610.220	0.000
105	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Temperature	610.330	0.000
106	Intercept + Light + Large-Fish Density (Down) + Temperature	610.334	0.000
107	Intercept + Light + Large-Fish Density (Down) + Discharge	610.405	0.000
108	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge	610.436	0.000
109	Intercept + Juvenile Length + Light + Temperature	610.460	0.000
110	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge	610.918	0.000
111	Intercept + Juvenile Length + Light + Small-Fish Density + Temperature	611.447	0.000
112	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density	611.648	0.000

Table F-2
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
113	Intercept + Temperature + Turbidity	611.892	0.000
114	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density	612.051	0.000
115	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge	612.208	0.000
116	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density	612.293	0.000
117	Intercept + Juvenile Length + Light + Large-Fish Density (Side)	612.409	0.000
118	Intercept + Juvenile Length + Temperature + Turbidity	612.897	0.000
119	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	613.021	0.000
120	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density	613.099	0.000
121	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density	613.223	0.000
122	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density	613.279	0.000
123	Intercept + Large-Fish Density (Down) + Temperature + Turbidity	613.419	0.000
124	Intercept + Small-Fish Density + Temperature + Turbidity	613.735	0.000
125	Intercept + Large-Fish Density (Side) + Temperature + Turbidity	613.854	0.000
126	Intercept + Discharge + Temperature + Turbidity	613.896	0.000
127	Intercept + Juvenile Length + Small-Fish Density + Temperature + Turbidity	614.027	0.000
128	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	614.090	0.000
129	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	614.298	0.000
130	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature + Turbidity	614.339	0.000
131	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side)	614.432	0.000
132	Intercept + Large-Fish Density (Down) + Small-Fish Density + Temperature + Turbidity	614.528	0.000
133	Intercept + Juvenile Length + Large-Fish Density (Side) + Temperature + Turbidity	614.645	0.000
134	Intercept + Juvenile Length + Large-Fish Density (Down) + Temperature + Turbidity	614.733	0.000
135	Intercept + Juvenile Length + Discharge + Temperature + Turbidity	614.896	0.000
136	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Temperature + Turbidity	615.012	0.000
137	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	615.050	0.000
138	Intercept + Large-Fish Density (Down) + Discharge + Temperature + Turbidity	615.385	0.000
139	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature + Turbidity	615.428	0.000

Table F-2
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
140	Intercept + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	615.593	0.000
141	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	615.603	0.000
142	Intercept + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	615.726	0.000
143	Intercept + Small-Fish Density + Discharge + Temperature + Turbidity	615.735	0.000
144	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	615.824	0.000
145	Intercept + Juvenile Length + Small-Fish Density + Discharge + Temperature + Turbidity	616.021	0.000
146	Intercept + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature + Turbidity	616.325	0.000
147	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature + Turbidity	616.336	0.000
148	Intercept + Juvenile Length + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	616.480	0.000
149	Intercept + Juvenile Length + Large-Fish Density (Down) + Discharge + Temperature + Turbidity	616.612	0.000
150	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	616.890	0.000
151	Intercept + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	617.499	0.000
152	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	617.742	0.000
153	Intercept + Juvenile Length + Discharge + Turbidity	618.337	0.000
154	Intercept + Light + Large-Fish Density (Side)	618.610	0.000
155	Intercept + Juvenile Length + Turbidity	618.716	0.000
156	Intercept + Juvenile Length + Light + Large-Fish Density (Down)	619.119	0.000
157	Intercept + Juvenile Length + Large-Fish Density (Side) + Turbidity	619.135	0.000
158	Intercept + Juvenile Length + Large-Fish Density (Side) + Temperature	619.994	0.000
159	Intercept + Turbidity	620.054	0.000
160	Intercept + Discharge + Turbidity	620.130	0.000
161	Intercept + Juvenile Length + Large-Fish Density (Down) + Discharge + Turbidity	620.287	0.000
162	Intercept + Juvenile Length + Small-Fish Density + Discharge + Turbidity	620.303	0.000
163	Intercept + Juvenile Length + Large-Fish Density (Side) + Discharge + Turbidity	620.353	0.000
164	Intercept + Juvenile Length + Large-Fish Density (Down) + Turbidity	620.394	0.000
165	Intercept + Juvenile Length + Discharge + Temperature	620.463	0.000
166	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side)	620.628	0.000
167	Intercept + Large-Fish Density (Side) + Temperature	620.701	0.000
168	Intercept + Juvenile Length + Small-Fish Density + Turbidity	620.729	0.000
169	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Turbidity	620.975	0.000

Table F-2
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
170	Intercept + Discharge + Temperature	621.060	0.000
171	Intercept + Small-Fish Density + Turbidity	621.087	0.000
172	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Turbidity	621.157	0.000
173	Intercept + Large-Fish Density (Side) + Turbidity	621.256	0.000
174	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature	621.285	0.000
175	Intercept + Small-Fish Density + Discharge + Turbidity	621.533	0.000
176	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature	621.630	0.000
177	Intercept + Juvenile Length + Large-Fish Density (Side) + Discharge + Temperature	621.764	0.000
178	Intercept + Large-Fish Density (Down) + Discharge + Turbidity	621.878	0.000
179	Intercept + Large-Fish Density (Down) + Turbidity	622.001	0.000
180	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Temperature	622.015	0.000
181	Intercept + Large-Fish Density (Side) + Discharge + Turbidity	622.073	0.000
182	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Discharge + Turbidity	622.135	0.000
183	Intercept + Large-Fish Density (Side) + Small-Fish Density + Temperature	622.147	0.000
184	Intercept + Large-Fish Density (Side) + Small-Fish Density + Turbidity	622.231	0.000
185	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Turbidity	622.234	0.000
186	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	622.329	0.000
187	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Turbidity	622.348	0.000
188	Intercept + Juvenile Length + Small-Fish Density + Discharge + Temperature	622.463	0.000
189	Intercept + Juvenile Length + Large-Fish Density (Down) + Discharge + Temperature	622.486	0.000
190	Intercept + Large-Fish Density (Side) + Discharge + Temperature	622.504	0.000
191	Intercept + Large-Fish Density (Down) + Small-Fish Density + Turbidity	622.706	0.000
192	Intercept + Small-Fish Density + Discharge + Temperature	622.723	0.000
193	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Turbidity	622.958	0.000
194	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature	623.020	0.000
195	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Turbidity	623.025	0.000
196	Intercept + Large-Fish Density (Down) + Discharge + Temperature	623.032	0.000
197	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature	623.223	0.000
198	Intercept + Large-Fish Density (Down) + Small-Fish Density + Discharge + Turbidity	623.530	0.000
199	Intercept + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	623.547	0.000

Table F-2
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
200	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature	623.614	0.000
201	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature	623.614	0.000
202	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	623.786	0.000
203	Intercept + Light + Small-Fish Density	623.846	0.000
204	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Turbidity	623.901	0.000
205	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	624.048	0.000
206	Intercept + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	624.069	0.000
207	Intercept + Temperature	624.182	0.000
208	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Turbidity	624.249	0.000
209	Intercept + Juvenile Length + Large-Fish Density (Down) + Temperature	624.415	0.000
210	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature	624.485	0.000
211	Intercept + Juvenile Length + Discharge	624.532	0.000
212	Intercept + Juvenile Length + Temperature	624.680	0.000
213	Intercept + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature	624.740	0.000
214	Intercept + Large-Fish Density (Down) + Temperature	624.808	0.000
215	Intercept + Large-Fish Density (Down) + Small-Fish Density + Temperature	624.827	0.000
216	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	624.924	0.000
217	Intercept + Small-Fish Density + Temperature	625.022	0.000
218	Intercept + Juvenile Length + Light + Small-Fish Density	625.191	0.000
219	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	625.557	0.000
220	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	625.607	0.000
221	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Temperature	625.673	0.000
222	Intercept + Juvenile Length + Small-Fish Density + Temperature	626.314	0.000
223	Intercept + Juvenile Length + Small-Fish Density + Discharge	626.336	0.000
224	Intercept + Juvenile Length + Large-Fish Density (Down) + Discharge	626.406	0.000
225	Intercept + Juvenile Length + Large-Fish Density (Side) + Discharge	626.473	0.000
226	Intercept + Light + Large-Fish Density (Down)	626.808	0.000
227	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Discharge	627.976	0.000

Table F-2
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Chinook Salmon at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
228	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Discharge	628.241	0.000
229	Intercept + Small-Fish Density + Discharge	628.244	0.000
230	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge	628.424	0.000
231	Intercept + Discharge	629.147	0.000
232	Intercept + Large-Fish Density (Down) + Small-Fish Density + Discharge	629.388	0.000
233	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge	630.003	0.000
234	Intercept + Juvenile Length + Large-Fish Density (Side)	630.080	0.000
235	Intercept + Large-Fish Density (Side) + Small-Fish Density + Discharge	630.205	0.000
236	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density	630.248	0.000
237	Intercept + Large-Fish Density (Down) + Discharge	631.107	0.000
238	Intercept + Large-Fish Density (Side) + Discharge	631.159	0.000
239	Intercept + Large-Fish Density (Down) + Small-Fish Density	631.177	0.000
240	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge	631.291	0.000
241	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density	631.354	0.000
242	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density	631.462	0.000
243	Intercept + Large-Fish Density (Side) + Small-Fish Density	631.917	0.000
244	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side)	631.943	0.000
245	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density	632.264	0.000
246	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge	633.084	0.000
247	Intercept + Juvenile Length + Light	634.876	0.000
248	Intercept + Juvenile Length + Large-Fish Density (Down)	636.158	0.000
249	Intercept + Large-Fish Density (Side)	637.589	0.000
250	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side)	639.383	0.000
251	Intercept + Light	643.386	0.000
252	Intercept + Large-Fish Density (Down)	644.650	0.000
253	Intercept + Small-Fish Density	645.493	0.000
254	Intercept + Juvenile Length + Small-Fish Density	646.461	0.000
255	Intercept + Juvenile Length	654.921	0.000
256	Intercept Only	664.049	0.000

Notes: AIC_c = Akaike's Information Criterion adjusted for small sample sizes; *wi* = model weight; temperature = water temperature
Source: Present study

Table F-3
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Steelhead at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
1	Intercept + Light + Discharge + Temperature	190.054	0.035
2	Intercept + Light + Small-Fish Density + Discharge + Temperature	190.575	0.027
3	Intercept + Light + Temperature	190.730	0.025
4	Intercept + Light + Discharge + Temperature + Turbidity	191.236	0.019
5	Intercept + Light + Small-Fish Density + Discharge	191.689	0.015
6	Intercept + Light	191.690	0.015
7	Intercept + Light + Small-Fish Density + Temperature	191.694	0.015
8	Intercept + Light + Small-Fish Density	191.720	0.015
9	Intercept + Small-Fish Density	191.881	0.014
10	Intercept + Light + Large-Fish Density (Down) + Discharge + Temperature	191.934	0.014
11	Intercept + Large-Fish Density (Side) + Small-Fish Density	192.027	0.013
12	Intercept + Juvenile Length + Light + Discharge + Temperature	192.059	0.013
13	Intercept + Light + Large-Fish Density (Side)	192.071	0.013
14	Intercept + Temperature	192.120	0.012
15	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density	192.120	0.012
16	Intercept only	192.147	0.012
17	Intercept + Light + Large-Fish Density (Side) + Discharge + Temperature	192.155	0.012
18	Intercept + Large-Fish Density (Side)	192.277	0.011
19	Intercept + Light + Discharge	192.343	0.011
20	Intercept + Light + Large-Fish Density (Side) + Temperature	192.369	0.011
21	Intercept + Small-Fish Density + Temperature	192.556	0.010
22	Intercept + Light + Small-Fish Density + Discharge + Temperature + Turbidity	192.605	0.010
23	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	192.689	0.009
24	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature	192.711	0.009
25	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge + Temperature	192.722	0.009
26	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge	192.772	0.009
27	Intercept + Juvenile Length + Light + Temperature	192.810	0.009
28	Intercept + Light + Temperature + Turbidity	192.816	0.009
29	Intercept + Light + Large-Fish Density (Down) + Temperature	192.828	0.009
30	Intercept + Small-Fish Density + Discharge	192.984	0.008

Table F-3
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Steelhead at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
31	Intercept + Light + Discharge + Turbidity	193.004	0.008
32	Intercept + Small-Fish Density + Turbidity	193.005	0.008
33	Intercept + Discharge + Temperature	193.013	0.008
34	Intercept + Small-Fish Density + Discharge + Temperature	193.151	0.007
35	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Temperature	193.201	0.007
36	Intercept + Light + Large-Fish Density (Side) + Discharge	193.218	0.007
37	Intercept + Light + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	193.251	0.007
38	Intercept + Small-Fish Density + Temperature + Turbidity	193.256	0.007
39	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Temperature	193.320	0.007
40	Intercept + Juvenile Length + Light + Discharge + Temperature + Turbidity	193.327	0.007
41	Intercept + Large-Fish Density (Side) + Temperature	193.345	0.007
42	Intercept + Light + Large-Fish Density (Down) + Discharge + Temperature + Turbidity	193.373	0.007
43	Intercept + Light + Large-Fish Density (Side) + Discharge + Turbidity	193.462	0.006
44	Intercept + Light + Large-Fish Density (Down) + Discharge	193.466	0.006
45	Intercept + Light + Turbidity	193.490	0.006
46	Intercept + Light + Large-Fish Density (Side) + Turbidity	193.519	0.006
47	Intercept + Light + Large-Fish Density (Down)	193.545	0.006
48	Intercept + Light + Small-Fish Density + Temperature + Turbidity	193.568	0.006
49	Intercept + Large-Fish Density (Side) + Small-Fish Density + Discharge	193.593	0.006
50	Intercept + Large-Fish Density (Side) + Small-Fish Density + Temperature	193.616	0.006
51	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density	193.626	0.006
52	Intercept + Discharge	193.629	0.006
53	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density	193.639	0.006
54	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density	193.658	0.006
55	Intercept + Light + Small-Fish Density + Turbidity	193.697	0.006
56	Intercept + Light + Small-Fish Density + Discharge + Turbidity	193.716	0.006
57	Intercept + Juvenile Length + Light	193.729	0.006
58	Intercept + Large-Fish Density (Side) + Small-Fish Density + Turbidity	193.768	0.005
59	Intercept + Juvenile Length + Light + Small-Fish Density	193.809	0.005
60	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge	193.811	0.005

Table F-3
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Steelhead at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
61	Intercept + Juvenile Length + Light + Small-Fish Density + Temperature	193.815	0.005
62	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge	193.817	0.005
63	Intercept + Large-Fish Density (Down) + Small-Fish Density	193.828	0.005
64	Intercept + Large-Fish Density (Down)	193.851	0.005
65	Intercept + Temperature + Turbidity	193.946	0.005
66	Intercept + Juvenile Length + Small-Fish Density	193.953	0.005
67	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Discharge + Temperature	194.038	0.005
68	Intercept + Large-Fish Density (Side) + Discharge	194.072	0.005
69	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature	194.090	0.005
70	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density	194.120	0.005
71	Intercept + Juvenile Length	194.127	0.005
72	Intercept + Juvenile Length + Temperature	194.136	0.005
73	Intercept + Large-Fish Density (Down) + Temperature	194.148	0.004
74	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side)	194.156	0.004
75	Intercept + Juvenile Length + Light + Large-Fish Density (Side)	194.159	0.004
76	Intercept + Turbidity	194.188	0.004
77	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Discharge + Temperature	194.197	0.004
78	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density	194.220	0.004
79	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Turbidity	194.249	0.004
80	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side)	194.297	0.004
81	Intercept + Large-Fish Density (Side) + Turbidity	194.303	0.004
82	Intercept + Juvenile Length + Large-Fish Density (Side)	194.309	0.004
83	Intercept + Juvenile Length + Light + Discharge	194.332	0.004
84	Intercept + Large-Fish Density (Down) + Small-Fish Density + Temperature	194.354	0.004
85	Intercept + Light + Large-Fish Density (Side) + Temperature + Turbidity	194.362	0.004
86	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature	194.459	0.004
87	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Temperature	194.486	0.004
88	Intercept + Small-Fish Density + Discharge + Temperature + Turbidity	194.499	0.004
89	Intercept + Small-Fish Density + Discharge + Turbidity	194.535	0.004
90	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature	194.552	0.004

Table F-3
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Steelhead at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
91	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	194.615	0.004
92	Intercept + Juvenile Length + Small-Fish Density + Temperature	194.656	0.003
93	Intercept + Large-Fish Density (Side) + Discharge + Temperature	194.698	0.003
94	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	194.701	0.003
95	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature + Turbidity	194.744	0.003
96	Intercept + Large-Fish Density (Down) + Discharge + Temperature	194.756	0.003
97	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge + Temperature + Turbidity	194.780	0.003
98	Intercept + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	194.799	0.003
99	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	194.825	0.003
100	Intercept + Large-Fish Density (Down) + Discharge	194.860	0.003
101	Intercept + Light + Large-Fish Density (Down) + Discharge + Turbidity	194.864	0.003
102	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge	194.866	0.003
103	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	194.867	0.003
104	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature	194.880	0.003
105	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge	194.923	0.003
106	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Temperature	194.925	0.003
107	Intercept + Light + Large-Fish Density (Down) + Temperature + Turbidity	194.926	0.003
108	Intercept + Juvenile Length + Light + Temperature + Turbidity	194.927	0.003
109	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge	194.928	0.003
110	Intercept + Juvenile Length + Discharge + Temperature	194.958	0.003
111	Intercept + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	195.005	0.003
112	Intercept + Discharge + Temperature + Turbidity	195.079	0.003
113	Intercept + Juvenile Length + Small-Fish Density + Discharge	195.083	0.003
114	Intercept + Large-Fish Density (Down) + Small-Fish Density + Discharge	195.085	0.003
115	Intercept + Juvenile Length + Light + Discharge + Turbidity	195.088	0.003
116	Intercept + Large-Fish Density (Down) + Small-Fish Density + Turbidity	195.094	0.003
117	Intercept + Juvenile Length + Small-Fish Density + Turbidity	195.106	0.003
118	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature	195.127	0.003
119	Intercept + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature	195.252	0.003
120	Intercept + Juvenile Length + Small-Fish Density + Discharge + Temperature	195.267	0.003

