BAY-DELTA FISHERIES RESOURCES: Review of the Available Scientific Information Regarding Salmonids

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San Luis & Delta-Mendota Water Authority

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Acronyms

BA	Biological Assessment
BDCP	Bay Delta Conservation Plan
BiOp	biological opinion
CDFG	California Department of Fish and Game
cfs	cubic foot/feet per second
Chl *a*	Chlorophyll *a*
cm	centimeter
CPUE	catch per unit effort
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CWT	coded wired tag
D-1641	1995 Bay-Delta Water Quality Control Plan

DPM	Delta Passage Model
DPS	distinct population segment
DWR	California Department of Water Resources
E:I	Export to Inflow
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FERC	Federal Energy Regulatory Commission
HORB	Head of Old River
IOS	Interactive Object-oriented Simulation
JPE	juvenile production estimate
JSATS	Juvenile Salmon Acoustic Telemetry System
km	kilometer
MAF	million acre-feet
µg L-1	microgram(s) per liter
mm	millimeter
OBAN	Oncorhynchus Bayesian Analysis
OCAP	Operational Criteria and Plan
OMR	Old and Middle Rivers
PFMC	Pacific Fisheries Management Council
POC	particulate organic carbon
PTM	Particle Tracking Model
RBDD	Red Bluff Diversion Dam
RPA	Reasonable and Prudent Alternatives
SAV	submerged aquatic vegetation
SI	Sacramento Index
SJRA	The San Joaquin River Agreement
SLDMWA	San Luis & Delta-Mendota Water Authority
SRTTG	Sacramento River Temperature Task Group
SWC	State Water Contractors
SWRCB	State Water Resources Control Board
SWP	State Water Project
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VAMP	Vernalis Adaptive Management Plan

ES EXECUTIVE SUMMARY

ES1. Introduction

In several scheduled workshops, the State Water Resources Control Board (State Water Board) will receive information regarding the scientific and technical basis for potential changes to the 2006 Water Quality Control Plan for the Bay-Delta. The following materials related to salmonid species within the Sacramento-San Joaquin Rivers/Bay-Delta Estuary have been prepared by the State Water Contractors (SWC) and the San Luis & Delta-Mendota Water Authority (SLDMWA) to help inform the workshop on Bay-Delta Fishery Resources.

The SWC and SLDMWA have compiled and assessed available scientific information on fishery resources in the Bay-Delta estuary and summarized that information in two papers, one on Pelagic Fish (submitted separately), and this paper, on salmonid species within the Bay-Delta estuary and Central Valley watersheds of the Sacramento and San Joaquin Rivers.

The best available information shows that multiple interacting variables affect Central Valley salmonid population dynamics. While uncertainty remains regarding which stressors, if any, may be the primary drivers of species abundance, the most recent data suggest that predation throughout the watershed, as well as upstream habitat and ocean conditions are among the most important factors.

The considerable physical changes that have occurred since settlement, including construction of rim dams, channelization of Delta waterways, and eliminating access to floodplains, wetlands and other habitats, have significantly and detrimentally affected salmonids. The complex estuarial problems that have resulted cannot be rectified through additional releases from reservoirs or increased outflow from the Delta. Focus should also be placed on restoring functions necessary to restore salmon abundance.

And, overemphasizing flow regimes as a restoration mechanism for protecting salmonids is unlikely to provide meaningful, long-term benefits to the species and may do more harm than good. As a primary example, one of the most critical factors in winter-run and spring-run Chinook salmon abundance is careful coldwater pool management during the spawning and upstream juvenile rearing periods. Requiring additional reservoir releases could deplete coldwater reserves for use in later months and later years to such an extent that winter-run and spring-run Chinook salmon’s risk of extinction could be increased.

ES2. Findings

Results from a substantial body of scientific research in the past two decades and more recent lifecycle modeling have collectively provided a robust picture of the behavior and needs of Central Valley salmonids. The scientific literature shows that increasing the abundance and distribution of Central Valley salmonids requires considering all the stressors on salmonid species. Continued or increased management of water projects without addressing other direct and indirect stressors will not reduce threats to species’ survival and recovery and may contribute to further declines in salmonid species.

Specific findings detailed in this report include the following:

- Upstream conditions (including water temperature and suitability of spawning habitat), predation, and ocean conditions (for rearing and ocean harvest) are significant drivers of survival and abundance for fall-run, late fall-run, winter-run, and spring-run Chinook salmon.

- Salmonids spend most of their lifecycles upstream of the Delta and in the ocean. Most salmonids spend 2% to 9% of their lifecycles (between 1 week to 3 months) in the Delta;
- There is a weak positive relationship between river flow and survival of juvenile Chinook salmon and Central Valley steelhead. Existing flows would have to be substantially increased to provide even modest improvement in juvenile migration survival to and through the Delta and even such modest improvements are uncertain in the absence of improvements to adjacent habitat conditions;
- Maintaining adequate upstream coldwater pool volumes is critically important to salmonid reproduction and abundance. Increased reservoir releases to augment Delta inflows or outflows could adversely impact cold water pool management in the summer and fall and the long-term viability of some salmonid species;
- Additional Delta inflows or outflows will have no effect on ocean conditions, which appears be a major determinant of salmonid abundance;
- Tidal flows overwhelm (i.e., are approximately 10 times larger than net Delta outflow) in the western Delta. Thus, even doubling Delta outflows will not significantly affect juvenile salmonid migration rates through the Delta.

ES3. Salmonid Lifecycles

The reproductive success, survival, growth, and overall abundance of Central Valley salmonids are impacted by a wide variety of factors, including flows, water temperature, availability and habitat suitability for spawning and rearing, seasonal inundation of floodplains, predation, and recreational and commercial fishing practices. As a result, the length of individual life stages and species abundance varies between species, rivers and years.

Central Valley Rivers support four Chinook salmon species: winter-run, spring-run, fall-run, and late fall-run, as well as steelhead. These species are anadromous fish that spawn in freshwater but rear for most of their lifecycles in coastal ocean waters. Chinook salmon and steelhead migrate upstream from the ocean, through the Delta, and into Central Valley Rivers during the fall, winter, and spring months depending on species (and the name for Chinook salmon, such as winter-run, reflects the seasonal timing of adult upstream migration). For some species, rearing occurs in upstream areas followed by a downstream migration as smolts (physiologically capable of the transition from freshwater to saltwater), while other species migrate downstream shortly after emergence to rear in the lower reaches of the rivers or the Bay-Delta until ready to move into saltwater. Salmonids are generally distributed throughout the Central Valley, except for Winter-run Chinook which spawn and rear only in the mainstem of the Sacramento River.

The timing of some salmonid lifecycle stages varies between species. For example, after emergence, rearing in upstream river reaches varies from 4 to 42 weeks for Chinook species and between one to two years for steelhead. Late Fall-run Chinook and Steelhead only use the Delta as a migration corridor for 1 to 2 weeks, but Fall-run Chinook, Spring- run Chinook, and Winter-run Chinook may spend between 2 and 12 weeks within the Bay-Delta before migrating to the ocean. Because salmonids typically have a 3 year lifespan, the time they spend in the Delta varies between 2 and 9 percent of their lifespan.

Although flow is often suggested as a predictor of salmonid abundance (with high flows one year resulting in increased upstream adult migration in subsequent years), the relationship between flow and abundance is characterized by high variability. Higher instream flows during the late winter and spring months (even in sequential years) may or may not result in increased salmonid survival and abundance. Because land-based factors that affect salmonid survival and abundance have been studied for several decades, ocean conditions (including food abundance) is often suggested as an important (and little understood) determinant of salmonid abundance.

ES4. Regulatory and Habitat Enhancement Programs

A number of regulatory requirements have been implemented to enhance and protect critical and essential habitat for Central Valley Chinook salmon, steelhead, and other aquatic resources within the Bay-Delta estuary and Central Valley Rivers and tributaries. Although these programs have improved fish abundance in some locations and seasons, variability in salmonid abundance remains.

These regulations include actions by the State Water Resources Control Board, Central Valley and San Francisco Bay Regional Water Quality Control Boards, National Marine Fisheries Service (NMFS), Central Valley Project Improvement Act (CVPIA), California Department of Fish and Game (CDFG) agreements, Federal Energy Regulatory Commission (FERC) actions, and Pacific Fisheries Management Council (PFMC) decisions, such as ocean harvest restrictions.

In addition, over the past decade a number of habitat improvement and enhancement projects have been designed and implemented as part of programs such as CALFED and the CVPIA Anadromous Fish Improvement Program. These programs have resulted in spawning gravel augmentation and habitat restoration, reduced risk of entrainment mortality through installation of fish screens on previously unscreened water diversions, and installed new fish ladders to improve access to upstream habitat. Additional beneficial actions include improved access to seasonally inundated floodplains, channel margin habitat, tidal wetlands, hatchery management, harvest regulations and other actions to reduce stressors on salmonids. The Data Assessment Team and salmon decision tree management process have also helped improve conditions for salmonids. However, even with these measures, salmonid abundance continues to vary.

ES5. Analytical Tools and Lifecycle Models

Results of recent lifecycle modeling suggest that upstream conditions, ocean conditions for rearing and ocean harvest, and predation primarily drive salmon survival and abundance.

Several analytical tools have been developed to provide a framework to identify and evaluate potential management actions, assess the relative importance of individual stressors on overall population dynamics, and allow comparative cost/benefit assessments. However, many of these tools were developed to address specific management actions, life stages, or addressed only a limited geographic area.

Recent lifecycle models more accurately reflect differences in life stages, geographic distribution, and factors that influence spawning, growth, survival, and abundance. Lifecycle models provide a tool for assessing the relative importance of various factors on the abundance of adults as reflected by the beneficial or adverse effects of stressors at each life stage. These models provide an analytical framework for application of the best available scientific information regarding the response of a given life stage to a management action or environmental condition. Lifecycle models can also help identify future monitoring or research that could improve model assumptions and better identify functional relationships.

ES6. Linkages between Flow and Salmonid Survival

There is a weak positive relationship between river flow rate and juvenile salmonid survival. The scientific literature suggests that enormous changes in flow are necessary to achieve even a small change in survival in the Sacramento and San Joaquin rivers and even such modest

improvement is uncertain. Increasing flows through reservoir releases or reduced diversions will not restore many of the functions that Central Valley rivers and the Delta provided in the past. Elevated water temperatures and predation are important factors that substantially impact salmonid survival and changes in reservoir operations or rates of diversion will not resolve these issues. Tidal hydrodynamics will overwhelm any perceived benefits of changes in reservoir operations or rates of diversion for juvenile salmonid migration in the Delta.

ES6.1 Biological Roles of River Flows

River flows and associated olfactory parameters serve as environmental cues for adult salmonid attraction and upstream migration to spawning habitat. Instream flows are needed to provide sufficient water depths for adult upstream passage and adult holding in the upper reaches of rivers prior to spawning. River flows also help to regulate water temperatures, increase dissolved oxygen levels, flush fine sediments that deposit on gravels used for spawning, and remove metabolic waste from incubating salmonid eggs. Flows also transport macroinvertebrates and zooplankton from upstream areas to rearing juveniles. Pulse flows in the winter and spring, increase turbidity, and seasonal increases in water temperature provide cues for downstream migration of juvenile salmonids.

ES6.2 Use of Flows to Regulate Water Temperature

Dam and levee construction, loss of wetlands, and reduced floodplain inundation within the Central Valley have limited the geographic distribution of salmonids and reduced species abundance. Various projects and programs have been implemented to address these adverse effects, including reservoir coldwater pool management and timed flow releases to maintain suitable water temperatures below those reservoirs. Because water in river channels is exposed to ambient air and solar radiation, water temperatures increase as a function of distance downstream of a dam until a thermal equilibrium is reached. Thus, while in spring, summer and fall, coldwater pool releases can reduce instream water temperatures in limited river reaches below dams, for most of the Sacramento River and all of the Delta such releases have no effect on instream water temperatures.

Flow augmentations have been suggested as a tool to increase abundance of desired fish species in the Bay-Delta estuary. Modeling of the potential impact of increased reservoir releases suggest that reservoir storage and thus available cold water at Shasta, Oroville, Trinity and Folsom Reservoirs would be substantially impacted by winter and spring releases (between November and June).

Reservoirs that reach dead pool—particularly in consecutive years—would expose downstream salmonids to stress and mortality from elevated water temperatures, reduce instream flow and physical habitat, and could reduce population abundance and increase risk of species extinction. Adverse impacts would also be likely for coldwater resident fish such as rainbow trout downstream as well as fish populations within the reservoirs. If ambient air temperatures increase in the future due to climate change, water temperatures would also increase, and the severity of adverse effects to salmonids and other fish species from coldwater pool depletion would likely increase.

ES6.3 Relationship between Flow and Survival

Numerous studies have been conducted in the Sacramento and San Joaquin river systems and in the Delta in the past 25 years to examine the relationship between flow and salmonid survival, and how changes in river flows affect migratory processes for juvenile salmonids. In general, studies have also shown high total mortality (70 to 80%) for juvenile salmon migrating downstream in the Sacramento River before they reach the northern Delta.

Survival studies have identified a positive trend of increased juvenile survival during migration when river flows are higher. However, these studies show: 1) high variability in juvenile survival for a given flow; 2) a weak relationship between survival and flow, which indicates that flow does not explain a substantial proportion of the observed variation in survival; and 3) a substantial increase in flow would be required to achieve a small increase in predicted salmonid survival.

Tidal flows are typically much larger that net Delta inflows. As a result, Delta inflows and outflows are likely to be overwhelmed by tidal hydrodynamics.

ES7. Salmonids in the Sacramento River System

Despite the construction of dams on the river and most major tributaries, analyses of Sacramento River hydrology indicate that the system continues to be characterized by winter and spring pulse flows from storm events that increase turbidity and contribute to migration cues for juvenile salmonids. Producing pulse flows through reservoir releases will not increase turbidity in the system, mimic seasonal increases in water temperatures, directly affect fish size, or improve and migration cues.

The Sacramento River and its tributaries, including the American, Feather and Yuba rivers, and Battle, Clear, Butte, Deer, Mill and a number of other creeks tributary to the river, support populations of Chinook salmon and steelhead. Access to spawning and rearing habitat for salmonids in the Sacramento River basin has been severely modified due to dam construction, river and stream channelization, levee construction and rip-rapped bank protection, reclamation of tidal wetlands and channel margin habitat, and management of areas for flood control purposes that historically functioned as seasonally inundated floodplain habitat. Water diversions have altered the magnitude and seasonal timing of flows. The introduction of non-native fish and other aquatic species has altered fish community dynamics.

Survival of juvenile Chinook salmon during emigration through the Sacramento River and Delta are positively correlated to fish size (larger juvenile salmon typically have higher survival rates) and Sacramento River flows, but are not significantly related to either the percentage of direct losses as recorded as tag group salvage at the State Water Project (SWP) and Central Valley Project (CVP) export facilities or combined SWP and CVP export rates (indirect effect).

Results of coded wire tag (CWT) survival studies have shown that survival of juvenile salmon migrating downstream through the lower Sacramento River and Delta is highly variable within and among years. Survival rates are weakly correlated with Sacramento River flow and Delta inflow and outflow during the seasonal migration period. In addition, fish size and migration timing can have significant effects on juvenile Chinook salmon survival during emigration.

Studies on downstream migration, using coded wire tag mark-recapture techniques, report higher survival rates for juvenile salmon that migrate in the Sacramento River and lower survival rates for those that migrate into the interior Delta through the Delta Cross-Channel and Georgiana Slough. Recent results from limited acoustic tagging studies have confirmed results of the earlier studies showing higher mortality for salmonids migrating into Georgiana Slough. The performance of a non-physical barrier at Georgiana Slough was tested in 2011 and 2012, and appears to have reduced juvenile salmonid migration into the interior Delta.

Acoustic tagging studies undertaken in the past decade have added substantially to the body of scientific information that can be used in investigating mechanisms and factors that affect juvenile salmon survival. However, until recently, this technology has been limited to relatively large, surgically implanted tags requiring the use of larger (greater than 100mm), hatchery-raised salmon which may not be representative of the survival of smaller salmon fry and smolts during downstream migration. Advancements in acoustic tag technology (allowing use of smaller fish) are continuing and are expected to substantially improve the understanding of juvenile salmonid survival, and address uncertainty from earlier studies.

ES8. Salmonids in the San Joaquin River System

A substantial decline in survival over time not related to river flow or exports has been identified. It has been hypothesized that ocean rearing conditions and increasing abundance of predatory fish in the south Delta may be factors contributing to the trend of declining salmon survival.

The primary San Joaquin River tributaries, the Merced, Tuolumne, and Stanislaus rivers, support spawning and rearing of fall-run Chinook salmon and small populations of steelhead.

The San Joaquin River basin fall-run Chinook salmon population has been characterized by high variability in adult returns to the system that may reflect a cyclical pattern in abundance related to cyclical ocean rearing conditions (e.g., Pacific Decadal Oscillation). In addition, the San Joaquin system is characterized by substantially less freshwater runoff when compared to the Sacramento River basin, which is reflected in lower instream flows and frequently greater seasonal water temperatures that affect habitat quality and availability, reproductive success, survival, and overall abundance of Chinook salmon and steelhead within the San Joaquin basin. In addition, striped bass and other predatory fish are common in the lower reaches of the river, particularly in the spring months when juvenile salmonids are migrating downstream through these reaches.

Juvenile salmon mortality rates for fish that migrate downstream via the interior Delta are generally thought to be higher than for salmon that remain in the mainstem San Joaquin River based on results of CWT survival studies. To reduce salmonid migration via the interior Delta, a rock barrier was tested for several seasons at the Head of Old River. Results of CWT survival studies conducted using juvenile fall-run Chinook salmon released into the lower San Joaquin River show greater salmon survival when the temporary rock barrier was installed at the Head of Old River during the spring. More recently, a non-physical (e.g., bubble curtain) barrier was tested, which showed that the barrier was approximately 80% effective in deterring tagged juvenile salmon from entering Old River. However, the results also showed that predation on juvenile salmon within a scour hole in the San Joaquin River immediately downstream of the barrier altered salmon behavior and survival.

The 1995 Bay-Delta Water Quality Control Plan (D-1641) established the Vernalis Adaptive Management Plan (VAMP) to investigate the effects on juvenile salmonid survival of San Joaquin River flows at Vernalis, SWP and CVP exports, and the installation of physical barrier at Old River. Results of CWT survival studies performed from 2000 to 2006 as part of VAMP did not detect a statistically significant relationship between SWP and CVP exports and survival, although a positive relationship between San Joaquin River flow and survival has been identified in both VAMP survival studies and analysis of spring flows when juvenile salmonids were migrating.

Results of CWT survival studies have also detected a substantial decline in survival over time that was not related to river flow or exports, and thus appears to be in response to another factor. It has been hypothesized that in addition to ocean rearing conditions, increasing abundance of predatory fish over the past decade in the south Delta may be a factor contributing to the trend of declining salmon survival.

ES9. Salmonids in the Bay-Delta

The dominant factor affecting hydrodynamic conditions in the Delta is diurnal tidal action. The flow in Delta channels, as well as salinity intrusion into Suisun Bay and the Delta, is complex and driven to a large extent by tidal stage.

The Bay-Delta estuary serves as a migratory pathway for upstream immigrating adult and downstream emigrating juvenile salmonids and serves as short-term rearing habitat for juveniles of some salmonid species during their migration to the ocean.

Habitat in the Delta has been extensively modified through loss of most tidal wetlands and seasonally inundated floodplains that produced food as well as cover, velocity refugia, and rearing habitat for juvenile salmonids. In addition, species composition and trophic dynamics of the Bay-Delta food web have changed in response to the introduction of non-native fish, macroinvertebrates, aquatic plants, nutrients and contaminants. The recent expansion of submerged aquatic vegetation and increases in water clarity (due to reductions in turbidity) provide advantages to some introduced predators of juvenile salmonids.

SWP and CVP export operations, as well as in-Delta diversions affect conditions for migrating salmonids in the Delta. Depending on Delta inflows and the rate of in-Delta diversions and SWP and CVP exports, the direction and magnitude of flows in interior Delta channels can be altered and “reverse flows” can occur in Old and Middle Rivers (OMR). These flow modifications and other stressors affect hydrodynamics within the Bay-Delta and may impact the route selection, migration rate, and the behavioral response of juvenile salmon during migration through the Bay-Delta.

The scientific literature shows in-Delta survival of juvenile Chinook salmon during emigration through the Delta is related to fish size (larger juvenile salmon typically have higher survival rates) and Sacramento River flows, but are not significantly related to either the percentage of the CWT fish salvaged at the SWP and CVP export facilities (direct loses) or combined SWP and CVP export rates (indirect effect).

Additional studies have shown that the numbers of fish salvaged at the SWP and CVP export facilities provides an index of smolt survivorship to San Francisco Bay, and survivorship to the Delta has a much stronger influence on salvage than does export rate.

Ongoing research on the Delta Passage Model (DPM) suggests it will provide an opportunity to integrate various survival mechanisms, and make it possible to link route choices and survival in each route to flow and water operations in the Delta and estimate the magnitude of indirect mortality related to pumping volume.

ES10 Salmonids in the Ocean

Ocean conditions are an important factor impacting salmonid survival and abundance in terms of both successful rearing and ocean harvest of adults. Changes in ocean conditions can have a major impact on salmonid abundance that cannot be addressed through Delta or upstream flow changes.

Chinook salmon and steelhead spend a considerable portion of their lifecycle inhabiting coastal marine waters. Many salmonids enter the ocean as young of the year juveniles and reside in ocean waters for a period of 2 years or more. The survival of smolts at the time of ocean entry is thought to be the most critical phase for salmonids during their residence in the ocean.

During their ocean residency, juvenile and sub-adult salmonids forage and grow, and food availability is a critical factor influencing their growth and survival. Food availability in coastal marine waters varies in response to a number of factors that include coastal upwelling and ocean temperatures and currents. When productivity is low available food supplies for juvenile rearing salmonids is reduced resulting in reduced growth rates, increased mortality, and reduced adult abundance. When ocean productivity is good juvenile salmon survival is high resulting in strong year classes with high adult abundance.

Coastal upwelling and other oceanographic processes that influence productivity are characterized by cyclic patterns with recurrence intervals that may vary from years to decades. For example, ocean productivity was very low in the Gulf of the Farallones in 2005 and 2006 which was correlated with low adult salmon returns in 2007, 2008, and 2009. In response to the low numbers of adult salmon in the population the commercial and recreational fisheries were curtailed to protect the weak stocks.

Harvest of sub-adult and adult Chinook salmon in ocean commercial and recreational fisheries has a strong effect on the number of adults that return to spawn in the Central Valley. Harvest rates are regulated and have been reduced in recent years to help protect winter-run and spring-run Chinook salmon.

Central Valley Chinook salmon inhabiting the ocean include both wild fish and those produced in Central Valley fish hatcheries. Wild salmon populations cannot sustain harvest rates as high as for those stocks produced in hatcheries, but there is currently no program in place to distinguish wild from hatchery-produced fish. Mark-select fisheries (where all hatchery fish are marked) have been used as a management tool in the Northwest to protect wild salmon. Similar changes to ocean harvest management would improve abundance of wild Central Valley Chinook salmon.

ES11 Conclusion

Efforts to increase salmonid abundance in recent decades have resulted in some improvements, but significant annual population variability remains. As salmonids only spend between 2 and 9 percent of their lifespan within the Delta, proposed management actions focused on the estuary must be evaluated within the context of the species' entire lifecycles.

Ongoing research is improving our understanding of how various factors affect salmonid reproductive success, growth, health, and survival, but the complex interaction of those factors results in substantial uncertainty. Advances in applying acoustic tag technology, development and refining lifecycle models and other analytic tools, continued experience in applying results of monitoring to adaptive management decisions, and improved understanding of salmonid population dynamics serve to reduce uncertainty in identifying effective restoration and other actions that protect and improve conditions for Central Valley salmonids.

1 Overview of Central Valley Salmonids

This section describes the legal status of each Central Valley anadromous salmonid species, their life history characteristics, seasonal timing and geographic distribution of each species, and the seasonal distribution in habitat use for each salmonid. This information serves as part of the foundation and framework for understanding the relative contribution of river flows, Delta hydrodynamics, and exports, as well as stressors affecting the population dynamics of salmonids upstream of the Delta and within the ocean, on the survival and movement patterns of juvenile salmonids.

1.1 Legal Status

Sacramento River winter-run Chinook salmon were listed by the National Marine Fisheries Service (NMFS) as a threatened species in 1989 under emergency provisions of the federal Endangered Species Act (ESA), and formally listed as threatened in 1990 (55 FR 46515). The Sacramento River winter-run Chinook salmon Evolutionary Significant Unit (ESU) includes all naturally spawned populations of winter-run Chinook salmon in the Sacramento River and its tributaries as well as two artificial propagation programs: winter-run Chinook salmon produced from the Livingston Stone National Fish Hatchery and released as juveniles into the Sacramento River and winter-run Chinook salmon held in a captive broodstock program maintained at Livingston Stone National Fish Hatchery (70 FR 37160). The ESU consists of a single population that is confined to the upper Sacramento River. The ESU was reclassified as endangered under the federal ESA in 1994 (59 FR 440) due to increased variability of run sizes, expected weak returns as a result of two small year classes in 1991 and 1993, and a 99 percent decline between 1966 and 1991.

NMFS reaffirmed the listing of Sacramento River winter-run Chinook salmon as endangered in 2005 (70 FR 37160) and included the Livingston Stone National Fish Hatchery population within the listed population. Winter-run Chinook salmon are also classified as an endangered species under the California ESA. Critical habitat for winter-run Chinook salmon has been designated by NMFS and includes the Sacramento River, Delta, and northern portions of San Francisco Bay.

The Central Valley spring-run Chinook salmon ESU was listed as a threatened species under the federal ESA in 1999 (64 FR 50394). The ESU includes all naturally spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries in California, including the Feather River. In 2004, NMFS proposed that Central Valley spring-run Chinook salmon remain listed as threatened (69 FR 33102). This proposal was based on the recognition that the ESU continues to face risks from having a limited number of remaining populations (i.e., three existing populations from an estimated 17 historical populations), a limited geographic distribution, and potential hybridization with Feather River Hatchery spring-run Chinook salmon, which are genetically distinct from other populations in Mill, Deer, and Butte creeks. NMFS issued its final decision in 2005 to retain the status of Central Valley spring-run Chinook salmon as threatened (70 FR 37160). This decision also included the Feather River Hatchery spring-run Chinook salmon population as part of the ESU. Spring-run Chinook salmon are also listed as a threatened species under the California ESA. Critical habitat for spring-run Chinook salmon has been designated by NMFS and includes the Sacramento River, Delta, and northern portions of San Francisco Bay.

The fall- and late fall-run Chinook salmon ESU includes all naturally spawned populations of fall- and late fall-run Chinook salmon in the Sacramento and San Joaquin river basins and their tributaries east of Carquinez Strait (64 FR 50394). NMFS determined in 1999 that listing Central Valley fall- and late fall-run Chinook salmon was not warranted. The Central Valley fall- and late fall-run Chinook salmon ESU were reclassified as a federal Species of Concern (69 FR 19975) in 2004. The species are not listed under the

California ESA. Critical habitat has not been designated for either fall-run or late fall-run Chinook salmon because the species are not listed under the ESA; however, fall- and late fall-run Chinook salmon habitats are protected under the Magnuson-Stevens Fishery Conservation and Management Act as Essential Fish Habitat, which includes Central Valley rivers, the Delta, and San Francisco Bay.

The Central Valley steelhead distinct population segment (DPS) was listed by NMFS in 1998 as a threatened species under the federal ESA, and includes all naturally spawned populations of steelhead in the Sacramento and San Joaquin rivers and their tributaries, including the Bay-Delta (63 FR 13347). Steelhead from San Francisco and San Pablo bays and their tributaries are excluded from the Central Valley DPS, but are included in the Central California Coast DPS. In 2006, NMFS issued its final decision to retain the status of Central Valley steelhead as threatened (71 FR 834). This decision included the Coleman National Fish Hatchery and Feather River Hatchery steelhead populations. Critical habitat for Central Valley steelhead has been designated by NMFS and includes the Sacramento River, Delta, and San Francisco Bay.

1.1.1 Salmonid Life History

Winter-run, fall-run, late fall-run, and spring-run Chinook salmon and steelhead are anadromous species that spawn in freshwater but rear for a portion of their lifecycles in coastal marine waters (Williams 2006, Healey 1991). The general salmonid lifecycle is shown in Figure 1-1. The fecundity (number of eggs produced) by salmon and steelhead varies among species and individuals but typically is approximately 5,000 eggs/female (Williams 2006). For the population to remain stable, only two of these eggs need to survive to become reproductive adults (cohort replacement). A variety of mortality sources affect the numbers of eggs and juveniles that survive to adulthood and subsequently spawn (NMFS 2010). The seasonal timing, geographic distribution, life history characteristics, population dynamics, and environmental sensitivities of each individual species and their lifestages are important factors used in assessing the potential impacts stressors have on the species.

1.1.1.1 Adult Salmonid Migration

Chinook salmon and steelhead migrate upstream from the ocean, through the Delta, and into Central Valley rivers during the fall, winter, and spring months (the name for Chinook salmon, such as winter-run, reflects the seasonal timing of adult upstream migration) depending on the species. Chinook salmon exhibit two characteristic freshwater life history types (Williams 2006, Healey 1991). Stream-type adult Chinook salmon enter freshwater months before spawning, and their offspring reside in freshwater one or more years following emergence. Ocean-type Chinook salmon, in contrast, spend significantly less time in freshwater, spawning soon after entering freshwater as adults and migrating to the ocean as juvenile young-of-the-year or yearling smolts within their first year. (Healey 1991) Appropriate stream flows and cool water temperatures upstream are more critical for the survival of Chinook salmon exhibiting the stream-type life history behaviors due to their residence in freshwater both as adults and juveniles over the warmer summer months. Some adult species (e.g., fall-run and late fall-run Chinook and steelhead) are sexually mature when they enter freshwater, while other adult species (e.g., spring-run and winter-run Chinook salmon) are sexually immature and hold in upstream freshwater for a period of time before spawning.

1.1.1.2 Spawning

Chinook salmon spawn in clean, loose gravel in swift, relatively shallow riffles; or along the margins of deeper river reaches where suitable water temperatures, depths, and velocities favor redd (gravel nest) construction and oxygenation of incubating eggs. Spawning occurs in the upper reaches of rivers and streams in areas characterized by gravels with interstitial spaces that allow water to easily flow through the spawning gravels within the redd and a low percentage of fine material with suitable size, in areas where water temperatures during spawning are cool (preferably less than 57 F [Williams 2006]). The female digs a shallow depression in the gravel (redd) where the eggs are deposited and fertilized by the male. The fertilized eggs are then covered by a shallow layer of gravel. Water flow through the gravel and water temperatures are two factors that affect hatching success (Williams 2006). After hatching, the young salmonids (alevin stage) remain in the gravel redd until they have absorbed the yolk-sac and begin to emerge into the surface waters.

1.1.1.3 Fry Emergence and Rearing

Young salmonids (fry) typically inhabit river and stream areas where water depths are relatively shallow and water velocities are reduced (e.g., channel margins) and where they can feed on small zooplankton and macroinvertebrates (Bjornn and Reiser 1991, Reiser and Bjornn 1979). Fry seek streamside habitats containing beneficial aspects, such as riparian vegetation and associated substrates, which provide aquatic and terrestrial invertebrates, predator avoidance cover, and slower water velocities for resting (NMFS 1996). Higher juvenile salmon growth rates have been associated with shallow water habitats, as opposed to the deeper main river channels, partially due to greater prey consumption rates, as well as favorable environmental temperatures (Sommer *et al.* 2001a,b). As the juveniles grow, they tend to inhabit deeper water areas with higher velocities where they forage on macroinvertebrates and drift insects (Williams 2006). For some salmonid species, such as fall-run and winter-run Chinook salmon, juvenile rearing in freshwater is relatively short (months), with some juveniles rearing in upstream areas and migrating downstream as smolts (physiologically capable of the transition from freshwater to saltwater) and others in the population migrating downstream shortly after emergence as fry to rear in the lower reaches of the rivers and the Delta until ready to move into saltwater (Williams 2006). In other species, such as late fall-run and spring-run Chinook salmon and steelhead, the juveniles rear in the upstream river habitat for 1 year before migrating downstream through the Delta into the ocean.

1.1.1.4 Ocean Lifecycle

Juvenile salmonids typically rear for at least 2 to 3 years in coastal marine waters, where they feed on marine macroinvertebrates (e.g., krill, amphipods, squid) and small fish (Williams 2006). Sub-adult and adult Chinook salmon are harvested in coastal commercial and recreational fisheries, while steelhead (because of their diet) are not vulnerable to ocean harvest. Both adult Chinook salmon and steelhead are harvested in relatively low numbers in the inland recreational fisheries within San Francisco, San Pablo, and Suisun bays, the Delta, and Central Valley rivers.

Central Valley Chinook salmon begin their ocean life in the coastal marine waters of the Gulf of the Farallones from where they distribute north and south along the continental shelf primarily between Point Conception and Washington State (Healey 1991). Upon reaching the ocean, juvenile Chinook salmon feed on larval and juvenile fishes, plankton, and terrestrial insects (Healey 1991, MacFarlane and Norton 2002). Chinook salmon grow rapidly in the ocean environment, with growth rates dependent on water temperatures and food availability (Healey 1991). The first year of ocean life is considered a critical period of high mortality for Chinook salmon that largely determines survival to harvest or spawning (Beamish and Mahnken 2001, Quinn 2005).

Central Valley Chinook salmon remain in the ocean for 2 to 5 years. Fall-run and late fall-run Chinook salmon mature in the ocean before returning to freshwater to spawn. Spring-run and winter-run Chinook salmon return to freshwater as immature adults as indicated by the several months they spend in upstream rivers before spawning. Ocean conditions during the salmonid ocean residency period are important, as exemplified by the substantial adverse effect of the 1983 El Niño on the size and fecundity of Central Valley fall-run Chinook salmon (Wells *et al.* 2006).

1.1.2 Seasonal Timing and Geographic Distribution of Salmonids

The seasonal timing and geographic distribution of Central Valley salmonids within the Delta and its watersheds are described below. Additional information on the life history, habitat requirements, population dynamics, and factors affecting Central Valley salmonids is presented by Williams (2006), Healey (1991) McEwan (2001) and others.

1.1.2.1 Winter-run Chinook Salmon

Adult winter-run Chinook salmon migrate upstream from the Pacific Ocean through the Bay-Delta estuary during November through March moving upstream into the Sacramento River near Redding during December through April with the greatest movement during late-February through late-March. The adults are sexually immature when migrating upstream and hold in the mainstem river for a period of months prior to spawning. Spawning occurs in the mainstem Sacramento River downstream of Keswick Dam from April through August with the greatest spawning activity during May. Egg incubation occurs between April and late-September. Juvenile rearing and emigration typically occurs between July and February in the upper river with juvenile migration downstream through the Delta between late-November and May.

Winter-run Chinook salmon spawning is currently limited to the mainstem Sacramento River in the reach from Keswick Dam to Red Bluff (Figure 1-2), although the actual distribution of spawning and egg incubation within the reach varies among years in response to water temperatures, adult abundance, and other factors (Williams 2006). During the seasonal migration period, juvenile and adult winter-run Chinook salmon use the Sacramento River, Delta, and downstream bays (e.g., Suisun, San Pablo, and central San Francisco bays) as juvenile rearing habitat and as a migratory corridor. Critical habitat for winter-run Chinook salmon includes the Sacramento River, Delta, and downstream bays to the Golden Gate Bridge (58 FR 33212, 1993).

1.1.2.2 Spring-run Chinook Salmon

Adult spring-run Chinook salmon migrate upstream from the Pacific Ocean through the Bay-Delta estuary during January through mid-May, moving upstream into the Sacramento River near Redding and major tributaries such as Mill, Deer, and Butte creeks and the Feather River during late-March through September with the greatest movement during May. The adults are sexually immature when migrating upstream and hold in the mainstem river and tributaries for a period of months prior to spawning. Spawning typically occurs during late-August through September with the greatest spawning activity during September. Egg incubation occurs between September and January. Juvenile rearing typically includes one portion of the population moving downstream as fry and another portion rearing within the upper reaches of the river and tributaries for 1 year and then migrating downstream as smolts between approximately September and early May. Juvenile migration downstream through the Delta typically occurs between late-November and August although the majority of juvenile migration occurs during the late-winter and spring.

Spring-run Chinook salmon inhabit a variety of Central Valley rivers and creeks, including the mainstem Sacramento River downstream of Keswick Dam, Clear Creek, the Feather River, and tributaries such as Mill, Deer, Antelope, Big Chico, Battle, and Butte creeks. The majority of spring-run Chinook salmon adults migrate into Sacramento River tributaries such as Mill, Deer, and Butte creeks for adult holding, spawning, and juvenile rearing. The geographic distribution of spring-run Chinook salmon spawning includes both the mainstem Sacramento River and a number of major tributaries, as shown in Figure 1-3.

During the seasonal periods of adult and juvenile migration, the Sacramento River, Delta, and downstream bays serve as juvenile rearing habitat and a migratory corridor for both adult and juvenile spring-run Chinook salmon. Critical habitat for spring-run Chinook salmon includes the Sacramento River, tributaries supporting spring-run such as Deer, Mill, and Butte creeks, the Delta, and downstream bays to the Golden Gate Bridge (70 FR 52488, 2005).

1.1.2.3 Fall- And Late Fall-Run Chinook Salmon

Historically, Central Valley fall-run Chinook salmon spawned in all major tributaries, as well as the mainstem of the Sacramento and San Joaquin rivers. A large percentage of fall-run Chinook spawning in the Sacramento and San Joaquin rivers historically occurred in the lower gradient reaches of the rivers downstream of sites now occupied by major dams. As a result of the geographic distribution of spawning and juvenile rearing areas, fall-run Chinook salmon populations in the Central Valley were not as severely affected by early dam building as were spring- and winter-run Chinook salmon and steelhead that used higher elevation habitat for spawning and rearing (Yoshiyama *et al.* 1998).

Fall-run Chinook salmon inhabit a variety of Central Valley rivers and creeks, including the mainstem Sacramento River downstream of Keswick Dam, the Feather and American Rivers, the Mokelumne, Tuolumne, Merced, and Stanislaus Rivers, and other tributaries. The geographic distribution of fall-run Chinook salmon spawning includes both the mainstem Sacramento River and a number of major tributaries, as shown in Figure 1-4. The majority of fall-run Chinook salmon adults migrate into the Sacramento River and its tributaries for adult holding, spawning, and juvenile rearing.

Central Valley fall-run Chinook salmon exhibit an ocean-type life history. Adult fall-run Chinook salmon migrate through the Delta and into Central Valley rivers from July through December and spawn from October through December. Peak spawning activity usually occurs in October and November. The life history characteristics of late fall-run Chinook salmon are not well understood; however, they are thought to exhibit an ocean-type life history. Adult late fall-run Chinook salmon migrate through the Delta and into the Sacramento River from October through April and may wait 1 to 3 months before spawning from January through April. Peak spawning activity occurs in February and March. Chinook salmon typically mature between 2 and 6 years of age (Myers *et al.* 1998). The majority of Central Valley fall-run Chinook salmon spawn at age 3.

Central Valley fall-run Chinook salmon fry migrate downstream into the lower rivers and estuary in January, with peak fry abundance occurring in February and March. A later emigration of fall-run Chinook salmon smolts occurs from April through June. Fall-run Chinook salmon fry continue to rear in the upper estuary and emigrate as smolts during the normal smolt emigration period. Fall-run Chinook salmon smolts arriving in the estuary from upstream rearing areas typically migrate quickly through the Delta and Suisun and San Pablo bays.

The entire population of the Central Valley fall-/late fall-run Chinook salmon ESU pass through the Delta as upstream migrating adults and emigrating juveniles. Young fall/late fall-run Chinook salmon migrate through the Delta towards the Pacific Ocean and use the Delta for rearing to varying degrees, depending on their life stage (fry vs. juvenile) and size, river flows, and time of year.

Late fall-run Chinook salmon spawning is currently limited to the mainstem Sacramento River in the reach from Keswick Dam to Red Bluff (see Figure 1-2) and Battle Creek. Juvenile late fall-run Chinook salmon rear in the upper Sacramento river and migrate downstream as yearlings.

1.1.2.3.1 Central Valley Steelhead

Adult steelhead migrate upstream from the Pacific Ocean into San Pablo, Suisun and other bays, during the late summer and early fall. They appear to forage in these more saline waters for a period of time before migrating upstream into the rivers during the late fall and winter when upstream water temperatures are more suitable. Spawning typically occurs in the mainstem Sacramento River downstream of Keswick Dam between late-November and April with the greatest spawning activity during the period from January through March. Egg incubation occurs between April and late-September. Juvenile rearing and emigration typically occurs between December and April in the upper river. Juvenile steelhead rear within the river year-round for a period of typically 1 to 2 years before migrating downstream to the ocean. Juvenile migration downstream through the Delta typically occurs between late-September and May. The seasonal timing of migration, spawning and egg incubation, and juvenile emigration varies somewhat among Central Valley rivers (McEwan 2001, McEwan and Jackson 1996).

Central Valley steelhead are broadly distributed within many of the waterways shown in Figure 1-5, including the mainstem Sacramento River, many of the upstream tributaries, and the Feather, Yuba, American, Mokelumne, and Cosumnes rivers. Steelhead also inhabit Clear, Mill, Deer, Antelope, Butte creeks, and other smaller tributaries. A modest number of wild steelhead is also produced in the lower American, Mokelumne, Cosumnes, and Stanislaus rivers. Recent evidence also shows steelhead occurring on other tributaries to the lower San Joaquin River. Critical habitat for Central Valley steelhead includes the Sacramento and San Joaquin rivers and their tributaries supporting steelhead, the Delta, and downstream bays to the Golden Gate Bridge (70 FR 52488, 2005).

1.1.3 Seasonal Distribution in Habitat Use

Chinook salmon and steelhead inhabit the Delta for only a short period of their respective life cycles. A generalized approximation of the duration that salmon and steelhead inhabit each of their habitats is summarized in Tables 1-1 and 1-2, below, based on general life history information from Williams (2006), Healey (1991) McEwan (2001) and others. The actual periods of occupation in each habitat vary by individual and in response to environmental conditions, growth rates, maturation, and other factors. These figures show that salmonids use Delta waters as habitat for only a short duration (typically 2-9 percent of their total life cycle in a typical 3-year life span), with the majority of their lives spent in the ocean. Upstream, Delta and marine habitats all serve important functions in the population dynamics of the species, although factors affecting upstream and ocean conditions have a particularly strong impact on the reproductive success and abundance of salmonids in the Central Valley.

Table 1-1. Generalized estimates of the number of weeks a 3-year-old salmonid spends in upstream, Delta, and ocean habitats.

Lifestage	Fall-run Chinook	Late Fall-run Chinook	Spring-run Chinook	Winter-run Chinook	Central Valley Steelhead
Upstream adult migration through the Delta	1-2	1-2	1-2	1-2	1-2
Adult migration and upstream holding	2-4	2-4	20-24	28-32	2-4
Spawning and egg incubation	10-12	10-12	10-12	10-12	10-12
Juvenile rearing in upstream areas	16-20	42	4-42	4-24	42-104
Juvenile migration and rearing in the Delta	2-12	2-4	2-12	2-12	2-4
Juvenile and sub-adult rearing in the ocean	106-125	92-99	64-119	74-111	30-99

Table 1-2. Generalized estimates of the percentage of its life cycle a 3-year salmonid spends in upstream, Delta, and ocean habitats

Percentage of a 3-year Life Span:	Fall-run Chinook	Late Fall-run Chinook	Spring-run Chinook	Winter-run Chinook	Central Valley Steelhead
Inhabiting Upstream Areas	18-23%	35-37%	22-50%	27-44%	35-77%
Inhabiting the Bay Delta	2-9%	2-4%	2-9%	2-9%	2-4%
Inhabiting the Ocean	68-80%	59-64%	41-76%	47-71%	19-64%

Note: These percentages of time when salmonids occupy various habitats are generalized. Actual timing may vary among runs and years in response to life history diversity and environmental conditions.

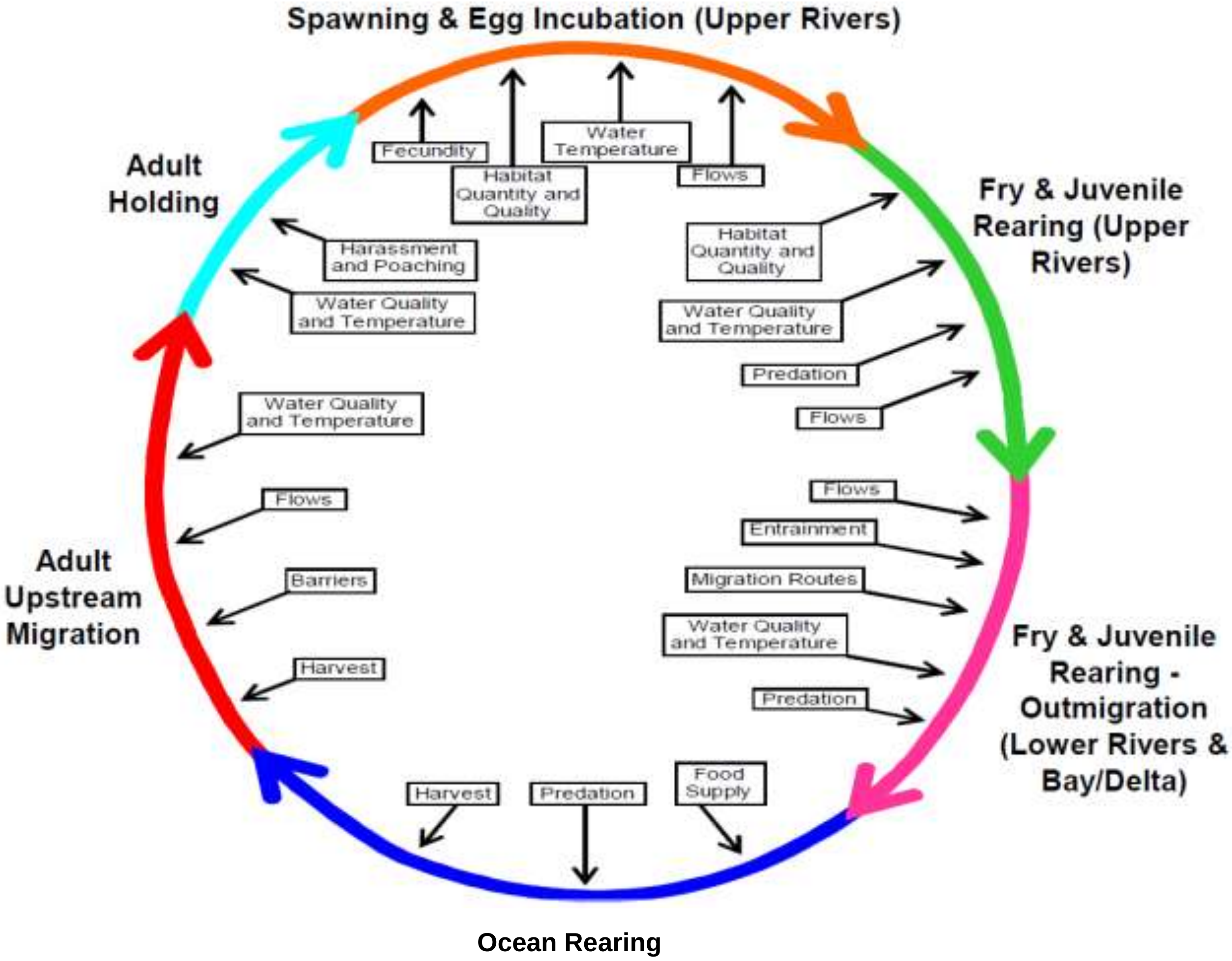

Figure 1-1. Generalized life history of Central Valley Chinook salmon and steelhead (Source: Vogel 2011). On the Sacramento River upstream habitat is defined as areas upstream of Sacramento. On the San Joaquin River upstream habitat is defined as areas upstream of Vernalis. The Delta is defined for this purpose as the area downstream of Sacramento and Vernalis to Chipps Island. The estuary is defined for this purpose as the area downstream of Chipps Island to the Golden Gate. Ocean rearing habitat is defined as coastal marine waters outside of the Golden Gate.

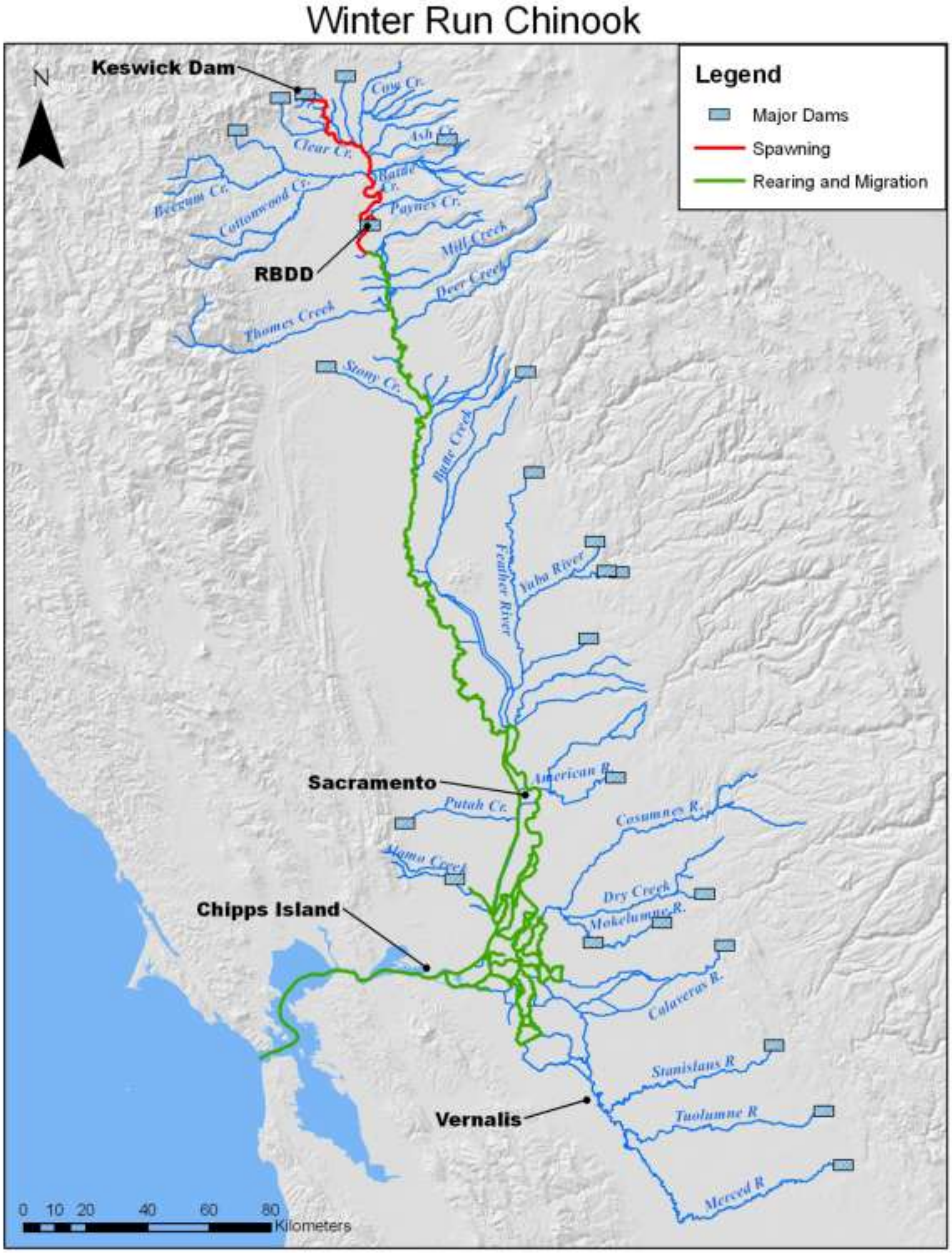

Figure 1-2. **Geographic distribution of winter-run Chinook salmon in the Central Valley.**

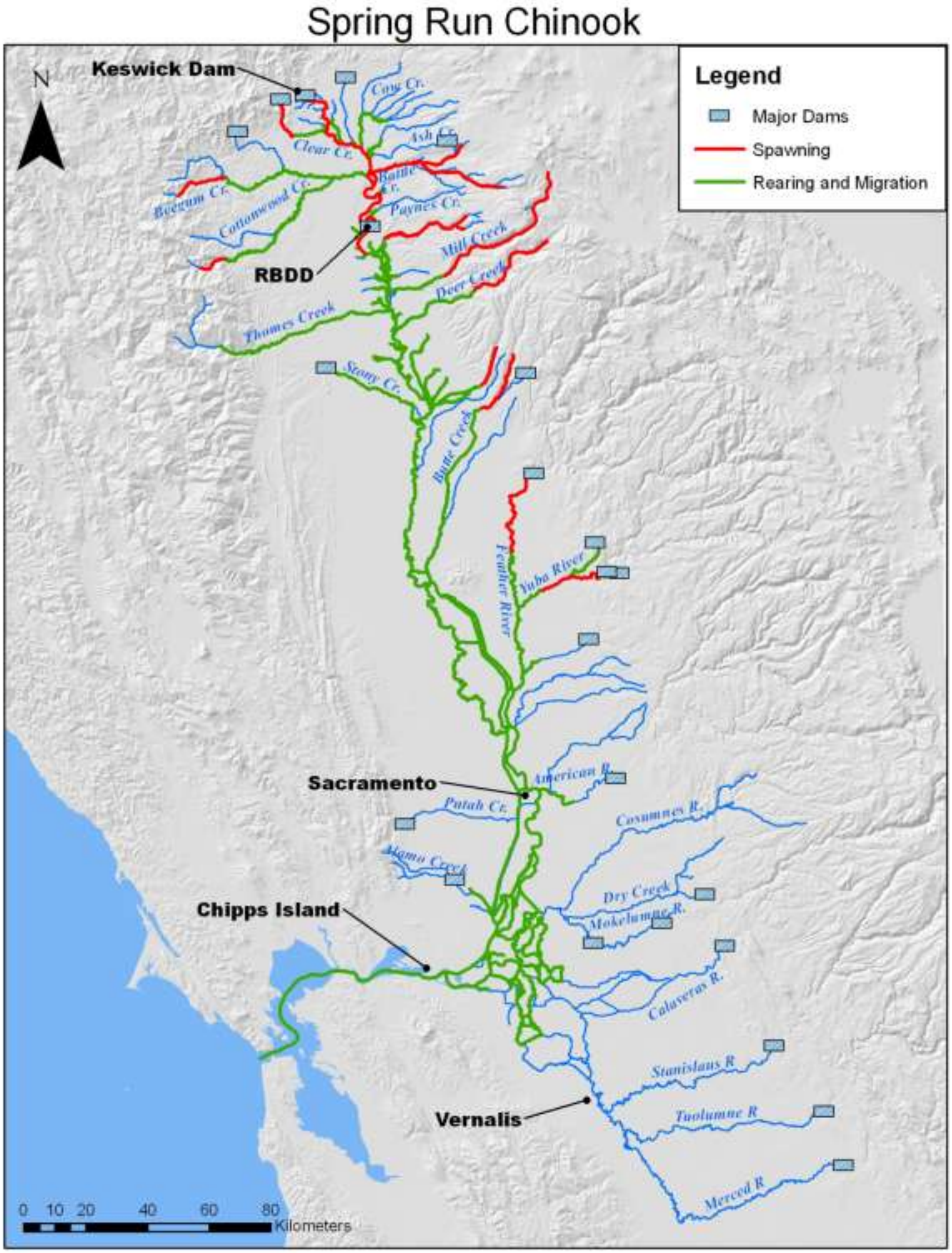

Figure 1-3. Geographic distribution of spring-run Chinook salmon in the Central Valley.

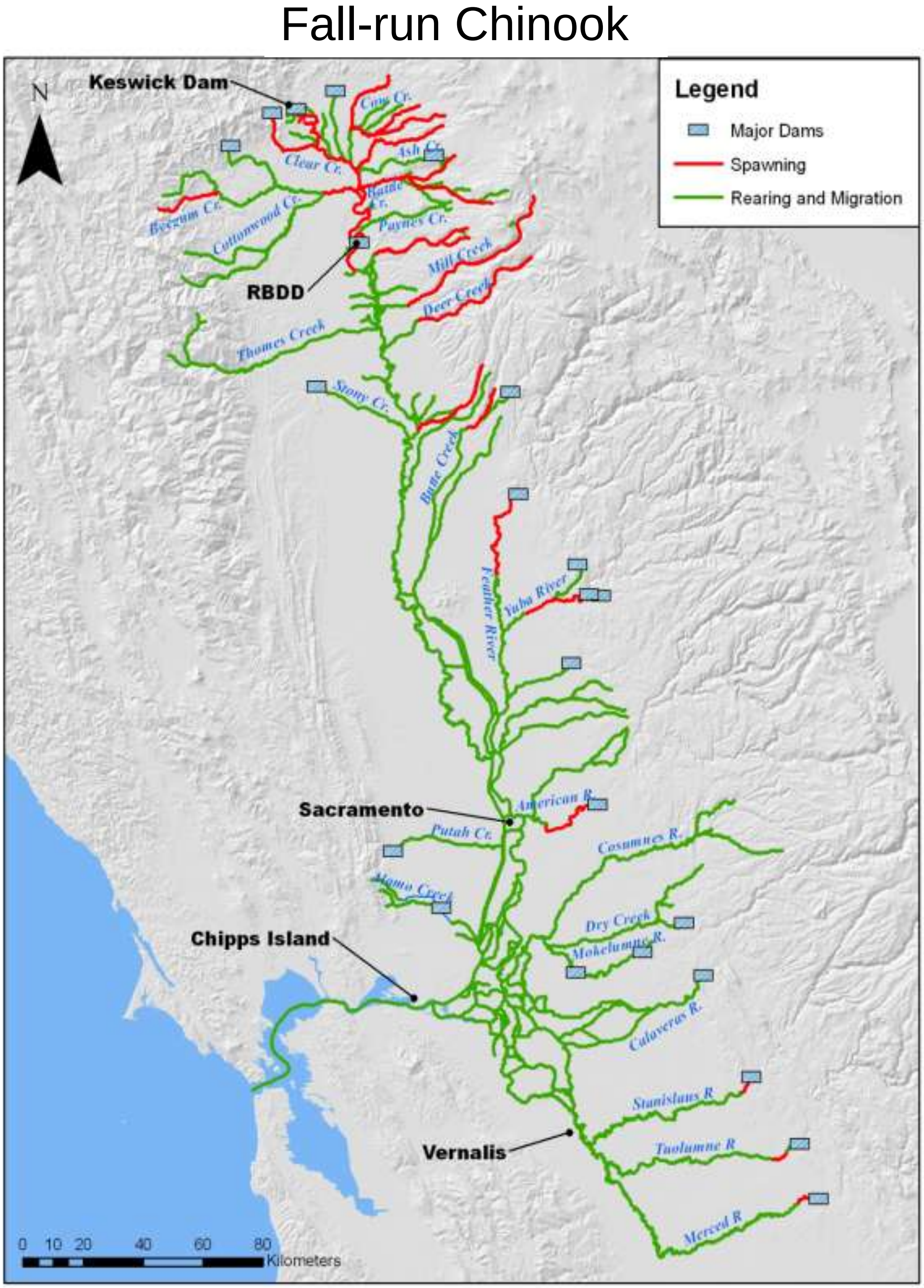

Figure 1-4. **Geographic distribution of fall-run Chinook salmon in the Central Valley.**

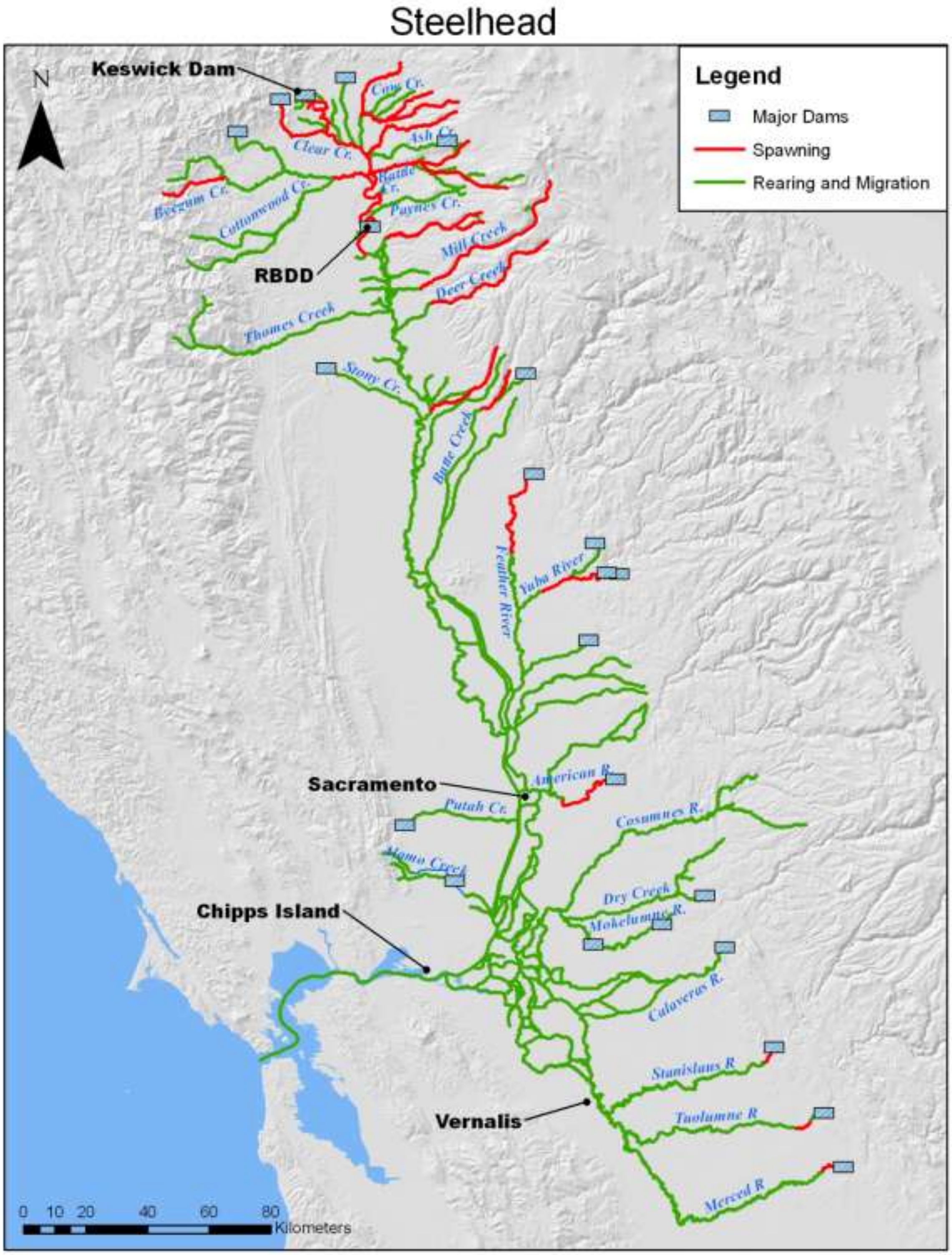

Figure 1-5. **Geographic distribution of steelhead in the Central Valley.**

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2 Stressors Affecting Central Valley Salmonids

The survival, growth, reproductive success, and overall abundance of Central Valley salmonids are affected by a wide variety of stressors (NMFS 2010). Many of these stressors occur independent of flow conditions, while other stressors are affected by flows. Many stressors with a strong effect on salmonid population dynamics and abundance occur in upstream spawning and juvenile rearing habitat, as well as in coastal marine rearing habitat for juvenile and sub-adult salmonids. Factors affecting salmonid survival also occur in the Delta. These diverse stressors affect salmonids in different habitats and at different lifestages in a complex, interacting manner. Numerous restoration, management, and regulatory actions have been taken to improve and protect salmonids in habitats located upstream of the Delta, within the Delta, and within the ocean, as discussed in Section 3, but the complexities involving stressors create uncertainty regarding how any particular management action may affect the species on a holistic level. Therefore, as recommended by NMFS (2010), to the greatest extent possible, proposed management actions must be evaluated within the context of the array of stressors acting on the species within the framework of the lifecycle of the species.

This section provides an overview of stressors affecting Central Valley salmonids, discusses changes to the six Primary Constituent Elements for these salmonids identified by NMFS (2010), and discusses the risks to salmonids from predation by non-native species.

2.1 Overview of Stressors

Historical changes in the Bay-Delta landscape have affected numerous components of salmonid habitat. The complex assemblage of floodplains, freshwater and tidal wetlands, open water, and upland habitats historically provided valuable space for rearing, spawning, migration, and refuge from predators for salmonids. The extensive changes to the Delta landscape have reduced, fragmented, and isolated these habitats. Where land and water were once intricately connected, in the current Bay-Delta landscape, levees maintain complete separation in most Delta areas of the watershed.

The draft salmonid recovery plan (NMFS 2010) and Bay Delta Conservation Plan (BDCP) draft Effects Analysis (BDCP 2010) discuss many of the stressors that adversely impact salmonids. These stressors include, but are not limited to, the following (not in order of importance):

- Loss of access to higher elevation habitat in the upper watersheds as a result of dams;
- Exposure to elevated water temperatures, particularly in the upper river reaches where spawning and egg incubation occur;
- Exposure to elevated water temperatures upstream during juvenile rearing and over summering (especially for juvenile steelhead) and in the Delta during downstream juvenile migration;
- Reductions in escapement of adults to spawning grounds, contributing to reduced juvenile production in the subsequent generation (stock-recruitment);
- Exposure to adverse flow conditions such as large fluctuations in flows and high scouring flows during egg incubation;
- Reverse flow conditions in the central and south Delta;
- Entrainment into SWP and CVP export facilities, as well as a large number of other diversions;
- Spawning gravel quality and availability;

- Reduced food production in upstream juvenile rearing habitats;
- Loss of riparian habitat from levees and bank protection;
- Loss of access to seasonally inundated floodplain habitat;
- Loss of access to shallow water low velocity juvenile rearing habitat from levees and bank protection;
- Loss of tidal marsh habitat for juvenile rearing and food production;
- Exposure to adverse water quality conditions including point and non-point source pollutants, depressed dissolved oxygen concentrations, and other constituents;
- Loss of spawning and rearing habitat due to erosion and sedimentation;
- Loss of spawning gravel and rearing habitat as a result of mining as well as channel modifications due to dredging and dredge spoil disposal;
- Migration delays and exposure to increased predation due to physical river passage impediments;
- Predation mortality by native and non-native fish and other wildlife including species that are managed as a sport fishing resource such as striped bass and largemouth bass;
- Commercial, recreational, by catch, and illegal harvest;
- Effects of hatchery operations and artificial propagation;
- Competition and predation by introduced exotic species;
- Infectious disease (especially in the hatcheries);
- Climate variation including droughts and flood flows; and
- Ocean conditions that affect productivity of food resources and predation.

2.2 Changes to Primary Constituent Elements

Recovery planning for Central Valley salmonids includes six PCEs identified by NMFS (2010a) and considered essential for conservation of Central Valley salmonids: (1) freshwater spawning sites, (2) freshwater rearing sites, (3) freshwater migration corridors, (4) estuarine areas, (5) nearshore marine areas, and (6) offshore marine areas. As explained below, the composition and overall extent of these habitat areas have changed over time (refer to the discussion in Section 1 regarding salmonid life history for a further discussion of habitat requirements).

2.2.1 Spawning Habitat

Chinook salmon and steelhead spawning sites include those reaches with instream flows, water quality, and substrate conditions suitable to support spawning, egg incubation, and larval development. Dam construction has not only blocked salmonid access to suitable upstream spawning habitat, it has also affected upstream flows and water temperatures, spawning gravel recruitment and other habitat conditions where salmonid spawning now occurs downstream of dams (NMFS 2010a).

2.2.2 Freshwater Rearing Habitat

Rearing habitat quality is strongly affected by habitat complexity, food supply, and vulnerability to avian and piscivorous predators. The channeled, leveed, and riprapped river reaches and sloughs common in the Sacramento and San Joaquin rivers and throughout the Delta typically have low habitat diversity and complexity, low abundance of food organisms, and offer little protection from predation by fish and birds.

Freshwater rearing habitat has a high conservation value because salmonid juvenile life stage is dependent on the function of this habitat for successful growth and survival and recruitment to the adult population (Williams 2006). A more thorough evaluation of the potential benefits to salmonids of improved floodplain habitat is presented in Attachment A.

Waterway channelization, dam operations, reduction in gravel and large woody debris, loss of riparian vegetation, water diversions and other control features such as weirs and gates, are examples of changes that have affected habitat quality, availability, and function for juvenile salmonid rearing (NMFS 2010a). As an example, over the past 150 years, approximately 1,335 miles of levees were constructed in the Delta, and many in-Delta channels were widened, straightened, deepened, and connected, and in some instances gated (The Bay Institute 1998). These man-made changes have collectively altered the pattern and extent of diurnal tidal flows. Most upstream rivers and many of the contributing streams have been modified with dams, diversions, or other “improvements” that have separated channels from their floodplains, thus changing inflow patterns and reducing sediment and nutrient inputs to the ecosystem.

2.2.3 Freshwater Migration Corridors

Freshwater migration corridors for Chinook salmon and steelhead, including river channels and Delta waterways, support mobility, survival, and food supply for juveniles and adults. To be most beneficial to salmonids, migration corridors should be free from obstructions (passage barriers and impediments to migration), have favorable water quantity (instream flows) and quality conditions (seasonal water temperatures), and contain natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels, and undercut banks. As discussed above, a number of Delta channels have been gated, and most upstream rivers and many of the contributing streams have been modified with dams, diversions, or other structures that can affect migration by not allowing for adequate passage or providing suitable migration cues; in some instances, they also may provide false attraction (Mysick 2001).

Salmonid access to and use of wetlands and floodplain habitat is also important (Bottom *et al.* 2011, Sommer 2001a,b, 2004). Floodplain inundation provides rearing habitat for juvenile salmonids that take advantage of the high productivity on the floodplain (Poff *et al.* 1997; Sommer *et al.* 2001a, b; Feyrer *et al.* 2004; Schramm and Eggleton 2006; Grosholz and Gallo 2006). During periods of connection between floodplains and rivers, juvenile salmonids can move on and off the floodplain to forage or rear (Moyle *et al.* 2007). The low-velocity, shallow, and vegetated conditions of the floodplain serve also as a refuge from the fast, turbid waters of the river during high flows (Sommer *et al.* 2001a; Jeffres *et al.* 2008).

Before European settlement, the Sacramento and San Joaquin rivers flowed through approximately 400,000 acres of wetlands and other aquatic habitats in the Bay-Delta (Lund *et al.* 2007, The Bay Institute 1998). The primary landscapes included flood basins in the north, tidal islands in the central Bay-Delta, and a complex network of channels formed by riverine processes in the south. Over the past 150 years, however, approximately 95 percent of the tidal wetlands were lost due to reclamation and development (The Bay Institute 1998).

2.2.4 Estuarine Areas

Estuarine migration and juvenile rearing habitats should be free of obstructions (i.e., dams and other barriers) and provide suitable water quality, water quantity (river and tidal flows), and salinity conditions to support juvenile and adult physiological transitions between fresh and salt water. Natural cover, such as submerged and overhanging large wood, aquatic vegetation, and side channels, provide juvenile and adult foraging. Estuarine areas function to support juvenile salmonid growth, smolting, avoidance of predators, and provide a transition to the ocean environment.

Channelization, levee construction and stabilization, wetland reclamation, water diversions, discharges, marinas and other structures, as well as loss of cover and habitat complexity are examples of landscape changes that have affected habitat quality, availability, and functions of the Bay-Delta estuary as habitat for salmonids (NMFS 2010a).

2.2.5 Ocean Habitats

Biologically productive coastal waters are an important habitat component for Central Valley Chinook salmon and steelhead. Nearshore marine rearing areas include those habitats free from obstructions (i.e., man-made sea walls and jetties) with water quality conditions and forage (including marine invertebrates and fishes) that support salmonid growth and maturation.

Offshore marine areas with water quality conditions and forage, including aquatic invertebrates and fishes, supporting salmonid growth and maturation are important in determining survival and growth and ultimately adult abundance. Results of various analyses (e.g., Lindley *et al.* 2009, Wells *et al.* 2006) have shown the importance of coastal upwelling and ocean current patterns on phytoplankton and zooplankton production in coastal waters and subsequent survival and abundance of salmonids.

In addition to natural upwelling and coastal currents that affect habitat conditions and food supplies for salmonids rearing in the ocean, commercial and recreational Chinook salmon harvest directly affects survival and abundance of Central Valley salmon (Williams 2006).

2.3 Risks from Predation by Non-Native Fish Species

A growing body of scientific evidence strongly suggests that predation of juvenile salmonids by the increasing numbers of largemouth bass and other non-native fish species in the Delta is a major factor contributing to reduced survival and abundance of Chinook salmon and Central Valley steelhead. A number of non-native predatory fish inhabit the Delta, including largemouth bass, striped bass, and sunfish. Fishery surveys are periodically conducted to collect data that can be used to assess general patterns in the abundance, size, distribution, and relative species composition of the Delta fish community. Relevant data are available from several time periods over the past 3 decades: 1980-83, 1995, 1997, and 1999, 2001-2003, and 2008-2010 (Conrad *et al.* 2010a). These fishery surveys differed from traditional midwater trawl sampling in that they used a boat-mounted electrofisher that sampled fish in areas near shorelines, adjacent to in-river structures, and where submerged aquatic vegetation (SAV) (e.g., *Egeria densa*) is common. In recent years, these surveys have been used to better document the relationship between SAV and non-native predatory fish (Feyrer and Healey 2003, Brown and Michniut 2007, Nobriga and Feyrer 2007, Nobriga *et al.* 2005).

These fishery survey results show an increasing abundance trend in largemouth bass and sunfish over the last three decades. These data show that sunfish abundance (catch per unit effort [CPUE]) increased from an average of 0.04 in 1980-1983 to approximately 0.11 in 2008-2010 (Figure 2-1).

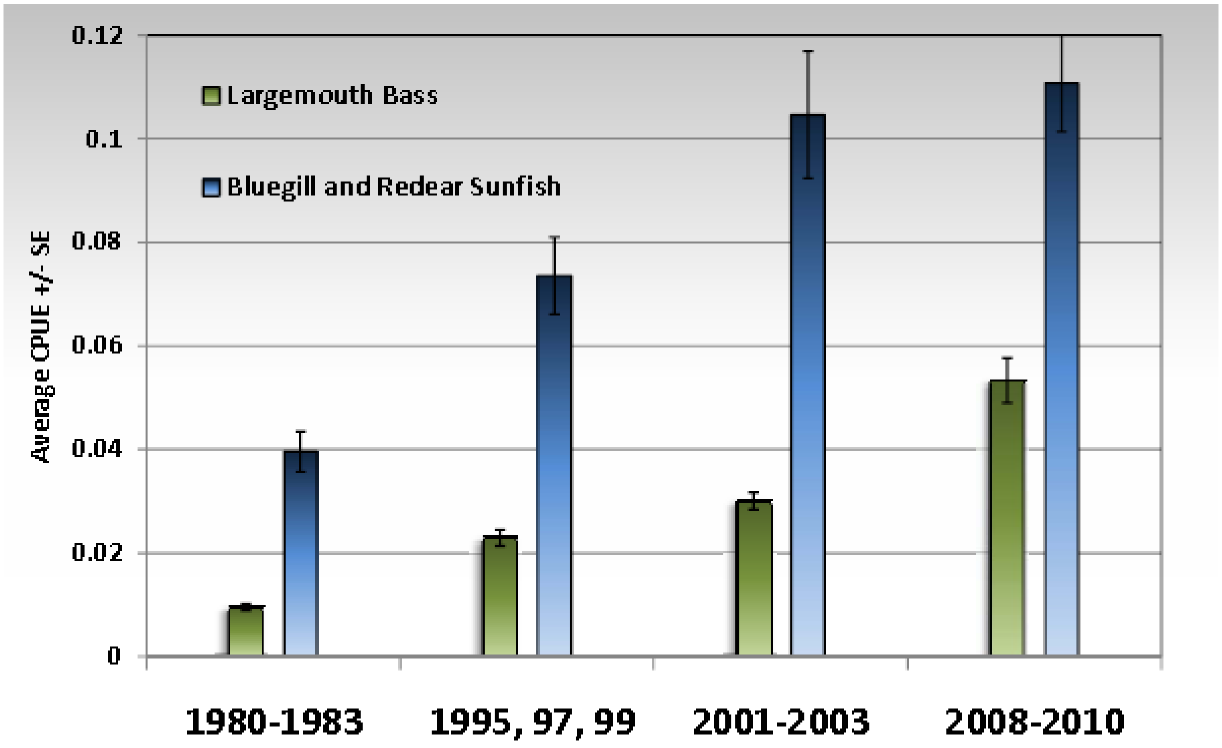


Figure 2-1. Trends in largemouth bass and sunfish abundance in the Delta (Source: Conrad *et al.* 2010a).

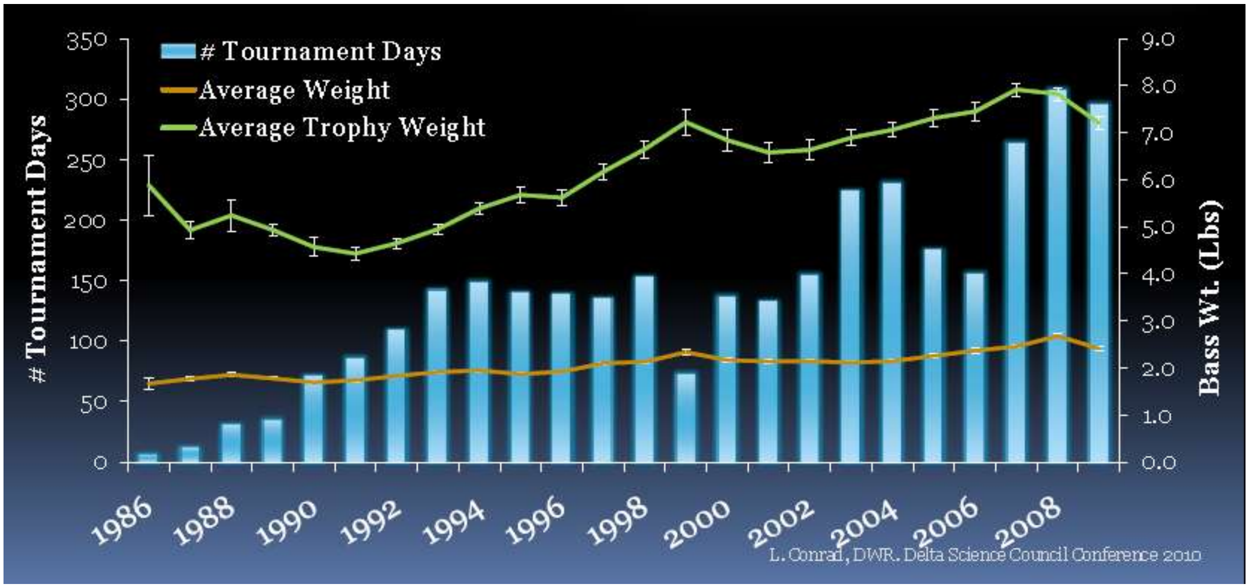
This represents a nearly 300 percent increase in sunfish abundance in the Delta in less than 30 years. Abundance trends for largemouth bass are even more stark; CPUE for the species in the 1980-1983 period averaged approximately 0.01, but increased to approximately 0.055 in 2008-2010 (Figure 2-2). This reflects a more than five-fold increase in abundance for the species in three decades. Fish salvage monitoring at the SWP and CVP export facilities has also shown a substantial increase in the number of largemouth bass collected in recent years, particularly since the early 1990s (Nobriga 2009).

Increased largemouth bass abundance observed in Delta fishery surveys is consistent with growing Delta bass tournament fishing days in the last 25 years (Figure 2-2). Bass fishing tournament days increased from fewer than 10 days in 1986 to approximately 300 days in 2008-2009 (Conrad *et al.* 2010b). That is, largemouth bass tournament fishing has increased by a factor of approximately 30 over the past 2 decades and now supports a major recreational fishery. The Delta is now considered a world-class largemouth bass fishery. Thousands of anglers fish Delta waters, and nationally televised (e.g., Bass Masters), as well as local and regional tournaments are conducted throughout the year.

In addition to the increasing trend in largemouth bass abundance, the fishery surveys also show that the size of largemouth bass inhabiting the Delta has increased significantly in the past decade (Figure 2-3). In particular, there has been a marked increase in the occurrence of bass larger than 300 mm between the 1995 and 2009 surveys. The increasing size of largemouth bass is also apparent in the escalating average weight of trophy bass caught in the Delta (Figure 2-2). The average size of trophy bass has increased from approximately 5 to 5.5 pounds in the late 1980s and early 1990s to nearly 8 pounds in recent years.

The increase in both bass abundance and size in recent years reflects the favorable habitat conditions (e.g., increased SAV), particularly in the central and south Delta. For example, the data appear to show that the increased amount of SAV within the Delta has created more usable cover and foraging habitat for largemouth bass and sunfish (Conrad *et al.* 2010a and b, Conrad *et al.* 2011). The increase in predatory fish abundance in the Delta appears to be primarily largemouth bass and sunfish. The striped bass population has fluctuated in abundance over the past several decades, but there is no evidence that striped bass abundance has increased sufficiently in the past decade to account for the observed decline in juvenile salmon survival.

Largemouth bass and sunfish typically inhabit lakes and areas with abundant structural cover (e.g., docks, woody debris, SAV, etc.) where flows and water velocities are reduced. Water clarity in the Delta, particularly in the spring (Figure 2-4), has increased, presumably resulting from a decrease in sediment inflow to the Delta, the effects of SAV on settlement of fine sediment, and a reduction in sediment re-suspension. These conditions have resulted in improved conditions over the past decade for site-oriented visual predators, such as largemouth bass, that may have increased their predation efficiency.



L. Conrad, DWR. Delta Science Council Conference 2010

Figure 2-2. Number of largemouth bass tournament days in the Delta and trend in average weight of trophy bass (Source: Conrad *et al.* 2010b).

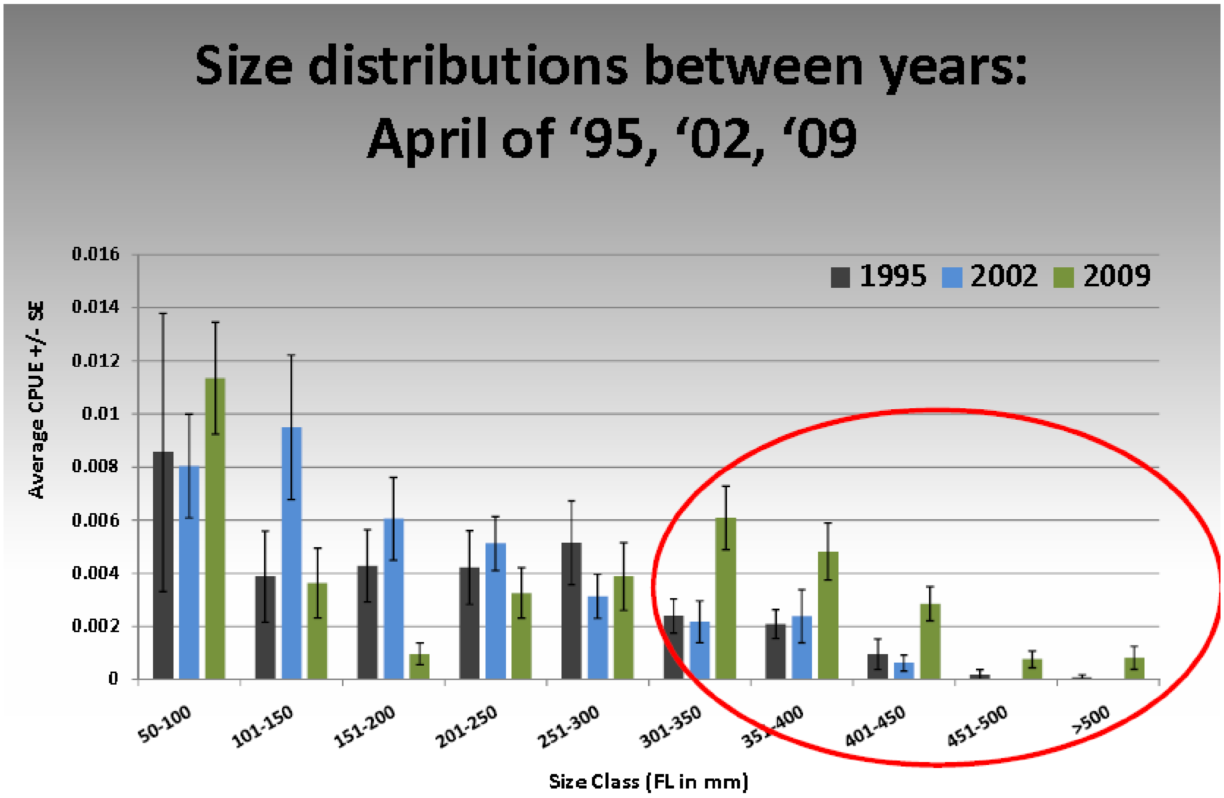


Figure 2-3. **Length frequency trends in largemouth bass collected in the Delta (Source: Conrad *et al.* 2010a).**

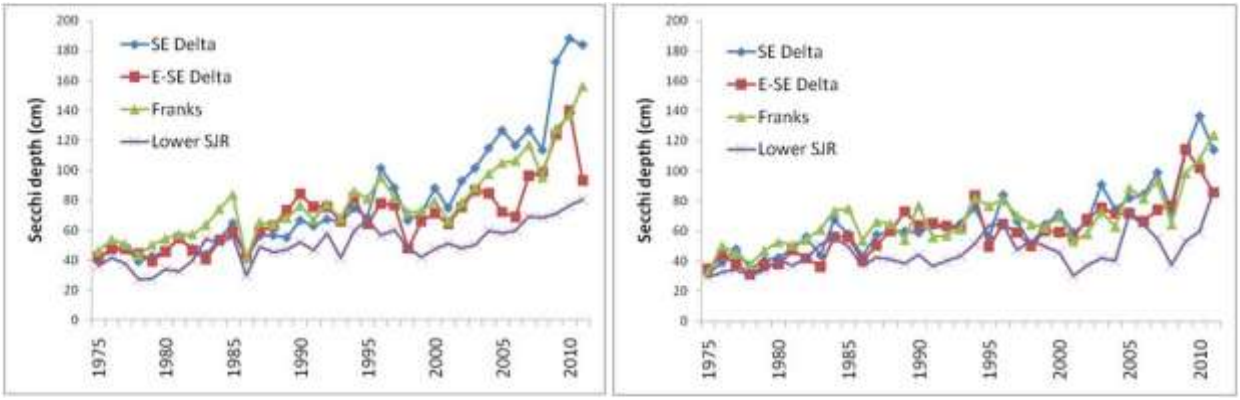


Figure 2-4. **Changes in water clarity in the Delta over time as measured by Secchi depth. Left panel represents average March-June conditions and right panel represents average July – October conditions (Source: SWC/SLDMWA 2012).**

It is well documented that larger bass prey primarily on crayfish and small fish (Conrad *et al.* 2010a), including salmonids. Largemouth and other bass, thus, represent a significant source of predation mortality for many of the forage fish inhabiting the Delta (e.g., juvenile Chinook salmon and steelhead, smelt, shad, and others).

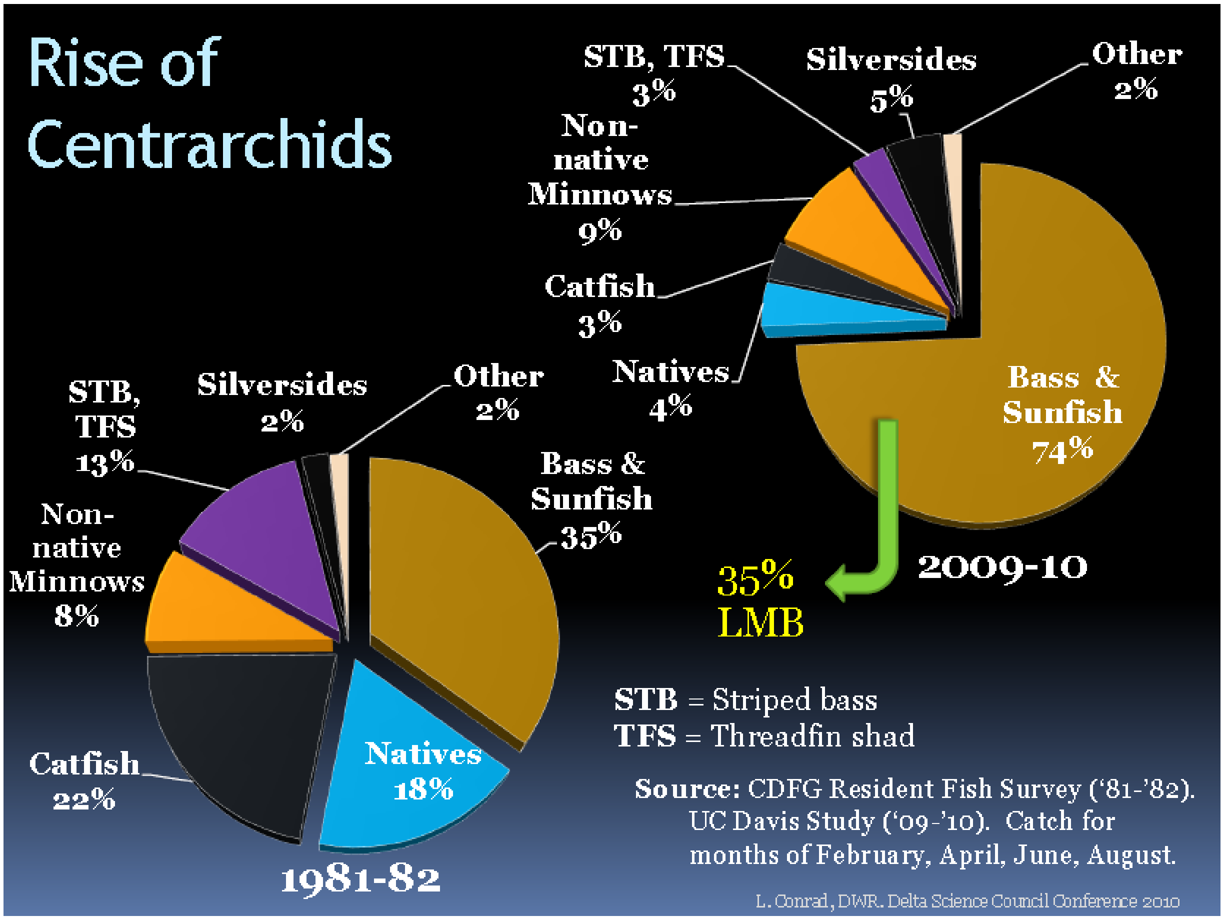
The increasing non native bass and sunfish abundance trend has contributed to a change in the Delta fish community's species composition. Fishery survey data show a trend of increasing abundance of non-native fish inhabiting the Delta (Figure 2-5). During surveys in 1981-1982 native fish comprised 18 percent of the fish collected. In recent years, the relative contribution of native fish to the Delta community has declined to approximately 4 percent, as reflected in surveys in 2009-2010. By contrast, the relative contribution of bass and sunfish to the Delta fish community doubled from about 35 percent in 1981-1982 to about 74 percent in the 2009-2010 surveys Largemouth bass represented 35 percent of the fish collected in the most recent surveys.

There is mounting scientific evidence, including the increasing trend in the abundance and size of largemouth bass inhabiting the Delta and observations of declining survival of juvenile salmon, that over the past decade predation mortality by non-native fish has become a major factor adversely impacting the survival and abundance of juvenile Chinook salmon and other native fish in the Delta. Predation mortality by striped bass and largemouth bass has been identified as a major factor reducing the survival of juvenile salmon and steelhead entering Clifton Court Forebay (Gingras 1997, Clark *et al.* 2009), at fish salvage release sites (Miranda *et al.* 2010), and at other locations within the Central Valley rivers and Delta such as the Head of Old River (Bowen *et al.* 2009, Bowen and Bark 2010).

2.4 Recommendations

As shown in this section (and in Section 2), a wide range of environmental and biological factors affect habitat quality and availability, reproductive success, growth, and survival of Central Valley salmonids, in addition to the magnitude and seasonal timing of flows. NMFS, therefore, has recommended that when evaluating the potential effects of various management strategies, focus should be placed on the needs of each salmonid species across its entire lifecycle, and how any proposed management action may positively or adversely affect habitat suitability, growth, survival, movement, and the overall population dynamics of the species of interest (NMFS 2010a).

Given the complex habitat conditions in the Delta that provide cover for predatory fish and the hydrologic conditions in the Delta dominated by tidal flows rather than Delta inflows, increased or minimum Delta inflows or outflows are unlikely to have any effect on the abundance or distribution of either largemouth bass or sunfish in the Delta. Increased Delta inflow would not be expected to change the seasonal temperature conditions in the Delta or other elements of largemouth bass and sunfish habitat.



Rise of Centrarchids

STB = Striped bass
TFS = Threadfin shad

Source: CDFG Resident Fish Survey ('81-'82). UC Davis Study ('09-'10). Catch for months of February, April, June, August.

L. Conrad, DWR. Delta Science Council Conference 2010

Figure 2-5. Change in fish species composition in surveys conducted in 1981-1982 and 2009-2010 (Source: Conrad *et al.* 2010 b).

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3 Existing Regulations Intended to Provide Protections and Habitat Enhancement

A number of regulatory requirements have been implemented to enhance and protect critical and essential habitat for Central Valley Chinook salmon, steelhead, and other aquatic resources within the Bay-Delta estuary and Central Valley rivers and tributaries. These regulations include, but are not limited to, actions by the State Water Resources Control Board, Central Valley and San Francisco Bay /Regional Water Quality Control Boards, NMFS, U.S. Bureau of Reclamation (Reclamation) Central Valley Project Improvement Act (CVPIA) requirements, California Department of Fish and Game (CDFG) agreements, Federal Energy Regulatory Commission (FERC) actions, Pacific Fisheries Management Council (PFMC) decisions, and other actions. (Table 3-1)

For example, SWRCB D-1641 limits SWP and CVP export rates during the salmon emigration period to not more than 65 percent of Delta inflow prior to February 1, and to not more than 35 percent of Delta inflow after February 1. D-1641 also requires that the Delta Cross Channel gates be closed beginning February 1 for the protection of juvenile emigrating salmon and steelhead and that the gates be closed for up to 45 days additional during the November through January period based on requests of the state and federal fishery agencies. In addition, the NMFS (2009) Long-Term Operational Criteria and Plan (OCAP) Biological Opinion limits direct losses of winter-run and spring-run Chinook salmon and steelhead as part of authorized levels of incidental take. These or similar take restrictions are expected to continue in effect until BDCP implementation is authorized.

Also, the Data Assessment Team (DAT), temperature task group and salmon decision tree management processes which currently provide a framework for assessing near real-time information on salmonid migration patterns, salvage, hydrodynamic conditions within the rivers and Delta for us in making adaptive management recommendations are expected to continue to protect and improve conditions for Central Valley salmonids.

In addition, over the past decade a significant number of habitat improvement and enhancement projects have been designed and implemented in Central Valley rivers and other aquatic habitats to benefit salmonids and other aquatic species as part of programs such as CALFED and the CVPIA Anadromous Fish Improvement Program.

Ongoing and completed actions have resulted in improvements to upstream and downstream fish passage, installation of state-of-the-art positive barrier fish screens on previously unscreened water diversions (e.g., Glenn-Colusa Irrigation District, RD108, RD1004, Sutter Mutual, and others), instream flow improvements, and physical habitat enhancement projects. The Red Bluff Diversion Dam (RBDD), which historically delayed or blocked salmonid migration to the Sacramento River’s upper reaches, is being replaced by a pumping plant and positive barrier fish screen. (Sacramento River Watershed Program 2012).

These and other projects benefit Central Valley Chinook salmon, steelhead, and their habitat through spawning gravel augmentation and habitat restoration, reduced risk of entrainment mortality through installation of fish screens on larger water diversion projects, and improved fish ladders and access to upstream spawning and rearing habitat provided by projects on Butte and Battle creeks, among others. Additional beneficial actions include improved access to seasonally inundated floodplains, channel margin habitat, tidal wetlands, hatchery management, harvest regulations and other actions to reduce stressors on salmonids.

Upstream enhancement projects are expected to continue throughout the interim period until BDCP implementation to improve salmonid habitat conditions and migration, and reduce and avoid entrainment losses at a numerous water diversion located along the Sacramento River by operating existing positive barrier fish screens. (BDCP is currently being developed as conservation actions intended to further reduce stressors on salmonids as well as improve habitat quality and availability.)

Ocean harvest restrictions intended to reduce adverse effects on Chinook salmon are also expected to remain in effect during the interim period.

Table B-1 in Attachment B summarizes many of the existing regulations and protections benefiting Central Valley salmonids and their habitat.

3.1 Considerations in Setting Future Regulatory Protections

Considering all stressors on salmonids and their habitats should influence the selection of appropriate management actions, including the determination of whether minimum instream flows or Delta outflows are appropriate. For example, delta smelt have a 1-year lifecycle, are limited in their distribution to the Delta, are subject to a wide variety of mortality sources, and have life history characteristics that increase their risk of jeopardy in response to short-term impacts. In contrast, species like Chinook salmon and steelhead live for 3 to 5 years or more, have multiple cohorts dispersed between freshwater and marine environments, have a wide geographic distribution, and have life history characteristics that reduce their risk of adverse impacts in response to short-term conditions (e.g., short drought conditions).

In assessing the risk of adverse impacts or benefits to salmonids at a population level resulting from a proposed management action or conservation actions, consideration should also be given to the duration of the action relative to the species’ lifespan and life history. In addition, one should consider the potential magnitude of the action’s effect on one or more lifestages, the geographic location of the potential effect relative to the distribution of all lifestages and population segments of the species, abundance of the species, including recent trends in cohort replacement rates, and the potential for cumulative impacts on the species. Applying lifecycle models and other analytic tools (Section 4) is key to effectively assess the potential for beneficial and adverse effects on salmonids in response to changes in water temperatures, habitat suitability for a given life stage in terms of water velocity and depth and other factors, access to suitable spawning and rearing habitat, and effects of river and tidal flows on survival during migration, harvest regulations, and other factors.

Table 3-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Shasta Division/Shasta & Keswick Dams	Sacramento River water temperature objectives	<56°F, April 1 – Sept. 30; <60 °F, Oct. 1 – 31 at Red Bluff Diversion Dam (RBDD)[1]	State Water Resources Control Board (SWRCB)
		< 56°F Keswick Dam to Bend Bridge with initial targets, based on May 1 Shasta cold water (<52°F) volume, as follows[2]: >3.6 MAF - Bend Bridge 3.3 - 3.6 MAF - Jellys Ferry <3.3 MAF - Balls Ferry	National Marine Fisheries Service (NMFS)
	Sacramento River Temperature Task Group (SRTTG)[3]	Convened to formulate, monitor & coordinate annual temperature control plans	SWRCB
	Shasta Reservoir target minimum end of year carry-over storage (1.9 MAF)	To increase probability that sufficient cold water pool will be available to maintain suitable Sacramento River water temperatures for winter-run Chinook the following year	NMFS
	Sacramento River flows (releases from Keswick Dam)	Minimum flows: 3,250 cfs October 1 – March 30	SWRCB, CVPIA
	Flow ramp down rates from Shasta Dam	Apply following schedule between July 1 and March 31[4]: • Reduce flows sunset to sunrise only • ≥6,000 cfs; < 15%/night and 2.5%/hour • 4,000 to 5,999 cfs; <200 cfs/night and 100 cfs/hour • 3,250 to 3,999 cfs; <100 cfs/night	NMFS
Red Bluff Diversion Dam	Gate operations	Gates raised from September 15 to May 14[5]	NMFS
	Sacramento River Water temperature objectives	<56°F, April 1 – Sept. 30; <60 °F, Oct. 1 – 31	SWRCB

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[1] Allows flexibility when water temperatures cannot be met at RBDD. Temperature management plan developed each year by the Sacramento River Temperature Task Group (SRTTG).

[2] Based on temperature management plan developed annually by the SRTTG.

[3] The SRTTG is composed of representatives of SWRCB, NMFS, FWS, DFG, Reclamation, WAPA, DWR & Hoopa tribe.

[4] Variations to ramping rate schedule allowed under flood control operations

[5] Provides flexibility to temporarily allow intermittent gate closures (up to ten days, one time per year) to be approved on a case-by-case basis to meet critical diversion needs. Reclamation will reopen the gates for a minimum of five consecutive days, prior to June 15 of the same year in a manner that will be least likely to adversely affect water deliveries.

Table 3-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Wilkins Slough	Navigation Flow Objective	Minimum of 5,000 cfs at Wilkins Slough gauging station on the Sacramento River; can relax standard to 3,500 cfs for short periods in critical dry years[6]	USBR
Oroville/Feather River Operations	Feather River minimum flows	600 cfs below Thermalito Diversion Dam when Lake Oroville elevation <733 ft MSL increasing to 1,000 cfs April through September if Lake Oroville elevation >733 ft MSL; Flows generals kept < 2,500 cfs August through April to avoid stranding salmonids	DWR & DFG Agreement
American River Division/Folsom & Nimbus Dams	American River minimum flow standards	Minimum 250 cfs January 1 to September 14 & 500 cfs September 15 to December 31 measured at the mouth of American River	SWRCB
	American River temperature objectives	Reclamation to develop, in coordination with the American River Operations Group and NMFS, annual water temperature control plan to target 68°F at Watt Avenue Bridge	NMFS
Eastside Division	Support of San Joaquin River requirements and objectives at Vernalis	Vernalis flow requirements February to June, Vernalis water quality objectives	SWRCB
New Melones Dam & Reservoir Operations	Flows for fish & wildlife; dissolved oxygen standards at Ripon	Release a minimum of 98,000 acre-feet of water to lower Stanislaus River below Goodwin dam	SWRCB & DFG
Delta Cross Channel	Gate Closures	Gates closed February through May, 14 days May 21 to June 15, 45 days November 1 to January 1 to protect Sacramento River salmonids	SWRCB
Tracy & Banks Pumping Plants	Pumping Curtailments	Protect listed salmonids; meet export/Inflow ratio, X2, delta outflow requirements	SWRCB; NMFS

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[6] While commercial navigation no longer occurs between Sacramento and Chico Landing, long-term water users diverting from the river have set their pump intakes just below a minimum flow requirement of 5,000 cfs at Wilkins Slough. Diverters are able to operate for extended periods at flows as low as 4,000 cfs at Wilkins Slough; pumping operations become severely affected and some pumps become inoperable at flow less than 4,000 cfs. While no criteria have been established for critically dry years, the standard can be relaxed to a minimum flow of 3,500 cfs for short periods to conserve water storage in Shasta Reservoir and manage for multiple project and environmental objectives.

Table 3-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Contra Costa Canal operations	Diversion rate limits, fish screens	Protect listed salmonids	NMFS
Ocean Salmon Harvest	All California ocean commercial and sport salmon fisheries are currently managed by PFMC harvest regulations	Conservation Objective = 122,000 to 180,000 natural and hatchery Sacramento River Fall Run Chinook (SRFC) salmon spawners[7] Ocean commercial and recreational harvest in the ocean was banned in 2008 and 2009	NMFS, California Fish and Game Commission, Pacific Fishery Management Council
Inland Salmon Harvest	Zero bag limit on the American River, Auburn Ravine Creek, Bear River, Coon Creek, Dry Creek, Feather River, Merced River, Mokelumne River, Napa River, San Joaquin River, Stanislaus River, Tuolumne River, Yuba River, and the Sacramento River except for a one salmon bag limit in the Sacramento River from Red Bluff Diversion Dam to Knights Landing from November 1 to December 31.	To protect fall-run Chinook salmon stocks starting in 2008	California Fish and Game Commission

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[7] The conservation objective has been set by the Pacific Fishery Management Council in the Salmon Fishery Management Plan.

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4 Lifecycle Modeling and other Analytical Tools

4.1 Introduction

Analytical tools are available that can be used to evaluate the predicted benefits of various management actions on salmonids' population dynamics and survival. These tools assess the relative contribution of various stressors to salmonid species. These tools allow comparative cost/benefit assessments for management actions. These tools can also be used to assess the relative importance of a stressor on the overall species' population dynamics and provide a framework for identifying and evaluating potential management actions.

Following is a brief discussion of available lifecycle modeling and analytical tools. A more detailed discussion of these tools will be submitted by SWC/SLDMWA in conjunction with the State Board's November 2012 Analytical Tools Workshop.

Lifecycle modeling can play a powerful role in evaluating the interrelationships among individual factors that give rise to broad patterns in population dynamics. Understanding the processes that produce such patterns is key to developing management principles (Levin 1992). Ruckelshaus *et al.* (2002) conclude that using better models in making management decisions is one obvious way to change how risks to salmon populations are managed.

Multiple efforts have been undertaken to develop effective models for Central Valley salmon. Williams (2006) classifies these models into two general categories: estimation models, which estimate parameter values by directly fitting the model to available data; and simulation models, which take parameter values from literature or other sources. An example of an estimation model is the Bayesian hierarchical state-space model developed by Newman and Lindley (2006), which incorporates multiple data sources to roughly predict juvenile out-migration based on data for juveniles from the preceding year. An example of a simulation model is the SALMOD model (Bartholow *et al.* 1997 Bartholow 2004), which combines information regarding run timing with fine-scale data regarding spatial and temporal variations in flow and temperature to define computational units which are then used to assess the effects of river flow and water temperatures on the production of Chinook salmon in the upper Sacramento River.

While the results of these earlier models have provided valuable insights, their narrow focus and limited geographic area reduce their utility in assessing the relative impact on overall population viability of actions at specific locations and affecting specific salmonid life stages (Rose *et al.* 2011, Zeug *et al.* 2012). A framework is needed for organizing the body of information regarding the impact of changes in environmental variables (e.g., flow, temperature, exports, harvest, and physical habitat), for quantifying the effects of these changes on the abundance of salmon at each life stage (e.g., development, migration, and maturation), and for evaluating the resulting impact on overall population viability. Lifecycle models provide such a framework. Both scientists and managers have increasingly recognized the utility of lifecycle models for evaluating salmon population responses to management actions (Ruckelshaus *et al.* 2002), and a recent review of salmon recovery efforts in California's Central Valley recommended their use (Good *et al.* 2007).

4.2 IOS Lifecycle Model

The Interactive Object-oriented Simulation (IOS) model has undergone extensive development and interagency review and is currently the only Central Valley Chinook salmon lifecycle model that has been published in the peer reviewed scientific literature (Zeug *et al.* 2012) and that has been specifically designed to incorporate life stages, geographic areas, and influencing factors at a scale closely matching those affected by alternative water management actions. The model was developed by Cramer Fish Sciences to simulate the interaction of environmental variables with all life stages of winter-run Chinook salmon in the Sacramento River, Sacramento-San Joaquin Delta, and Pacific Ocean. Fish behaviors modeled by IOS include emergence (eggs to fry), rearing, migration, and maturation (ocean phase). The IOS model dynamically simulates responses of salmon populations across these model-stages to changes in environmental variables or combinations of environmental variables in the geographical areas specified for each model-stage, and enables scientists and managers to investigate the relative importance of specific environmental variables by varying a parameter of interest while holding others constant; an approach similar to the testing of variables in a laboratory setting. The IOS lifecycle model estimates adult escapement, which is the primary key to population viability over time.

Figure 4-1 shows a map of the Sacramento River and Delta and the approximate geographic distribution of salmonid lifestages included in the IOS model.

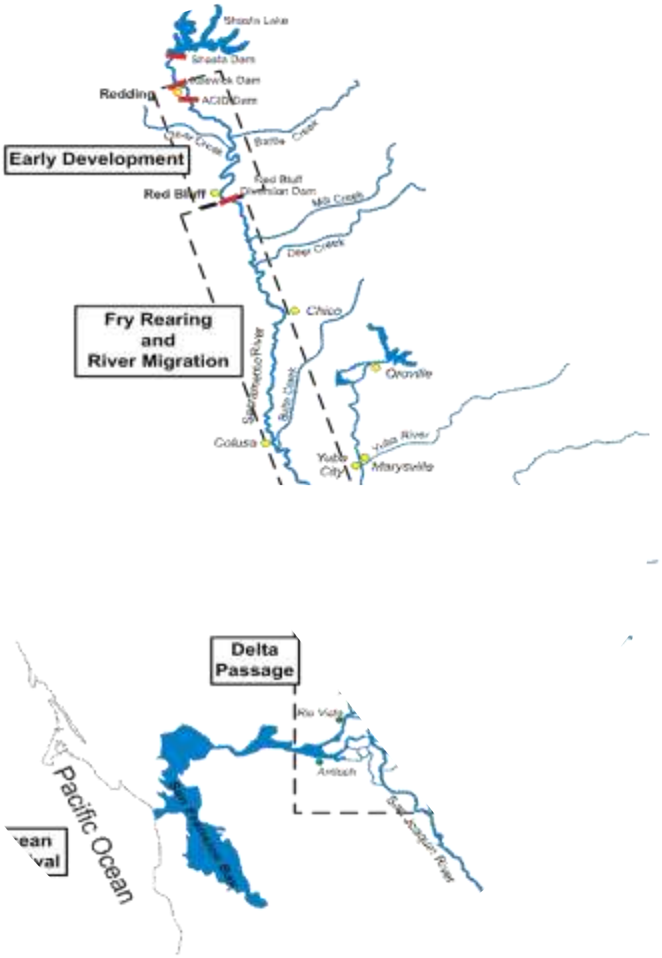

Figure 4-1. Map of the Sacramento River and the Sacramento-San Joaquin Delta, including approximate areas defined by model-stages.

4.3 Delta Passage Model

The Delta Passage Model (DPM) is a stochastic simulation model developed by Cramer Fish Sciences to evaluate the water management actions’ impacts and conservation measures on the survival of Chinook salmon smolts as they migrate through the Delta. The DPM is not a lifecycle model, but is incorporated as a sub-model in the IOS lifecycle model (described above), comprising the *Delta Passage* model-stage. A detailed DPM description is included in the peer reviewed IOS lifecycle model paper (Zeug *et al.* 2012). The DPM is also used as a stand-alone model to analyze Delta survival and routing.

The DPM simulates juvenile Chinook salmon smolt migration as they enter the Delta from the Sacramento River, Mokelumne River, and San Joaquin River, and estimates survival through the Delta to Chipps Island. The DPM comprises eight reaches and four junctions (Figure 4-2) selected to represent the primary salmonid migration corridors where fish and hydrodynamic data are available. The model can also provide survival estimates for specific reaches or life stages. The DPM can be used to inform which management actions likely have the most benefit for improving smolt survival, as well as locations in the Delta where such actions are likely to have the most benefit—a level of detail which aggregated estimates of survival through the Delta cannot provide. DPM model development has been made possible by the results of acoustic tagging studies, which have demonstrated repeatable migration routing patterns at junctions as well as different survival rates among routes.

The DPM uses the best available empirical data to parameterize model relationships and inform uncertainty, thereby utilizing the greatest amount of data available to dynamically simulate responses of smolt survival to changes in model inputs or parameters in the model. Figure 4-3 shows an example of the best available data used in the model. The DPM is primarily based on Sacramento Basin studies of late fall-run and San Joaquin basin studies of fall-run Chinook, but it has been applied to winter-run, spring-run, late fall-run, Sacramento fall-run, Mokelumne River fall-run, and San Joaquin fall-run Chinook salmon by adjusting emigration timing and by assuming that all migrating Chinook salmon smolts respond similarly to Delta conditions.

Although studies have shown considerable variation in emigrant size, with Central Valley Chinook salmon migrating as fry, parr, or smolts (Brandes and McLain 2001; Williams 2006), the DPM relies predominantly on data from acoustic tagging studies of large (>140 mm) smolts. Unfortunately, survival data is limited for small (fry-sized) juvenile emigrants due to the difficulty of tagging such small individuals. Therefore, the DPM should be viewed as a smolt survival model only, most applicable to large smolts (>140 mm), with the fate of pre-smolt emigrants not incorporated in the model.

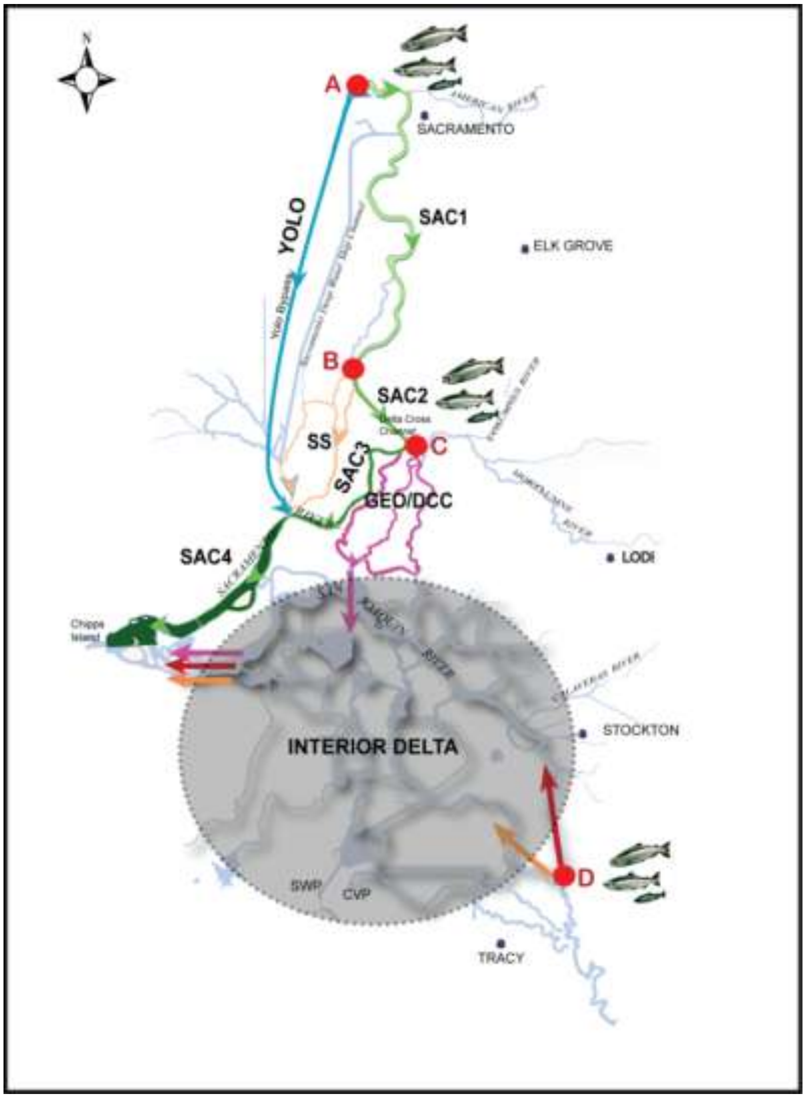

Figure 4-2. **Map of the Sacramento-San Joaquin Delta showing the modeled reaches and junctions of the Delta applied in the DPM. Bold headings label modeled reaches and red circles indicate model junctions. Salmon icons indicate locations where smolts enter the Delta in the DPM.**

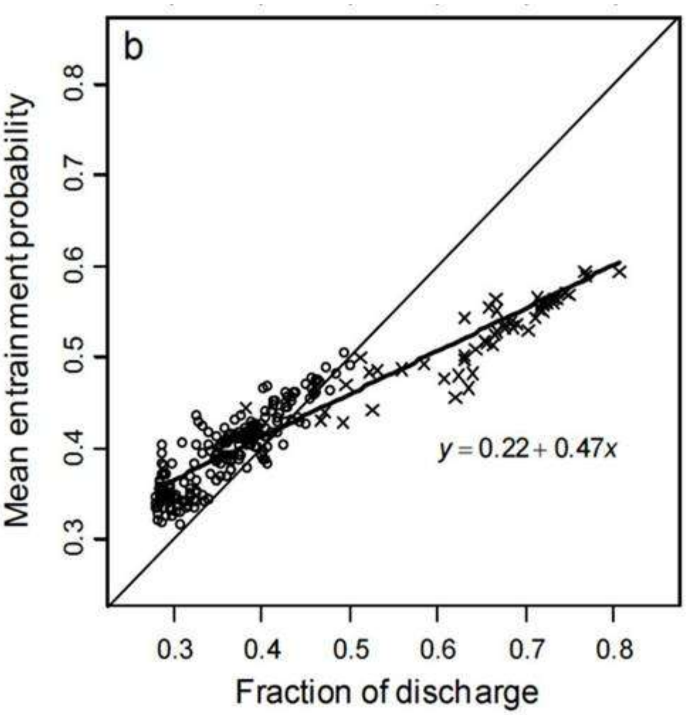

Figure 4-3. Figure from Perry (2010) depicting the mean entrainment probability (proportion of fish being diverted into reach Geo/DCC) as a function of fraction of discharge (proportion of flow entering reach Geo/DCC). In the DPM, this linear function is applied to predict the daily proportion of fish movement into Geo/DCC as a function of the proportion of flow movement into Geo/DCC. A circle indicates when the DCC gates were closed and X indicates when the DCC gates were open.

4.4 SALMOD Model

SALMOD simulates how habitat changes affect freshwater salmon population dynamics (Bartholow *et al.* 1997, Bartholow 2004). It was developed to link fish production with flow, as described by the Physical Habitat Simulation System (PHABSIM) model. SALMOD was used in the Biological Assessment (BA) for the National Marine Fisheries Service 2009 Salmon BiOp (USBR 2008), and is described in the BA as follows:

> "SALMOD simulates population dynamics for all four runs of Chinook salmon in the Sacramento River between Keswick Dam and RBDD. SALMOD presupposes egg and fish mortality are directly related to spatially and temporally variable microhabitat and macrohabitat limitations, which themselves are related to the timing and volume of streamflow and other meteorological variables. SALMOD is a spatially explicit model in which habitat quality and carrying capacity are characterized by the hydraulic and thermal properties of individual mesohabitats, which serve as spatial computation units in the model. The model tracks a population of spatially distinct cohorts that originate as eggs and grow from one life stage to another as a function of water temperature in a computational unit. Individual cohorts either remain in the computational unit in which they emerged or move, in whole or in part, to nearby units. Model processes include spawning (with redd superimposition), incubation losses (from either redd scouring or dewatering), growth (including egg maturation), mortality due to water temperature and other causes, and movement (habitat and seasonally induced). SALMOD is organized around physical and environmental events on a weekly basis occurring during a fish's

> biological year (also termed a brood year), beginning with adult holding and typically concluding with fish that are physiologically “ready” to begin migration towards the ocean. Input variables, represented as weekly average values, include streamflow, water temperature, and number and distribution of adult spawners” (USBR 2008, p.9-25).

SALMOD does not simulate the influence of environmental variables on salmonid population dynamics during the river migration, Delta migration, or ocean maturation phases of the salmonid life cycle. Thus, SALMOD is not used to estimate adult escapement; the primary key to population viability over time. The life stages and geographic areas addressed by SALMOD are contained and described in the IOS lifecycle model using similar functional relationships.

4.5 OBAN Model

The Oncorhynchus Bayesian Analysis (OBAN) is a statistical model developed by Hendrix (2008) and used to quantify uncertainties in potential outcomes and long-term population viability due to variations in environmental conditions, but not to compare population effects at the spatial and temporal scale of specific management actions. OBAN is described in a recent NMFS review of salmon lifecycle models (NMFS 2012) as follows:

> OBAN is a statistical life cycle model that includes life stages based on a Beverton-Holt function. OBAN defines the transformation from one life stage to the next in terms of survival and carrying capacity. Unlike the mechanistic models, it does not consider the timing of movement between stages or habitats. Additionally, the survival and carrying capacity parameters are determined by a set of time varying covariates. There is no specific mechanistic relationship between the parameters and the survival and carrying capacity. The weighting terms for the influence of environmental covariates on the Beverton-Holt functions are established by fitting the model to spawner recruit data. (NMFS 2012, p.5).

Unlike the IOS lifecycle model, OBAN does not compare population effects at the spatial and temporal scale of specific management actions. Also, the OBAN model has not been published in a peer reviewed scientific journal, and no detailed description of model relationships or coefficients is currently available.

4.6 NMFS Lifecycle Model

NMFS has recently proposed developing a new lifecycle model for Central Valley salmonids. After holding a June 2011 Independent Panel Workshop in which existing lifecycle models were reviewed (Rose *et al.* 2011), NMFS concluded that none of the existing models was sufficiently well suited for use in supporting the OCAP and BDCP Biological Opinions. An important consideration in this decision was the perceived need for complete ownership and control of the model (NMFS 2012). To that end, NMFS proposed the development of its own lifecycle model for winter-run Chinook. The proposal was completed in February 2012 and conveyed to Reclamation and the California Department of Water Resources (DWR) in March 2012. The initial model is to be completed and available for use by NMFS to evaluate OCAP Reasonable and Prudent Alternatives (RPAs) by December 2013. NMFS’ approach to the new lifecycle model is summarized in the proposal as follows:

> The NMFS lifecycle model needs to be able to translate the effects of detailed water project operations into population effects. There are at least two ways this might be approached: (1) a brand-new coupled physical and individual-based biological simulation model or (2) linking existing physical models to a population-level stage-structured lifecycle model through state-transition parameters that are a function of the environment (as described by the physical models). We are pursuing the latter strategy because we

> are more certain it will yield useful products in time for the OCAP and BDCP processes, and because it will be easier to analyze, understand and explain model outputs.
>
> Our work will proceed on four fronts—development and refinement of the lifecycle modeling framework; application, improvement and integration of physical models; development of linkages between physical model outputs and stage-transition parameters; and assembly of data sets needed to determine the physical-biological couplings and assess overall model performance. Periodically, we will integrate work in these four areas to produce assessment tools ("lifecycle models") that can address increasingly complex management scenarios. Along the way, we will work with interested parties (especially agency staff responsible for the Biological Opinions) to guide development, through periodical workshops and webinars. We will deliver working models, analyses of select scenarios, documentation, and peer-reviewed publications (NMFS 2012, p.3).

At this time, the NMFS lifecycle model is under development; the lifecycle model is at least a year or more from completion. As a result, the use of available models such as IOS is necessary for the current evaluation and planning of management actions, and to provide important feedback for the development and use of future models such as the NMFS lifecycle model.

4.7 Recommendations

Central Valley salmonids have a complex and diverse life history. Many factors affect the species' reproductive success, growth, health, survival, and abundance. Lifecycle models provide a tool for assessing the relative importance of various factors on the abundance of adults as reflected through beneficial and adverse effects of stressors at each life stage. Lifecycle models for salmonids have been developed for use in evaluating the predicted effects of alternative management actions and climate change on the population dynamics of salmon in the Pacific Northwest and elsewhere (Scheuerell *et al.* undated, Rivot *et al.* 2004, Crozier *et al.* 2008, Kope *et al.* undated, Noble *et al.* 2009). These models provide an analytical framework for applying the best available scientific information to determine a given life stage response to a management action or environmental condition. Lifecycle models can also help identify future monitoring and necessary experiments to improve model assumptions and functional relationships. Advanced modeling tools currently exist, and additional tools are being developed and refined, that can and should be applied to the effects analysis of any proposed management actions on the population dynamics of Central Valley salmonids.

The State Board should thoroughly and carefully apply the best available scientific tools when it evaluates the potential efficacy of proposed management actions under consideration, including flow requirements.

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5 The Biological Effects on Salmonids of a Natural Flow Regime in the Sacramento River

The State Water Board's 2010 Flow Criteria Report (SWRCB 2010) identifies a percentage of natural (unimpaired) flows as an approach to improving conditions for salmonids and other aquatic resources in the Bay-Delta estuary. This section discusses historic conditions related to flows, current conditions, and the modeled impacts of a natural or unimpaired flow approach on salmonids.

We incorporate by reference the discussion in Section 6 (pp. 6-1 to 6-8) of the SWC/SLDMWA written comments submitted for Workshop 1. In brief, those comments explain the differences between unimpaired flows and natural flow, confirm that variability in flows in the post-Project period is generally greater than pre-Projects, describe the biological functions of natural flows (including the findings that flow regimes typically confound other environmental factors), that the relationship between flows and species abundance is generally subject to significant uncertainty, particularly in estuaries, and that reservoir releases cannot restore the functionality of the highly altered Delta. Reservoir releases typically have relatively low turbidity and do not provide the functions that natural stormwater runoff from a watershed served in providing a range of flow, temperature, and turbidity cues that stimulate salmonid migration and other processes.