Table F-3
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Steelhead at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
121	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Discharge	195.279	0.003
122	Intercept + Light + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	195.294	0.003
123	Intercept + Large-Fish Density (Down) + Small-Fish Density + Temperature + Turbidity	195.300	0.003
124	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Temperature	195.338	0.002
125	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Temperature + Turbidity	195.378	0.002
126	Intercept + Juvenile Length + Small-Fish Density + Temperature + Turbidity	195.385	0.002
127	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	195.390	0.002
128	Intercept + Juvenile Length + Large-Fish Density (Side) + Temperature	195.405	0.002
129	Intercept + Large-Fish Density (Side) + Temperature + Turbidity	195.415	0.002
130	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	195.435	0.002
131	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature	195.446	0.002
132	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Turbidity	195.463	0.002
133	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Temperature	195.473	0.002
134	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Discharge + Temperature + Turbidity	195.505	0.002
135	Intercept + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	195.527	0.002
136	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge	195.536	0.002
137	Intercept + Light + Large-Fish Density (Down) + Turbidity	195.539	0.002
138	Intercept + Juvenile Length + Discharge	195.568	0.002
139	Intercept + Juvenile Length + Light + Turbidity	195.578	0.002
140	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Discharge	195.587	0.002
141	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Discharge + Turbidity	195.607	0.002
142	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Turbidity	195.617	0.002
143	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Turbidity	195.618	0.002
144	Intercept + Juvenile Length + Light + Large-Fish Density (Down)	195.645	0.002
145	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Turbidity	195.648	0.002
146	Intercept + Discharge + Turbidity	195.685	0.002
147	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Turbidity	195.689	0.002
148	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Turbidity	195.714	0.002
149	Intercept + Juvenile Length + Light + Small-Fish Density + Temperature + Turbidity	195.719	0.002
150	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Discharge	195.722	0.002

Table F-3
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Steelhead at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
151	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Temperature	195.739	0.002
152	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density	195.750	0.002
153	Intercept + Large-Fish Density (Down) + Turbidity	195.765	0.002
154	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density	195.767	0.002
155	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density	195.814	0.002
156	Intercept + Juvenile Length + Light + Small-Fish Density + Turbidity	195.815	0.002
157	Intercept + Large-Fish Density (Down) + Temperature + Turbidity	195.856	0.002
158	Intercept + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Turbidity	195.872	0.002
159	Intercept + Juvenile Length + Light + Small-Fish Density + Discharge + Turbidity	195.872	0.002
160	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Turbidity	195.892	0.002
161	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge	195.903	0.002
162	Intercept + Juvenile Length + Large-Fish Density (Down)	195.918	0.002
163	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density	195.930	0.002
164	Intercept + Juvenile Length + Temperature + Turbidity	195.955	0.002
165	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge	195.967	0.002
166	Intercept + Large-Fish Density (Side) + Discharge + Turbidity	196.023	0.002
167	Intercept + Juvenile Length + Large-Fish Density (Side) + Discharge	196.087	0.002
168	Intercept + Juvenile Length + Turbidity	196.186	0.002
169	Intercept + Juvenile Length + Large-Fish Density (Down) + Temperature	196.214	0.002
170	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature	196.222	0.002
171	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side)	196.278	0.002
172	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature + Turbidity	196.292	0.002
173	Intercept + Juvenile Length + Large-Fish Density (Side) + Turbidity	196.372	0.001
174	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Turbidity	196.376	0.001
175	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side)	196.378	0.001
176	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Turbidity	196.386	0.001
177	Intercept + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	196.475	0.001
178	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Temperature	196.477	0.001
179	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Temperature + Turbidity	196.516	0.001
180	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature	196.584	0.001

Table F-3
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Steelhead at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
181	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	196.617	0.001
182	Intercept + Juvenile Length + Small-Fish Density + Discharge + Temperature + Turbidity	196.642	0.001
183	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature	196.647	0.001
184	Intercept + Large-Fish Density (Down) + Small-Fish Density + Discharge + Turbidity	196.651	0.001
185	Intercept + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature + Turbidity	196.655	0.001
186	Intercept + Juvenile Length + Small-Fish Density + Discharge + Turbidity	196.660	0.001
187	Intercept + Juvenile Length + Large-Fish Density (Side) + Discharge + Temperature	196.705	0.001
188	Intercept + Large-Fish Density (Down) + Discharge + Temperature + Turbidity	196.722	0.001
189	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	196.724	0.001
190	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature	196.734	0.001
191	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	196.789	0.001
192	Intercept + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	196.794	0.001
193	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	196.798	0.001
194	Intercept + Juvenile Length + Large-Fish Density (Down) + Discharge + Temperature	196.822	0.001
195	Intercept + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	196.827	0.001
196	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	196.888	0.001
197	Intercept + Large-Fish Density (Down) + Discharge + Turbidity	196.907	0.001
198	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	196.909	0.001
199	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature + Turbidity	196.939	0.001
200	Intercept + Juvenile Length + Large-Fish Density (Down) + Discharge	196.942	0.001
201	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	196.951	0.001
202	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Discharge + Turbidity	197.012	0.001
203	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	197.024	0.001
204	Intercept + Juvenile Length + Discharge + Temperature + Turbidity	197.036	0.001
205	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge	197.049	0.001
206	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Temperature + Turbidity	197.050	0.001
207	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge	197.069	0.001

Table F-3
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Steelhead at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
208	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	197.160	0.001
209	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Discharge	197.211	0.001
210	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Turbidity	197.223	0.001
211	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature	197.274	0.001
212	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature	197.388	0.001
213	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Temperature + Turbidity	197.452	0.001
214	Intercept + Juvenile Length + Light + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	197.462	0.001
215	Intercept + Juvenile Length + Large-Fish Density (Side) + Temperature + Turbidity	197.490	0.001
216	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature + Turbidity	197.525	0.001
217	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature	197.533	0.001
218	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Temperature + Turbidity	197.560	0.001
219	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	197.584	0.001
220	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	197.598	0.001
221	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Turbidity	197.607	0.001
222	Intercept + Juvenile Length + Discharge + Turbidity	197.659	0.001
223	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Turbidity	197.665	0.001
224	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	197.683	0.001
225	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge	197.685	0.001
226	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Turbidity	197.771	0.001
227	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Turbidity	197.787	0.001
228	Intercept + Juvenile Length + Large-Fish Density (Down) + Turbidity	197.858	0.001
229	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Turbidity	197.868	0.001
230	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Turbidity	197.873	0.001
231	Intercept + Juvenile Length + Large-Fish Density (Down) + Temperature + Turbidity	197.948	0.001
232	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge	198.003	0.001
233	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Turbidity	198.005	0.001
234	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Small-Fish Density + Discharge + Turbidity	198.056	0.001
235	Intercept + Juvenile Length + Large-Fish Density (Side) + Discharge + Turbidity	198.083	0.001

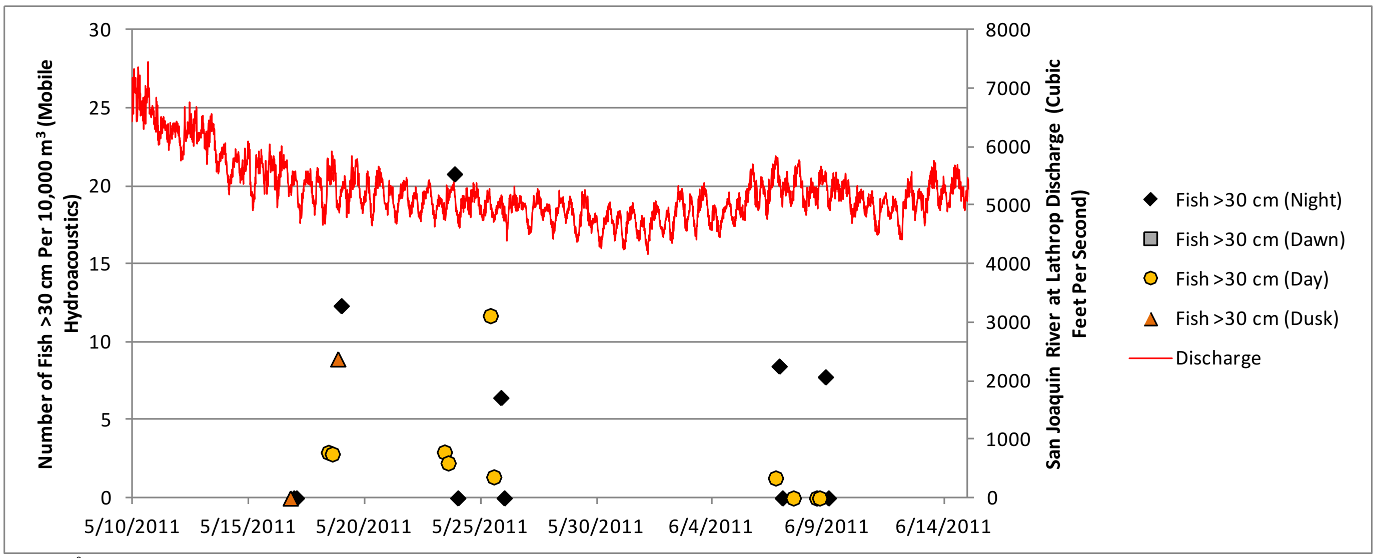
Table F-3
Model Fit (AIC_c) and Weight (w_i) for the Generalized Linear Modeling of Predation Probability of Acoustically Tagged Juvenile Steelhead at the Head of Old River in 2011 and 2012

Model Rank	Variables	AIC_c	w_i
236	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature + Turbidity	198.444	0.001
237	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Turbidity	198.492	0.001
238	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	198.614	0.000
239	Intercept + Juvenile Length + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	198.651	0.000
240	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature	198.740	0.000
241	Intercept + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	198.760	0.000
242	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Discharge + Turbidity	198.805	0.000
243	Intercept + Juvenile Length + Large-Fish Density (Down) + Discharge + Temperature + Turbidity	198.815	0.000
244	Intercept + Juvenile Length + Large-Fish Density (Down) + Small-Fish Density + Discharge + Temperature + Turbidity	198.824	0.000
245	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	198.827	0.000
246	Intercept + Juvenile Length + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	198.860	0.000
247	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	198.933	0.000
248	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature	198.954	0.000
249	Intercept + Juvenile Length + Large-Fish Density (Down) + Discharge + Turbidity	199.017	0.000
250	Intercept + Juvenile Length + Light + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	199.019	0.000
251	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Temperature + Turbidity	199.066	0.000
252	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Temperature + Turbidity	199.640	0.000
253	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Turbidity	199.763	0.000
254	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Turbidity	200.131	0.000
255	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Small-Fish Density + Discharge + Temperature + Turbidity	200.811	0.000
256	Intercept + Juvenile Length + Large-Fish Density (Down) + Large-Fish Density (Side) + Discharge + Temperature + Turbidity	200.882	0.000

Notes: AIC_c = Akaike's Information Criterion adjusted for small sample sizes; *wi* = model weight; temperature = water temperature
Source: Present study

APPENDIX G

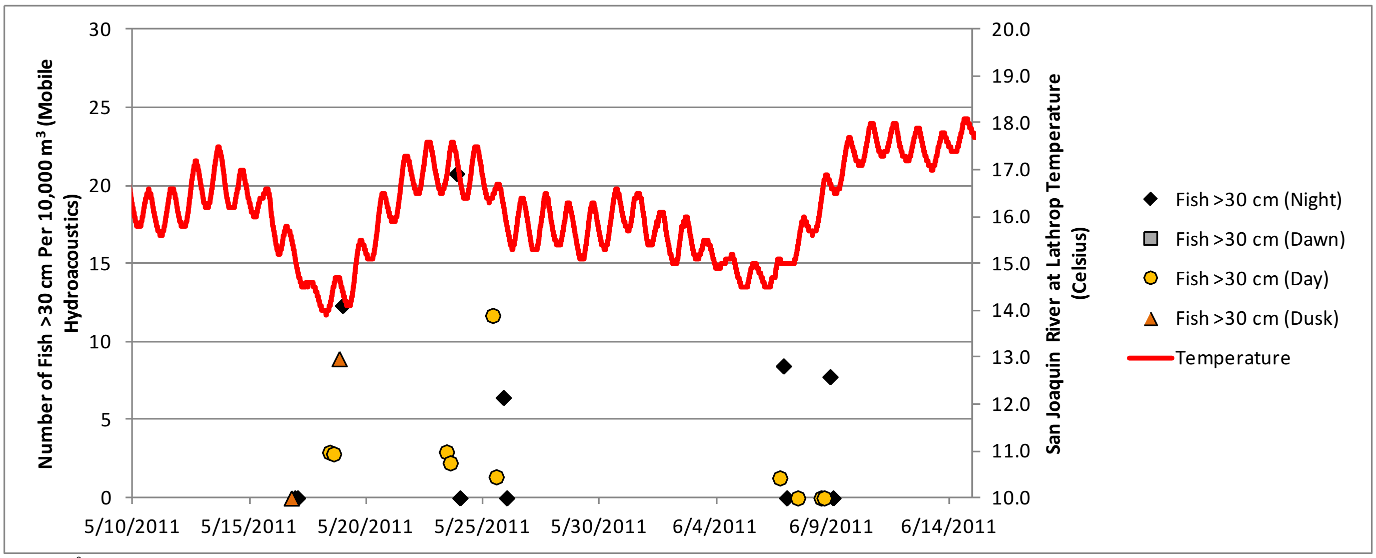
Plots of Environmental Variables and Large-Fish Density from Mobile Hydroacoustic Surveys



Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

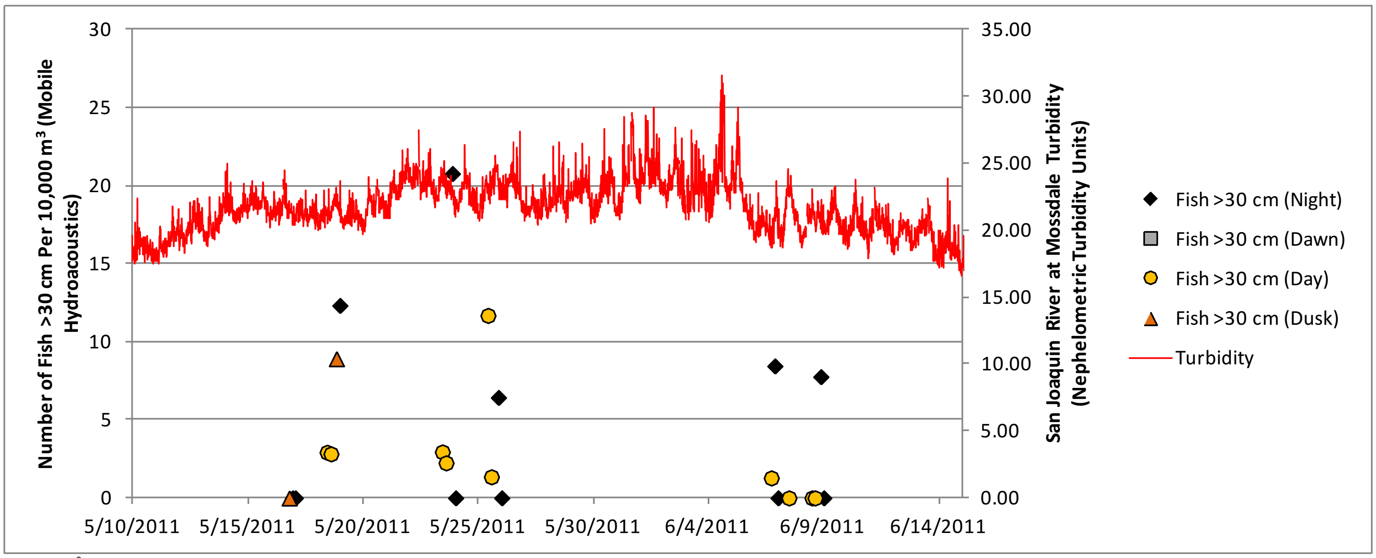
Figure G-1 **Estimated Large-Fish Density in Relation to River Discharge and Photoperiod Observed During Down-Looking Mobile Hydroacoustic Surveys in 2011**



Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

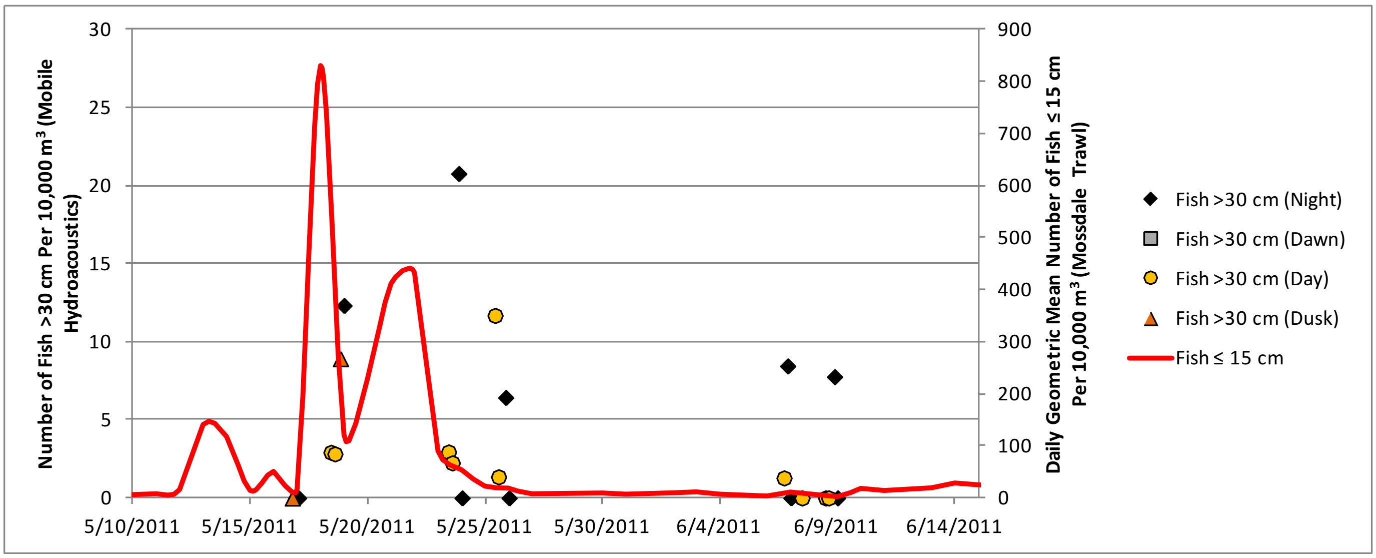
Figure G-2 **Estimated Large-Fish Density in Relation to Water Temperature and Photoperiod Observed During Down-Looking Mobile Hydroacoustic Surveys in 2011**



Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

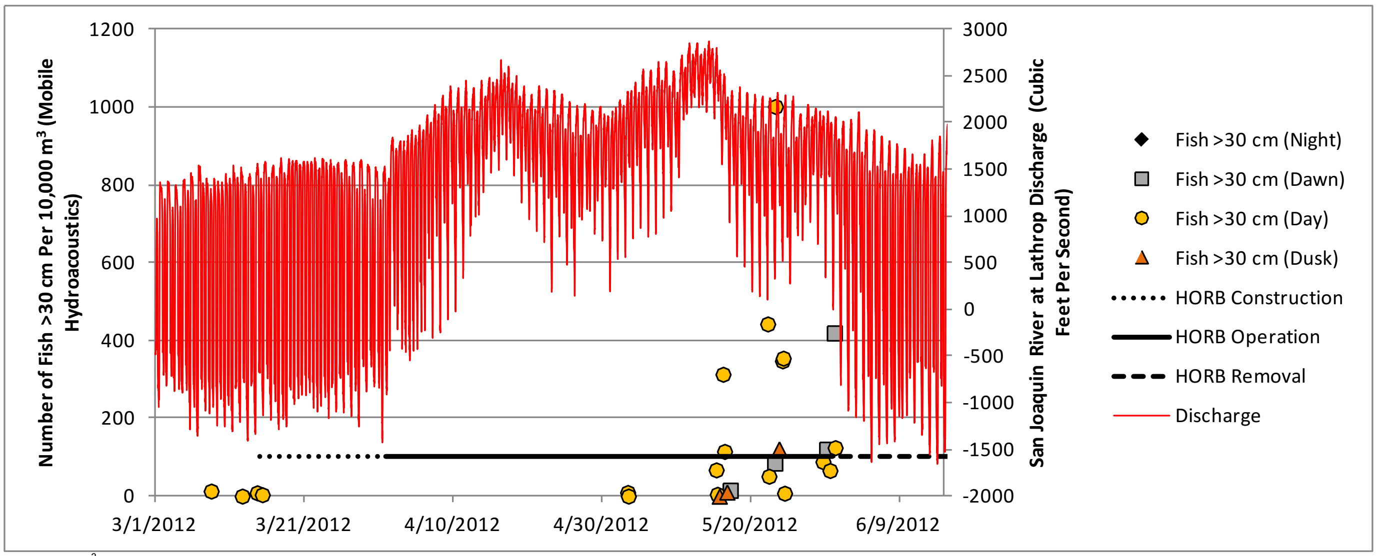
Figure G-3 **Estimated Large-Fish Density in Relation to Turbidity and Photoperiod Observed During Down-Looking Mobile Hydroacoustic Surveys in 2011**



Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; ≤15 cm = less than or equal to 15 centimeters

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

Figure G-4 **Estimated Large-Fish Density in Relation to Small-Fish Density and Photoperiod Observed During Down-Looking Mobile Hydroacoustic Surveys in 2011**

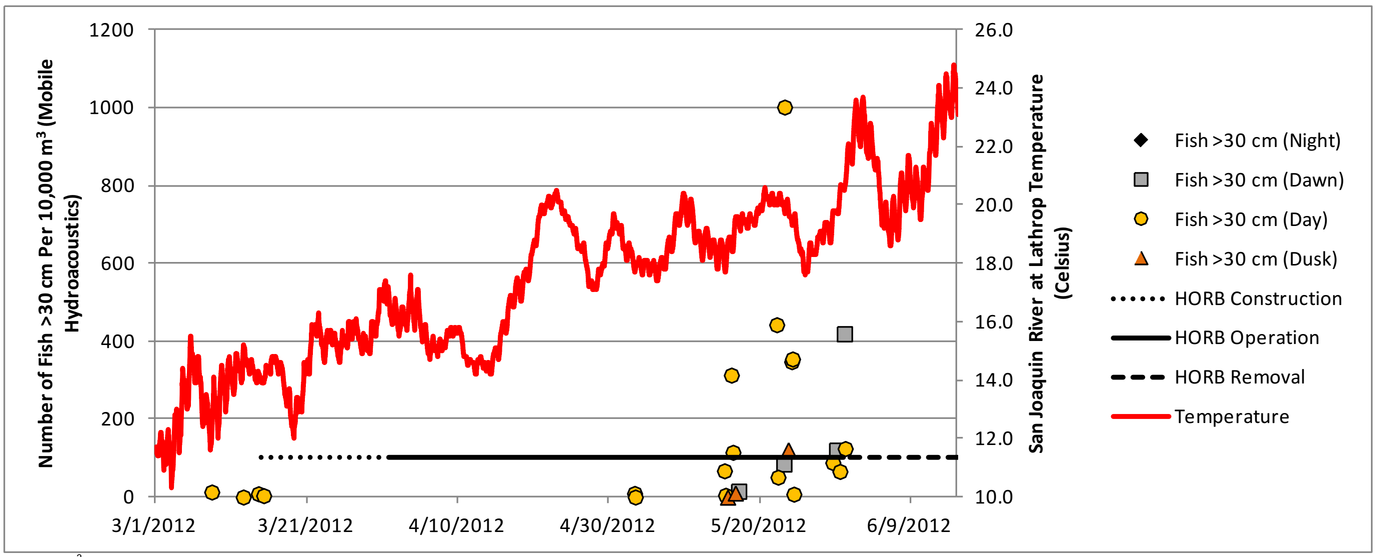


Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; HORB = Head of Old River Barrier

Horizontal black line indicates Head of Old River physical rock barrier construction, operation, and removal period

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

Figure G-5 Estimated Large-Fish Density in Relation to River Discharge, Photoperiod, and Physical Barrier Status Observed During Down-Looking Mobile Hydroacoustic Surveys in 2012

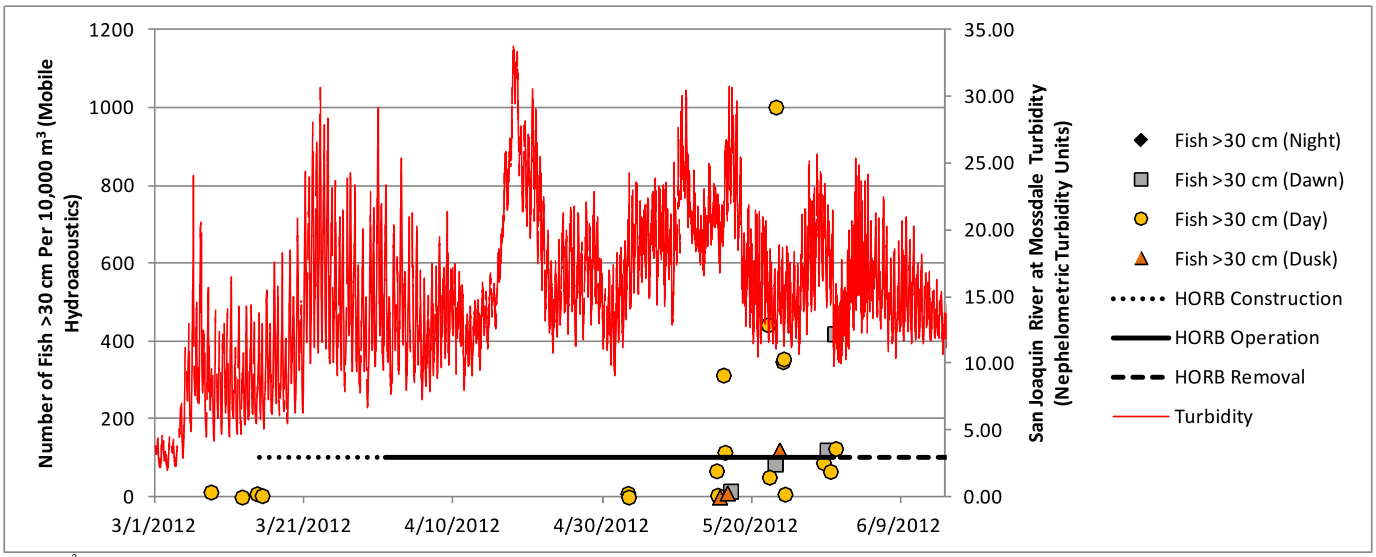


Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; HORB = Head of Old River Barrier

Horizontal black line indicates Head of Old River physical rock barrier construction, operation, and removal period

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

Figure G-6 **Estimated Large-Fish Density in Relation to Water Temperature, Photoperiod, and Physical Barrier Status Observed During Down-Looking Mobile Hydroacoustic Surveys in 2012**

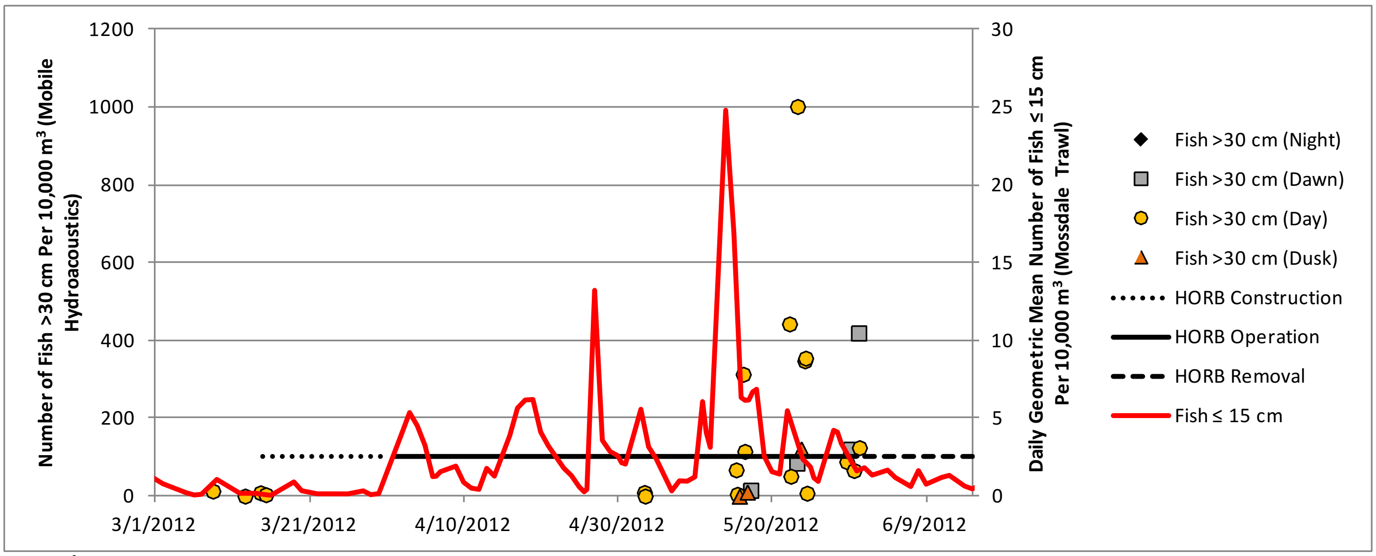


Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; HORB = Head of Old River Barrier

Horizontal black line indicates Head of Old River physical rock barrier construction, operation, and removal period

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

Figure G-7 **Estimated Large-Fish Density in Relation to Turbidity, Photoperiod, and Physical Barrier Status Observed During Down-Looking Mobile Hydroacoustic Surveys in 2012**

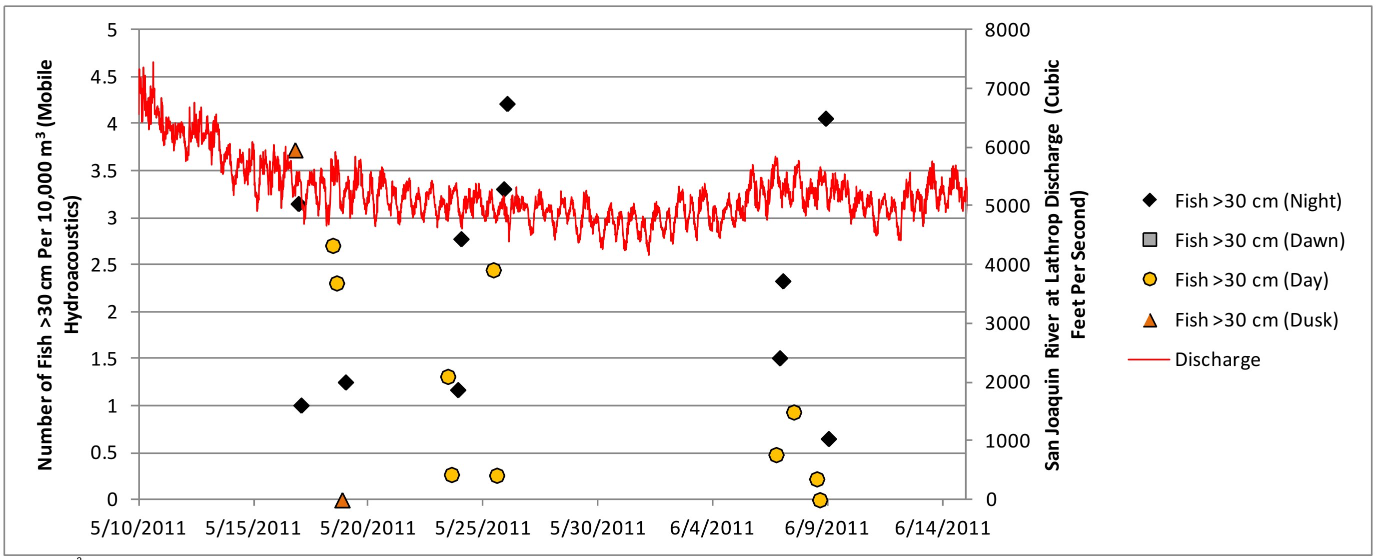


Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; HORB = Head of Old River Barrier; ≤15 cm = less than or equal to 15 centimeters

Horizontal black line indicates Head of Old River physical rock barrier construction, operation, and removal period

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

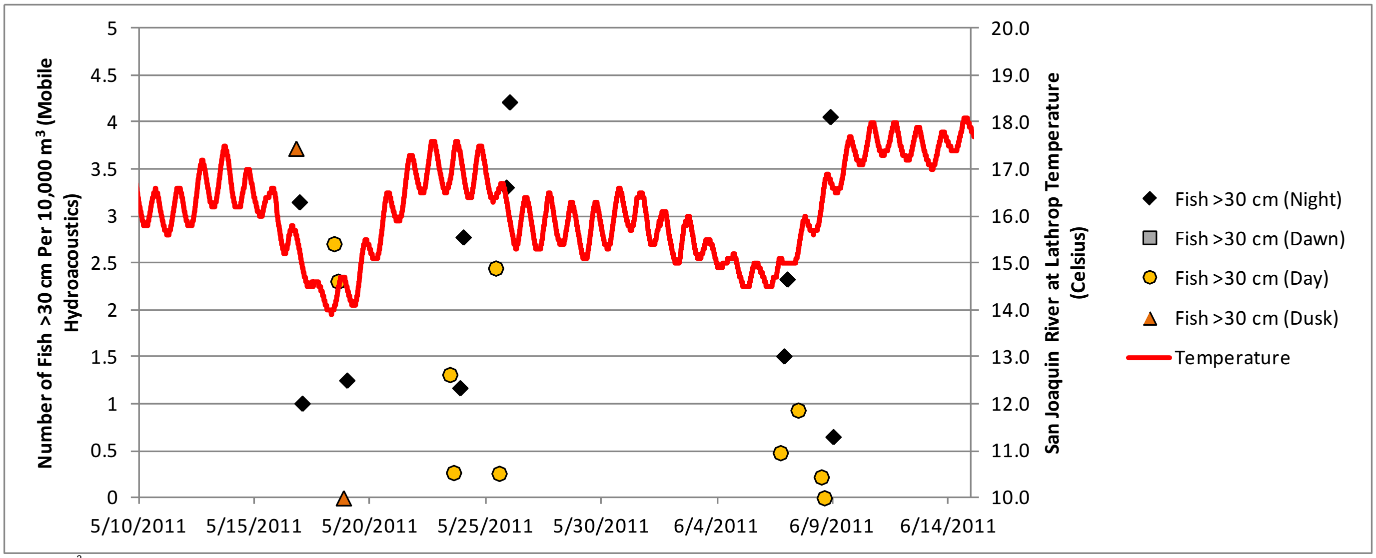
Figure G-8 **Estimated Large-Fish Density in Relation to Smaller-Fish Density, Photoperiod, and Physical Barrier Status Observed During Down-Looking Mobile Hydroacoustic Surveys in 2012**



Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters

Source Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

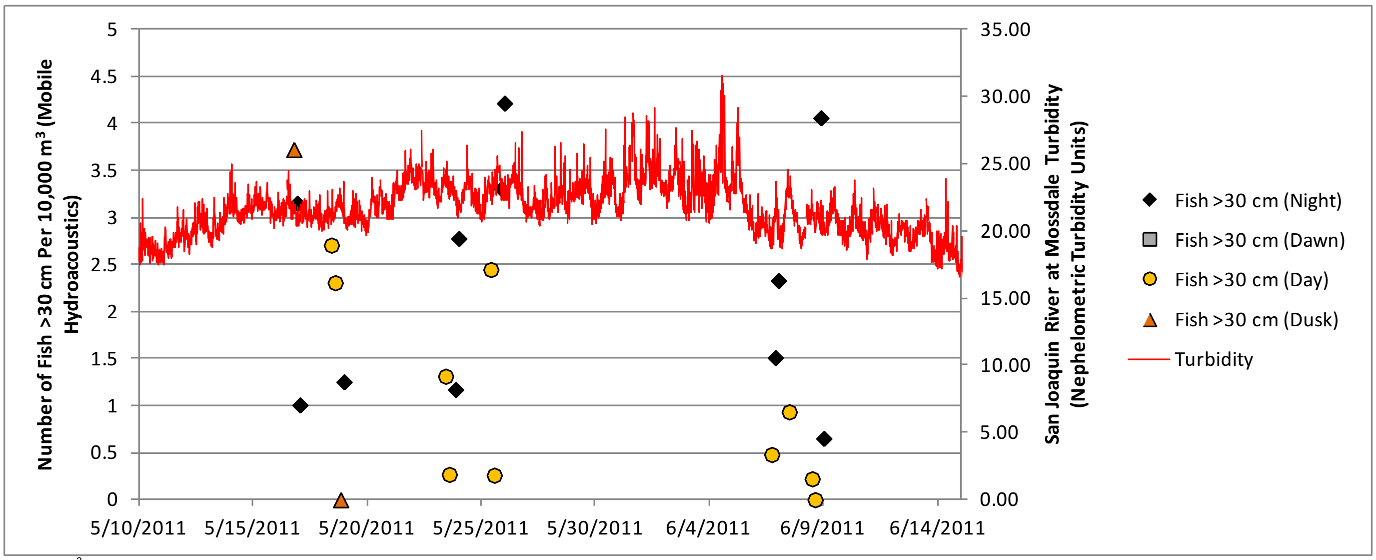
Figure G-9 **Estimated Large-Fish Density in Relation to River Discharge and Photoperiod Observed During Side-Looking Mobile Hydroacoustic Surveys in 2011**



Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

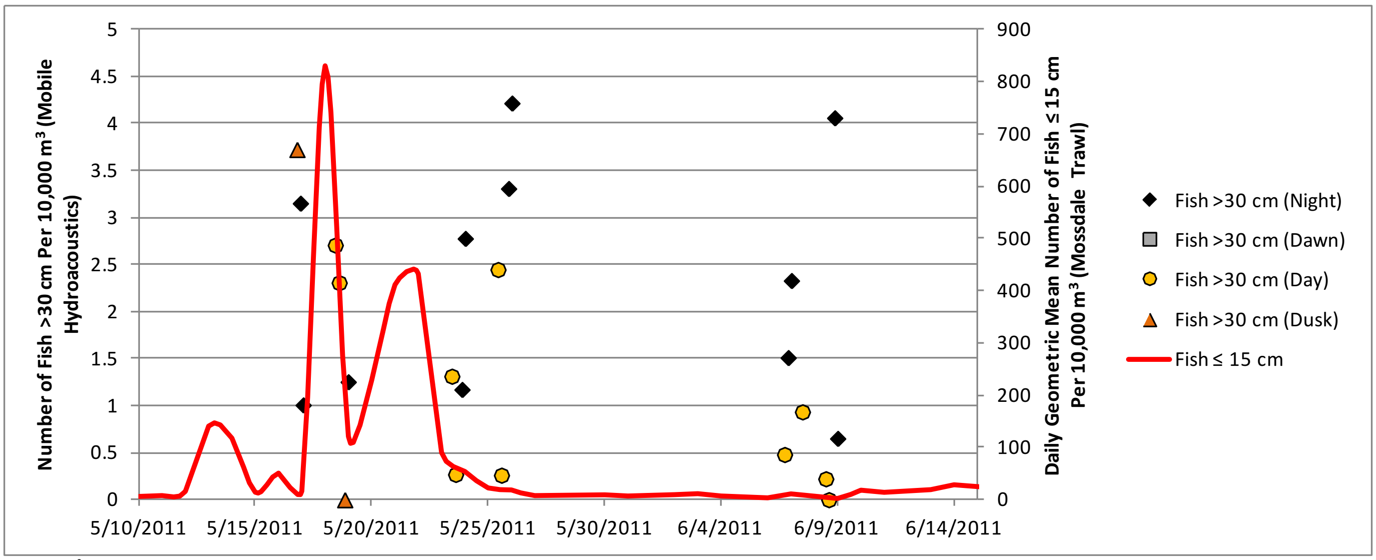
Figure G-10 **Estimated Large-Fish Density in Relation to Water Temperature and Photoperiod Observed During Side-Looking Mobile Hydroacoustic Surveys in 2011**



Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

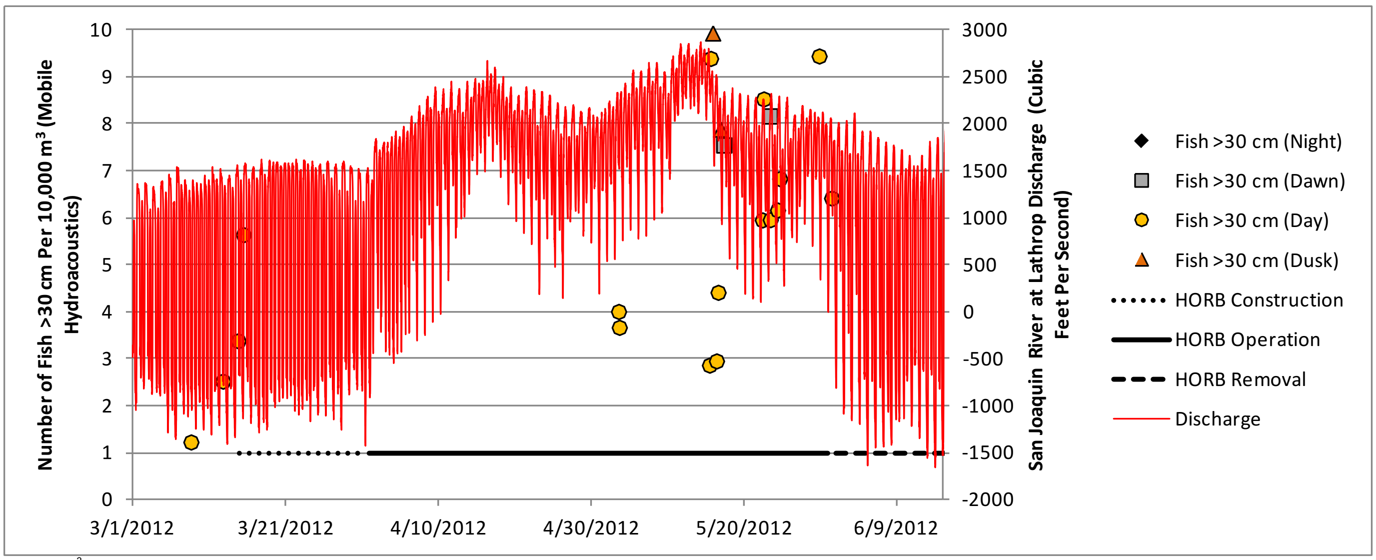
Figure G-11 **Estimated Large-Fish Density in Relation to Turbidity and Photoperiod Observed During Side-Looking Mobile Hydroacoustic Surveys in 2011**



Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; ≤15 cm = less than or equal to 15 centimeters

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

Figure G-12 **Estimated Large-Fish Density in Relation to Smaller-Fish Density and Photoperiod Observed During Side-Looking Mobile Hydroacoustic Surveys in 2011**

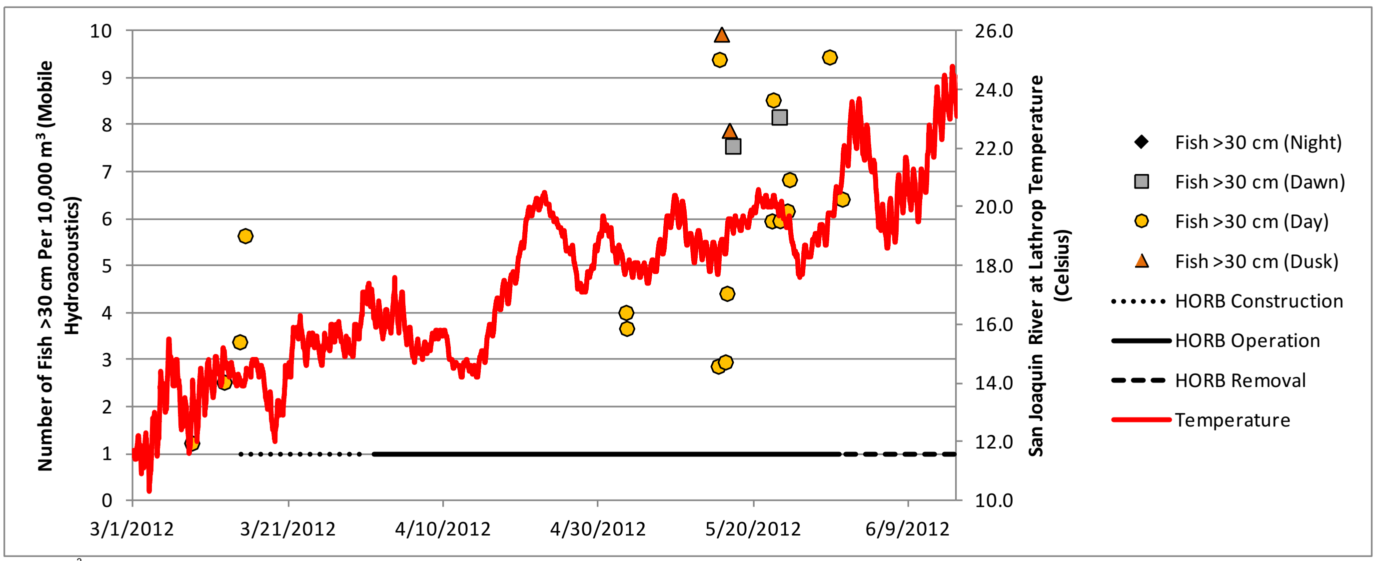


Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; HORB = Head of Old River Barrier

Horizontal black line indicates Head of Old River physical rock barrier construction, operation, and removal period

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

Figure G-13 **Estimated Large-Fish Density in Relation to River Discharge, Photoperiod, and Physical Barrier Status Observed During Side-Looking Mobile Hydroacoustic Surveys in 2012**

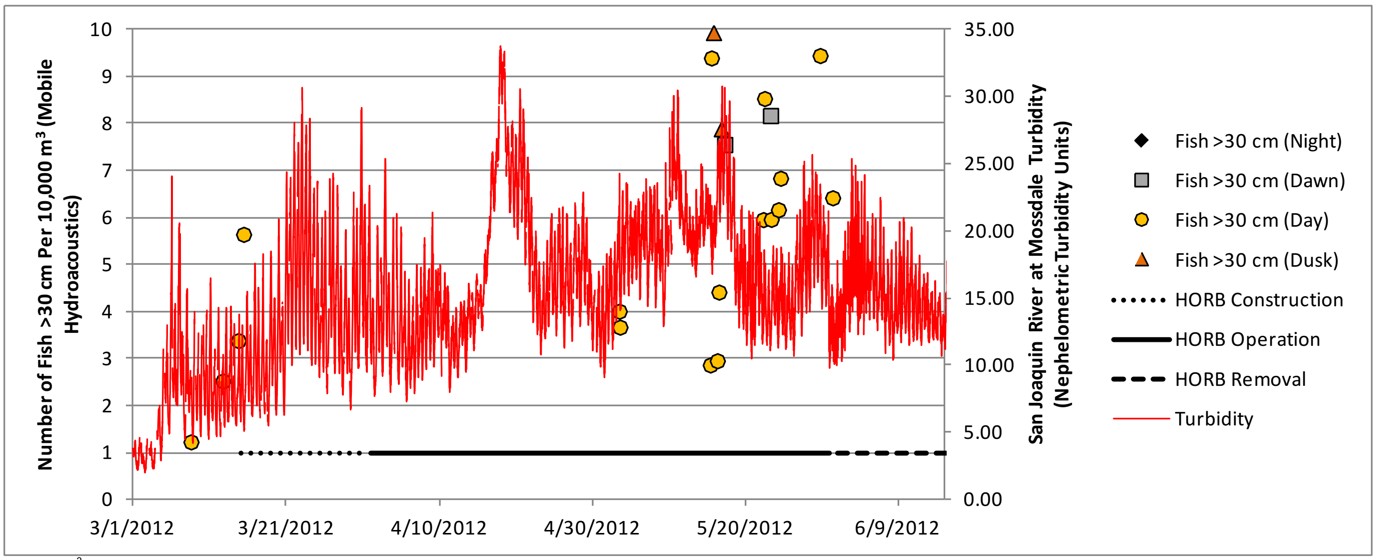


Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; HORB = Head of Old River Barrier

Horizontal black line indicates Head of Old River physical rock barrier construction, operation, and removal period

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

Figure G-14 **Estimated Large-Fish Density in Relation to Water Temperature, Photoperiod, and Physical Barrier Status Observed During Side-Looking Mobile Hydroacoustic Surveys in 2012**

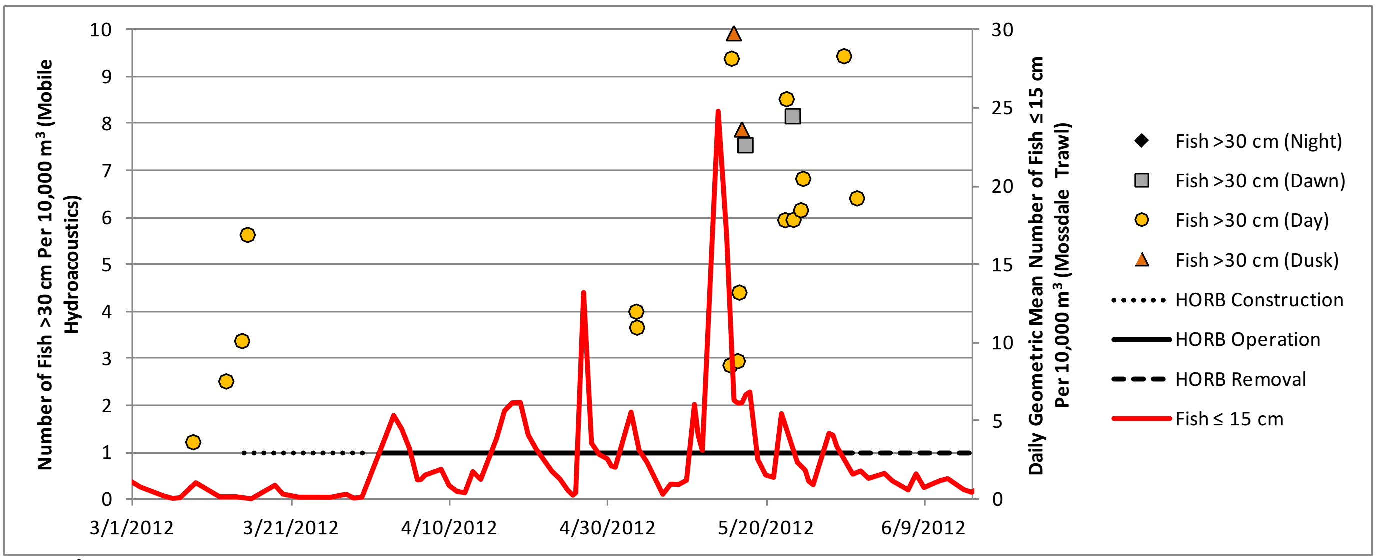


Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; HORB = Head of Old River Barrier

Horizontal black line indicates Head of Old River physical rock barrier construction, operation, and removal period

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

Figure G-15 **Estimated Large-Fish Density in Relation to Turbidity, Photoperiod, and Physical Barrier Status Observed During Side-Looking Mobile Hydroacoustic Surveys in 2012**



Notes: m^3 = cubic meters; >30 cm = greater than 30 centimeters; HORB = Head of Old River Barrier; ≤15 cm = less than or equal to 15 centimeters

Horizontal black line indicates Head of Old River physical rock barrier construction, operation, and removal period

Sources: Present study (hydroacoustic data) and Baldwin, pers. comm., 2013; Dempsey, pers. comm., 2013 (California Data Exchange Center data)

Figure G-16 **Estimated Large-Fish Density in Relation to Smaller-Fish Density, Photoperiod, and Physical Barrier Status Observed During Side-Looking Mobile Hydroacoustic Surveys in 2012**

APPENDIX H

Illustrative Example of Striped Bass Predation Using Bioenergetics Modeling

H.1 METHODS

Bioenergetics modeling was used to provide perspective on an estimated potential fish consumption by predatory fishes at the Head of Old River (HOR) study area in relation to densities of prey fish in the local area. Similar methods were used by Miranda et al. (2010) to estimate the potential for consumption by predatory fish at the fish salvage facilities (Byron, California) release sites. The analysis focused on striped bass (*Morone saxatilis*) because angling catch rates at the HOR study area suggest that this species may be the most common of the four focal fish species during this study period. In addition, bioenergetics modeling parameters have been developed for this species in the San Francisco Bay/Sacramento–San Joaquin Delta (Loboschefsky et al. 2012) and not for any of the other focal fish species.