5.1 Natural Flow: Historical Context

Historically, Central Valley salmonids evolved and adapted to natural flow conditions and the associated changes in seasonal water temperatures that would potentially affect each life stage. Winter-run Chinook salmon that hold as adults in rivers during the late winter, spring, and summer months prior to spawning had access to high elevation habitats in the upper reaches of the watershed where water temperatures were cool throughout the year. These upper watershed areas provided suitable habitat for holding adults, spawning, egg incubation, and juvenile rearing (Williams 2006).

Steelhead and spring-run Chinook salmon also accessed high elevation habitat prior to the construction of the major rim dams. Fall-run Chinook salmon migrated upstream later in the fall when seasonal water temperatures were declining. Spawning and egg incubation occurred, and continues to occur, during the late fall and winter when temperatures are naturally cool. These lower temperatures also provided suitable habitat further downstream at lower elevations in the valley floor. As a result of construction of major rim dams such as Shasta and Keswick, winter-run, other salmon runs and steelhead no longer have access to suitable habitat located in the upper reaches of the Central Valley watershed. Instead, the species are now restricted to lower elevation valley floor habitat where suitable water temperature conditions are maintained through reservoir storage and management to provide seasonal cold water releases to meet the temperature requirements of these species through their freshwater life stages.

From a habitat perspective, in Central Valley rivers such as the Sacramento, Feather, American, Mokelumne, Merced, Tuolumne, and Stanislaus rivers, major habitat modifications occurred as a result of dam construction for flood control and water supply. Farther downstream in the Sacramento and San Joaquin river channels, modifications in the form of levee construction, channelization, and bank protection using rip-rap has further altered habitat conditions and affected how salmonids respond to changes in flow. For example, historically, increased streamflow in response to natural runoff during the winter and spring months resulted in seasonal inundation of shallow channel margin habitat, floodplain, and tidal wetlands (Figure 5-1). These areas provided juvenile salmonids with rearing habitat, cover and protection from predators, and increased food resources. These habitat functions are now mostly lost or substantially diminished for Central Valley salmonids. Figure 5-2 shows a cross section through a channelized and leveed reach of the Sacramento River where a substantial increase in river flow (e.g., an increase of 10,000 cfs in this example) results in a very minimal increase in the quality or availability of suitable habitat for juvenile rearing or migrating salmon or steelhead. Habitat modification is therefore a major factor to consider when evaluating unimpaired flow effects on management strategies for Central Valley salmonids.

5.1.1 Current Conditions, with a Focus on Coldwater Pool Management and Winter-Run

Winter-run Chinook salmon currently have a single population that relies on the upper Sacramento River immediately downstream of Keswick Dam for adult holding, spawning and egg incubation, and for juvenile rearing habitat. With only one population, winter-run salmon have an increased risk of adverse population effects (e.g., jeopardy of extinction) when compared to species with multiple independent viable populations that are geographically dispersed throughout Central Valley rivers. High mortality of pre-spawning-adults, incubating eggs, or rearing juveniles in any given year has the potential to eliminate one complete year class from the winter-run salmon population. The loss of all or a major part of one year class of winter-run salmon will adversely impact recovery of the species, as illustrated by the decline in adult abundance observed in 2007 in response to poor ocean-rearing conditions. The depletion of reservoir storage and coldwater pool volumes during the summer has potential adverse effects on winter-run, not only in the first year, but also for carryover storage in following years, particularly if conditions are dry in those following years. Thus, depletion of coldwater pool volumes in one year could be disastrous for winter-run abundance and upstream habitat, particularly if the following year is dry.

Adult winter-run salmon spawn in the Sacramento River during the summer months when air temperatures in the Redding area are typically hot. Spawning and egg incubation continue to occur through the summer months. Salmon eggs are the most thermally sensitive lifestage, with exposure to water temperatures above 57 F (13.9 C) resulting in a rapid increase in egg mortality (Boles 1988). Management of reservoir storage and coldwater within Shasta Reservoir represents a major factor affecting the hatching success and subsequent abundance of winter-run Chinook salmon (NMFS 2010a). In the event that coldwater is depleted from Shasta Reservoir prior to fry emergence, mortality would be expected to increase rapidly as water temperatures increase above 57 F (BDCP 2010, NMFS 2010a, Williams 2006).

Under current regulation, reservoir storage is actively managed to maintain coldwater for release during the summer to meet the temperature requirements for incubating winter-run salmon eggs (see Section 3). Even under current coldwater pool management and release conditions, the hydrology regime needed to support salmonid spawning and rearing in the upper watershed has sometimes proven difficult to achieve despite active modifications to the management strategy on a near real-time basis during the summer and fall months.

5.1.2 Assessing the Potential Biological Effects on Salmonids of Alternative Natural Flow Management

The SWRCB (2010) and others have expressed interest in developing alternative flow management strategies intended to benefit Central Valley salmonids and other aquatic resources. Mimicking natural flow patterns has been proposed by several investigators as a method for maintaining flow functions for fishery habitat (Poff *et al.* 1997, Richter *et al.* 1996, Poff and Zimmerman (2010). Altering the instream flow releases from upstream reservoirs to mimic natural flow regimes, however, has the potential to result in adverse effects on fish and their habitat. Assessing the effects of modifications to flow regimes on various fishery resources requires consideration of changes in hydrologic conditions (instream flows, ramping and potential for dewatering and stranding) as well as changes in reservoir storage and coldwater pool available to meet downstream temperature requirements for salmonid adult holding, spawning and egg incubation, juvenile rearing, and migration. Experience gained over the past decade in assessing potential habitat changes for proposed projects such as BDCP have resulted in development and refinement of a variety of analytical tools that will be the subject of discussion in Workshop 3.

Preliminary hydrologic modeling of potential changes in upstream reservoir storage and instream flows has been performed by MBK Engineers (2011), Water and Power Policy Group 2012, and HDR *et al.* 2011. Preliminary results suggest that there is a potential to substantially alter reservoir storage dynamics and instream flows through altered flow regimes that would adversely affect salmonids. Results of these analyses show that reservoir storage at Shasta, Oroville, Trinity and Folsom Reservoirs may be substantially impacted by winter and spring releases under the unimpaired flow conditions when compared to current operations. The average change in carryover storage and the percentage of years when the storage at each of the four reservoirs would be at dead pool under the three unimpaired flow regimes examined in these analyses would significantly increase.

Reductions in coldwater pool storage and the increased frequency of reservoirs reaching dead pool—in some cases potentially over a number of consecutive years--would expose salmonids to elevated water temperatures, reduce instream flow and physical habitat, likely lead to high mortality and stress for salmonids inhabiting areas downstream of each of the dams, and ultimately reduce population abundance and increase the species' risk of extinction. These conditions would be expected to adversely affect winter-run, spring-run, fall-run, and late fall-run Chinook and steelhead downstream of Shasta and Keswick dams, spring-run and fall-run Chinook and steelhead on the Feather River, fall-run Chinook and steelhead on the American River, and all salmonids inhabiting the Trinity River.

Impacts would also be expected for coldwater resident fish such as rainbow trout downstream of the dams. As a result depleting reservoir storage, impacts would also be expected to habitat and abundance of resident fish such as bass, crappie, bluegill, catfish, kokanee, and trout that inhabit upstream reservoirs. Additional application of hydrologic simulation models, in combination with water temperature modeling and salmonid population modeling (e.g., SALMOD, DPM, IOS), would be required to fully and quantitatively evaluate the frequency, magnitude, and population benefits and impacts of these conditions to each of the salmonids inhabiting Central Valley rivers.

Future changes in climate that result in greater seasonal air temperatures would make the expected adverse impacts of higher water temperatures even more severe on salmonids This could conceivably lead to a greater risk of adverse population level impacts on salmonid spawning, egg incubation, juvenile rearing, and adult holding in reaches of Central Valley rivers under the unimpaired flow regime than predicted in these analyses and contribute to a substantial increase in the risk of significant adverse impacts to salmonids in the future when compared to current reservoir and instream flow operations.

Further, high releases of flow under the unimpaired flow strategy during the winter and spring months would not only deplete reservoir storage and coldwater pool volumes, it would also lead to significant reductions in instream flows later in the summer, and during the fall and early winter. That is, releasing higher volumes of stored water in the winter, spring, and early summer months not only reduces coldwater storage, it also depletes the volumes of water available for release in later months. The resulting reduced river flows in the fall and early winter months—before the precipitation season ordinarily brings more water to the system—would further contribute to reduced salmonid habitat quality and availability for those lifestages that over-summer in the upper reaches of the river, such as rearing juvenile steelhead.

Reduction in instream flows in the summer and fall would reduce habitat quality and availability (reduced water depth and velocity) for pre-spawning adult winter-run and spring-run Chinook salmon holding in the Sacramento River downstream of Shasta and Keswick dams, as well as for pre-spawning holding habitat for spring-run salmon adults on the Feather and Trinity rivers. Reduced flows in the fall months

(September – December) would adversely impact habitat and temperatures for fall-run Chinook salmon spawning and egg incubation on the Sacramento, Feather, American, and Trinity rivers. Reduced summer and fall flows would also be expected to impact habitat and seasonal water temperatures for oversummering juvenile steelhead on the Sacramento, Feather, American, and Trinity rivers. A reduction in summer and fall flows would also impact habitat conditions in the rivers for resident rainbow trout and other fish species.

Flow reduction in the summer and fall months would not only impact physical habitat conditions (wetted cross section, water depths and velocities) for salmonids, it would also further exacerbate species exposure to elevated water temperatures later in the summer and fall months when juvenile lifestages of salmon and steelhead are present in the rivers. Although increased river flows in the winter and spring under the unimpaired flow strategy may provide benefits to some species and lifestages for fish (e.g., juvenile salmon and steelhead migration in the winter and spring, Delta outflows for pelagic species further downstream in the estuary), increased flow releases and depletion of coldwater pool storage and reduction in stream flow during the summer and fall months would result in adverse impacts to other salmonid species, including the increased potential for high mortality of all naturally-reproducing salmon and steelhead populations inhabiting the Sacramento River basin and a high risk of extinction of winter-run Chinook salmon that currently only inhabit the Sacramento River mainstem.

These preliminary model analyses regarding potential impacts to coldwater pool volumes, as well as the effects analyses for BDCP and other potential water project operations, illustrate the value of using models such as CALSIM to examine expected changes in flows and reservoir operations that could occur under an altered hydrologic regime. These hydrologic models can be used to examine changes in reservoir storage, the effects of changes in carryover storage over multiple years, and changes in river flows over wide ranging conditions. Hydrologic model results can then be integrated with water temperature simulation modeling to determine seasonal changes in the water temperature conditions at various locations downstream of major dams. Water temperature modeling results then provide the input for assessing changes in salmonid egg mortality (e.g., USBR egg mortality model) and rearing habitat for juvenile salmonids (e.g., SALMOD). Results of these models also provide input for juvenile survival models (DPM) and for lifecycle models (e.g., IOS) that can be used to further assess potential effects of a change in flow regimes on salmonid habitat and population dynamics. These models can also be modified to assess the potential incremental and cumulative effects of future climate change scenarios on Central Valley salmonids.

Given the potential for modifications to Sacramento River winter – spring flows to adversely impact upstream habitat for all species of Central Valley salmonids, resident coldwater species, and species inhabiting the reservoirs, detailed qualitative analysis of potential adverse impacts to salmonids is required as part of the evaluation of any proposed increased flow regime. Operation conditions effects on the expected survival, reproduction, abundance, and risk of extinction for all Central Valley salmonids must be examined in detail.

Given the anticipated adverse outcomes to salmonids associated with increasing releases and reducing coldwater pool volumes, we believe a management option other than a rigid increased flow strategy is required. A conservative approach should be established to protect the greatest number of winter-run eggs and subsequent habitat conditions for juvenile winter-run. Spring-run and fall-run spawning and steelhead rearing conditions should also be protected. An appropriate alternative management strategy may include reducing reservoir releases during the winter and spring months to conserve the coldwater pool for as long as possible, recognizing that a reduction in releases will result in a reduction in the area of suitable habitat downstream below Keswick Dam (e.g., the 11-mile reach to Clear Creek), the Feather River downstream of Oroville Dam, the American River downstream of Nimbus Dam, and on the Trinity River.

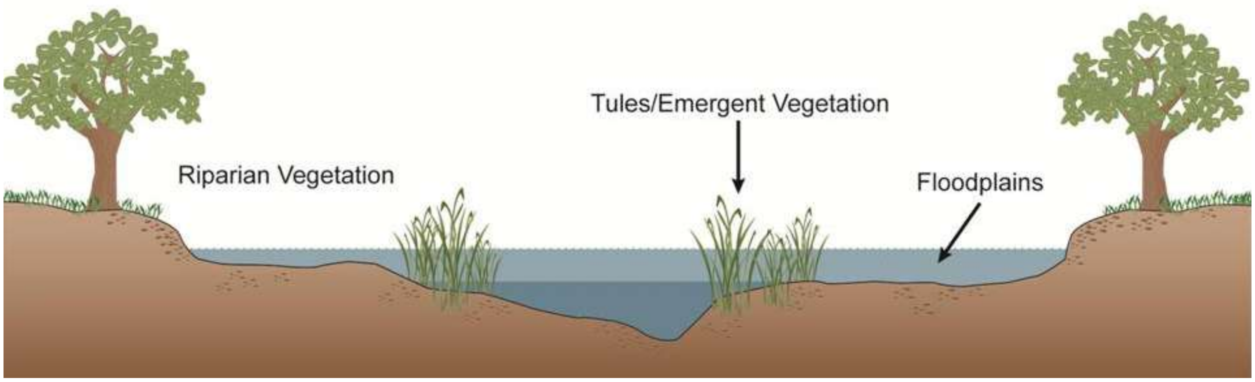

Figure 5-1. **Cross section through a natural (historic) Sacramento River channel showing the change in habitat as a function of changes in river flow.**

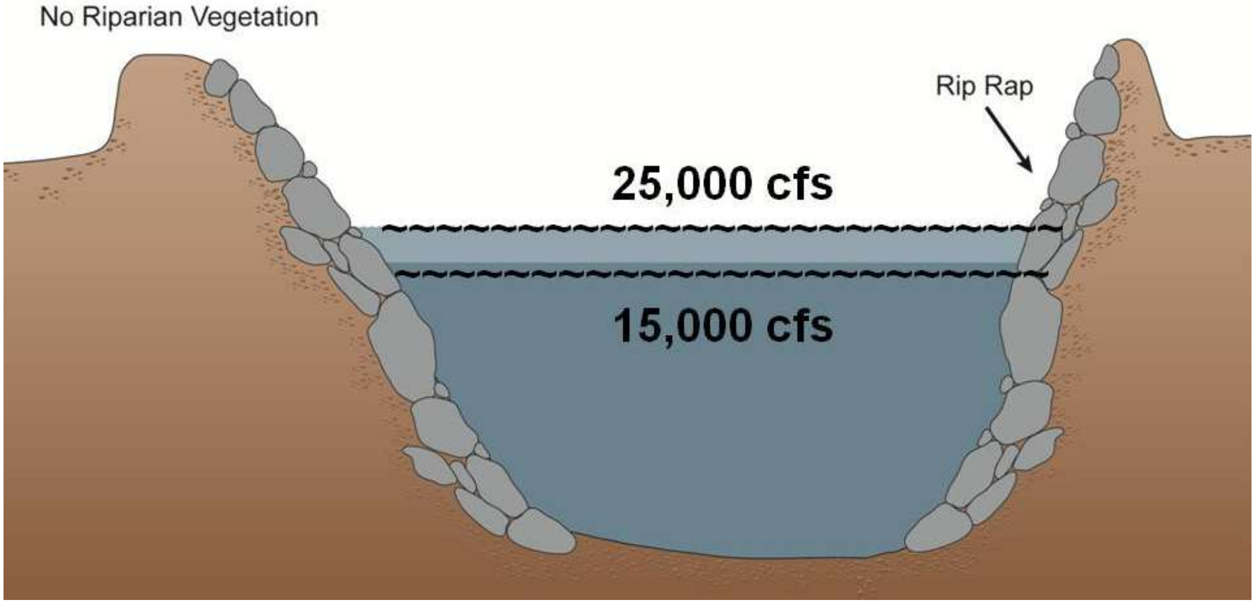

Figure 5-2. **Cross section through a channelized reach of the Sacramento River showing the change in habitat as a function of changes in river flow.**

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6 Linkage between River Flow and Salmonid Survival

Over the last twenty-five years numerous studies have been conducted in the Sacramento and San Joaquin river systems and in the Delta to examine migration pathways, migration rates, and survival, and to investigate how changes in river flows affect juvenile salmonids migratory processes (e.g., Kimmerer 2008; Blake *et al.* 2012; Newman and Rice 1988, 2002; Newman and Brandes 2009; Baker and Morhardt 2001, Newman 2008; Brandes and McLain 2001; Perry 2010; Michel 2010; SJRGA 2011). Ongoing acoustical tag investigations are currently examining juvenile salmonids and steelhead movement patterns in response to river flow and to tidal hydrodynamics within the Delta (e.g., 2012 Stipulation Study, Six-Year Steelhead Survival Study, NMFS Sacramento River acoustic studies, etc.). These studies, which are discussed in greater detail in Sections 7, 8, and 9 indicate that:

- The relationship between river flow and juvenile salmonid survival is weak (large changes in river flow are needed to achieve even a small change in salmonid survival).
- Factors other than flow, including exposure to elevated water temperatures and predation, impact survival and reduce potential benefits of changes in river flows.
- Hydrologic conditions in the Sacramento River provide good conditions for juvenile salmon migration, including continuing seasonal flow pulses that serve as migration cues.
- Salmon survival in the San Joaquin River has declined over time independent of river flow, apparently due to increased predation mortality.
- Tidal hydrodynamics are important for migration and survival of juvenile salmonids in the Delta. Greater upstream flow releases will not overcome this tidal influence.
- Increasing seasonal flow alone will not restore many of the functions that the rivers and Delta provided historically (e.g., increased access to suitable rearing habitat in channelized reaches, etc.).
- Newly developed analytical tools are improving our ability to track juvenile salmonids and to better understand their movements and needs.
- The Particle Tracking Model (PTM) is not an appropriate tool for evaluating juvenile salmonid behavior.

6.1 General Significance of River Flows for Salmonids

River flows support a variety of important functions for salmonids (Section 5). River flow and associated olfactory parameters serve as the environmental cues for adult salmonid attraction and upstream migration to natal spawning habitat. Instream flows are needed to provide sufficient water depths for adult upstream passage and adult holding in the river’s upper reaches prior to spawning (Williams 2006). River flows also help to regulate water temperatures in the river’s upper reaches, which currently provide suitable habitat for adult salmonid holding, spawning and egg incubation, and juvenile rearing (Boles 1988).

As a result of exposure to seasonally high air temperatures and solar radiation, particularly during the spring, summer, and fall months, water temperatures increase as a function of distance traveled downstream of a dam until thermal equilibrium is reached with atmospheric conditions. That is, once water temperature reaches thermal equilibrium in given atmospheric conditions, increasing flow does not result in a decrease in water temperatures. For example, water temperatures in the Delta during the spring period of juvenile salmonid migration are in thermal equilibrium with then-existing atmospheric conditions. As a result, and particularly in light of the distance between reservoirs and the Delta, increased releases of water from upstream reservoirs will not result in a decrease in water temperature in the Delta (Deas and Lowney 2000).

Future climate change could lead to even more elevated Central Valley water temperatures, resulting in exposing various salmonid lifestages to higher water temperatures, which would contribute to increased mortality and reduced health and abundance of salmonid species. As discussed in Sections 5, reservoir storage levels and current coldwater pool management have been important elements in maintaining suitable habitat conditions for salmonids in many Central Valley rivers, particularly under dry and critically dry hydrologic conditions (NMFS 2010a, USBR 2008).

River flow provides water depth, velocity, and wetted channel that are attributes of salmonid habitat in the upper reaches of Central Valley rivers downstream of impassable dams. Flows can provide for suitable dissolved oxygen levels, for the flushing of fine sediments that deposit on gravels used for spawning, and as a substrate for macroinvertebrate production that provides food for rearing juvenile salmonids. Flows are also needed to provide sufficient water depths for adult spawning as well as to provide interstitial flows through gravels to provide oxygen and remove metabolic waste from incubating salmonid eggs. If flows are reduced after a salmon redd has been formed and eggs deposited, the risk of dewatering the incubating eggs and egg mortality can increase. In contrast, if river flows are too high during egg incubation, gravel and eggs and alevins may be scoured out of the redd, resulting in salmon mortality (Williams 2006).

Flows also provide the transport mechanism for delivering macroinvertebrates and zooplankton downstream to areas where food is accessible to juvenile salmonids. However, if water velocities are too great, habitat quality within the river for juvenile rearing, especially fry, may be reduced (USFWS 1986). If flows and water levels fluctuate substantially, there may be an increased risk that juvenile salmonids will be stranded in unsuitable habitats as flows recede. This could result in mortality associated with exposure of salmon to elevated water temperatures, desiccation, and predation by birds and other wildlife.

6.1.1 Flow Levels: A Balancing Act for Salmon

Instream flow and habitat quantity is needed for salmon adults, spawning and egg incubation, and juvenile rearing within the Central Valley rivers' upper reaches and is dependent on numerous factors that frequently change over time, including stream gradient, substrate, geomorphic characteristics, and water temperatures. Too much flow can result in decreased habitat quality and availability, just as too little flow may reduce habitat conditions for various lifestages of salmonids (USFWS 1986).

On balance, imposing inflexible minimum Delta inflow or outflow requirements that require greater reservoir releases is likely to adversely impact salmonids. Requiring increased instream flows for downstream purposes may result in degrading river habitat conditions for salmonids (e.g., higher than suitable water velocities) as well as depleting reservoir storage and coldwater pool reserves needed to maintain suitable temperature conditions for salmonids during the spring, summer, and fall in upstream habitat areas. As discussed in Section 5, flow regimes that deplete coldwater pool storage and/or substantial seasonal fluctuation in instream flows, such as those that could occur with imposing a natural flow strategy, may substantially and adversely affect habitat conditions and the salmonid survival require careful analysis.

6.1.1.1 Current Flow Conditions and Functions in Central Valley Rivers as Related to Salmonids

Hydrologic conditions within Central Valley rivers and the Delta are dynamic and vary substantially in response to precipitation and runoff. Large variation in hydrology occurs between years (e.g., wet and dry years), between seasons (e.g., winter and spring and summer and fall), as well as on hourly and daily time steps. Hydrodynamic conditions within the Delta are further complicated by strong tidal dynamics where tidal flows may be an order of magnitude or greater than inflows from the tributary rivers (see SWC/SLDMWA written comments for Workshop 1). Local flow dynamics at channel junctions and those influenced by bathymetry, channel configuration, submerged and emergent vegetation, and the influence of export operations are even more complex.

A major biological challenge when working on Central Valley salmonids is understanding and predicting changes in habitat conditions and behavioral response of different salmonid species and lifestages as they encounter these changes in flow conditions. There is a relatively strong body of scientific information developed through Instream Flow Incremental Methodology studies on habitat suitability for salmon and steelhead in response to changes in water velocity and water depth based on river flow, substrate, cover, and water temperatures within the upstream habitats where salmonids spawn and juveniles rear (e.g., USFWS 1986, 1996, 2005; Bartholow 2004; USBR 2008; and Stillwater Sciences 2009). Salmonid response, particularly juveniles, to changes in flow conditions within the rivers' lower reaches and in the Delta tidal areas is much less understood.

In the past, juvenile Chinook salmon were marked with coded-wire tags (CWT) and released at various locations with their survival rates and migration rates estimated based on recaptures downstream (see Sections 7, 8, and 9 for additional discussion). Results of these mark-recapture studies were frequently difficult to interpret, included small sample sizes for recaptured fish, produced variable results, and provided no detailed information on the behavioral response of fish to flows or route selection or specific locations where mortality is high. Despite these limitations, results of an extensive number of CWT mark-recapture studies on both the Sacramento and San Joaquin rivers over the past 2 decades (hundreds of tests using tens of millions of juvenile salmon) provide useful information on trends in survival and how various factors such as river flow, Delta Cross-Channel gate operations, Head of Old River Barrier, etc.) affect survival (Brandes and McLain 2001, Newman and Brandes 2009, Kimmerer 2008, SJRGA 2006, Newman and Rice 2002).

Over the past 10 years, significant advances have been made in the applying acoustic tag technology to assess the juvenile salmonids' response to flow changes, route selection, migration rates, and reach-specific survival rates (Perry 2010, Michel 2010, SJRGA 2011, Blake *et al.* 2012, and others).

I-D acoustic tag results provide useful information about juvenile salmonids response to flow splits and reach-specific survival. 2-D and 3-D acoustic tag detection arrays have also been used to map the specific location of tagged salmonids within the water column that can then be matched with detailed information on local water velocities and current patterns at the specific location corresponding to each individual fish. Acoustic tag monitoring is virtually continuous and can be used to examine the behavioral response of fish to complex river and tidal flows during the day and at night. Using this more detailed information on fish movement and survival, in combination with monitoring flows, turbidity, water temperatures, changes in gate and export operations, etc., a more refined understanding of the response of juvenile salmonids to flows and the functions that flows serve for salmonids, is starting to emerge.

Although general information is available on the behavioral response and functions of these flow-related processes, the application of more sophisticated acoustic tagging and monitoring in the future will provide new insights into the role of flows affecting these functions and the response of various salmonid lifestages to these environmental conditions. Using this new body of scientific information, more detailed and robust analyses of the potential effects of variation in natural flows and managed flows will be developed. Information on changes in micro- and macro-habitat selection, migration timing and rates, survival, and other factors is currently being developed and analyzed. Results of these studies, both within the rivers and tidal Delta, will provide insight into how these flow-related functions can be managed and enhanced in the near future. Results of these emerging studies will also be used to assess how salmonids are using newly restored habitats with the Delta and rivers, identifying specific management actions (e.g., predator control) to improve juvenile salmonid survival, and other factors such as the use of pulse flows to stimulate migration that are intended to improve Central Valley salmonid survival and abundance in the near future.

6.2 Overview: Studies of the Relationship between Flow and Salmonid Survival

As discussed in greater detail in Sections 7, 8 and 9, many flow-survival studies results conducted on Central Valley rivers regarding juvenile salmonids show a general, but weak trend of increased juvenile survival during migration through the rivers and Delta when river flows are higher (Newman and Rice 2002, Newman and Brandes 2009, Newman 2008, SJRGA 2006, Brandes and McLain 2001). However, these survival studies show: (1) high variability in the actual survival of juvenile salmonids at a given flow, as reflected in the scatter of survival estimates (observations of both high and low survival at a given flow); (2) low r^2 values (reflecting that the relationship between survival and flow is weak and flow alone does not explain a substantial proportion of the observed variation in juvenile survival); and (3) based upon the low slope of the flow-survival relationship, that a substantial increase in flow is required to achieve a relatively small predicted increase in salmonid survival. Results of the studies conducted to date, however, have been based on simple relationships with river flow alone and have not separated the effects of increased flows with low turbidity reservoir releases from the functions provided by natural flow that also include increased turbidity. Such increased turbidity is expected to serve to improve juvenile survival through reducing the risk of predation mortality.

The high observed variation in the flow-survival relationship for juvenile salmonids (primarily based on mark-recapture results for fall-run and late fall-run Chinook salmon produced in Central Valley fish hatcheries) reflects, in part, the large number of factors other than river flow that affect species survival (Section 2). As just one example, salmonid exposure to predation is a major factor affecting juvenile survival. Indeed, migration studies show 50 percent or more of migrating juvenile salmonids are lost before they reach the Delta (Michel 2010, MacFarland *et al.* 2008).

Several conceptual models have been advanced to support the notion that higher instream flows will benefit juvenile salmonid survival. One suggested mechanism is that, at higher flows, the downstream rate of juvenile migration would be faster and, therefore, juvenile salmonids would have reduced exposure to potential predators. However, the available data do not support this theory. Results of CWT and acoustic tag studies discussed more thoroughly below indicate that while juvenile downstream migration transit time in portions of the Sacramento River upstream of the Delta may decrease as instream flows increase, salmonid migration rates in the Delta actually decrease as the juveniles move downstream into areas subject to tidal influence (Michel 2010). These studies show that the relationship between river flow and migration rates (time from release to recapture downstream at Chipps Island) is very weak and does not support the theory that increasing river flow will result in faster migration rates through the Delta or reduced exposure to in-Delta predation mortality (see Sections 7, 8, and 9).

A second suggested mechanism is that juvenile salmonids use changes in river flow and turbidity as environmental cues for downstream migration. Increased flow and increased turbidity (and potentially concurrent decreased air and water temperatures) typically occur in response to stormwater runoff in the Central Valley watersheds. As flows increase and turbidity becomes more elevated, the conceptual model would suggest that juvenile salmonid vulnerability to predators such as striped bass and largemouth bass would decrease which, in turn, would contribute to increased juvenile salmonid survival during migration. However, the data do not consistently support these predictions. Results of field monitoring studies do not show that pulse flows releases from upstream reservoirs provide the same biological cues and functions as naturally occurring storm events. Several studies have been conducted in Central Valley rivers that use short-duration (days) managed pulse flow releases from reservoirs in an effort to stimulate the downstream movement of juvenile salmon (e.g., pulse flow studies conducted on the Mokelumne River by EMBUD (unpub. data) and on the Stanislaus River (Demko and Cramer 1995, 1997 and Demko *et al.* 2000, 2001). These tests have produced variable and inconclusive results.

Smolt migration appears to be controlled largely by growth rate and fish size, physiologic transformation to smolts (e.g. ATPase levels), and patterns of seasonally increasing water temperatures. The studies suggest that natural pulse storm flow events and increased turbidity are likely important migration cues for juvenile salmonids. However, higher, stabilized flows via required instream flows, pulse flow releases, or similar mechanisms do not provide a similar benefit to juvenile salmonids. Thus, stabilizing river flows in a manner that reduces or eliminates pulse flow variation needed for juvenile salmonid migration cues (i.e., “flat lining” river flows) is unlikely to provide meaningful benefit to salmonid migration (del Rosario and Redler undated, Jager and Rose 2003).

To a large extent, existing reservoir operations during the winter and spring months (most of which are primarily designed to meet flood control requirements and to control runoff from local watersheds and tributaries) help to maintain the pulse flow and turbidity cues that are important for salmonids.

In sum, the functions and inter-relationships among flow and habitat quality and availability, growth, survival, reproductive success, and abundance of salmonids are complex. The available data show that there is high variability and low certainty/predictability in flow-survival relationships, although the data also show a general trend toward increased salmonid survival as flow increases during downstream migration. Fixed flows or managed pulse flow releases are unlikely to provide significant benefit to the species. As discussed in Section 5, such releases may actually deplete coldwater pool volumes in a way that harms salmonids. At base, the focus should be on improving habitat functions for salmonids, not simply releasing more water to arbitrarily increase flows.

6.2.1 Improved Monitoring Technology and Analytical Tools

The ability to respond flexibly to current in-river and reservoir conditions, through coldwater pool management and application of near-real time monitoring results, has improved conditions for salmonids over the last 3 decades. Improvements in monitoring technology and analytical tools have also helped to address uncertainty in evaluating the response of juvenile salmonids to factors such as route selection, behavior, survival, and flow changes (including river flow, Delta tidal hydrodynamics, and export operations [Perry 2010; Michel 2010; SJRGA 2010, 2011]).

The Instream Flow Incremental Method and other analytical tools have been developed and applied to Central Valley rivers for use in evaluating instream flow schedules that meet the habitat requirements of the various lifestages of salmonids (e.g., USFWS 1996, 2011, and others). Acoustic tag technology (Figure 6-1) has been used to develop detailed information on juvenile salmon and steelhead migration through the Delta. The technology is continuing to be refined and improved to provide better signal transmission, longer battery life, smaller tag size and the ability to successfully tag smaller salmonids. There have also been marked improvements in technologies designed for tracking and mapping juvenile salmonid movement in three dimensions.

Data obtained from application of these new and improved technologies can be analyzed in conjunction with information about local flow patterns to improve habitat and passage conditions for juvenile salmonids. The technologies can also be used to analyze the benefits of fish guidance projects, such as non-physical barriers (e.g., the “bubble curtains” tested in the San Joaquin River at the Head of Old River and on the Sacramento River at Georgiana Slough) (Bowen *et al.* 2009, Bowen and Bark 2010).

Data generated using these improved monitoring technologies are now being integrated into analytic tools designed to improve our understanding of salmon biology, the response of juvenile salmonids to flows and other environmental conditions, and the role of predation in juvenile salmonid mortality. The predictive capacity of models and other tools has also improved, particularly with their integration into life cycle modeling efforts. The rapid development of these new tools has only recently begun, and these efforts are continuing to expand and provide new information that will be directly applicable to informing management decisions in the future. For example, NMFS and others are currently conducting a large-scale acoustic tag study of juvenile hatchery and wild salmonids migrating through the upper Sacramento River and its tributaries downstream through the Delta; however, results of this large-scale study are not expected to be available for several years (Hayes 2012, Klimley *et al.* 2012).These circumstances point to the idea that the science should be allowed to develop, and maximum flexibility in management and operations should be retained to implement what the scientific data show and will show.

6.2.1.1 PTM is an inadequate tool for predicting movement of juvenile salmon

PTM has been used to predict how juvenile salmonid may respond to different water export management strategies and to justify regulation of Delta flow rates, such as OMR flow levels, during the spring period of juvenile salmonid migration through the Delta (See 2009 NMFS Biological Opinion RPA Action IV.2.3 (overturned by federal court).) However, PTM simply simulates the movement of neutrally buoyant particles in response to local flow patterns. It has been shown that neutrally buoyant particles do not provide reliable predictions of the movement of juvenile salmon and steelhead, both of which swim actively and respond behaviorally to their environment (NMFS 2012).

USBR and DWR (2009) and NMFS (2012) report results of a test to validate PTM results as they apply to predicting the movement of juvenile Chinook salmon. The study examined the relationship, or lack thereof, between PTM predictions and observations of CWT salmon released in April-May as part of the Vernalis Adaptive Management Plan (VAMP) and earlier San Joaquin River survival studies (1995-2006) and recaptured in Chipps Island trawling. Results of the test (Figures 6-2 and 6-3) confirmed that PTM results are not a reliable predictor of salmon movement and are inappropriate for developing and evaluating the effects of management actions on movement and survival of juvenile Chinook salmon. Actual monitoring of juvenile salmon migration, survival, and response to local hydrodynamics using acoustically tagged fish (Figure 6-1) has recently provided new scientific information on actual juvenile migration rather than relying on PTM simulation runs.

Newly developed analytic tools, including the DPM (Section 4), serve as more informative analytical frameworks for analyzing acoustic tag monitoring and other data related to movement and survival of juvenile salmonids. These new tools have proven to be more valuable instruments than PTM for evaluating juvenile salmonid movement patterns and survival in response to potential management actions, such as increased Delta inflows and outflows, modified exports and changes in OMR flow levels.

Additional information on river flows and hydrologic conditions in the Central Valley rivers is presented in the SWC/SLDMWA written comments submitted in conjunction with and during the State Board’s workshop on Ecosystem Changes.

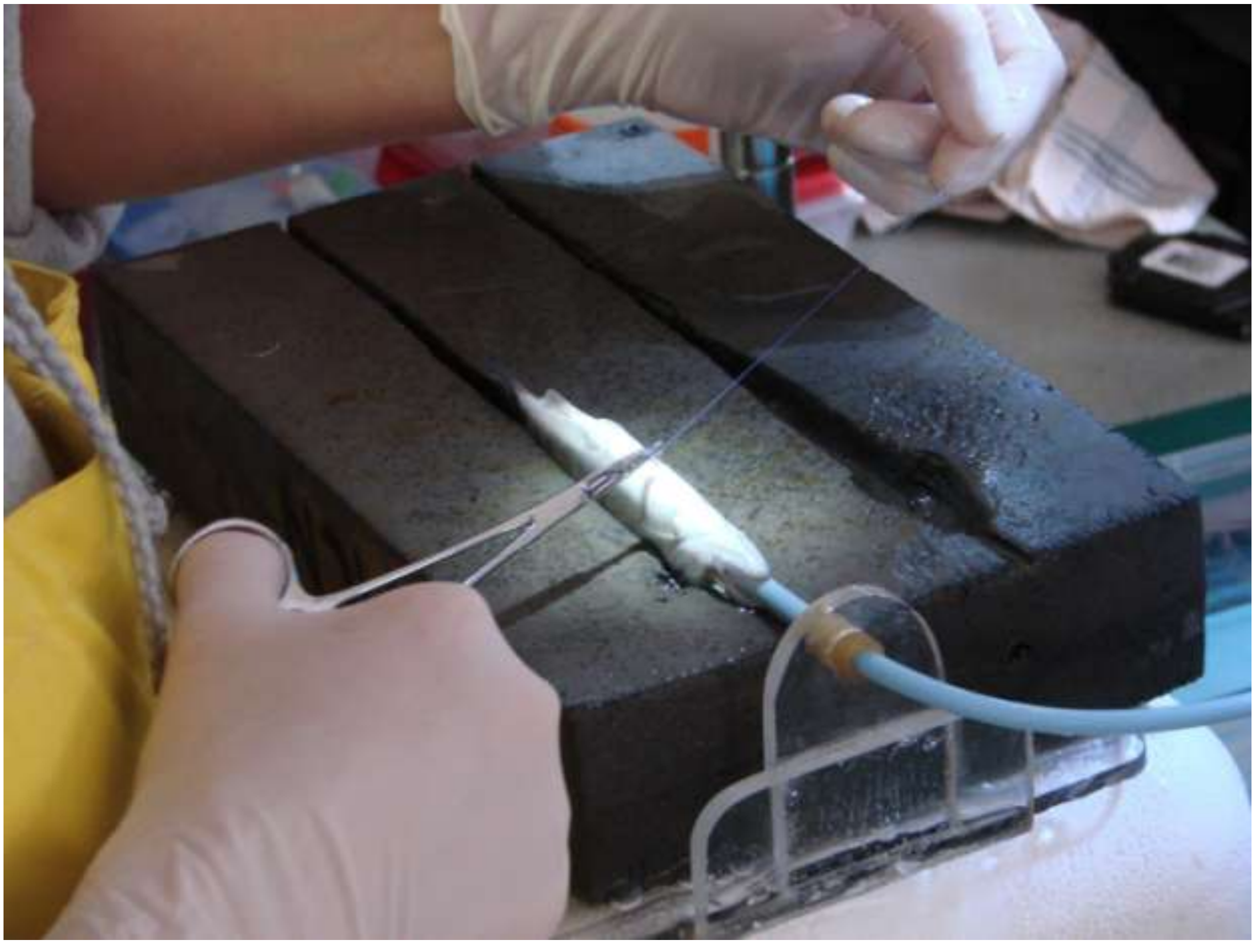

Figure 6-1. **Surgically implanting an acoustic tag into a juvenile Chinook salmon.**

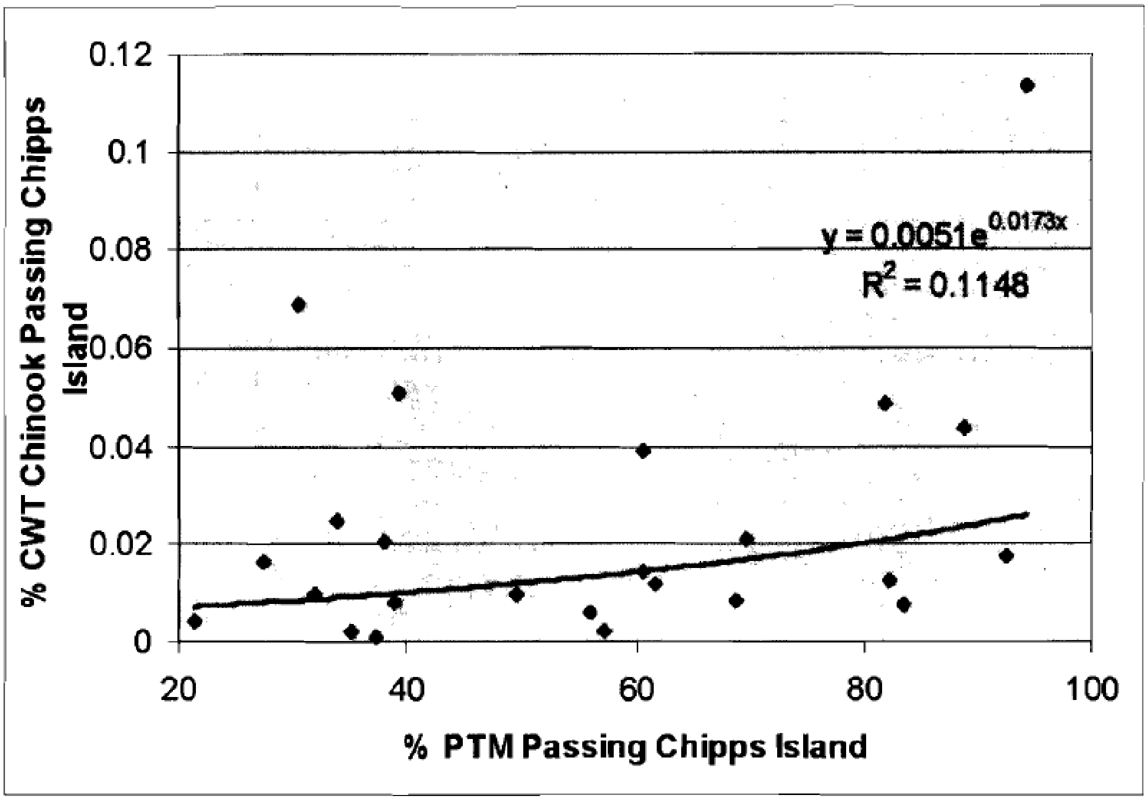

Figure 6-2. Results of a validation test of the percentage of particles in a PTM model scenario passing Chipps Island and corresponding percentage of CWT juvenile Chinook salmon to Chipps Island (Source: USBR and DWR 2009, NMFS 2012).

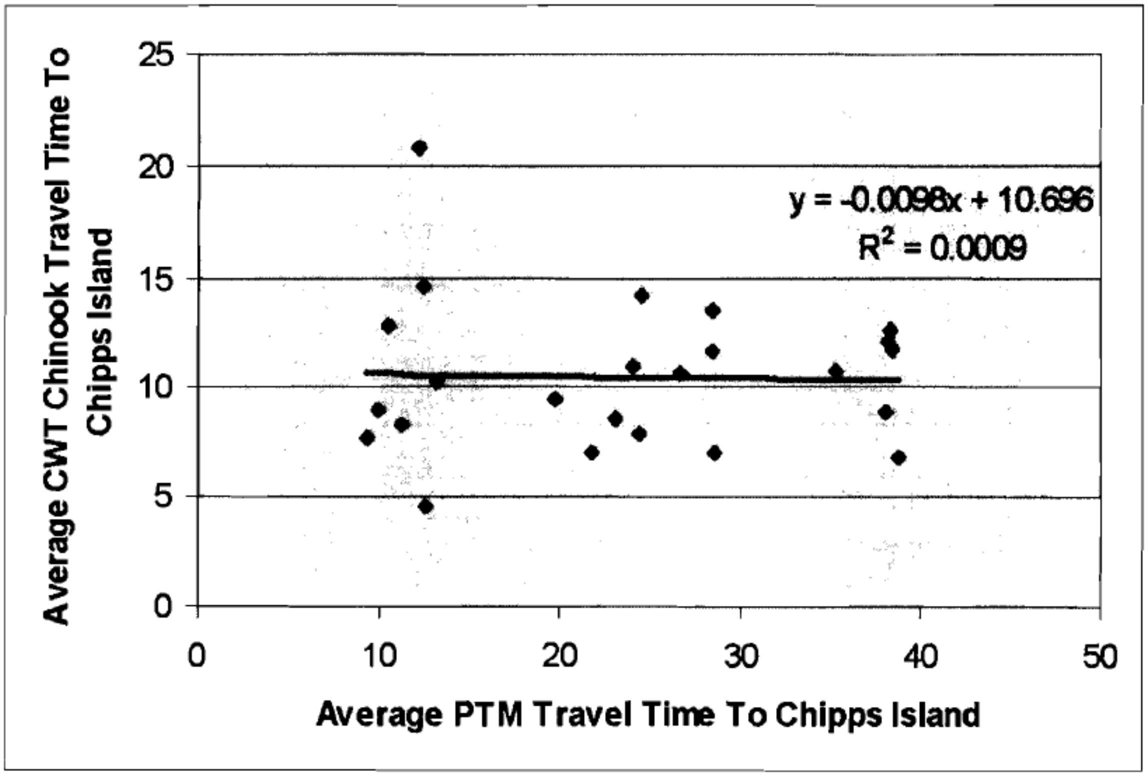

Figure 6-3. **Results of a validation test of the travel time of particles in a PTM model scenario passing Chipps Island and corresponding average travel time of CWT juvenile Chinook salmon to Chipps Island (Source: USBR and DWR 2009, NMFS 2012).**

6.2.1.2 Addressing Uncertainty

Scientific monitoring and experimentation in the Central Valley has evolved significantly over the past several decades. Rapid advances in the precision and level of detail available on movement patterns, survival, and the response of juvenile salmonids have been made over the past 10 years with the application of acoustic tagging technology. These advances serve to improve and refine our understanding of the functions of river and tidal hydrodynamics, and other factors, for salmonids and help reduce the level of uncertainty in the evolving scientific foundation for identifying and testing alternative management strategies. The level of uncertainty now and in the future is expected to be further reduced based on the following:

- The continued development of an integrated multidisciplinary collaborative monitoring program;
- Continued development and refinements to monitoring tools such as 3-D acoustic tag tracking;
- Continued research to evaluate functions and processes that are proving to be beneficial in habitats such as Liberty Island, Yolo Bypass, Suisun Marsh and elsewhere;
- Collaboration with research investigations on similar salmonid issues in the Northwest;
- Developing habitat restoration projects that are based on habitat suitability of various species and lifestage, reflect natural functions and processes such as sediment resuspension (turbidity);
- Development of new analytical tools, models, and statistical analyses that can be used as a framework for organizing and integrating research results;

Despite these efforts, variation and uncertainty will continue to be part of future management. Hydrologic variation within and among years, the occurrence of extended drought, introduction and colonization by additional non-native species that may impact food supplies and trophic dynamics, and predator-prey balance remain future uncertainties. The timing, magnitude, and effects of future climate change affecting Central Valley hydrology, temperatures, and ocean-rearing conditions for salmonids are major areas of future uncertainty. Management and monitoring strategies in the future will need to be flexible and adaptable to respond to these and other changes, and areas of uncertainty.

6.3 Recommendations

Analytical tools and applying emerging technologies, such as improving acoustic tag monitoring, provide the current scientific foundation for rapid advances in the body of scientific information on how salmonids respond to environmental factors. These near-future advances will provide new insights into flow functions in context with various other environmental factors that affect spawning and reproductive success, juvenile rearing, migration patterns and survival within the rivers and Delta. There continues to be uncertainty in these functional relationships that will be reduced through applying new tools in the near future.

7 Sacramento River System

7.1 Background on Salmonid Use of the Sacramento River System

The Sacramento River and its tributaries, including the American, Feather and Yuba rivers, and Battle, Clear, Butte, Deer, Mill and numerous other creeks tributary to the river, support populations of Chinook salmon and steelhead. Fall-run, late fall-run, spring-run, and winter-run Chinook salmon as well as Central Valley steelhead are produced in the Sacramento River watershed. The watershed also provides habitat for resident rainbow trout and various other fish and aquatic species. Salmon and steelhead are also produced in hatcheries located on the American and Feather rivers and Battle Creek. Habitat conditions for salmonids in the main rivers are affected by instream flow releases from upstream dams that also directly influence water temperatures in the main river channels immediately downstream from the dams. The geographic distribution of primary spawning and juvenile rearing habitat in the Sacramento River basin for salmonids is shown in Figures 1-3, 1-4, and 1-5.

Habitat conditions for salmonid spawning, rearing, and migration in the Sacramento River basin’s major rivers have been severely modified as discussed in Section 2. In addition, introducing non-native fish and other aquatic species such as striped bass, largemouth bass, American shad, threadfin shad, silversides, and other predators has altered fish community dynamics within the Sacramento River watershed. Annual variation in hydrologic conditions within the watershed has also resulted in wide variation in habitat conditions, particularly in wet year flood conditions and dry year drought conditions.

In response to these and other factors, salmonid populations in the Sacramento River watershed have experienced both high and low abundance periods (GranTab 2011). Winter-run and spring-run Chinook salmon population abundance (adult escapement), as well as Central Valley steelhead abundance, have shown a general declining trend over the past 3 decades. Fall-run Chinook salmon are the most abundant salmonid inhabiting the basin and have also had the greatest support by hatchery production. Although fall-run salmon abundance has fluctuated substantially in recent years, the species continues to support both commercial and recreational harvest (Boydstun 2001). A number of stressors affect these species directly and indirectly (Section 2) as do a number of specific management requirements and programs intended to enhance and protect salmonid species and their habitats (Section 3).

7.1.1 Winter and Spring Pulse Flows

As discussed above, juvenile Chinook salmon and steelhead have evolved to respond to pulse flows and increased turbidity associated with storm activity during the winter and spring juvenile migration period. There has been concern that upstream reservoir storage operations could virtually eliminate short-duration flow cues for salmonids on the lower Sacramento River in the winter and spring (NMFS 2010a). To test this hypothesis, we analyzed pulse flow conditions using river daily flow measurements at the Red Bluff Diversion Dam (RBDD) over the period May 2005 through April 2006 to reflect conditions in the upper reaches of the Sacramento River. We used DAYFLOW data of daily flows at Freeport to represent flow conditions in the lower reaches of the Sacramento River. (DAYFLOW data were compiled for the period from December through May for the period from 2001 through 2011 using daily flows, a 3-day running average and a 7-day running average.)

Analysis of results of daily flows for one example year at the RBDD are shown in Figure C-1 in Attachment C. Analysis of results of daily flows at Freeport are shown in Figures C-2 through C-12.

These data show that there is substantial daily flow variation (peak pulse flows greater than two times the baseflow) in the upper and lower river reaches of the Sacramento River in response to storms and precipitation, reservoir releases, and runoff events within the watershed. Variation in natural flows and turbidity within the mainstem and tributaries during the winter and spring juvenile salmonid migration period will continue to provide environmental cues and opportunities for juvenile emigration from the Sacramento River system.

7.1.1.1 Juvenile Chinook Salmon Survival in the Sacramento River

Numerous significant experimental studies have been conducted to assess juvenile Chinook salmon survival as they migrate downstream through the Sacramento River and Delta (Brandes and McLain 2001, USFWS unpub. data). The survival studies began in 1993. CWT juvenile salmon were released at various locations in the upper reaches of the Sacramento River, and survival was estimated based on tagged salmon recaptures in trawling at Chipps Island. These CWT studies were repeated using salmon of various origins and sizes, and changing seasonal timing of release, location of release, and environmental conditions, most notably variation in Sacramento River flows. Data from upper Sacramento River releases are available from over 100 studies conducted by USFWS. More recently, acoustic tag studies have been conducted to estimate the survival of juvenile Chinook salmon (primarily late fall-run Chinook salmon produced in the Coleman National Fish Hatchery located on Battle Creek near Redding). The acoustically tagged salmon are released into the upper river, and their survival is estimated based on acoustic monitoring at various locations along the river, Delta, and San Francisco Bay estuary (Michel 2010, Perry 2010).

Examples of reach-specific survival estimates for late fall-run Chinook salmon migrating downstream in the Sacramento River developed by MacFarland *et al.* (2008) are shown in Figure 7-1. Results of this study showed that juvenile salmon experienced relatively high mortality in the upper reaches of the Sacramento River, upstream of the Delta, with approximately 70 to 80 percent of the juvenile salmon lost in the riverine reaches of the system before entering the estuary. The study also showed that the overall mortality of juvenile salmon migrating downstream through the Sacramento River and Delta averaged approximately 90 percent (10 percent survival) by the time the fish entered coastal marine waters through the Golden Gate.

The MacFarland study results were consistent with the results of a 3-year acoustic tagging study conducted by Michel (2010) using late fall-run Chinook salmon as they migrated from the upper Sacramento River downstream through the Delta and Bay (Figure 7-2). Both studies showed approximately 95 percent mortality between the upper river release sites and coastal marine waters Overall, the survival rate from the upper Sacramento River to the Golden Gate was 3.9 percent (+/- 0.6 percent for studies conducted in 2007, 2008, and 2009; Michel 2010).

Although the reach-specific mortality rate in the upper river (above Colusa Bridge to Jelly's Ferry - river kilometers 325 to 518) in the Michel (2010) study was relatively low per 10km reach, the cumulative mortality over the long migration through the upper reach showed substantial juvenile salmon losses before they reach the Delta and Bay. The lowest survival rates, observed by Michel (2010), typically occurred in the San Francisco estuary (Golden Gate to Chipps Island - river kilometers 2 to 70), where survival ranged from 67 to 90 percent per 10km reach, as compared with survival in the Delta (93.7 percent/10km; Chipps Island to Freeport - river kilometers 70 to 169), similar to that observed in the upper reaches of the Sacramento River (Figure 7-2). The highest survival rates per 10km segment were observed in the lower Sacramento River reach (98.1 to 100 percent/10km; Freeport to above Colusa Bridge - river kilometers 169 to 325). Results of the acoustic tag study conducted by Michel (2010) also showed that juvenile salmon migration rates are not constant; instead, they vary between the riverine reaches, Delta, and estuary. Migration rates were greatest in the riverine reach and decreased as the tagged salmon moved downstream into more tidally dominated habitats in the Delta, Suisun, San Pablo, and central San Francisco Bay (Figure 7-3).

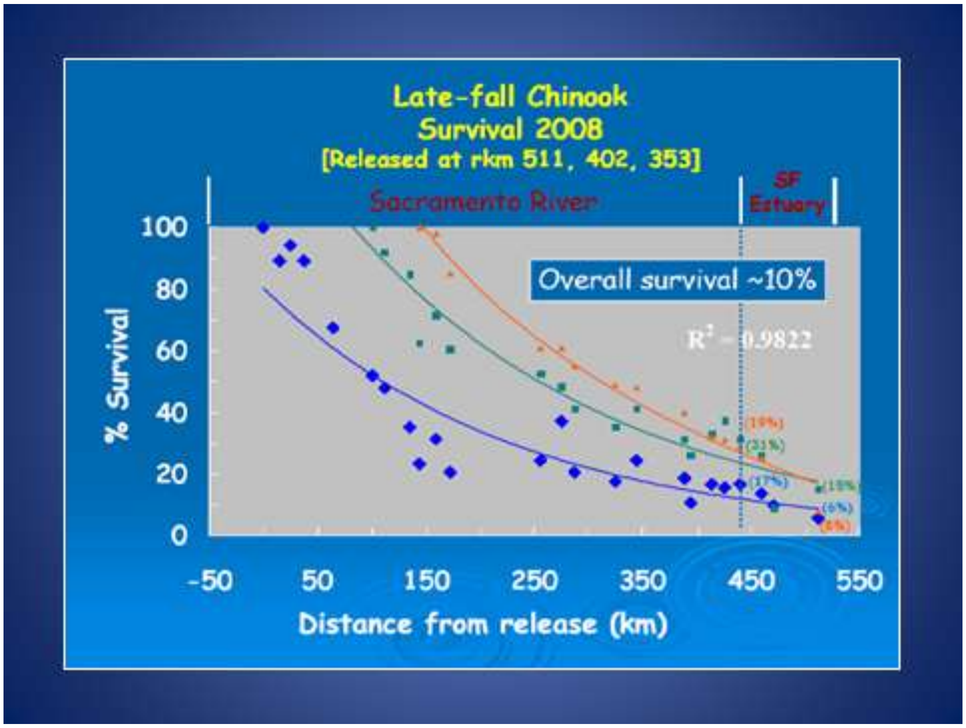

Figure 7-1. **Results of acoustic tag studies on late fall-run Chinook salmon survival during migration through the Sacramento River, Delta, and estuary (Source: MacFarland *et al.* 2008)**

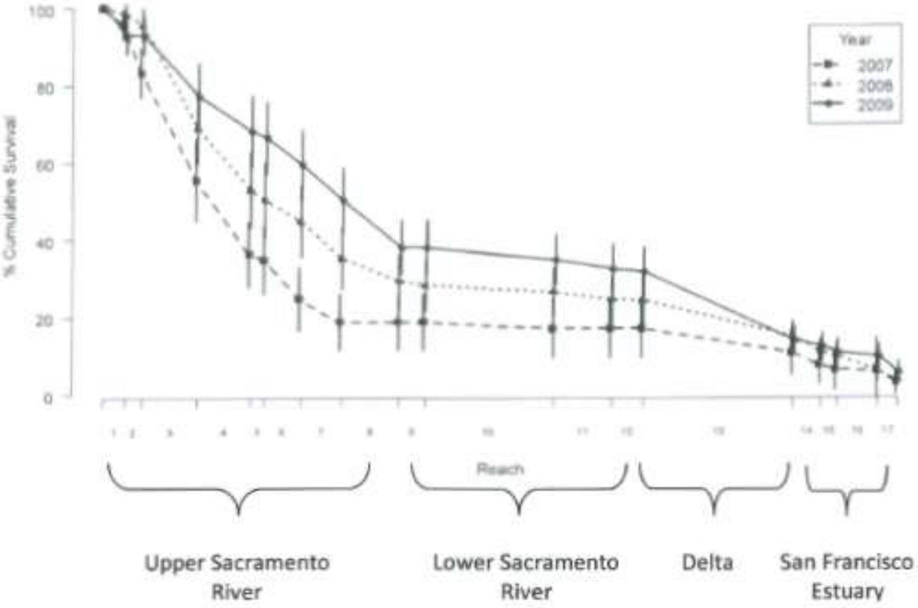

Figure 7-2. **Reach-specific survival estimates for late fall-run Chinook salmon juveniles migrating downstream in the Sacramento river, Delta, and estuary over 3 years (Source: Michel 2010).**

An important question in evaluating results of all mark-recapture studies (both CWT and acoustic tag) is whether results derived from studies using hatchery-reared salmon are representative of the behavior and survival of wild salmon. Results of a very preliminary set of acoustic tag tests by Michel (2010) suggest that, although the point estimates of reach-specific survival for hatchery and wild salmon are similar (Figure 7-4), the hatchery salmon appear to have greater variability in survival when compared to wild salmon.

A similar issue arises regarding the use of late fall-run Chinook salmon for acoustic tagging because they are larger yearling fish and more easily tagged using current acoustic technology than are smaller fish (Perry 2010, Perry *et al.* 2010). Data obtained from these larger yearling salmon may not be representative of survival and migration behavior of smaller young-of-the-year salmon fry and smolts (Perry 2010, Zeug *et al.* 2012, S. Hayes pers.com). In addition, studies conducted using Chinook salmon may not be representative of survival of yearling steelhead migrating through the Sacramento River watershed and Delta. Moreover, although results of these acoustic tagging studies provide valuable information on movement and survival of juvenile salmon, they have been conducted over only a few years under a limited range of environmental conditions. Thus, the data obtained are likely insufficient standing alone to evaluate flow-survival relationships for juvenile salmon. Similar studies using juvenile steelhead, wild and hatchery stock comparisons, and salmon smaller than the relatively large yearling late fall-run Chinook are beginning in 2012 by NMFS. The issue of using surrogate species, such as hatchery produced Chinook salmon as a surrogate for wild salmon, has been raised as a concern (Murphy *et al.* 2011, Smith *et al.* 2002, Wiens *et al.* undated). Results of comparative survival studies using various species of hatchery and wild stocks will provide useful insight into the application of surrogates in determining migration and survival rates for Central Valley salmonids.

7.1.1.2 Flow-Survival and Effects of SWP/CVP Exports on Salmon Survival

Juvenile Chinook salmon and Central Valley steelhead migrate from upstream rearing habitat through the Delta and into coastal marine waters. Juvenile migration within the Delta typically occurs during the winter and spring months. During their migration through the Delta, juvenile salmon and steelhead are vulnerable to direct losses (entrainment and salvage) at the export facilities as well as mortality from a variety of other sources. These other sources of mortality (stressors) include predation by fish (e.g., striped bass, largemouth bass, Sacramento pikeminnow, etc.) and birds; exposure to toxins; entrainment at unscreened agricultural, municipal, and industrial water diversions; exposure to seasonally elevated water temperatures; and other factors (NMFS 2010a).

It has been hypothesized that changes in Delta channel hydrodynamics may indirectly affect juvenile salmon and steelhead survival by modifying tidal and net downstream current patterns in a manner that alters their migration pathways, thereby increasing their vulnerability to interior Delta mortality sources (Kimmerer 2008). For example, it has been hypothesized that changes in the direction and magnitude of tidal and current flows within the central Delta (e.g., Old and Middle rivers) during the salmonid emigration period leads to movement of juveniles into the central Delta which, in turn, contributes to delays in downstream migration and increased salmonid mortality (NMFS 2009).

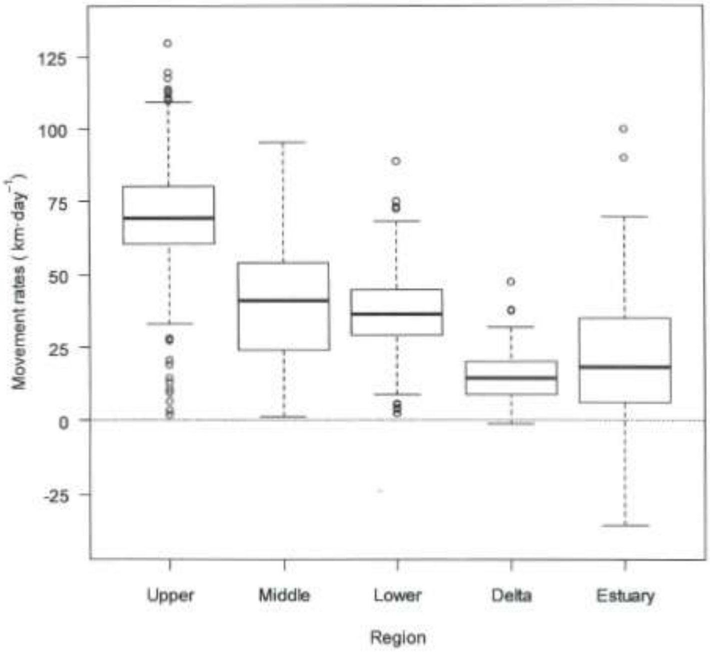

Figure 7-3. **Reach specific migration rates for acoustically tagged late fall-run Chinook salmon in the Sacramento River, Delta, and estuary (Source: Michel 2010).**

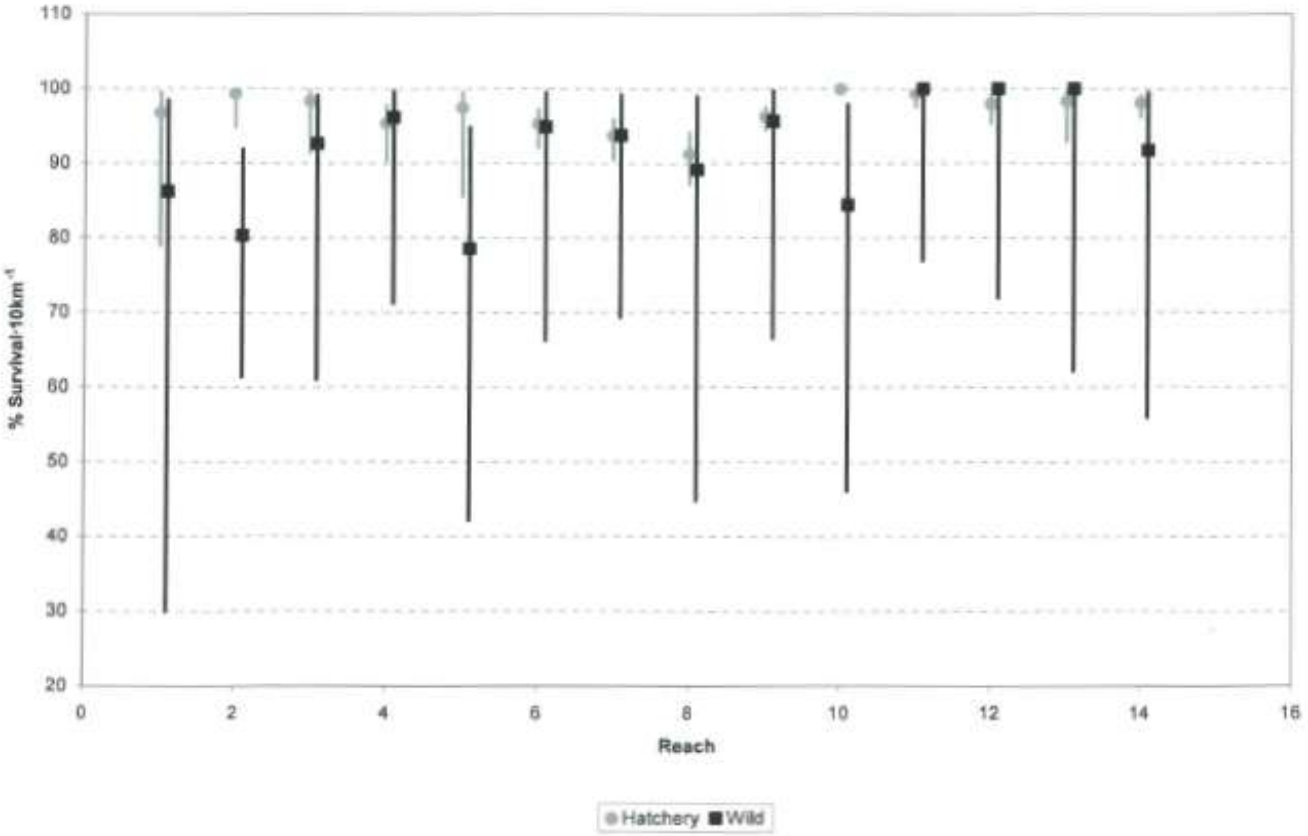

Figure 7-4. Results of a preliminary comparison of survival rates for wild and hatchery origin juvenile Chinook salmon in the Sacramento River, Delta, and estuary (Source: Michel 2010).

According to this hypothesis, the survival of juvenile salmon and steelhead migrating through the Delta would be lower when export rates are high, and salmonid survival would be higher when exports are low. However, the purported incremental contribution, if any, of higher SWP and CVP export levels to total mortality of juvenile salmon and steelhead during migration through the Delta has not been quantified.

7.1.1.3 Survival Study Analysis

To help address these management questions, additional analyses have been conducted using results of CWT studies designed and implemented by USFWS to investigate survival relationships for juvenile salmon migrating downstream through the Sacramento River and Delta. The USFWS has conducted over 100 survival studies on the Sacramento River using juvenile winter-run, spring-run, and fall-run Chinook salmon over the past 3 decades. The juvenile salmon used in these studies have primarily originated in the Coleman National Fish Hatchery and the Livingston-Stone Fish Hatchery, both located on Battle Creek, a tributary to the Sacramento River upstream of the RBDD.

Limited CWT tests have also been performed using wild juvenile salmon collected from the Sacramento River and tributaries. For this analysis, survival study results where the marked salmon were released into the upper reaches of the river system were used to represent juvenile Chinook salmon emigrating from upstream rearing areas (e.g., Sacramento River, Clear Creek, Butte Creek, etc.). These upstream releases typically occurred during the winter and spring months coinciding with the seasonal period and conditions when wild salmon and steelhead migrate downstream through the lower river and Delta. The studies included juvenile salmon typically ranging in length from approximately 50 to 110 mm. The survival study data utilized were limited to those tests in which more than 10,000 fish were released. Limiting the analysis to these larger releases was intended to increase the statistical reliability of the study results and the probability that CWT salmon would subsequently be detected in recapture sampling at the export facilities and at Chipps Island. Survival estimates were calculated for multiple tag codes when more than one tag code was used in a release. The CWT mark-recapture CWT releases used in our analysis included results from 118 studies with a combined total of over 14,200,000 juvenile salmon released.

For each of the CWT survival studies, marked fish were collected at the SWP and CVP fish salvage facilities as part of routine monitoring. The numbers of marked fish were expanded to account for the time spent sampling at each facility in accordance with standard procedures for fish salvage monitoring (expanded salvage estimates were compiled by USFWS for each CWT group). Marked salmon were also recaptured by USFWS in trawling conducted at Chipps Island, located within Suisun Bay in the western Delta, and used to calculate survival estimates based on expansion for sampling effort (all survival estimates were calculated by USFWS). Survival estimates from CWT studies based on USFWS fishery sampling for juvenile salmon at Chipps Island has been found to be highly correlated (r^2= 0.76) with the independent measure of salmon survival based on expanded catch of adults in the ocean (SJRGA 2006). As part of routine fishery monitoring during the survival studies, information on the date of release for each tag code as well as the initial and final dates of recapture is recorded.

The dates of release and the last dates of recapture in each study were used in our analyses to estimate the rate of migration of juvenile salmon downstream through the Delta and to assess the flow and export conditions that occurred within the Delta during the migration period. For purposes of this analysis, two periods were used to assess flow and export conditions for each CWT release group: average conditions 30 days and 60 days prior to the date of last recapture. The range in dates reflects the variability in the duration of fish passage through the Sacramento River and Delta observed in these studies and the conditions within the Delta during downstream passage. Information on hydrologic conditions during each CWT survival study, including Sacramento River flow, Delta inflow, SWP and CVP combined exports, and Delta outflow was obtained from the DWR DAYFLOW database. We used the results of the survival studies to analyze the potential relationship between SWP and CVP export rates and both direct losses (percentage of each tagged group of salmon recaptured at the fish salvage facilities) and indirect (total) juvenile salmon mortality during migration through the river and Delta.

7.1.1.3.1 Direct mortality of juvenile salmon and steelhead and diversion rates at the SWP and CVP export facilities

For these analyses a direct loss index, as a result of SWP and CVP export operations, for each CWT survival test was calculated based on the percentage of the number of fish released and the expanded estimate of salvage of that tag group in the combined SWP and CVP fish salvage. For the study data analyzed, the percentage of CWT salmon released into the upper Sacramento River collected at the fish salvage facilities averaged 0.03 percent (n=118; 95 percent CI = 0.0145), with a range from 0 to 0.53 percent. The estimated percentage of each CWT group recaptured at the SWP and CVP fish salvage facilities was then plotted against the average combined export rate over the 30- and 60-day periods prior to the date of the last fish recaptured.

It was hypothesized that if SWP and CVP export rates were an important factor affecting the percentage of salmon from the Sacramento River collected in export facility salvage (direct losses), the percentage of tagged fish recaptured at the salvage facilities would increase when export rates were higher. Figure 7-5 shows the results of the analysis based on average export rates for the 30 days prior to the last recapture. Results for average exports for the 60 days prior to the last recapture are shown in Figure 7-6. Results of a linear regression model with 95 percent confidence intervals are also depicted in Figures 7-5 and 7-6.

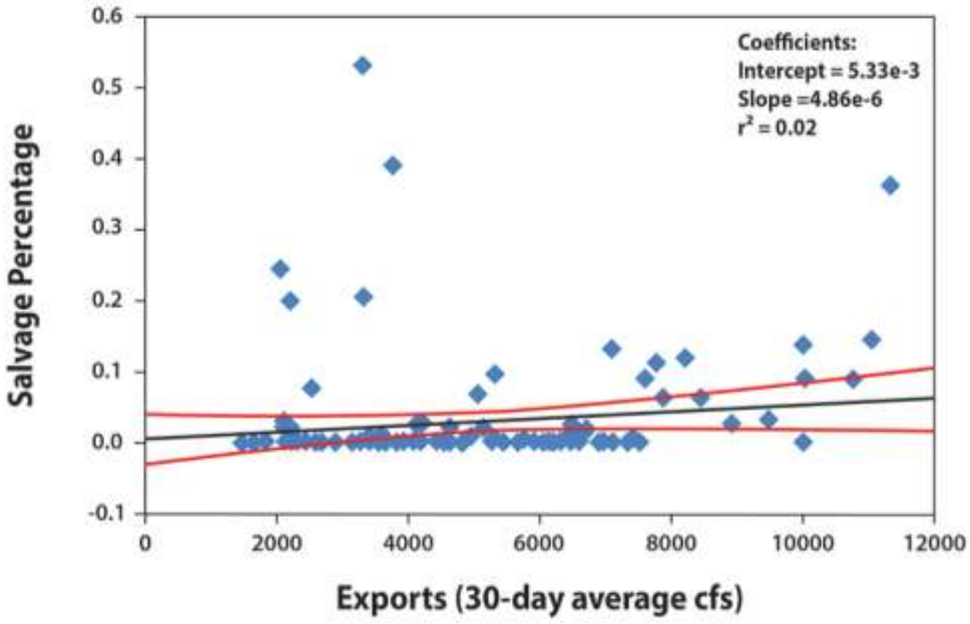

Figure 7-5. Relationship between SWP and CVP exports (30-day average) and percentage salvage (1980-2001).

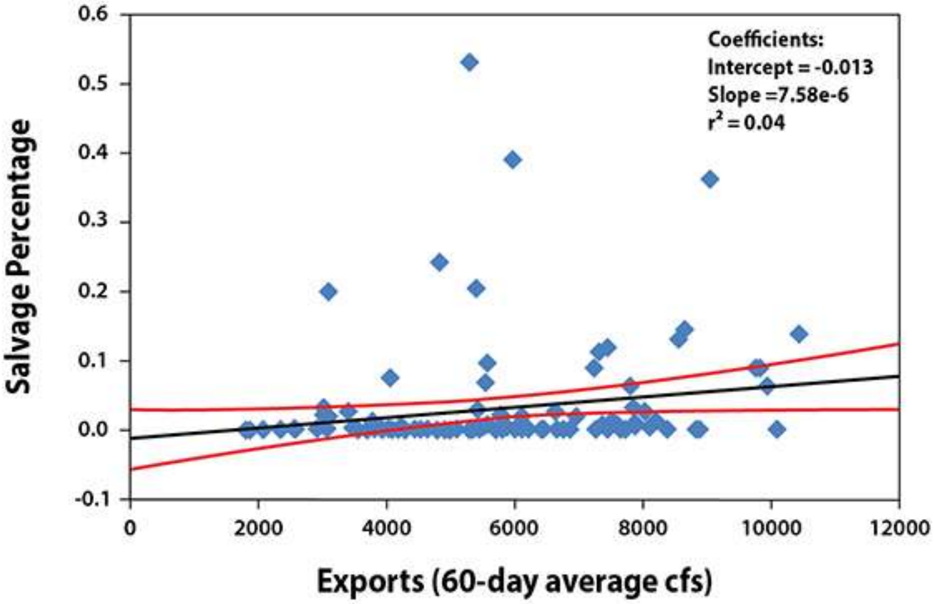

Figure 7-6. **Relationship between SWP and CVP exports (60-day average) and percentage salvage (1980-2001).**

Overall, results of this analysis showed that the relationship between export rate and salmon salvage was characterized by very flat slopes (slopes < 0.0001) and low correlation coefficients (r^2 = 0.02 for the 30-day exports and 0.04 for the 60-day exports). The relationship between combined SWP and CVP export rates and the percentage of each tag group recaptured (direct loss) was not statistically significant for the 30-day (p=0.12) average export rate. The relationship between the percentage of salvage and average export rate over a 60-day period was significant (p=0.04); however, the relationship was extremely weak (r^2 = 0.04). *There was no evidence based on results of these analyses of CWT data that direct losses of salmon migrating downstream in the lower Sacramento River and through the Delta experience greater direct losses as a result of increases in SWP or CVP export rates*.

Due to the level of uncertainty and variability associated with other factors affecting direct losses as well as with the underlying functional relationships, NMFS uses results of CWT salmon releases on the Sacramento River as surrogates for spring-run Chinook salmon to assess the level of incidental take at the export facilities as a percentage of juvenile salmon migration through the Delta. NMFS also uses the annual juvenile production estimate (JPE) for juvenile winter-run salmon, which estimate is used as the basis for regulating take levels (to less than 1-2 percent) at the export facilities.

7.1.1.3.2 Indirect (total) mortality of juvenile salmon and steelhead and diversion rates at the SWP and CVP export facilities

Results of salmon survival studies conducted within the Sacramento River and Delta over the past 3 decades have shown that (1) total survival (the overall survival estimate for a specific group of tagged salmon from the point of release to Chipps Island in these analyses) has been highly variable within and among years, and (2) total survival rates have been low in some years. Over the 118 survival studies included in our analysis—all based on CWT salmon released into the upper Sacramento

River—the average survival rate to Chipps Island was 0.29 (29%; n=118; 95 percent CI = 0.04) with a range from 0.016 to 1.0. (Studies in which no CWT salmon were collected were not included in the analysis; maximum calculated survival rates were truncated at 1.0).

A key question for Delta management is whether SWP and CVP export rates are a factor affecting (indirect effect) the survival of juvenile salmon during migration. If SWP and CVP exports are a major factor affecting survival within the Delta, total salmon survival should be reduced in those years when export rates are high and increased in those years when export rates are low (Figure 7-7). If SWP and CVP export rates are not a major factor affecting Delta survival, there should be no relationship between total Delta survival and combined exports during the seasonal period when juvenile salmon are migrating through the lower river and Delta (Figure 7-7).

To test this hypothesis, the estimates of total Delta survival from the CWT survival studies were plotted against average SWP and CVP export rates 30 days and 60 days prior to the date of last recapture for each CWT group of juvenile salmon between 1980 and 2001. Results of the analysis are shown in Figure 7-8 using a 30-day average for exports. In Figure 7-9, the results use a 60-day average for exports (results of the linear regression and 95 percent CI are shown for each analysis). The slopes of the regressions were low (<0.0001) and were characterized by a high variance (r^2= 0.01 for the 30-day average and 0.02 for the 60-day average).

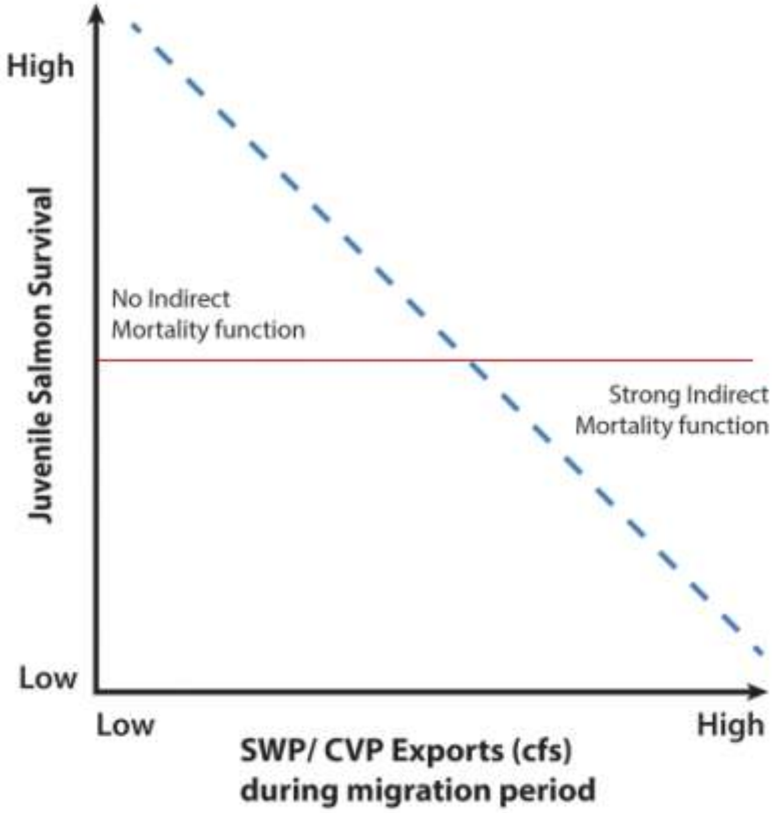

Figure 7-7. **Hypothesis regarding the effect of SWP/CVP exports on indirect mortality of juvenile salmon.**

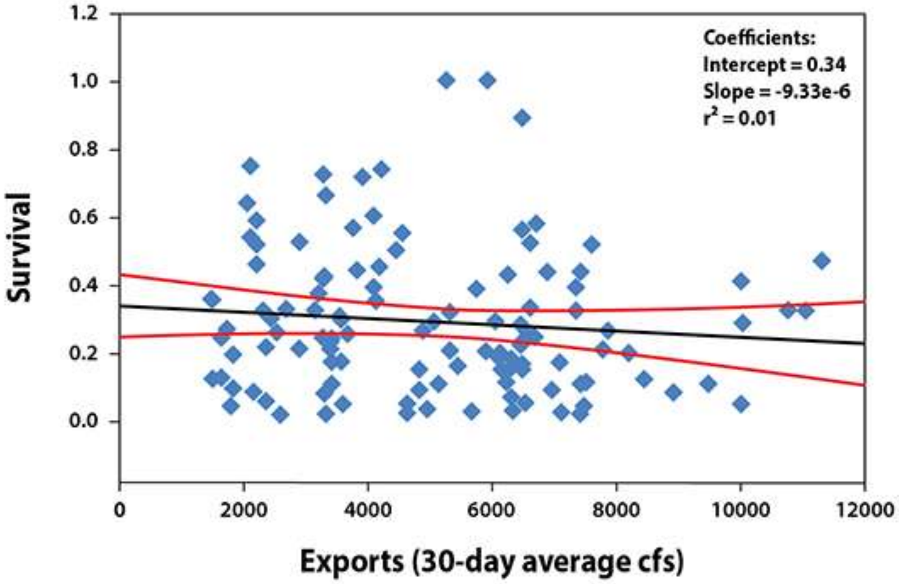

Figure 7-8. **Relationship between SWP and CVP exports (30-day average) and Delta salmon survival (1980-2001).**

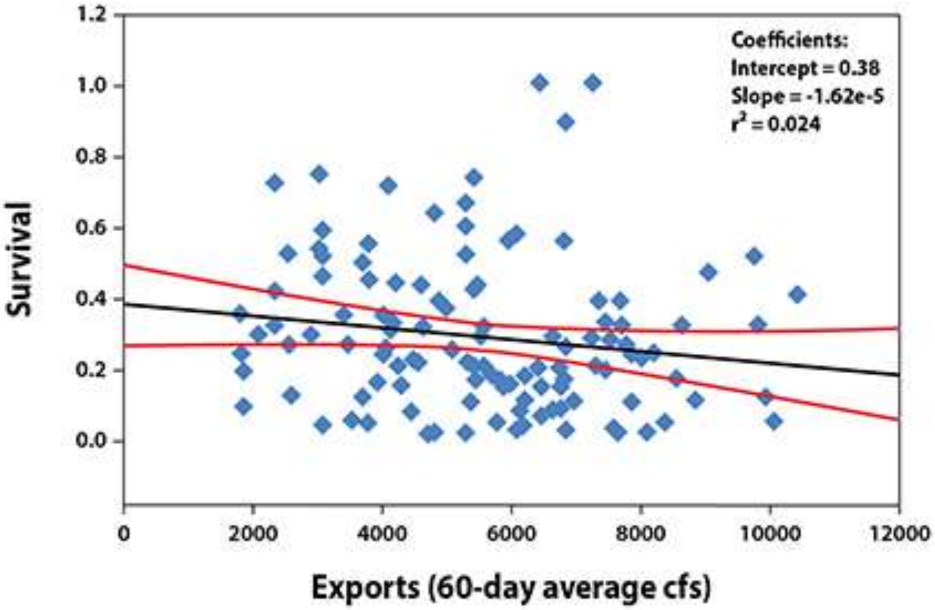

Figure 7-9. **Relationship between SWP and CVP exports (60-day average) and Delta salmon survival (1980-2001).**

The relationship between juvenile salmon survival in the Delta and combined SWP and CVP export rates was not statistically significant for either the 30-day average export rate ($p=0.27$) or the 60-day average export rate ($p=0.1$). Results of these analyses show that SWP and CVP exports, overall, are a small incremental factor affecting survival of juvenile salmon and that regulating exports would not have a strong predictive effect on total survival of juvenile salmon within the Delta.

7.1.1.4 River Flow Rates and Salmon Survival

Results of the USFWS CWT survival studies were also used to explore the interrelationship, if any, between juvenile salmon survival and general environmental factors, such as Sacramento River flow, Delta inflow and Delta outflow. Results of our analyses showed similar relationships between Delta survival and Sacramento River flow, Delta inflow, and Delta outflow (all were significant at $p<0.001$) for both the 30-day and 60-day averaging periods. (Because Sacramento River flow, Delta inflow, and Delta outflow were all found to be autocorrelated, only Sacramento River results are presented in the following analyses).

For example, Figures 7-10 and 7-11 show the relationship between juvenile salmon survival and average Sacramento River flows (cfs) 30 and 60 days prior to the date of last recapture. Although these relationships show a statistically significant increasing trend in survival as river flow increases ($p < 0.001$ for both the 30-day and 60-day average flow rates) during the emigration period, the relationships are characterized by high variability (low r^2 values for the regression analyses; $r^2=0.18$ for the 30-day average flow and $r^2=0.17$ for the 60-day average flow).

It has been hypothesized that juvenile salmon migrate downstream at a faster rate when Sacramento River flows are higher. A faster rate of downstream migration in response to higher river flows would be expected to reduce the time during which juvenile salmon are vulnerable to predation mortality. *Results of the analysis of CWT salmon released into the upper Sacramento River, however, did not detect any relationship between juvenile transit rate as a function of average Sacramento River flow over either a 30-day (Figure 7-12) or 60-day (Figure 7-13) period. Instead, the data showed that increasing Sacramento River flow does not result in increased salmon migration rates through the river and Delta*. Results of acoustic tag studies conducted by Michel (2010) suggest that there are differences in reach-specific migration rates (Figure 7-3) that could not be detected based on analysis of the CWT releases. Analysis of the CWT study results also showed an increasing trend in juvenile salmon survival as a function of fish size (Figure 7-14). These results are consistent with other studies that show increased juvenile salmonid survival as the fish grow larger (Reisenbichler *et al.* 1981).

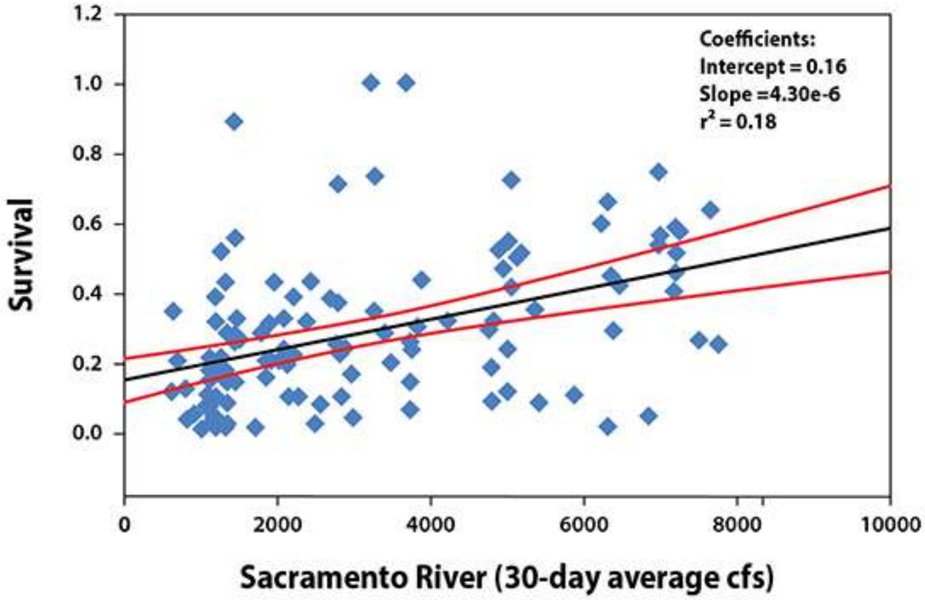

Figure 7-10. **Relationship between Sacramento River flow (30-day average) and Delta salmon survival (1980-2001).**

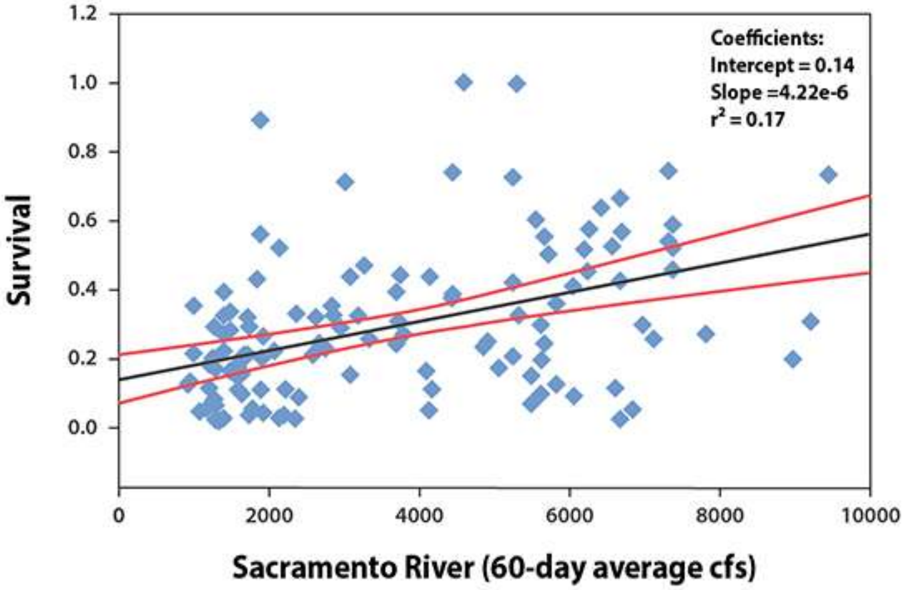

Figure 7-11. **Relationship between Sacramento River flow (60-day average) and Delta salmon survival (1980-2001).**

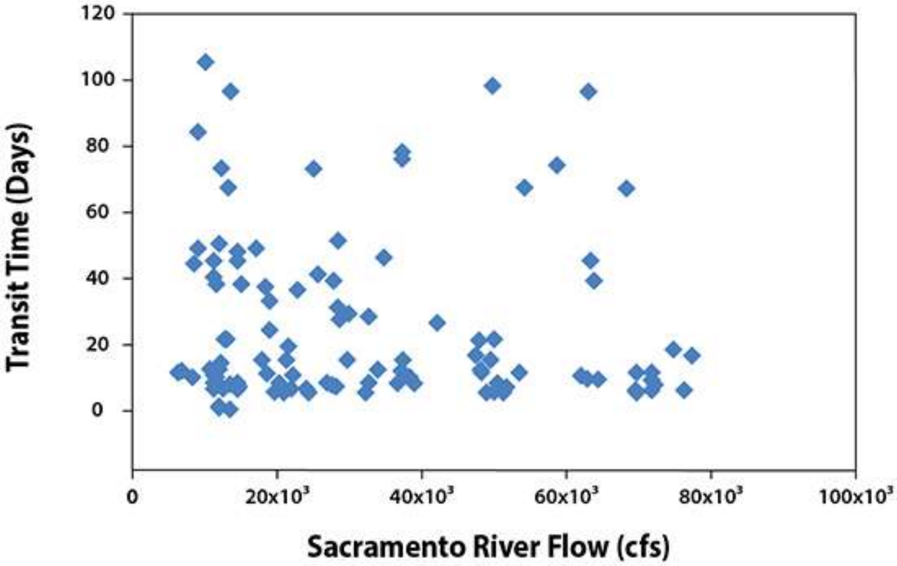

Figure 7-12. **Relationship between Sacramento River flow (30-day average) and salmon transit time (1980-2001).**

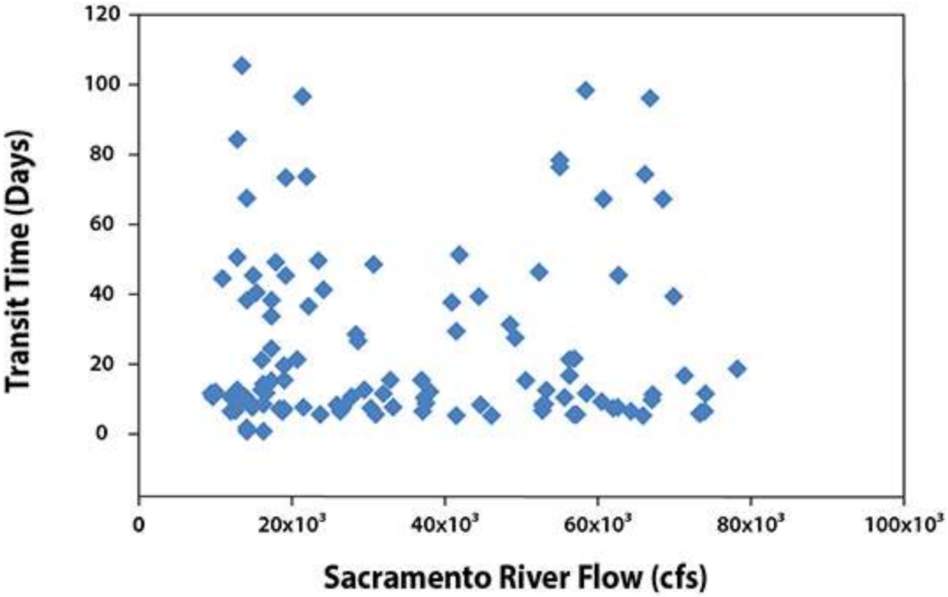

Figure 7-13. **Relationship between Sacramento River flow (60-day average) and salmon transit time (1980-2001).**

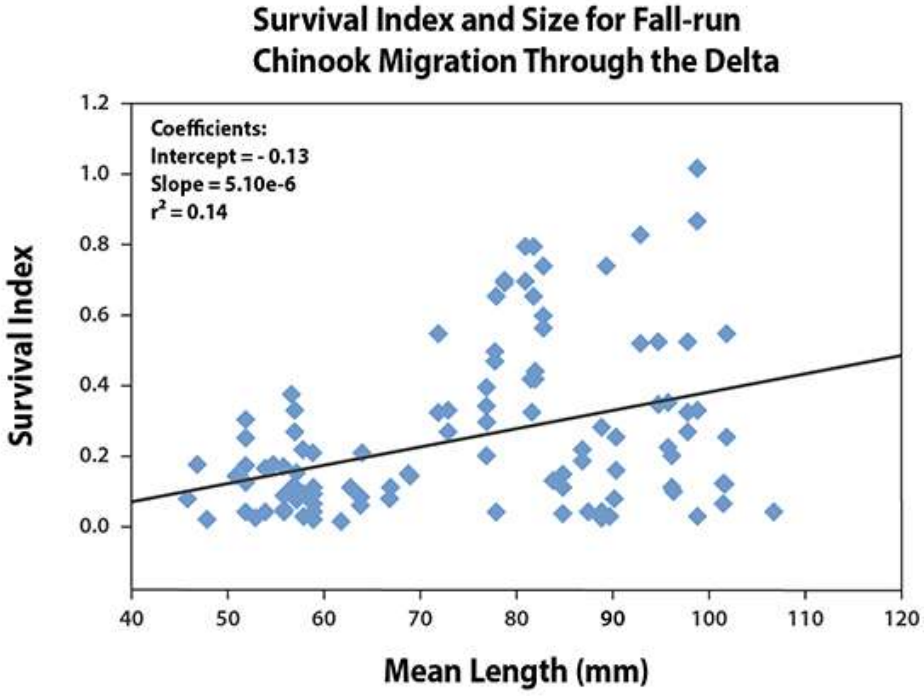

Figure 7-14. Relationship between salmon length at release and survival (1980-2001).

7.1.1.4.1 Multiple Linear Regression Analyses

A multiple linear regression analysis was used to examine the relative contribution of river and Delta flows and SWP and CVP export rates on observed juvenile salmon survival reflected in the USFWS CWT survival studies. Multiple regression analyses allow the statistical determination of the incremental contribution of various factors included in the analysis (some factors such as Delta Cross Channel gate operations, seasonal water temperature, fish health, etc. were not included in the regression analysis; variables included in the analysis were the percentage of tagged fish recaptured at the SWP and CVP salvage facilities, average length of salmon in each release group, Sacramento River flow, and combined SWP and CVP export rate) on observed total Delta survival (as estimated based on USFWS recaptures at Chipps Island).

The multiple regression analyses showed a statistically significant relationship between salmon survival and both fish length and Sacramento River flow. Results of the multiple regression analysis using the 30-day average river flow and export rates showed that the relationship between total Delta survival was significantly related to fish length ($p<0.001$) and Sacramento River flow ($p=0.003$), but not significantly related to either combined SWP and CVP export rate ($p=0.39$) or the percentage of fish salvaged ($p=0.95$). The overall relationship had a relatively low correlation coefficient ($r^2 = 0.29$). The statistical results showed a weak positive relationship between survival and both fish length and river flow, no significant relationship with SWP and CVP exports, and were characterized by high variation and low certainty.

The same analysis was undertaken using a 60-day period and produced similar results. The multiple regression analysis using the 60-day average Sacramento River flow and SWP and CVP combined export rate showed that total Delta survival was significantly related to fish length ($p<0.001$) and Sacramento River flow ($p=0.001$), but was not significantly related to either combined SWP and CVP export rate (p = 0.27) or the percentage of fish salvaged (p = 0.67). The overall relationship between Sacramento River flow and combined Project export rates had a relatively low correlation coefficient ($r^2 = 0.31$).

Results of our analyses were consistent in showing that total Delta survival of juvenile Chinook salmon during emigration through the Sacramento River and Delta was related to both fish size (larger juvenile salmon typically have higher survival rates) and Sacramento River flows (survival rates were higher at higher flows), but were not significantly related to either the percentage of the tag group salvaged at the SWP and CVP export facilities (direct loses) or combined SWP and CVP export rates (indirect effect).

The USFWS CWT mark-recapture studies provide useful and important information regarding the survival of juvenile Chinook salmon migrating through the lower Sacramento River and Delta. The studies have limitations in that capture efficiency varies within and among years in sampling at Chipps Island based on fish size, Delta outflow, and other factors. In addition, sampling at one location, such as Chipps Island, does not provide fine-grained resolution regarding salmonid migration pathways, the duration of migration through various reaches of the river and Delta, and the mortality rate within various reaches. Sampling at a single location also leads to a low probability of detection, particularly for larger juveniles that may avoid capture in conventional trawl sampling. To address many of these issues NMFS, the University of California, the U.S. Army Corps of Engineers, DWR, and others have recently implemented a large-scale acoustic tagging program to investigate salmonid migration patterns, pathways, rates, and mortality within the Sacramento River and Delta. Results of this acoustic tagging program are expected to provide improved understanding of the relationships between river and Delta flows, exports, and other factors on survival of juvenile salmon and steelhead (Klimley *et al.* 2012).

7.1.1.5 2012 JSATS Study

To address the above-described concerns and to provide more detailed information on the movement patterns, behavior, and survival of juvenile salmon, NMFS, UC Davis, Cramer Fish Sciences, DWR, and the USFWS are currently implementing an expanded acoustic tagging study (Hayes 2012). A pilot study using the Juvenile Salmon Acoustic Telemetry System (JSATS) to evaluate Sacramento River Chinook salmon emigrants was conducted during the spring of 2012. An array of 54 receivers was deployed from Battle Creek on the upper Sacramento and the Feather River to the Golden Gate in April 2012. Juvenile fall-run (410 fish) and spring-run (139 fish) Chinook salmon from the Coleman and Feather River hatcheries were tagged and released as part of various experiments. The juvenile salmon used in this pilot study ranged in length from 76-130 mm, thus demonstrating that acoustic tags can be successfully used to monitor movement and survival of smaller juvenile salmon (Hayes 2012). Results of the 2012 pilot study are not yet available but will be used in refining the experimental design for a larger study planned for 2013 (Hayes 2012).

The 2013 acoustic tag study will be designed to track the movement and survival of juvenile winter-run and spring-run Chinook produced in hatcheries, as well as wild fall-run and spring–run juvenile Chinook collected from Deer and Mill creeks. Beginning in the fall of 2012 and continuing through spring 2015, the team will work to (1) install an array of acoustic tag receivers throughout the Sacramento Basin (approximately 100 receivers), (2) conduct tagging and release efforts on roughly 1000 to 1500 acoustically tagged juvenile salmonids per year, (3) manage a joint data base on all data and (4) conduct laboratory experiments regarding tagging effects on fish survival. The release sites and receiver locations for the expanded acoustic study are shown in Figure 7-15. Data to be collected from these new acoustic tag studies will significantly advance the scientific understanding of juvenile salmon migration on the Sacramento River, inform future management decisions, and address a number of areas of uncertainty. Data from similar acoustic tag studies to be conducted on juvenile steelhead as part of the Six Year study on the San Joaquin River are also expected to substantially advance our understanding of salmonid biology in the Central Valley.

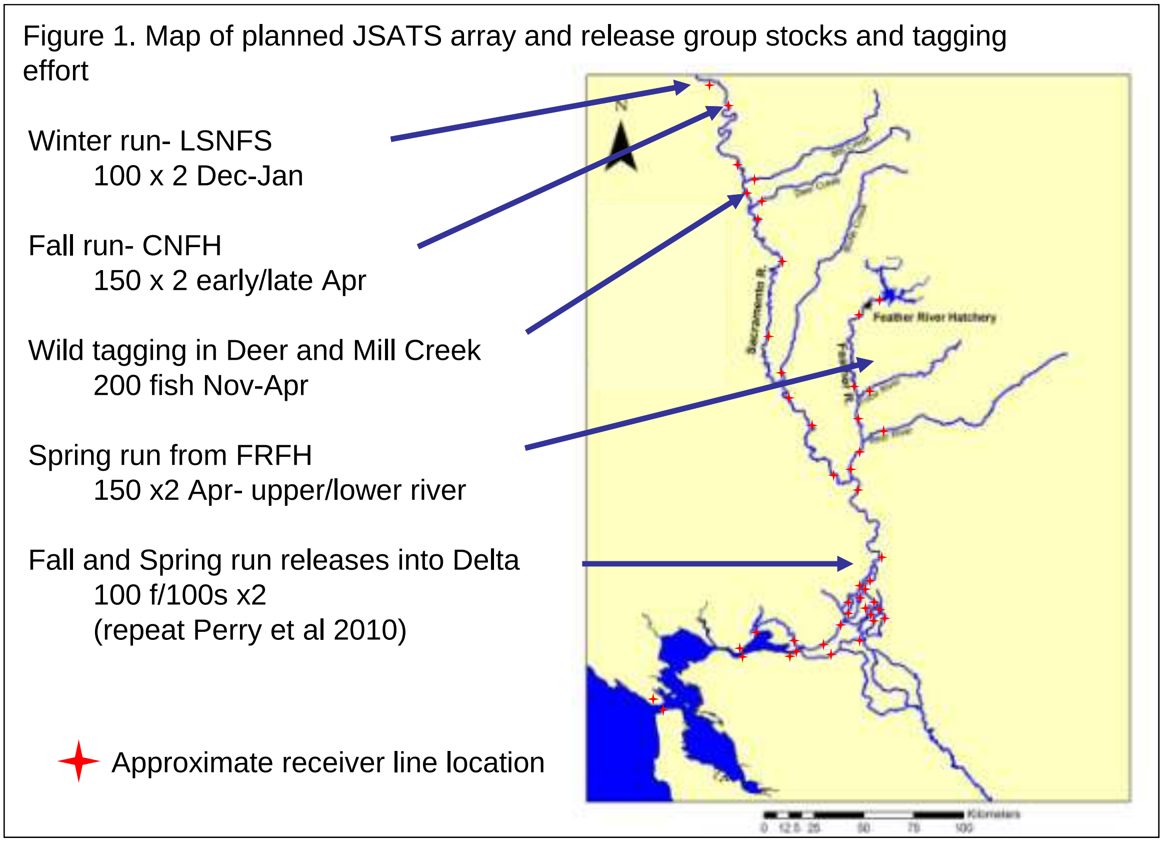

Figure 1. Map of planned JSATS array and release group stocks and tagging effort

Winter run- LSNFS
100 x 2 Dec-Jan

Fall run- CNFH
150 x 2 early/late Apr

Wild tagging in Deer and Mill Creek
200 fish Nov-Apr

Spring run from FRFH
150 x2 Apr- upper/lower river

Fall and Spring run releases into Delta
100 f/100s x2
(repeat Perry et al 2010)

✦ Approximate receiver line location

Figure 7-15. Map of the study area for acoustic tracking of hatchery and wild juvenile salmon on the Sacramento River, Delta, and estuary (Source: Hayes 2012).

7.1.1.6 Non-Physical Barrier at Georgiana Slough

Results of survival studies using both CWT and acoustically tagged juvenile salmon (Brandes and McLain 2001, Perry 2010) suggest that juvenile salmon may experience greater mortality if they migrate from the Sacramento River into the interior Delta through Georgiana Slough. Georgiana Slough (Figure 7-16) is a natural channel that meets the Sacramento River near Walnut Grove. It has been hypothesized that the increased juvenile salmon mortality observed for those fish that enter the slough results from their longer migration pathway and resulting increased exposure to water diversions and predators within the Delta. Georgiana Slough serves as an important channel for recreational boating. Sacramento River water flowing into the channel improves interior Delta water quality. Therefore, blocking the slough entirely for the purpose of guiding juvenile salmon down the mainstream Sacramento River is not feasible. As an alternative to a physical barrier (e.g., radial gates such as those used at the Delta Cross Channel or a rock barrier such as that used at the Head of Old River), DWR investigated the use of a non-physical barrier at Georgiana Slough.

Combining underwater light, sound, and air bubbles the non-physical barrier discourages salmon from entering the interior Delta. The non-physical barrier was installed and tested in the Sacramento

River at Georgiana Slough during the winter and spring of 2011 and 2012 (Figure 7-17; DWR 2012). Acoustically tagged late fall-run Chinook salmon produced at the Coleman Hatchery (and juvenile steelhead in 2012) were released into the Sacramento River immediately downstream of the confluence of Steamboat Slough, approximately 6 miles upstream of Georgiana Slough (Figure 7-18) to test the barrier's efficacy. Small groups of tagged fish were released at intervals throughout the day and night to represent various sunlight and tidal conditions. The barrier was cycled on and off during the tests. Tagged salmon were monitored using a three-dimensional acoustic tracking network (Figure 7-19) to determine their movement, behavior, and response, as well as the barrier's guidance efficiency. Analyzing the three-dimensional "tracks" left by each tagged fish, predation estimates could also be made as juvenile salmon pass through the study area. The results conducted in 2011 are reported by DWR (2012). The 2012 results are currently being reviewed.

The Georgiana Slough studies provide another example of the recent application of sophisticated acoustic tagging studies to investigate the response of juvenile salmon to flow splits, tidal currents, and water velocities, as well as the species' behavioral response to environmental conditions within the Delta. The studies also serve as a powerful tool for assessing the effectiveness of a potential non-physical barrier management action for protecting and improving the survival of juvenile salmonids as they migrate downstream through the Sacramento River and Delta. Through the application of experiments and improving technology, substantial strides have been made in understanding salmon biology in the Delta over the past 5 years. Expanded studies are currently being planned and implemented that will further contribute to the body of scientific information available for making management decisions.

Figure 7-16. Delta map showing Georgiana Slough (DWR 2012).

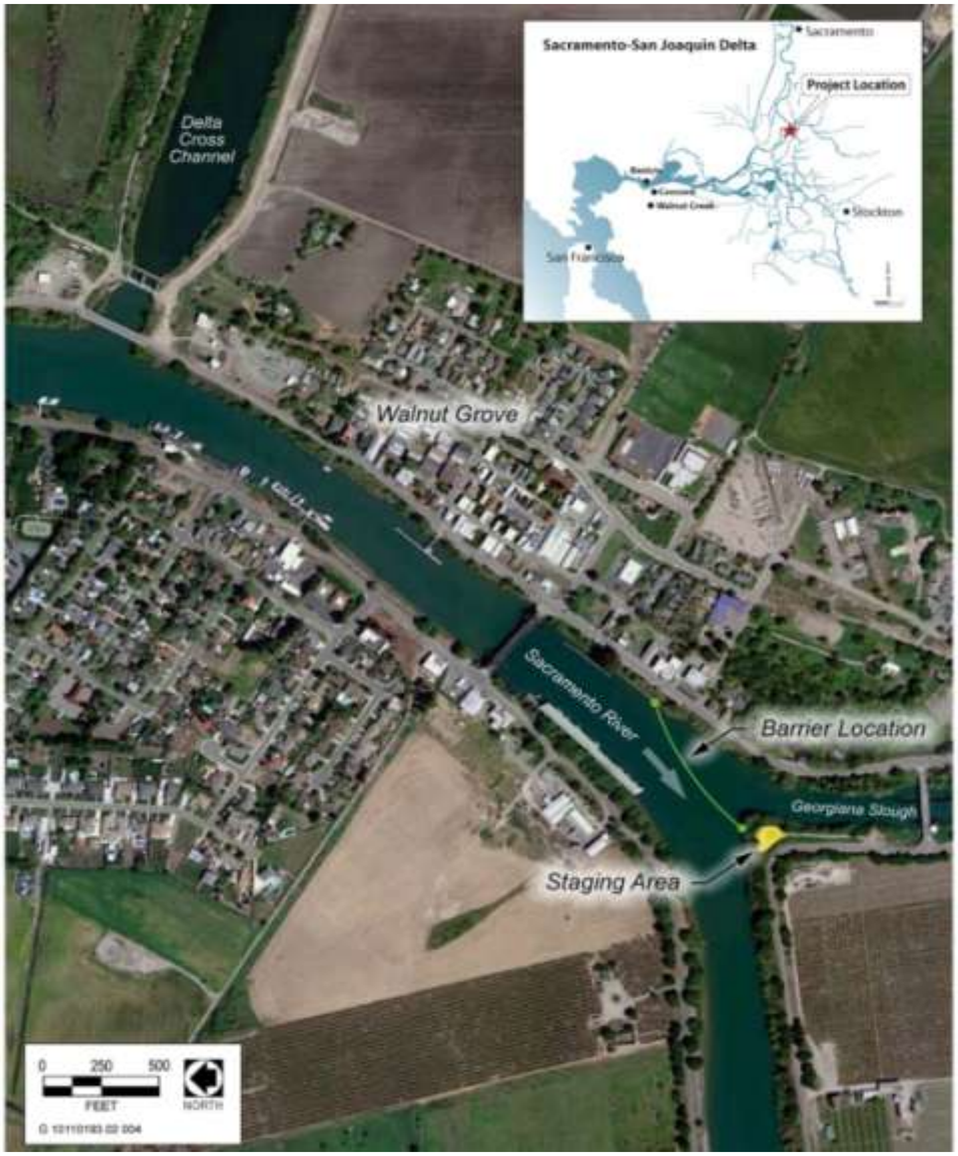

Figure 7-17. Sacramento River in the vicinity of Walnut Grove showing the location of the non-physical barrier tested in 2011 and 2012 (DWR 2012).

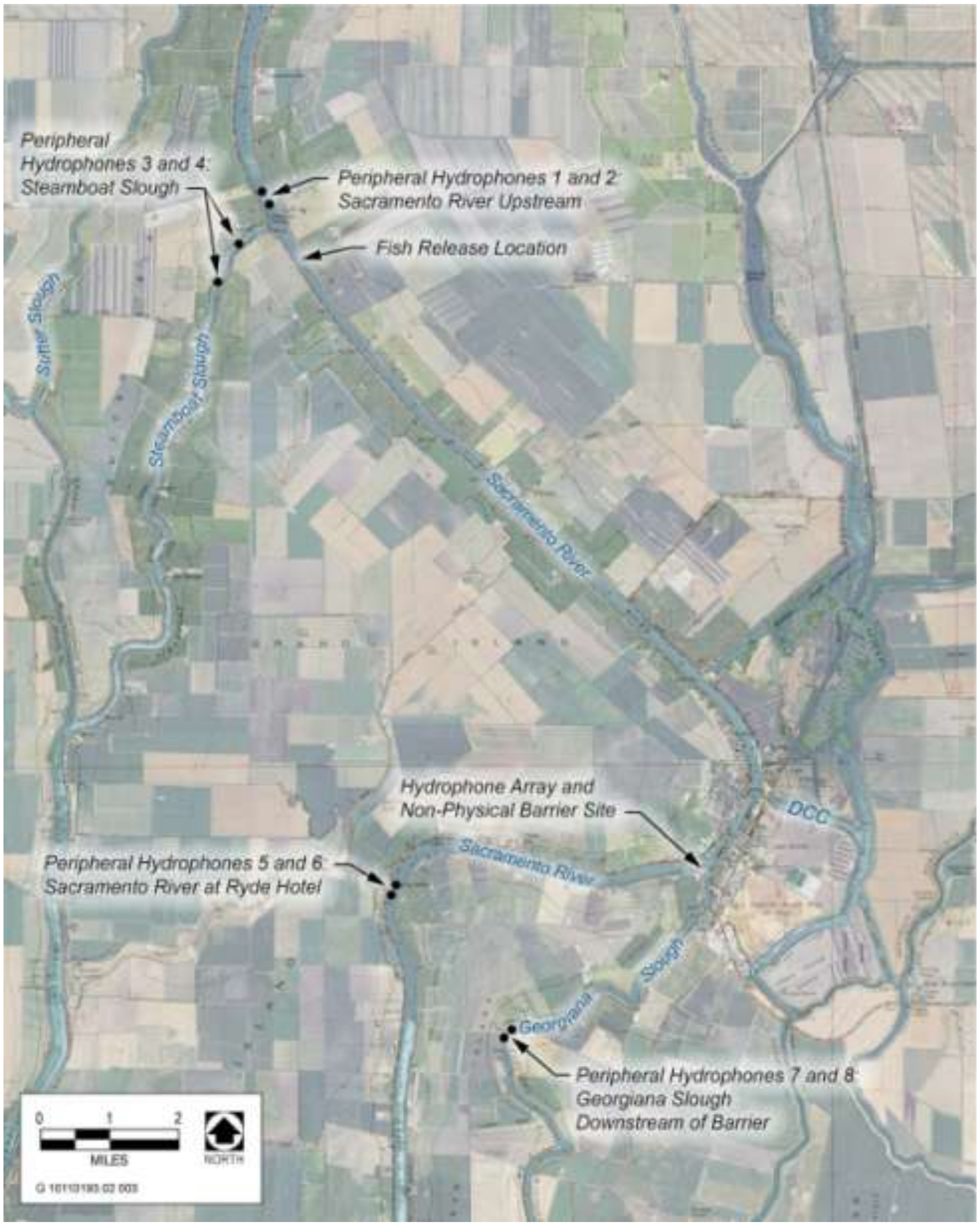

Figure 7-18. Map showing the basic experimental design for the 2011 and 2012 Georgiana Slough non-physical barrier acoustic tag tests (DWR 2012).

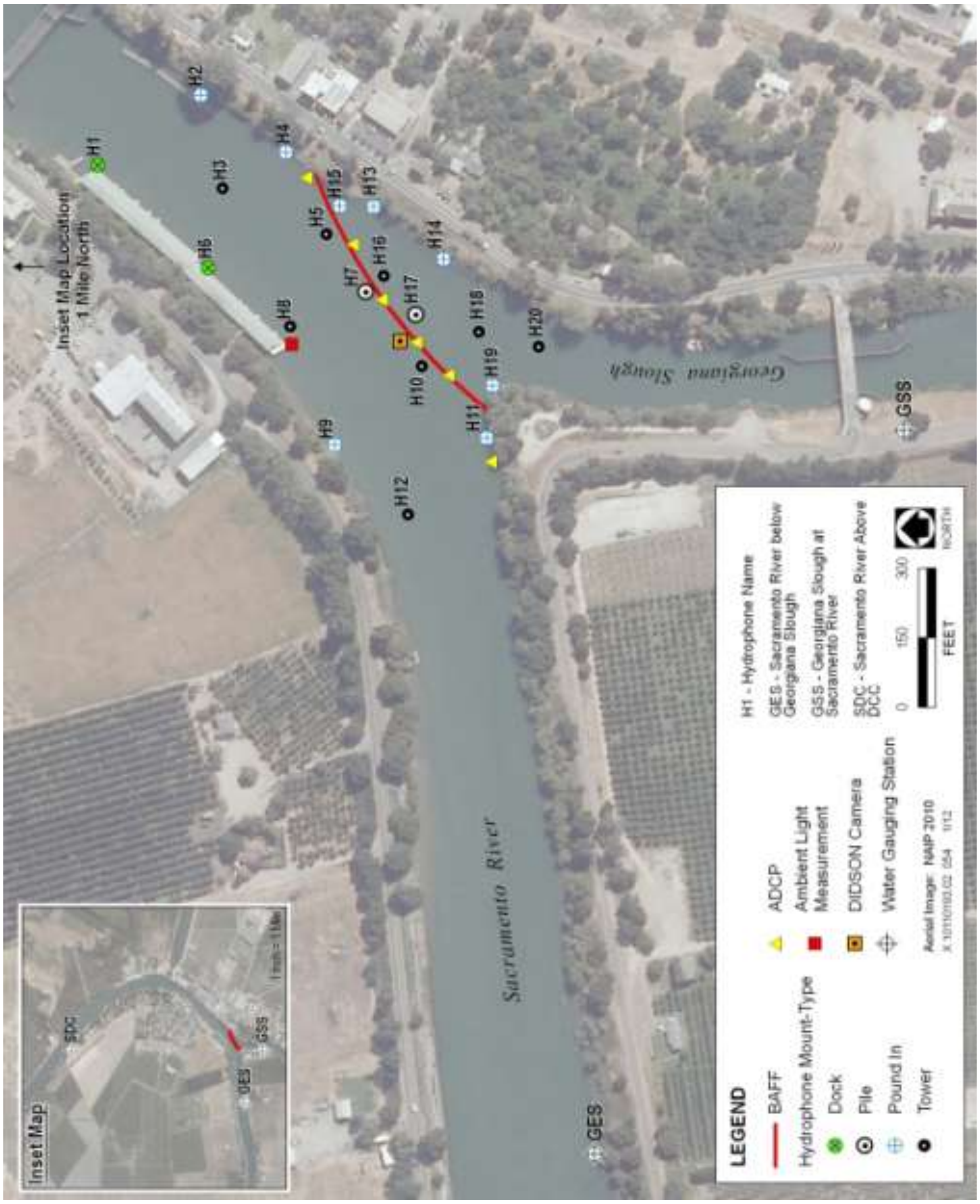

Figure 7-19. **Deployment of 3-dinensional acoustic tag detector array associated with the Georgiana Slough non-physical barrier tests (DWR 2012).**

8 San Joaquin River System

8.1 Background on Salmonid Use of San Joaquin River System

The primary San Joaquin River tributaries—the Merced, Tuolumne, and Stanislaus rivers—support spawning and rearing of fall-run Chinook salmon. These tributaries also support small populations of steelhead, as well as resident rainbow trout and other fish species. A fish hatchery located on the Merced River produces juvenile fall-run Chinook salmon. Restoration efforts are underway to re-establish self-sustaining, naturally reproducing populations of spring-run and fall-run Chinook salmon on the mainstem San Joaquin River downstream of Friant Dam (USBR 2012).

The San Joaquin River basin fall-run Chinook salmon population has been characterized by high variability in adult returns to the river system (Figure 8-1) that reflect a pattern in abundance thought in part to reflect cyclical ocean rearing conditions (e.g., Pacific Decadal Oscillation) although no detailed analyses have been developed to rigorously test the potential relationship between ocean conditions and adult salmon returns to the San Joaquin River basin. In addition, the San Joaquin River tributaries and mainstem river are characterized by substantially less freshwater runoff when compared to the Sacramento River basin, which is reflected in lower instream flows and frequently greater seasonal water temperatures that affect habitat quality and availability, reproductive success, survival, and overall abundance of Chinook salmon and steelhead within the San Joaquin basin. Striped bass and other predatory fish are common in the lower reaches of the river, particularly in the spring months when juvenile salmonids are migrating downstream through these reaches.

The lower San Joaquin River channels contain little to no seasonally inundated floodplain at typical late winter and spring flow levels. With adequate flows, these areas would otherwise serve as habitat and provide increased organic material and food supplies to juvenile rearing salmon and other aquatic species. Historically, an area of depressed dissolved oxygen in the vicinity of the Stockton shipping channel contributed to decreased habitat quality in the lower reach of the river. Efforts to provide additional aeration have led to recent improvements in dissolved oxygen concentrations in the lower river (Newcomb 2010).

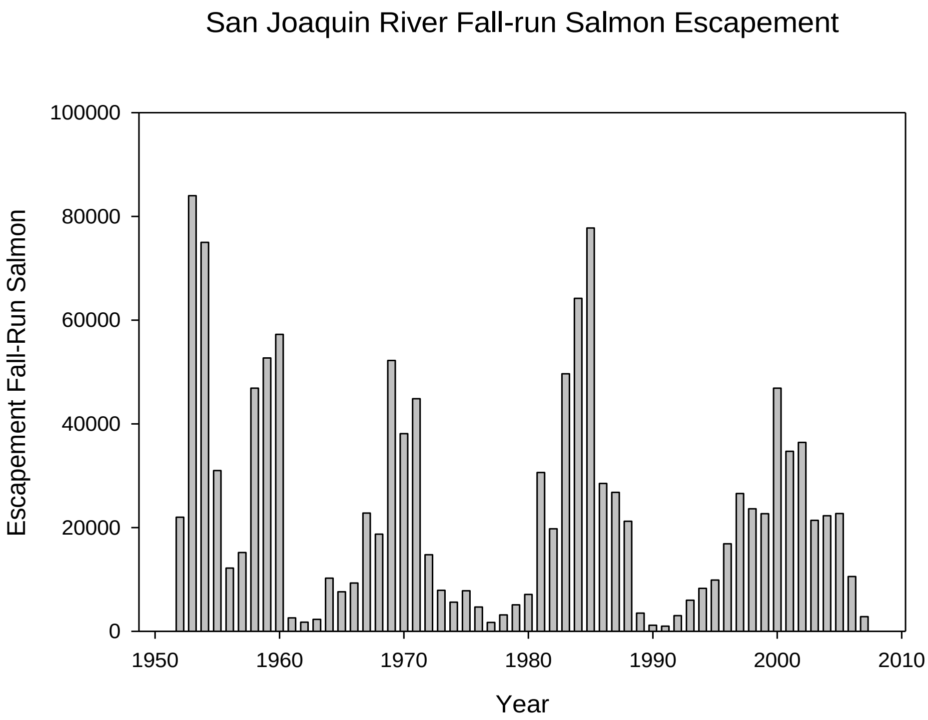

Figure 8-1. Adult fall-run Chinook salmon escapement to the San Joaquin River basin (Source: GranTab 2011).

8.1.1 Head of Old River

The Head of Old River is a channel that diverges from the lower San Joaquin River downstream of Mossdale. Old River can serve as a pathway for juvenile salmonids to migrate from the mainstem river into the interior Delta. Juvenile salmon mortality rates in the interior Delta are generally thought to be higher than for salmon in the mainstem San Joaquin River based on results of CWT survival studies.

CWT survival studies conducted using juvenile fall-run Chinook salmon released into the lower San Joaquin River show greater salmon survival when the temporary rock barrier is installed at the Head of Old River during the spring (SJRGA 2006). From 2000 to 2004 and in 2007, a physical (rock) barrier was installed at the Head of Old River (HORB) when river flow was less than 7,000 cfs to block the movement of salmon smolts into Old River and to encourage the fish to continue their migration down the San Joaquin River’s mainstem. High flows in 2005 and 2006 prohibited installation of the barrier. Due to concerns about delta smelt protection expressed by the Delta Smelt Working Group and as a result of orders issued by the Court in *NRDC v. Kempthorne*, the HORB physical barrier has not been installed since 2008.

In 2009 DWR, in cooperation with Reclamation, began testing a non-physical behavior barrier at the Head of Old River. The non-physical barrier included a combination of light, sound, and air bubble curtains to guide juvenile salmon away from the Head of Old River and to encourage their downstream migration in the mainstem lower San Joaquin River. Installing the non-physical (bubble) barrier was premised, in part, on extensive laboratory and field testing of such barriers over the past several decades.

San Joaquin-Old River non-physical barrier field testing occurred in the spring (April-May) of 2009 and 2010 (Bowen *et al.* 2009, Bowen and Bark 2010). The bubble barrier’s effectiveness in guiding juvenile salmon away from entering Old River was analyzed based on a series of comparative tests with the barrier on and off. Preliminary results in 2009 show that the barrier was approximately 80 percent effective in deterring tagged juvenile salmon from entering Old River. (Figure 8-2 shows an example of an acoustically tagged salmon that was effectively guided downstream into the mainstem San Joaquin River by the barrier). The results also showed that predation on juvenile salmon within a scour hole in the San Joaquin River immediately downstream of the barrier altered salmon behavior and survival (Figure 8-3 shows an example of a juvenile Chinook salmon that was preyed on in the vicinity of the barrier).

The non-physical barrier data show that the barrier can provoke a strong behavioral response by juvenile salmon that may substantially reduce juvenile salmon migration into Old River. Testing the non-physical bubble barrier in spring 2009 and 2010 showed high guidance efficiency that could potentially be used to reduce the risk of juvenile salmon migrating into Old River and, thereby, reduce the risk of entrainment and salvage losses. The 2009 and 2010 studies also showed high predation rates on juvenile salmon in the area adjacent to and immediately downstream of the barrier.