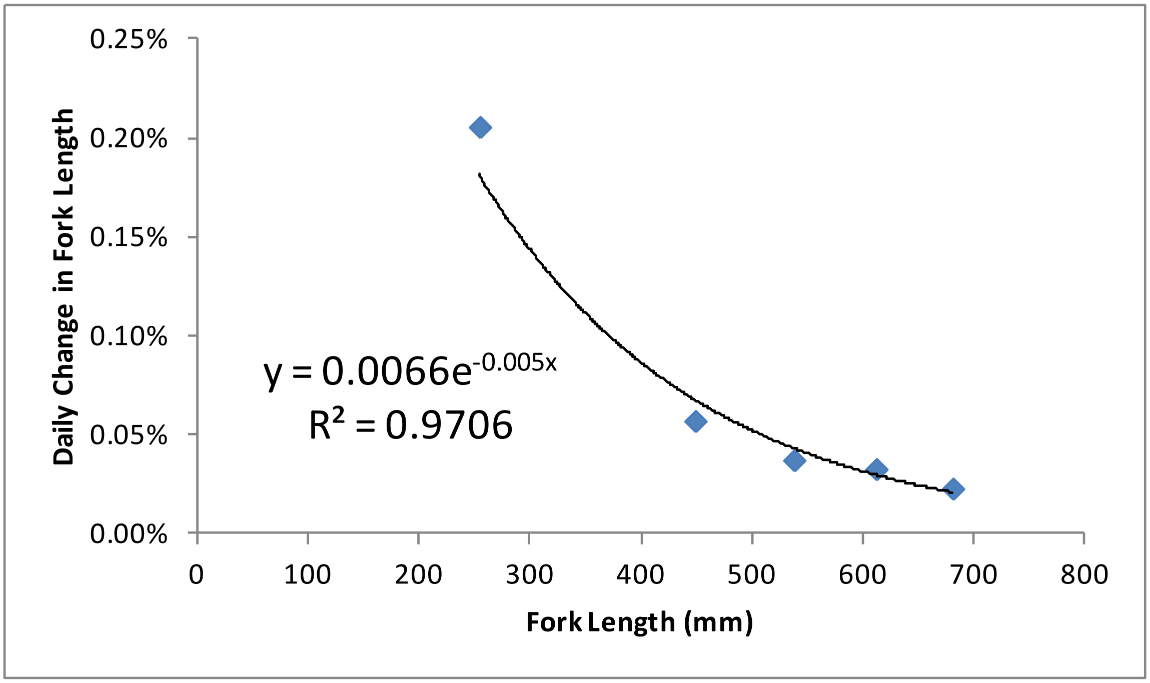
The bioenergetics modeling was conducted using the software Fish Bioenergetics 3.0 (Hanson et al. 1997). This software estimates the food requirements of predatory fish given their energy requirements for growth, metabolism, and other processes. The main model inputs for predatory fish include an estimate of growth (start and end mass over a certain period) and energy density. The main inputs for predator food include the percentage of diet biomass made up by fish and other sources, and the energy density of the dietary items. The main environmental input affecting metabolism is water temperature. The model as implemented for the present study did not segregate by sex, or address bimaturation or ocean emigration as factors. As described herein, the model used for the present study essentially assumed that the density of striped bass occurring at the HOR study area during the study period remained constant (although the same individuals were not necessarily present all the time).

The first stage of the modeling was to develop start and end predator mass during the period of interest, which was taken over a 61-day spring period from April 1 through May 31. The striped bass bioenergetics model produced estimates of striped bass size at ages that can be used to provide an indication of growth rate for different sizes of fish (Loboschefsky, pers. comm., 2013) (Table H-1). The difference in average striped bass fork length (FL) between summer and fall was expressed as a daily percentage change in length from the starting length in spring (Figure H-1).

Table H-1
Estimated Seasonal Fork Length (mm) of Striped Bass from Bioenergetics Modeling[1]

Age	Spring	Summer	Fall	Winter
1	172	188	204	220
2	254	301	353	412
3	448	471	493	516
4	537	555	573	592
5	611	629	646	664
6	680	694	709	723

Note: mm = millimeters
[1] Males and females combined. Striped bass exhibit bimaturation with males maturing at age 2 and females between ages 4 and 6.
Source: Loboschefsky, pers. comm., 2013



Note: mm = millimeters

Source: Present study, based on data from Loboschefsky, pers. comm., 2013

Figure H-1 Daily Percentage Change in Striped-Bass Fork Length Assumed in Bioenergetics Modeling

From this point forward, fork length is expressed in centimeters (cm) instead of millimeters (mm). This relationship was used to estimate start and end mass for striped bass at the midpoint of size classes from 30 to 35 cm total length (TL) to 100 to 105 cm TL (applying a conversion from TL to FL from FishBase.org [FL = TL/1.072961; Froese and Pauly 2011] and a conversion from FL to mass [0.0066*(FL in mm) 3.12; Kimmerer et al. 2005]) (Table H-2). Applying this procedure to larger sizes of striped bass involves extrapolation beyond the range of the seasonal fork length show in in Table H-1. Striped bass energy density was assumed to be 6,488 Joules per gram (J/g) across all size classes (Hanson et al. 1997: A-5).

Striped bass diet composition was based on interpolation of values used by Loboschefsky et al. (2012), wherein 0.82 of the diet biomass for age 2 striped bass (25.4 cm FL in spring) was fish and 0.99 of the biomass for age 3 striped bass (44.8 cm FL in spring) was fish (Table H-3). Fish prey energy density was assumed to be 4,800 J/g (Loboschefsky et al. 2012), and the remainder of the diet was assumed to have an energy density of 3,000 J/g, similar to other potential striped bass prey shown by Loboschefsky et al. (2012).

The detailed model parameters and equations used in the bioenergetics modeling are presented by Hanson et al. (1997: A-5) and summarized in Table H-4. Two sets of parameters were used, one for 32.5-cm to 47.5-cm fish, and another for fish 52.5 cm and greater, based on the transition of males to adulthood. As previously noted, the model did not account for potential differences between male and female striped bass as they were not treated separately, and there was no accounting for energy expended for reproductive purposes.

Table H-2
Assumed Start/End Mass of Striped Bass at the Midpoint of Size Classes from 30–35 cm Total Length to 100–105 cm Total Length

Start TL (cm)	Start FL (cm)	Start Mass (g)	Daily Growth (%)	Growth from April 1 to May 31 (cm)	Final FL (cm)	Final Mass (g)
32.5	30.3	364.1	0.15	2.7	33.0	474.4
37.5	35.0	569.0	0.11	2.5	37.4	703.0
42.5	39.6	840.8	0.09	2.2	41.8	995.3
47.5	44.3	1,189.6	0.07	1.9	46.2	1,360.7
52.5	48.9	1,625.6	0.06	1.7	50.6	1,809.1
57.5	53.6	2,159.2	0.05	1.5	55.1	2,350.7
62.5	58.3	2,800.7	0.04	1.3	59.5	2,996.3
67.5	62.9	3,560.8	0.03	1.1	64.0	3,756.9
72.5	67.6	4,450.2	0.02	0.9	68.5	4,643.6
77.5	72.2	5,479.5	0.02	0.8	73.0	5,667.6
82.5	76.9	6,659.8	0.01	0.7	77.6	6,840.4
87.5	81.6	8,001.8	0.01	0.6	82.1	8,173.4
92.5	86.2	9,516.7	0.01	0.5	86.7	9,678.1
97.5	90.9	11,215.4	0.01	0.4	91.3	11,366.0
102.5	95.5	13,109.3	0.01	0.3	95.9	13,248.6

Notes: cm = centimeters; FL = fork length; g = grams; TL = total length

Source: Present study, based on data from Loboschefsky, pers. comm., 2013

Table H-3
Assumed Proportional Biomass of Fish in Striped Bass Diet at the Midpoint of Size Classes from 30 to 35 cm Total Length to 100 to 105 cm Total Length

Start TL (cm)	Fish as Proportion of Diet Biomass
32.5	0.862851
37.5	0.903686
42.5	0.944521
47.5	0.985356
52.5	0.99
57.5	0.99
62.5	0.99
67.5	0.99
72.5	0.99
77.5	0.99
82.5	0.99
87.5	0.99
92.5	0.99
97.5	0.99
102.5	0.99

Notes: cm = centimeters; TL = total length

Source: Present study, based on data from Loboschefsky et al. 2012

Table H-4
Parameter Values Used in Striped Bass Bioenergetics Modeling

Variables	32.5 to 47.5 cm TL	52.5 to 102.5 cm TL
Consumption Variables		
CA (mass-dependence function intercept, 1-gram fish at optimum water temperature)	0.302	0.302
CB (mass-dependence coefficient)	-0.252	-0.252
CK1 (temperature-dependence fraction of maximum rate, increasing portion of curve)	0.255	0.323
CK4 (temperature-dependence fraction of maximum rate, decreasing portion of curve)	0.9	0.85
CQ (lower water temperature at which temperature dependence is a small fraction [CK1] of maximum rate)	6.6	7.4
CTL (water temperature at which temperature dependence is reduced fraction [CK4] of maximum rate, increasing portion of curve)	32	30
CTM (water temperature [≥CTO] at which dependence is still 0.98 of the maximum rate, decreasing portion of curve)	29	28
CTO (water temperature at which dependence is 0.98 of the maximum rate, increasing portion of curve)	18	15
Equation	3	3
Egestion & Excretion Variables		
Equation	1	1
FA (constant proportion of consumption)	0.104	0.104
UA (constant proportion of assimilated energy [consumption minus egestion])	0.068	0.068
Respiration Variables		
ACT (activity multiplier)	1	1
BACT (water temperature dependence coefficient of swimming speed at water temperatures below RTL)	0	0
Equation	1	1
RA (specific weight of oxygen consumed by a 1-gram fish at 0°C and zero swimming speed)	0.003	0.003
RB (slope of the allometric mass function for standard metabolism)	-0.218	-0.218
RK1 (intercept for swimming speed above cutoff temperature)	1	1
RK4 (mass dependence coefficient for swimming speed at all temperatures)	0	0
RQ (rate at which the function increases over relatively low water temperatures)	0.076	0.076
RTL (cutoff temperature at which the activity relationship changes)	0	0
RTM (maximum lethal temperature, but set to zero)	0	0
RTO (coefficient for swimming speed dependence on metabolism)	0.5	0.5
SDA (specific dynamic action, i.e., the proportion of assimilated energy lost to the cost of assimilating foodstuffs, especially proteins)	0.172	0.172

Notes: cm = centimeters; TL = total length

Source: Hanson et al. 1997: A5

Mean daily water temperature data from April 1 through May 31 in 2011 and 2012 for the San Joaquin River at Lathrop (SJL) station were used for input to the bioenergetics modeling.

The bioenergetics modeling provided the estimated total fish prey biomass consumption from April 1 through May 31 by a single striped bass within each of the size classes from 30-35-cm TL to 100-105-cm TL, from which a mean daily fish biomass consumption of each size class was derived. This size range covers most of the striped bass typically collected with fyke traps on the Sacramento River (DuBois et al. 2012).

An illustrative example of potential consumption at the HOR study area was provided using the consumption estimates derived from bioenergetics modeling. This example has appreciable uncertainty, and is intended to illustrate the means by which consumption estimates can be derived using the results from bioenergetics modeling. The size composition of striped bass was estimated using size composition estimated from the mobile hydroacoustic surveys. The mean daily fish biomass consumed by a single striped bass was then calculated as the mean daily average consumption across all size classes, weighted by the proportion of all individuals in each size class. This mean consumption estimate for a single fish then was multiplied by the mean density of fish observed in the side-looking mobile hydroacoustics to give a mean daily consumption estimate per 10,000 cubic meters for the HOR study area, which then was converted to an estimate for the HOR study area based on the approximate volume of the HOR study area from bathymetry data.

The side-looking hydroacoustic data were used for density estimates because these data may more accurately reflect the pelagic distribution of striped bass, whereas the down-looking hydroacoustic data may include demersal species such as common carp (which were abundant in visual observations made near the 2012 Head of Old River Barrier [HORB]). The density specific consumption estimates were used to illustrate the potential consumption of fish prey in relation to prey fish biomass density entering the HOR study area.

Note that the bioenergetics modeling described here assumes a static size composition and density of striped bass at the HOR study area, but makes no assumptions about the length of time that striped bass may spend at the site. Residence times for striped bass at the HOR study area tends to be quite short (see Section 6.3.1, "Data from Acoustically Tagged Predatory Fish"), but the modeling implicitly assumes replacement of emigrating individuals by the same density of immigrating individuals. Prey biomass was estimated from the Mossdale trawl data, with a particular focus on juvenile Chinook salmon, by converting fork length to biomass using equations from Kimmerer et al. (2005) and Froese and Pauly (2011).

Fish growth rates may be higher than the "average" rates assumed herein if more efficient prey capture is facilitated by habitat conditions (e.g., at water diversion structures; see Vogel 2011: Figure 42). In addition, neither the identity of predatory fish from echoes nor the extent to which small-fish density at Mossdale represents small-fish density at the HOR study area are known. As described later herein, the illustrative example of consumption at the HOR study area makes numerous assumptions; these assumptions generally include considerable uncertainty. Nevertheless, the illustrative example serves to provide some speculation on the estimated potential consumption rate, which then provides context for additional estimates of predation on acoustically tagged juvenile salmonid by striped bass.

H.2 RESULTS

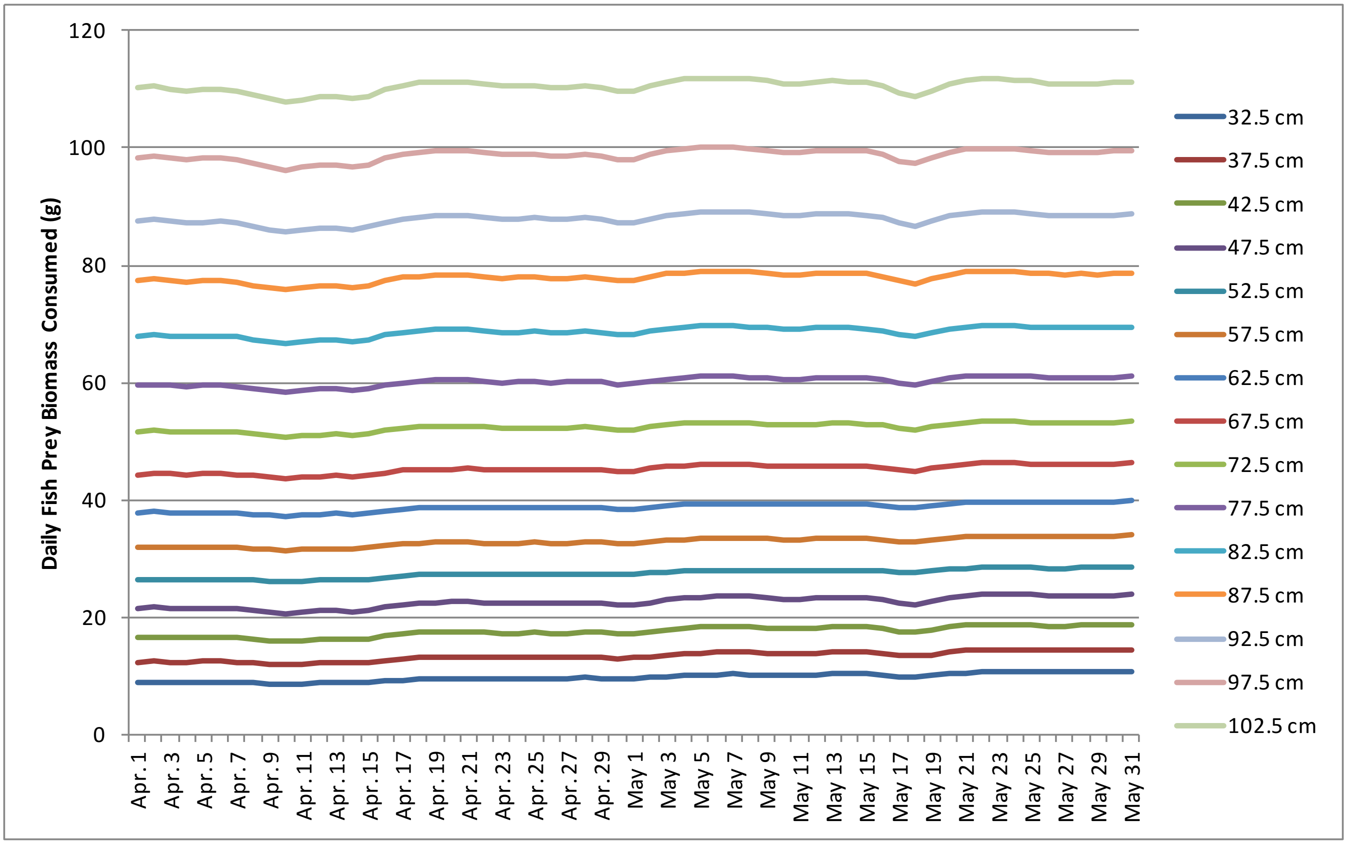
H.2.1 STRIPED BASS FISH PREY CONSUMPTION RATES

Bioenergetics modeling of potential consumption of fish prey by striped bass estimated that a 32.5-cm TL striped bass growing at an average rate and experiencing the 2011 water temperatures found near the HOR study area (San Joaquin River near Lathrop) would consume an average of approximately 9.8 grams of fish prey per day from April 1 to May 31 (Table H-5; Figure H-2). The daily consumption by the largest size of striped bass considered (102.5 cm) for the same water temperature was estimated to be 110.5 grams. To provide some perspective to these results, application of the length/weight relationship from Kimmerer et al. (2005) suggests that a 50-mm FL juvenile Chinook salmon weighs approximately 1.3 grams and a 100-mm FL juvenile Chinook salmon weighs approximately 13.7 grams. Thus, for example, a 62.5-cm striped bass might consume around three 100-mm juvenile Chinook salmon per day to satisfy its bioenergetics requirements (i.e., juveniles similar in size to the experimental fish used in the present study), based on the modeling results.