The 2009 and 2010 bubble barrier tests provide strong evidence that a non-physical barrier, although requiring further testing, has the potential to reduce the vulnerability of Chinook salmon to entrainment losses and to increase juvenile survival for Chinook salmon migrating downstream in the lower San Joaquin River.

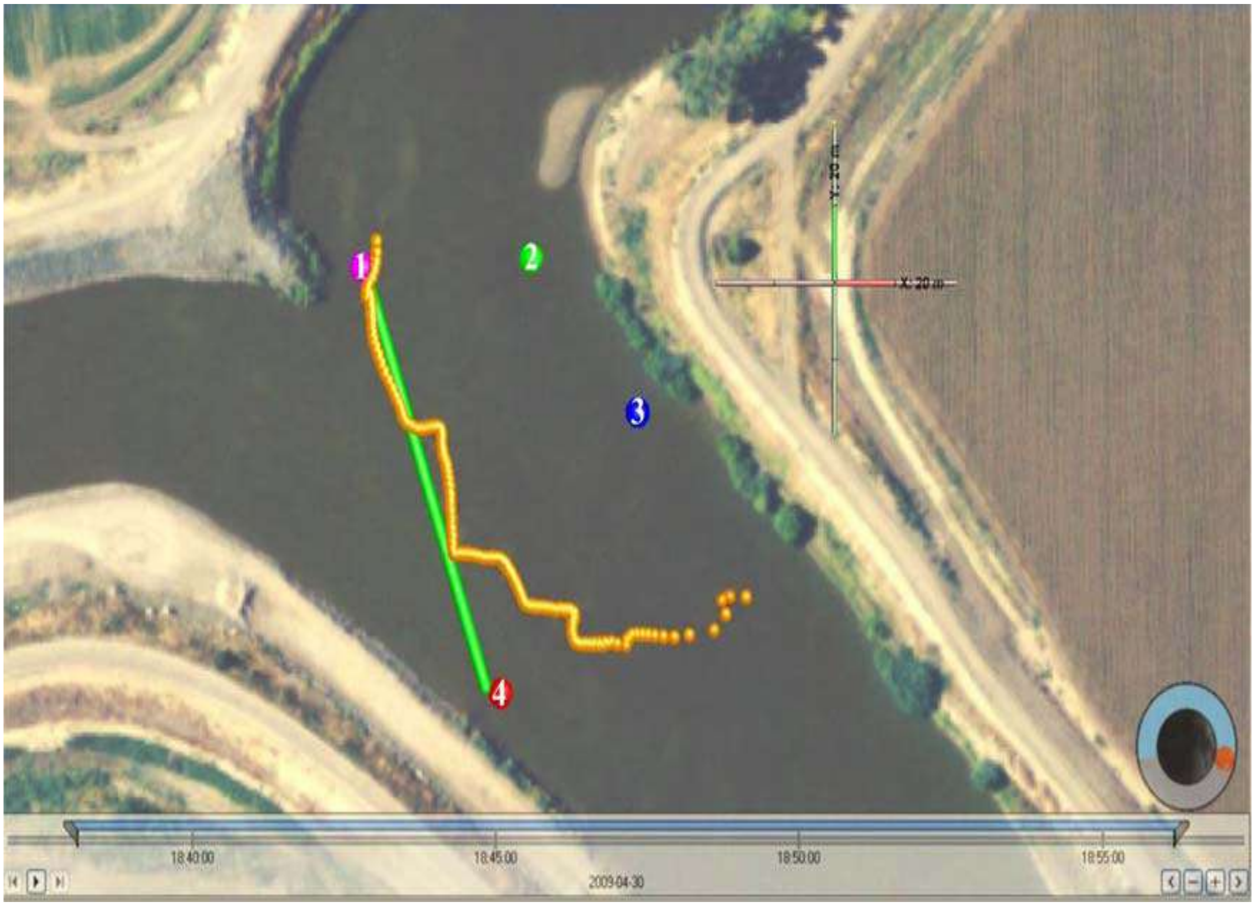

Figure 8-2. **Acoustic tag tracking results for a juvenile Chinook salmon (yellow track) that was effectively guided downstream by the non-physical barrier (green line) at the Head of Old River (Source Bowen *et al.* 2009).**

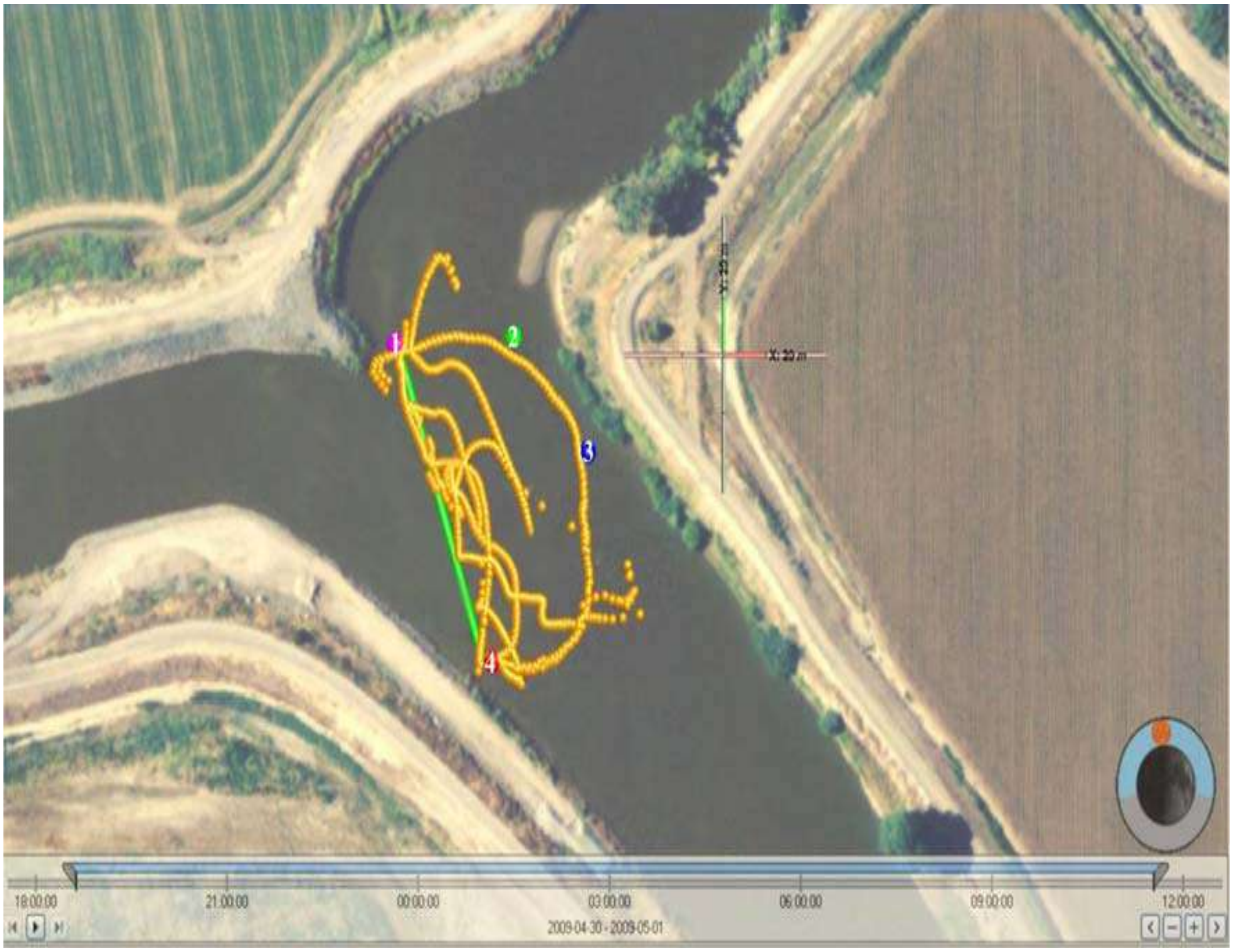

Figure 8-3. **Acoustic tag tracking results for a juvenile Chinook salmon (yellow track) that was preyed upon in the vicinity of the non-physical barrier (green line) at the Head of Old River (Source Bowen *et al.* 2009).**

8.1.2 VAMP Studies: Juvenile Chinook Salmon Survival

The 1995 SWRCB Water Quality Control Plan (D-1641) established the VAMP to investigate the effects of San Joaquin River flows at Vernalis, SWP and CVP exports, and the installation of the Head of Old River Barrier on juvenile salmonid survival. The studies, which became known as “The San Joaquin River Agreement” and VAMP, are integral parts of D-1641 and served as the cornerstones of a commitment to implement the Water Quality Control Plan for the lower San Joaquin River and the San Francisco Bay-Delta Estuary. The VAMP experimental design was developed to address concerns with earlier survival studies conducted during periods when river flows were highly variable. Those earlier studies contributed to increased uncertainty about the relationship between river flow and juvenile salmon survival.

The VAMP experiment was initiated in 2000 as a large-scale, long-term (12-year) management program designed to protect and study juvenile Chinook salmon migrating from the San Joaquin River through the Sacramento-San Joaquin Delta. It was also intended as a scientific experiment to determine how salmon survival rates may change in response to alterations in San Joaquin River flows and SWP/CVP exports with the HORB installed.

VAMP’s specific experimental objectives included quantification of juvenile salmon smolt survival under a set of six San Joaquin River flow rates (3,200 to 7,000 cfs) and SWP/CVP export rates (1,500 to 3,000 cfs). To achieve these objectives, VAMP provided for a steady pulse flow (target flow) at the Vernalis gauge on the San Joaquin River (upstream of the Delta) during a consecutive 31-day period in the months of April and May, along with a simultaneous reduction in SWP/CVP exports. The specific VAMP target flow and Delta export levels were established based on a forecast of the San Joaquin River flow that would occur during the pulse flow period absent the VAMP (Existing Flow). Any supplemental water (beyond otherwise existing San Joaquin River flows) needed to achieve the VAMP target flows, up to a limit of 110,000 acre-feet, was provided by the San Joaquin River Group Authority member agencies through coordinated operation of dams on the three major San Joaquin River tributaries upstream of Vernalis: the Merced River, the Tuolumne River and the Stanislaus River.

The original experimental design for VAMP also included two mark-recapture studies to be performed each year during the mid-April to mid-May juvenile salmon outmigration period to provide estimates of salmon survival under each of the six sets of VAMP San Joaquin River flow rates and CVP/SWP export rates. Chinook salmon survival indices under each of the experimental conditions were to be calculated based on the numbers of marked salmon released and recaptured in each year. Absolute survival estimates were also to be calculated and used to evaluate relationships between salmon survival and San Joaquin River flow and CVP and SWP exports.

The original VAMP experimental design included multiple release locations (Durham Ferry, Mossdale, and Jersey Point; Figure 8-4), and multiple recapture locations (Antioch, Chipps Island, SWP and CVP salvage operations, and in the ocean fisheries). The use of data collected from multiple release and recapture locations was intended to allow for more thorough evaluation of juvenile Chinook salmon survival (as compared with recapture data based upon one sampling location and/or one series of releases). The VAMP release and recapture locations were consistent from one year to the next, providing a greater opportunity to assess salmon survival over a range of Vernalis flows and SWP/CVP exports, with and without the presence of the HORB. Releases of juvenile salmon smolts at Jersey Point served as a control for recaptures at Antioch and Chipps Island. This allowed for the calculation of survival estimates based on the ratio of survival indices from marked salmon recaptured from upstream (Durham Ferry and Mossdale) and downstream (control release at Jersey Point) releases. The use of ratio estimates as part of the VAMP study design factored out potential differential gear efficiencies at Antioch and Chipps Island within and among years. The studies used CWT juvenile Chinook salmon during the early years of the survival program and acoustically tagged juvenile salmon during later years.

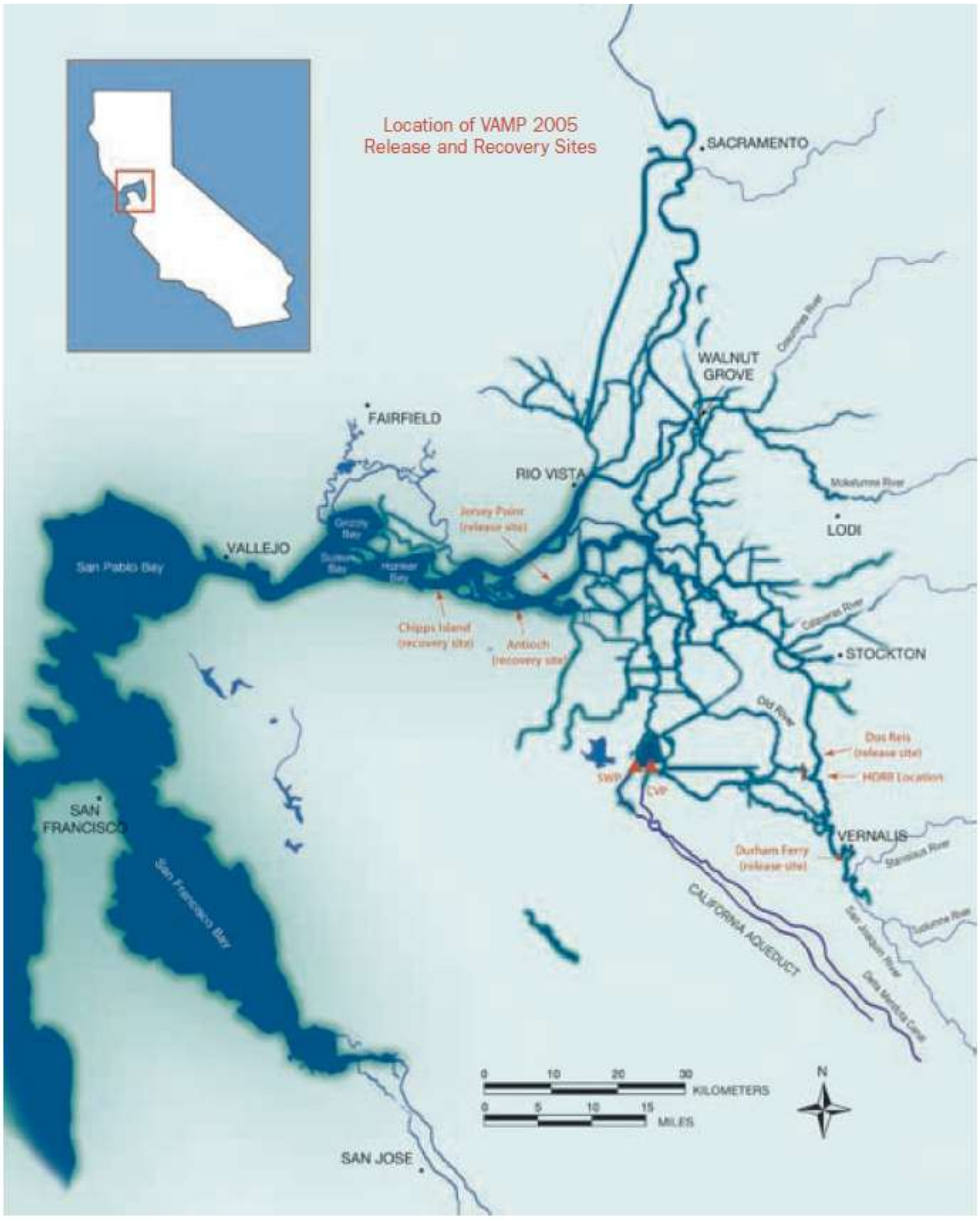

Figure 8-4. Map showing the location of VAMP survival study release and recapture sites for CWT juvenile Chinook salmon.

The VAMP experimental test conditions, namely, flow at Vernalis, SWP/CVP export rates, and the I:E ratio, between April 2000 and May 2010 are summarized in Table 8-1. As reflected in the table, in all years but 2001, the I:E ratio tested rarely exceeded 2:1 by a significant amount (San Joaquin River flows to exports). At no time did the ratio of flows to exports under VAMP exceed 3:1, with the exception of the high flow years (2005 and 2006) when (contrary to the study design) the HORB could not be installed.

Table 8-1. Summary of river flows, export rates, and the ratio of inflow to exports tested as part of VAMP between 2000 and 2010.

Year	Vernalis Flow (cfs)	SWP/CVP Exports (cfs)	San Joaquin River Inflow:Export rate
April 15-May 15, 2000	5,869	2,155	2.7:1
April 15-May 15, 2001	4,224	1,420	3:1
April 15-May 15, 2002	3,301	1,430	2.3:1
April 15-May 15, 2003	3,235	1,446	2.2:1
April 15-May 15, 2004	3,155	1,331	2.4:1
May 1-31, 2005[1]	10,390	2,986	3.4:1
May 1-31, 2006[1]	26,020	1,559/5,748	16.7:1/4.5:1
April 22-May 22, 2007[2]	3,263	1,486	2.2:1
April 22-May 22, 2008[2]	3,163	1,520	2.1:1
April 19-May 19, 2009[2]	2,260	1,990	1.1:1
April 25 – May 25, 2010[2]	5,140	1,520	3.4/1

[1] The HORB was not installed in 2005 and 2006 as a result of high river flow.

[2] The designed CWT survival studies were not conducted in 2007-2011. Studies undertaken in those years were modified to examine species behavior and vulnerability to predation using acoustically tagged juvenile salmon.

Between 2000 and 2006, the full VAMP study plan required the use of 400,000 CWT Chinook, but in several years, the full allocation was not provided due to the limited number of available juvenile fall-run Chinook salmon from the Merced Hatchery and competition with other studies.

During 2007, a sufficient number of test fish were not available from the Merced River Fish Hatchery to permit a CWT study. Instead, an acoustic telemetry monitoring study was performed that year, which used fewer than 1,000 juvenile salmon (this study design continued through 2011). Juvenile Chinook salmon from the Merced River Hatchery were surgically implanted with acoustic transmitters (Figure 6-1) capable of emitting an electronic signal for up to 3 weeks. Chinook salmon survival indices under the experimental conditions using the acoustic-tagged salmon were not possible due to the lack of acoustic receivers at Jersey Point and Chipps Island. However, detailed data were collected regarding salmon smolt behavior and mortality conditions within the south Delta.

8.1.2.1 VAMP Study Results

The VAMP survival studies using CWT juvenile hatchery-raised salmon and conducted between 2000 and 2006 showed the following:

- As a result of hydrologic conditions, the studies conducted reflected San Joaquin River inflow to SWP and CVP exports limited to ratios of approximately 2:1 or greater, rather than the greater range of flow and export conditions anticipated in the original study design;
- The VAMP studies conducted when San Joaquin River flows were less than 7,000 cfs did not test juvenile steelhead survival or river flow to export ratios of 4:1 or more, per the experimental design;

- The studies did not identify a statistically significant relationship between salmon survival and SWP/CVP exports;
- Survival of juvenile salmon during their downstream migration was found to be significantly related to flow levels in the San Joaquin River at Vernalis when the HORB was installed (Figure 8-5). There were substantially lower juvenile salmon survival rates as a function of flow when the HORB was not installed (Figure 8-5);
- The relationship between juvenile salmon survival and the ratio of flow/exports was characterized by high variability (Figure 8-6);
- There was no clear relationship between smolt survival and San Joaquin River flow without the HORB installed within the range of flows actually tested under VAMP. However, an apparent relationship was identified between adult escapement and Vernalis flow during the juvenile migration period 2-1/2 years earlier (Figure 8-7) when examined over a wider range of flow conditions (SJRGA 2006);
- Regressions between survival from Mossdale and Durham Ferry to Jersey Point using Chipps Island, Antioch, and ocean recoveries showed no clear relationship with flow/export ratios within the range of E:I ratios tested under VAMP. However, an apparent relationship was identified between adult escapement and the E:I ratio 2-1/2 years earlier when tested over a wider range of E:I ratios (Figure 8-8); and
- Survival tests conducted when river flow:export rates were greater than 3:1 (2005 and 2006) occurred during high flow conditions in the river that were outside the framework of managed flows included in the VAMP experimental design. High flow conditions in these years also prevented installation of the barrier at the Head of Old River. Because increased river flow was found to be a significant factor affecting juvenile survival in the VAMP studies, the effect of exports under high river flow conditions (i.e., when ratios of flow:export that were greater than 3:1) could not be detected statistically.

Results from the modified VAMP studies of acoustically tagged juvenile salmon conducted from 2007 to 2011 showed:

- Predation is a major source of mortality for juvenile salmon in the lower San Joaquin River and Delta;
- Acoustic tagging offers the opportunity to examine fish behavior and migration within the lower San Joaquin River and Delta; however, the number of fish tagged and monitored in the modified VAMP studies was low, and numerous technical problems emerged while implementing these studies; and

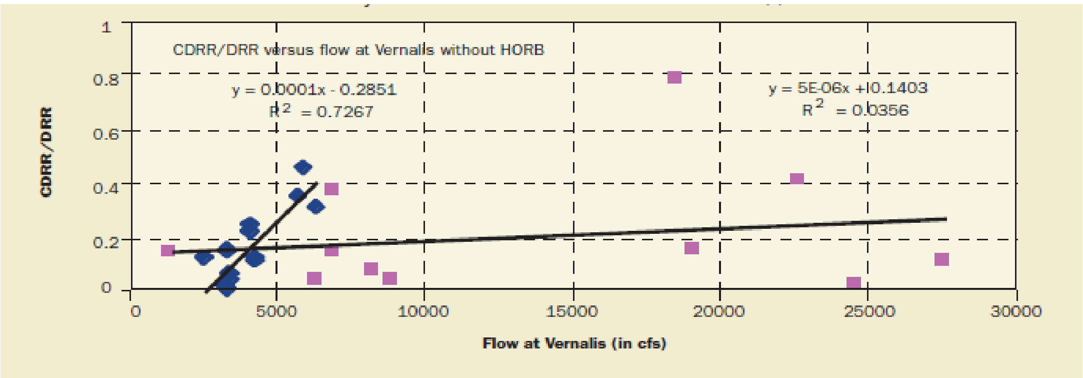

Figure 8-5. Results of CWT survival studies on the lower San Joaquin River as a function of average flow at Vernalis over a 10-day period after release with and without the Head of Old River Barrier (Source: SJRGA 2006).

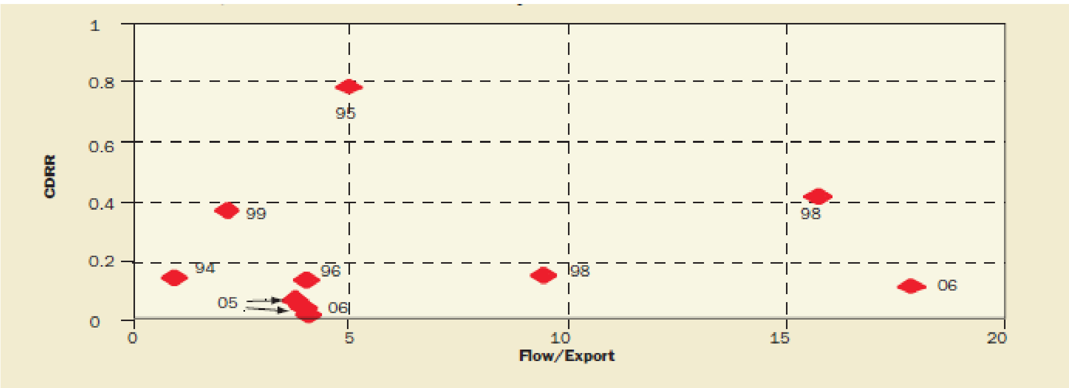

Figure 8-6. Survival of CWT juvenile Chinook salmon released into the San Joaquin River at Durham Ferry and Mossdale (corrected for Jersey Point controls) as a function of the average Vernalis flow/Export rate over a 10 day period following release without the Head of Old River Barrier (Source: SJRGA 2006).

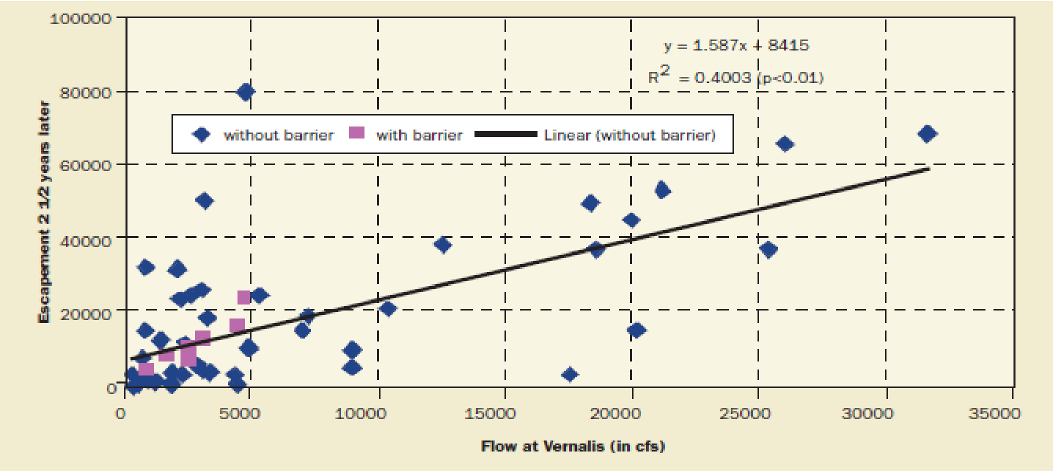

Figure 8-7. Relationship between adult Chinook salmon escapement and average Vernalis flows 2-1/2 years earlier (Source: SJRGA 2006).

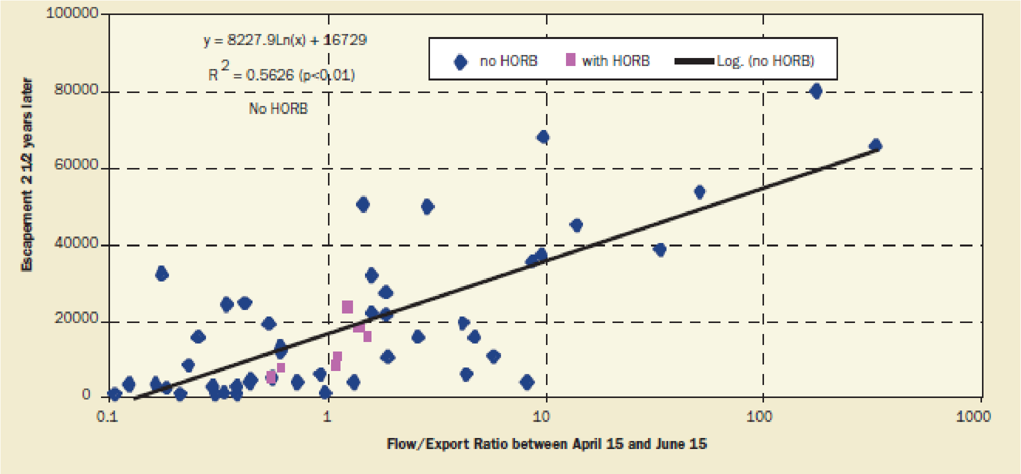

Figure 8-8. **Relationship between adult Chinook salmon escapement and average Vernalis flow/Export ratio 2-1/2 years earlier (Source: SJRGA 2006).**

- Acoustic monitoring studies from the modified, post 2006 VAMP experiments were unable to provide survival estimates at Antioch or Chipps Island, or in the ocean, comparable to those developed as part of the VAMP experiments conducted from 2000 to 2006 using the CWT. Thus, the acoustic tag data currently available cannot be used to assess, in the longer term, the role of San Joaquin River flow and SWP/CVP exports on juvenile salmon survival.

Overall, the VAMP survival studies showed a strong negative trend in juvenile fall-run salmon survival as a function of time (year), which was independent of the rates of flow and exports (Figure 8-9). The negative trend in survival was observed in absolute survival estimates using CWT salmon recaptured in sampling for juveniles at Chipps Island, as well as in sampling of adults from the ocean fishery. The negative trend was apparent for salmon released at Durham Ferry, Mossdale, and Dos Reis (Figure 8-10). Although the biological mechanisms and factors that resulted in the negative survival trend have not been determined, there is no evidence that the trend was the result of variation in Vernalis flow or SWP/CVP exports during the mid-April to mid-May period of these tests. It has been hypothesized that an increase in the abundance of predatory fish, such as largemouth bass, in the south and central Delta over the past decade may have been a major factor contributing to the declining trend in survival. Results of acoustic tagging studies conducted in the lower San Joaquin River and Delta in recent years provide additional support for the hypothesis that predation mortality for juvenile salmon is high.

8.1.2.2 Risk from Predation by Non-Native Fish Species

As discussed in Section 2, results of recent acoustic tag studies have shown evidence of high predation rates for juvenile salmon migrating through the lower San Joaquin River and Delta. Predation mortality by striped bass and largemouth bass has been identified as a major factor reducing the survival of juvenile salmon and steelhead entering Clifton Court Forebay (Gingras 1997, Clark *et al.* 2009), at fish salvage release sites (Miranda *et al.* 2010), and at other locations within the Central Valley rivers and Delta such as the Head of Old River (Bowen *et al.* 2009, Bowen and Bark 2010). Given the complex habitat conditions in the Delta that provide cover for predatory fish and the hydrologic conditions in the Delta dominated by tidal flows rather than Delta inflows, increased or minimum Delta inflows or outflows are unlikely to have any effect on the abundance or distribution of either largemouth bass or sunfish in the Delta. Increased Delta inflow would not be expected to change the seasonal temperature conditions in the Delta or other elements of largemouth bass and sunfish habitat.

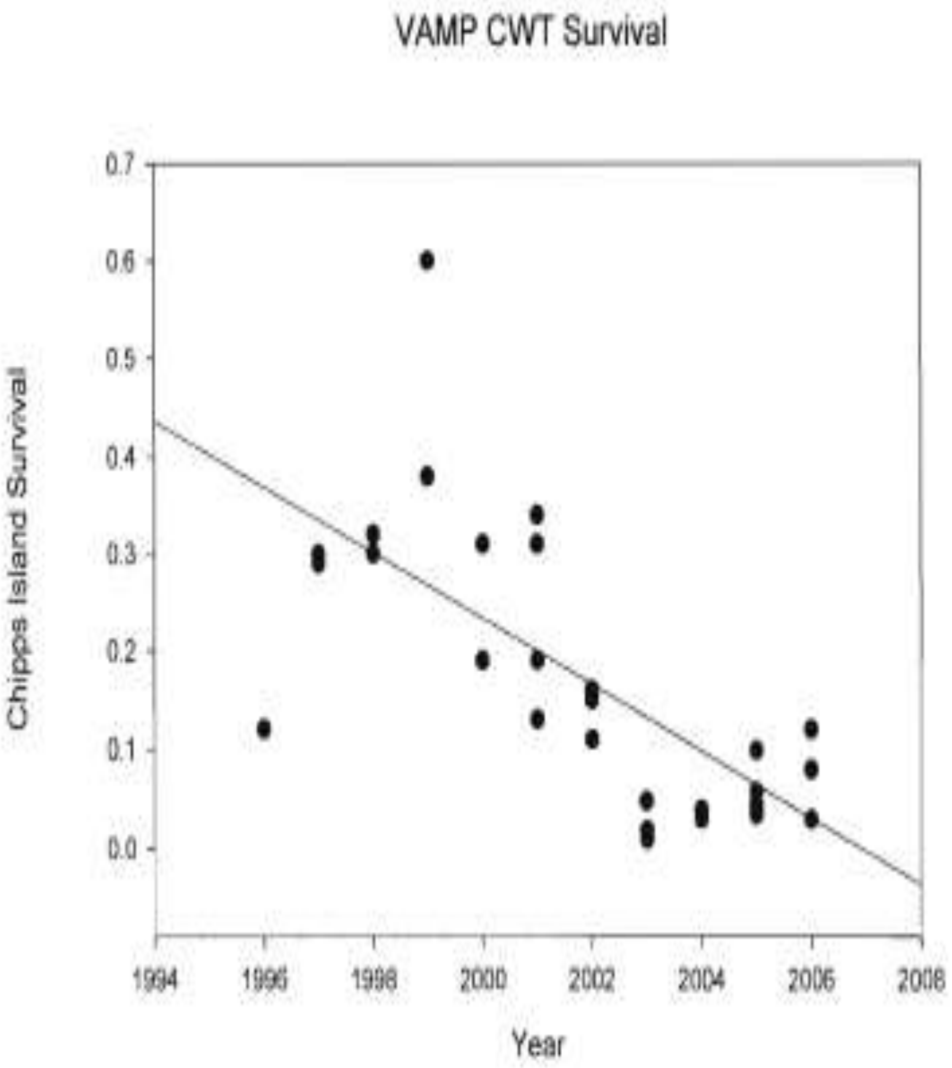

Figure 8-9. **Trend in juvenile fall-run Chinook salmon survival in the lower San Joaquin River and Delta measured during VAMP studies (Source: SJRGA 2006).**

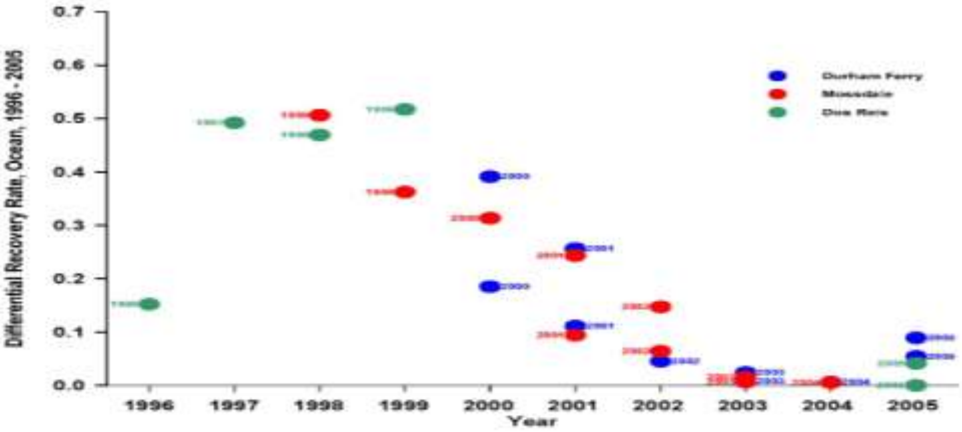

Exhibit 2. Declining trend over time in differential survival of Chinook salmon emigrating from the lower San Joaquin River as reflected in recaptures in the ocean fishery (Source: S. Greene, DWR, pers com.).

Figure 8-10. Juvenile salmon survival over time as a function of release site in the lower San Joaquin River (Source: S. Greene, pers. com.)

9 Delta

9.1 Background on Salmonid Use of Delta

The Delta serves as a migratory pathway for upstream immigrating adult and downstream emigrating juvenile salmonids. The Delta provides a transition area from upstream freshwater habitats in the rivers that serve as spawning and juvenile rearing habitat to coastal marine waters where salmonids rear and grow for a substantial proportion of their lifecycles. As discussed in Section 2, the Delta has been extensively modified, resulting in diminished habitat quality and availability for salmonids, and the species composition and trophic dynamics of the Delta have changed in response to the introduction and population expansion of non-native fish, macroinvertebrates, and aquatic plants.

SWP and CVP export operations, as well as the large number of individual in-Delta diversions, are several of the other factors that affect the Delta's dynamic conditions. Depending on Delta inflows and export rates and other Delta diversions, the direction and magnitude of flows in interior Delta channels can be altered and "reverse flows" can occur in Old and Middle rivers. These and other stressors (Section 2) can affect habitat quality and availability within the Delta, the migration pathways and behavioral response of juvenile salmon during migration through the Delta, as well as the species' health, growth, and survival.

Notwithstanding the effect of diversions on flows in Delta channels, the dominant factor affecting hydrodynamic conditions in the Delta is tidal action. The flow in Delta channels, as well as salinity intrusion into Suisun Bay and the Delta, is complex and driven to a large extent by tidal stage. The direction of flow in many areas of the Delta is determined by ebb and flood tidal conditions. Adding Delta inflows has very little impact on tidal action.

9.2 New Studies and Technologies

Much of the early research on juvenile salmonid migration and survival relied on CWT mark-recapture studies. In more recent years, innovations in acoustic tag technology have contributed to applying remote sensing to assess juvenile salmonid migration rates and pathways, predation, survival rates, and how various management actions (e.g., VAMP, 2012 Stipulation Study, etc.) affect the behavior and survival of juvenile salmon and steelhead during their migration through the Delta. There have also been a number of recent advances in other analytic tools and statistical analyses useful for application to salmonid issues, such as DSM2, and the Delta Passage Model.

Comprehensive analysis of data collected regarding juvenile salmonid migration, tidal hydrodynamics, water quality, fish surveys and the effects of flows and exports using these new technologies have contributed to an improved understanding of the Delta and its function as a salmonid migration pathway and as juvenile rearing habitat. Current information and technologies have also been extensively used in developing large-scale management programs, such as CVPIA and BDCP.

9.2.1 Acoustic Tagging Studies

Significant advances in recent years in the application of acoustic tag technology offer the opportunity to develop detailed information on the movement patterns and survival of individual salmon and steelhead as they migrate through Delta channels. Combining data regarding fish movement from the acoustic tag studies with data on water velocities, water quality, and other environmental conditions has substantially expanded the technical foundation for examining the response of juvenile salmonids to various management actions and environmental conditions.

9.2.1.1 Sacramento River Acoustic Tag Studies

Perry (2010) and Perry *et al.* (2010) used acoustically tagged late fall-run Chinook to track salmon behavior and route selection within the Delta. Figure 9-1 illustrates the acoustic tag detector array used by Perry to determine salmon migration pathways and movement rates as well as to develop estimates of reach-specific survival rates. Using results of these acoustic tag experiments, Perry was able to determine the probability that a juvenile salmon will select a given migration route at flow splits as a function of the fraction of Sacramento River flow entering each pathway (Figure 9-2). In the past, a basic assumption had been made that juvenile salmon and steelhead migrating through the Delta selected their routes as a direct proportion of the flow entering the route (e.g., fish follow in direct proportion to the flow). Perry's study provides empirical information on the behavior of juvenile salmon encountering a flow split. That information has now been integrated into new analytical tools, such as the DPM, used for simulating salmon migration and survival.

Results of the acoustic tag survival studies conducted by Perry also provide detailed information on reach-specific survival rates. These results (Figure 9-3) show that juvenile salmon migrating downstream in the mainstem Sacramento River or through Steamboat and Sutter sloughs typically had higher survival when compared to those fish that migrated into the interior Delta through the Delta Cross Channel or Georgiana Slough. These recent acoustic tracking study data are similar to the results from earlier CWT experiments, but provide an additional level of fine-grained, reach-specific information that is difficult to obtain using CWT tests. That said, the results of the Perry (2010) acoustic tagging studies include a limited number of tests over a 3-year period (2007, 2008, and 2009) and, therefore, reflect a relatively narrow range of environmental conditions. The acoustic tag studies done by Michel (2010) were also conducted over a 3-year period. Both the Perry (2010) and Michel (2010) studies were conducted using relatively large yearling late fall-run Chinook salmon and may not be representative of migration behavior or survival of other runs of Chinook salmon and steelhead. NMFS, USBR, DWR, and others are developing and conducting additional acoustic tag studies beginning in 2013 to address some of these shortcomings over the next 5 years.

DWR has applied high-resolution three-dimensional acoustic tagging technology to assess juvenile salmon movement and response to the non-physical barrier at Georgiana Slough (Section 7). The three-dimensional acoustic tag tracking system has the advantage of providing very high resolution data on the position of each fish within the water column and how each fish is responding to localized changes in channel configuration and water velocity fields. The technology can also evaluate factors such as localized predation mortality (Bowen *et al.* 2008, 2009, 2010) and the efficacy of potential management actions designed to benefit salmonids, such as the use of a non-physical barrier to guide the migration pathways of juvenile salmonids. Application of the three-dimensional tracking technology is best suited for relatively small areas where detailed high resolution information is needed. For the majority of Delta studies on salmonid migration route selection and survival, simpler one-dimensional acoustic detection is typically used and is still appropriate (Perry 2010, Michel 2010).

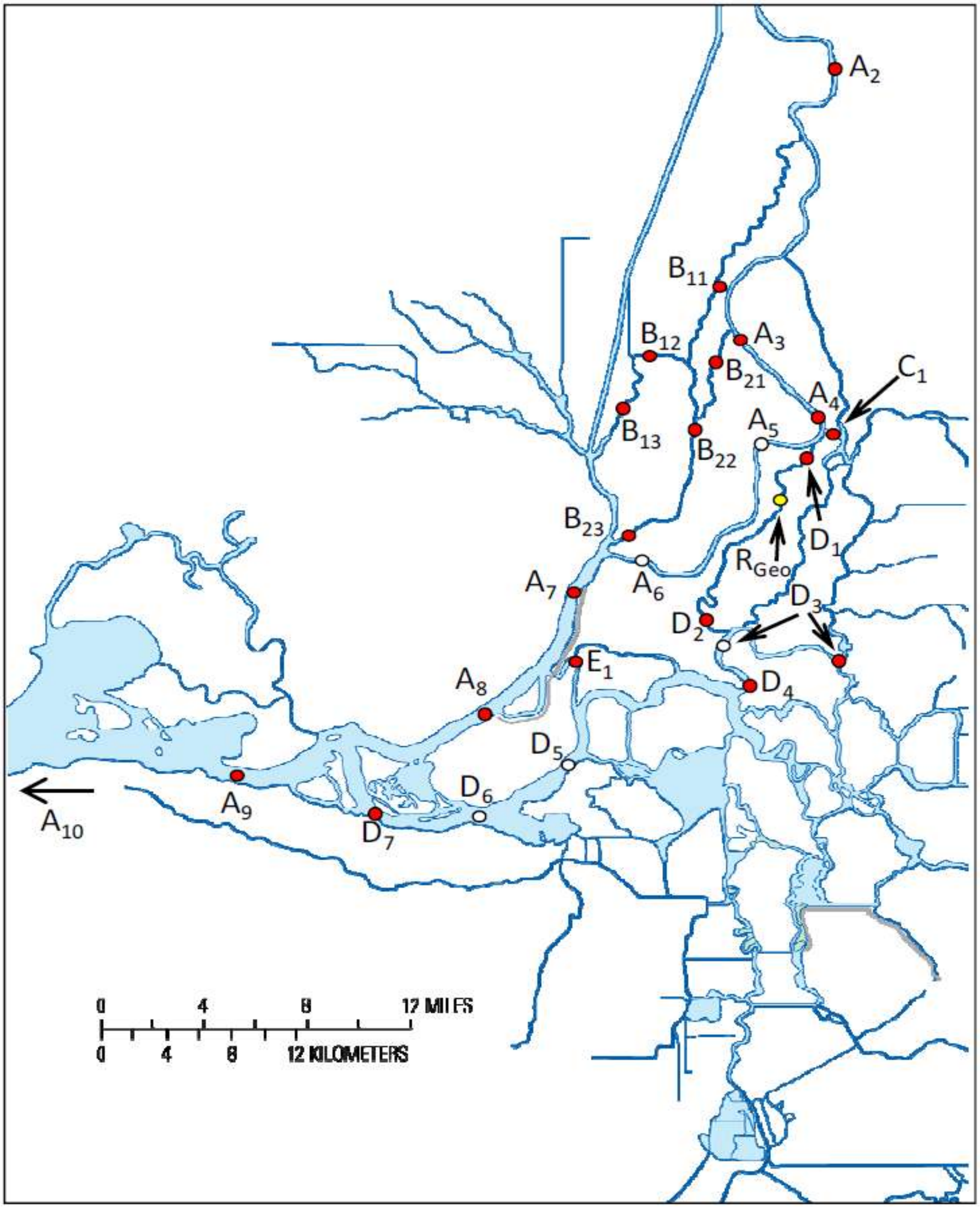

Figure 9-1. **Acoustic receiver sites monitored in the north Delta and Sacramento River during acoustic tag studies using late fall-run Chinook salmon during the winter of 2009 (Source: Perry 2010). Open circles denote telemetry stations used in 2008 but not in 2009. The Sacramento release site was 19 river kilometers upstream of Site A_2. The Georgiana Slough release site is shown as the yellow circle labeled R_{Geo}.**

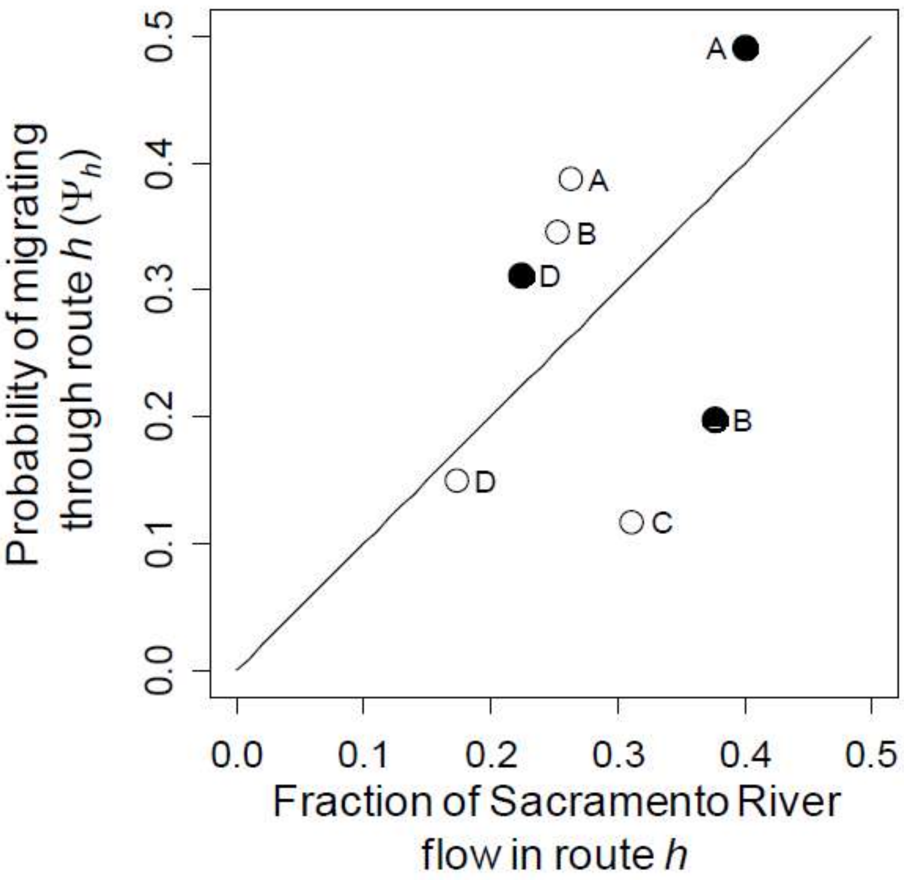

Figure 9-2. **Relationship between the fraction of Sacramento River water flowing into various north Delta channels and the probability of acoustically tagged juvenile late fall-run Chinook salmon migrating through the route (Source: Perry 2010). The open circles represent releases in December 2007 and the filled circles reflect releases in January 2008. Data labels A-D represent the Sacramento River, Steamboat and Sutter sloughs, the Delta Cross Channel, and Georgiana Slough, respectively.**

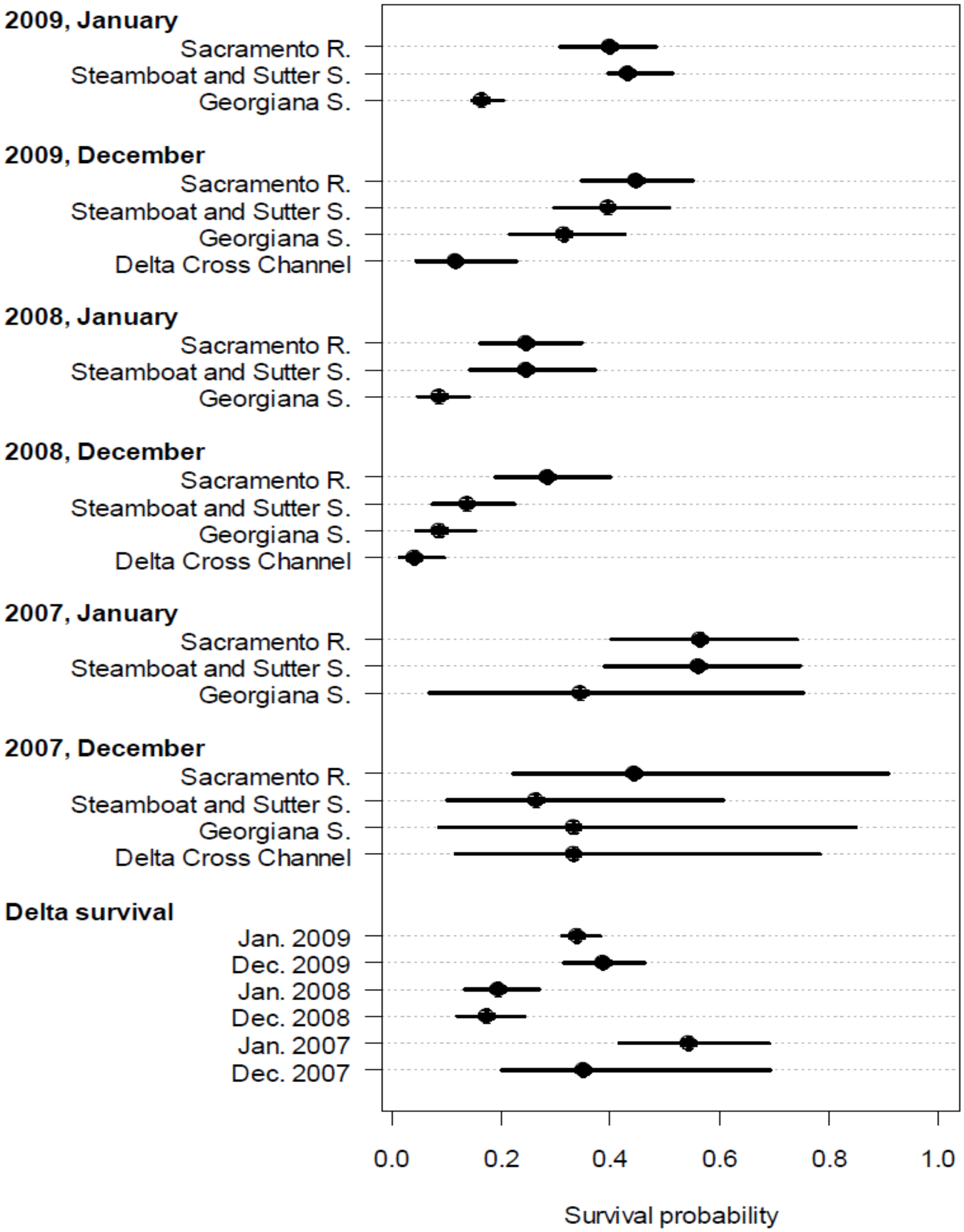

Figure 9-3. Route-specific survival estimates for migration of acoustically tagged juvenile late fall-run Chinook salmon in north Delta channels in 2007-2009 (source: Perry 2010).

9.2.1.2 San Joaquin River Acoustic Tag Studies

During the spring of 2012, two extensive acoustic monitoring programs were conducted to determine juvenile steelhead migration pathways and survival in the Delta based on juvenile steelhead releases into the lower San Joaquin River: (1) the Six-Year Steelhead Survival Study managed by Reclamation and required by the 2009 NMFS OCAP Biological Opinion; and (2) the 2012 Stipulation Study designed collaboratively by NMFS, DWR, and water users to provide data on the response of juvenile steelhead to hydrodynamic conditions in the central Delta as a function of various levels of OMR reverse flows.

The Six-Year Study released steelhead into the lower San Joaquin River at Durham Ferry. Stipulation Study steelhead were released farther downstream in the vicinity of Stockton, upstream of Turner Cut. For the Six-Year study, a network of acoustic tag detectors was deployed in the lower San Joaquin River and Delta, augmented by additional tag detectors through central and south Delta channels (Figure 9-4) designed to assess steelhead movement.

Data collected by the Stipulation Study tag detectors were downloaded daily or weekly, depending on site. Preliminary data on tag presence at each location was made available throughout the study period for use in managing south Delta export operations and OMR reverse flow levels. Detailed data analyses for both studies are currently underway.

A preliminary analysis examining the change in steelhead migration in response to OMR reverse flows has been undertaken. Project managers evaluated the hypothesis that steelhead would preferentially migrate downstream in the mainstem San Joaquin River when OMR levels were low (lower level of reverse flow), but would migrate more frequently into the central and south Delta—as reflected by the occurrence of acoustically tagged steelhead detected in Old and Middle rivers—when OMR reverse flows were greater (more negative).

The preliminary analysis used acoustic tag detections for steelhead released as part of the Six-Year study. Those fish were greater in number than those used in the Stipulation Study and were released further upstream of the Delta, thus giving the fish more time to acclimate to Delta conditions before encountering Delta channels leading to the south Delta, and were part of a larger sample size than the Stipulation Study. The number of fish entering the study area was represented by the quantity of acoustically tagged steelhead detected in the lower San Joaquin River at Site 9 (Figure 9-4). The number and percentage of tagged steelhead subsequently detected in Middle River at Site 2 and in Old River at Site 3 were used as an indicator of fish moving from the San Joaquin River into the central and south Delta. The number and percentage of tagged steelhead detected downstream at Site 11 (Prisoners Point) were used as an indicator that steelhead had successfully migrated downstream in the mainstem San Joaquin River. The preliminary analysis did not attempt to correct for variation in tag detection, calculate reach-specific survival or migration rates, or account for fish that may have been preyed. These issues will be addressed in detail in the complete data analysis.

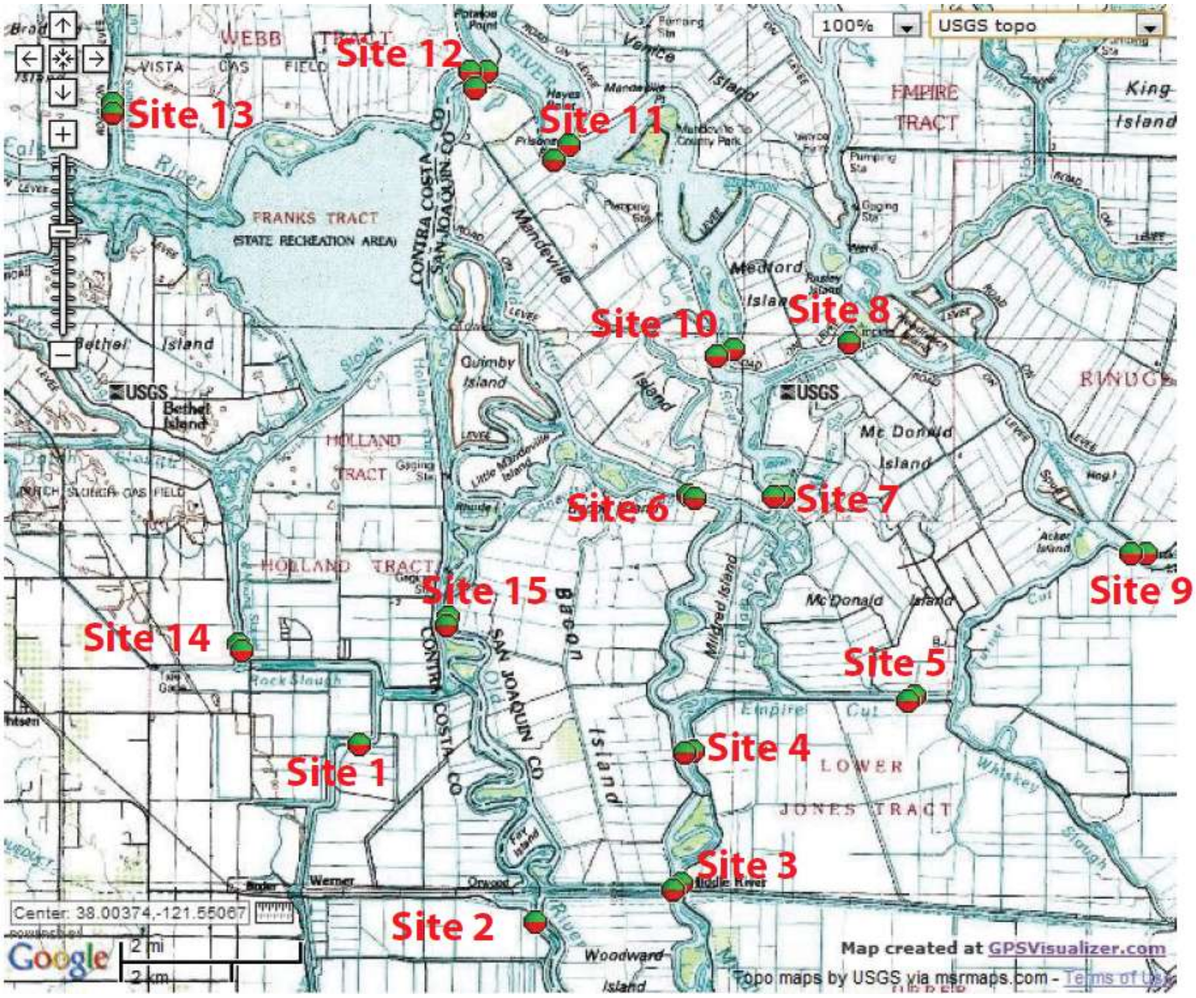

Figure 9-4. **Map of the central and south Delta showing acoustic tag monitoring locations deployed as part of the 2012 Stipulation Study of juvenile steelhead migration through the Delta in response to OMR flows.**

Table 9-1 summarizes the results of the preliminary acoustic tag analysis from the 2012 San Joaquin River steelhead study. The data were grouped under three separate export conditions: steelhead detected at Site 9 (the control site for this analysis) when OMR on the subject day was (1) less than -2,000 cfs, (2) between -2,000 and -4,000 cfs, and (3) greater than -4,000 cfs. Of the 395 steelhead deemed to have entered the Delta at Site 9, 24 were subsequently detected at Site 2 in the south Delta, 39 at Site 3 (also in the south Delta), and 120 downstream in the San Joaquin River and Prisoners Point (Site 11). The percentage of steelhead detected in the south Delta was 6 percent at Site 2 and 8 percent at Site 3 when OMR was less than -2,000. These results were similar to the results when OMR flows ranged between -2,000 and -4,000 cfs (4 percent detected at Site 2 and 8 percent at Site 3). The percentage of steelhead detected in the south Delta grew when OMR was greater than -4,000 (10 percent at Site 2 and 18 percent at Site 3); however, the sample size was substantially lower when OMR was greater than -4,000 cfs when compared to the other two conditions (Table 9-1).

The percentage of steelhead detected downstream at Prisoners Point was similar when OMR flows were less than -2,000 cfs (34 percent) and greater than -4,000 cfs (39 percent). This suggests that OMR did not have a substantial effect on the success of steelhead migrating downstream through the San Joaquin

River. When OMR flows ranged between -2,000 to -4,000 cfs (22 percent), the percentage of steelhead detected downstream was lower than expected.

These preliminary results require additional review and detailed analysis. At a minimum, they demonstrate that acoustic tag technology can be utilized to test alternative management proposals and the actual response of the target species. The technology also offers opportunities to use near real-time (daily) data to assist in management decision making and to develop empirical field data for target species usable to refine and validate predictions of simulation models and other analytical tools.

Table 9-1. Preliminary analysis of juvenile steelhead movement in the central and south Delta during spring 2012 in relation to OMR reverse flows.

	OMR Less than -2000 cfs	OMR Between -2000 & -4000 cfs	OMR Greater than -4000 cfs	Total	Percentage when OMR was Less than -2000 cfs	Percentage when OMR was -2000 to -4000 cfs	Percentage when OMR was Greater than -4000 cfs
Number of fish through Site 9 with:	169	149	77	**395**			
Number of fish from Site 9 to Site 2 with:	10	6	8	**24**	6	4	10
Number of fish from Site 9 to Site 3 with:	13	12	14	**39**	8	8	18
Number of fish from Site 9 to Site 11 with:	57	33	30	**120**	34	22	39

9.2.1.3 Lower Sacramento River/Delta Flow-Survival Relationship

The effect of Sacramento River flow on survival of juvenile fall-run Chinook salmon through the Delta has been assessed using results of USFWS CWT studies and flow data. Juvenile fall-run Chinook salmon were released into the lower Sacramento River in the vicinity of Sacramento (Verona to Clarksburg) and recaptured in USFWS trawling at Chipps Island to assess survival through the Delta (Brandes and McLain 2001). The analyses used DAYFLOW data regarding average flow at Freeport or Rio Vista over a 14-day period following each release. The duration of migration for each release group was calculated based on the time between release and the first fish recaptured at Chipps Island as well as the time to the last fish recaptured at Chipps Island. For many of the releases, multiple CWT codes were used. Results of the analysis were summarized separately by individual tag codes (typically, a release group of approximately 25,000 fish) and for the composite of multiple tag codes for those fish released at the same time and location (group survival).

Results of the analysis of survival as a function of Sacramento River flow at Freeport are shown in Figure 9-5. Survival as a function of flow at Rio Vista is shown in Figure 9-6. Results of these analyses show similar trends with high variability and low r^2 values (r^2=0.07 for flow at Freeport and r^2=0.03 for flow at Rio Vista), and relatively flat slopes to the regression lines, *suggesting that a relatively large change in* *flow would be required to achieve a relatively small change in survival (with high uncertainty).* These results are similar to results generated from CWT releases that occurred in the upper Sacramento River (Figures 7-10 and 7-11), suggesting that Sacramento River flow within the range evaluated has only a small effect on juvenile salmon survival for fish released into the upper watershed (upstream of Red Bluff Diversion Dam) and for those fish released downstream in the vicinity of Sacramento.

Results of salmon survival studies were plotted against time (independent of Sacramento River flows, exports, etc.) for both individual survival estimates (Figure 9-7) and for group survival estimates (Figure 9-8) based on tests conducted between 1996 and 2009. These results were also characterized by high variability; however, there was a general declining trend in survival as a function of time for both regressions. The declining survival over time observed in these data for the Sacramento River releases was similar, although not as pronounced, as the declining trend observed for fall-run Chinook salmon released on the San Joaquin River (Figure 8-9). *These results suggest that factors changing in the Delta that have affected juvenile salmon survival in recent years (e.g., increased predation mortality) are doing so independent of river flow and export operations.*

Additional analyses were performed to examine the relationship between Sacramento River flow and the rate of salmonid migration, as reflected by the number of days between the time of release and time of recapture. Results of the analysis of number of days to first recapture at Chipps Island as a function of flow are summarized in Figure 9-9 for flow at Freeport and Figure 9-10 for flow at Rio Vista. Results of the analysis of

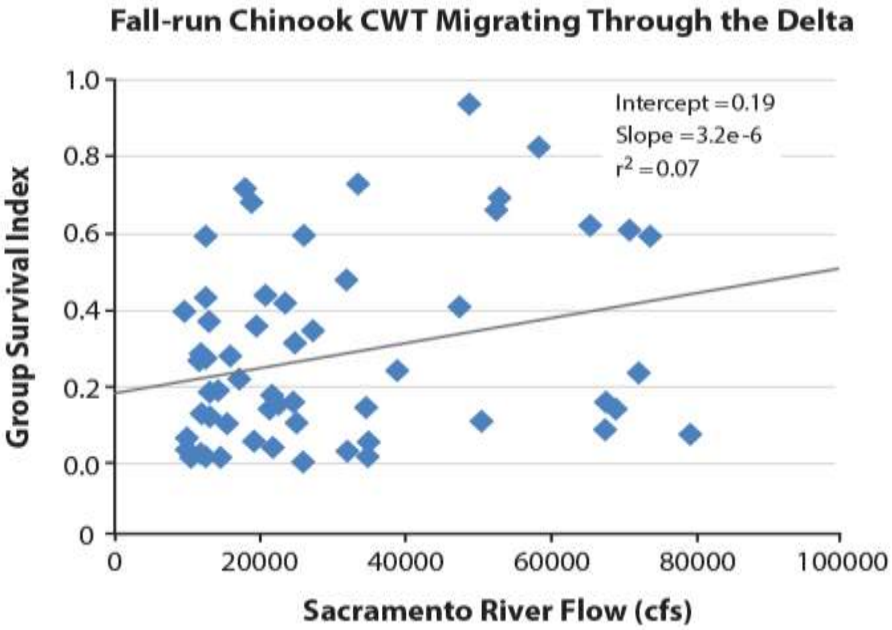

Figure 9-5. Relationship between average Sacramento River flow at Freeport over a 14-day period after release and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento.

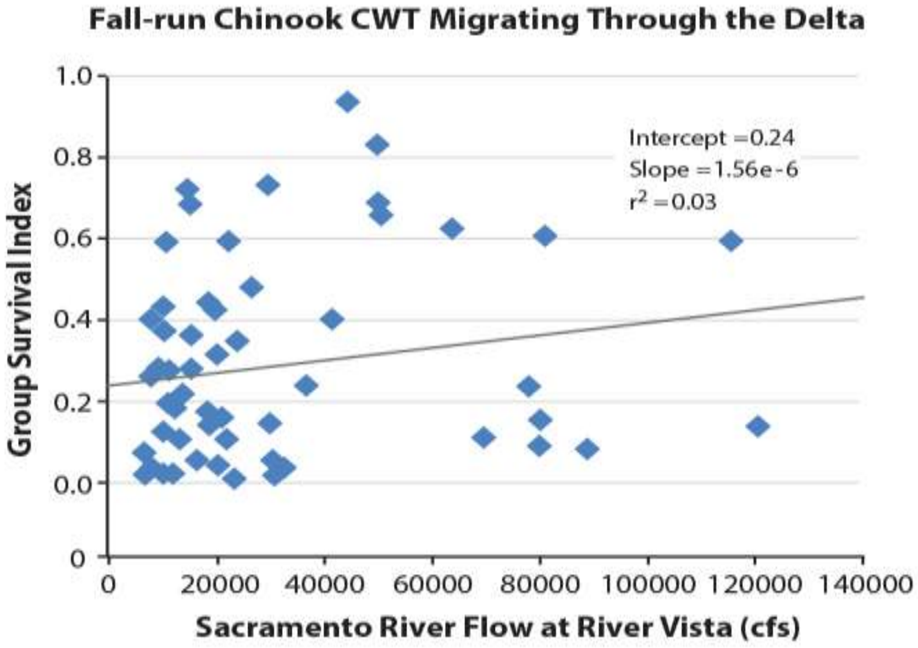

Figure 9-6. Relationship between average Sacramento River flow at Rio Vista over a 14-day period after release and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento.

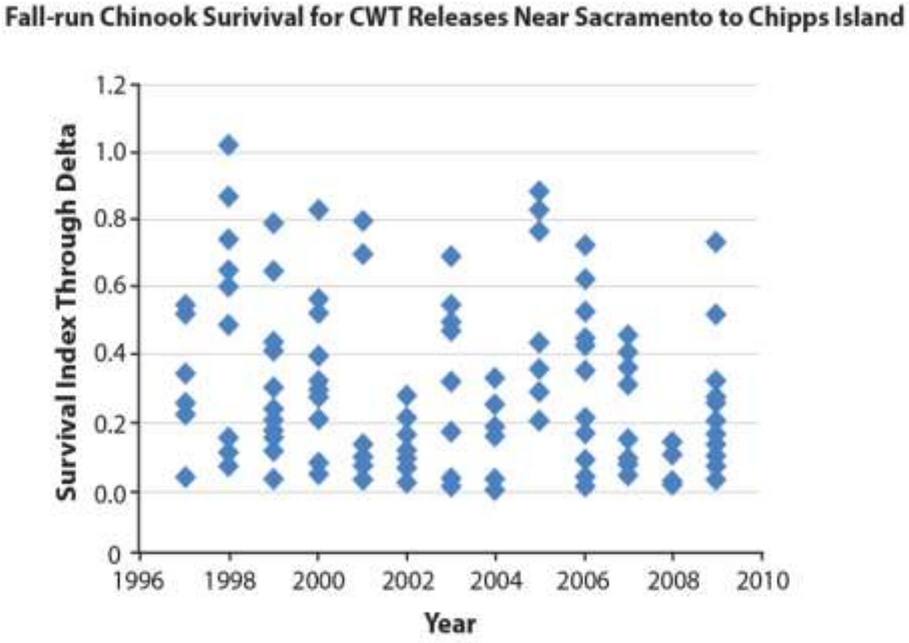

Figure 9-7. Relationship between year and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento.

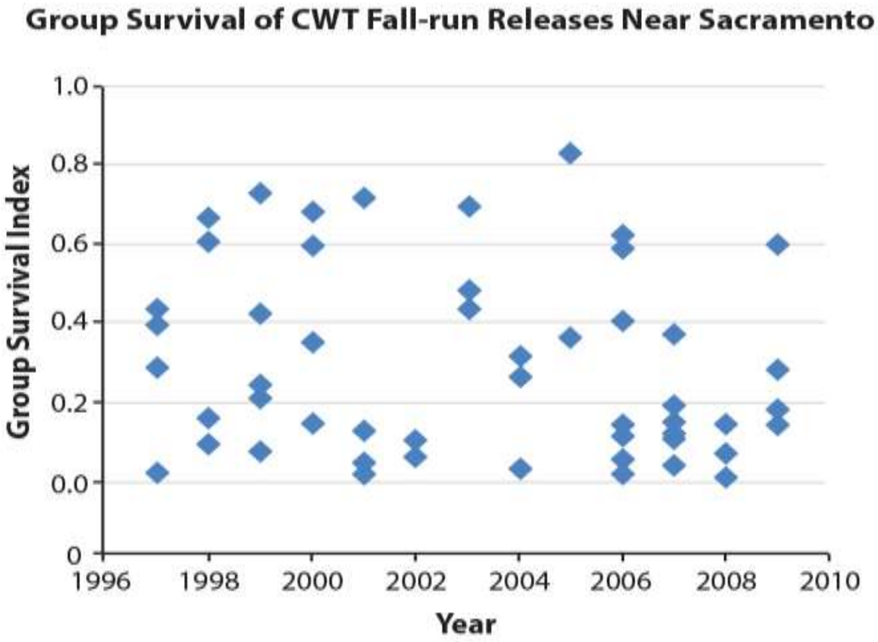

Figure 9-8. **Relationship between year and juvenile fall-run salmon group survival to Chipps Island for CWT fish released in the vicinity of Sacramento.**

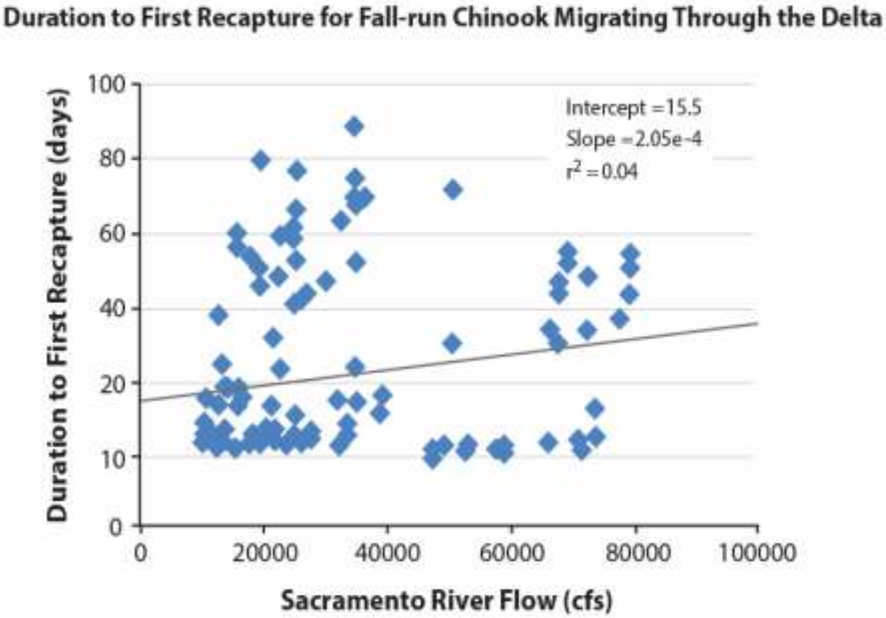

Figure 9-9. **Relationship between average Sacramento River flow at Freeport over a 14-day period after release and the duration to first recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.**

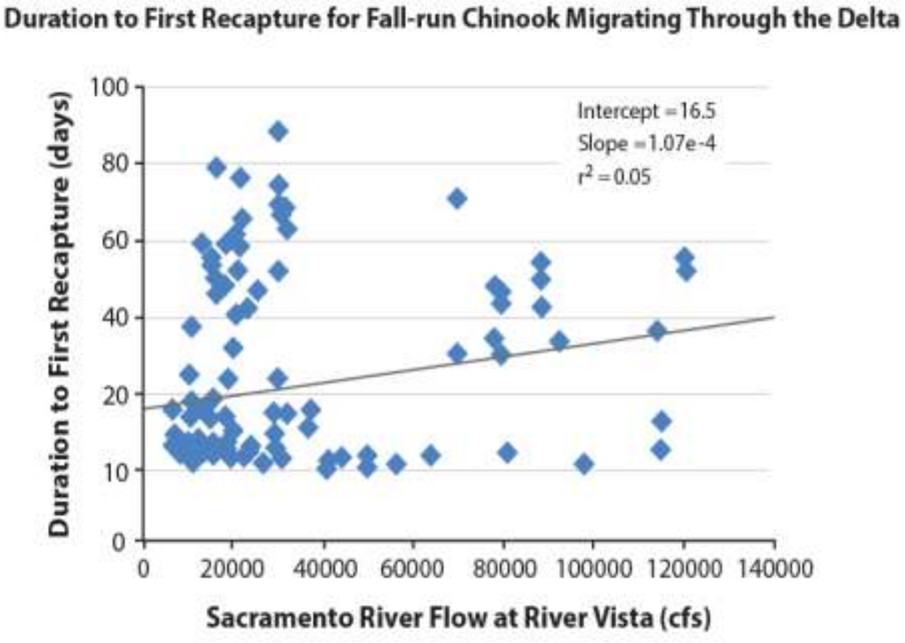

Figure 9-10. **Relationship between average Sacramento River flow at Rio Vista over a 14-day period after release and the duration to first recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.**

number of days to last recapture at Chipps Island as a function of flow are summarized in Figure 9-11 for flow at Freeport and Figure 9-12 for flow at Rio Vista. All of these relationships are characterized by high variability but, surprisingly, showed positive slopes. A positive slope to these regressions suggests a trend of increasing migration duration as river flow increased. *These results do not suggest that increasing river flow would be an effective strategy for reducing the duration of migration for juvenile Chinook in the lower Sacramento River.* Results of the ongoing acoustic tagging experiments will provide additional data that can be used to further evaluate the potential relationship between river flow and reach-specific migration rates.

The complexity of interacting variables affecting salmonid abundance year-to-year is reflected in two examples of Chinook salmon returns that have occurred in the last six years. For example, high river flows occurred in 2004 and 2005. Thus, it was expected that the abundance of fall-run Chinook salmon adults returning two to four years later would improve. In fact, the abundance of fall-run Chinook salmon adults returning to the Central Valley (and other rivers) in 2007(96,141 fall-run adults), 2008 (71,870 fall-run adults), and 2009 (53,129 fall-run adults) was extremely low, resulting in an emergency closure of the commercial and recreational fishery (Lindley *et al.* 2009).

Similarly, flows in the Sacramento River during the late winter and spring of 2006 were high throughout the juvenile salmonid migration period and were expected to improve survival and increase adult abundance. Average instream flows in the Sacramento River measured at Freeport during the 2006 migration period were 68,459 cfs in January, 50,211 cfs in February, 67,873 cfs in March, 74,842 cfs in April, and 52,835 cfs in May (Table 9-2). The flows during the 2006 migration season were substantially greater than in many other years. Despite these flow conditions, the escapement of adult fall-run Chinook salmon returning to the Central Valley two and one-half years later in 2008 and 2009 (71,870 and 53, 129 adults, respectively) represented the lowest level of abundance in the last 50 years (GranTab 2011).

By contrast, far lower Sacramento River flows at Freeport of approximately 9,000 to 21,000 cfs in the late winter and spring of 2009 is expected to produce a fall-run adult abundance in the ocean of 819,000 this year. (PFMC Feb. 12 Pre Season Report 1) Escapement estimates of fall-run Chinook salmon adults to the Central Valley are not yet available for 2012.

These examples illustrate the complexity of interacting factors that affect the population dynamics of Central Valley salmonids and the high degree of uncertainty that increasing reservoir releases or modifying export levels will result in a desired improvement in survival and abundance.

Table 9-2. Sacramento River average monthly flows (cfs) at Freeport and estimated adult fall-run Chinook salmon abundance.

	2006	2009
January	66,459 cfs	9,147 cfs
February	50,211 cfs	19,977 cfs
March	67,873 cfs	21,176 cfs
April	74,842 cfs	11,924 cfs
May	52,835 cfs	15,436 cfs
Estimated adult fall-run salmon abundance	53,129 2009	819,000 2012

2006 abundance is based on Central Valley escapement with no ocean or inland harvest; Source Chinookprod (2011)

2012 adult fall-run Chinook salmon abundance estimate (in the ocean and not escapement) is based on CDFG estimate of ocean stock; PFMC 2012

9.2.1.4 OMR Reverse Flow and Salmon Salvage

A substantial effort has been devoted to evaluating the potential relationship between OMR reverse flows and salvage of juvenile Chinook salmon at the SWP and CVP export facilities. Results of early analyses were criticized as being based on raw salvage (the expanded salvage estimate for a given period of time and species) as a function of OMR reverse flow. These early estimates did not adjust for the size of the fish population in a given year; applying such a raw salvage analysis, salvage may increase not as a function of OMR reverse flow, but rather as a function of increased abundance of juvenile salmon.

Revised analyses use normalized salvage (Deriso 2010), which is the expanded salvage estimate divided by the estimated abundance of that species passing through the Delta. Results of the normalized salvage as a function of OMR reverse flows are shown in Figure 9-13 for juvenile winter-run Chinook salmon (December-March) and Figure 9-14 for juvenile spring-run Chinook salmon (March-May). *Results of both of these analyses show no relationship between the magnitude of OMR reverse flow and normalized salvage over a range of OMR reverse flows exceeding -8,000 cfs* (Deriso 2010).

9.2.1.5 Export:Inflow Ratio and Salmon Salvage

The export:inflow ratio has been used as a method for managing south Delta export levels to protect sensitive fish from the risk of entrainment into the export facilities. D-1641 uses the E:I ratio to prescribe the percentage of water flowing into the Delta that can be exported during the later winter and spring (35 percent maximum exports) and during the summer, fall, and early winter (65 percent maximum exports).

Analyses have been performed to assess the relationship between the E:I ratio and juvenile salmon salvage (Deriso 2010). Results of the analysis for juvenile winter-run Chinook salmon are presented in Figure 9-15 for the seasonal period from December-March of 2000-2007. The analysis showed no relationship between the E:I ratio and the entrainment index for juvenile winter-run salmon but did show two unusually high data points. A second analysis was performed by Deriso (2010) using the same data for juvenile winter-run salmon which excluded the two outlier data points (Figure 9-16). That analysis showed a slight negative trend, with decreasing salvage as the E:I ratio increased. The two unusually high levels of salvage shown in Figure 9-15 appear to be outliers, however, complete results of the statistical analyses are shown with (Figure 9-15) and without (Figure 9-16) the two unusually high data points. Results of the statistical analyses were similar in showing very little relationship between the E:I ratio and salvage each with low r^2 values ($r^2 = 0.004$ from Figure 9-15 and $r^2 = 0.0891$ from Figure 9-16). A similar analysis was performed using data on juvenile spring-run Chinook salmon salvage during the months of March – May over the period from 2000 to 2007.

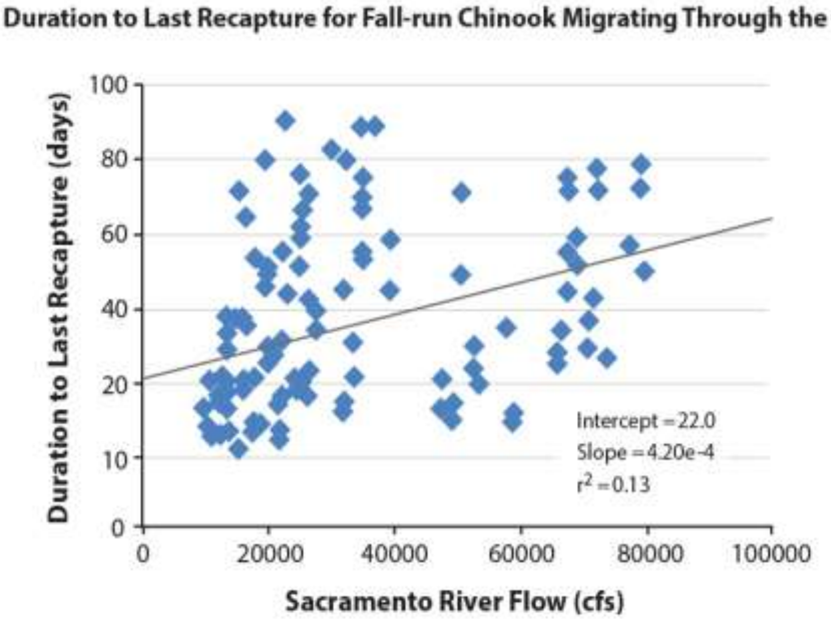

Figure 9-11. **Relationship between average Sacramento River flow at Freeport over a 14-day period after release and the duration to last recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.**

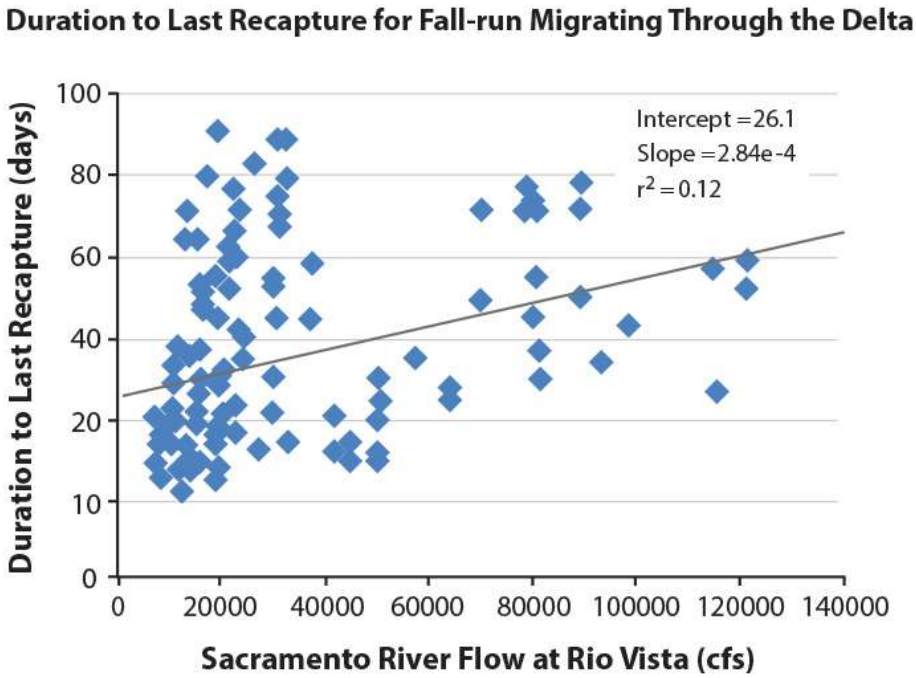

Figure 9-12. Relationship between average Sacramento River flow at Rio Vista over a 14-day period after release and the duration to last recapture at Chipps Island for CWT fish released in the vicinity of Sacramento.

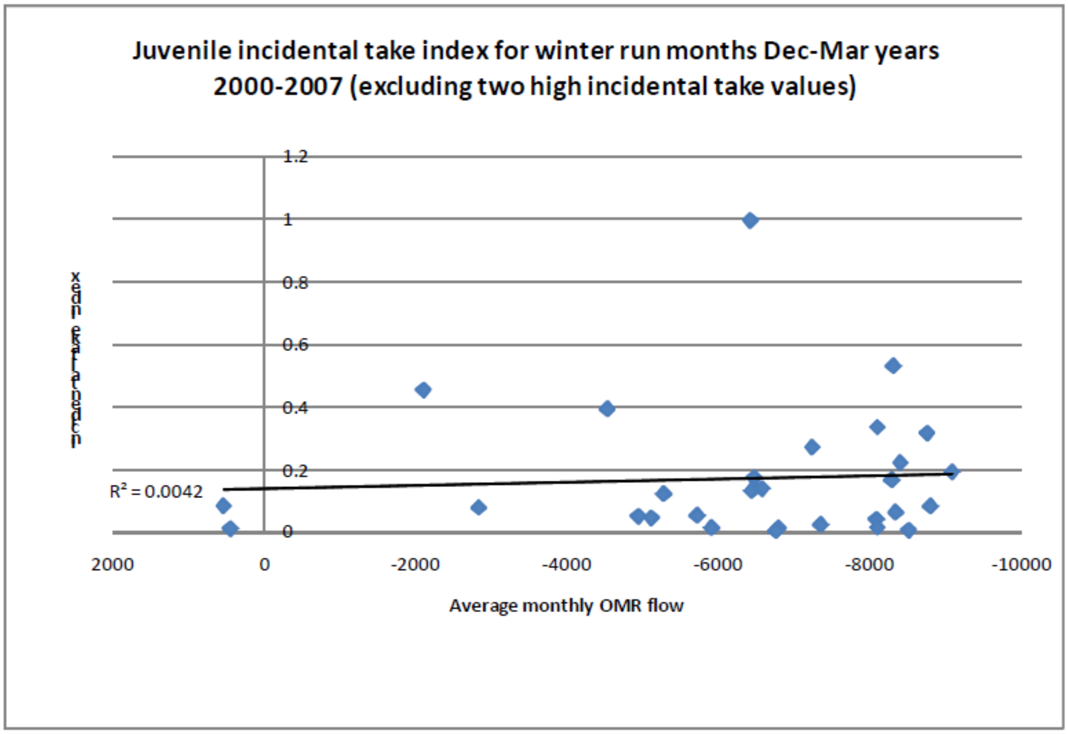

Figure 9-13. Relationship between OMR for south Delta exports and salvage of juvenile winter-run Chinook salmon at the export facilities during December-March 2000-2007 excluding two unusually high observations of salvage (Source: Deriso 2010).

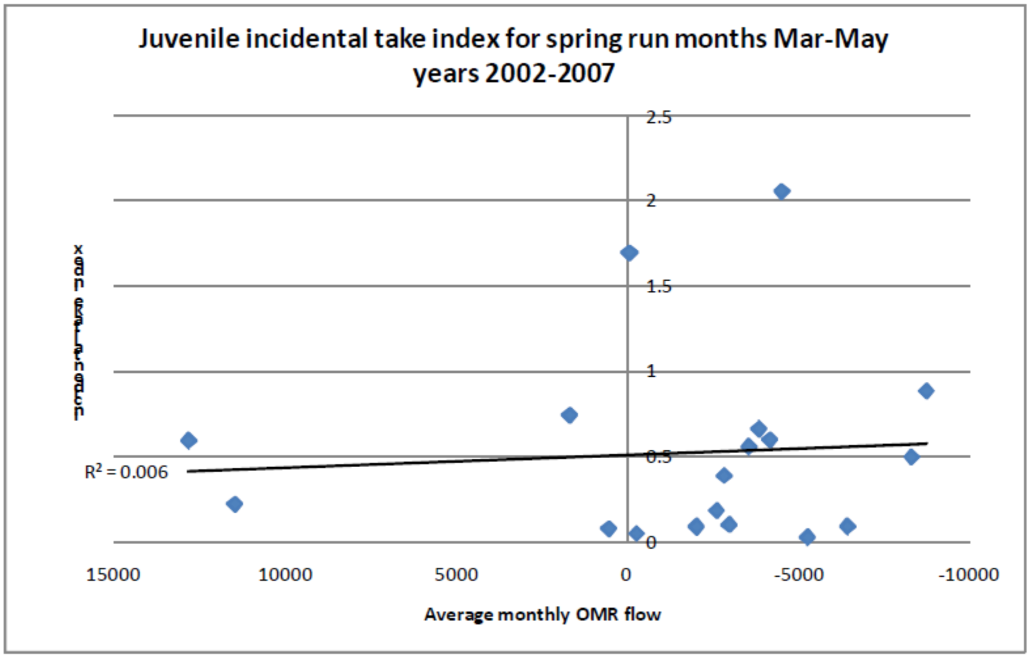

Figure 9-14. Relationship between OMR for south Delta exports and salvage of juvenile spring-run Chinook salmon at the export facilities during March-May 2002-2007 (Source: Deriso 2010).

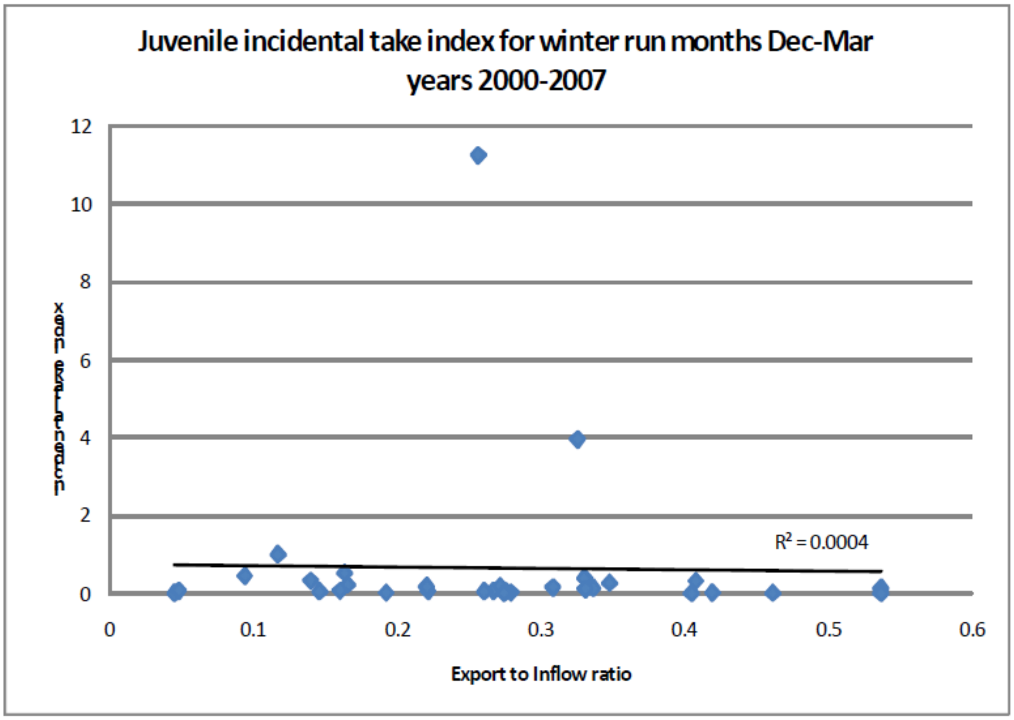

Figure 9-15. Relationship between E:I ratio for south Delta exports and salvage of juvenile winter-run Chinook salmon at the export facilities during December-March 2000-2007, all data included (Source: Deriso 2010).

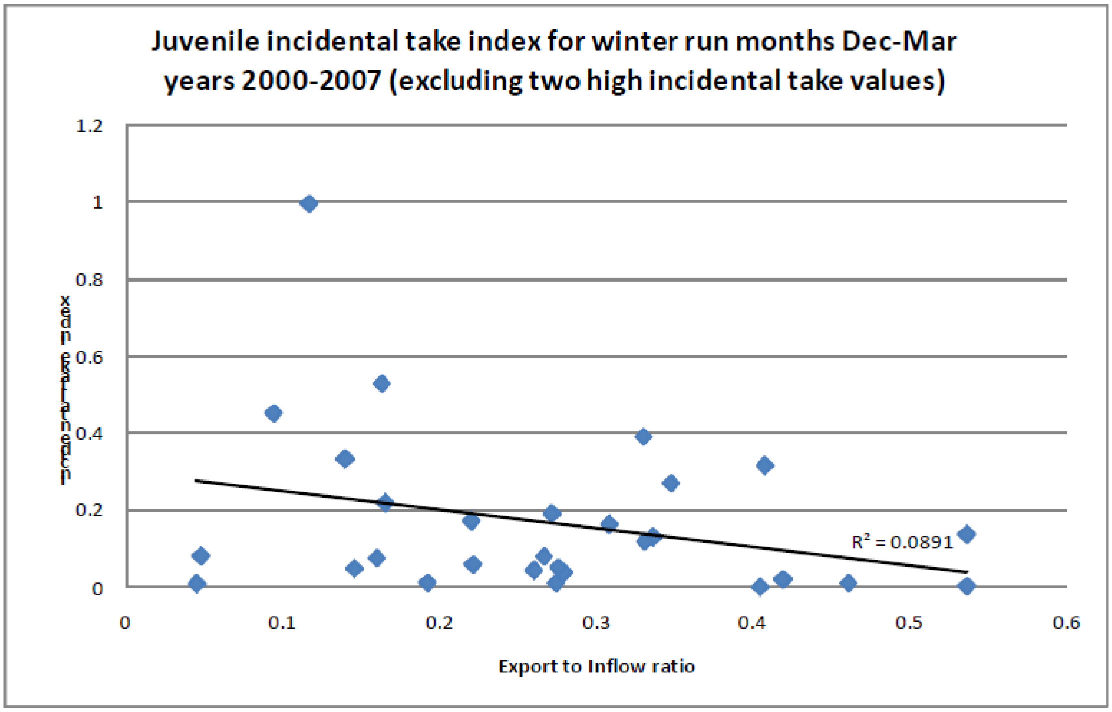

Figure 9-16. **Relationship between E:I ratio for south Delta exports and salvage of juvenile winter-run Chinook salmon at the export facilities during December-March 2000-2007 excluding two unusually high observations of salvage (Source: Deriso 2010).**

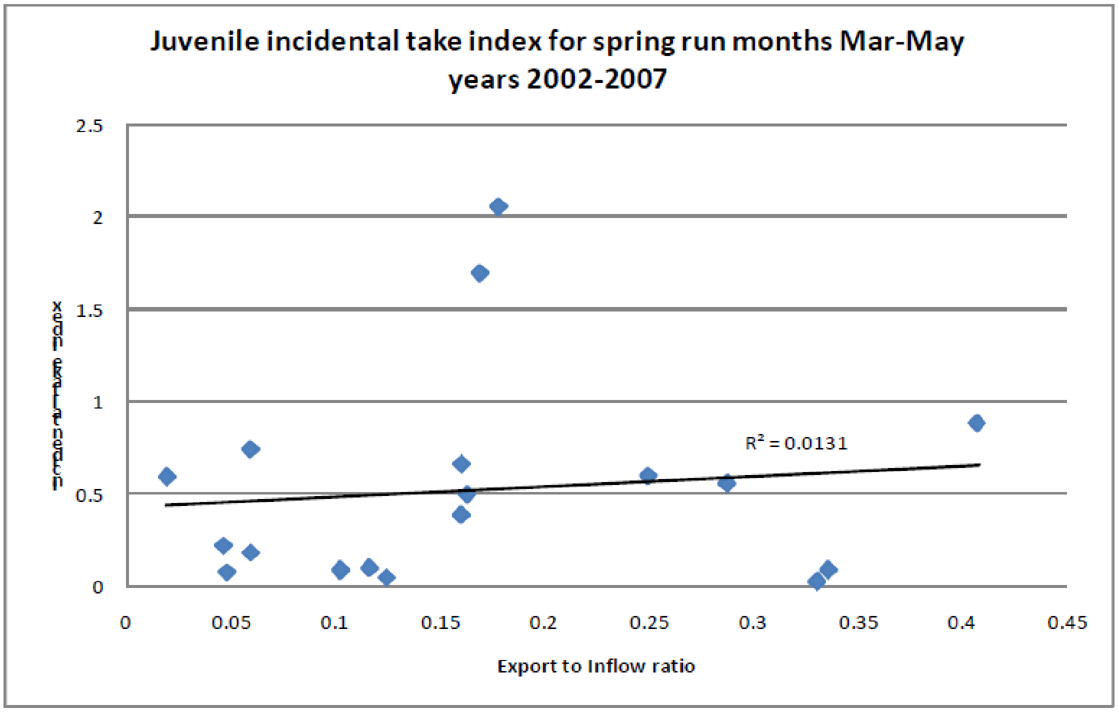

Figure 9-17. **Relationship between E:I ratio for south Delta exports and salvage of juvenile spring-run Chinook salmon at the export facilities during March-May 2002-2007 (Source: Deriso 2010).**

(Figure 9-17). These results showed a slight positive slope. For all three of these analyses, the r^2 values were very low (0.004 to 0.08), and the slopes were all close to zero, suggesting that there is little or no direct relationship between juvenile winter-run and spring-run Chinook salmon salvage and the E:I ratio during the seasonal period when these salmon juveniles are migrating through the Delta. Additional analysis of results of acoustic tagging studies conducted in the Delta will provide further information on the potential direct and indirect effects of south Delta export operations on the migration and risk of entrainment of juvenile salmon and steelhead in the future.

9.2.1.6 Predation on Juvenile Steelhead within Clifton Court Forebay

Results of mark-recapture studies conducted by releasing juvenile fall-run and late fall-run Chinook salmon into Clifton Court Forebay (Figure 9-18), and subsequently monitoring the number of tagged fish collected in SWP fish salvage operations, showed that salmon losses in the Forebay were high (Gingras 1997). Juvenile salmon used in these tests ranged in length from 44 to 112 mm. Estimates of pre-screen losses of these juvenile salmon in the Forebay in 8 studies conducted between 1976 and 1993 ranged from 63.3 to 99.2 percent, with an overall average of 86.5 percent. Predation within the Forebay by species such as striped bass was identified as the cause of the high mortality. It was hypothesized that the high mortality rates applied to smaller juvenile Chinook salmon, but pre-screen losses for larger yearling steelhead were expected to be substantially lower.

To test the pre-screen loss of yearling steelhead in the Forebay, a series of experiments was developed and conducted in 2005, 2006, and 2007 (Clark *et al.* 2009). Juvenile steelhead were tagged with various methods, including PIT and acoustic tags, and released in small groups at the radial gate at the head of the Forebay when the gate was open. Striped bass were also captured with hook and line within the Forebay and their movements monitored using acoustic tags. Based on pre-screen loss estimates using PIT tags, the loss was 82 percent with 95 percent confidence intervals of 3 percent. Results of these tests confirmed that there are predation hot-spots within the Delta where predation mortality on juvenile salmon and steelhead can be very high.

Figure 9-18. Clifton Court Forebay.

9.2.1.7 SWP/CVP Salvage Rates for Salmonids

Survival estimates for spring-run salmon have been developed by USFWS based on results of CWT mark-recapture studies conducted on the mainstem Sacramento River using late fall-run Chinook salmon juveniles as a surrogate for spring-run. Late fall-run Chinook salmon have been used as surrogates because spring-run salmon are not available in large numbers from hatcheries on the Sacramento River for use in testing. In addition, juvenile production in the tributaries is difficult to quantify (e.g., no estimates comparable to the winter-run Juvenile Production Estimate (JPE) are available for juvenile spring-run salmon production). However, tagged juvenile salmon reared at the Coleman National Fish Hatchery have sometimes been released into Battle Creek between late-November and mid-January to simulate the downstream migration and survival of juvenile spring-run Chinook salmon.

The USFWS has released CWT late fall-run salmon for use as surrogates to estimate spring-run Chinook salmon expanded salvage (to account for the time when salvage is sub-sampled but have not been expanded to account for pre-screen losses) at the SWP and CVP export facilities as a percentage of the number of tagged fish released (Tables 9-3 and 9-4). Annual expanded salvage estimates of the percentage of tagged salmon that were subsequently salvaged range from 0 to 0.46 percent, and have averaged 0.12 percent. These spring-run salvage estimates are consistent with actual salvage of winter-run Chinook salmon as a function of the JPE (Table 9-5). Estimated spring-run and winter-run salvage by the Projects are thus both consistently low (less than 0.5 percent) under a variety of export rates OMR reverse flows, and river inflows into the Delta. While the estimates of salvage have been variable, they do not show a trend of either increasing or decreasing salvage as a percentage of the number of CWT surrogate salmon released.

Table 9-3. Summary of survival estimates and expanded salvage for CWT juvenile late fall-run Chinook salmon (spring-run surrogates) from release to Chipps Island. Cohorts contributing to the 2007 escapement are highlighted in gray.

Water year	Release Groups	Number Released [1]	Number Recovered [2]	Survival Index	Expanded SWP/CVP Salvage	% Salvage
1994	3	186,876	66	43.6%	370	0.198%
1995	3	392,918	65	25.7%	423	0.108%
1996	3	360,346	83	38.5%	0	0.000%
1997	3	376,416	87	40.7%	386	0.103%
1998	2	265,217	80	38.5%	28	0.011%
1999	3	228,128	36	28.6%	202	0.089%
2000	3	177,902	17	16.3%	152	0.085%
2001	3	227,132	75	47.1%	443	0.195%
2002	3	261,716	84	53.1%	1,208	0.462%
2003	2	201,505	40	20.0%	466	0.231%
2004	3	226,788	32	18.8%	0	0.000%
2005	2	190,985	68	54.3%	171	0.090%
2006	2	258,999	42	20.1%	77	0.030%
2007	2	244,892	21	11.1%	162	0.066%
Average	**3**	**257,130**	**57**	**32.6%**	**302**	**0.119%**

[1] All CWT fish were reared in the Coleman Hatchery and were released into Battle Creek between late November and mid-January.

[2] CWT fish were recovered in the USFWS midwater trawl at Chipps Island.

Table 9-4 depicts the results of a similar CWT mark-recapture study in which late fall-run juvenile Chinook salmon (Coleman National Fish Hatchery origin) were released during February and March at the Red Bluff Diversion Dam on the upper Sacramento River (average juvenile lengths ranging from 38 to 58 mm representing young-of-the-year juveniles) and recovered at the SWP and CVP fish salvage facilities. Although a smaller number of tagged fish were released in the RBDD study, results showed expanded salvage estimates ranging from 0 to 0.036 percent. These CWT release experiments have typically salvaged a low percentage of released fish. *Overall, results for all the analyses performed using CWT salmon to assess SWP and CVP salvage (Table 9-6) show a consistent pattern of very low salvage*. These results are again consistent with the calculated low juvenile winter-run Chinook salmon salvage.

Table 9-4. Release and percent expanded salvage of coded-wire tagged Coleman National Fish Hatchery late-fall run Chinook released at Red Bluff Diversion Dam during February and March, for years 1995 and 1999-2006. Released Chinook are assumed to act as surrogates for emigrating juvenile spring-run Chinook salmon. Data from summary of CWT release and recoveries from CDFG's website: http://www.delta.dfg.ca.gov/jfmp/docs/1993%20%202006%20CI%20survival%20table%20Updated%20Jun.2007.pdf

Water Year	Released	Ave. Size (mm)	Expanded Salvage Recoveries			% Salvaged
			SWP	CVP	Total	
1995	92202	49	0	0	0	0.000
1999	38725	38	0	0	0	0.000
2000	96139	57	12	6	18	0.019
2001	91007	46	0	9	9	0.010
2002	49774	52	12	6	18	0.036
2003	100043	58	0	24	24	0.024
2004	98623	51	0	6	6	0.006
2005	47276	53	0	0	0	0.000
2006	49700	48	0	0	0	0.000

*Water years 2005 and 2006 correspond with spring-run brood years 2004 and 2005 which contributed to 2007 adult escapement.

Table 9-5. **Winter-run Chinook salmon juvenile production estimates (JPE) entering the Delta, expanded loss of juvenile winter run (excluding clipped fish) at export pumps, and percentage of winter-run juveniles lost at the pumps. JPE estimates from Bruce Oppenheim, NMFS. Expanded loss data downloaded from CDFG at ftp://ftp.delta.dfg.ca.gov/salvage.**

Water Year	JPE	Expanded Loss			% Juvenile Loss
		SWP	CVP	Combined	
1995	74,500	476	565	1,040	1.40
1996	338,107	4,650	2,637	7,287	2.16
1997	165,069	326	187	514	0.31
1998	138,316	1,178	632	1,810	1.31
1999	454,792	3,161	554	3,715	0.82
2000	289,724	4,705	562	5,267	1.82
2001	370,221	18,825	1,212	20,037	5.41
2002	481,555	2,776	537	3,313	0.69
2003	1,798,275	6,250	559	6,809	0.38
2004	2,089,491	6,984	712	7,696	0.37
2005	488,345	1,247	126	1,373	0.28
2006	1,277,486	2,279	322	2,601	0.20
2007	3,739,069	1,742	1,556	3,298	0.09%
2008	589,900			1,316	0.22%
2009	617,783			1,948	0.17%
2010	1,179,633			4,024	0.34%

*Water years 2005 and 2006 correspond with winter-run brood years 2004 and 2005 which contributed to 2007 adult escapement.

Table 9-6. Summary of coded wire tag mark-recapture studies, 1993-2009 (Source: USFWS unpublished data).

Percent of all Tagged Salmon Smolts Released from 1993-2009 that Suffered Direct Mortality at the Export Pumps												Total Fish Released	Total Fish Lost
River	Source of Fish	Species	Release Location	Number of Release Groups	Average Number of Fish Per Group	Percent Direct Mortality per Release Group							
						Banks Pumping Plant			Tracy Pumping Plan				
						Min	Ave	Max	Min	Ave	Max		
Sacramento River System	Coleman Hatchery	Late fall-run	Hatchery	58	218,305	0.00	0.40	2.99	0.00	0.04	0.30	12,661,690	55,711
			Delta[2]	28	111,754	0.00	0.72	6.43	0.00	0.06	0.37	3,129,112	24,407
		Fall-run	Hatchery	31	493,467	0.00	0.08	2.13	0.00	0.00	0.07	15,297,477	12,238
			Delta[2]	26	82,947	0.00	0.05	0.36	0.00	0.00	0.02	2,156,622	1,078
	Coleman/Livingston Stone Hatcheries[1]	Winter-run	Upper Sacramento River	18	108,919	0.00	0.05	0.28	0.00	0.01	0.03	1,960,542	1,176

Percent of all Tagged Salmon Smolts Released from 1993-2009 that Suffered Direct Mortality at the Export Pumps												Total Fish Released	Total Fish Lost
River	Source of Fish	Species	Release Location	Number of Release Groups	Average Number of Fish Per Group	Percent Direct Mortality per Release Group							
						Banks Pumping Plant			Tracy Pumping Plan				
						Min	Ave	Max	Min	Ave	Max		
	Feather River Hatchery	Fall-run	Hatchery	13	114,296	0.00	0.00	0.01	0.00	0.00	0.00	1,485,848	0
			Delta[2]	89	113,920	0.00	0.03	0.41	0.00	0.00	0.02	10,138,880	3,042
			Delta[3]	21	94,442	0.00	0.36	1.43	0.00	0.51	1.44	1,983,282	17,255
		Spring-run	Hatchery	6	649,981	0.00	0.00	0.00	0.00	0.00	0.01	3,899,886	0
	Tagged Wild Fish	Spring-run	Butte Creek	11	121,726	0.00	0.01	0.04	0.00	0.00	0.00	1,338,986	134
	Mokelumne River Hatchery	Fall-run Yearlings	Hatchery	12	96,570	0.00	0.27	1.33	0.01	0.04	0.10	1,158,840	3,592
		Fall-run	Hatchery	38	109,408	0.00	0.02	0.21	0.00	0.01	0.08	4,157,504	1,247

Percent of all Tagged Salmon Smolts Released from 1993-2009 that Suffered Direct Mortality at the Export Pumps												Total Fish Released	Total Fish Lost
						Percent Direct Mortality per Release Group							
						Banks Pumping Plant			Tracy Pumping Plan				
River	**Source of Fish**	**Species**	**Release Location**	**Number of Release Groups**	**Average Number of Fish Per Group**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**		
			Delta[2]	14	90,938	0.00	0.09	1.15	0.00	0.01	0.13	1,273,132	1,273
San Joaquin River System	Merced River Hatchery	Fall-run Yearlings	Hatchery	3	71,943	2.81	4.24	5.56	1.26	2.28	2.81	215,829	14,072
		Fall-run	Hatchery	36	185,142	0.00	1.06	9.64	0.00	0.30	1.55	6,665,112	90,646
			Delta[2]	23	145,292	0.00	0.70	5.25	0.00	0.20	1.31	3,341,716	30,075
Totals				**427**								**70,864,458**	**255,947**
Average Number of Fish per Release Group					**166,000**	**Average loss for all fish released**				**0.4%**			

[1]Consists of Coleman Hatchery releases from 1993-1997 and Livingston Stone releases from 1998-2009

[2]Consists of releases into the Sacramento River at locations between Red Bluff Diversion Dam and Sacramento and in the Delta

[3]Consists of releases into the San Joaquin River near Mossdale and downstream in the Delta

9.2.1.8 Salvage as an index of survival rather than of mortality

Estimates of smolt survival through the Delta have been derived primarily from CWT-marked test groups of juvenile hatchery Chinook released in or near the Delta. Since 2006, technological advances in miniaturization of signal-emitting tags (radio and acoustic) have made it possible to track individual smolts passing through the Delta. This has allowed for more precise estimates of survival and analysis of the factors affecting smolts within the Delta. Notwithstanding this improved technology, fish management agencies have continued to use the number of fish salvaged at the CVP and SWP fish salvage facilities as their primary index of mortality related to SWP and CVP exports.

As described in greater detail below, we undertook a series of analyses using data on smolt salvage to test the traditional hypothesis that increased smolt salvage de facto leads to increased mortality to smolts attributable to export pumping. Contrary to the traditional hypothesis, we determined that increasing salvage at the SWP and CVP fish facilities primarily corresponds with increased abundance of smolts in the Delta, rather than overall increased smolt mortality. We determined that mortality is better estimated by accounting for the proportion of smolts using the various routes through the Delta rather than simply calculating mortality based upon salvage.

Recent tagging studies of Chinook smolt passage through the Delta (Newman 2008) show that fish salvage at the export pumps is not a meaningful indicator of smolt mortality as they pass through the Delta (Figure 9-19). Direct mortality at the export facilities has generally been calculated as a multiple of the number of fish salvaged. The number of fish saved (salvaged) has been used to estimate the number that died, and thus rates of salvage have become synonymous with fish mortality. If salvage rate is an index of mortality rate (per the hypothesis), then independent estimates of smolt survival should show that survival decreases as salvage increases. Such comparisons can be and have been made for CWT smolts. However, these comparisons show no relationship between salvage and juvenile survival rates (Figure 9-19).

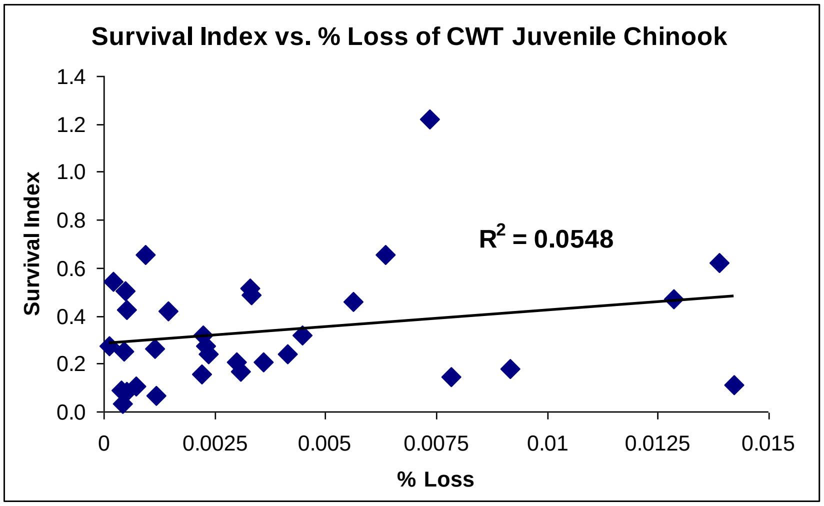

Figure 9-19. Relationship of Chinook smolt survival through the Delta to expanded percent loss of the same CWT groups at the CVP and SWP fish facilities. Data and survival estimates from Newman (2008) for late-fall CWT groups released during fall – winter in the Sacramento River Delta. The relationship is not significant.

The size and timing of juvenile salmon captures at Chipps Island correspond to seasonal trends in salmon abundance reflected in salvage at the fish facilities. When more smolts are passing through the Delta (as indexed by Chipps Island Trawl catches), more smolts are salvaged (Figure 9-20). Analyses of salmon monitoring data also show that once the effect of smolt abundance passing through the Delta is accounted for, the remaining variation in salvage rates is statistically related to Delta inflow and water temperature, but only weakly or not at all to export volume. For Sacramento River smolts, the effect of exports was insignificant (P = 0.17) and for San Joaquin River smolts, the effect was marginally significant (P = 0.06), but small.

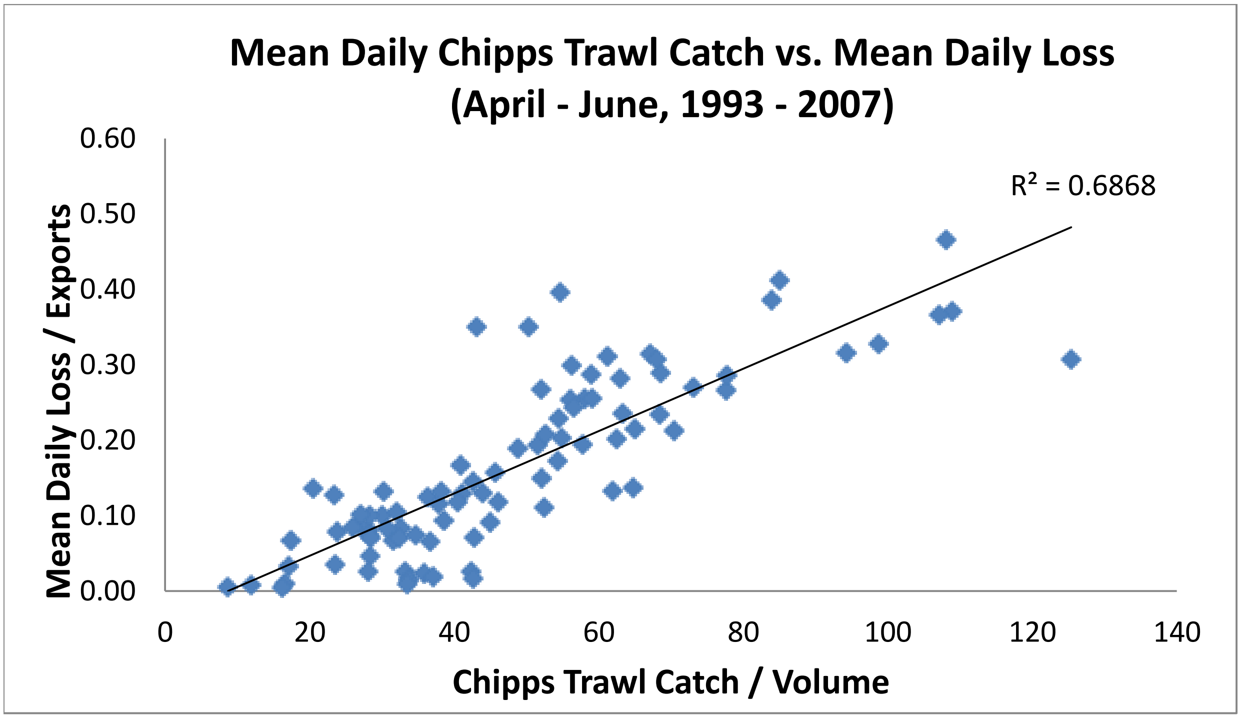

Figure 9-20. **Correlation of expanded loss at the Delta pumps to the index of smolt abundance entering San Francisco Bay (Chipps Trawl catch/day). Each point is a monthly average across 1993-2007 for all juvenile Chinook combined. This demonstrates that catch at fish facilities reflects abundance of fish surviving through the Delta.**

We used CWT releases of Chinook salmon from Coleman National Fish Hatchery over the 10-year period 1997-2006 to statistically analyze the factors that related to the proportion of those fish that were salvaged. The highest correlation was a positive relationship with catch of the CWT in Chipps trawl, followed by a positive relationship to Sacramento flow and a negative relationship to San Joaquin flow. With these variables in the model, the added effect of export volume was insignificant (P= 0.17). The sign and magnitude of effect from these variables indicates that higher survivorship (not mortality) through the Delta (indicated by catches in Chipps trawl) leads to more fish arriving at the export facilities, and this is further increased as flows in the Sacramento increase, but decreases as flows in the San Joaquin River increase. These opposite flow effects from the two rivers reflect their effects on Delta hydrodynamics–the proportion of flow arriving at the pumps from the Sacramento River increases as the ratio of Sacramento flow is more dominant and decreases as San Joaquin flow becomes more prominent.

Similarly, the analyses showed that the proportion of San Joaquin CWT fish recovered increases as their catch in the Chipps trawl increases and as the proportion of San Joaquin flow entering Old River increases, but decreases as temperature and flow in the San Joaquin increases. Again the signs and magnitude of effects are intuitive: Old River flows directly to the export facilities, while the San Joaquin River, after passing the Head of Old River, guides fish further away from the export facilities. As was true for Sacramento CWT fish, the salvage rate of San Joaquin CWT fish was not significantly correlated to export rate after the effects of these other variables was accounted for.

Conclusions from these analyses include:

- Numbers of fish salvaged at the south Delta export facilities provide an index of smolt survivorship to San Francisco Bay;
- Survivorship to the Delta has a much stronger influence on salvage than does export rate; and
- Parsing of fish salvage abundance into (1) numbers contributed by smolt abundance, and (2) numbers drawn in by pumping will require a mechanistic analysis of how fish choose pathways through the Delta.

The DPM provides the needed integration of mechanisms and makes it possible to link route choices and survival in each route to flow and water operations in the Delta. The proportion of smolts that take different routes through the Delta is presently being analyzed for the acoustic tagging studies conducted in 2012. The 2012 data will expand the number of channel junctions within the Delta for which the proportionate routing of smolts can be estimated, and this information will be incorporated into the Delta Passage Model during the fall of 2012. Then, it will be possible to estimate the magnitude of indirect mortality related to pumping volume.

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10 Ocean Conditions

Ocean conditions are an important factor impacting salmonid survival and abundance in terms of both successful rearing and ocean harvest of adults (Lindley *et al.* 2009). Changes in ocean conditions can have a major impact on salmonids that cannot be addressed through Delta or upstream flow changes.

Chinook salmon and steelhead spend a considerable proportion of their lifecycle inhabiting coastal marine waters. See Tables 1-1 and 1-2. Many salmonids enter the ocean as young of the year juveniles and reside in the marine habitat for a period of several years or more (Williams 2006). The survival of smolts at the time of ocean entry is thought to be the most critical phase for salmon during their residence in the ocean (Quinn 2005).

During their ocean residency, juvenile and sub-adult salmonids forage and grow, and food availability is a critical factor influencing their growth and survival. Food availability in coastal marine waters varies in response to a number of factors that include coastal upwelling and ocean temperatures and currents. Coastal upwelling and other oceanographic processes that influence productivity are characterized by cyclic patterns with recurrence intervals that may vary from years to decades. For example, ocean productivity was very low in the Gulf of the Farallones in 2005 and 2006, which was correlated with extremely low adult salmon returns in 2007, 2008, and 2009 that were thought to reflect poor food availability and high juvenile mortality in the ocean (Lindley *et al.* 2009). In response to the low numbers of adult salmon in the population the commercial and recreational fisheries were curtailed to protect the weak stocks.

Ocean upwelling and productivity have been good in recent years and the estimated number of adult fall-run Chinook salmon in coastal waters in 2012 is among the highest levels (approximately 800,000 adults) in the past decade. A similar pattern in adult abundance and escapement was observed in 2000 when the Central Valley adult escapement of 478,000 fish was the highest level since the early 1950s. Escapement in 2000 was exceeded in 2001 when approximately 600,000 adult salmon returned to the Central Valley and again in 2002 when adult escapement was approximately 850,000 fish (GranTab 2011).

The decline in adult Chinook salmon escapement in 2007 raised a number of concerns about factors contributing to the observed decline. In 2009, NMFS scientists (Lindley *et al.* 2009) compiled and analyzed information to determine whether ocean conditions were a major factor contributing to the observed decline in 2007 salmon adult escapement. The NMFS scientists found that ocean conditions were poor for salmon growth and survival in 2005 and 2006 and were the primary cause of the decline. Indices of ocean production, water currents, and oceanographic conditions such as upwelling, as measured by the Wells Ocean Productivity Index and the Northern Pacific Oscillation Index, indicated that conditions for salmonids declined substantially in the mid-2000s. Salmon stocks outside of the Bay-Delta estuary—and thus outside the influence of Delta environmental conditions and CVP/SWP export operations—also reported declines during the same period, including a marked reduction in coho salmon populations in Oregon and northern California. The NMFS and other studies of ocean conditions in the mid-2000s, along with the corresponding declines in coastal coho salmon populations, provide strong evidence that poor ocean conditions were the major factor affecting adult salmon escapement in 2007.

Observations from adult escapement in 2008 of approximately 72,000 adults and 2009 when adult escapement was approximately 53,000 adults demonstrate that coastal productivity has a strong influence on juvenile salmon growth and survival in the ocean. When coastal conditions are poor, survival declines and adult abundance is low. In contrast, the estimated adult abundance in 2000-2002 and 2012 indicates that salmon populations continue to be robust and have the capacity to produce large numbers of adults in those years when ocean conditions and productivity are good for juvenile rearing. Variability in ocean rearing conditions contributes substantially to the overall population dynamics of Central Valley salmonids and to variability in adult production and escapement among years (Lindley *et al.* 2009, Wells *et al.* 2008).

In addition to variability in ocean productivity, which affects juvenile growth and survival in the ocean, juvenile and sub-adult salmonids are also vulnerable to predation by fish, birds, and marine mammals during their ocean residency. Variation in ocean temperatures and current patterns affect the species composition and abundance of predatory fish that potentially prey on juvenile and sub-adult salmonids. There is very little quantitative information regarding the movement patterns and survival of juvenile salmonids in the ocean. Recent advances in acoustic tagging technology have provided monitoring tools that are expected to provide greater insight into the movements of juvenile salmonids in coastal areas as well as improved information about the magnitude of predation mortality as a factor affecting salmonid survival and abundance during their ocean rearing phase.

Fall-run Chinook salmon support an important commercial and recreational fishery. However, Central Valley salmon populations appear to overlap substantially in their distribution in the ocean and, therefore, there is the risk that protected winter-run and spring-run Chinook salmon will also be harvested.

To address the concern regarding incidental take of protected salmon in the coastal fishery, NMFS recently completed a revised Biological Opinion for ocean salmon harvest (NMFS 2010b). The Pacific Fishery Management Council (PFMC) has also reduced ocean salmon harvest in recent years (PFMC 2012).

Ocean fisheries harvest management objectives are designed to allow harvest of Chinook salmon that are in excess of the goals for spawner abundance (escapement) to the Sacramento and San Joaquin river systems (Boydstun 2001). These goals are established by the PFMC and are expressed as a range of 122,000 to 180,000 hatchery and natural Chinook returning to the Central Valley (CV). Thus, harvest regulations are more liberal when abundance is predicted to exceed this range and is increasingly restricted as abundance approaches the lower limit of the range.

As a result, the fraction of Central Valley Chinook salmon harvested in the ocean varies widely across years. The exploitation rate (harvest) has ranged from over 80 percent in the early 1990s to only 1 percent in 2009 (Figure 10-1). The effect of variable harvesting is even greater when the impact is viewed as the fraction of fish that is allowed to survive rather than as the fraction that is harvested. The fraction allowed to survive has ranged over four-fold, from 15 percent to 60 percent, even excluding the much greater increases in survival from curtailed harvest during 2008-2010 (Figure 10-2; ChinookProd 2011).

Mandated reductions in ocean salmon harvest are expected to provide improved protection for winter-run and spring-run Chinook salmon, and also contribute to increased escapement of all salmon runs to Central Valley rivers (NMFS 2010b). Since steelhead are not caught in the commercial or recreational fishery, changes in harvest regulations for salmon are not expected to have any effect on adult steelhead abundance or escapement.