Table H-5
Estimated Mean Daily Fish Prey Consumption from April 1 through May 31 by Striped Bass Ranging in Total Length from 32.5 cm to 102.5 cm for Water Temperatures Recorded at the San Joaquin River near Lathrop in 2011 and 2012

Length (cm)	Mean Daily Fish Prey Consumption (grams)	
	2011	2012
32.5	9.77	11.10
37.5	13.38	15.27
42.5	17.59	20.17
47.5	22.58	26.01
52.5	27.47	31.80
57.5	32.84	38.17
62.5	38.76	45.22
67.5	45.26	52.98
72.5	52.38	61.51
77.5	60.16	70.85
82.5	68.66	81.04
87.5	77.90	92.13
92.5	87.93	104.17
97.5	98.78	117.20
102.5	110.48	131.24

Note: cm = centimeters
Source: Present study

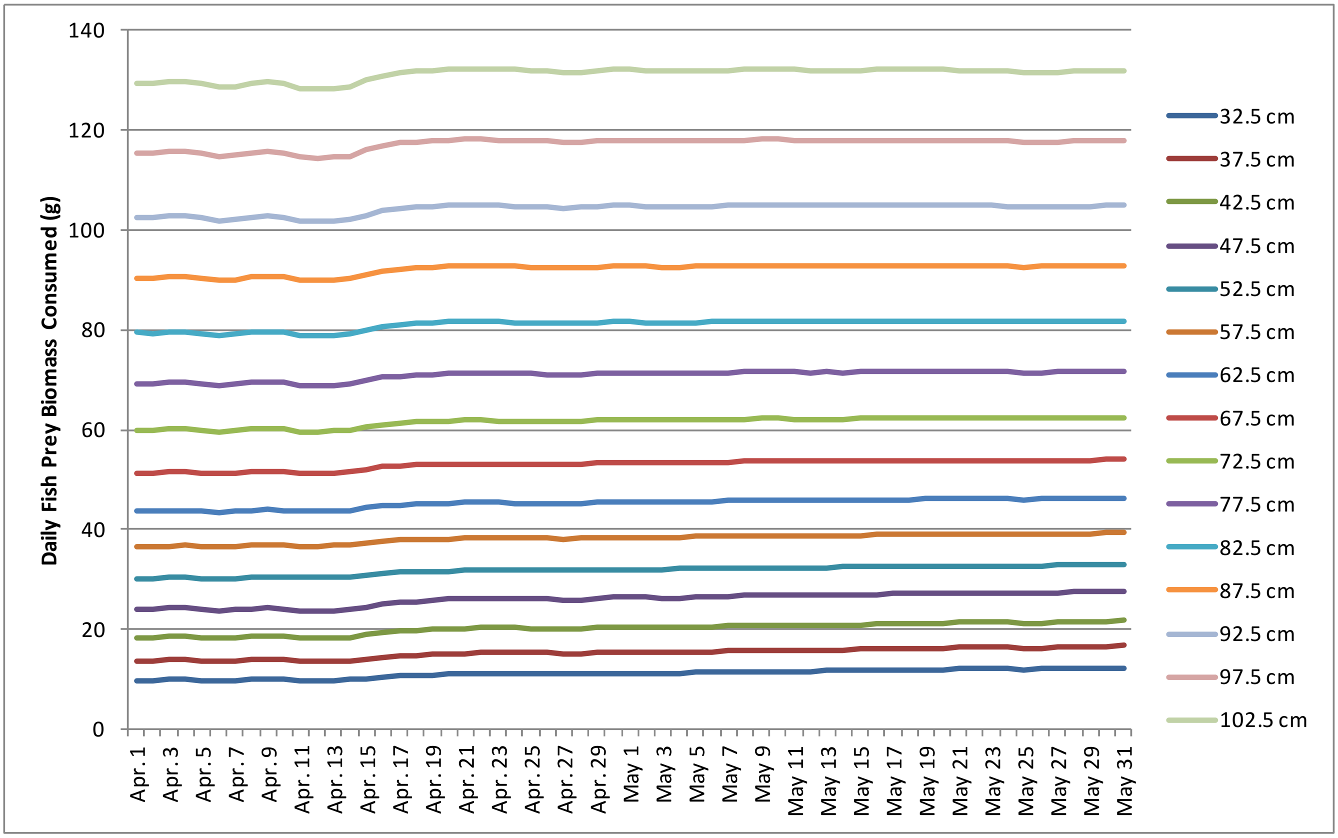


Notes: g = gram; cm = centimeter; TL = total length

Source: Present study

Figure H-2 **Estimated Daily Biomass of Fish Prey Consumed by Striped Bass of 32.5 cm to 102.5 cm TL from April 1–May 31, Based on 2011 Water Temperature Data at the Head of Old River**

Water temperature for April 1 through May 31, 2012, averaged 18.0 degrees Celsius (°C) (range: 14.5 to 21.3°C), which was higher than in 2011 (mean 15.8°C, range: 14.0 to 18.1°C). Assuming the same growth rate of striped bass in both years, water temperature effects on metabolism may have led to greater prey consumption requirements for 2012 than in 2011 (Table H-5; Figures H-2 and H-3). The mean daily fish prey consumption rate was estimated to be 13.7% greater in 2012 than in 2011 for a 32.5-cm striped bass, and the difference between years increased with increasing fish size, so that the mean daily fish prey consumption rate of a 102.5-cm striped bass was estimated to be 18.8% greater in 2012 than in 2011.



Notes: g = gram; cm = centimeter; TL = total length

Source: Present study

Figure H-3 **Estimated Daily Biomass of Fish Prey Consumed by Striped Bass of 32.5 cm to 102.5 cm TL from April 1–May 31, Based on 2012 Water Temperature Data at the Head of Old River**

H.2.2 Illustrative Example Based Upon Assumptions

An illustration of the possible calculations that can be made using the results (from Section H.2.1, "Striped Bass Fish Prey Consumption Rates") is provided here for consumption of prey fish at the HOR study area by striped bass. The calculations are illustrative estimates and not meant to represent actual consumption rates due to the high uncertainties associated with the estimates. As noted in Section H.1, "Methods," it was assumed that the side-looking mobile hydroacoustic data provides an estimate of striped bass density and size distribution at the HOR study area. The size distribution of fish greater than 30 cm TL based on fish echoes detected is shown in Table H-6; fish larger than 105 cm were excluded because it is uncertain whether they would represent striped bass or other fish species. (Targets as large as approximately 425 cm were detected by side-looking surveys in 2012.)

Assuming that this is a reasonable size distribution for striped bass capable of preying on juvenile Chinook salmon, the weighted mean daily consumption of fish prey per striped bass can be worked out by combining the mean daily prey fish consumption (Table H-5) with the size composition (Table H-6). This gives estimates of daily mean fish prey biomass consumed per striped bass of 20.9 grams in 2011 and 29.9 grams in 2012. The mean density of large fish greater than 30 cm TL from the mobile hydroacoustic surveys in May and June 2011 was 1.7 fish per 10,000 cubic meters (m^3) (see Appendix G, Figure G-12). Assuming these fish were all striped bass and had the size distribution shown in Table H-6, the daily consumption of prey fish in 2011 would be 36.6 grams per 10,000 m^3. The mean density of large fish greater than 30 cm TL from the mobile hydroacoustic surveys in May 2012 was 8.8 fish per 10,000 m^3 (see Appendix G, Figure G-16). Assuming these fish were all striped bass and had the size distribution shown in Table H-6, the daily consumption of prey fish in 2012 would be 264.5 grams per 10,000 m^3.

Table H-6
Size Frequency (Total Length, cm) of Fish Observed with Side-Looking Mobile Hydroacoustics

Length Class Midpoint (cm)	Percentage of Fish Observed	
	2011	2012
32.5	37	25
37.5	16	21
42.5	13	10
47.5	10	12
52.5	7	8
57.5	3	6
62.5	4	6
67.5	3	3
72.5	3	2
77.5	0	2
82.5	1	1
87.5	1	1
92.5	1	2
97.5	0	2
102.5	0	2

Notes: cm = centimeters
Fish greater than these sizes were excluded
Source: Present study

The estimates of daily consumption of prey fish for striped bass in the HOR study area can be compared to densities of small-bodied (less than 15 cm FL) prey fish from Mossdale trawling. Note again that the calculation is illustrative; factors such as gear efficiency of the trawl are unknown and likely affect prey species caught and their associated densities. The mean biomass density of prey fish for the period of May 16 through June 8, 2011, during which hydroacoustic surveys occurred (see Appendix G, Figure G-12) was 66.1 grams per 10,000 m^3. The mean biomass density of prey fish for the period of May 3 through May 31, 2012, during which mobile hydroacoustic surveys also occurred (see Appendix G, Figure G-16), was 20.3 grams per 10,000 m^3. The daily consumption rate for 2011 (36.6 grams per 10,000 m^3; see previous) was 55% of the prey fish biomass density. The daily consumption rate for 2012 (264.5 grams per 10,000 m^3; see previous) was greater than 1,300% of the prey fish biomass density.

Estimates of prey fish biomass density are significantly lower in relation to the potential daily consumption rate of striped bass. However, accounting needs to be made of the potential influx of prey fish into the area of the HOR study area. This can be done using estimates of discharge at Mossdale combined with prey fish biomass density.

Thus, assuming the prey-fish biomass density estimated from Mossdale trawling was moving downstream at a rate equivalent to discharge at Mossdale, an estimated mean 178.6 kg of prey fish entered the HOR study area each day during the period in 2011 noted previously, compared with 18.5 kg per day in 2012. As described in Section 2.2.3, "Local Fish Assemblage," an appreciable portion of the small-fish assemblage consisted of marked or unmarked juvenile Chinook salmon in these two years, as indicated by trawling at Mossdale.

The final piece of this illustrative example is to estimate daily consumption by striped bass by multiplying estimated daily consumption rate per 10,000 m^3 by the volume of the HOR study area. Bathymetric data were available for most zones of the study area, and to account for river stage, it was assumed that water depth was an additional 1 m on top of the mean absolute elevations of each zone. Thus, it was estimated that the HOR study area had a volume of 63,257 m^3 (including only zones 1 through 64, to account for the 2012 HORB). The resulting daily estimates of all prey fish consumption by striped bass were 0.231 kg per day in 2011 and 1.67 kg per day in 2012. Based on the daily influx of prey fish estimated, this amounted to an estimated mean predation rate of 0.001 (0.13%) in 2011 and 0.09 (9.04%) in 2012. Repeating the calculations and only considering (unmarked) juvenile Chinook salmon prey biomass density, estimated predation rates were 0.0042 (0.42%) in 2011 and 0.174 (17.4%) in 2012.

In summary, the illustrative example provided (based upon the assumptions presented herein), indicates that the prey fish biomass density is significantly lower than the potential daily consumption rate capable by striped bass. The estimated mean predation rate of all prey fish consumed by striped bass ranged from less than 1% to 9% in 2011 and 2012, respectively. Similarly, predation by striped bass on unmarked juvenile Chinook salmon ranged from less than 1% to 17% in 2011 and 2012, respectively.

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APPENDIX I

Route Entrainment Analysis at Head of Old River, 2009 and 2010
(Reproduced from SJRGA 2013, Chapter 7)

CHAPTER 7

ROUTE ENTRAINMENT ANALYSIS AT HEAD OF OLD RIVER, 2009 AND 2010

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Methods

Supplementary analyses were conducted of the relationship between river conditions and the probability of remaining in the San Joaquin River at the head of Old River in 2009 and 2010. These analyses were based on the results of the data processing performed in the survival analysis of the 2009 and 2010 VAMP studies (SJRGA 2010, SJRGA 2011). Only detections classified as coming from live salmon smolts were used in this analysis. More information on data processing and the predator filter in the 2009 and 2010 studies is described in SJRGA, 2010 and SJRGA, 2011.

Analysis methods were the same as those used in the 2011 route entrainment analysis (Chapter 5). In addition to the covariates used in the 2011 route analysis, the status of the non-physical barrier at the head of Old River at the time of fish arrival at the barrier was included in the 2009 and 2010 analyses:

$$B_i = \begin{cases} 1, & \text{barrier open at arrival of tag } i \\ 0, & \text{barrier closed at arrival of tag } i \end{cases}$$

(data courtesy of the U. S. Bureau of Reclamation). Interaction effects between the barrier status and river flow, water velocity, and flow proportion were tested in the flow, velocity and flow proportion models, respectively.

Results

2009 Results

A total of 365 tags were observed passing the acoustic receivers in either the San Joaquin River or Old River near the head of Old River in 2009, with associated observations of river conditions. Of these 365 fish, 192 were observed entering Old River, while the other 173 remained in the San Joaquin River past the head of Old River. River flow and water velocity measured at the SJL gaging station in the San Joaquin River near Lathrop were very highly correlated in 2009 (r=0.99), with flow values ranging from -1,287 cfs to 2,133 cfs (average = 898 cfs) when tagged fish were passing the SJL gaging station and the OH1 gaging station in Old River just downstream of its divergence from the San Joaquin River. A description of the gaging station locations can be found in Chapter 4. Negative values of flow indicate reverse flow at the SJL gaging station. At the OH1 gaging station, flow and water velocity were also highly correlated (r=0.96), with flow values ranging from 203 cfs to 2,186 cfs (average = 1,515 cfs) when tagged fish passed the SJL and OH1 gaging stations. No reverse flow was observed at the OH1 station. Flow at the SJL station was moderately negatively correlated with flow at the OH1 gaging station (r=-0.48). Water velocity measures from the two gaging stations were also moderately negatively correlated (r=-0.37). Water velocity at the SJL station ranged from -0.88 ft/s to 1.55 ft/s (average = 0.75 ft/s), while at the OH1 station, it ranged from 0.11 ft/s to 1.58 ft/s (average = 1.03 ft/s) while tagged fish passed the gaging stations. Flow proportion into the San Joaquin River was moderately correlated with flow into the San Joaquin River (r=0.57), with negative values of flow proportion corresponding to reverse flow at the SJL gage. Flow proportion into the San Joaquin River during the time of tagged fish passage of the gaging stations (pQ_{iA}) ranged from -722% to 91% (average = 10%), omitting one extreme negative value of -2,180%. The extreme negative values occurred when flow was reversed at the SJL gage and nearly the same magnitude as the positive flow at the OH1 gage. Because flow proportion was negative only under conditions of reverse flow, the reverse flow covariate (uQ_{iA}) was omitted from the multivariate analysis with the flow proportion model.

Results of the single-variate analyses relating route entrainment at the head of Old River to river conditions found significant effect of both flow and velocity at both the SJL and the OH1 gaging stations (P<0.0005 in each case, Table 7-1). Flow proportion into the San Joaquin River and the occurrence of reverse flow at the SJL gage were also significantly correlated with route entrainment (P<0.0001 in both cases), as was change in both velocity and flow at OH1 (P<0.0001 in both cases). The status of the non-physical barrier (on versus off) was significantly correlated with route entrainment (P=0.0010), as were exports at CVP (P=0.0010) and combined exports throughout the Delta (P=0.0040). However, exports at SWP alone were not significantly correlated with route entrainment at the head of Old River (P=0.2709). Fork length, release group, change in flow and velocity at SJL, and change in flow proportion into the San Joaquin were not significantly correlated with route entrainment, either (P>0.3 in each case; Table 7-1).

The single-variate analyses may suggest possible relationships, but due to confounding among the independent covariates and the possibility of a causal relationship with an unmonitored factor, it is not possible to conclude that changes in any of the significant single-variate measures directly produce changes in route entrainment at the head of Old River. Multi-variate analysis may shed more light on which covariates are worthy of further study, although causal relationships are still not discernible.

Multivariate analyses also found significant effects of flow and velocity at both the SJL and OH1 gaging stations, as well as flow proportion into the San Joaquin River, with significantly different effects when the non-physical barrier was on (barrier = 1) than when it was off (barrier = 0) (Table 7-2). All three models (flow, velocity, and flow proportion) adequately fit the data (P>0.9), but the flow model accounted for more variation in route entrainment than either water velocity (ΔAIC=6.56) or flow proportion (ΔAIC=27.33) (Table 7-2). The flow model predicted the route entrainment probability according to:

$$\widehat{\psi_A} = \frac{exp(-1.20 + 0.002Q_A - 0.001Q_B)}{1 + exp(-1.20 + 0.002Q_A - 0.001Q_B)}$$

when the barrier was off, and

$$\widehat{\psi_A} = \frac{exp(-9.07 + 0.005Q_A + 0.002Q_B)}{1 + exp(-9.07 + 0.005Q_A + 0.002Q_B)}$$

when the barrier was on.

For flow at OH1 fixed at the mean observed value there when tagged fish were passing (1,515 cfs), increases in flow at SJL were predicted to increase the probability of a tagged fish remaining in the San Joaquin River, with a steeper increase if the barrier was on (Figure 7-1). For flow at SJL fixed at its mean observed value (893 cfs), increases in flow at OH1 were predicted to increase the probability of a tagged fish remaining in the San Joaquin River if the barrier was on, but were predicted to decrease the probability of remaining in the San Joaquin if the barrier was off (Figure 7-2).