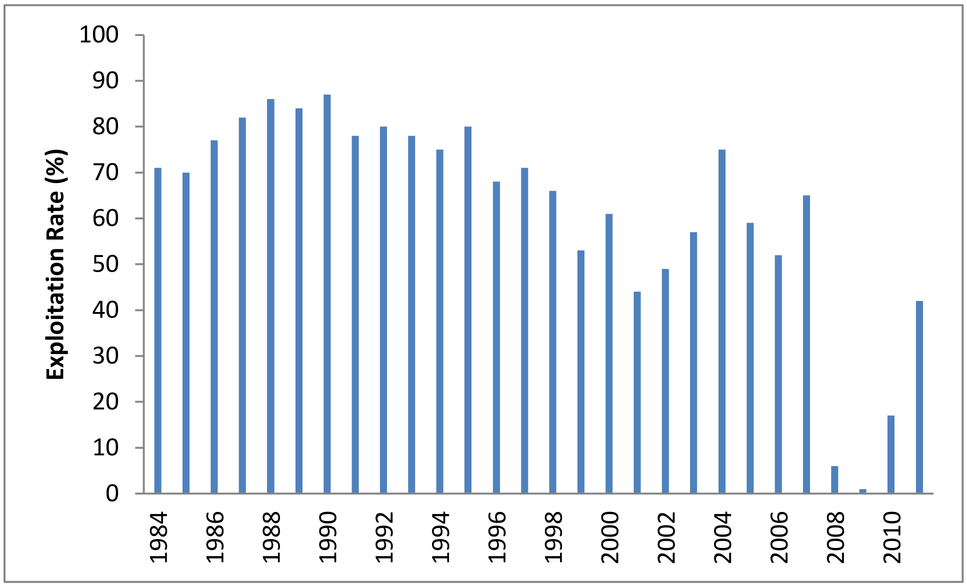

Figure 10-1. Sacramento River fall-run Chinook salmon exploitation rates (Source: PMFC 2012).

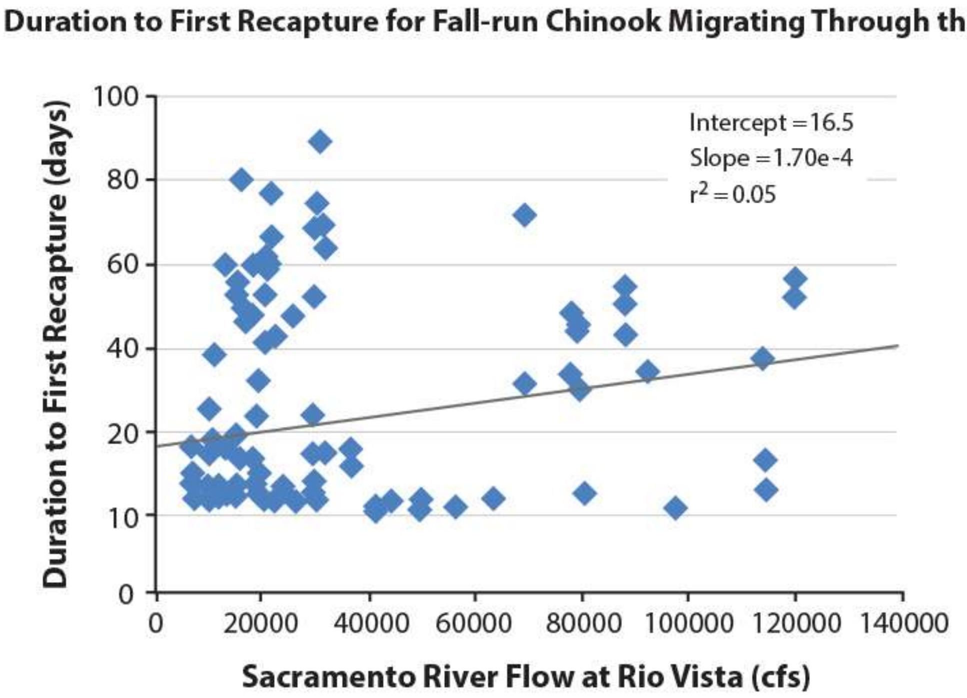

Figure 10-2. The Sacramento Index (SI) and relative levels of its components. The Sacramento River fall Chinook escapement goal range of 122,000-180,000 adult spawners is noted on the vertical axis.

The ocean fishery off California's coast for Central Valley Chinook salmon is a mixed-stock fishery reflecting a combination of runs of salmon as well as wild and hatchery produced Chinook salmon. Fall-run Chinook salmon are produced in greatest numbers in Central Valley hatcheries and are the primary target of the ocean fishery. Currently, a constant fractional marking program is employed in which 25 percent of the salmon produced in Central Valley hatcheries are CWT and their adipose fin is clipped as an external mark. Other than those fish with an adipose fin clip commercial and recreational anglers have no way of determining whether a salmon that has been caught was produced in a hatchery or was a wild fall-run, winter-run, late fall-run, or spring-run salmon. Fishery regulations currently do not specify that only hatchery produced salmon can be harvested.

Because hatcheries have been efficient in producing juvenile fall-run Chinook salmon, harvest regulations in past years have allowed very high harvest rates that, while theoretically sustainable by hatchery operations, exceed the harvest rate that a wild salmon population can support. In Washington, salmon harvest in the ocean is limited to only hatchery produced fish through use of a mark-select fishery. In a mark-select fishery only adult salmon that have an adipose fin clip can be harvested. Wild fish are reflected by an intact adipose fin and are required to be released.

Pyper *et al.* (2012) evaluated the potential effects of a mark-select fishery on ocean harvest and escapement of Sacramento River fall-run Chinook salmon. Based on model results , Pyper *et al.* (2012) estimated that actual adult escapement would have increased approximately 119 percent on average over the 1988-2007 period had a mark-select fishery been in place. During the recent period when fishing regulations have more strictly controlled the harvest rate (Figures 10-1 and 10-2), the estimated increase in natural-origin salmon escapement ranged from 24 to 48 percent depending on model assumptions (Pyper *et al.* 2012). The model results also showed that implementing a mark-select harvest regulation would result in reductions in commercial and recreational ocean harvest, with the magnitude of impact to the fishery depending on the proportion of the ocean salmon population composed of hatchery-origin salmon.

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Attachment A:
Floodplain Habitat Benefits for Aquatic Productivity and Native Fishes

Introduction

This appendix reviews the benefits that floodplains can provide the Sacramento-San Joaquin Delta ecosystem. Natural floodplains are one of Earth's most productive and biologically diverse ecosystems (Tockner and Stanford 2002). Floodplains can provide ecosystem benefits at several spatial scales. Habitat mosaics within the floodplain, such as riparian forest, support a wide array of species including birds (Gardali *et al.* 2006, Golet *et al.* 2008). When inundated, the floodplain also benefits species that can directly access these aquatic habitats, such as fishes that spawn or forage on the floodplain (Moyle *et al.* 2007). Finally, floodplains can potentially provide regional benefits by exporting food resources such as phytoplankton to downstream systems (Sommer *et al.* 2004, Ahearn *et al.* 2006, Lehman *et al.* 2008).

Key attributes of functional floodplains

Seasonal flooding and hydrological connectivity are prerequisites for ecologically functional floodplains (Junk *et al.* 1989, Mahoney and Rood 1998, Galat *et al.* 1998, Tockner *et al.* 2000, Tockner and Stanford 2002, Bunn and Arthington 2002, Ward 2002, Rood *et al.* 2005, Kondolf *et al.* 2006). A range of hydrologic events is necessary to maintain the ecological integrity of riverine aquatic ecosystems (Poff *et al.* 1997, Bunn and Arthington 2002). Key attributes of ecologically functional floodplains include: (1) hydrologic connectivity between the river and the floodplain, (2) a variable flow regime that reflects seasonal precipitation patterns and retains a range of both high and low flow events, and (3) sufficient spatial scale to encompass dynamic processes and for floodplain benefits to accrue to a meaningful level (Opperman *et al.* 2010).

Most Central Valley floodplains, however, are severed from their rivers by levees, channelization and flow regulation (Mount 1995). Infrastructure and management for water supply and flood control have altered river hydrologic and geomorphic function by eliminating spring flooding, reducing variability of flows, and altering sediment transport (TBI 1998, Williams *et al.* 2009). This river-floodplain disconnect affects functional attributes of floodplains, including reduced nutrient replenishment and associated food web development, and decreased variability of flood-dependent habitats (Jeffres *et al.* 2008, Opperman *et al.* 2010).

Different floodplain processes emerge at increasing levels of floods, which Opperman and others (2010) categorized as floodplain activation, floodplain maintenance, and floodplain resetting floods. Floodplain activation flows (FAF) are frequent (1-3 year recurrence interval), small-magnitude floods that reconnect the river and floodplain, often for long duration and several times in a season (Opperman *et al.* 2010). The FAF is the smallest flood pulse event that initiates substantial beneficial ecological processes (Williams *et al.* 2009). Floodplain maintenance floods are higher magnitude and are capable of bank erosion and sediment deposition on the floodplain (Florsheim and Mount 2002, Opperman *et al.* 2010). Finally, floodplain resetting floods are rare (<5 percent exceedance probability), very high magnitude events that produce extensive geomorphic change, such as scouring of floodplain surfaces and channel avulsion (Opperman *et al.* 2010).

Ecological processes are more dependent on duration and timing of floodplain inundation than simply magnitude of flows (Poff *et al.* 1997, Booth *et al.* 2006, Opperman *et al.* 2010). Frequent, prolonged inundation is essential for activating key processes of an ecologically functional floodplain, in both tropical (e.g., Junk *et al.* 1989) and temperate systems (Williams *et al.* 2009, Opperman *et al.* 2010). During periods of inundation, floodplains provide very different habitat conditions than found in the adjacent river channel. As water spreads onto the floodplain, velocity slows and sediment drops out of suspension. Because floodplain water is often less turbid than river water, inundated floodplains can support greater rates of photosynthesis from aquatic vascular plants and algae (including both attached algae and phytoplankton) (Tockner *et al.* 1999, Ahearn *et al.* 2006). This enhanced primary productivity in turn supports high secondary productivity (Junk *et al.* 1989, Grosholz and Gallo, 2006).

Floodplains in the Sacramento-San Joaquin Delta Region

The functional floodplain concepts are illustrated by studies of the Yolo Bypass (e.g., Sommer *et al.* 2001a&b, 2003), Cosumnes River (e.g., Mount *et al.* 2003, Swenson *et al.* 2003, Jeffres *et al.* 2008), and Sacramento River (e.g., Williams *et al.* 2009). These concepts are currently being applied to restoration of the upper San Joaquin River, such as the floodplain activation flow and design of seasonal floodplain habitat to benefit migrant rearing of juvenile Chinook salmon (*Oncorhynchus tshawytscha*).

The Yolo Bypass

The 24,000-ha Yolo Bypass is the largest floodplain of the Sacramento-San Joaquin Delta (Sommer *et al.* 2003). This engineered floodplain (61-km long and 3-km wide) is not immediately adjacent to a main river, but rather receives floodwaters through discrete locations. The floodplain is inundated during winter and spring in about 60 percent of years. During high flow events, Yolo Bypass can have a discharge of up to 14,000 m^3/s, representing 75 percent of total Sacramento River basin flow. Under typical flood events, water spills into Yolo Bypass at Fremont Weir when Sacramento basin flows surpass approximately 2000 m^3/s. At higher basin flows (>5000 m^3/s), Sacramento Weir also spills. When flood waters recede, the basin empties through a permanent tidal channel along the eastern edge of Yolo Bypass. The floodplain is relatively well drained, but several isolated ponds remain perennially inundated (Feyrer *et al.* 2004). The Yolo Bypass supports fish and waterfowl in seasonally inundated habitats during winter and spring, and agriculture during summer (Sommer *et al.* 2001b).

Cosumnes River

The Cosumnes River drains from the Sierra Nevada into the eastside of the Delta. The Cosumnes River is one of the few Central Valley rivers without a major dam regulating its flows. As such, the river still maintains a variable seasonal flow regime typical of Mediterranean systems, experiencing winter flooding from rainfall (November-February) with peak flows of up to 2,650 m^3/s (1997), smaller floods fed by snowmelt (March-May), and low to no late summer and fall flows (Booth *et al.* 2006). Levees constructed starting in the late 1800s still constrain much of the river channel (Florsheim and Mount 2002). The lowest reach of the river is influenced by freshwater tides of the Delta. Currently, over 688 ha of restored and remnant riparian forest, including stands of valley oak (*Quercus lobata*) forest, occur along the lower Cosumnes River.

At the Cosumnes River Preserve, approximately 100 hectares of floodplain were functionally reconnected to the river when levees were breached intentionally in October 1995 and by floods in January 1997 (Swenson *et al.* 2003). Previously, the river overtopped its banks established connectivity every 5 years when flows exceeded approximately 50 m^3/s. After the 1995 breach, this occurred earlier and more frequently (1.5 year recurrence interval) at half that flow (25 m^3/s) (Florsheim and Mount 2003, Florsheim *et al.* 2006). Variable floods produced a range of geomorphic and ecological outcomes. Flows exceeding 100 m^3/s deposited and eroded sediment on the floodplain. The January 1997 floods (2,650 m^3/s, 150-year recurrence interval) caused extensive levee failure along the river. These flows correlate to the floodplain activation, floodplain maintenance, and floodplain resetting flows (Opperman *et al.* 2010).

Sacramento River

Much of the Sacramento River no longer has frequently inundated active floodplains. This reflects the fact that small, frequent spring flood events have been reduced since the construction and operation of large dams in the Sacramento Valley (Williams *et al.* 2009), as well as levee construction and channel incision. Williams and others (2009) defined the Floodplain Activation Flow (FAF) for Sacramento River lowland floodplains, in particular the confined leveed reaches downstream of Colusa and are adjacent to the largest area of former and potentially restorable floodplain in the system. The FAF must occur with a suitable duration and timing to produce identifiable ecological benefits, must allow hydraulic connectivity between the river and the floodplain during the period of flooding, and occur with sufficient frequency to make ecological benefits meaningful inter-annually. The FAF for the lower Sacramento River is the river stage that is exceeded in at least 2 out of 3 years and sustained for at least 7 days between March 15 and May 15 (Williams *et al.* 2009).

Williams and others (2009) concluded that the biggest opportunities for floodplain restoration lie in the bypasses. Levee setbacks on the Sacramento River for improved flood conveyance could increase the amount of active floodplains, but only with increased release of small spring flood pulses from upstream reservoirs or grading of the newly-established floodplains down to the current FAF stage. A recent example that applied the FAF concept is the flood control levee setback project at the confluence of the Bear and Feather Rivers, including a swale excavation to improve river-floodplain connectivity and reduce fish stranding (Williams *et al.* 2009).

Floodplain Benefits

Riparian Forest and Scrub Communities

Disturbance events such as floods provide conditions necessary for the regeneration of riparian tree species (Mahoney and Rood 1998, Mount *et al.* 2003, Rood *et al.* 2005). Floods create diverse topography on the floodplain. In 1995, high flows brought a pulse of sediment onto the floodplain in finger-like deposits up to 5 m deep and a few hundred meters long. Finer silts remained in suspension longer and were deposited in thin layers across the floodplain (Florsheim and Mount 2002, Florsheim *et al.* 2006). Subsequent floods reworked floodplain sediments and scoured out channels nearly 4 m below the original elevation (Florsheim and Mount 2002).

Riparian plant communities are shaped by inundation dynamics (Junk *et al.* 1989, Mahoney and Rood 1998) and height above the water table (Stromberg *et al.* 1991, Marston *et al.* 1995), which are both influenced by floodplain topography (Florsheim and Mount 2002). The habitat mosaic at the restored Cosumnes floodplain included cottonwood and willows on elevated sandbars, herbaceous vegetation in scoured areas, and emergent wetland plants in some permanent floodplain ponds. The varied physical structure of riparian vegetation supports diverse wildlife in the Central Valley, including many songbird species (Gardali *et al.* 2006, Wood *et al.* 2006, Golet *et al.* 2008).

Aquatic Productivity

Primary production within the Delta estuary is inherently low because of high turbidity and low light levels, rather than nutrient limitations (Jassby *et al.* 2002, Lopez *et al.* 2006). Detrital inputs dominate the organic matter supply of the riverine and estuarine systems, but much of this is not readily bioavailable except via a microbial pathway (Sobczak *et al.* 2002 and 2005). Phytoplankton comprise a small fraction of the Delta's organic matter supply, yet they provide the most significant food source for zooplankton (Müller-Solger *et al.* 2002, Sobczak *et al.* 2005). Stocks of zooplankton have declined significantly since the 1970s (Orsi and Mecum 1996). The declining productivity of pelagic food webs has been proposed as a contributing factor to population declines of native fishes (Bennett and Moyle 1996, Baxter *et al.* 2008, Glibert 2010).

In contrast, Central Valley floodplains can produce high levels of phytoplankton and other algae, particularly during long-duration flooding that occurs in the spring (Sommer *et al.* 2004, Ahearn *et al.* 2006). The shallow water depth and long residence time in floodplains facilitate settling of suspended solids, resulting in reduced turbidity and increased total irradiance available for phytoplankton growth in the water column (Tockner *et al.* 1999). At the Cosumnes River Preserve, the inundated floodplain progressed from a physically driven system when connected to the river floods, to a biologically driven pond-like system with increasing temperature and productivity once inflow ceased (Grosholz and Gallo 2006). Periodic small floods boosted aquatic productivity of phytoplankton (measured as chlorophyll a) by delivering new pulses of nutrients, mixing waters, and exchanging organic materials with the river (Ahearn *et al.* 2006). Aquatic productivity was greater in floodplain ponds than in river sites (5-10 times greater chlorophyll-a values and 10-100 times greater zooplankton biomass) (Ahearn *et al.* 2006, Grosholz and Gallo 2006). Zooplankton biomass increased rapidly following each flood event to a peak approximately 7 – 25 days after disconnection from the river, with highest observed values (approximately 1,000 – 2,000 mg/m^3) at approximately 21 days (Grosholz and Gallo 2006).

As reviewed by Lehman and others (2008), phytoplankton produced on the floodplains are often higher in nutritional quality than phytoplankton found in rivers because they have a wider spherical diameter and thus higher carbon content (Hansen *et al.* 1994, Lewis *et al.* 2001). Diatoms and green algae, which are the dominant algal species in the Yolo Bypass (Lehman *et al.* 2008), have the highest cellular carbon content in the San Francisco Estuary phytoplankton community (Lehman 2000, Hansen *et al.* 1994). Laboratory trials with cladocerans indicate that phytoplankton was the most biologically available carbon source and produced the highest growth rate (Mueller Solger *et al.* 2002, Sobczak *et al.* 2002) (Figure A-1). Zooplankton may be food limited if phytoplankton concentrations drop below a level corresponding to 10 µg/L Chl *a* (Muller-Solger *et al.* 2002). This is important because these zooplankton are a primary food source for numerous Delta fish species.

Studies of the Yolo Bypass provide evidence of the incremental value of floodplain habitat to the conservation of large rivers (Sommer *et al.* 2001a&b, 2003). Chlorophyll a levels were significantly higher in the floodplain than in the river, and were negatively associated with flow. These results were consistent with longer hydraulic residence times, increased surface area of shallow water, and warmer water temperatures. Copepods and cladoceran densities were similar in the river and its floodplain, and were mostly negatively associated with flow. Chironomids were positively correlated with flow (discharge and flow velocity); these organisms were one to two orders of magnitude more abundant in the Yolo Bypass floodplain than the adjacent Sacramento River channel (Sommer *et al.* 2001a).

Providing river–floodplain connectivity can enhance production of lower trophic levels at relatively rapid time scales (Sommer *et al.* 2004). In the Yolo Bypass, some food web organisms can respond within days and attain high densities soon after inundation, including smaller fast-growing algae (e.g., picoplankton, small diatoms, nanofragellates), vagile organisms such as drift insects, and organisms associated with wetted substrate such as chironomids. These organisms, particularly chironomids, provide a food source to fish that is available prior to the development of food web productivity associated with long residence times (e.g., phytoplankton and zooplankton responses to inundation) (Sommer *et al.* 2004).

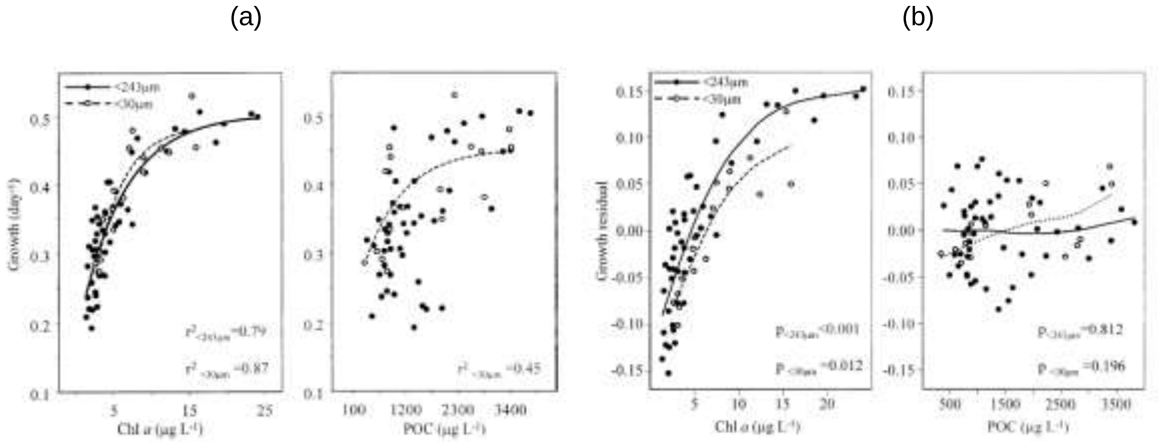

Figure A-1. Growth rate of *Daphnia* with algae and particulate organic carbon (POC). (a) Nonlinear regressions results of Daphnia growth rates against size fractionated Chl *a* and particulate organic carbon (POC). Growth rate is higher with algae (as measured by chlorophyll a concentrations) than with POC, (b) Partial residual plots of Chl *a* and POC effects on growth from a general additive model. Growth is higher with larger algae (seston <243 μm) than small (<30 μm). From Mueller-Solger *et al.* 2002.

Consequently, a potential benefit of floodplain restoration is an increase in the productivity of food webs that support Delta fish species (Ahearn *et al.* 2006). For example, Delta smelt and longfin smelt are two species dependent on zooplankton. Floodplains have been proposed as “productivity pumps” (Junk *et al.* 1989) that can export food resources, especially algae, to support food webs in downstream communities (Sommer *et al.* 2001b, Ahearn *et al.* 2006, Lehman *et al.* 2008). By periodically pulsing small “floodplain activation floods,” it may be possible to pump high concentrations of algae to downstream waters (Ahearn *et al.* 2006). Analysis of suspended algal biomass in the Cosumnes River channel and floodplain by Ahearn and others (2006) documented an increase in Chl *a* concentrations on the floodplain during periods of river-floodplain disconnection, and subsequent increase in Chl *a* in the river when connection was restored (Figure A-2). This illustrates export of floodplain-produced algae to downstream aquatic ecosystems during flood events.

Cloern (2007) used a nitrogen-phytoplankton-zooplankton model to illustrate how shallow habitats sustain fast phytoplankton growth and net autotrophy (photosynthesis exceeds community respiration), whereas deep, light-limited habitats within the Delta channels sustain low phytoplankton growth (Jassby *et al.* 2002) and net heterotrophy. Lopez and others (2006) found that surplus primary production in shallow habitats provided potential subsidies that likely supported zooplankton in neighboring habitats, except in areas heavily colonized by the invasive clam *Corbicula fluminea*. Lehman and others (2008) suggested that the quantity and quality of riverine phytoplankton biomass available to the aquatic food web could be enhanced by passing river water through a floodplain such as the Yolo Bypass during the flood season.

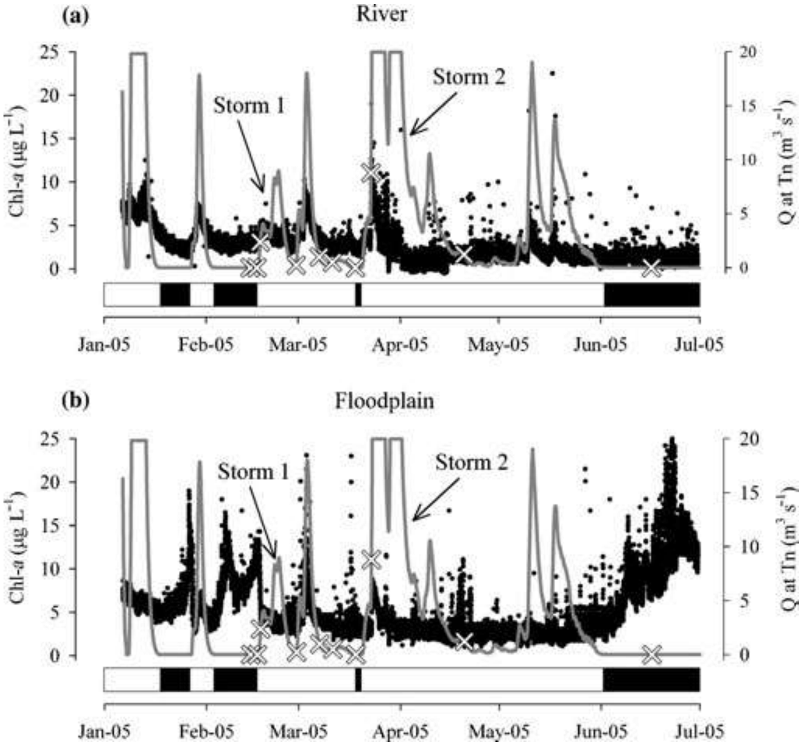

Figure A-2. **Chlorophyll *a* (Chl *a*) concentration time series from (a) the river and (b) the floodplain pond at the Cosumnes River Preserve. Dates when Chl *a* distribution was measured are marked on the hydrograph with an "x". Black bars represent periods of disconnection with the river. The hydrograph plateaus on the three largest storms because the river discharge exceeded the rating curve. Note the increase in Chl *a* on the floodplain when the river and floodplain are disconnected. From Ahearn *et al.* 2006.**

Spawning and Rearing Habitat for Native Fish

Floodplain inundation provides spawning and rearing habitat for fish that take advantage of the high productivity on the floodplain (Poff *et al.* 1997, Sommer *et al.* 2001a&b, Feyrer *et al.* 2004, Schramm and Eggleton 2006, Grosholz and Gallo 2006). During these periods of connection to the river, fish can move on and off the floodplain to spawn or forage (Moyle *et al.* 2007). Further, the low-velocity, shallow, and vegetated habitats of the floodplain serve as a refuge from the fast, turbid waters of the river during high flows (Sommer *et al.* 2001a, Jeffres *et al.* 2008).

The Sacramento splittail (*Pogonichthys macrolepidotus*) is perhaps the most floodplain-dependent species in the Delta (Sommer *et al.* 1997). Adults migrate onto the inundated floodplain to spawn on vegetation in February-March at both the Cosumnes floodplain (Moyle *et al.* 2007) and the Yolo Bypass (Sommer *et al.* 2004). Juveniles rear on the floodplain and depart when it drains in April-May, achieving better condition on the floodplain than in river habitats (Ribeiro *et al.* 2004).

Juvenile Chinook salmon also benefit from floodplains as foraging and refuge habitat. Juveniles migrate downstream onto floodplains in February to March to forage on the abundant invertebrates in the flooded vegetation, prior to emigrating to the sea (Moyle *et al.* 2007, Grosholz and Gallo 2006). At the Cosumnes River, growth rates of juveniles (mean length 54-55 mm) reared 54 days in enclosures were faster on ephemeral floodplain habitats (80-86 mm) than in the river (64 mm) (Jeffres *et al.* 2008) (Figures A-3 to A-4). The predominant prey was zooplankton in the floodplain ponds; benthic macroinvertebrates, amphipods and larval fish in submerged floodplain vegetation; and dipterans and coleopterans and insect drift in the river (Figure A-5).

At the Yolo Bypass, juvenile Chinook salmon grow larger and are in better condition than those in the river (Sommer *et al.* 2001a). Drift macroinvertebrates, such as chironomids and terrestrial invertebrates, are an important food resource for fish. Yolo Bypass salmon had significantly more prey in their stomach than salmon collected in the Sacramento River (Sommer *et al.* 2001a and 2004). Chironomids were the primary food resource for juvenile Chinook and were 1-2 orders of magnitude more abundant in the floodplain than the adjacent Sacramento River channel (Sommer *et al.* 2001a). However, the increased feeding success may have been partially offset by significantly higher water temperatures on the floodplain habitat, resulting in increased metabolic costs for young fish. The higher water temperatures were a consequence of the broad shallow shoals, which warm faster than deep river channels. Through bioenergetic modeling, Sommer and others (2001a) concluded that floodplain salmon had substantially better feeding success than fish in the Sacramento River, even when the prey data were corrected for increased metabolic costs of warmer floodplain habitat.

Figure A-3. Comparison of juvenile Chinook salmon reared 54 days at the Cosumnes River Preserve in (1) intertidal river habitat below the floodplain (left) and (2) floodplain vegetation (right). From Jeffres *et al.* 2008.

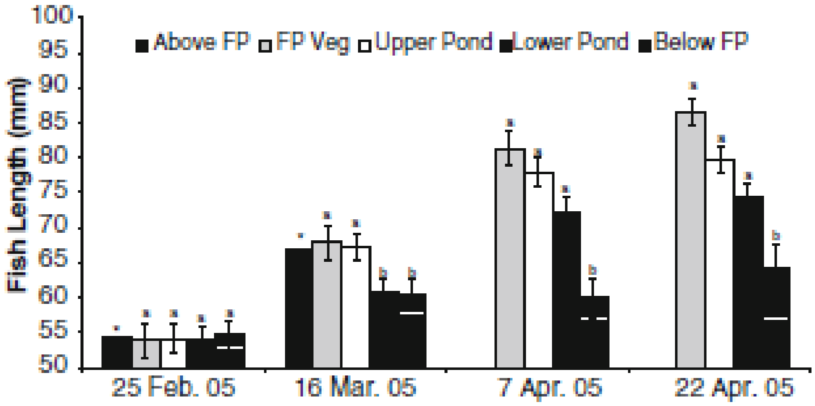

Figure A-4. **Size (mean fork length ± standard error) of juvenile Chinook at the Cosumnes River Preserve reared in floodplain habitats (FP Veg, Upper Pond, and Lower Pond) and river channel sites (Above FP and Below FP) over four sampling sessions during the 2005 flood season. Habitats with different letters are statistically different. Asterisks indicate habitats not included in the statistical analysis. From Jeffres *et al.* 2008.**

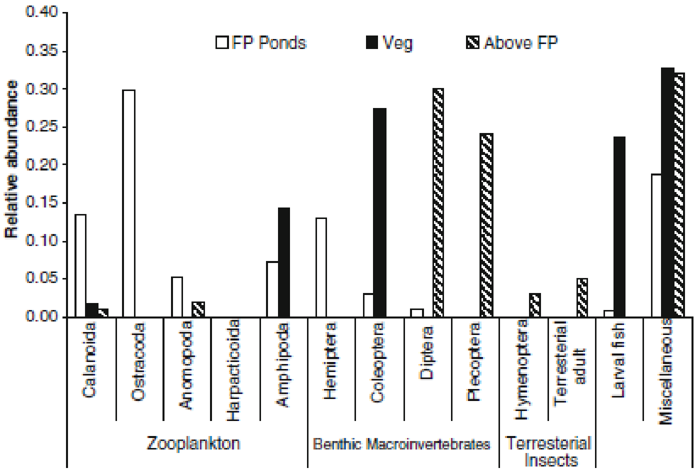

Figure A-5. **Relative abundance of prey items in juvenile Chinook salmon on the Cosumnes River (1) floodplain ponds, (2) floodplain vegetation, and (3) river channel above (upstream) from the floodplain. From Jeffres *et al.* 2008.**

Recreating the historical pattern of seasonal inundation can create habitat uniquely suited for floodplain-dependent native fishes and less hospitable for non-native fish. Native fish species that evolved with California's pattern of seasonal precipitation typically used the floodplain earlier in the year (February-May) (Figure A-6). In contrast, non-native species that evolved in temperate regions with year-round precipitation tend to arrive later and remain longer on the floodplain (April-July), spawn under warmer conditions (Moyle 2002), and are stranded more often when the floodplain drains and ponds dry out (Moyle *et al.* 2007). Fish stranding in shallow ponds at the end of the flooding season was a concern for floodplain restoration. However, remarkably few native fishes (splittail and Chinook salmon) were found in Cosumnes ponds once the river-floodplain connection was lost (Moyle *et al.* 2007). Similarly, juvenile Chinook salmon experienced low stranding rates in the Yolo Bypass Wildlife Area's managed wetlands after flood events (Sommer *et al.* 2005). It appears that floodplain-adapted fish species have the capacity to find their way off the floodplain before it becomes disconnected (Moyle *et al.* 2007).

Perennial aquatic habitat such as ditches and floodplain ponds are dominated by non-native fishes, as seen at the Cosumnes Preserve (Moyle *et al.* 2007) and the Yolo Bypass (Feyrer *et al.* 2004). Based on their observations at Cosumnes, Crain and others (2004) recommended that an optimal flood regime for native California fishes should include early season, cold water events that persist long enough for bursts in algal and invertebrate productivity, followed by spring draining of the floodplain before it warms and favors non-native species.

Predation is one mechanism that could lead to low native fish abundance in shallow-water habitats in the Delta. Some known predators of native Delta fish include striped bass, largemouth bass, and Sacramento pikeminnow (Nobriga and Feyer 2007). Predation is highest during spring (March-May) and during summer (June-August) (Nobriga and Feyrer 2007). Though there has been little investigation of predation on native fishes on floodplains, the observed seasonal use patterns and relative absence of piscivores suggest that floodplains offer native fishes a competitive advantage over non-native predators (Moyle 2007, Nobriga and Feyrer 2007). This differential pattern of habitat use is a rare opportunity where habitat restoration for native fishes does not simultaneously benefit non-native fishes that are potential predators or competitors.

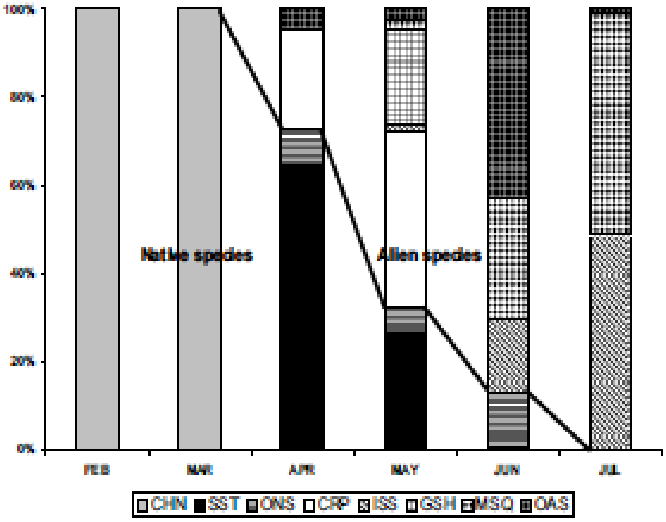

Figure A-6. **Monthly percent abundance of juvenile fishes on the Cosumnes River floodplain for the year 2000. The line connects the dividing line between native and non-native (alien) species. Native fish were predominant early in the season. CHN = Chinook salmon, SST = splittail, ONS = other native species, CRP = carp, ISS = inland silverside, GSH = golden shiner, MSQ = western mosquitofish, OAS = other alien species (From Moyle *et al.* 2007).**

Conclusion

Floodplains can provide a variety of benefits at different spatial scales depending on hydrologic regime, connectivity between river-floodplain habitats, and life history requirements of species. The magnitude of benefit for foodwebs and fish depends on the area that experiences frequent inundation (Opperman *et al.* 2010). The restored floodplain (100 ha) at the Cosumnes River can provide local benefits, but it is likely too small to accrue meaningful benefits for the broader Delta estuary (Opperman *et al.* 2010). Larger floodplain areas such as the Yolo Bypass (24,000 ha), however, have the capacity to influence fish at the population scale. For example, the duration of inundation of the Yolo Bypass is a strong predictor of year-class strength for splittail for the entire Central Valley and Delta system (Sommer *et al.* 1997, Feyrer *et al.* 2008). Longer inundation periods of weeks can maximize foodweb productivity, but even short inundation periods of days can provide ecosystem benefits (Sommer *et al.* 2004). For a food-limited system such as the Delta, it is reasonable to expect that any subsidy of food from floodplains has the potential to benefit the Delta foodweb.

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Attachment B

Table B-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Shasta Division/Shasta & Keswick Dams	Sacramento River water temperature objectives	<56°F, April 1 – Sept. 30; <60 °F, Oct. 1 – 31 at RBDD[1]	State Water Resources Control Board (SWRCB)
		< 56°F Keswick Dam to Bend Bridge with initial targets, based on May 1 Shasta cold water (<52°F) volume, as follows[2]: • >3.6 MAF - Bend Bridge • 3.3 - 3.6 MAF - Jellys Ferry • <3.3 MAF - Balls Ferry	National Marine Fisheries Service (NMFS)
	Sacramento River Temperature Task Group (SRTTG)[3]	Convened to formulate, monitor & coordinate annual temperature control plans	SWRCB
	Shasta Reservoir target minimum end of year carry-over storage (1.9 MAF)	To increase probability that sufficient cold water pool will be available to maintain suitable Sacramento River water temperatures for winter-run Chinook the following year	NMFS
	Sacramento River flows (releases from Keswick Dam)	Minimum flows: 3,250 cfs October 1 – March 30	SWRCB, CVPIA
	Flow ramp down rates from Shasta Dam	• Apply following schedule between July 1 and March 31[4]: • Reduce flows sunset to sunrise only • ≥6,000 cfs; < 15%/night and 2.5%/hour • 4,000 to 5,999 cfs; <200 cfs/night and 100 cfs/hour • 3,250 to 3,999 cfs; <100 cfs/night	NMFS

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[1] Allows flexibility when water temperatures cannot be met at RBDD. Temperature management plan developed each year by the Sacramento River Temperature Task Group (SRTTG).

[2] Based on temperature management plan developed annually by the SRTTG.

[3] The SRTTG is composed of representatives of SWRCB, NMFS, FWS, DFG, Reclamation, WAPA, DWR & Hoopa Tribe.

[4] Variations to ramping rate schedule allowed under flood control operations

Table B-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Red Bluff Diversion Dam	Gate operations	Gates raised from September 15 to May 14[5]	NMFS
	Sacramento River Water temperature objectives	<56°F, April 1 – Sept. 30; <60 °F, Oct. 1 – 31	SWRCB
Wilkins Slough	Navigation Flow Objective	Minimum of 5,000 cfs at Wilkins Slough gauging station on the Sacramento River; can relax standard to 3,500 cfs for short periods in critical dry years[6]	USBR
Oroville/Feather River Operations	Feather River minimum flows	600 cfs below Thermalito Diversion Dam when Lake Oroville elevation <733 ft MSL increasing to 1,000 cfs April through September if Lake Oroville elevation >733 ft MSL; Flows generals kept < 2,500 cfs August through April to avoid stranding salmonids	DWR & DFG Agreement
American River Division/Folsom & Nimbus Dams	American River minimum flow standards	Minimum 250 cfs January 1 to September 14 & 500 cfs September 15 to December 31 measured at the mouth of American River	SWRCB
	American River temperature objectives	Reclamation to develop, in coordination with the American River Operations Group and NMFS, annual water temperature control plan to target 68°F at Watt Avenue Bridge	NMFS
Eastside Division	Support of San Joaquin River requirements and objectives at Vernalis	Vernalis flow requirements February to June, Vernalis water quality objectives	SWRCB
New Melones Dam & Reservoir Operations	Flows for fish & wildlife; dissolved oxygen standards at Ripon	Release a minimum of 98,000 acre-feet of water to lower Stanislaus River below Goodwin Dam	SWRCB & DFG

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[5] Provides flexibility to temporarily allow intermittent gate closures (up to 10 days, one time per year) to be approved on a case-by-case basis to meet critical diversion needs. Reclamation will reopen the gates for a minimum of 5 consecutive days, prior to June 15 of the same year in a manner that will be least likely to adversely affect water deliveries.

[6] While commercial navigation no longer occurs between Sacramento and Chico Landing, long-term water users diverting from the river have set their pump intakes just below a minimum flow requirement of 5,000 cfs at Wilkins Slough. Diverters are able to operate for extended periods at flows as low as 4,000 cfs at Wilkins Slough; pumping operations become severely affected and some pumps become inoperable at flow less than 4,000 cfs. While no criteria have been established for critically dry years, the standard can be relaxed to a minimum flow of 3,500 cfs for short periods to conserve water storage in Shasta Reservoir and manage for multiple project and environmental objectives.

Table B-1. Examples of current regulations intended to protect and enhance fishery habitat for Central Valley salmonids.

Location/Facility	Description	Management Objective	Regulating Entity
Delta Cross Channel	Gate Closures	Gates closed February through May, 14 days May 21 to June 15, 45 days November 1 to January 1 to protect Sacramento River salmonids	SWRCB
Tracy & Banks Pumping Plants	Pumping Curtailments	Protect listed salmonids; meet export/Inflow ratio, X2, delta outflow requirements	SWRCB; NMFS
Contra Costa Canal operations	Diversion rate limits, fish screens	Protect listed salmonids	NMFS
Ocean Salmon Harvest	All California ocean commercial and sport salmon fisheries are currently managed by PFMC harvest regulations	Conservation Objective = 122,000 to 180,000 natural and hatchery Sacramento River Fall Run Chinook (SRFC) salmon spawners[7] Ocean commercial and recreational harvest in the ocean was banned in 2008 and 2009	NMFS, California Fish and Game Commission, Pacific Fishery Management Council
Inland Salmon Harvest	Zero bag limit on the American River, Auburn Ravine Creek, Bear River, Coon Creek, Dry Creek, Feather River, Merced River, Mokelumne River, Napa River, San Joaquin River, Stanislaus River, Tuolumne River, Yuba River, and the Sacramento River except for a one salmon bag limit in the Sacramento River from Red Bluff Diversion Dam to Knights Landing from November 1 to December 31.	To protect fall-run Chinook salmon stocks starting in 2008	California Fish and Game Commission

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[7] The conservation objective has been set by the Pacific Fishery Management Council in the Salmon Fishery Management Plan.

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Attachment C

Sacramento River Flows at Red Bluff Diversion Dam and Freeport

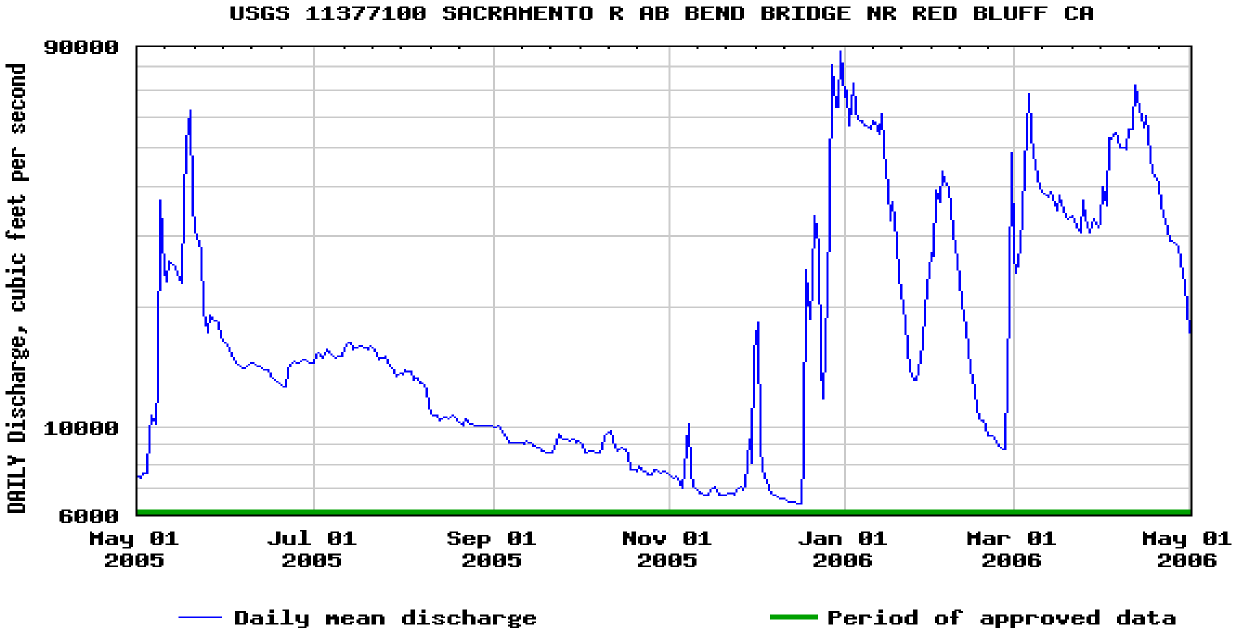

Figure C-1. **Daily flows on the Sacramento River at Red Bluff Diversion Dam from May 1, 2005-May 1, 2006(Source: USGS).**

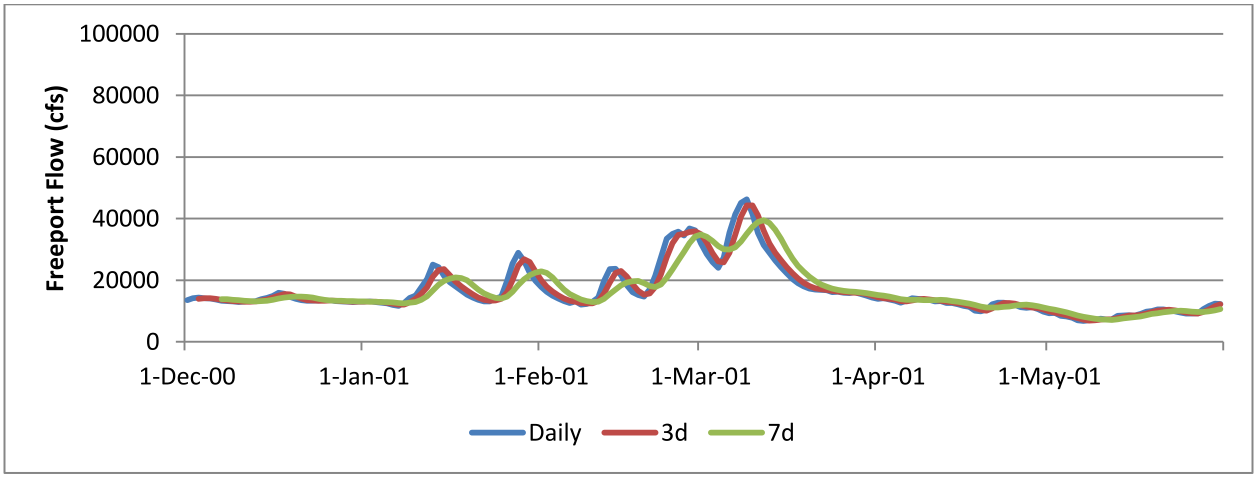

Figure C-2. **Daily flow in the Sacramento River at Freeport - 2001(Source: DWR DAYFLOW).**

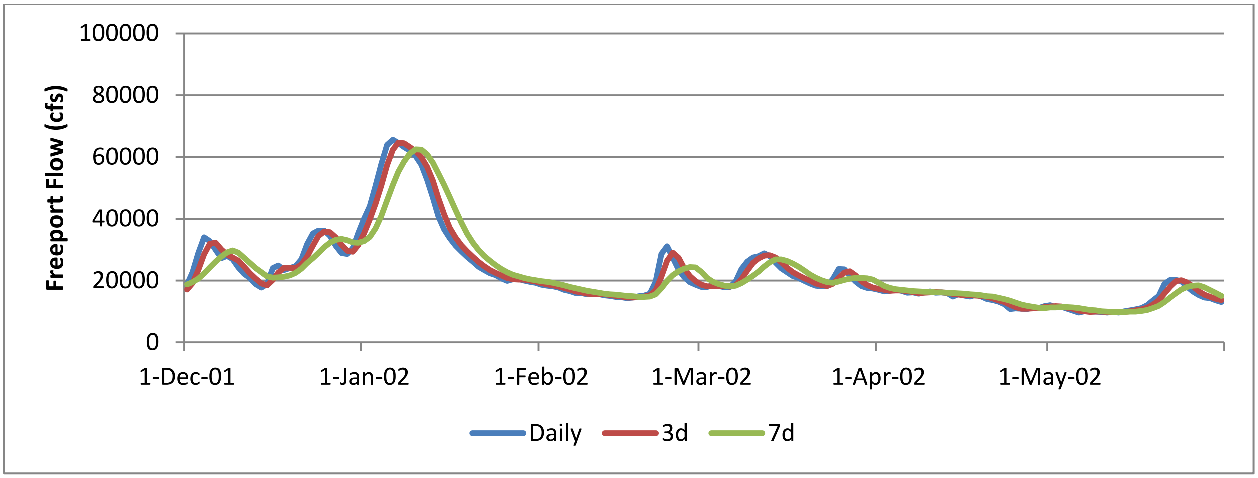

Figure C-3. Daily flow in the Sacramento River at Freeport – 2002 (Source: DWR DAYFLOW).

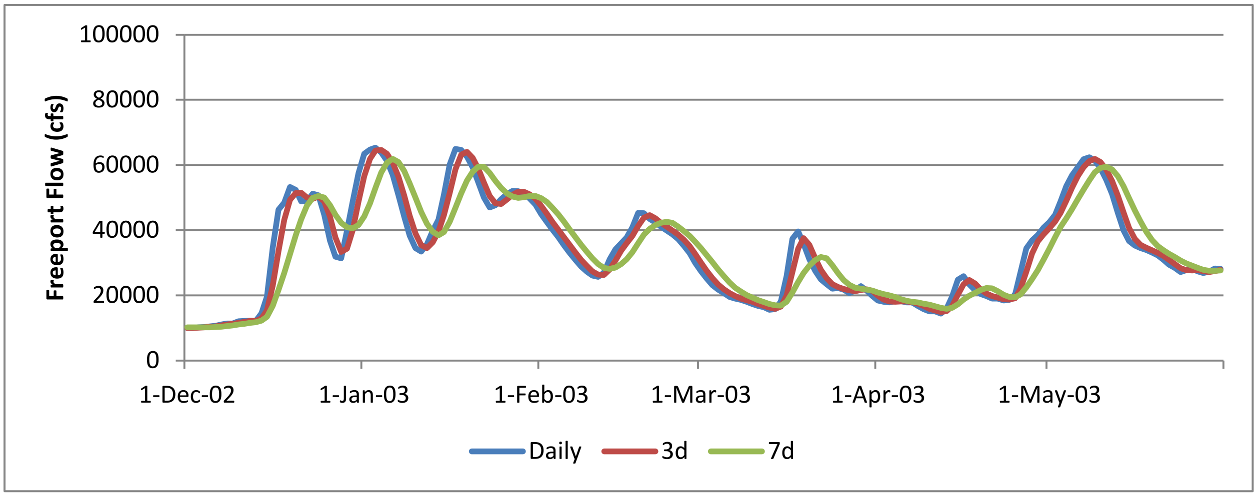

Figure C-4. Daily flow in the Sacramento River at Freeport – 2003 (Source: DWR DAYFLOW).

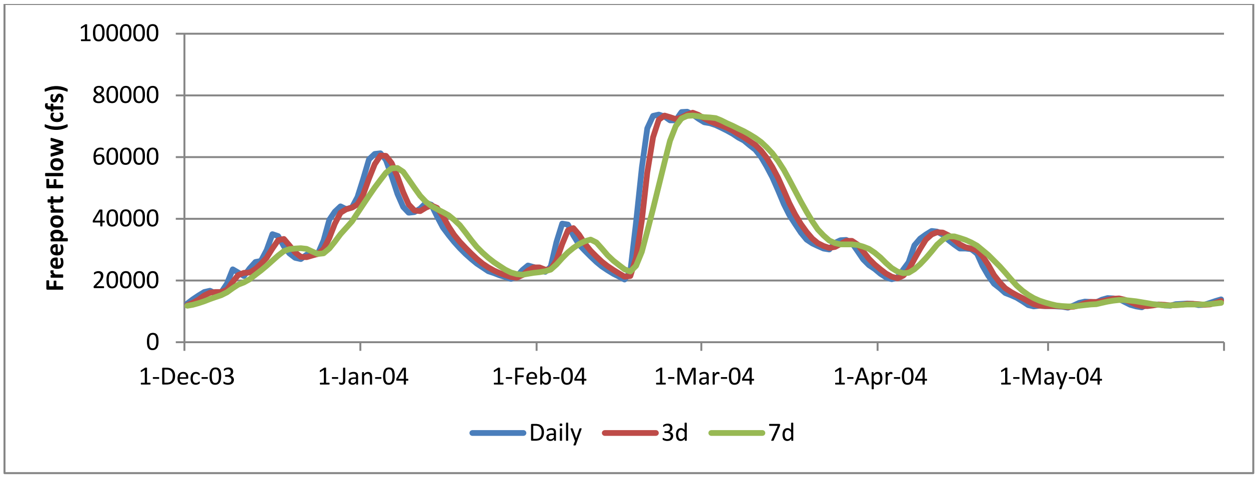

Figure C-5. Daily flow in the Sacramento River at Freeport – 2004 (Source: DWR DAYFLOW).

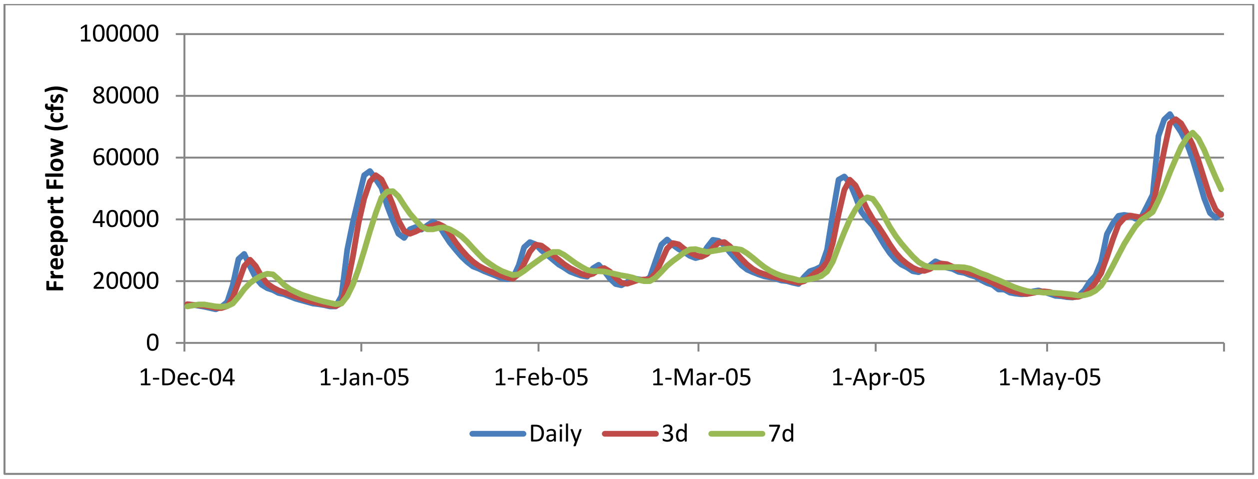

Figure C-6. Daily flow in the Sacramento River at Freeport - 2005 (Source: DWR DAYFLOW).

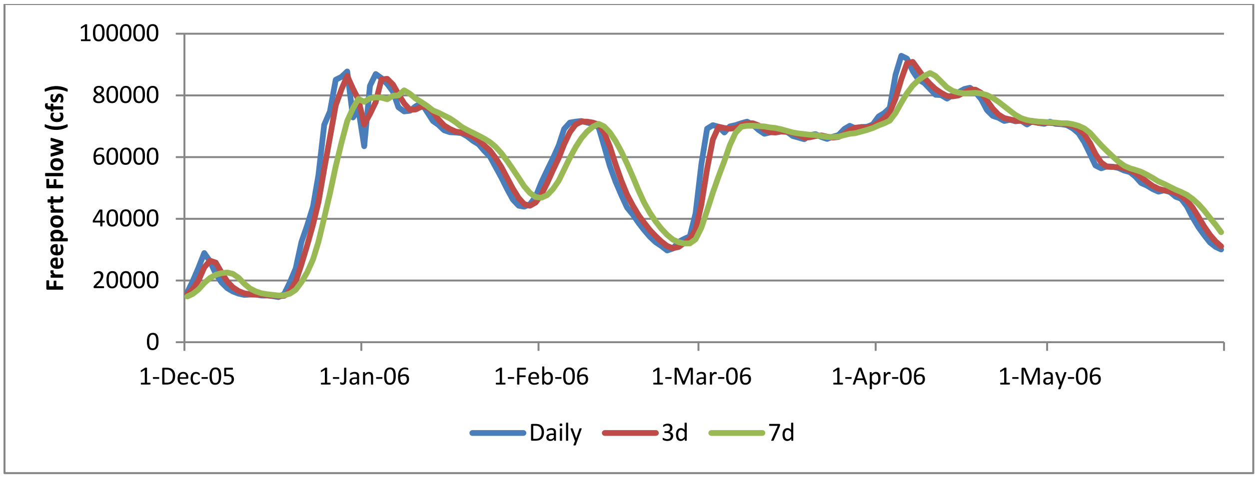

Figure C-7. **Daily flow in the Sacramento River at Freeport - 2006 (Source: DWR DAYFLOW).**

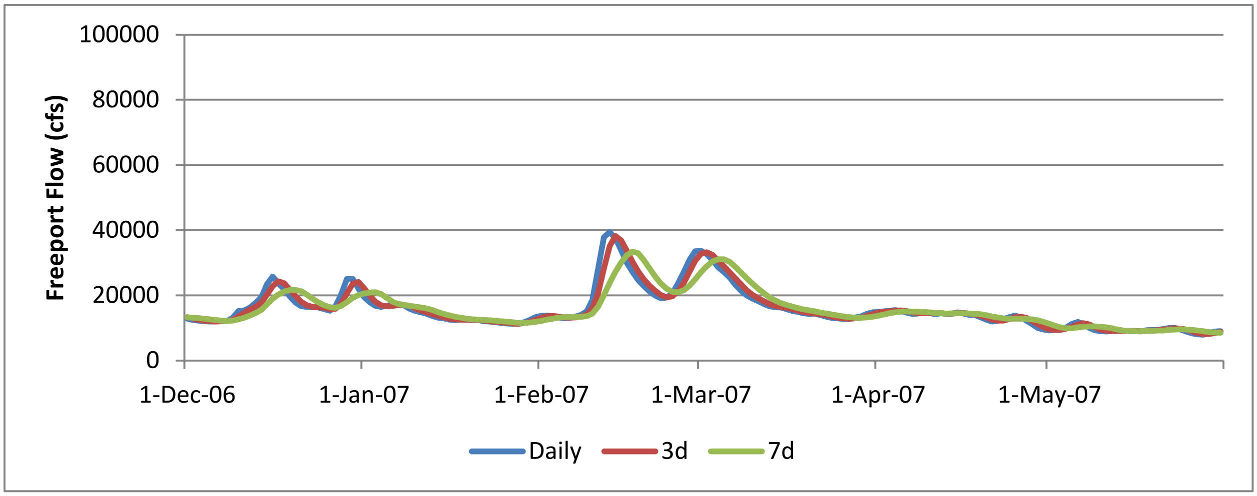

Figure C-8. **Daily flow in the Sacramento River at Freeport - 2007 (Source: DWR DAYFLOW).**

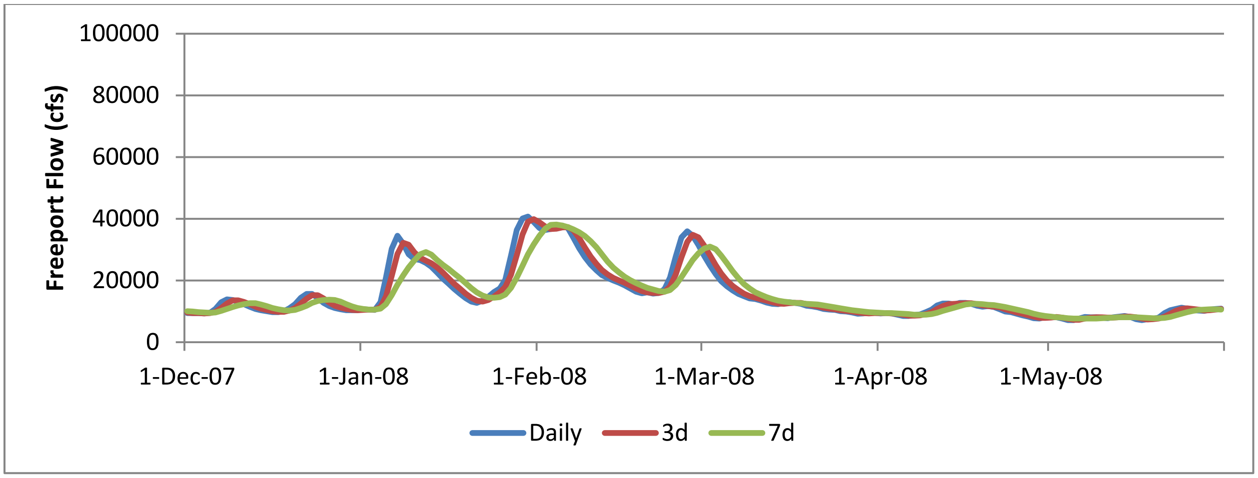

Figure C-9. Daily flow in the Sacramento River at Freeport - 2008 (Source: DWR DAYFLOW).

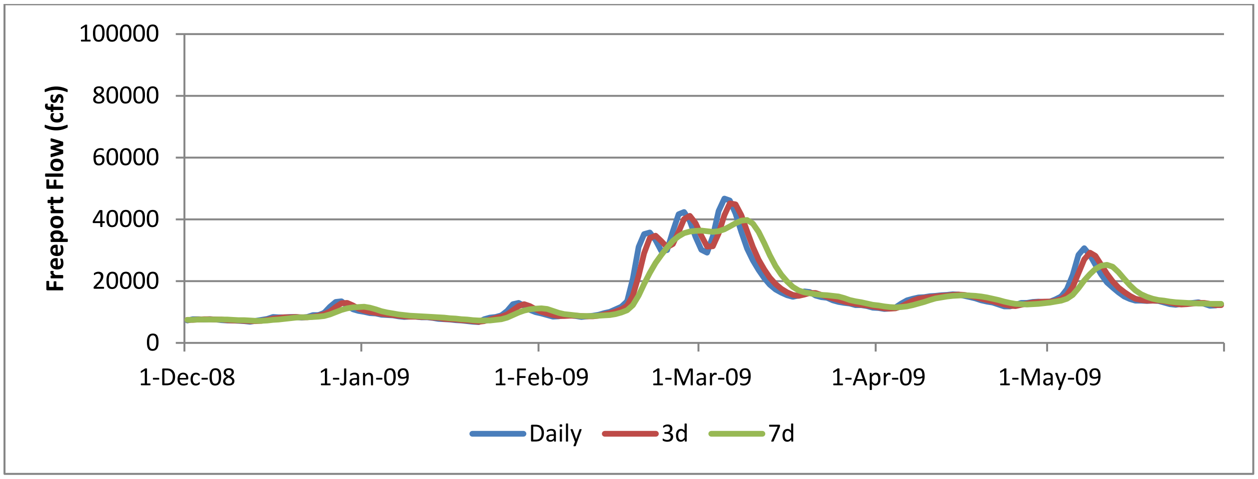

Figure C-10. Daily flow in the Sacramento River at Freeport - 2009 (Source: DWR DAYFLOW).

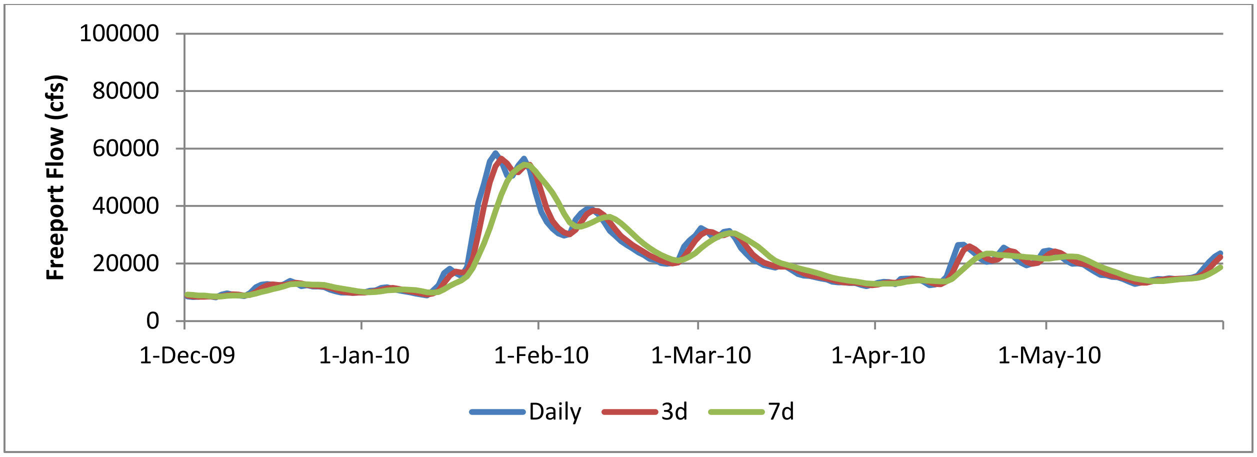

Figure C-11. Daily flow in the Sacramento River at Freeport - 2010 (Source: DWR DAYFLOW).

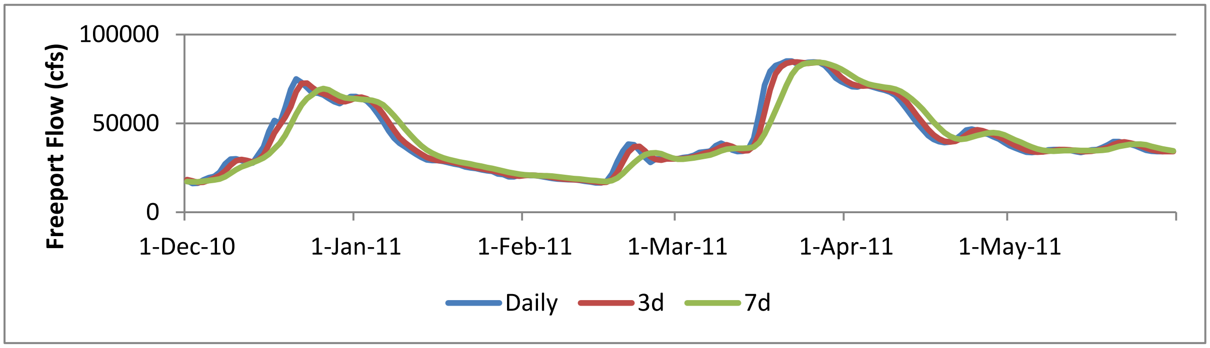

Figure C-12. Daily flow in the Sacramento River at Freeport - 2011 (Source: DWR DAYFLOW).

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Priming the productivity pump: flood pulse driven trends in suspended algal biomass distribution across a restored floodplain

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SUMMARY

1. Chlorophyll *a* (Chl *a*) distribution across a 0.36 km^2 restored floodplain (Cosumnes River, California) was analysed throughout the winter and spring flood season from January to June 2005. In addition, high temporal-resolution Chl *a* measurements were made *in situ* with field fluorometers in the floodplain and adjacent channel.
2. The primary objectives were to characterise suspended algal biomass distribution across the floodplain at various degrees of connection with the channel and to correlate Chl *a* concentration and distribution with physical and chemical gradients across the floodplain.
3. Our analysis indicates that periodic connection and disconnection of the floodplain with the channel is vital to the functioning of the floodplain as a source of concentrated suspended algal biomass for downstream aquatic ecosystems.
4. Peak Chl *a* levels on the floodplain occurred during disconnection, reaching levels as high as 25 $\mu g\ L^{-1}$. Chl *a* distribution across the floodplain was controlled by residence time and local physical/biological conditions, the latter of which were primarily a function of water depth.
5. During connection, the primary pond on the floodplain exhibited low Chl *a* (mean = 3.4 $\mu g\ L^{-1}$) and the shallow littoral zones had elevated concentrations (mean = 4.6 $\mu g\ L^{-1}$); during disconnection, shallow zone Chl *a* increased (mean = 12.4 $\mu g\ L^{-1}$), but the pond experienced the greatest algal growth (mean = 14.7 $\mu g\ L^{-1}$).
6. Storm-induced floodwaters entering the floodplain not only displaced antecedent floodplain waters, but also redistributed floodplain resources, creating complex mixing dynamics between parcels of water with distinct chemistries. Incomplete replacement of antecedent floodplain waters led to localised hypoxia in non-flushed areas.
7. The degree of complexity revealed in this analysis makes clear the need for high-resolution spatial and temporal studies such as this to begin to understand the functioning of dynamic and heterogeneous floodplain ecosystems.

Keywords: Cosumnes River, flood pulse, floodplain, phytoplankton, restoration

Introduction

A floodplain can be envisioned as a physical and chemical sieve through which river water and associated dissolved and particulate matter move. High surface roughness and slow water velocities across the floodplain not only create conditions favourable for retention of coarse woody debris and particulate

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matter, but also increase transient storage and so enhance the biological processing of dissolved and particulate constituents. As such, many floodplains have been shown to be sediment and particulate organic carbon sinks while simultaneously exporting autochthonous carbon (e.g. dissolved organic carbon, algal biomass, leaf litter) to the river (Robertson *et al.*, 1999; Tockner *et al.*, 1999; Valett *et al.*, 2005). The importance of this resource exchange and transformation between the river and its floodplain is widely acknowledged (Cuffney, 1988; Junk, Bayley & Sparks, 1989; Ward, 1989; Thorp & Delong, 1994). Furthermore, it is the dynamic nature of this exchange that makes natural floodplains among the most productive and diverse ecosystems on earth (Mitsch & Gosselink, 2000; Tockner & Stanford, 2002). Maintaining ecosystem productivity/diversity and resource exchange mechanisms in floodplains has thus been promoted as a central element in the justification for a growing number of floodplain restoration projects in California (CALFED, 2000; Stromberg, 2001), and globally (Patten, 1998).

In California, there has been a 91% reduction in wetland habitat – from just over 2 million ha before 1800 to 184,000 ha in 1986 (Dahl, 1990). The large majority of these wetlands were floodplain habitats (Faber *et al.*, 1989), which once carpeted California's Central Valley. Historical accounts attest to networks of floodplain forests up to 10 km wide (Jepson, 1893). A large portion of the Central Valley was essentially a shallow lake for a few months each year. Today the world's most elaborate network of impoundments, levees, and canals route flow through confined riverine areas (Mount, 1995) transporting water upwards of 900 km for consumptive uses and reducing forested floodplain habitat to <4% of the valley floor (Katibah, Drummer & Nedeff, 1984; Hunter *et al.*, 1999). The alteration of this once extensive linkage between terrestrial and aquatic environments has subsequently impacted the ecological services that floodplains provide the Central Valley, such as transforming nutrients (Hubbard & Lowrance, 1996), exporting organic matter (Wetzel, 1992), providing freshwater habitat for the migration, reproduction and rearing of native fishes (Moyle *et al.*, 2003; Crain, Whitner & Moyle, 2004) and mitigating flood damage to human settlements (Sommer *et al.*, 2001).

The ecological effects of river–floodplain disconnection are multi-faceted and are particularly pronounced in complex food webs, such as those in large floodplain rivers. In the California Bay–Delta (the confluence of the Sacramento and San Joaquin rivers draining the Central Valley) declines in biota abundance, from zooplankton (Kimmerer & Orsi, 1996) to native fish (Bennett & Moyle, 1996), have been linked to a shortage of food resources (Foe & Knight, 1985; Jassby & Cloern, 2000). Mitigation strategies for reinvigorating the base of the food web have included recommendations for restoring floodplain habitat (Jassby & Cloern, 2000; Schemel *et al.*, 2004). This habitat, it is thought, was once very productive and exported large quantities of high quality (i.e. rich in algae) organic matter to the Delta (Jassby & Cloern, 2000).

The notion of floodplains as 'productivity pumps' has been previously proposed (Junk *et al.*, 1989) and characterised (Furch & Junk, 1992; Tockner *et al.*, 1999; Baldwin & Mitchell, 2000). Periodic river–floodplain connection and disconnection isolates and subsequently mobilises parcels of water on the floodplain. These waters – depending upon residence time, antecedent hydrologic conditions, and river–floodplain system biogeochemistry – are often more productive than adjacent channel waters (Junk *et al.*, 1989; Schemel *et al.*, 2004). As such floodplains can 'feed' the channel with valuable food resources in much the same way that littoral zones in lakes subsidise pelagic food webs (Delgiorgio & Gasol, 1995; Lucas *et al.*, 2002; Larmola *et al.*, 2004). Although it is widely accepted that floodplains are productive ecosystems, considerably less is known about where on the floodplain productivity is greatest and what controls the distribution of these highly productive areas.

Results from research on a Danubian floodplain by Hein *et al.* (1999, 2004), revealed the importance of hydrologic controls on the spatial distribution of phytoplankton biomass. They found that sections of the floodplain intermittently connected with the river had higher productivity than isolated areas of the floodplain, which shifted toward prevailing bacterial secondary production. Van den Brink *et al.* (1993) found similar results in the Lower Rhine where floodplain lake proximity to the nutrient-rich main channel determined lake productivity. Of the 100 lakes studied, those most directly connected to the main channel via flood flows and seepage exhibited the greatest suspended algal biomass. These studies and others (see Hamilton & Lewis, 1990; Knowlton &

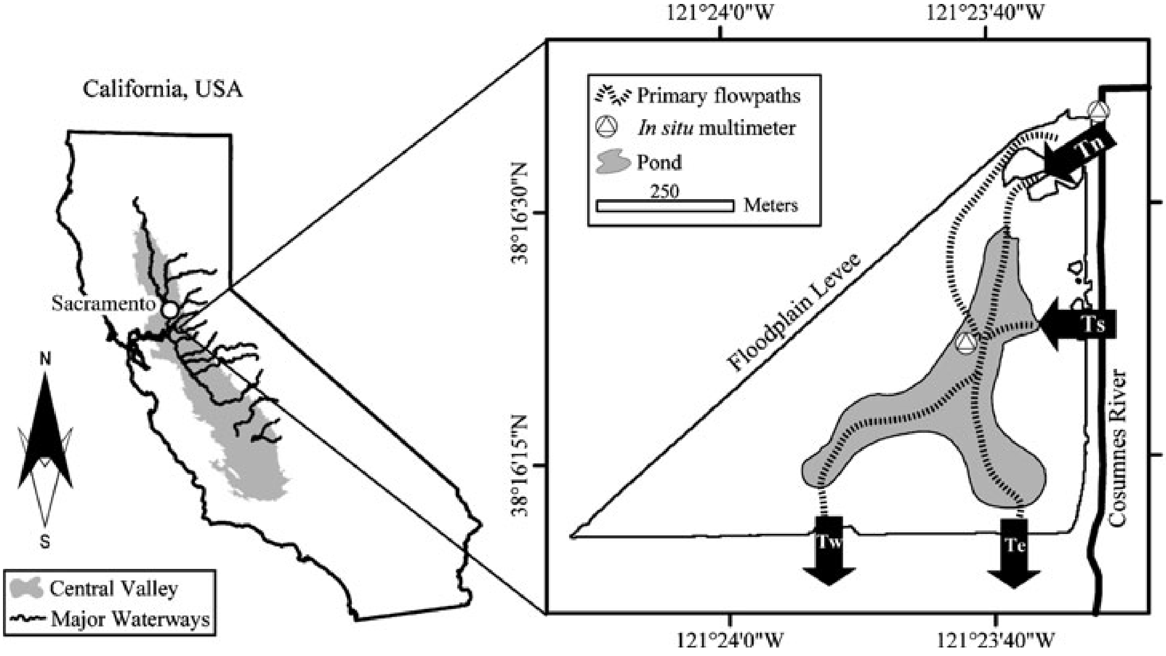

Fig. 1 Map of the study site in Central California. The inset shows the restored triangle floodplain with location and direction of flow through primary breaches in the levees. The inset also displays the location of the *in situ* data collection sondes and the paths of primary flow through the floodplain pond.

Jones, 1997; Pithart, 1999; Izaguirre, O'Farrell & Tell, 2001) show that the distribution of suspended algal biomass on floodplains is, in large part, a function of residence time which is in turn controlled by riverine hydrology.

The objective of this study was to identify the environmental variables that control suspended algal biomass concentration and distribution across the surface of a restored floodplain. Additionally, it was our aim to identify what role the flood pulse played in importing, exporting, and redistributing algal biomass on the floodplain. Understanding the spatial and temporal dynamics of floodplain biogeochemistry is vitally important if river managers and scientists are to be successful in creating and maintaining the ecological services provided by these complex habitats.

Methods

Study area

Our study site is located within the confines of the Cosumnes River Preserve, a restored floodplain habitat located 34 km south of Sacramento, CA, that is managed by a consortium of federal, state and non-governmental agencies. A former agricultural field dedicated to tomato production, the study site is now a 0.36 km^2 triangular floodplain surrounded by levees (Fig. 1). In 1997, four breaches were engineered along the east and south levees to reconnect the riparian floodplain with the adjacent Cosumnes River. Additionally, a Y-lobed pond and isolated smaller pond were constructed to foster habitat heterogeneity. When connected with the river, water flows from north to south, moving onto the floodplain through breaches Triangle North (Tn) and Triangle South (Ts) and off the floodplain through breaches Triangle East (Te) and Triangle West (Tw) (Fig. 1). Since completion of the restoration, floodwater has carried large woody debris, sediment, coarse and fine particulate organic matter, and the occasional piece of farming equipment onto the restored floodplain. Sand accumulation rates measured in 1999 and 2000 were estimated between 0.19 and 0.39 m yr^{-1} near the breaches (Florsheim & Mount, 2002). As the sediment-laden floodwaters have moved across the floodplain in successive stages (1997 – present), substrate differentiation, topographic changes, and vegetation recruitment have occurred. The floodplain is still in early successional stages of riparian vegetation establishment, with dominant species of cottonwood (*Populus fremontii*), willow (*Salix* spp.) and oak (*Quercus lobata*) covering <10% of the floodplain (Trowbridge, Kalmanovitz & Schwartz, 2005). Without a dominant overstory, the floodplain has a very productive community of aquatic macrophytes and epiphytic algae, which thrive in shallow areas. As flooding initiates in the winter the annual shallow water vegetation is absent, but as the season progresses these macrophytes come to dominate all areas on the floodplain save the ponds. Although not the focus of this study, macrophytes and epiphytic algae play an important role in floodplain biogeochemistry (Scheffer, 1999), hydrogeomorphology (Hughes, 1997), ecology (Petry, Bayley & Markle, 2003) and productivity (dos Santos & Esteves, 2004).

The study site is near the mouth of the unimpounded Cosumnes River at 2 m above mean sea level. The river has a long-term (1907–2002) mean daily discharge of 14.4 $\mathrm{m^3\ s^{-1}}$ (USGS gage no. 11335000). Average precipitation in the upper watershed is 804 mm $\mathrm{year^{-1}}$ and 445 mm $\mathrm{year^{-1}}$ in the lowlands, with the majority of the rainfall occurring between December and March. Rainfall-induced flooding occurs on the floodplain during this period, after which time flooding is primarily driven by snowmelt in the upper basin (Ahearn *et al.*, 2004). By June the flood season has ended and the floodplain steadily dries until the floodwaters return (usually the following December). During 2005 the floodplain and river were connected for 123 days between January 1 and June 1, with only 23 days of disconnection.

Field methods and materials

The majority of the data were collected with YSI 6600 multiparameter sondes (Yellow Springs Instruments, Yellow Springs, OH, U.S.A.). The sondes were capable of simultaneous acquisition of values for dissolved oxygen (DO), total dissolved solids (TDS), temperature, turbidity, and fluorescence (a proxy for Chl *a*). Uniformly calibrated sondes were placed in the river at Tn and in the main floodplain pond (Fig. 1). A third sonde was interfaced with a Global Positioning System unit (Garmin Rino 120; WAAS enabled; Garmin International Inc., Olathe, KS, U.S.A.) and used to rove across the floodplain logging position and water quality parameters every 40 m on average. The sonde was submerged (approximately 0.5 m) and lashed to a canoe in order to facilitate roving in the ponds (average maximum depth = 3.17 m); in the shallow areas (littoral zones) a calibration cup was used to skim water off the surface without disturbing the benthos. This roving process was conducted 22 times between 02 February 2005 and 16 June 2005 with an average of 120 spatial data points recorded on each campaign. Rising limb, peak and falling limb dynamics were characterised multiple times; in this study we present data from 10 days on the rising and falling limb of the flood hydrograph and during periods of river-floodplain disconnection. These 10 days were selected after data analysis revealed that 12 sampling days produced incomplete or corrupt data (because of disturbance of the benthos during sampling, equipment malfunctions and improper coverage of the floodplain surface). Autosamplers (ISCO 3600; Teledyne ISCO Inc., Lincoln, NE, U.S.A.) were located at Tn, Te, and Tw and set to collected water samples every 2 h during storms. Water from these samples, as well as from grab samples, were filtered for Chl *a* analysis within 48 h of collection. Chl *a* was measured from a 300 mL subsample using standard extraction and fluorometry techniques (Clesceri, Greenberg & Eaton, 1998). When sonde measurements and water sampling were simultaneous, extracted Chl *a* values were regressed against fluorescence values from the YSI sondes ($r^2 = 0.93$). The converted fluorescence values are reported herein as Chl *a* ($\mu\mathrm{g\ L^{-1}}$). Stage gages were positioned at each breach and set to collect data every 10 min. The resultant information was used to generate hydrographs and determine when the floodplain and the river were connected.

Computing methods and materials

We conducted our spatial analysis using a geographical information system (ArcGIS v. 9.0; ESRI, Redlands, CA, U.S.A.) to utilise a number of inherent spatial analysis tools (compilation, visualisation, interpolation and extraction). We assembled field data into a personal geodatabase and generated a number of spatial descriptors from independent spatial data layers. These descriptors included depth, determined as an inverse correlate to a high-resolution digital elevation model (2 m, see Florsheim & Mount, 2002) and perpendicular distance to primary flow path. Flow paths were delineated and digitised on-screen using the field observations and ancillary data, such as orthorectified aerial photographs, as backdrops. An analysis mask was created by segmenting the digital elevation model at the 3.9 m (above mean sea level) contour, which best approximated the high water mark of the seasonal flood regime.

We employed inverse-distance weighting (IDW) as an interpolation technique to spatially infer water quality at unsampled locations within the floodplain. IDW is a simple, exact surface interpolator taking the form of eqn 1,

$$Z = \frac{\sum_{n=1}^{N} \frac{Z_i}{d_i^P}}{\sum_{n=1}^{N} \frac{1}{d_i^P}} \qquad (1)$$

where Z is the value of the interpolated point, Z_i is a known value at a fixed point, and N is the total number of points used in the interpolation. Spatial determinants in the equation are d, the distance between fixed and interpolated points evaluated in the neighbourhood and P, a neighbourhood weighting term. We used values of $N = 12$ and $P = 0.5$ for all interpolated surfaces, which in effect lessens the influence of immediate neighbours on the interpolated value. IDW, as employed in ArcGIS Spatial Analyst Extension (see Watson & Philip, 1985 for specific implementation notes), takes advantage of spatial boundaries, such as our analysis mask of the triangle floodplain, by using a variable neighbourhood. The output surface is sensitive to clustering and the presence of outliers (Watson & Philip, 1985). To minimise these potential errors, our field collection strategy centred on observed transitions in concentration and we eliminated *post hoc* numerical outliers from our geodatabase. Comparatively, IDW has been used to infer plankton concentrations in lakes (Winder & Schindler, 2004), nutrient concentrations in soil (Arhonditsis *et al*., 2002) and depth to groundwater in riparian zones (Merritt & Cooper, 2000), among many applications. Additionally, IDW has also been shown to perform well over small areas (<100 ha) using a fine raster resolution (≤5 m; Robinson & Metternicht, 2005).

We constructed IDW surfaces for 10 dates, interpolating values for Chl *a*, DO, TDS, turbidity and temperature, resulting in 50 individual raster datasets.

Statistical analysis

In order to analyse differences in constituent concentrations in the pond and littoral areas of the floodplain the field data were categorised into pond and littoral samples (*n* approximately 60 in each category). A Student's *t*-test was applied to characterise the significance of any differences in mean concentration between samples in the littoral area and pond area (Zar, 1984). Statistica data analysis software was used for this purpose and the results are reported in Table 1. In order to determine which chemical and physical parameters were driving Chl *a* concentrations during a representative falling limb and disconnection day, multiple linear regression was used. Independent variables included temperature, TDS, turbidity, DO, elevation and distance from primary

Table 1 Comparison between mean values for five constituents from the pond and shallow littoral regions of the floodplain (average $n = 60$) for 10 days during 2005

Date	Hydrologic phase	Mean DO (%)		Mean Chl *a* (μg L^{-1})		Mean turbidity (NTU)		Mean TDS (mg L^{-1})		Mean temperature (°C)	
		Pond	Littoral	Pond	Littoral	Pond	Littoral	Pond	Littoral	Pond	Littoral
14-Feb-05	Stagnant	102.7*	97.4	13.4*	10.9	5.7	6.7*	83.1	101.0*	14.0	14.2*
16-Feb-05		91.9	97.2	15.3*	12.4	5.8	7.4*	82.6	89.3*	13.4	14.4*
16-June-05		115	114.7	15.4	14.0	14.9*	13.1	35.3	38.3	21.7	21.7
17-Feb-05	Rising limb	91.5*	81.2	9.2	10.4*	16.9*	13.1	83.8	84.6*	11.4	11.8*
23-Mar-05		92.4	90.7	11.6*	9.9	86.4*	69.0	59.6	59.5	11.3	11.9*
23-Feb-05	Falling limb	117.8*	104.0	2.4	3.2*	17.0*	13.8	65.1	67.5*	12.4	13.8*
7-Mar-05		84.2	100.4*	5.0	6.6*	9.4*	8.6	79.3	80.4	17.9	18.9*
11-Mar-05		126.0	124.9	3.5	4.0*	9.0	9.5	73.1	80.3*	21.5	21.2
18-Mar-05		134.6*	119.4	3.7	6.0*	5.4	6.4*	52.0	78.0*	16.1	16.0
20-Apr-05		125.3*	96.3	2.4	3.2*	7.9	8.3	46.2	52.5*	16.2*	15.2

*Indicates that the mean constituent concentration within the pond and littoral areas are significantly different as determined by a Student's *t*-test ($P > 0.05$).

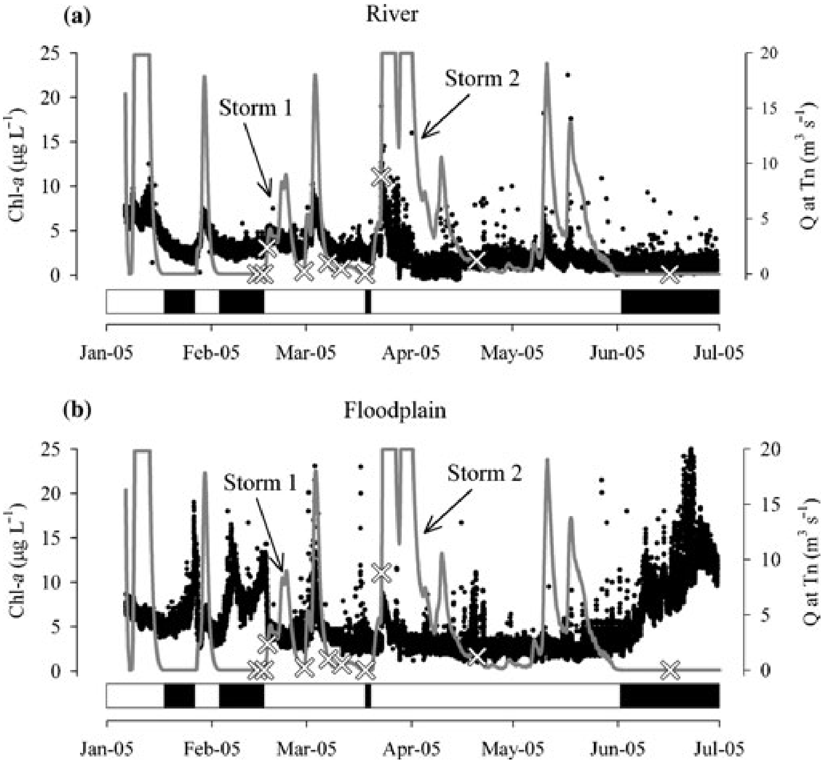

Fig. 2 Chl *a* concentration time series from (a) the river and (b) the floodplain pond. Dates on which Chl *a* distribution across the floodplain was measured are marked on the hydrograph with an (×) Black bars above the *x*-axis represent periods of disconnection with the river. The hydrograph plateaus on the three largest storms are because of river discharge exceeding the rating curve. Note the increase in Chl *a* on the floodplain when the river and floodplain are disconnected.

flowpath. The data were checked for normality and log transformations were applied where necessary. Next a stepwise regression analysis was conducted with only significant independent variables include in the model (Helsel & Hirsch, 1992).

Results

Priming the productivity pump

Water year 2005 (October 2004 to September 2005) was an above average year for precipitation with 525 mm of rain falling on the lower Cosumnes River Watershed, 134% of normal. The resulting high flows connected the river with the restored floodplain for a total of 128 days beginning on 01 January 2005. In contrast in 2002, a dry year, the floodplain was connected with the river for only 22 days. Because of above normal precipitation, disconnection time between flood events was reduced. When the floodplain did disconnect, however, water chemistry on the floodplain began to diverge from river chemistry. Most notably temperature (data not shown) and Chl *a* concentration on the floodplain began to rise while the river remained unchanged (Fig. 2). There were three periods of brief disconnection in 2005, (i) 20 January 2005 to 28 January 2005, (ii) 05 February 2005 to 18 February 2005 and (iii) 18 March 2005 to 20 March 2005 (Fig. 2), with intervening storm events; the final disconnection between the river and floodplain in 2005 occurred on 05 June 2005. The first two periods of disconnection were marked by elevated levels of Chl *a* on the floodplain, peaking at 19 and 18 μg L^{-1} Chl *a*, respectively, before being flushed out by the subsequent storms (Fig. 2). During these same periods Chl *a* in the river averaged 4.8 μg L^{-1} and showed little variation about the mean. The first two periods of disconnection both exhibited a lag time between the point of disconnection and the point at which Chl *a* levels on the floodplain began to rise: in January the lag was 5 days, in February it was 2 days. The last period of disconnection in March was apparently too brief for floodplain chemistry to diverge from river chemistry (1.5 days), so Chl *a* values in the floodplain and the river remained comparable. It should be noted that the sonde measuring Chl *a* on the floodplain was located in the pond and that Chl *a* patterns differed significantly between the pond and the shallows, but despite variation across the floodplain Chl *a* levels at all floodplain locations were almost always higher than channel Chl *a* concentrations.

Intra-floodplain resource redistribution

Storm 1. In order to characterise the effect of the flood pulse on Chl *a* distribution on the floodplain, we conducted water quality mapping before, during and after storm events. There were seven significant storms in the 2005 flood season but for this analysis we focus on two (Fig. 2). The first storm analysed (18–28 February 2005) was preceded by a 13 day period of river–floodplain disconnection (Fig. 2); as such Chl *a* levels in the pond were high (Fig. 3a). Floodwaters brought low Chl *a* (Fig. 3b), turbid water (Fig. 3c) onto the floodplain, and displaced antecedent water with high Chl *a* from the pond. The majority of the antecedent waters were flushed out of the floodplain (0.53 kg Chl *a*), but Fig. 3d,e indicate that some algal biomass was transported into the south-westerly corner, where it apparently augmented respiration rates. DO percent saturation in this zone subsequently dropped from a previous 3-day mean of 60% (6.2 mg L^{-1}) to approximately 30% saturation (3.0 mg L^{-1}) on 23 February 2005 (Fig. 3e). A concomitant fish (*Oncorhynchus tshawytscha*) enclosure study on the floodplain observed 100% mortality of the juvenile salmonids in this low DO zone (C. A. Jeffres, unpubl. data). Our combined observations indicate that the redistribution of suspended algal biomass, and subsequent impact on respiration rates, can contribute to the creation of dynamic hypoxic zones that have adverse impacts on some aquatic fauna.

Storm 2. The storm on 23 March 2005 to 07 April 2005, exhibited a different pattern, as it was preceded by a period of river–floodplain disconnection of only 1.5 days, not long enough for Chl *a* to increase in the pond (Fig. 3f). Instead of displacing high Chl *a* water out of the pond, this storm moved the relatively low Chl *a* pond waters into the shallow littoral areas (Fig. 3g), in the process flushing most of the littoral waters while trapping some against the far south-westerly corner. This storm was the largest of the season and was characterised by high Chl *a* (16.7 μg L^{-1}) concentrations in the channel water during the rising limb. The combination of high Chl *a* inflowing water, low Chl *a* displaced pond water, and high Chl *a* displaced littoral water, created a complex mixing front as patches of antecedent floodplain waters stacked up against encroaching floodwaters (Fig. 3g).

Alternating zones of phytoplankton production

The distribution of phytoplankton across the floodplain was dependent upon river connectivity and hydrograph position. We detail here the three patterns in Chl *a* distribution, which emerged during the rising limb, falling limb and disconnection. During periods of disconnection, the pond exhibited elevated Chl *a* concentration (3-day mean = 14.7 μg L^{-1}) while the shallows had significantly lower concentrations (3-day mean = 12.4 μg L^{-1}; Table 1). Fig. 3a shows the spatial distribution of Chl *a* on 16 February 2005, a representative disconnection day. A multipile linear regression analysis of all the measured and calculated parameters (Chl *a*, turbidity, temperature, TDS, DO, depth, distance from primary flowpath) revealed that variation in the Chl *a* content of these standing waters could be explained by a linear combination of water depth (expressed as the inverse of elevation), distance from primary flowpaths, TDS, DO, and turbidity ($\text{Chl}\,a_{16\ \text{February}} = 0.75$ turbidity $- 0.33$ elevation $+ 0.31$ DO $- 0.22$ TDS $- 0.21$ flow distance $+ 20.6$, $r^2 = 0.66$, $P < 0.001$; Table 2). DO and turbidity are not Chl *a* drivers in this system, rather they are by-products of phytoplankton concentration and distribution. Phytoplankton growth or decomposition can control DO concentrations, while algal cells can interfered with optical turbidity reading. TDS and distance from flowpath are metrics of residence time as evapoconcentration and material dissolution on the floodplain increased TDS in those waters which were not flushed and the degree of flushing was dependant on the distance from the primary flowpaths. Thus, this analysis indicates that there is a relationship between water depth (inverse of elevation), residence time and Chl *a* concentration distribution across the floodplain.

During the falling limb, stable primary flowpaths developed across the floodplain and Chl *a* distribution remained consistent until the next period of disconnection or flooding. Fig. 3f, shows a representative falling limb Chl *a* distribution. On this day, 18 March 2005, 60% of the variance in Chl *a* concentration could be explained by a linear combination of distance from flowpath and TDS ($\text{Chl}\,a_{18\ \text{March}} = 0.56$ TDS $+ 0.39$ flow distance $+ 2.14$, $r^2 = 0.60$, $P < 0.001$; Table 2). This relationship indicates that during the falling limb Chl *a* is most concentrated in those areas of high residence time (the distal littoral zones). During each falling limb

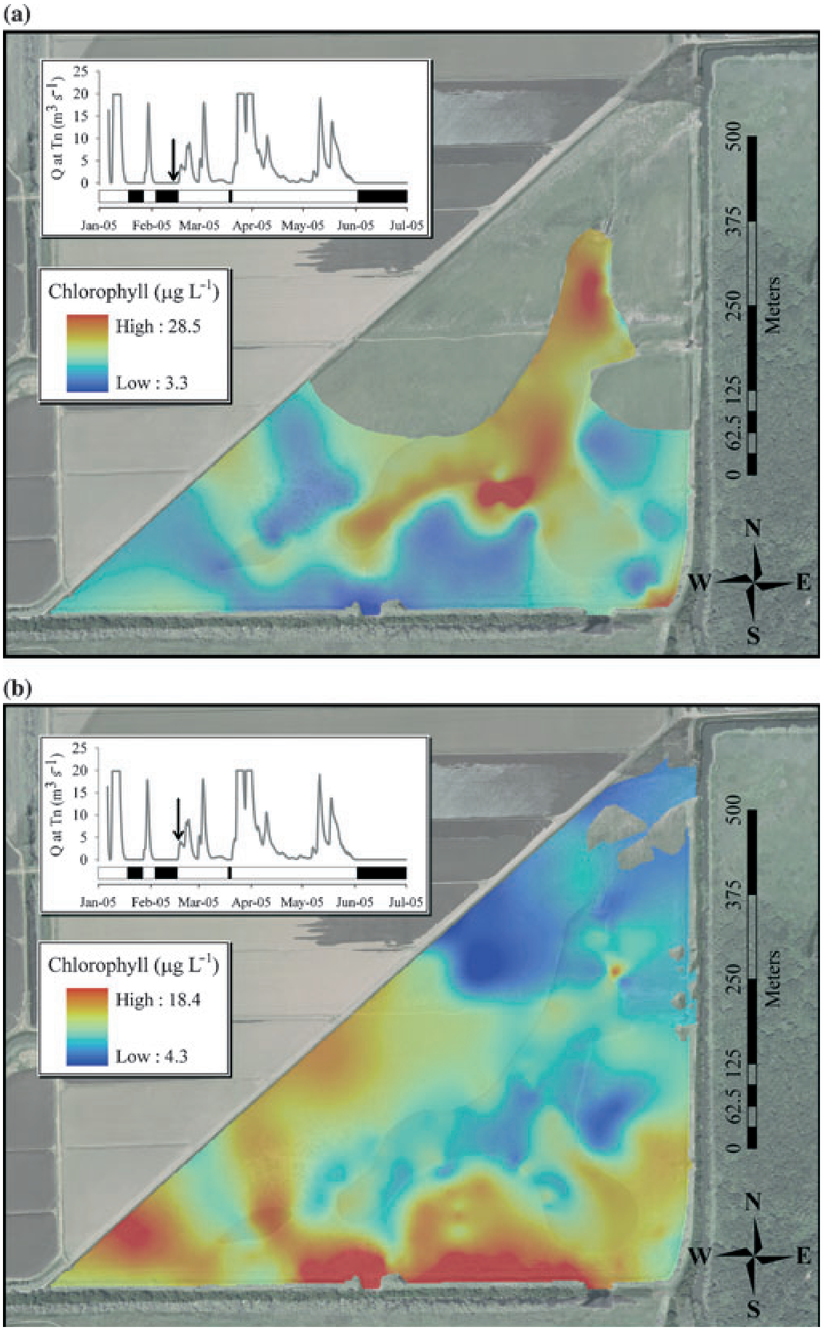

Fig. 3 Water quality distribution maps depicting Chl *a*, turbidity, and DO at different stages of flooding. Each map is accompanied by an inset hydrograph with an arrow showing the hydrograph position when the data were collected. During disconnection on 16 February 2005 (a) Chl *a* was greatest in the pond and the floodplain was only partially inundated. When a subsequent storm arrived the (b) high Chl *a* water was pushed off the floodplain and into the south-westerly corner by (c) turbid flood water. The algal biomass from the pond was then (d) trapped in the south-westerly corner where it augments respiration and (e) contributed to a decrease in DO. Later in the season there was a brief period of disconnection before a large storm (f–h). Unlike on 16 February 2005, Chl *a* on 18 March 2005 was (f) concentrated in the shallows and low in the pond. The rising limb of the subsequent storm pushed this (g) low Chl *a* water into the shallows and flushed them out, trapping some vestiges on high Chl *a* littoral water against the far south-westerly corner. A rising limb turbidity distribution map (h) clearly shows the mixing front between antecedent floodplain waters and flood waters from the river. Note that the scale bars on the various maps are optimised to show the full spectrum of colours for each day (spatially normalised) and so are not equal between maps (temporally normalised)

quantified, the distal littoral areas had significantly greater suspended algal biomass (5-day mean = 4.6 µg L^{-1}) than the deep flowing zones (5-day mean = 3.4 µg L^{-1}) on the floodplain (Table 1). This observed Chl *a* distribution is opposite the distribution characterised during periods of river-floodplain disconnection, during which time the deep primary flowpaths (pond) had higher Chl *a* concentrations than the littoral zones.

During the rising limb of the hydrograph Chl *a* distribution was a function of the position and concentration of inflowing waters versus those of antecedent floodplain waters. As the translation and mixing of waters on the rising limb is very dynamic, relative concentrations of Chl *a* in the deep and littoral areas are not so easily modelled. Of the 2 days in which Chl *a* was quantified on the rising limb of a storm each exhibited opposite spatial concentration

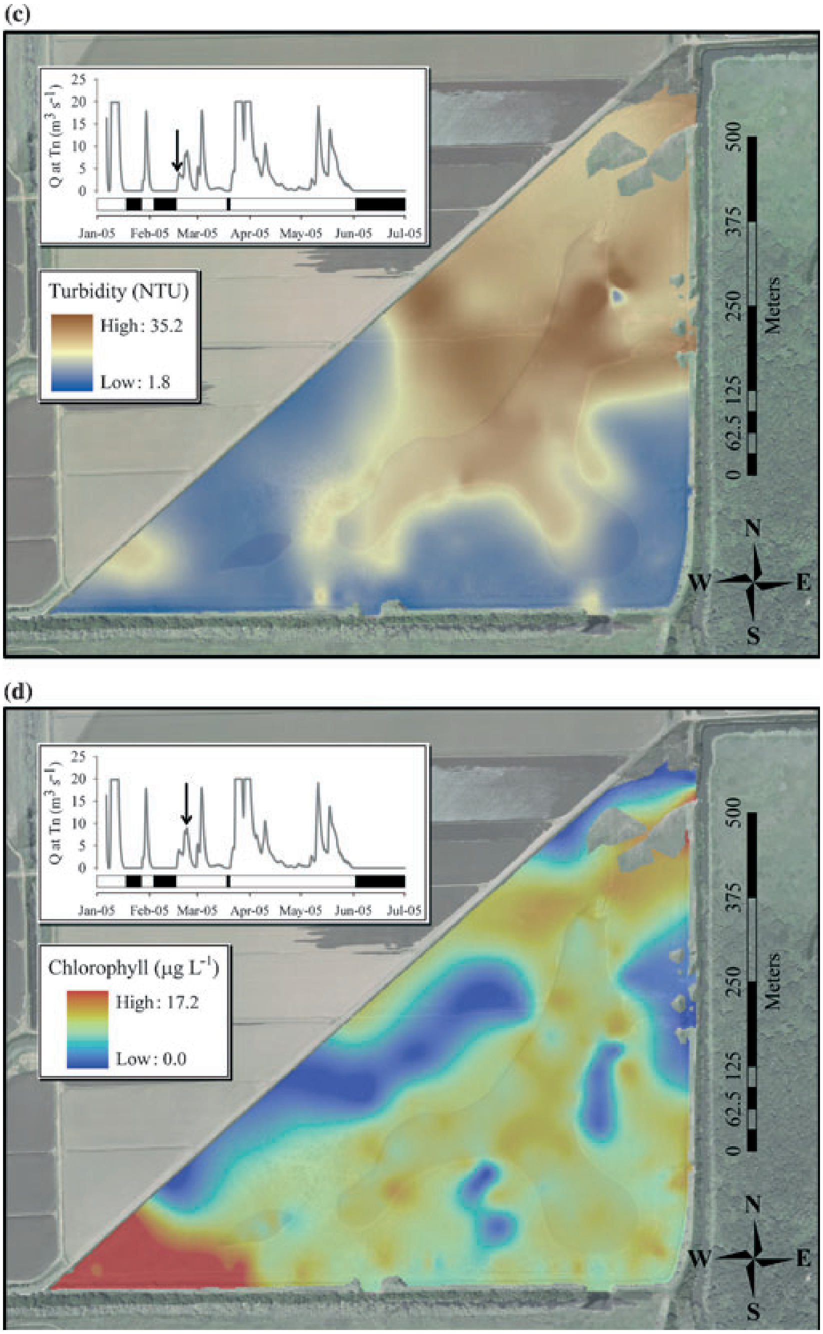

Fig. 3 (*Continued*)

patterns (Table 1) and we were not able to meaningfully model Chl *a* concentration distribution with local environmental variables.

If phytoplankton-rich antecedent waters exist on the floodplain prior to flooding (as was the case with storm 1; Fig. 4), the rising limb of the hydrograph can be ecologically significant for downstream receiving waters. The two storms in 2005 that arrived after periods of stagnation on the floodplain exhibited elevated Chl *a* on the rising as well as falling limbs (see Fig. 4 for an example of one), the other five storms had minimal Chl *a* flushing associated with them. In this study we focused on two storms (storms 1 and 2; Fig. 2) where antecedent waters were pushed off the floodplain, one in which the 'productivity pump' was 'primed' – that is Chl *a* levels on the

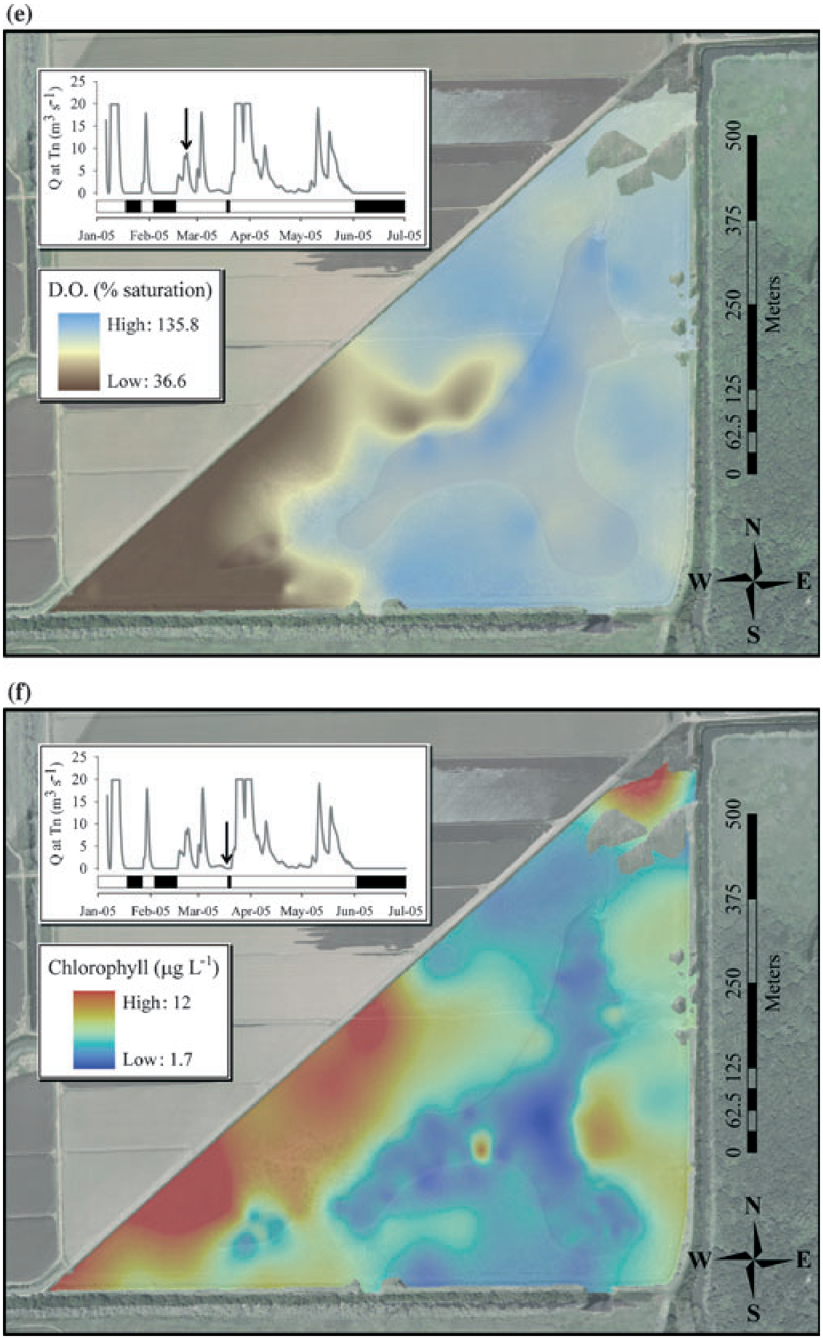

Fig. 3 (*Continued*)

floodplain where five to six times higher than in the channel (Fig. 3a) – and one in which the pump was not primed, and Chl *a* levels on the floodplain and in the channel were similar (Fig. 3f). Water volume data from the floodplain revealed that prior to the 17 February 2005 flood (when the floodplain was 'primed') 158 m^3 was held in the pond and 208 m^3 in the shallows. If we take the average Chl *a* value and area of the ponds and littoral zones and assume that all the water was pushed out of the floodplain, a simple calculation reveals that the ponds exported 0.32 kg ha^{-1} of Chl *a* and the littoral zones exported 0.075 kg ha^{-1} of Chl *a*. So it would seem that when a flood arrives after a period of river-floodplain disconnection the pond is the dominant source of Chl *a* exported from the floodplain. If the floodplain is not 'primed' when flooding occurs, the shallows and deep zones of the floodplain equally contribute to Chl *a*

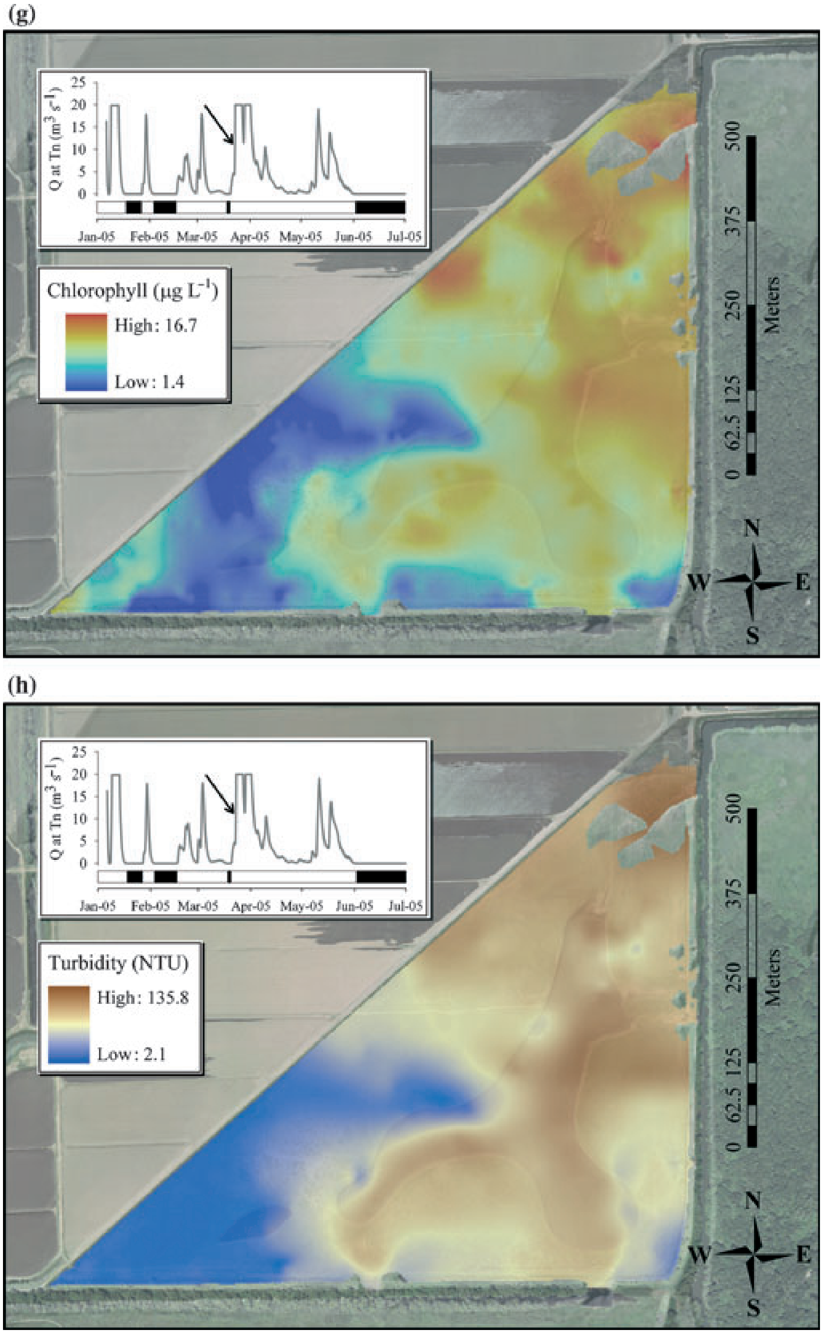

Fig. 3 (*Continued*)

export from the floodplain. A similar calculation for the 23 March 2005 flood reveals 0.08 kg ha^{-1} Chl *a* exported from the ponds and 0.07 kg ha^{-1} from the shallows. This phenomenon intimates that the relationship between deep and shallow water habitat across the inundated floodplain is an important factor in determining the influence of the floodplain on channel material budgets during flooding events.

Discussion

The importance of the floodplain to the fluvial and ecological dynamics of the riverine ecosystem is rooted in the complexity of the ecotone, both hydrological (e.g. highly variable residence times and depths) and structural (e.g. complex topography and vegetative cover), relative to the nearby channel. Such

Table 2 Results from a multiple linear regression analysis of Chl *a* (dependent variable) with a suite of physical (elevation, flow distance*) and chemical (DO, TDS, temperature, and turbidity) independent variables. Only significant and independent predictor variables were included in the model.

Date	*n*	r^2	SE	Independent variables	β	*P*-level
16-Feb-05	156	0.66	2.03	Intercept	20.57	<0.001
				Turbidity	0.75	<0.001
				Elevation	−0.33	<0.001
				DO	0.31	<0.001
				TDS	−0.22	0.014
				Flow distance	−0.21	0.001
18-Mar-05	222	0.60	0.78	Intercept	2.14	<0.001
				TDS	0.56	<0.001
				Flow distance	0.39	<0.001

*Flow distance is analogous to the perpendicular distance from the primary flowpaths across the floodplain.

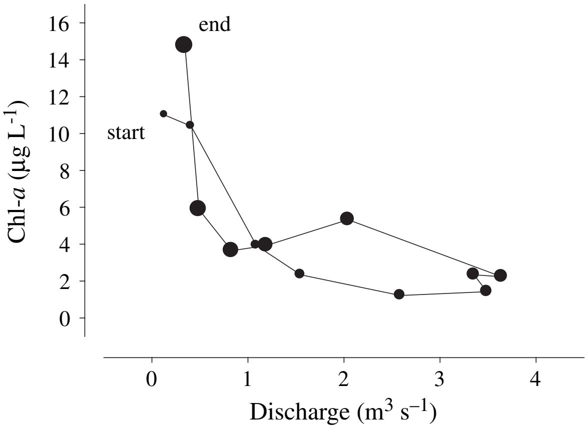

Fig. 4 Chlorophyll *a* hysteresis loop from storm 1 at a floodplain exit breach (Tw). As an indication of the temporal trend of the loop the data points increase in size from 16 February 2005 23:00 to 27 February 2005 20:00. The loop indicates that Chl *a* concentrations leaving the floodplain are elevated on the early rising and late falling limbs of the storm.

complexity gives rise to dynamic zones of phytoplankton production on the floodplain, which may be absent within the river channel itself. The complexity of floodplain systems, particularly the dynamic spatial and temporal dimensions, also gives rise to difficulties in conducting research in these ecosystems. For example, previous research (see Van den Brink *et al.*, 1993; Hein *et al.*, 2004) on floodplain phytoplankton distribution has had to focus on compartmentalised flooded riparian areas (because of study site size and complexity) without examining the hydro-ecosystem as a continuous unit of varying depth, residence time and vegetative cover. The relatively small area (36 ha) of our study site made such an analysis possible; and with high-resolution monitoring, we were able to characterise aspects of the floodplain which have been previously under-appreciated.

Many floodplains, including the Cosumnes River Preserve, can be envisioned as a series of small ponds and floodplain channels with extensive and dynamic littoral zones (Junk *et al.*, 1989). Flow from the river will invariably connect a number of these deep water zones before returning to the channel while distal areas (shallow littoral zones at our site) will not be as thoroughly flushed. This creates a condition whereby residence time at any given point on the floodplain is a function of distance from the primary flowpath through the floodplain. Concordantly, our data show that during flooding Chl *a* is elevated in the littoral zones of the floodplain (Table 1), that is, the zones which are distal to primary flowpaths and where residence time is high. As such, the ‘inshore retention concept’ (Schiemer *et al.*, 2001), which states that retention in littoral backwater areas is a major determinant of biological processes in large rivers, is also applicable to flow-through floodplains during flooding. Phytoplankton production in distal areas of the floodplain will be most significant for downstream environments and organisms when the littoral zones drain; indeed a hysteresis analysis of storm 1 indicates that Chl *a* concentrations are elevated during the falling limb when the floodplain is draining (Fig. 4). The two primary factors, which explain this phenomenon are (i) export of algal biomass from littoral area and (ii) increased residence time on the falling limb promoting autochthonous production on the floodplain. Each of the seven storms in 2005 exhibited this same pattern of elevated Chl *a* on the falling limb. Other studies (Schemel *et al.*, 2004; Sommer *et al.*,

2004) have also shown that, on the falling limb of the hydrograph, water egressing from floodplains is enriched with organic material relative to river channel water.

We have postulated that the functioning of the floodplain productivity pump is contingent upon connection and disconnection between the floodplain and the channel. Indeed the data indicate that some of the highest Chl *a* concentrations are exported from the floodplain on the rising limb of storms after a period of disconnection (Fig. 2). It should be noted that the study floodplain was artificially small (because of constriction from bounding levees) and that in a natural lowland floodplain, flood water residence time on the floodplain would be much greater. A higher residence time during flooding may alter the relative importance of the connection–disconnection cycle for the generation of high concentrations of phytoplankton.

Of course, phytoplankton is not the only valuable carbon resource that is exported from floodplains. It has been shown that attached algae can account for a substantial portion of the biomass in productive shallow waters (Moncreiff, Sullivan & Daehnick, 1992; Kaldy *et al.*, 2002) and be the primary foundation for floodplain aquatic food webs (Bunn, Davies & Winning, 2003). During large floods litter and attached algae – primarily transported as coarse particulate organic matter (CPOM) – may be disturbed and transported from the floodplain to the channel. Indeed, many studies that have quantified CPOM budgets for lowland floodplains have found the floodplains to be CPOM sources (Cuffney, 1988; Cellot, Mouillot & Henry, 1998; Tockner *et al.*, 1999). Tockner *et al.* (1999) found that a restored floodplain on the Danube, Austria exported 0.5 kg ha^{-1} $year^{-1}$ of Chl *a* and 21 kg ha^{-1} $year^{-1}$ of CPOM and 240 kg ha^{-1} $year^{-1}$ of DOC. If we convert these values to equivalent carbon loading with an assumed C : Chl *a* of 40 (Cloern, Grenz & Vidergar-Lucas, 1995) and C : CPOM of 0.5 (Schwarzenbach, Gschwend & Imboden, 2003) then it would appear than the floodplain exported 20 kg C ha^{-1} $year^{-1}$ as Chl *a* and 10.5 kg C ha^{-1} $year^{-1}$ as CPOM and 240 kg C ha^{-1} -$year^{-1}$ as DOC. So it is apparent from this study (one of the few that have quantified Chl *a*, CPOM and DOC export from floodplains) that DOC is the dominant form of carbon export followed by Chl *a* and CPOM. Of these three carbon resources Chl *a* has the highest nutrient content (Muller-Solger, Jassby & Muller-Navarra, 2002) and is considered a valuable subsidy to downstream aquatic ecosystems (Jassby & Cloern, 2000). Because of these factors (mass of carbon export and food resource quality) it would seem that a focus on Chl *a* dynamics is warranted. The form in which carbon is exported from the floodplain will be dependant on the relative contribution from different carbon pools. When the hydrology of an agricultural riparian habitat is restored the system will evolve from an open body of water dominated by macrophytes and algae to a riparian forest with a closed canopy; this will in turn shift the quality and source of food resources exported from the floodplain to the channel.

Alternating zones of phytoplankton production were a conspicuous feature within our data set. We characterised productive littoral zones during periods of flow-through when waters in the deep primary flow paths were being continually flushed with river water. When the channel hydraulically disconnected from the floodplain, Chl *a* levels across the entire floodplain increased, but it was the deep zones, which exhibited the highest Chl *a* concentrations. Aside from depth, the other primary difference between the shallow and the deep zones in our study system is residence time. Hein *et al.* (2004) compared side-arm channels of the Danube and examined relationships between residence time within the side-arms and Chl *a* values. They concluded that residence time is related to Chl *a* hyperbolically with maximum Chl *a* occurring when the water in the side-arm was approximately 10 days old. They attribute the Chl *a* decrease after 10 days to grazing pressure from a growing population of metazooplankton (Keckeis *et al.*, 2003). Indeed, in laboratory experiments moderate populations of the cladoceran *Simocephalus vetulus* (biomass 1.6 mg L^{-1}) have been shown to decrease phytoplankton biomass by a factor of 13.6 within 1 h (Pogozhev & Gerasimova, 2005). The variation in depth between the littoral and ponded zones exaggerates this grazing pressure as it has been shown that, in vegetated littoral zones, productivity reducing factors such as nutrient competition, shading and excretion of allelopathic substances by macrophytes can initiate top–down trophic control of phytoplankton by a relatively moderate population of filter feeders (Scheffer, 1999). A temporal analysis of the data indicates that these processes evolve through the flooding season. As macrophyte communities grew rapidly beginning in March, the temperature differential between the deep and shallow zones decreased with the unshaded pond eventually growing warmer than the shallows (Table 1). So it would seem that a combination of residence time and depth variability between habitats creates distinct physical and biological conditions which (i) favour phytoplankton growth in the shallow habitat that is not actively flushed during connection and (ii) during disconnection favour phytoplankton growth in deep water areas where residence time is intermediate, and shading and competition from macrophytes are low.

One of the most novel aspects of this study was the fact that we were able to characterise the complex nature of resource redistribution across the floodplain during flooding. The creation of a water–water ecotone (Izaguirre *et al.*, 2001) or perirheic zone (Mertes, 1997) between antecedent water and river water moving onto the floodplain has been shown to have important ecological ramifications, as the encroaching river water imports nutrients and disturbs floodplain waters across the perirheic front (Engle & Melack, 1993). We have shown that the hydraulic push from the inflowing river water also redistributes patches of antecedent water on the floodplain causing translation, mixing and the creation of a complex perirheos between a shifting mosaic of antecedent waters, not merely between the river water and floodplain water. Mertes (1997) defined the perirheos by analysing variation in turbidity across a number of large floodplains. We believe that this may result in an over-simplified view of patch dynamics on the floodplain as adjacent patches may have equivalent suspended sediment content but differing Chl *a* concentration, nutrient status, temperature, etc. By comparing Fig. 3g,h we can see that a relatively simple turbidity map belies the underlying patch complexity, which is revealed in the Chl *a* coverage. Fig. 3h depicts two distinct patches of water, turbid flood water originating form the channel and less turbid displaced floodplain waters. Fig. 3g however, clearly shows three patches of water on the floodplain, high Chl *a* flood water from the channel, low Chl *a* water displaced from the pond (see Fig. 3f), and an isolated patch of high Chl *a* littoral water in the far south-westerly corner. Each of these patches were characterised with at least 20 sampling points and the concurrent data collected (temperature, TDS, DO) all support our assertion that there exists a complex mixing front as patches of antecedent floodplain waters are stacked up against encroaching floodwaters. Our data indicate that the interaction of patches during flooding – realised in the intra-floodplain transfer of suspended algal biomass from deep water habitat to warm, shallow water habitat – can contribute to a precipitous decline in DO and create local conditions unfavourable for floodplain fishes (Fig. 3b,d). We have also shown how clear, less productive, pond water can be pushed into the productive littoral zone and displace high Chl *a* water (Fig. 3g). Obviously, these intra-floodplain transfers play an important role in floodplain dynamics and as such, the perirheic zone may be more complex then originally envisioned.

It is widely acknowledged that floodplains play a vital role in lowland river ecology. The idea of the floodplain as a productivity pump which requires a two stroke connection–disconnection series in order to efficiently export resources to the channel has been previously hypothesised (Schemel *et al.*, 2004), but never explicitly quantified. In the present paper we show how a disconnection period of at least 2 days is required for the ponded water on the floodplain to begin to produce elevated levels of Chl *a*. If a subsequent flood arrives when these levels are high there will be a substantial mass of Chl *a* exported from the floodplain (as high as 4.68 kg). Suspended algal biomass on the floodplain was correlated with residence time and depth. Zones of maximum phytoplankton production alternated between the pond and the littoral zone dependant upon residence time and local growth conditions (e.g. shading, competition). Storms entering the floodplain not only pushed antecedent floodplain waters off the floodplain but also redistributed floodplain resources creating areas of hypoxia in those areas that were not flushed. The composite perirheic front, which develops during storms on the floodplain adds another layer of complexity to the already diverse algal patch dynamics, which are driven by residence time and local physical and biological conditions. If, as it has been proposed (Jassby & Cloern, 2000), floodplains are to be managed as sources of high quality organic matter for deficient downstream aquatic ecosystems then the information garnered from studies such as these becomes vital to restoration efforts.

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