2010 Results

A total of 430 tags were observed passing the acoustic receivers in either the San Joaquin River or Old River near the head of Old River in 2010, with associated observations of river conditions. Of these 430 tagged fish, 228 were observed entering Old River, while the other 202 fish remaining in the San Joaquin River past the head of Old River. River flow and water velocity measured at the SJL gaging station in the San Joaquin River at times when tagged fish were passing were highly correlated in 2010 (r=0.95). Observed flow values ranged from 909 cfs to 3,595 cfs (average = 2,595 cfs), and observed velocity values ranged from 0.5 ft/s to 2.3 ft/s (average = 1.6 ft/s). River flow and water velocity measured at the OH1 gaging station in Old River when tagged fish were passing were also highly correlated (r=0.92), with flow values ranging from 1,703 cfs to 3,404 cfs (average = 2,777 cfs) and velocity values ranging from 0.9 ft/s to 2.0 ft/s (average = 1.5 ft/s). There was little or no correlation between flow (r=0.04) or

Table 7-1
Results of Single-variate Analyses of Route Entrainment at the Head of Old River in 2009

Year	Covariate	F-test		
		F	df1, df2	P
2009	Velocity at SJL[a]	212.8572	1, 363	<0.0001
2009	Flow at SJL[a]	193.7478	1, 363	<0.0001
2009	Flow proportion into San Joaquin[a]	174.0139	1, 363	<0.0001
2009	Reverse flow into San Joaquin[a]	151.5927	1, 363	<0.0001
2009	Change in velocity at OH1[a]	40.8793	1, 347	<0.0001
2009	Flow at OH1[a]	22.6527	1, 363	<0.0001
2009	Change in flow at OH1[a]	16.8309	1, 347	<0.0001
2009	Velocity at OH1[a]	12.8934	1, 363	0.0004
2009	Barrier[a]	11.0410	1, 363	0.0010
2009	Exports at CVP[a]	10.9377	1, 363	0.0010
2009	Combined Exports[a]	8.3972	1, 363	0.0040
2009	Exports at SWP	1.2159	1, 363	0.2709
2009	Change in velocity at SJL	0.9906	1, 347	0.3203
2009	Fork Length	0.7137	1, 363	0.3988
2009	Release Group	0.8675	6, 358	0.5189
2009	Change in flow proportion into San Joaquin	0.3984	1, 347	0.5283
2009	Change in flow at SJL	0.0628	1, 347	0.8023

[a] Significant at 5% level

Figure 7-1
Fitted Probability of Remaining in the San Joaquin River at the Head of Old River versus River Discharge Measured at the SJL Gaging Station near Lathrop, CA, for River Discharge at OH1 Gaging Station in Old River Fixed at its Average (1,515 cfs), with 95% Confidence Bands, in 2009. Barrier is Non-Physical Barrier at Head of Old River

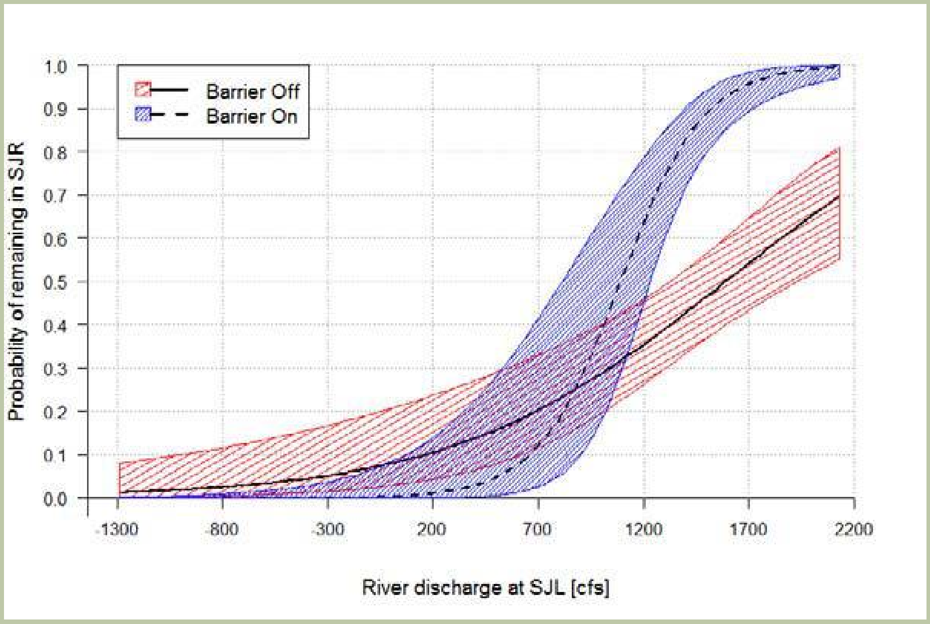


Figure 7-2
Fitted Probability of Remaining in the San Joaquin River at the Head of Old River versus River Discharge Measured at the OH1 Gaging Station in Old River, for River Discharge at SJL Gaging Station near Lathrop, CA, Fixed at its Average (893 cfs), with 95% Confidence Bands, in 2009. Barrier is Non-Physical Barrier at Head of Old River

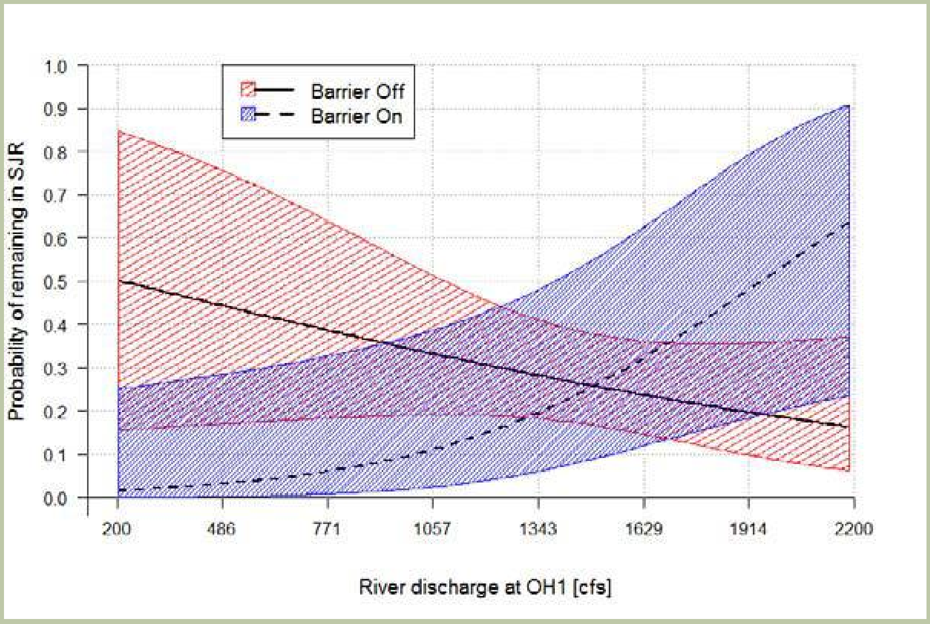


Table 7-2
Results of Multivariate Analyses of Route Entrainment at the Head of Old River in 2009

Model Type	Covariate[a]	Estimate	S.E.	t-Test		
				t	df	P
Flow	Intercept	-1.0723	0.2704	-3.966	359	<0.0001
	Q_A	1.6324	0.3647	4.476	359	<0.0001
	Q_B	-0.2749	0.209	-1.315	359	0.1893
	Barrier	0.0632	0.666	0.095	359	0.9244
	Q_A*Barrier	3.7580	1.2102	3.105	359	0.0021
	Q_B*Barrier	1.0539	0.3813	2.764	359	0.0060
Goodness-of-fit: χ^2=2.5464, df=13, P=0.9991; AIC = 289.60						
Velocity	Intercept	-1.0640	0.2808	-3.776	360	0.0002
	V_A	1.7445	0.3938	4.430	360	<0.0001
	V_B	-0.3070	0.1728	-1.776	360	0.0766
	Barrier	-0.5429	0.8145	-0.667	360	0.5052
	V_A*Barrier	3.3994	1.2618	2.694	360	0.0074
Goodness-of-fit: χ^2=2.9471, df=13, P=0.9981; AIC = 296.16						
Flow Proportion	Intercept	-1.8121	0.5039	-3.596	361	0.0004
	pQ_A	5.7413	1.4593	3.934	361	0.0001
	Barrier	-0.7723	1.3045	-0.592	361	0.5542
	pQ_A*Barrier	7.4123	4.2399	1.748	361	0.0813
Goodness-of-fit: χ^2=6.3064, df=13, P=0.9343; AIC = 316.93						

[a] continuous covariates (Q_A, Q_B, V_A, V_B, pQ_A) are standardized

Table 7-3
Results of Single-variate Analyses of Route Entrainment at the Head of Old River in 2010

Year	Covariate	F-test		
		F	df1, df2	P
2009	Barrier[a]	14.4717	1, 428	0.0002
2009	Flow proportion into San Joaquin[a]	13.5411	1, 428	0.0003
2009	Flow at SJL[a]	9.0700	1, 428	0.0027
2009	Velocity at SJL[a]	7.1774	1, 428	0.0077
2009	Flow at OH1[a]	4.8240	1, 428	0.0286
2009	Change in velocity at OH1	3.1450	1, 413	0.0769
2009	Velocity at OH1	2.8854	1, 428	0.0901
2009	Combined Exports	1.3152	1, 428	0.2521
2009	Change in flow at OH1	1.2129	1, 413	0.2714
2009	Change in velocity at SJL	0.5482	1, 428	0.4595
2009	Fork Length	0.3062	1, 428	0.5803
2009	Release Group	0.7067	6, 423	0.6444
2009	Exports at SWP	0.0752	1, 428	0.7841
2009	Change in flow proportion into San Joaquin	0.0479	1, 413	0.8268
2009	Change in flow at SJL	0.0329	1, 428	0.8562
2009	Exports at CVP	0.0223	1, 428	0.8813

[a] Significant at 5% level

Table 7-4
Results of Multivariate Analyses of Route Entrainment at the Head of Old River in 2010

Model Type	Covariate[a]	Estimate	S.E.	t-Test		
				t	df	P
Flow	Intercept	-0.5463	0.1473	-3.710	426	0.0002
	Q_A	0.3302	0.1054	3.134	426	0.0018
	Q_B	-0.2623	0.1022	-2.568	426	0.0106
	Barrier	0.7947	0.2022	3.930	426	< 0.0001
Goodness-of-fit: χ^2=17.3751, df=18, P=0.4975; AIC = 566.94						
Flow Proportion	Intercept	-0.5432	0.1471	-3.693	427	0.0003
	pQ_A	0.3944	0.1089	3.623	427	0.0003
	Barrier	0.7828	0.2018	3.880	427	0.0001
Goodness-of-fit: χ^2=13.9929, df=18, P=0.7296; AIC = 567.00						
Velocity	Intercept	-0.5470	0.1472	-3.718	426	0.0002
	V_A	0.3606	0.1099	3.282	426	0.0011
	V_B	-0.3044	0.1066	-2.856	426	0.0045
	Barrier	0.7966	0.2023	3.938	426	< 0.0001
Goodness-of-fit: χ^2=12.6394, df=18, P=0.8125; AIC = 567.80						

[a] continuous covariates (Q_A, Q_B, V_A, V_B, pQ_A) are standardized

velocity (r=0.28) at SJL and flow at OH1 during times of fish passage in 2010, although there was moderate correlation between changes in flow at SJL and observed velocity at OH1 (r=-0.48), and between changes in flow at OH1 and observed velocity at SJL (r=0.53). Observed flow proportion into the San Joaquin River at times of fish passage ranged in value from 25% to 62% (average = 48%), and was highly correlated with flow measured at SJL (r=0.91). Because flow was never reversed in the San Joaquin River during the time of fish passage in 2010, the reverse flow covariate (uQ_{iA}) was always equal to 1, and so was omitted from the analyses. There was little variation in CVP exports during fish passage through the head of Old River in 2010 (830 – 1,506 cfs, average = 928 cfs), with only slightly more variation in SWP exports (0 – 709 cfs, average = 574 cfs). Combined exports throughout the Delta ranged from 1,541 to 1,760 cfs (average = 1,663 cfs). There was little or no observed correlation between flow and velocity measures and measures of exports at either CVP, SWP, or combined (|r|<0.3).

Results of the single-variate analyses relating route entrainment at the head of Old River to river conditions found significant effects of changes in barrier status (on *vs.* off; P=0.0002), flow proportion into Old River (P=0.0003), flow (P=0.0027) and velocity (P=0.0077) measured at SJL at time of fish passage, and flow at OH1 at time of fish passage (P=0.0286) (Table 7-3). No other covariates were significant at the 5% level.

Multivariate analyses also found significant effects of flow and velocity at both the SJL and OH1 gaging stations, as well as flow proportion into the San Joaquin River and barrier status (Table 7-4). All three models (flow, velocity, and flow proportion) adequately fit the data (P>0.4). AIC detected little difference among the three models (ΔAIC $\leq$ 0.86), and estimated regression coefficients were similar among the three models (Table 7-4). The flow model had the lowest AIC, and predicted the route entrainment probability according to:

$$\widehat{\psi_A} = \frac{exp(0.35 + 0.0005Q_A - 0.0008Q_B)}{1 + exp(0.35 + 0.0005Q_A - 0.0008Q_B)}$$

when the barrier was off, and

$$\widehat{\psi_A} = \frac{exp(1.15 + 0.0005Q_A - 0.0008Q_B)}{1 + exp(1.15 + 0.0005Q_A - 0.0008Q_B)}$$

when the barrier was on.

When flow at OH1 was fixed at its mean observed value when tagged fish were passing (2,777 cfs), increases in flow at SJL were predicted to increase the probability of a tagged fish remaining in the San Joaquin River (Figure 7-3). For flow at SJL fixed at its mean observed value (2,595 cfs), increases in flow at OH1 were predicted to decrease the probability of a tagged fish remaining in the San Joaquin River (Figure 7-4). Regardless of the flow level at either

Figure 7-3
Fitted Probability of Remaining in the San Joaquin River at the Head of Old River versus River Discharge Measured at the SJL Gaging Station near Lathrop, CA, for River Discharge at OH1 Gaging Station in Old River Fixed at its Average (2,777 cfs), with 95% Confidence Bands, in 2010. Barrier is Non-Physical Barrier at Head of Old River

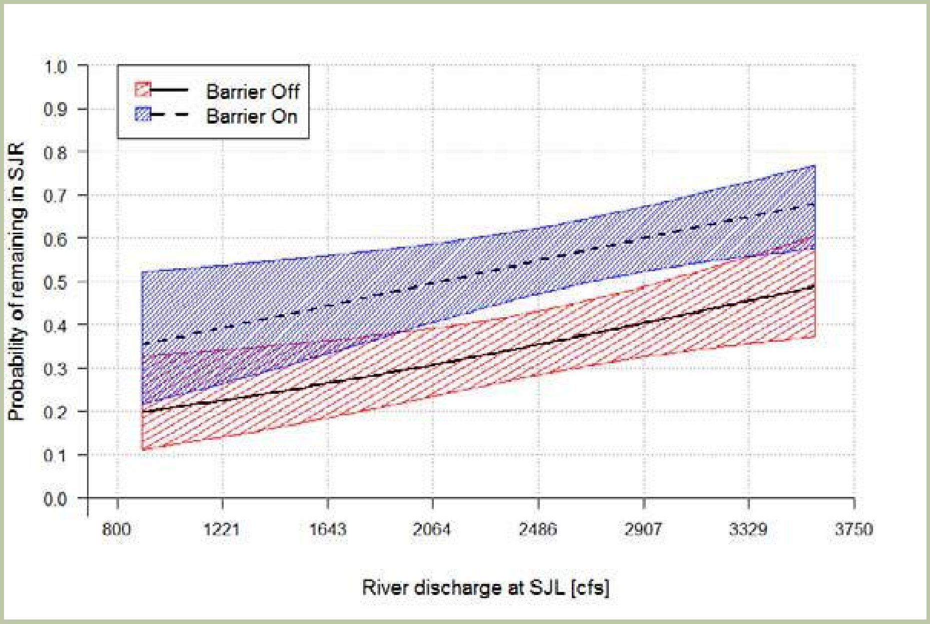
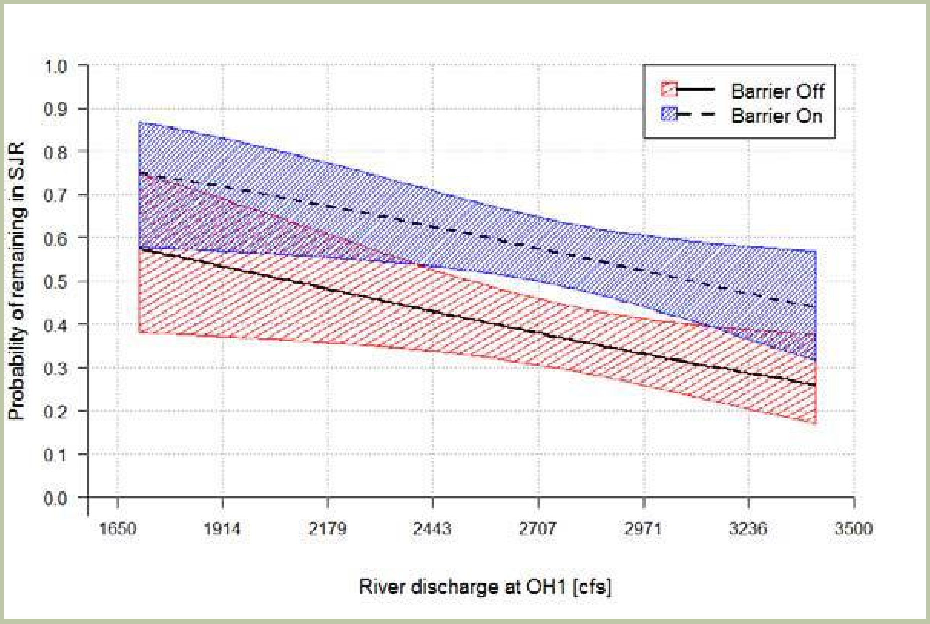


Figure 7-4
Fitted Probability of Remaining in the San Joaquin River at the Head of Old River versus River Discharge Measured at the OH1 Gaging Station in Old River, for River Discharge at SJL Gaging Station near Lathrop, CA, Fixed at its Average (2,595 cfs), with 95% Confidence Bands, in 2010. Barrier is Non-Physical Barrier at Head of Old River



OH1 or SJL, the probability of remaining in the San Joaquin River at the head of Old River was predicted to be higher when the non-physical barrier was turned on than when it was turned off (Figures 7-3 and 7-4; Table 7-4).

Summary

Both the 2009 and 2010 analyses found that increases in flow measured in the San Joaquin River near Lathrop (SJL) were associated with increased probability of remaining in the San Joaquin at the head of Old River. However, the 2009 analysis found an interaction effect between barrier status and flow measured in Old River near its head (OH1), with increases in Old River flow associated with increased probability of entering Old River when the barrier was off, but not when the barrier was on. In 2010, increases in Old River flow were associated with increased probability of entering Old River regardless of barrier status. More fish stayed in the San Joaquin River under all flow conditions in 2010 when the barrier was on than when it was off.

APPENDIX J

Recommended Aspects of a Pilot Predatory Fish Relocation Study

The only available published Sacramento–San Joaquin Delta (Delta) study of predator control efforts (Cavallo et al. 2013) serves as a potential template for the type of study that might be considered as a pilot predator relocation effort at the Head of Old River (HOR) study area. Such a new study would have direct relevance to inform the proposed Bay Delta Conservation Plan (see Section K.2, "Predation Reduction," in Appendix K, "Relevant Aspects of the Proposed Bay Delta Conservation Plan"). The results of the present study (see Chapter 6, "Results," and Chapter 7, "Discussion") could guide any future pilot predator relocation efforts. The recommended features of any pilot predator relocation study should include the following:

- Before/after control impact (BACI) study design:
  - Predator relocation should occur from an impact area (e.g., the HOR study area), with one or more control areas (e.g., reference sites 1, 2, and 4 from the present study).
  - Depending on the resources available, it may be advantageous to vary the control sites and impact sites to provide tests of predator relocation feasibility under varying circumstances (e.g., abiotic and biotic habitat parameters, season). This may be especially relevant if predation at the control sites is similar or greater in magnitude than at the HOR study area.
- Survival of managed species through the HOR study area should be the main response variable of interest:
  - For the HOR study area, this would be primarily acoustically tagged juvenile Chinook salmon.
  - Other species of interest would include juvenile steelhead, notwithstanding the issues in determining survival of this species from acoustic tagging (see subsection "Chinook Salmon Compared to Steelhead" in Section 7.1.4, "Juvenile Salmonid Routing Including Barrier Effects" of Section 7, "Discussion").
  - Sufficient numbers of individuals and releases would be needed to establish survival estimates robust enough to discriminate changes of management significance (and management should provide guidance on establishing criteria to determine what such a level of change would be).
- Changes in predator abundance should be a secondary response variable of interest:
  - The catch per unit effort and cumulative catch during the relocation/removal phase of the study would provide a measure of the effectiveness of the capture methods implemented, as undertaken by Cavallo et al. (2013). Predator capture efforts should cover a wide range of age, sexual maturity, and sex of all potential predatory fish species.
  - In addition to changes in abundance generated during predator capture/relocation, other supplementary methods could be used (e.g., hydroacoustics, as in the present study; see, for example, Section 6.3, "Behavior and Density Changes in Predatory Fishes" in Section 6, "Results").
- Results from the present study should be used to identify areas, timing, and/or habitat conditions to target for fish removal and methodological considerations:
  - The scour hole and adjacent areas in the San Joaquin River below the Old River divergence clearly deserve emphasis on predatory fish capture efforts, but some coverage throughout the area may be

desirable because of the large fish that were shown to exist throughout the area in the side-looking mobile hydroacoustic surveys (see subsection on “Areas Occupied and Diel Changes in Depth” in Section 6.3.2, “Hydroacoustic data”, of Section 6, “Results”).

  - To reduce capture bias, differing sampling methods should be investigated and incorporated (e.g., electrofishing may be appropriate for nearshore areas, whereas active capture may be required in offshore areas, and other means may be required at the scour hole).
  - Depending on the resources available, it may be advantageous to acoustically tag predators proposed for relocation to identify and account for resident and homing behaviors.

- Variable intensity of effort:
  - Differing levels of capture/relocation effort should be compared to determine what level is necessary to achieve an effect (e.g., whether daily removal gives the same effect as removal every other day).
- Holding of captured predatory fish in net pens:
  - As with Cavallo et al. (2013), predatory fish could be captured and held in net pens until the study was completed, avoiding the need to sacrifice the predatory fishes.
  - Ancillary studies could be undertaken on these fish (e.g., examination of stomach contents by gastric lavage immediately after capture, documentation of growth rate based on a known ration; this could be useful for bioenergetics modeling).
- Consideration of bycatch, particularly listed species:
  - Different methods would need to be evaluated for the relative risk to listed species, both during study planning and by documentation of catch during the study.
  - Permit terms for any predator relocation pilot study would be likely to limit the potential capture gear (or its intensity of use), in any case.
- Inclusion of important covariates in assessed changes in survival:
  - As demonstrated by Cavallo et al. (2013), factors such as changes in discharge also may be important and should be studied and included in integrated analyses, if appropriate.
  - The present study found that visibility (light level and turbidity) were associated with different survival rates in the HOR study area, and this should be considered further.
- Careful documentation of personnel, equipment, time requirements, and resulting costs:
  - Such documentation would inform the cost estimates associated with Conservation Measure 15 (Localized Reduction of Predatory Fishes) in the public draft Bay Delta Conservation Plan (DWR 2013).

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APPENDIX K

Relevant Aspects of the Proposed Bay Delta Conservation Plan

The public draft Bay Delta Conservation Plan's (BDCP's) conservation strategy proposes two conservation measures that are directly relevant to management activities at the Head of Old River (HOR) study area (DWR 2013): Conservation Measure 1 (Water Facilities and Operation) includes an operable HOR gate, and Conservation Measure 15 (Localized Reduction of Predatory Fishes) includes actions to reduce predation at known hotspots within the BDCP plan area, including the HOR study area. More details about each of these measures are provided herein in Sections K.1, "Operable HOR Gate," and K.2, "Predation Reduction." The public draft BDCP also proposes Conservation Measure 16 (Nonphysical Fish Barriers), which includes the use of non-physical barriers similar to those tested at the HOR study area (Bowen et al. 2012; Bowen and Bark 2012; the present study) and Georgiana Slough (DWR 2012; Perry et al. 2012) to route covered fish species along migration pathways that have better survival prospects. This is not discussed further because of the BDCP's proposal for an operable HOR gate. In addition, the revised administrative draft BDCP also proposes various conservation measures for habitat restoration near the HOR study area, which are outlined in Section K.3, "South Delta Habitat Restoration."

K.1 OPERABLE HOR GATE

The public draft BDCP's Conservation Measure 1 (Water Facilities and Operation) includes an operable HOR gate, described as follows (DWR 2013: 3.4–13):

> A new permanent, operable gate at the Head of Old River (at the divergence from the San Joaquin River) would be constructed and operated to protect outmigrating San Joaquin River salmonids in the spring and to provide water quality improvements in the San Joaquin River in the fall. Operation of the gate can vary from completely open (laying flat on the channel bed) to completely closed (erect in the channel, prohibiting all flow from the San Joaquin River to Old River), with the potential for operations in between that would allow partial flow. The actual operation of the gate would be determined by real-time operations based on actual flows and/or fish presence.

The draft environmental impact report/statement for the BDCP describes the gate as approximately 64.0 meters long by 9.1 meters wide, with a top elevation of 4.6 meters (North American Vertical Datum of 1988); seven bottom-hinged gates would be in place, approximately 38.1 meters long (DWR et al. 2013: 3C–44). A vertical slot, self-regulating fishway with four sets of baffles would be provided for passage of adult salmonids and sturgeon. The approximately 12.2-meter-long by 3.0-meter-wide fishway would be constructed of reinforced concrete and would be designed according to National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service guidelines for Chinook salmon, steelhead, and green sturgeon. Stoplogs would be used to close the fishway when not in use. The final main component of the operable HOR gate would be a boat lock, 6.1 meters wide by 21.3 meters long (DWR et al. 2013: 3C–44). The boat lock would be constructed of sheet piles and would include two 6.1-meter-wide by 3.0-meter-high bottom-hinged gates on each end.

The public draft BDCP describes the real-time operations of the operable HOR gate as follows (DWR et al. 2013: 3.4–27):

> The gate will be managed under RTOs [real time operations] from January 1 through June 15, and October 1 through November 30, based on real-time monitoring for the presence/absence of covered fishes, hydrologic conditions, and species risk. In determining the opening and closure of the Head of Old

River gate, the fish and wildlife agencies' goal is to have the gate closed as much as possible in February through June 15; however, the gate may be open subject to RTO for purposes of water quality, stage, and flood control considerations. The final BDCP document will provide operational guidance for use by project operators in implementing these provisions.

Final designs and operation of the gate in an implemented BDCP may differ from the prior description.

K.2 NONNATIVE PREDATORY FISHES REDUCTION

The public draft BDCP's Conservation Measure 15 (Localized Reduction of Predatory Fishes) proposes to "reduce populations of nonnative predatory fishes at specific locations and eliminate or modify holding habitat for nonnative predators (predators) at selected locations of high predation risk (i.e., predation 'hotspots')" (DWR 2013: 3.4-294). The intent of the conservation measure is to relieve predation pressure at locations of concern, rather than to "entirely remove predators at any location or substantially alter the abundance of predators at the scale of the Delta system." (DWR 2013: 3.4-294). A number of predation hotspots are identified in the conservation measure, including the HOR. Conservation Measure 15 is proposed to include the following elements (DWR 2013: 3.4-300):

- Hotspot pilot program. Implement experimental treatment at priority hotspots, monitor effectiveness, assess outcomes, and revise operations with guidance from the Adaptive Management Team.
- Research actions. Via the adaptive management program, support focused studies to resolve key uncertainties.

If demonstrably effective, the hotspot pilot program will be developed in three successive stages. During the first stage, a few treatment sites will be experimentally evaluated to test the general viability of various predator reduction methods. Secondary reduction actions, such as removal of abandoned vessels, may be implemented to determine if they will be effective on a large scale. After the initial scoping stage is complete, and if shown to be effective, the second stage will consist of implementation of a pilot program with a larger range of treatment sites and refined techniques, incorporating what is learned from the first stage. The main focus at this stage is to study the efficacy of predator reduction on a larger scale to determine whether it is making a demonstrable difference and/or has any unintended ecological consequences (i.e., unexpected changes to foodweb dynamics that may have negative effects on covered fish species). The pilot program may include such activities as direct predator reduction at hotspots (e.g., Clifton Court Forebay, head of Old River scour hole, the Georgiana Slough sites, and SWP/CVP salvage release sites) and removal of old human-made structures (e.g., pier pilings, abandoned boats).

To minimize uncertainty about the appropriate management regime necessary to maintain and enhance survival of covered fishes, effectiveness monitoring will be implemented with the pilot program. The pilot program would begin with a preliminary assessment phase to compare two approaches for reducing local predator abundances: removal of predator hotspot structures (e.g., abandoned boats, derelict pier pilings) and general predator reduction in reaches with known high predation loss.

The pilot program will be carefully monitored and refined to determine whether either of these practices is effective. If the pilot program shows that the main issues are resolvable, the third stage would consist of a defined predator reduction program (i.e., defined in terms of predator reduction techniques and the sites and/or areas of the Plan Area where techniques will be employed). Research and monitoring would continue throughout the duration of the program to address remaining uncertainties and ensure the measures are effective (i.e., that they reduce numbers and densities of predators and increase survival of covered salmonids).

The conservation measure description outlines guidelines and techniques for pilot projects under the hotspot pilot program, with the experimental portions emphasizing some of the main principles used by Cavallo et al. (2013) and described in Appendix J, "Recommended Aspects of a Pilot Predatory Fish Relocation Study" (e.g., before and after studies; DWR 2013: 3.4-303). Potential methods of localized predatory fish reduction are discussed in relation to advantages and limitations, with a number of methods deemed feasible (e.g., electrofishing, hook and line, passive trapping, gill netting, active capture—trawling/beach seining and lottery fishing with volunteer anglers), and several described as unsuitable or infeasible (e.g., dewatering/water level fluctuation, chemical treatment—rotenone, pulsed pressure waves, and release of hatchery-reared prey fish containing oral piscicide). The types of habitat favorable to nonnative predatory fish that may be modified or eliminated include features such as submerged human-made structures (e.g., abandoned boats, derelict structures, bridge piers), water diversion facilities (e.g., intakes, forebays), channel features (e.g., the scour hole at the HOR study area), and salvage release sites (DWR 2013: 3.4–308).

The BDCP's Conservation Measure 15 would benefit from knowledge gained as a result of any scour hole alteration or predator relocation research efforts undertaken at the HOR (see Section "Study Feasibility of Physical Habitat Reconfiguration," and Section "Conduct a Pilot Predatory Fish Relocation Study"). Communication and coordination of efforts before BDCP implementation would allow refinement of the conservation measure, particularly with respect to feasibility and cost. Cost assumptions are presented in the public draft BDCP (DWR 2013: 8-40).

The results of the present study and other existing studies already have the power to inform uncertainties regarding the proposed Conservation Measure 15. For example, daily predator reduction/relocation appears warranted, based on the often-short residence time and appreciable turnover of predatory fish at the HOR study area (see Section 7.3.1, "Residence Time of Predatory Fishes" in Section 7, "Discussion") and elsewhere (e.g., Cavallo et al. 2013a). However, as noted in Appendix J, "Recommended Aspects of a Pilot Predatory Fish Relocation Study," experimentation with differing levels of predator relocation intensity would be informative to guide optimization of effort. The broad seasonal window for predator reduction/relocation may be narrowed based on seasonality of the fish species, size, and sexual maturity at the HOR study area (see Section 7.3.3, "Changes in Density of Predatory Fishes"). Covered fish seasonality (e.g., outmigration timing of juvenile Chinook salmon from the San Joaquin basin) also clearly is a relevant factor, as is the potential for recovery of spring-run Chinook salmon under the San Joaquin River Restoration Program that may give broader outmigration (and emigration) timing. Changes to the level of effort applied to predator reduction/relocation efforts may be warranted based on hydrologic and other conditions on an annual basis or within specific years. In the present study, large-fish density was associated negatively with discharge (see Section 7.3.3, "Changes in Density of Predatory Fishes"), and juvenile Chinook salmon survival was associated positively with turbidity (see Section 7.2, "Predation on Juvenile Salmonids, Including Barrier Effects"). Perhaps more predator reduction/relocation effort would have been justified in 2012 than 2011, for example.

K.3 SOUTH DELTA HABITAT RESTORATION

The proposed BDCP includes several conservation measures intended to improve Delta habitat for covered species, including fish, of which some would be in the south Delta subregion close to the HOR study area (DWR 2013). Conservation Measure 4 (Tidal Natural Communities Restoration) proposes restoration of a minimum of 5,000 acres of tidal freshwater emergent wetland, tidal perennial aquatic, and tidal mudflat habitat in the south Delta Restoration Opportunity Area (ROA); the southeastern edge of this ROA is immediately adjacent to the HOR study area (see Figure 5E.4-1 in DWR 2013). Conservation Measure 5 (Seasonally Inundated Floodplain Restoration) proposes restoration of up to 10,000 acres of seasonally inundated floodplain in the south Delta area. Conservation Measure 6 (Channel Margin Enhancement) proposes enhancement of 20 miles of channel margin, primarily in the north Delta (e.g., mainstem Sacramento River, Sutter/Steamboat Sloughs), but with some smaller extent (e.g., 5 miles) possible in other areas such as the San Joaquin River near the HOR study area. Conservation Measure 7 (Riparian Natural Community Restoration) proposes to restore native riparian forest and scrub in association with Conservation Measures 4 through 7: 2,300 acres by year 15 of the BDCP, and 5,000 acres by year 40 of the BDCP. At least 3,000 acres of the restoration is proposed to take place in restored floodplains associated with Conservation Measure 6, and, therefore, would occur in the south Delta subregion.

The South Delta Habitat Working Group (SDHWG) was convened by the California Department of Water Resources in summer 2011 to identify opportunities for improving habitat in the southern part of the Delta for integration into the BDCP (ESA PWA 2013). Although flood management is not an objective of the BDCP process, the habitat improvements identified by the SDHWG were developed in a way that integrates flood management considerations and other economic benefits. As part of the SDHWG's efforts, several conceptual restoration corridors have been analyzed for their potential to provide a combination of ecological benefits to covered species (e.g., fall-run Chinook salmon from the San Joaquin River region) and flood control (see Figure EA.1.1-1 in ESA PWA 2013):

- Corridor 1A: Levee setbacks on both banks of the San Joaquin River from Vernalis to Interstate 5.
- Corridor 1B: An alternative version of Corridor 1A along the San Joaquin that includes only a right-bank levee setback and connection of Walthall Slough with the San Joaquin River via a weir.
- Corridor 2A: Expansion of the Paradise Cut flood bypass and modifications to Paradise Cut weir.
- Corridor 2B: An expanded version of Corridor 2A that also includes levee removal around Fabian Tract. Corridor 2B is essentially Corridor 2A plus Fabian Tract.
- Corridor 3: Selected levee setbacks along Middle River on Union Island.
- Corridor 4: Levee setbacks on Roberts Tract along the left bank side of the San Joaquin River and on a short reach of the right bank of Old River.

As noted by ESA PWA (2013:EA.1-2), while developed at an early, conceptual level of detail, work to-date suggests that these corridors would support achievement of the BDCP Conservation Measures 4 through 7, and simultaneously achieve ancillary benefits in flood risk reduction.

K.4 REFERENCES

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